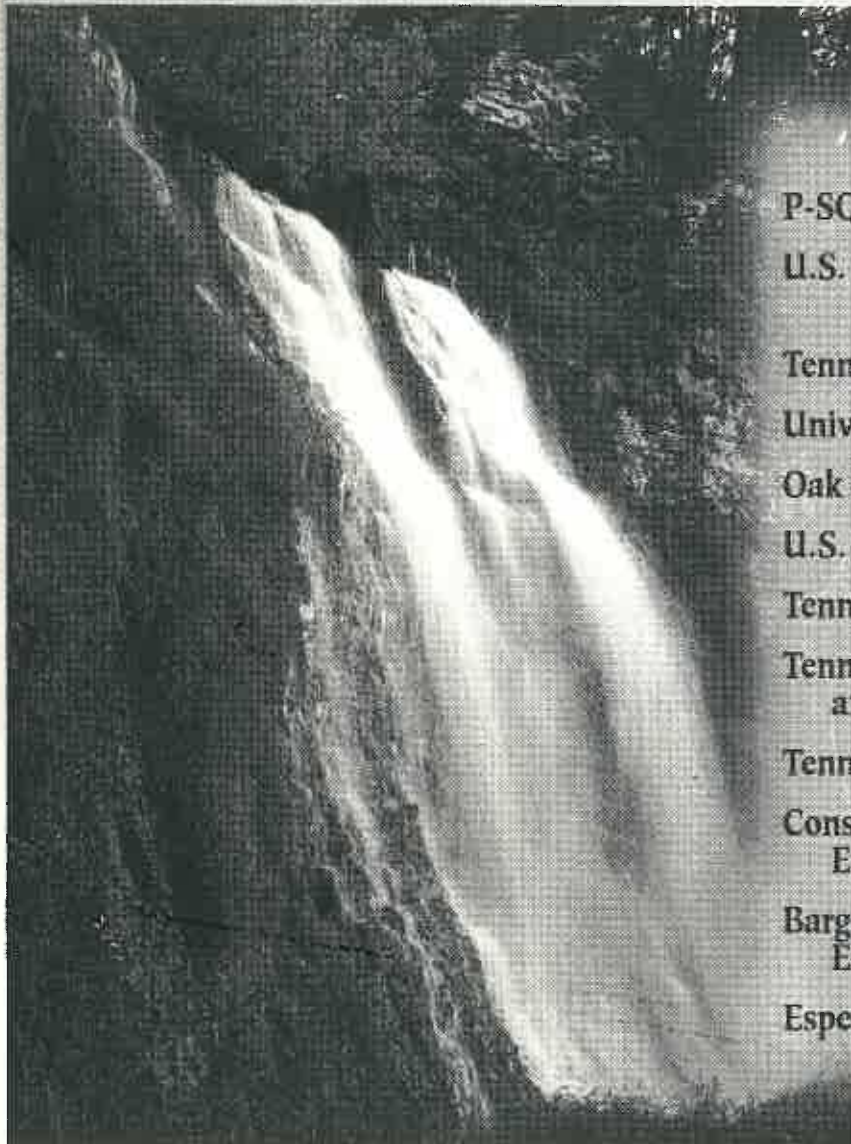


Extended Abstracts from
**Seventh Tennessee
Water Resources Symposium**



Sponsored by:

P-SQUARED Technologies, Inc.

U.S. Geological Survey,
Water Resources Division

Tennessee Technological University

University of Tennessee, Knoxville

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U.S. Army Corps of Engineers

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Tennessee Dept. of Environment
and Conservation

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Espey Huston and Associates

In Cooperation with the
Tennessee Section of the American Water Resources Association
Nashville, Tennessee 1997

*Maxwell House Hotel
Nashville, Tennessee*

February 24-26, 1997

Extended Abstracts from

Seventh Tennessee Water Resources Symposium and Student Symposium

Maxwell House Hotel
Nashville, Tennessee
February 24-26, 1997

Compiled and Edited by

Tim Gangaware,
Elise LeQuire,
Kirsten Perry,
and
Tina Cordy

Sponsored by

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Nashville, Tennessee
1997

PREFACE

These proceedings represent the seventh gathering of water resource professionals in Tennessee under the sponsorship of the Tennessee Section of the American Water Resources Association. The purpose of this symposium are: 1) to promote communication on water research and management, and 2) to encourage cooperation among the diverse range of water professionals in the state. All of the previous water resources symposia have been very successful, demonstrating the important role of these gatherings.

It has been my pleasure and privilege to be allowed to lead this organization this past year. We have some real challenges in front of us this next year or so. It is a fact that federal budgets will shrink, with unknown results to programs at state and federal levels. It will take some time for the effects of this restructuring to be fully played out with respect to staffing, people's careers and provision for their families. This uncertainty makes the need for routine gatherings of water resource professionals, students, and interested citizens even more important! Programs may come and go, but there is an ever increasing real demand on our state's resources, and the people who will be managing these resources will likely be us. The emphasis of this year's symposium couldn't be more appropriate.

Given these uncertain times, it is with even more gratitude that we should thank all those who helped put together this year's symposium. The officers of the Tennessee Section, including Susan Hutson and Anne Hoos of the USGS, Mike Sale of ORNL, Janet Herrin of the TVA, and Tim Gangaware (UT) have been outstanding in providing the leadership necessary to pull this year's symposium together. In addition to the officers, I want to thank the Organizing Committee members made up of Susan Jacks of TVA, Mike Eiffe of P2T, Roger Clapp an independent consultant, Dale Huff of ORNL, Rick Lowhorn of Tennessee Technological University, Hal Mattraw of the USGS, Greg Upham of the Tennessee Department of the Agriculture, and Tim Higgs of the Army Corps of Engineers. Thanks to Lori Mercer of the USGS for helping make the registration go smoothly. I want to give a special thanks to Kirsten Perry of P2T for her indefatigable support. Please search out these people to express your appreciation.

As a taxpayer and citizen of this great nation, I know we need to make adjustments, yet I realize that they will be painful. But the future is bright before us as these pains bring about a catharsis from which new vision and leadership will rise to manage and protect our great natural resources. Our officers for next year, I am confident, will rise to meet the challenge!

Paul M. Craig, P.E., President of AWRA Tennessee State Section and of P-SQUARED Technologies, Inc.

7TH TENNESSEE WATER SYMPOSIUM

Time	Scheduled activities
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MONDAY, FEBRUARY 24

6:30 pm	Registration Desk Open
7:00 pm	Opening Reception and Poster Session

TUESDAY, FEBRUARY 25

8:00 am	Registration Desk Open			
8:30 am	Panel Discussion: <i>Watershed Initiatives in Tennessee</i>			
10:00 am	Coffee Break			
	SESSION 1A	SESSION 1B	SESSION 1C	SESSION 1D
10:30 am	WATERSHED MANAGEMENT #1	GROUNDWATER SUPPLY	HAZARDOUS WASTE MANAGEMENT	STUDENT SYMPOSIUM #1
12:00	Lunch Break			
1:00 pm	WATERSHED MANAGEMENT #2	POLICIES/PROGRAMS	KARST #1	STUDENT SYMPOSIUM #2
2:30 pm	Refreshment Break			
3:00 pm	GIS/WATERSHED MANAGEMENT	TECHNOLOGY	KARST #2	STUDENT SYMPOSIUM #3
4:30 pm	Adjourn Concurrent Sessions			
5-7:00 pm	RECEPTION & POSTER SESSION			
6:00 pm	TENNESSEE SECTION AWRA BUSINESS MEETING			

WEDNESDAY, FEBRUARY 26

8:00 am	Registration Desk Open		
	SESSION 2A	SESSION 2B	SESSION 2C
8:30 am	GROUNDWATER #1	SURFACE WATER MODELING #1	RESERVOIR MANAGEMENT/NPS
10:00 am	Coffee Break		
10:30 am	GROUNDWATER #2	SURFACE WATER MODELING #2	WETLANDS
12:00	Lunch Break		
1:00 pm	GROUNDWATER #3	URBAN HYDROLOGY/STORM- WATER #1	ECOLOGICAL RESOURCES/MANAGEMENT
2:30 pm	Refreshment Break		
3:00 pm	GROUNDWATER #4	URBAN HYDROLOGY/STORM- WATER #2	ADVANCED WASTE TREATMENT TECHNOLOGY
4:30 pm	Adjourn Concurrent Sessions and Symposium		

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WATERSHED INITIATIVES IN TENNESSEE

Panel: Jim Nance, Director of the Division of Agricultural Resources, Tennessee Department of Agriculture; Carol Chandler, Natural Resources Conservation Center, Agricultural Service Center; Donald Anderson, Project Engineer, and Wayne Poppe, Co-Author, Clean Water Initiative of the Tennessee Valley Authority; Michael Bradley, Assistant District Chief of the U.S. Geological Survey, Water Resources Division; Paul Davis, Director of the Division of Water Pollution Control, Tennessee Department of Environment and Conservation.

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PANEL DISCUSSION

TUESDAY, FEBRUARY 25

8:30 a.m.

WATERSHED

INITIATIVES

IN TENNESSEE

Moderator: Dodd Galbreath, Policy Coordinator for the Tennessee Environmental Policy Office,
Tennessee Department of Environment and Conservation

Panel: Jim Nance, Carol Chandler, Donald Anderson, Wayne Poppe, Michael Bradley, Paul Davis

**TENNESSEE DEPARTMENT OF AGRICULTURE
DIVISION OF AGRICULTURAL RESOURCES**

Jim Nance¹

The Tennessee Department of Agriculture through its Agriculture Resources Division is actively involved in assisting the agricultural community of the state with a program designed to reduce soil erosion and to improve the quality of run-off water associated with farming activities. The main focus of the program is to provide technical assistance to landowners for installing best management practices and to provide some degree of financial cost-share assistance in the process. The program is state-wide in scope, encompassing all 95 counties.

The State's Nonpoint Source Program also housed in the Division addresses nonpoint-source pollution in several areas other than agriculture; for example, urban run-off, hydrologic modification, construction, silvaculture, land disposal, and mineral extraction. Funding for this program is sourced from Section 319 (h) of the Clean Water Act administered by the Environmental Protection Agency. The required state match comes from the state's cost-share program and from in-kind and dollar contributions from local participants.

¹Tennessee Department of Agriculture, Division of Agriculture Resources, Ellington Agriculture Center, Box 40627, Nashville, Tennessee 37204.

**THE WATERSHED APPROACH
OF THE NATURAL RESOURCES CONSERVATION SERVICE,
U.S. DEPARTMENT OF AGRICULTURE,
TENNESSEE**

Carol Chandler¹

The Natural Resources Conservation Service's watershed approach to planning and implementation is a "ground up" method which insures that local concerns are identified and analyzed. The central focus is on county level local working groups. The NRCS District Conservationist works directly with this group. District Conservationists from hydrologic unit teams to determine the best ways to identify and treat common problem areas or watersheds. The HUA team, or individual DCs, may request input from technical specialists, public affairs specialists, and others from both NRCS and other agency personnel. Public comments and suggestions are solicited throughout the planning and implementation process. NRCS personnel, along with other partners, are available to the local public to address their concerns. *Active* diverse partnerships are essential to fully address concerns in a cost-effective, timely fashion.

¹Natural Resources Conservation Service, Agricultural Service Center, 286 East Main St., Gallatin, TN 37066, (615) 230-9267.

WATERSHED-BASED MANAGEMENT: TVA'S CLEAN WATER INITIATIVE

**Dr. Wayne Poppe, Manager
Tennessee Valley Authority Clean Water Initiative**

Don Anderson¹

Since TVA was created, we have sought to exert a positive influence on water quality principally by supporting and working cooperatively with federal and state regulatory agencies and with cities, industries, and individual water users. The Clean Water Initiative continues this watershed approach and adapts it to the complex water issues and competitive environment facing us today. It brings a holistic and integrated approach not only to maximizing water resource benefits but to identifying water quality issues and to developing solutions that take into account local, political, economic, and regulatory realities. It has four key features that distinguish it. It is watershed-based; it relies on multi-disciplinary teams; it is guided by resource assessments; and it incorporated a system of resource-based performance measures.

WATERSHED BASED

The first key feature of our Clean Water Initiative is its focus on watersheds as the primary management unit. Water problems seldom follow political boundaries, nor do their solutions. Water problems are usually manifestations of problems which originate on the land. In the Tennessee Valley for example the largest source of nonpoint source pollution is sediment form erosion on farmlands, construction and mining sites, and stream banks. It is essential for us to recognize the water, the land, and the human communities they support as an integrated whole. The Clean Water Initiative is an effort to incorporate this point of view into all we do, including our organizational structure. The Tennessee Valley has been subdivided into 12 watershed areas which are the basis for staff assignments and operational planning. These large watersheds are further divided into approximately 600 hydrologic units which become the framework for specific projects.

TEAM APPROACH

Multi-disciplinary River Action Teams are assigned to each of the twelve major watershed. These teams are responsible for assessing resource conditions and building partnerships with governments, businesses, and citizen volunteers to address protection and improvement needs. Teams become familiar with resource conditions and with community needs and expectations.

¹Tennessee Valley Authority, Clean Water Initiative, 460 West Summit Hill Dr., Knoxville, TN 37902-1499, (423) 632-8502.

Their assignment to a specific watershed provides the opportunity to develop cooperative relationships with stakeholders and to build community trust. They combine the skills of water resource professionals with the skills of community specialists and environmental educators. Teams are empowered to decide how to focus TVA resources and address protection and improvement needs allowing a rapid response to evolving or newly discovered problems and opportunities.

RESOURCE ASSESSMENT

The Clean Water Initiative, like other resource programs, requires adequate data to guide watershed protection and improvement activities. Biological and other data types are combined with data from other agencies and input from stakeholders to create a snapshot of current conditions in each of the approximately 600 hydrologic units in the Valley. This assessment guides the teams to the areas where efforts should be concentrated. More intensive data collection in targeted areas may include additional biological evaluation, chemical or bacteriological studies, or aerial ecological conditions in 30 reservoirs and check fecal coliform bacteria levels in water samples from about 260 recreation areas.

We are committed to collecting the data necessary to make good management decisions but experience has shown that watershed data does not have to be perfect to be reliable. We make management decisions with the best available information and then adjust as new information becomes available. Limited data, obtained cheaply and quickly, is often adequate. Exhaustive studies and research-oriented projects are rarely called for.

PERFORMANCE MEASUREMENT

The fourth and last key functions of our Clean Water Initiative is performance measurement. Performance measures focus on the approximately 600 hydrologic units, small watersheds from 10 to 100 square miles in size. The aim is to increase the number of hydrologic units meeting desired uses and to decrease the amount of TVA resources relative to the financial and staff resources provided by local cooperators, in other words to reduce the ratio of TVA to public/private contributions. We call these outcome measures.

We gauge our progress toward these **OUTCOMES** by tracking the number of improvement activities or **OUTPUTS** conducted both monthly and annually. Monthly output measures include the number of:

- Hydrologic units assessed,
- reservoirs rated,
- hydrologic units with pollution sources analyzed,
- pollution reduction projects,
- habitat restoration/improvement projects,
- public interest surveys conducted,

volunteer hours contributed,
local coalitions in place, and
cooperative funding proposals submitted.

Annual output measures which summarize the monthly measures include the number of hydrologic units:

with current assessments,
with problem causes identified,
with correction/improvement activities,
where coalitions are forming, and
where coalitions are sustainable.

The measures provide teams, the CWI business manager, and TVA upper management with regular feedback on our programs. Measures ensure that each activity undertaken is related to a specific need. Activities that do not contribute to improved performance are quickly eliminated.

CONCLUSION

TVA's Clean Water Initiative is not a departure from its long history of integrated resource management. It is, rather, a logical progression that builds on past experience and adapts to current situations. It is a watershed approach in every respect, from its staffing strategy to its use of performance measures. It is also an approach which requires TVA to work closely with its agency partners, with communities, and diverse interest groups to achieve its mission of sound resource management.

UNITED STATES GEOLOGICAL SURVEY
THE USGS NATIONAL WATER-QUALITY ASSESSMENT PROGRAM
AND STUDY UNITS
IN TENNESSEE

Michael W. Bradley¹

The U.S. Geological Survey has initiated the National Water-Quality Assessment Program (NAWQA) to describe the water-quality conditions and trends of the Nation's surface-water and ground-water resources and to provide a scientific understanding of the principal factors, natural and human, that affect the quality of those resources. The program includes data collection and analyses at local, study-unit, regional, and national levels. By addressing the goals of the program, the NAWQA studies will focus on conditions and water-quality issues that will aid regulators and resource managers at local, state, and federal levels.

The NAWQA program will consist of 60 study-unit investigations that include parts of most major river basins throughout the Nation. The study-unit investigations will be conducted in a nationally consistent manner to provide a framework for National and regional assessments and ensure that water-quality issues can be addressed by comparative studies.

The NAWQA program in Tennessee consists of the Upper Tennessee River Basin study unit, the Lower Tennessee River Basin study unit, and the Mississippi Embayment study unit. The Upper Tennessee River Basin study began in 1994 and encompasses the entire Tennessee River drainage basin upstream of Chattanooga, Tennessee. The Lower Tennessee River study is scheduled to begin in 1997 and will include the Tennessee River drainage basin downstream from Chattanooga to the mouth of the Tennessee River. The Mississippi Embayment study includes a significant part of West Tennessee. Major water-quality issues in the study units include non-point sources of sediment, bacteria, and nutrients, as well as sources of industrial and agricultural organic compounds.

¹ Assistant District Chief, Tennessee District, U.S. Geological Survey, Water Resources Division, 810 Broadway Suite 500, Nashville, TN 37203, (615) 736-5424.

TENNESSEE WATERSHED MANAGEMENT APPROACH

Paul E. Davis¹

The Tennessee Department of Environment and Conservation, Division of Water Pollution Control has implements a watershed-based approach to controlling water pollution and improving water quality. Division activities including planning, monitoring, assessment, wasteload allocation, and NPDES permits will be completed within the watershed framework. Watersheds are defined as the 8-digit USGS hydrologic Unit Code (HUC) and are combined in five groups according to year of implementation. Watersheds were placed in groups to divide work evenly across the six Water Pollution Control Field Offices and to address upstream watersheds earlier in the approach. The watershed management approach was initiated in the first group of watersheds in 1996. Following groups will be initiated in each subsequent year.

Through the watershed management approach, the Division will function in a more efficient and effective manner and will assure that NPDES permits are equitable and consistent. Watershed management activities are coordinated by the Watershed Management Section within the Division of Water Pollution Control.

¹ Director, Tennessee Division of Water Pollution Control, Watershed Management Section, 6th Floor L&C Annex, 401 Church Street, Nashville, TN 37243, (615) 532-0625, E-mail: pdavis@mail.state.tn.us.

SESSION 1-A

WATERSHED MANAGEMENT #1:

10:30-12:00

Barbara S. Hamilton, Sherry H. Wang, *Tennessee Watershed Management Approach Milestones.*

P.P. Piszczek, Y.R. Clark, D.B. George, C.J. O'Bara, J.A. Weeks, J.D. Wall, M.T. Davidson, *Demonstrating a Holistic Approach to Identifying and Costing Needs on a Watershed Basis.*

Chris Moyers, *Chickasaw-Shiloh RC&D Council Watershed-Based Projects.*

WATERSHED MANAGEMENT #2

1:00-2:30

TVA River Action Teams:

Donald Anderson, *Strategy Development and Project Selection.*

Bob Wallus, *Index of Biotic Integrity as an Ecological Health Indicator for Tennessee Valley Streams.*

Carmen Lane, *Building Coalitions in TVA's Clean Water Initiative.*

Donald Anderson, *Measuring Performance in TVA's Clean Water Initiative.*

GIS WATERSHED MANAGEMENT

3:00-4:30

David A. Padgett, Jennifer Powell-Hagar, *GIS Applications and Supporting Technology in the Assessment of Potential Impacts of Residential Development Upon an Urban Watershed.*

Jennifer L. Kazwell, *Comparison of Two Non-Point Source Pollution Models Utilizing Geographic Information Systems.*

Larry W. Moore, Surya Sahoo, *A GIS Approach for Identifying and Evaluating Critical Watersheds in West Tennessee.*

Norman A. Zehms, *Generation of HEC-1 Soils Classification Maps Using GIS: Interpolation of SCS Soils Maps for Unmapped Areas.*

TENNESSEE WATERSHED MANAGEMENT APPROACH MILESTONES

Barbara S. Hamilton,

and

Sherry H. Wang¹

INTRODUCTION

The Tennessee Department of Environment and Conservation, Division of Water Pollution Control has implemented a watershed-based approach to controlling water pollution and improving water quality. Through the watershed management approach, the Division will function in a more efficient and effective manner, will assure that NPDES permits are equitable and consistent, and will make better use of information from partner agencies.

The basic tenet of this approach is cyclic, iterative management based on geographic units. In Tennessee, watershed management will occur in 5-year cycles. Activities during the cycle include planning, data collection, monitoring, assessment, wasteload allocation, draft permits and watershed management plans, and final permits and plans (see Figure 1). Public meetings will be conducted at years 1, 3, and 5 of the cycle.

The state has been divided into 54 watersheds defined as the 8-digit USGS Hydrologic Unit Code (HUC). These watersheds are then combined in five groups according to year of implementation. Watersheds were placed in groups to divide work evenly across the six Water Pollution Control Field Offices and to address upstream watersheds earlier in the approach. The watershed management approach has been initiated in the first group of watersheds in 1996. Following groups will be initiated in each subsequent year (see Figure 2).

Watershed management activities are coordinated by the Watershed Management Section within the Division of Water Pollution Control.

GROUP ONE WATERSHED PUBLIC MEETINGS

Public meetings for group one watersheds were conducted during September and October, 1996.

¹Tennessee Division of Water Pollution Control, Watershed Management Section, 7th Floor L&C Annex, 401 Church Street, Nashville, TN 37243, bhamilton@mail.state.tn.us, swang@mail.state.tn.us, 615-532-0625.

Statewide invitations were sent to over 500 people, including NPDES permittees; consulting firms; county and city officials; environmental groups; federal, state, and local agencies; and, coalition groups and associations. Average meeting attendance was 27 attendees.

These public meetings were designed to inform the public about the Division's watershed approach and to seek public input regarding water quality issues and concerns. Stated issues and concerns varied according to audience composition and regional issues. A brief overview of public input is listed below:

**TABLE 1
GROUP ONE PUBLIC MEETING ISSUES/CONCERNS**

Watershed	Counties	Public Issues/Concerns
Watauga River	Johnson	Litter in streams/reservoirs
	Carter	Lack of public education
	Washington	Land protection
	Sullivan	Development of floodplains and lake shores Sediment
Ocoee River	Polk	Need expanded river use
		Recreation pressures
		Lack of water quality data
		Sediment
		Road construction
		Fish reintroductions
Watts Bar Reservoir/ L. Tennessee River	Roane	Destruction of riparian areas
	Loudon	Septic system and sewage treatment plant inputs
	Meigs	Groundwater contamination by landfill
	Rhea	Adequacy of reservoir monitoring
		Radioactive waste shipping and storage
Emory River	Morgan Cumberland Roane	Radioactive sediments
		Outstanding National Resource Waters designation
		Water quantity planning
		Dams
		Public participation in planning
		Sediment
		Clearcutting
		Mining and stone quarries
		Septic system and sewage treatment plant inputs
		Decrease in fish & mussel species
Stones River	Rutherford	Sediment
	Davidson	Top soil operations
	Wilson	Lack of public education
	Cannon	Development pressures
		Lack of water quality data
		Landfill
		Cattle access to streams Storage of tires along river

TABLE 1
GROUP ONE PUBLIC MEETING ISSUES/CONCERNS - CONTINUED

Harpeth River	Dickson	Road construction
	Williamson	Development pressures
	Davidson	Sediment and erosion
	Rutherford	Wild and Scenic River designation
	Hickman	Outstanding National Resource Water designation
		Lack of public education
		Need strategy to improve water quality
		Herbicide application at power lines
		Litter from canoe trips
		Sediment and erosion
South Fork Forked Deer River	Chester	Failed septic systems
	Henderson	Flooding/drainage
	Madison	Development pressures
	Haywood	Stream channelization and straightening
	Crockett	Intent of the watershed approach
	Lauderdale	Pollution trading in Tennessee
	Dyer	Litter
		Development/growth pressures
Nonconnah River	Shelby	Nonpoint source pollution, esp. from urban areas
		Development on floodplains
		Erosion
		Wetland loss
		Too much pollution
		Contamination of groundwater by surface water
		Manhole overflows
		Lack of public education
		Use of ecoregion reference streams as goal
		Impact of new approach on permit limits
		Need annual report of toxic releases

WATERSHED MANAGEMENT MONITORING STRATEGY

The Division's current water quality monitoring program will be modified to focus on watersheds. Watershed management monitoring strategies will be developed on a watershed-by-watershed basis. Individual strategies will be responsive to historic and current data availability, other agencies' monitoring efforts, field office expertise, and wasteload allocation (for permits) model input requirements. Monitoring within each watershed will occur during year 2 and 3 of the management cycle. Monitoring results will be reported in the watershed management plan and will be used for wasteload allocation model inputs and water quality assessments.

NEXT STEPS

In 1997, the following watershed management activities will occur in group one and two watersheds:

Group One Watersheds:

Monitoring

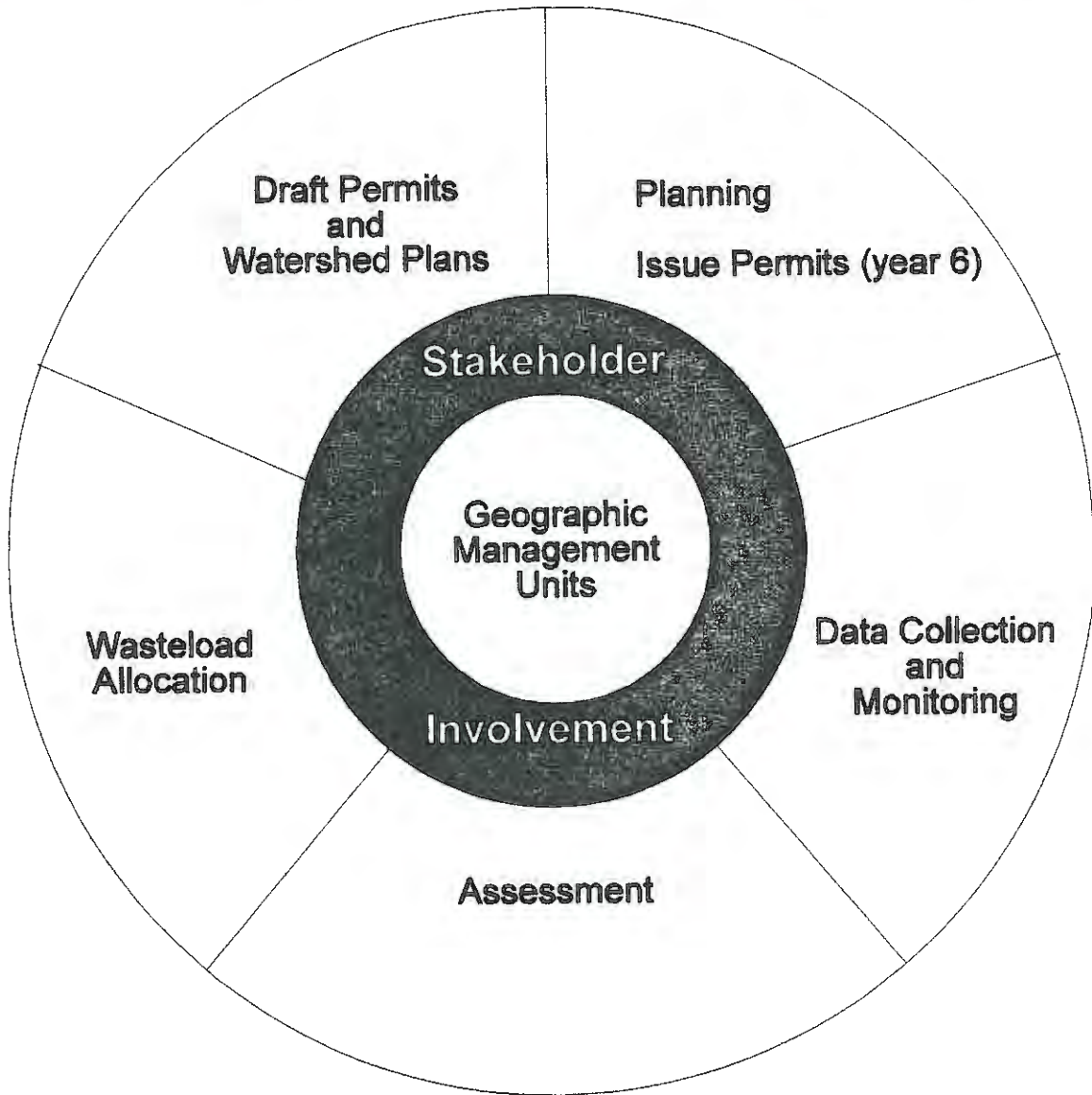
Existing Data Compilation

Group Two Watersheds

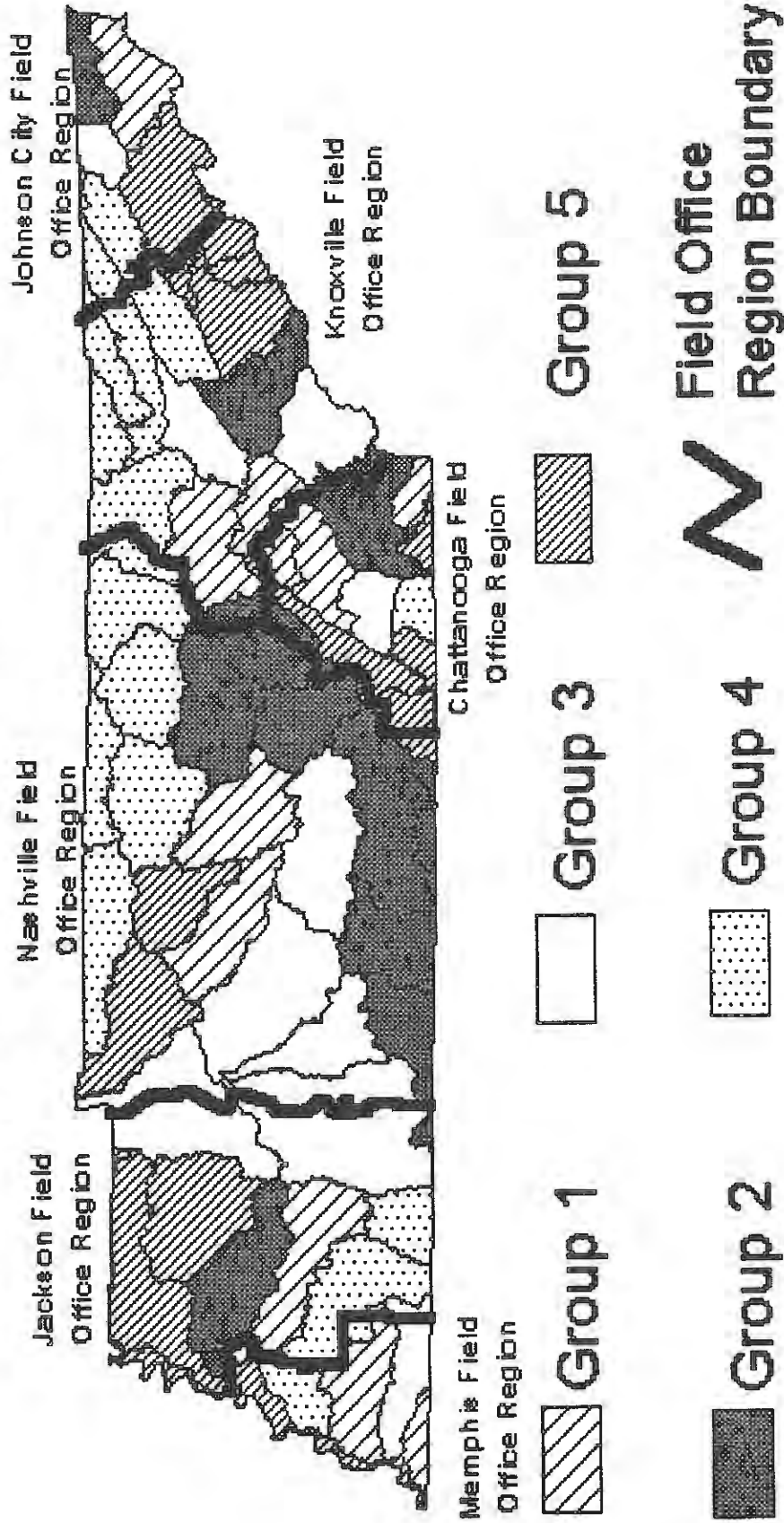
Existing Data Compilation

Public Meetings

Watershed Management Cycle



Tennessee's Watershed Management Groups



**DEMONSTRATING A HOLISTIC APPROACH
TO IDENTIFYING AND COSTING NEEDS
ON A WATERSHED BASIS**

P.P. Piszczek,

Y.R. Clark,

D.B. George,

C.J. O'Bara,

J.A. Weeks,

J.D. Wall,

and

M.T. Davidson¹

The development and modification of computer models for effective quantity and quality simulation of water resources, especially at the watershed level, has been important for research as well as planning and decision-making purposes. The development of a watershed quality model for the Richland Creek watershed in south-central Tennessee involves the integration of instream, groundwater, and overland flow quality and quantity models with an ARC/INFO Geographic Information System (GIS). This combination of watershed process models and GIS constitutes the framework for a comprehensive, community planning tool which simulates the environmental impacts and some of the financial demands of land and water management practices. The final output of the comprehensive model is in the form of a watershed quality index (WQI), which simplifies the process model output. In addition, the WQI helps a user to understand the ramifications of urban and agricultural land use alterations. A cost analysis component is also integrated into the model; this illustrates the financial requirements associated with land use alterations.

This Pilot project is designed for demonstration and utility using data specific to the Richland Creek watershed. However, it is intended to be versatile, with functionality in other watersheds throughout Tennessee and the United States using watershed-specific data.

¹Center for the Management, Utilization, and protection of Water Resources, Tennessee Technological University, Cookeville, TN 38505-0001.

**CHICKASAW-SHILOH RC&D COUNCIL
WATERSHED-BASED PROJECTS**

Chris Moyers¹

The Chickasaw-Shiloh RC&D council was authorized by the Secretary of Agriculture in January of 1996. The Council's area covers the eight counties of southwest Tennessee. Since the Council's authorization it has assisted the citizens of the area develop and implement approximately \$15,000,000 in projects.

The Council is a "grass roots" organization comprised of local citizens making and implementing decisions on natural resource issues and concerns in the area. One such project has been the Hatchie Bottomland Hardwoods Project (land treatment water quality project). The Council coordinated the efforts of nineteen different agencies, groups, and organizations that implement this project. The project began by assessing the needs of the producers of the area and to what extent they were willing to go to reduce erosion on contracted acres by a total of 61%. This project is just one of many the Council has implemented focusing on the needs of the local people.

¹Coordinator, Chickasaw-Shiloh RC&D, 235 Oil Well Rd., Jackson, TN 38305.

**TVA'S RIVER ACTION TEAM ACTIVITIES
DON ANDERSON, PROJECT ENGINEER
HOLSTON RIVER ACTION TEAM**

STRATEGY DEVELOPMENT AND PROJECT SELECTION

Presented by Donald Anderson, CWI Holston River Team

The Clean Water Initiative focuses on watersheds as the primary management unit and teams are the basic organizational unit. Multi-disciplinary River Action Teams are assigned to each of the twelve major watersheds. These teams develop specific strategies for each hydrologic unit within the framework of an overall business strategy. This ability to decide how and where to focus TVA resources allows a rapid response to evolving or newly discovered problems and opportunities. This presentation will describe some of the considerations teams use in developing watershed strategies and how this in turn is used to develop specific projects.

**INDEX OF BIOTIC INTEGRITY AS AN ECOLOGICAL HEALTH INDICATOR
FOR TENNESSEE VALLEY STREAMS.**

Presented by Bob Wallus

The Index of Biotic Integrity (IBI) is an assessment of environmental quality through application of ecologically based metrics to fish community data collected from a stream. IBI provides rapid low cost data for use in assessing aquatic resource condition and is TVA's principal tool for providing baseline data on the ecological health of watersheds in the Tennessee River drainage. IBI protocols originally developed for midwestern streams are being modified for use in the different ecoregions of the Tennessee Valley. These modifications are the result of analyses of fish community data collected from over 1,000 stream sites in five ecoregions partially drained by the Tennessee River watershed.

AN OVERVIEW OF TVA'S RESERVOIR BENTHIC MACROINVERTEBRATE COMMUNITY ASSESSMENT TECHNIQUES

Presented by Amy Wales, TVA

In 1990, TVA began sampling benthic macroinvertebrate communities on mainstem Tennessee River reservoirs as a part of its Vital Signs and Use Suitability Monitoring Program. The benthic community is one of six parameters used to measure the ecological health of TVA reservoirs. In 1995, changes in protocol were made to improve upon both timeliness and cost of benthic data collection. A brief history of TVA's reservoir benthic community assessment procedures will be given, as well as justification for the changes made, and an overview of the methodologies currently in use.

TVA'S RIVER ACTION TEAM ACTIVITIES CARMEN LANE, PROJECT ENGINEER HOLSTON RIVER ACTION TEAM

BUILDING COALITIONS IN TVA'S CLEAN WATER INITIATIVE

Presented by Carmen Lane, CWI Holston River Action Team

The primary approach River Action Teams take to assess and improve water resources is through partnerships. They work with local communities and other agencies to not only learn about the condition of rivers and streams, but also to determine the value of those resources to the community.

Information gained and shared from a broad range of cooperators not only insures that TVA's resources are focused on priority areas, but also that resources can be combined to accomplish more. By partnering with local groups on what they value, water resource stewardship will continue through the community long after agencies are gone. This presentation will describe why TVA River Action Teams place such importance on partnerships and coalitions and gives examples of these efforts across the Tennessee Valley.

MEASURING PERFORMANCE IN TVA'S CLEAN WATER INITIATIVE

Presented by Donald Anderson, CWI Holston River Team

A key component of the Clean Water Initiative is performance measurement. Performance measures focus on the approximately 600 hydrologic units, small watersheds from 10 to 100 square miles in size. The aim is to increase the number of hydrologic units meeting desired uses and to decrease the amount of TVA resources relative to the financial and staff resources provided by local cooperators. We gauge our progress toward these outcomes by tracking the number of improvement activities or outputs conducted both monthly and annually. Annual output measures include the number of hydrologic units with current assessments, with problem causes identified, with correction/improvement activities underway, and the status of local coalition development. These measures provide regular feedback on program performance and ensure that each activity undertaken is related to a specific need.

**GIS APPLICATIONS AND SUPPORTING TECHNOLOGY
IN THE ASSESSMENT OF POTENTIAL IMPACTS
OF RESIDENTIAL DEVELOPMENT
UPON AN URBAN WATERSHED**

David A. Padgett,

and

Jennifer Powell-Hager¹

INTRODUCTION

Radnor Lake, and its 957 acre watershed, became Tennessee's first State Natural Area in 1971 via a land trust purchase by the State Department of Conservation and thousands of concerned citizens. The lake was created in 1914 with the impoundment of Otter Creek by the Louisville and Nashville Railroad Company to furnish water for steam engines and livestock. Located within the Nashville/Davidson County Metropolitan Area, the lake and its ecologically extraordinary surroundings are a state designated "protected area" and "fragile forest." Fishing and removal of trees and flowers is prohibited.

Much of the privately owned land immediately adjacent to Radnor Lake has been systematically sold to developers over the past decade. Several subdivisions with densities of about one home per acre are either being built or are planned. Several environmental groups, including the Nature Conservancy, are attempting to protect the area from development pressure. To date, the increased residential land use is not considered a "watershed issue" by state environmental officials.

In this study, a geographical information systems (GIS) supported method will be developed and applied to the case of Radnor Lake. The goal of the study will be to assess the potential impact of continued development upon the Radnor Lake watershed. To date, no such study has been conducted on the area despite the fact that Radnor Lake managers have called attention to sedimentation and polluted runoff entering the watershed from adjacent construction sites.

RESEARCH DESIGN AND METHODOLOGY

Impacts brought by excessive overland flow will be modelled using topographic data digitized into GIS raster and vector format. Drainage basin precipitation-runoff response models

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supported by readily-available raster digital elevation models (DEMs) have been developed previously (Martz and Garbrecht, 1993; Pilon and McIntyre, 1996). Potential polluted runoff loads will be assessed using techniques akin to those developed by Barbe, Cruise and Mo (1996). Computerized storm hydrograph models will also be applied to assess the impact of future development upon the Radnor Lake watershed. Potential expansion of the human-built environment around the lake will be modelled through the integration of remotely sensed imagery and temporal GIS similar to the techniques applied by Buchanan and Acevedo (1996). The Radnor Lake basin model will be calibrated through comparison with data collected in the field. Calibration of watershed model results using observed data has been conducted successfully (Jeton and Smith, 1993; Luker, Samson, and Schroeder, 1993). A similar GIS based study assessing the impacts of development on water quality has been successfully completed (Coffin, Dorlester, and Fabos, 1995).

Work will begin with delineation of catchment and sub basins of the watershed. Low altitude air photos will be used to assess the degree of urban development to date in and around the protected area. Appropriate GIS methods will then be developed and applied to the study area. Results of the GIS applications will be used to design and suggest BMPs.

OBJECTIVES AND TIMETABLE FOR COMPLETION

1 - Watershed Delineation (March-May 1997)

The Radnor Lake watershed and associated sub-basins will be delineated using U.S. Geological Survey topographic maps. The watershed boundaries will be defined as inter-connected topographic highs with slopes draining toward Otter Creek, Radnor Lake, and associated tributaries. The watershed boundaries will first be drawn to scale, and then digitally entered into a GIS database.

2 - Landuse Assessment (March-May 1997)

The current and future status of commercial and residential development in and around the Radnor Lake Watershed will be determined through examination of aerial photographs. Watershed landuse maps will be created in order to determine potential sources of non-point source pollution. The landuse coverage will be digitally entered into a GIS database.

3 - Groundtruthing (May-June 1997)

In order to ensure that the GIS database is as accurate as possible, frequent visits will be made to the study site. Any anomalies noticed at the site will be corrected.

4 - Geographic Information Systems Applications (June-July 1997)

Following input of climatic and topographic data, various computer-driven hydrologic models will be applied to the Radnor Lake GIS database to determine the nature of potential runoff from the watershed.

5 - Assessment of Results (July 1997)

The results of the computer models will be compared with samples taken from the watershed itself. For example, the model may predict a given level of nitrogen pollution loading under current landuse conditions. If water samples taken from the Radnor Lake and/or Otter Creek come close to or match predicted concentrations of nitrogen, then it may be reasonably assumed that the model may be used to predict impacts of future landuse change.

6 - Reporting of Results to Decision-Makers (July-August 1997.....)

Projections of potential future pollution levels in Radnor Lake given continuing rates of development will be produced. The resulting report will be provided to local decision-makers, environmentalists, and developers. Interested parties will use the results to suggest designs for Best Management Practices (BMP) drainage structures to minimize the impact of development upon the Radnor Lake watershed.

EXPECTED RESULTS AND DELIVERABLES

Predicted impacts will be displayed graphically in computer-driven map format and will be available to the public at inter-active PC workstations in local libraries. During and after completion of the study, we will conduct seminars for Nashville residents on the potential impacts of continued urban sprawl upon water quality. Developers will be encouraged to employ Best Management Practices (BMPs) to minimize pollutant runoff from residential subdivisions and areas under construction. Seminars will be held at community centers, schools, and universities.

CITED WORKS

- Barbe, D.E., Cruise, J.F., and Mo, X. 1996. "Modeling the Buildup and Washoff of Pollutants on Urban Watersheds." *Water Resources Bulletin*, 32(3), pp. 511-520.
- Buchanan, J.T., and Acevedo, W. 1996. "Studying Urban Sprawl Using a Temporal Database." *Geo Info Systems*, 6(7):42-47.
- Coffin, Peter, Dorlester, and Fabos, Julius. 1995. "Nonpoint Source Water Quality Impacts in an Urbanizing Watershed," *In: EPA Seminar Publication, National Conference on Environmental Problem-Solving with Geographic Information Systems*, 142-150.
- Jeton, A.E., and Smith, J.L. 1993. Development of Watershed Models for Two Sierra Nevada Basins Using a Geographic Information System. *In: Geographic Information Systems and Water Resources*. Edited by John M. Harlin and Kenneth J. Lanfear, editors. American Water Resources Association, Bethesda, Maryland, pp. 251-258.
- Luker, S., Samson, S.A., and Schroeder, W.W. 1993. Development of a GIS Based Hydrologic Model for Predicting Direct Runoff Volumes. *In, Geographic Information Systems and Water Resources*. John M. Harlin and Kenneth J. Lanfear, editors. American Water Resources Association: Bethesda, Maryland, pp.

COMPARISON OF TWO NON-POINT SOURCE POLLUTION MODELS UTILIZING GEOGRAPHIC INFORMATION SYSTEMS

Jennifer L. Kazwell¹

ABSTRACT

In the past several years, there has been an emergence of concern for pollution of the environment. A recent issue has been non-point source pollutants from urban and agricultural areas. One of the largest contributors of non-point source pollutants is agricultural land. Sediment and nutrients such as nitrogen and phosphorous are the primary non-point source pollutants from agricultural watersheds. Due to concern regarding these pollutants, several non-point source pollution models have been developed to study the problem. Geographic Information Systems (GIS) have been a helpful tool in the utilization of these models.

The purpose of this study was to apply two non-point source pollution models to a portion of the Blood River drainage basin in Western Kentucky and Tennessee using data contained within the Kentucky Lake Geographic Information System. Blood River was chosen because past studies have shown the embayment to have high turbidities and chlorophyll-a concentrations. The study was part of a project in cooperation with the U.S. Department of Energy's (DOE) Oak Ridge National Laboratories in Oak Ridge, Tennessee, and Murray State University funded by the DOE EPSCOR (Experimental Program to Stimulate Competitive Research). The two models were compared with collected water samples from the river and with one another. The models applied were AGNPS, an agricultural non-point source pollution model and SWRRB, Simulator for Water Resources in Rural Basins.

A method for creating the input files for AGNPS using a GIS was developed by a former graduate student, Natalie Lane (1994).

The method was modified for this study to create input files for both models. Arc/Info software was used to develop the GIS layers.

Sampling was conducted at three locations in the drainage basin for three different storm events. The samples were analyzed at Hancock Biological Station, Murray State University. Samples were taken only one time during each storm event. Therefore, sediment and nutrient concentrations were only a snapshot of one time period during the runoff.

AGNPS was used to predict runoff totals, sediment yields, and nutrient loadings for each cell as well as for the entire drainage basin. SWRRB was used to predict the same parameters for ten sub-basins and the entire drainage basin. Results from both models were analyzed and compared. AGNPS predicted higher runoff values than SWRRB for the two storm events, February 17, 1995 and May 1, 1995. SWRRB consistently predicted higher values than AGNPS for sediment yield. General Linear Models were used to compare the predicted runoff and total

¹Masters' thesis, Murray State University, Sverdrup Civil, Inc., sverdrup-bh,sverdrup.com.

sediment yield values statistically. There were significant differences between the models, the event dates, and the sub-basins for both runoff and total sediment yield. There were interactions between the models and event dates, the models and sub-basins, and the event dates and sub-basins for runoff. There was only interaction between the models and sub-basins for total sediment yield.

The field samples were analyzed and results were compared with the models. AGNPS values compared more closely with the measured values for total suspended sediment. SWRRB predicted values for total suspended sediment were higher than both the measured values and AGNPS values. AGNPS was expected to perform better because the model was a distributed model and also because the model allowed for greater detail by dividing the basin into smaller cells. The smaller the area, the more homogeneous the area was as far as landuse/landcover and soil types. Therefore, a model that divided the basin into small parts was expected to perform better than one that used larger areas.

The comparison of AGNPS and SWRRB to measured samples proved valuable in determining the type of model that predicted non-point source pollution loadings best. The use of data which existed in KLGIS lessened the amount of time the project would normally take if information had not already been available as GIS coverages. Utilizing the techniques developed by Lane (1994) eased the process of preparing the data sets required by AGNPS.

A GIS APPROACH FOR IDENTIFYING AND EVALUATING CRITICAL WATERSHEDS IN WEST TENNESSEE

Larry W. Moore, Ph.D., P.E.,

and

Surya Sahoo, M.S.¹

INTRODUCTION

The U.S. Army Corps of Engineers proposes restoration work on the Middle Fork of the Forked Deer River (MFFDR). In the restoration reaches, a naturally meandering river channel capable of carrying normal flows would be restored. This project is jeopardized by certain tributary streams which are significant contributors of sediment which can form river channel blockages. To assure the success of the restoration effort, appropriate measures must be taken to reduce the quantities of sand and silt through Best Management Practices (BMPs) and/or other measures in critical MFFDR subwatersheds.

Geographic Information Systems allow the interactive analysis of spatial data related to watershed investigations. The design of this integrated GIS based application for watershed management includes an interface for watershed modelling and functions for the estimation of model parameter values. The primary attributes of this approach include ease of use, minimal equipment requirements, a generic database management system and use of a macro language. The integrated application will ultimately provide analytical and query tools to enhance the process of determining critical watersheds, and help users in producing maps, reports, and other output that can be used for watershed management in a cost-effective manner. An application is demonstrated for the 487 square mile watershed of the Middle Fork Forked Deer River (MFFDR) in west Tennessee that performs automatic derivation of watershed parameters for sediment modelling to facilitate subsequent identification of critical subwatersheds. Using the modelling approach developed as part of this research effort, various Best Management Practices for agricultural lands were evaluated to observe the impact on erosion and sedimentation in the 64 designated subwatersheds of the MFFDR.

¹University of Memphis, Civil Engineering Department, Memphis, Tennessee, 38152.

SESSION 1-B

GROUNDWATER SUPPLY

10:30-12:00

Robert G. Liddle, *Stream Hydrograph Analysis to Predict Groundwater Recharge and Discharge in the Cumberland Plateau.*

Albert E. Ogden, David S. Kaufman, *Compilation of Driller Well Records for Twenty Topographic Maps Around Murfreesboro, Tennessee.*

Arthur Bradfield, *Developing Ground-Water Resources in East Tennessee: Four Case Studies.*

POLICIES/PROGRAMS

1:00-2:30

Jennifer M. Kocak, *Technology Answering the Demand for Cleaner Water-Based Recreation: The Boating Industry Responds to the New EPA Regulations.*

Eric Hutton, *Tennessee's Environment: 25 Years of Progress, 1996.*

William M. Park, *EPA's Policy on Flexible State Enforcement Responses to Small Community Violations.*

TECHNOLOGY

3:00-4:30

Artur Kolodziejwski, Larry McKay, Norbert Thonnard, *Development of Krypton-85 as an Emerging Tool for Age-Dating Groundwater.*

Mel Eakins, Don Getty, *Design of Innovative Hydraulic Features for the Proposed Kentucky Lock.*

John Daughenbaugh, *A Flood Warning System in Appalachia: Harlan, KY.*

STREAM HYDROGRAPH ANALYSIS TO PREDICT GROUND WATER RECHARGE AND DISCHARGE IN THE CUMBERLAND PLATEAU ¹

Robert G. Liddle ²

ABSTRACT: Yearly continuous discharge hydrographs were obtained for 16 watersheds in the Cumberland Plateau area of Tennessee. Baseflow was separated from storm runoff using computerized hydrograph analysis techniques developed by the USGS. The programs RECESS, RORA, and PART were used to develop master recession curves, calculate ground water recharge, and ground water discharge respectively. Station records ranged from 1 year of data to 60 years of data with areas of 0.67 to 402 square miles. Recharge ranged from 7 to 28 inches of precipitation while ground water discharge ranged from 6 to 25 inches. Baseflow ranged from 36 to 69% of total flow. For sites with more than 4 years of data the median recharge was 20 inches/year and the 95 confidence interval for the median was 16.4 to 23.8 inches of precipitation. The results compared favorably with water budget calculations showing about 19 inches of recharge in the Cumberland Plateau. The software was easy to use and the results were beneficial in developing watershed ground water flow models.

ADDITIONAL KEY WORDS: software, modeling, water budget.

INTRODUCTION

The analysis of hydrologic impacts and assessment of water supply often require accurate surface and ground water modeling. Ground water recharge and discharge estimates are essential in using these models. One of the options in calculating ground water recharge is the use of empirical models such as hydrograph analysis. A hydrograph is generated from yearly continuous discharge measurements. The baseflow is separated from the storm runoff component graphically and the results can be used to calculate both ground water recharge, discharge and loss through consumption or evapotranspiration. Recent computer models have been developed to do this quickly. This project used several of these models to estimate recharge and discharge in the Cumberland Plateau province of East Central Tennessee.

¹ Paper presented at the American Water Resources Association, Tennessee Water Resources-Symposium, Nashville, TN., February 24-26, 1997.

² Rob Liddle is a hydrologist with the US Department of Interior, Office of Surface Mining, Suite 500, 530 Gay St. SW, Knoxville, TN 37902, (423) 545-4103, rliddle@ro.osmre.gov.

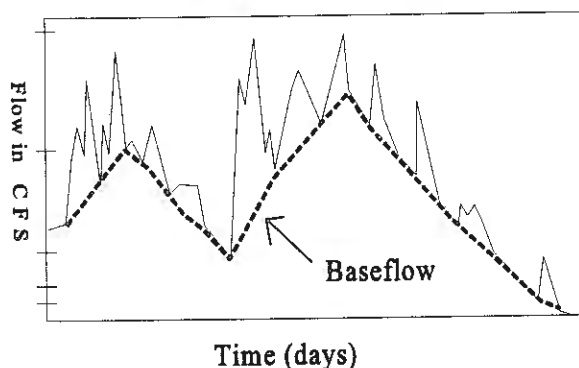
METHODS

Records provided in the U.S. Geological Survey's "Water Resources Data - Tennessee" were reviewed to find surface water gaging locations in the Cumberland Plateau region with at least one year of continuous daily flow records. Gauging sites needed to be at nick points in the watershed where it can be reasonably assumed that most of the ground water surfaces and recharges the stream prior to the gauge site. The watersheds needed to have local ground water flow as opposed to regional trans-valley ground water components. The steep topography of the Cumberland Plateau region makes these conditions easier to find than in other parts of the country. Stress relief fracturing is the predominant ground water flow component in these areas (Wyrick, 1981). The review identified 16 watersheds that met this criteria. The USGS in Knoxville supplied the raw data from Watstore in "2 and 3 Card" computer format. The sites that were studied follows:

<u>USGS #</u>	<u>Sq Mi.</u>	<u>Years</u>	<u>Description</u>
03407881	0.69	4	Anderson Br. - Montgomery
03407875	0.67	7	Bills Br near Hembree
03407877	2.19	5	Bowling Br. - Smokey Jct.
03409500	272.00	60	Clear Fork near Robbins

03407908	198.00	10	New River at Cordell
03544500	50.20	1	Richland Creek
03408815	3.62	5	Crooked Creek near Allardt
03408600	1.11	5	Long Br. Near Grimsley
03407882	0.92	4	Lowe Br - Montgomery
03571500	116.00	1	Little Sequatchie River
03408500	382.00	56	New River at New River
03409400	98.00	2	White Oak Cr. At Rugby
03571000	402.00	34	Sequatchie River - Whitwell
03407875	5.08	2	Shack Cr. At Hembree
03407876	17.20	7	Smokey Cr. at Hembree
03409000	13.50	1	White Oak Cr. At Sunbright

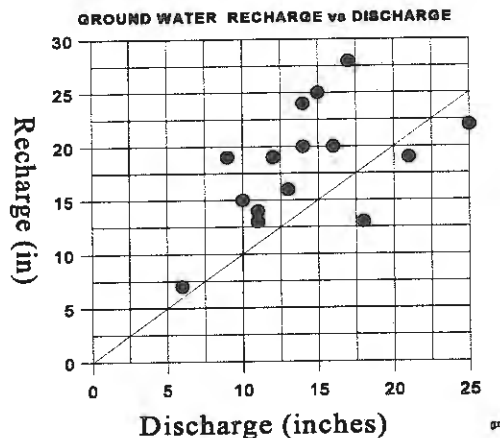
STREAM HYDROGRAPH



The procedure of hydrograph separation is discussed in standard hydrology texts (Singh, 1992; Fetter, 1988; Satterlund, 1992). The baseflow hydrograph is estimated from the total runoff hydrograph, the baseflow recession characteristics, and information about the watershed hydraulics. When baseflow is superimposed on a total flow hydrograph (See below) the groundwater or surface runoff for any time period may be calculated using trapezoids, planimeters or Simpson's Rule.

The streamflow records must be compared with temperature and precipitation data to properly interpret the hydrograph and develop the baseflow hydrograph. This process can become tedious when evaluating many years of record. Fortunately computer codes have been developed to allow this analysis to be done quickly. The project used the USGS programs RECESS, RORA, and PART to develop master recession curves, calculate recharge, and estimate ground water discharge, respectively (Rutledge, 1993). Documentation with the programs adequately explains the rationale and methods used in the code along with limitations of the programs. The model has been shown to compare reasonably well

with manual hydrograph methods. USGS Watstore data is easily compatible with the input format of the program although data can be entered manually.



RESULTS

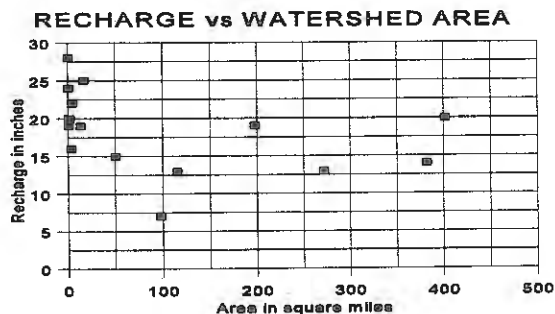
Results from model runs showed patterns that required further investigation to explain. Three sites were found to discharge more groundwater than watershed recharge as the following figure shows:

The three sites had 3, 3, and 5 inches more discharge than recharge with only 1, 2, and 1 years of record respectively. One watershed is the discharge zone of 2 regional sandstone aquifers. This means groundwater did not all originate from within the watershed. The other two sites may have had an unusually high recharge rate the prior year, may receive transbasin regional groundwater, may have had a significant groundwater flow under the gauging station, or may have had large snowmelt events that were incorrectly calculated as ground water discharge. These types of problems must be considered in evaluating any hydrograph models.

Most of the study sites were forested with significant flow from groundwater as the following figure shows: The median base flow percent of total flow was 47% with the 90% confidence limits of 41% and 53%. The smaller watersheds tended to have somewhat higher recharge rates, as the following figure shows, but the result is not statistically significant. Most of the smaller watersheds had few years of record and may be more susceptible to regional ground water flows.

An attempt was made to evaluate recharge versus elevation since the Cumberland Plateau mountains receive higher precipitation than the valley bottoms.

However, no statistical trend could be determined.



Three watersheds were evaluated based on their size and years of record. Clear Fork has an area of 272 square miles and 60 years of record. New River has 382 square miles and 56 years of record. Sequatchie River has 402 square miles and 34 years of record. These watersheds had 13, 14, and 20 inches of recharge per year respectively. Discharge was 11, 11, and 16 inches respectively. The Base Flow index was 45 %, 40 %, and 60 % respectively. These values may be indicative of similar size watersheds in Eastern Tennessee due to similarities in ground water hydraulics (fracture controlled) and precipitation.

The difference between ground water recharge and discharge may be assumed to be loss through consumption or more importantly, ground water evapotranspiration. The larger watersheds showed losses of about 3 inches of rain per year, which is in line with other studies conducted in eastern Appalachia showing 1 to 2 inches of losses (Rutledge, 1993, p.40).

For the Cumberland Plateau as a whole, data was summarized using only those watersheds with 4 or more years of record. The median recharge was 20 inches/year with a 90% confidence interval of 16.4 to 23.8 inches. The median groundwater discharge was 14 in/yr with a 90% confidence interval of 11.8 to 16.2 inches. The following figure shows the interquartile ranges, medians, means and extremes (Statgraphics):

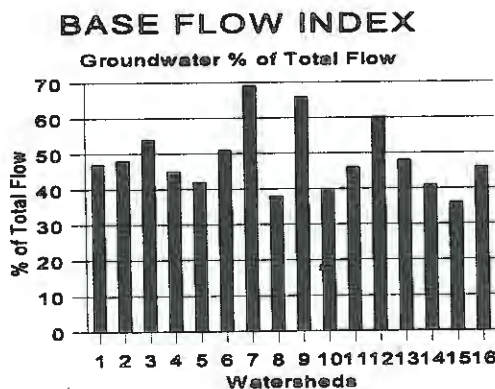
The supporting data and computer printouts are available from the Office of Surface Mining in Knoxville, TN. Below are the summary data for the individual watersheds evaluated:

Site	Recharge	Discharge	BF Index
Anderson	24 in	14 in	47 %
Bills	28	17	48
Bowling	20	14	54
Clear Fk	13	11	45

Cordell	19	12	42
Richland	15	10	46
Crooked	16	13	51
Long Br	20	16	69
Lowe Br	19	9	38
L Sequat.	13	18	66
New River	14	11	40
Rugby	7	6	46
Sequatchie	20	16	60
Shack	22	25	48
Smokey	25	15	41
Sunbright	19	21	36

Model Verification

Any model result should be calibrated with actual field data. This proved difficult for this study due to a lack of local ground water studies. As an alternative a monthly water balance can be calculated for the watershed of interest using information on precipitation, infiltration rates, soil moisture holding capacity, evaporation and transpiration. One such water budget was calculated independently by Skyline Coal Company (Skyline, 1996) using the Thornthwaite method. Rainfall was 63.9 inches, runoff was 19.9 inches or 31% of total precipitation. The water budget showed a yearly recharge rate of 19 inches per year (base flow index of 49%) for the Cumberland Plateau area near the Sequatchie River. This compares favorably with the model result of 20 inches per year for the Sequatchie River.



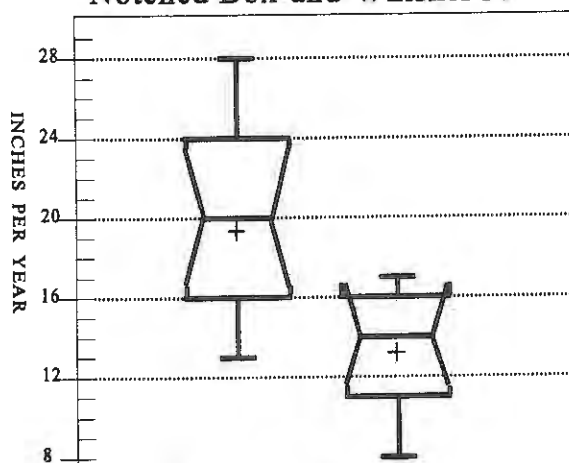
CONCLUSIONS

Recent computer codes enable a quick and thorough analysis of hydrographs for calculating ground water recharge and discharge. Readily available USGS daily

discharge records in computer format can be used in these models. Results, when calibrated, can be used for input parameters in ground water flow models. This study showed a median recharge rate of 20 inches/year for the Cumberland Plateau. The 90% confidence interval of the median was 16.4 to 23.8 inches/year.

ACKNOWLEDGMENT

Notched Box-and-Whisker Plot



Recharge Discharge
Sites w/ 4 or more years of data.

The author would like thank George Miller, Director and Willis Gainer, Supervisor, for their support of this project. The assistance of Bradley Brian, Hydrologist at the USGS in Knoxville for supplying the data in computer format is greatly appreciated. Finally, the cooperation of Skyline Coal Company for their water budget calculations that improve our understanding of the Cumberland Plateau hydrology.

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**COMPILATION OF DRILLERS WELL RECORDS
FOR TWENTY TOPOGRAPHIC MAPS
AROUND MURFREESBORO, TENNESSEE**

Albert E. Ogden,

and

David S. Kaufman¹

INTRODUCTION

Rutherford County and the surrounding area is the fastest growing portion of the State. Although municipal water is supplied to many residents, most of the area still relies on ground water. Unfortunately, most ground water studies of the area have been regional overviews (Galloway, 1919; Piper, 1932; Newcome, 1958; Newcome and Smith, 1962; Burchett and Moore, 1971). As a result, land buyers wishing to build a house have no idea as to how far they will need to drill, whether sufficient quantities of ground water even exist, or whether sulfur water which is prevalent, will likely be encountered. In addition, from a contaminant flow perspective, little information has been available to predict plume migration direction. One significant ground water study of the upper Stones River basin was made by Moore et. al. (1969) but even this does not provide the information necessary to fulfill the needs of rapid growth. Therefore, as a means to provide a more detailed data base for the region, a compilation of well drillers' logs was made for 20 topographic maps generally centered around Murfreesboro (Figure 1). This represents an area of approximately 1000 square miles.

HYDROGEOLOGIC SETTING

Most of the study area is situated within the Central Basin physiographic province, which is underlain by nearly flat-lying limestones of Ordovician age that have been gently upwarped to form the Nashville Dome. Most wells in the Central Basin are drilled to the Murfreesboro, Ridley, or Lebanon limestones, but some wells on the rim escarpments obtain water in the Bigby-Cannon perched upon the Hermitage Formation. A few deep wells have been drilled into the Knox Group. In addition, some wells were inventoried in the Eastern Highland Rim and the Western Highland Rim where ground water is usually obtained from the Mississippian-aged Ft. Payne chert where water is perched upon the Chattanooga Shale. Approximately 1000 feet of stratigraphic section exists in the study area between the top of the Knox Group and the Ft. Payne chert.

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METHODS

Drillers' well records were obtained from the Tennessee Division of Water Supply for the 20 topographic maps. Only wells field checked by State personnel and having latitude and longitude data were utilized. This data set includes information for over 600 wells. From geology maps and reported depth of well and depth to producing horizon, aquifer determination was made. Reported well yields were then grouped by aquifer and an average calculated. In addition, wells producing sulfur water were noted in an attempt to ascertain stratigraphic or aerial delineation of "bad water". Finally, the reported depth to water was subtracted from the estimated well top elevation and the data entered into a Rockware Utilities Software package to generate a potentiometric surface for each topographic map.

RESULTS

Of the 20 topographic maps shown on Figure 1 for which a broad inventory was made, six were investigated in more detail. This data set includes information for 191 wells. Table 1 summarizes the range in yield, average yield, percentage of wells producing less than 5 gpm, percentage of wells reported to have "good" water, and the average elevation of the aquifer. This last statistic enables a home-owner to calculate the expected depth to an aquifer by determining the surface elevation and subtracting the average elevation of the aquifer. The yield information demonstrates that production in limestone aquifers is highly dependent upon a well bore intersecting fractures although observation of outcrops during and after storm events demonstrates that a significant amount of water moves through bedding planes particularly in the thinner bedded formations such as the Lebanon Limestone. The lowest yielding aquifers are the massive bedded Bigby/Cannon and Carters limestones. The Bigby/Cannon is very cavernous and exposed primarily on hillslopes. Therefore, most of the available recharge likely enters sinkholes and runs through discrete conduits versus an integrated network of fractures. The Carters Limestone, as well as the Murfreesboro, are both confined aquifers throughout most of the study area being overlain by the Hermitage and Pierce formations, respectively. In general, where these aquifers are confined, yields are lower and sulfur is more abundant. The Murfreesboro Limestone is the most widely utilized aquifer in the study area and has some very high yields where it is exposed at the surface. Due to the thinness of the Pierce Limestone (25 ft.), it has been grouped on Table 1 with the Murfreesboro Limestone. Wells that begin in the Ridley Limestone but are drilled into the Pierce Formation, generally encounter highly mineralized sulfur water. The Pierce Formation is also the likely source of sulfur water in wells producing from the Murfreesboro Aquifer.

Newcome, Jr. (1958) reports that yields from the upper Knox dolomite for the Central Basin as a whole are generally very low and the water commonly of poor quality. He notes, and the authors of the present study concur, that yields and quality of the Knox usually are better near the center of the Nashville Dome. Table 1 shows that the upper Knox Aquifer in the area covered by the six topographic maps has an average yield of 19 gpm with only 21% having yields of less than 5 gpm. Unfortunately, 38% of the wells were reported to have bad water quality. Poor water quality in the Knox is undoubtedly due in part to deep confinement, but also is likely related to inter-formation

transfer of sulfur-bearing waters from the Pierce Formation since well casing seldom extends below the required upper 21 feet.

Figure 2 shows one of the twenty potentiometric surface maps made for the study. Due to the significant distance between wells, inaccuracies of welltop elevations and seasonal effects on water levels were generally overcome. In addition, outliers representing bad data or perched water were eliminated so that rather smooth water table contours could be generated. The potentiometric surface maps show that the "water table" is relatively flat and that a significant amount of ground water discharge occurs along the various forks of the Stones River in the Woodbury/Murfreesboro area.

CONCLUSIONS

Well drillers' logs have proven quite useful in understanding more about the occurrence, flow direction, and water quality of the study area. Although some of the reported data may not be accurate, the quantity of data appears to mask these outliers. Ground water movement in the area is generally through fractures, and thus well yields are highly variable. Therefore, an effort to delineate fracture zones through a photo-lineament analysis should be made before drilling. Whenever possible, drilling through the Pierce Formation should be avoided due to bad water quality. If drilling must go through the Pierce, consideration should be made to case and grout out the bad water. Due to the common low yield, poor quality, and great depth of the Knox dolomite, a home-owner should consider drilling a second shallow well versus continuing drilling to the Knox. Construction of the potentiometric surface maps, although still generalized, have provided valuable tools in helping to predict contaminant flow direction. Finally, the information compiled in this study has enabled the foundation to be laid for more in-depth investigations.

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Table 1

SUMMARY DATA FOR REPORTED WATER WELLS IN MURFREESBORO REGION OF MIDDLE TENNESSEE						
AQUIFER	# OF WELLS REPORTED	AVG. AQUIFER ELE. (ft)	YIELD (gpm)		% UNDER 5 gpm	WATER QUALITY %GOOD
			RANGE	AVG		
FT. PAYNE	31	1154	3-50	13.89	28	97
LEIPERS/CATHEYS	9	1095	2-50	13.25	50	89
BIGBY/CANNON	4	956	3-7	5	33	50
HERMITAGE	5	814	2-40	18	20	100
CARTERS	7	734	1-15	4.6	80	40
LEBANON	15	677	1-60	14.09	55	73
RIDLEY	27	559	1-40	10.25	33	72
PIERCE/MURFREESBORO	72	512	1-97	13.1	15	70
KNOX	23	314	1-75	19.26	21	62

SMYRNA	WALTERHILL	LASCASSAS	MILTON	AUBURNTOWN
ROCKVALE	MURFREESBORO	DILTON	READYVILLE	WOODBURY
ROVER	FOSTERVILLE	WEBBS JUNGLE	BEECH GROVE	HOLLOW SPRINGS
UNIONVILLE	DEASON	WARTRACE	NOAH	FREDONIA

Figure 1. Location of the 20 inventoried topographic maps. Stars indicate maps studied in more detail.

WALTERHILL QUADRANGLE

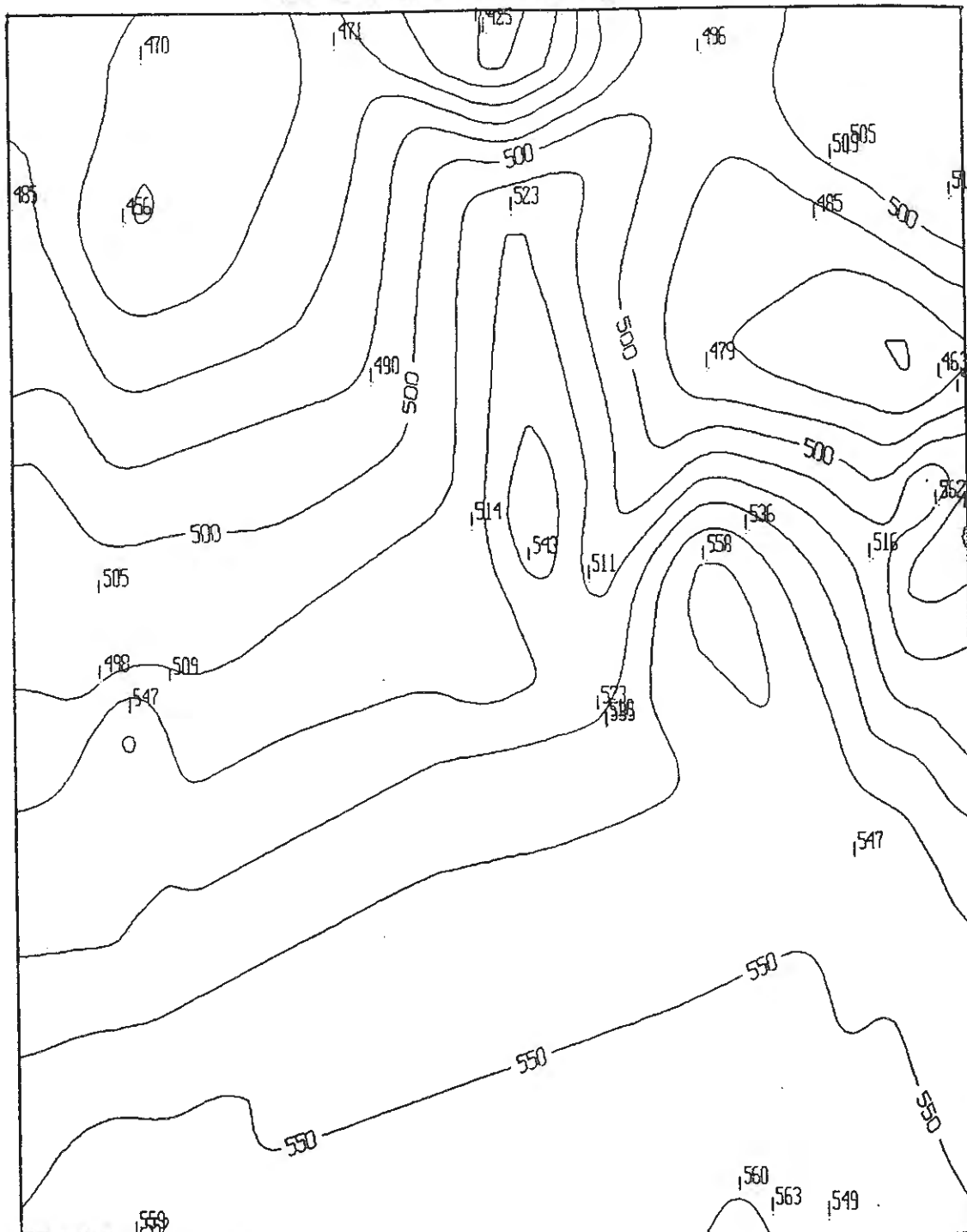


Figure 2. Potentiometric surface map for the Walterhill Quadrangle.

DEVELOPING GROUND-WATER RESOURCES IN EAST TENNESSEE: FOUR CASE STUDIES

***Arthur Bradfield, CGWP¹**

It is widely known that Public Water Systems (PWS) in west Tennessee can rely on ground water as a source for potable water. However, many utility managers and city officials may not be convinced that a plentiful supply of ground water can be found in middle and east Tennessee, as well. Tapping into the source is usually not as easy as drilling wells in the sand formations of west Tennessee, but the benefits are well worth the effort.

Because ground water does not fluctuate in quality like surface water, initial and long-term treatment costs are significantly lower. Filtration of ground water can usually be accomplished using direct filtration at considerable savings over the costs of conventional treatment of surface water. Ground water is less likely to be contaminated with man-made chemicals or organisms that cause disease, thereby providing a safer water supply for each customer.

The following four case studies conducted by Bradfield Environmental Services, Inc. are provided to illustrate how PWS in east Tennessee can save millions of dollars by developing their ground-water resources. Wells capable of producing 750 to 1300 gallons per minute (about one to two million gallons per day) were located and developed for water systems serving Erwin, Elizabethton, Decatur, and Athens, Tennessee. These PWS saved substantial amounts of money by avoiding conventional filtration of surface water supplies, building one treatment facility instead of two to filter spring supplies, and by avoiding expensive upgrades to existing treatment facilities.

ERWIN, TENNESSEE:

Problem: Erwin Utilities had relied primarily on springs as their raw water supply. Faced with requirements of the Surface Water Treatment Rule to filter springs under the influence of surface conditions, they were considering their options. These options included upgrades to existing facilities, building new treatment plants for their springs, or conventional filtration of water from the Nolichucky River. The river would obviously meet future demands for water, but would have required millions of dollars to build an intake structure and a conventional treatment facility.

Solution: A ground-water investigation conducted by BES, Inc. identified the Honaker formation as the most likely geologic formation in the area to produce ground water. Most streams lost flow

¹Bradfield Environmental Services, Inc., 2176 Hillsboro Road, Suite 120, Franklin, Tennessee 37069, (615-790-1000).

to the ground water system as they flowed across the Honaker formation. Seven test wells were drilled, of which two wells each produced 500 to 700 gallons per minute (gpm). These wells are currently being developed as ground-water supplies for Erwin Utilities. One well was determined not to be under the influence of surface conditions and will require only chlorination before distribution. Developing their available ground-water resources saved Erwin Utilities a substantial amount of money by reducing their construction expenses and long-term treatment costs.

ELIZABETHTON, TENNESSEE:

Problem: The filter plant for Big Springs was unable to handle occasional periods of high turbidity following rainfall, forcing the plant to be out of service for days at a time. The water system was faced with routing water a long distance around the city to supply the area normally serviced by Big Springs. In addition, another spring would require filtration under the Surface Water Treatment Rule. Both options were expensive and did not increase the available water supply for the City of Elizabethton.

Solution: A ground-water investigation was conducted in the vicinity of Big Springs, an area of about 10 square miles underlain by the Knox Group. Although the results of the initial study identified areas with favorable geologic and hydrologic conditions, six test wells failed to produce more than 50 gpm. The study area was expanded to include part of the nearby Buffalo Creek basin, an area draining about 40 square miles underlain by the Knox group and Honaker formation. Four more wells were drilled, three of which proved capable of producing 500 to 800 gpm.

Funding for the project allowed for drilling one more well. Permission was secured to drill another well upgradient from Big Springs in hopes of locating a source closer to the existing treatment facility. This well intercepted one fracture which supplied 1300 gpm. Pumping the well appeared to have little effect on the spring discharge, greatly increasing the available water supply for the Big Springs facility. Water quality is now being studied to determine if water from the well is subject to fluctuations in turbidity.

DECATUR, TENNESSEE:

Problem: The Town of Decatur was obtaining water from two springs, located on opposite ends of the area supplied by the Decatur Water System. In response to the Surface Water Treatment Rule, plans were under way to build two filter plants. Not only were two plants required, but the lease on one spring had expired. This was a problem, given the significant difference between what the owner of the spring thought the water was worth and the price the utility could afford to pay for the spring.

Solution: A ground-water investigation identified several areas with the potential for producing abundant ground water. Because of capital investments already made near Eaves Spring, the test

drilling program was limited to one area. The first well drilled was located down-gradient from the spring near the Tennessee River close to the contact between the Conasauga Group and the Knox Group. This well encountered gravel deposits from 130 to 170 feet below land surface that produced 650 gpm. Another well drilled near the spring produced about 100 gpm and a third well near well #1 encountered mud zones that would have made the well difficult to develop as a water source.

The Town of Decatur is now in the process of building one treatment facility instead of two. The yield of the new well, combined with the spring discharge, will produce sufficient water to meet demand. The cost for a second facility and court costs that may have been necessary to continue using the second spring were avoided. The well near the Tennessee River is considered to be under the influence of surface conditions, but is consistently producing water with a turbidity of about 1 NTU, a level that can be economically treated by direct filtration.

ATHENS, TENNESSEE:

Problem: The City of Athens, served by the Athens Utilities Board (AUB), obtains much of its water from Ingleside Spring. Approximately two thirds of the water treated by the AUB comes from Ingleside Spring (about 1250 gpm), along with additional water from Oostanaula Creek. The sources are combined before they reach a conventional treatment facility. Water from Oostanaula Creek has tested positive for *Cryptosporidium*, a protozoan known to cause disease in humans. The turbidity of water from Oostanaula Creek increases rapidly following rainfall, causing most of the water treatment problems and associated treatment costs for the AUB.

Solution: A ground-water investigation recently completed by Bradfield Environmental Services, Inc. identified areas of the Oostanaula Creek basin that are underlain by limestone and dolomite formations of the Knox Group. Stream discharge data indicated areas draining these formations were deficient in discharge relative to streams in areas of the basin underlain by shale. Six test wells were drilled. Of the 6 wells drilled, three wells produced several hundred gallons of water per minute. Two wells drilled in the Kingsport formation, were selected for aquifer tests. One well produced about 500 gpm while the fifth well drilled was pumped at over 1100 gpm. These wells will eliminate the need for the AUB to obtain water from Oostanaula Creek, thereby providing a safer water supply for the City of Athens.

There are several important components for a successful ground-water investigation. A favorable climate is needed, for without plenty of precipitation, there can not be sustained ground-water discharge. In Tennessee, we receive approximately 50 inches of rainfall each year. Much of the rain that does not leave a basin as surface runoff goes to replenish the ground-water system.

A second factor is favorable geology. The geology of the study area must be evaluated to locate those formations most likely to produce ground water. Geologic formations vary in the amount of pore space and fractures available to store and transmit ground water. Rock formations must have sufficient storage capacity to maintain ground-water discharge during dry periods. While there

are some areas, particularly in middle Tennessee, that are underlain by impermeable rock formations; much of middle and east Tennessee is underlain by more soluble limestone formations capable of producing abundant ground water.

Stream flow characteristics should also be studied to identify those stream reaches that are gaining water from the ground water systems and those streams that lose water to the underlying aquifer. Locating sites for test drilling based on hydrogeologic data will save money by minimizing the number of test wells required to locate a productive well.

Perhaps one of the most critical factors in determining the success of a ground-water investigation involves the commitment of water system management and city officials. When drilling for large volumes of ground water in areas underlain by rock formations, it is necessary to drill a sufficient number of test wells to achieve success. This can result in a degree of uncertainty regarding the total cost of developing a ground-water source, making some officials reluctant to try.

For example, it took only three wells to identify the best well for Decatur, Tennessee, but it took 11 wells to complete the investigation for the City of Elizabethton. Had Elizabethton officials decided to halt the test drilling program after the initial 6 wells funded were drilled, we would have failed to achieve the study objectives and all the money invested would have been considered wasted. As it turned out, Elizabethton has a 1300 gpm well near their existing facility and has located three additional sources of ground water that will meet future demands for water.

Ground-water professionals and engineers must continue to educate those charged with managing PWS, as well as those agencies that fund water projects, about the advantages and availability of ground water. While locating highly productive wells is not without risk, ground water is a viable option for many small to medium size PWS in middle and eastern Tennessee. One thing is certain: filtration of most surface water sources is the most expensive option. As the saying goes, "Nothing ventured, nothing gained". If the initial study of the geology and hydrologic characteristics of an area indicate the potential for ground water exists, it is usually worth going to the expense of a test drilling program.

TECHNOLOGY ANSWERING THE DEMAND FOR CLEANER WATER-BASED RECREATION: THE BOATING INDUSTRY RESPONDS TO NEW EPA REGULATIONS

Jennifer M. Kocak¹

INTRODUCTION

The Federal government has an established history of intervention into the activities of private industry *pro bono publico* - for the public good. The ability to intervene against activities deemed hazardous to the public health and welfare, and to regulate such practices is a legitimate and necessary legislative tool. Perhaps nowhere else has this policing power been more actively utilized in recent decades than in the realm of environmental protection. By necessity, much of this regulatory action has taken the form of coercive enforcement of environmental statutes, with clearly stated penalties for industry noncompliance. In a departure from this formula, the Environmental Protection Agency, in cooperation with the recreational boating industry, has devised a program targeted at voluntarily decreasing pleasure boat and personal water craft hydrocarbon emissions by 75% by 2025.

EFFECTS OF HYDROCARBONS

Hydrocarbons are a category of compounds containing molecular chains of hydrogen and carbon atoms. Thus, hydrocarbon is a broad and inclusive term. Here we are concerned with hydrocarbons generally associated with petroleum-based compounds, and specifically associated with lubricating oil and gasoline. Previously, it has received little attention. This lack of attention is despite knowledge by the scientific community that petroleum emissions have the potential to create large scale environmental damage to aquatic systems. Due to current refining processes, gasoline is more toxic than the crude petroleum from which it is derived. (Laws 1993 Chapter 13) Hydrocarbon emissions result in some of the most toxic effects recognized in the environment. These toxic effects maybe grouped into three categories:

- 1) effects associated with coating the organism;

This category is not characteristic of refined petroleum products like gasoline, and therefore is of little significance in this discussion.

- 2) effects associated with absorption and ingestion.

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Here, hydrocarbons become incorporated into the tissue of the organism. This is characteristic of refined petroleum products such as gasoline. Incorporation may ultimately reach concentrations sufficient to disrupt the normal functioning of the organism. (Laws 1993 p 433) The average individual is likely to encounter the effect of hydrocarbons in a more direct manner. Studies on fish tainting conclude that there is a strong positive correlation between the amount of petroleum products in water and the objectionable taste of the fish living in these waters.

3) effects associated with weathering.

This is a physical process associated with the evaporation of hydrocarbons into the atmosphere. Overall, hydrocarbons have limited solubility in water. Small amounts will dissolve in water, while the bulk will adhere to the surface. The hydrocarbon film thus formed impairs normal evaporation. Low-molecular-weight-hydrocarbons (gasoline) again prove to be the most potentially toxic, exhibiting both the highest levels of water solubility and the greatest rates of evaporation.

Because hydrocarbon pollution emitted from water craft is released slowly, and in an almost invisible state, the general population is ignorant of the potential volume of pollution generated. It was only after EPA attention that the massive amounts of hydrocarbons being emitted into the navigable waterways became apparent. Specifically,

The EPA's Certification Division has concluded that two-stroke outboard motors pass 25 percent of their total hydrocarbon intake into the environment. Outboard motors emit 1760 pounds of hydrocarbon material for every 1000 gallons of fuel. (Mele 1993 pp 27-29)

This translates into approximately 1.76 pounds of hydrocarbon per gallon of gasoline (approximately 352 pounds/yr/boater).

TECHNOLOGICAL ADVANCEMENTS

The EPA and the Boating industry have cooperatively selected three categories of outboard engineering whose technical refinement will allow boating industry compliance with Clean Air Act mandated hydrocarbon emissions reduction. This section describes in detail the current technology and the potential emission control technologies as well as pollutant levels for each technology for spark-ignition engines, four stroke technology, direct injection 2-stroke technology, and catalyst technology.

The current technology for outboard and personal watercraft is predominantly two-stroke. This technology was used on the first outboard and is still used today. Following the combustion of the air-fuel-oil mixture, the resulting exhaust goes are pushed form the cylinder. Inevitably portions of the air-fuel-water exits the cylinder along with exhaust gases. The result is up to 30

percent of fuel exits through the cylinder unburned with the high amounts of hydrocarbon. These engines will soon become a rarity to the boating industry while more efficient technologies increase in popularity. The recalibration of this current technology has been examined however these methods will achieve emission reductions lower than required. Therefore, this engine type may soon become non-existent.

Four-stroke engines were only sold by one company in the past. The new regulations have encourage the developments in the arena of four-stroke engines which are now being manufactured by four companies. Four-stroke technology eliminates the release of the air-fuel-oil mixture and thus greatly reduces the amount of hydrocarbon emissions. At one time this technology was limited by power-to-weight considerations. However the new technology spurred by the EPA regulations has encouraged modification to be made to make the use of four-stroke engines on outboard and personal watercraft.

Direct injection two-stroke technology is also becoming increasingly more common on outboard and personal watercraft. The cleaner type two-stroke technology directly injects the fuel into the combustion chamber, omitting the air-fuel-oil losses that occurred with the current two-stroke/spark-ignition technology. With direct injection designs, exhaust gases are pushed out from the combustion chamber with the air/oil mixture from the crank case. The provides the required hydrocarbon reduction along with a substantial improvement in fuel economy. There a currently two types of direct injection technology. The first uses air to provide the fuel injection and the second uses a mechanical means to develop injection pressures. The air assisted system is also know as the Orbital's Small Engine Fuel Injection System (SEFIS). This system was developed by Orbital Corp. Of Australia. In this system the Fuel and Oil Metering Pump controls the amount of fuel delivered to the pump based on speed and fuel flow. An example of this system is the 200hp DFI 2-stroke introduced by Mercury Marine.

The fourth and final form of technology is the use of a catalyst. Although catalyst can be used there are still a number technological hurdles that will need to be overcome. A main complication with the use of catalyst is that water is mixed with the exhaust for engine surface temperature and noise reduction. Catalyst must be designed so that it exists in the upstream point of water flow. Also severe packaging constraints make the use of catalyst with outboard and personal watercraft very difficult.

OBSERVATIONS AND CONCLUSIONS

The cooperative EPA-Boating Industry hydrocarbon emission reduction program as conceptualized marks a significant departure from a history of direct regulatory environmental programs. It is particularly noteworthy for its goals of reducing a pollutant form with the

potential to adversely effect all aspects of the systemic natura environment. The ultimate success or failure of the cooperative EPA-Boating Industry hydrocarbon emission reduction program will be founded on such intangible factors as continued commitment to the program by the contracting parties, the evaluation of watercraft technology, and the direction of market buying habits. Finally, with final assessment of program success or failure set more than a quarter century in the future, whatever actions are taken must truly stand the test of time.

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**EXCERPTS FROM THE EXECUTIVE SUMMARY
OF TENNESSEE'S STATE OF THE ENVIRONMENT REPORT:**

Tennessee's Environment: 25 Years of Progress, 1996

Eric Hutton¹

The past twenty-five years have seen great progress in overall environmental quality in Tennessee. Our streams, lakes, and air quality have improved dramatically. The local governments, citizens and businesses of the state have also improved their solid and hazardous waste handling methods. Since the General Assembly created the Stream Pollution Board in 1945, Tennessee has made much progress in protecting Tennessee's waterways and drinking water supplies. Since that time the state has increased its water programs to protect groundwater and to protect public drinking water from such contaminants as *Cryptosporidium* and bacteria. The Department has also promoted efforts to protect natural areas, such as the Ghost River portion of the Wolf River, and to restore degraded natural resources, such as the Pigeon River. Even with all of these improvements, vexing challenges still remain: maintaining compliance with the ground level ozone standard, posting of fish for contamination with toxic chemicals, increasing the miles of streams and acres of lakes that support their intended use, preventing contamination of groundwater, decreasing landfill space, protecting bio-diversity, and creating clean indoor environments. Now that many initial problems have been solved through regulatory strategies, it is time examine more closely the benefits of pollution prevention and of encouraging industry, environmental advocacy groups, educational institutions, and government to work together to meet these challenges through organizations like the Tennessee 2000 Initiative.

EXTENDED ABSTRACT

The State of the Environment Report examines the progress Tennessee has made in the past 25 years in protecting its environment: air emissions, river and stream contamination, wetlands protection, drinking water safety, solid and hazardous waste disposal, Superfund site cleanups, toxic chemical releases, natural area and heritage preservation to name just a few. It also examines the challenges ahead for the next 25 years and strategies available to meet those challenges.

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The Department of Environment and Conservation maintains numerous state parks and natural areas that showcase the natural treasures of Tennessee. These areas are as diverse as the cranberry bogs and the Highlands of Roan in East Tennessee, to the Cedar Glades and Rock Houses of Middle Tennessee, to the Ghost River Section of the Wolf River and Reelfoot Lake in West Tennessee. These areas provide us one of the perspectives of why we have environmental laws--to protect and preserve the condition and character of our natural areas. However, our society must also have clean water for citizens to drink, clean air for all citizens to breathe, and safe solid and hazardous waste disposal systems.

A little over 50 years ago it was not uncommon for cities to discharge untreated sewage into creeks and rivers and for industrial discharges to eliminate fish and other aquatic life from even large rivers. This situation began to change in 1944 when the Tennessee Valley Authority loaned Mr. S. Leary Jones to the Tennessee Department of Environment and Conservation. In 1945, Tennessee became the first southern state to pass a water pollution control law when the General assembly created the Stream Pollution Control Board. Since that early start, water quality has steadily improved. In 1972, 42 percent of the stream miles and 63 percent of the lake acreage were rated as supporting designated uses. In 1994 those numbers had increased to 65 percent of stream miles and 79 percent of lake acreage due to increased environmental protection and increased water quality monitoring. Many sections of our rivers are dramatically "more alive" than they were just a few years ago. For example, after North American Rayon installed its new effluent treatment facility, the species diversity of the downstream section of the Watauga River improved tremendously. The Pigeon River has also seen considerable improvement in its water quality as well due to improvements to an upstream papermill.

The effort to protect water quality has now expanded to include groundwater. Approximately 1.5 million Tennesseans rely on utilities that use groundwater, while another 400,000 citizens rely on private wells and springs. Tennessee's population, its diverse economy, and its varying ecoregions present a wide variety of challenges to groundwater quality: chemical usage by industry and commercial establishments, bacteria from surface water, solid and hazardous waste disposal practices, fertilizer and pesticide application, underground storage tanks, road salt application, and miscellaneous leaks and spills. Many of these threats are regulated by other TDEC divisions.

Tennessee is a national leader in providing safe drinking water to its citizens. No source of drinking water used by public water systems has been found to contain lead or copper in quantities of concern. Only 3 percent of Tennessee water systems were out of compliance during 1994. Nevertheless from October 1993 to September 1994, 19 percent of the population was potentially impacted by drinking water violations. Many of these violations were for failing to monitor for bacteria. With improved operator training, increased inspections, and improved testing capabilities, bacteriological monitoring violations have decreased steadily over the past 10 years. Tennessee requires that surface water be filtered to remove disinfection-resistant pathogens such as *Cryptosporidium parvum*. Incidences of waterborne illnesses in Tennessee are uncommon.

Other regulatory divisions that have an indirect impact on water quality include Solid and Hazardous Waste, Underground Storage Tanks, and Superfund. Each of these programs is designed keep harmful chemicals from entering Tennessee's waters. Since 1989 the amount of solid waste generated in the state has increased steadily from approximately 6 million pounds to 7.5 million pounds annually. Since the amount of waste diverted from landfills has also increased, however, the total amount of trash being landfilled has actually decreased. The Division of Solid Waste Assistance has established programs to recycle used oil and to hold collection events for household hazardous waste in each county.

Figures also show that Tennessee has exceeded the goal of a 25 percent reduction in the amount of hazardous waste generated. As of July 1995, out of a total of 27,450 operational underground petroleum storage tanks, 12,066 sites meet tougher new environmental standards. Of the 2,450 leaking tank sites that have been discovered, 29 percent have been cleaned up, and another 29 percent are involved in either corrective action or routine monitoring. The Superfund program has also been making progress. As of October 1996, 79 sites on the State Superfund list have been cleaned up. Five sites were removed from the National Priorities list during 1996.

While poor air quality can contribute to acid rain and harm aquatic life, air quality can also have a dramatic impact on human health as well. Across Tennessee in 1975, there were a total of 404 exceedances of air pollution standards for the criteria air pollutants: carbon monoxide, ozone, lead, TSP/fine particulate, and sulfur dioxide. By 1994 the number of exceedances had decreased to 5. A similar trend is observed in the Pollutant Standards Index for the period 1981 to 1994. Because of leaded gasoline, airborne lead was a wide-spread problem 20 years ago. At this time only two small areas in Shelby and Williamson counties do not achieve the lead standard. The two areas of the state that were previously designated as sulfur dioxide nonattainment areas are now meeting the standards and are being considered for reclassification. Prior to 1980 Nashville, Memphis, and Knoxville were not meeting standards for total suspended particulate, carbon monoxide, or ozone. However, today these areas all meet the current ambient standards.

Over the past 25 years, Tennessee has made extensive improvements in its environmental quality. However, vexing challenges still remain: maintaining compliance with the ground level ozone standard, posting of lakes and streams where fish show contamination with toxic chemicals, increasing the number of miles of streams and acres of lakes that support their intended uses, preventing contamination of groundwater, maximizing valuable landfill space, protecting bio-diversity, and creating clean indoor environments. Many initial problems have been solved through regulatory strategies; it is time to examine more closely the benefits of pollution prevention. A waste never produced cannot harm the environment or public health. Furthermore, companies that reduce waste at its source usually reap substantial returns on their investment. Cooperation between business leaders and environmentalists, through their joint participation in efforts such as the 2000 Initiative, are creating a new era of consensus building and planning that will be critical to meeting the challenges of the year 2020 and beyond.

**EPA'S POLICY
ON FLEXIBLE STATE ENFORCEMENT RESPONSES
TO SMALL COMMUNITY VIOLATIONS**

William M. Park¹

The issue of unfunded federal mandates has been a focal point in much of the debate over environmental regulatory reform that has taken place in the mid 1990s. Initially, attention centered on the huge price tag facing large cities and the aggregate impact nationally. A study by Ohio and the City of Columbus claimed 14 different mandates would cost city governments \$1.6 billion over the 1990-2000 period. A U.S. Conference of Mayors study, based on a survey of 314 cities, estimated the cost of unfunded mandates at \$11.3 billion for FY93. However, due to the economies of size associated with most of the infrastructure investments dictated by various mandates, small communities in rural areas have found themselves at the greatest disadvantage, facing in many cases an overwhelming fiscal burden. For example, EPA estimated the average annual incremental household cost of compliance with the 1986 amendments to the Safe Drinking Water Act to be about \$145 for the smallest regulated systems, versus \$12 for larger systems.

In response to the outcry, Republicans made unfunded mandates a key feature of their "Contract With America." Ultimately the Unfunded Mandate Reform Act was signed into law in March 1995. While this law does require documentation of the cost impacts of new mandates and benefit-cost evaluations of new regulations, it does little regarding existing mandates. However, a less visible movement has been occurring within a number of states since 1992 that seeks to provide a measure of relief to small communities from environmental mandates. In particular, "community environmental compliance flexibility projects" were undertaken in Idaho and Oregon, in cooperation with EPA Region 10. This movement culminated in a formal EPA policy statement in November 1995 that allows states to enter into agreements with local communities that provide an extended time period for reaching compliance. As a prerequisite to such agreements, a process must be undertaken at the local level to prioritize among competing environmental mandates on the basis of comparative risk. The lead paragraph of the policy statement reads as follows:

This policy expresses EPA's support for States' use of enforcement flexibility to provide compliance incentives for small communities. EPA acknowledges that States and small communities can realize environmental benefits by negotiating, entering into, and implementing enforceable compliance agreements and

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schedules that require communities to correct all of their environmental violations expeditiously while allowing the community to prioritize among competing environmental mandates on the basis of comparative risk. States may provide small communities an incentive to request compliance assistance by waiving part or all of the penalty for a small community's violations if the criteria of this policy have been met. If a State acts in accordance with this policy and addresses small community environmental noncompliance with compliance assistance in a way that represents reasonable progress toward compliance, EPA generally will not pursue a separate Federal civil administrative or judicial action for penalties or additional injunctive relief.

STATE-LEVEL SMALL COMMUNITY POLICY INITIATIVES

As noted above, initiatives in Idaho and Oregon were instrumental in leading to the announcement of the Small Communities Policy. However, parallel initiatives were arising in four other states in 1994 and 1995: Colorado, Nebraska, South Dakota, and Washington. Brief summaries of each state's approach and experience are presented below.

Idaho - The Idaho project was designed to assist specific "self-selected" Idaho communities, but also to provide a model for other states to consider. First, an assessment of each community's infrastructure needs was made, in light of the mandates faced. An assessment of each community's administrative and financial capacity was also made. Then, a priority-setting exercise was conducted for the City of Hagerman (1993 population 641), with the scope including both environmental and non-environmental mandates from the federal and state levels, as well as other non-mandated community funding priorities. Seven "needs" were presented, most but not all related to drinking water and wastewater treatment. For each need, a description of the health or environmental concerns was given, followed by an outline of viable options and projected costs. The project staff also assigned point values for each of the seven needs, up to 50 points based on the criteria of "benefits as a function of cost" and up to 50 points based on the "time line for regulatory compliance." Citizens were then asked to integrate the infrastructure needs related to federal mandates with the other non-mandated community funding priorities into a single prioritized list. The City of Hagerman was not actually out of compliance at the time the prioritization exercise was conducted, so no extended compliance agreement was necessary. However, the notion is that the capacity analyses and prioritized listing of infrastructure needs would provide the basis for development of such an agreement if and when one is needed.

Oregon - Oregon's program, now termed "Environmental Partnerships for Oregon Communities," differs from the Idaho approach in several important ways. The approach in Oregon has been to focus the prioritization process upon only environmental issues with existing compliance problems, with sensitivity toward broader local concerns. Participation by communities is voluntary, but to be selected communities must have "multiple environmental mandates, definable issues, clear jurisdiction to address the mandates and resolve issues, small population, limited resources and a commitment to resolve issues through public participation."

The process in Oregon begins with informational and educational meetings for citizens conducted by either DEQ, community leaders, or both. The next step is a diagnostic review of the city's compliance status with all potential environmental requirements. Following this, an evaluation is undertaken to determine the ecological, public health, and financial significance associated with compliance. Further education/information efforts take place at this stage, as well as elicitation of input from residents and interested parties. An "urgency analysis" is then conducted through which the State agencies assist the city in setting priorities for actions required to achieve compliance. The outcome of the process is a "Mutual Agreement and Order," a legally binding document that includes a time schedule for achieving compliance.

Colorado - In its 1995 session, the Colorado General Assembly passed the Small Community Environmental Flexibility Act, enabling the Department of Health and Environment to approve Integrated Environmental Compliance Agreements with municipalities, as well as counties and special districts, with a population of less than 2,500. The agreements provide up to 10 years for small communities to phase in compliance with applicable requirements, once a local planning and priority-setting process has been completed and a need is demonstrated based upon the adequacy of resources. In addition, the Department of Local Affairs is required by the act to provide assistance to small communities in the preparation of environmental priorities plans. The focus was expected to be on drinking water and wastewater issues, but as of June 1996 no communities had requested assistance in preparing a plan.

Nebraska - The Mandates Management Initiative in Nebraska uses an inter-governmental team process to help local leaders better understand regulations, analyze local issues to determine which pose the greatest risk to public health and environmental quality, prioritize them and find cost-effective, appropriate solutions for the problems identified. This approach is intended to increase regulatory flexibility and balance local fiscal and human resources with mandated requirements. The Initiative originated in the Office of the Governor, but now is operated out of the Department of Environmental Quality. The focus is strictly upon water and environmental quality, given that most of the 484 communities in Nebraska with populations below 2,500 provide public services only in the areas of drinking water, wastewater, and streets. While the criteria for targeting communities for participation now includes the presence of two or more regulatory issues, the focus of the process is not so much on arriving at a legal compliance agreement as it is assisting communities by coordinating technical and financial assistance, and identifying appropriate cost-effective technologies. Communities have also been selected in part on a geographic cluster basis, to enhance the possibilities of collaboration, e.g., sharing of workers or equipment. As of June 1996, the process had been nearly completed with 15 communities, while another 20 communities were in line to begin. Case study summaries illustrating both process and product have been completed for at least two communities.

South Dakota - The state of South Dakota operates what is called the ACTIVE Cities Program. This cooperative effort involves the Department of Environment and Natural Resources, EPA, and the non-profit Midwest Assistance Program, which is based in Minnesota. As of June 1996, five communities were participating on a voluntary basis in a process designed to provide them

with a greater degree of flexibility and control, as well as an opportunity to establish local priorities with regard to meeting environmental mandates.

Washington - The state of Washington just recently launched its Environmental Partnership with Washington Communities, based on careful review of Oregon's experience. Efforts are being made to develop interest among communities and gain the support of the Washington State Association of Cities. However, the Department of Ecology has been applying methods from the Small Towns Environment Program (STEP) for about four years to assist communities with their wastewater treatment systems. STEP is coordinated by the Rensselaerville Institute in Rensselaerville, New York and promotes use of local resources, controlling costs, and choosing the simplest technology. The Institute reports that the cost of "Self-Help Support System" water and wastewater projects averages 35 percent less than standard estimates, and that using STEP methods had saved more than \$150 million in nearly 150 communities as of 1994. In Washington, four communities have completed the STEP process, while eight more are in the early stages. The emphasis in Washington communities has been on use of volunteers, securing donations of materials or equipment, and consideration of alternative small-scale technologies.

CONCLUSIONS AND IMPLICATIONS

The announcement of EPA's Small Communities Policy in 1995 and the experience of a number of Midwestern and Western states over the past three years signals a significant reorientation in our approach to environmental regulation as it relates to small communities. This reorientation reflects a recognition that (1) opportunity costs are real and significant factors in the context of the allocation of limited fiscal resources by small communities, (2) analysis of benefits and costs at the margin may suggest that expensive upgrades in infrastructure can not be justified by the marginal benefits to be gained, at least not at the present time, and (3) providing the incentives of a time extension for compliance and protection from penalties can encourage communities to undertake what may be a valuable local environmental planning and prioritization process. What appears to be the critical uncertainty in the policy from the standpoint of practical implementation is exactly how communities are to "prioritize among competing environmental mandates on the basis of comparative risk." A related uncertainty has to do with exactly how "public notification and public participation" is to be incorporated into the process. An objective of the Idaho pilot project was to develop a model approach for other states and local communities to employ, but to what extent that has been accomplished is unclear.

According to the Small Communities Policy coordinator for EPA Region 4, there has been little interest shown on the part of states in the Southern region to date regarding the policy. Part of the explanation for this may be simple lack of awareness. However, there are surely hundreds, if not thousands of small communities in the South that are facing the kind of dilemma that this policy is intended to address. Perhaps the lack of interest is due to the different "culture" of environmental regulation that exists in the South. It may be that, as a result of the limited resources devoted to environmental regulation in many Southern states and the relatively weaker environmental values in the region, small communities are already being allowed on an informal

basis the flexibility and time extensions that are intended to be the products of the formal process called for by the policy. If so, then why go to all the trouble of an environmental planning and prioritization process, the kind of exercise small Southern communities may not be particularly inclined to do anyway? If so, then why raise a "red flag" by explicitly calling attention to a compliance problem? This disincentive was noted as a factor limiting interest or participation by some of the contacts in the six states discussed above.

**DEVELOPMENT OF KRYPTON-85
AS AN EMERGING TOOL
FOR AGE-DATING GROUNDWATER**

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and

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INTRODUCTION

Over the past 50 years, human activities have introduced a large number of contaminants into the atmosphere and hydrosphere, some of which can serve as environmental tracers for determining groundwater age and recharge rates. The content of ⁸⁵Kr in the atmosphere and in precipitation has continually increased since about 1950 due to releases from nuclear power plants and fuel processing. After recharging precipitation is isolated from the atmosphere, the ⁸⁵Kr content declines at a known rate (half life of 10.76 years) because of radioactive decay. By measuring the ⁸⁵Kr content in a groundwater sample it is then possible to determine how long it has been since the water infiltrated into the aquifer and to determine the recharge rate. As well, ⁸⁵Kr data can be used to infer groundwater flow paths, examine the influence of dispersion and identify young groundwaters that may be susceptible to contamination.

The ⁸⁵Kr isotope, with its half-life of 10.76 years, is expected to have a wide range of applications because it is present in the young, shallow groundwaters where most of the present contamination occurs. ⁸⁵Kr has also several major advantages over other atmospheric tracers, such as tritium or CFC's. These include: concentration of ⁸⁵Kr in the groundwater is not greatly affected by dispersion, activity of the ⁸⁵Kr in the atmosphere is steadily increasing due to growth of the nuclear industries, and as a chemically inert gas ⁸⁵Kr is not affected by geochemical and biological processes. Additionally, due to the fact that activity of the ⁸⁵Kr is expressed as a ratio

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of krypton-85 to the total dissolved krypton ($^{85}\text{Kr}/\text{Kr}$), the calculated age is not influenced by the recharge temperature, gas solubility, or minor losses during sampling.

CHEMICAL AND PHYSICAL PROPERTIES OF ^{85}KR

Krypton is a member of the family of noble gases which includes helium, neon, argon, krypton, xenon and radon. These are colorless, tasteless, and in general, chemically inert. ^{85}Kr is an unstable, beta-emitting isotope of krypton with a half-life of 10.76 years. Because of the characteristic inertness of the noble gases, this radionuclide tends to accumulate in the atmosphere with the concentration at any given point being determined by the rate at which it is introduced to the atmosphere, by meteorological diffusion and by radiological decay. Neither the oceans nor the land surfaces act as significant sinks.

SOURCES AND ABUNDANCE OF ^{85}KR IN THE ATMOSPHERE

Natural production of ^{85}Kr in the atmosphere occurs due to: (a) natural fission of uranium and thorium in the lithosphere and the ocean, and (b) neutron capture reactions from cosmic ray neutrons interacting with atmospheric Krypton-84. Natural production rates are estimated at <14 Ci (Schroder and Roether, 1975).

Anthropogenic production is responsible for most of the ^{85}Kr currently present in the atmosphere and in groundwater recharge. Anthropogenic sources of ^{85}Kr include: (a) nuclear weapon testing, (b) nuclear power reactors, particularly those using U-235, Pu-239, and U-233 (Schroder and Roether, 1975) as fuel, and (c) plutonium production. The rare noble gases such as Kr^{81} , Kr^{85} , Ar^{39} have isotopic abundance in the 10^{-11} to 10^{-15} range and 10^{-21} to 10^{-22} concentration in modern water. Levels of ^{85}Kr in the atmosphere have steadily increased from negligible values in the early 50's to around $55 \text{ dis} \cdot \text{min}^{-1} \cdot \text{mL}^{-1}$ in 1987 measured at European and North American monitoring stations (Rozanski and Florkowski, 1979, Weiss et al., 1989, Lehmann et al., 1993).

^{85}KR AS AN ENVIRONMENTAL TRACER IN GROUNDWATER

Large quantities of various chemical elements and their isotopes have been added to the atmosphere, mainly within the last 40-50 years, due to human activities. These chemicals have been recharged through precipitation to the groundwater at concentrations above natural levels on a global basis. The presence of these anthropogenic chemicals provides an estimate of the absolute age of groundwater and, therefore, an estimate of the susceptibility of an aquifer to contamination by either vertical leakage or lateral flow.

Krypton-85 measurements can be used to calculate groundwater ages directly if the following assumption are made: (1) recharge water is in equilibrium with the atmosphere; (2) krypton-85 is advectively transported with negligible dispersive mixing (i.e. plug flow); and (3) the saturated zone is a closed system with respect to dissolved gases. Under these conditions the water table in

the recharge region will have the atmospheric krypton-85 specific activity. As the water flows through the aquifer, the krypton-85 specific activity decreases by radioactive decay.

INFLUENCE OF DISPERSION

As groundwater moves through a geologic material, mixing of older and younger pore waters (dispersion) occurs, which can adversely affect the reliability of age determinations based on environmental isotopes. Dispersion is influenced by the degree of heterogeneity of the deposit and tends to have a greater effect on concentrations in cases where the input concentration is erratic, or forms "spikes", than in cases where input concentrations are constant or increasing.

The influence of dispersion on the concentration of krypton-85 in the groundwater is not expected to be significant. Numerical transport simulations by McMaster et al. (1995) show that if the input function is continually increasing, which is the case for ^{85}Kr , the distribution of the total dispersive mass is not substantially different than would occur if there were no dispersion. By comparison, if a tracer has a peaked input function, the distribution of the total dispersive mass changes significantly depending on the magnitude of dispersion in the aquifer.

INFLUENCE OF THE VADOSE ZONE

As precipitation containing volatile environmental tracers, such as ^{85}Kr and CFS's, percolates through the vadose zone there can be exchange with gases in the soil atmosphere. In cases where the atmospheric concentration of the environmental tracers is increasing with time, concentrations in the soil atmosphere will tend to be lower than the percolating groundwater. The resulting loss of tracers makes the water appear "older" than it actually is. After the water reaches the water table, there are no further losses to the soil atmosphere, but any subsequent concentration measurements and age determinations are affected by the "time lag" in the vadose zone.

The magnitude of the time lag is largely dependent on the diffusion coefficient of the gas, its solubility in water, the soil-water content of the unsaturated zone, and the water table depth (Cook and Solomon, 1995).

SAMPLING AND DEGASSING OF KR

The very low concentration of ^{85}Kr in water and the presence of other, more numerous krypton isotopes, usually require large water samples and special procedures for extraction and measurement of the ^{85}Kr . As a dissolved gas, the krypton-85 concentrations in groundwater samples can be affected by diffusion through the walls of the sampling devices and/or exposure to the modern atmosphere. For example, groundwater samples stored in polyethylene bottles can lose their distinctive ^{85}Kr signature within a few hours to a few days. To prevent excessive krypton exchange, groundwater samples are typically collected without exposure to the

atmosphere and the water or the gases removed from the water are isolated in tightly-sealed metal containers.

DECAY COUNTING

All radioactive elements are subject to disintegration from the moment they come into existence. The dating of radioactive materials depends on the correct determination of the ratios of original, or parent, materials to derived, or daughter products.

The concentration of ^{85}Kr in groundwater is very low (10^{-17} atmospheric concentration calculated at about 50-55 dpm/cc - Weiss et al., 1986). Some of the major limitations imposed by current analytical capabilities are: (1) excessive amount of time required to collect the sample, and (2) large volumes of extracted groundwater will likely be "contaminated" due to mixing groundwaters of different ages in the aquifer and/or intrusion of modern atmosphere.

RIS BASED MEASUREMENT

The analytical technique, currently employed by IRIM (Thonnard et al, 1986), consists of a multi-step process (Fig. 3-6) starting with: a) degassing of the sample, b) separating Kr from the remainder of the gas, c) going through a first isotopic enrichment reducing interfering isotopes by 10^5 , d) proceeding with a second isotopic enrichment of $\sim 10^3$, and finally e) detecting the rare Kr isotope in a time-of-flight mass spectrometer utilizing resonance ionization spectroscopy. A detection limit of ~ 100 ^{85}Kr atoms has been demonstrated in the final spectrometer (Thonnard et al., 1992). The improvements to the system, proposed by the Institute of Rare Isotope Measurements, will likely enable ^{85}Kr determination from 1 liter of water. The critical issue in this method is isolation of the collected and processed sample from modern atmosphere contamination which would result in a false age determination.

SUMMARY

The only and comparatively well-mixed reservoir of krypton is the atmosphere. The concentration of ^{85}Kr in the atmosphere is steadily increasing and is known with sufficient accuracy. Due to its inert nature and increasing input function the potential of using of ^{85}Kr as an environmental tracer is very high.

DESIGN OF INNOVATIVE HYDRAULIC FEATURES FOR THE PROPOSED KENTUCKY LOCK ADDITION

Mel Eakins,

and

Don Getty¹

INTRODUCTION

Kentucky Lock, a 110'x600' chamber associated with Kentucky Dam at Tennessee River Mile 22.4 in western Kentucky, is experiencing significant lockage delays due to increased barge traffic and the predominance of usage by tows longer than its chamber (resulting in tow breakage for lockage). The Nashville District Corps of Engineers in concert with its consultant, Harza Engineering Company/Parsons Brinckerhoff, and the Tennessee Valley Authority are in the process of designing a new 110'x1200' lock adjacent to and landward of the existing lock to alleviate these costly delays. Because of newly instituted cost savings and funding measures, this design process has focused on innovative measures to reduce construction costs without compromising safety. This paper outlines the procedures and processes used in the hydraulic design to meet these cost reduction goals. The lock's hydraulic features have been separated into three systems for discussion in this paper: 1) intake, 2) chamber, and 3) discharge.

INTAKE SYSTEM

Preliminary layouts of the proposed lock showed that its most economical location considering geotechnical constraints would be with its upstream miter gates 104 feet downstream of the existing lock's upstream miter gates. The feasibility of this layout requires that the intake system be constructed within a short reach bounded by the upstream miter gates and the upstream coffer dam. Because of this very limited space requirement, the design team decided to design a "through-the-sill" intake system instead of a more traditional side lateral system used on most modern locks of this lift. Since a through-the-sill intake system was untested for a lock of this size and lift² and since its viability was crucial to the lock's proposed location, the team designed and model tested the intake system prior to any other hydraulic feature.

The main design goal for the intake system was to minimize the formation of vortices under the

¹Respectively, Harza Engineering Company, Sears Tower, 233 S. Wacker Dr., Chicago, IL 60606-6392; U.S. Army Corps of Engineers, P.O. Box 1070, Nashville, TN 37202-1070.

²Normal lift for Kentucky Lock is 56 feet. Maximum design lift is 65 feet.

range of possible headwater/tailwater conditions. Factors that affect vortex formation include: approach velocities, submergence (based on invert elevation), intake geometry, and approach geometry. In order to minimize approach velocities (and thus, minimize vortex formation), the intake was designed as wide as possible, 75' for each intake (symmetrical about centerline of lock). The intake's height was set at 15 feet, which was the assumed height for the chamber's culvert, and its entrance was given a trumpet or bell mouth shape to minimize losses. Guidevanes were incorporated inside the intakes to enhance uniformity of flow as the width transitions from 75' down to the culvert width of 15'. After transitioning down to the culvert width, a traditional reverse tainter valve located in the lock wall is used to control flow. The entrance invert elevation of the intake system was initially set nearly as high as structural considerations would allow. This intake elevation was selected with the understanding that it could be lowered if vortex formation became a problem. Correspondingly, the invert of the approach topography was set just below the entrance invert elevation for a distance of 300 feet upstream with the understanding that its invert and basic configuration could change if warranted by vortex formation.

A 1:25 scale model of the intake system was constructed at the Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, MS. Its purpose was to ensure the viability of a through-the-sill intake system for this application and to refine the design of the entire intake system. The model includes the upstream topography, upstream features (i.e., floating guidewall, possible guardwall, and other possible diversion structures or walls), and basic configuration of the intakes. Tests of the initial configuration were encouraging. Unacceptable vortices were experienced for some headwater/tailwater conditions, but these type 3 and 4 vortices were unstable and it was felt that they could be reduced in magnitude by making minor design changes. The first change incorporated into the model was to place "skirts" under the floating guidewall in an attempt to reduce the eddy patterns caused by a jetty approximately 500 feet upstream of the lock. These skirts and subsequent total flow blockage measures (full height walls) did not have appreciable effects on vortex formation. The next modification was the removal of the jetty. However, this resulted in worse vortex conditions. Because of structural stability reasons, the proposed lock was moved 15 feet farther away from the existing lock. This relatively small movement in combination with the re-establishment of the jetty resulted in acceptable vortex conditions. Future tests are planned to further refine the design (possibly lower costs) but the present configuration meets all design criteria.

CHAMBER SYSTEM

A state-of-the-art filling system for a lock of this lift would be a bottom longitudinal system; however, the economics for the proposed lock (benefits for each minute of reduction in lockage time) are such that they cannot justify the higher costs for this filling system. Therefore, other systems that are less expensive but have longer associated filling/emptying times were investigated. Two filling systems that appeared to have promise from a cost perspective were evaluated in more detail: 1) a multiport system (a type of side port system developed by the TVA) and 2) a center longitudinal that has two culverts running down the center of the chamber

with traditional reverse tainter valves in the lock walls for filling and emptying control. Engineering and cost factors resulted in the selection of the multiport system as the preferred alternative. A culvert size analysis was also performed to determine the optimum culvert size. Factors considered in this evaluation included filling times, expected hawser stresses, compatibility with possible intake and discharge systems, and construction costs. The main analytical tool used in this analysis was an unsteady flow program, TFSIM, a program used by TVA's Norris Lab for various hydraulic applications. TFSIM has the capability to estimate hawser forces from computed water surface slopes within the chamber. Based on the TFSIM simulations and on cost estimates, the results of the comparative analysis showed that a 15'x15' culvert was preferable to larger, more expensive culverts. Associated filling times for 15'x15' culverts in a multiport configuration are computed to be on the order of 12 to 15 minutes. TFSIM was also utilized to develop the optimum arrangement and spacing for the 400, 10" diameter ports required in the chamber and in determining preliminary filling valve speeds.

In order to refine the hydraulic design of the chamber, a 1:25 scale physical model is being constructed at WES. This model will incorporate the intake system previously constructed and tested as well as the discharge system. Refinements in the chamber will include final spacing of its ports, configuration of the discharge trench, final elevation for the chamber floor, and a recommendation on filling and emptying valve speeds so as to not exceed the 5-ton hawser forces being used as a design constraint and so as to not create excessive turbulence within the chamber. Flow conditions at the intake and discharge systems can also influence the selection of design valve speeds.

DISCHARGE SYSTEM

The primary design goal for this discharge system was to ensure that a discharge cycle would not create unsafe conditions in the confined channel downstream and to ensure that velocities and turbulence would not have adverse environmental and maintenance consequences. A secondary design goal was to allow a tow to moor to the downstream guidewall during a discharge cycle. Two basic types of systems were considered during this design process. The first system developed was a "near field" system that would empty the lock's discharge into the lower approach. Even though this type of system may not be able to meet the secondary goal, it would probably meet the major goal and would be the lowest cost alternative. The second system conceptualized would discharge to a remote location so as to ensure that a tow could moor to the downstream guidewall without being impacted by the lock's discharge. These two systems are discussed below.

Interlaced Lateral System - After an alternative analysis, a type of bottom diffuser system, commonly referred to as an interlaced lateral system, was selected as the near-field discharge alternative. This design was patterned after a similar system used at the new lock at Bonneville Dam. Since the interlaced lateral system is the cheaper of the two basic systems and more likely the system to be ultimately selected for final design, it is being constructed in the first configuration of the physical model at WES. Variables that can be modified in the model to

affect this system's performance include: 1) emptying valve speeds, 2) centerline to centerline spacing between the laterals, 3) length of the downstream, landward lock wall, and 4) various excavation schemes in the lower approach. Data to be collected in the model to measure performance include downstream velocities, turbulence, water surface fluctuations and slopes, and hawser forces for moored tows on the downstream guidewall. It is proposed to use a floating guidewall with the interlaced laterals so fluctuations and water slopes are critical for its evaluation as well.

Side Channel System - After an alternative analysis that considered construction costs, construction feasibility, and operational feasibility, the configuration selected for the remote discharge system consists of an open channel located landward of a fixed downstream guidewall with an energy dissipation basin at its exit below the guidewall. Hydraulic design criteria for this side channel system were to limit velocities within the open channel to 20 feet per second (fps) and to limit its exit velocities to 10 fps. The unsteady flow computer program FEQ was utilized in the channel's design to ensure it met this design criteria. Additional numerical modeling of the channel's hydraulics using TFSIM is underway to refine the hydraulic design, and a physical model will be constructed if this system is ultimately selected as the preferred alternative.

A FLOOD WARNING SYSTEM IN APPALACHIA: HARLAN, KY

John S. Daughenbaugh¹

This effort was an integral part of, and follow-on support system to, the construction of the Flood protection and Flood Control Works for Harlan County, especially the city of Harlan, KY. Initial design proposal was disapproved by the Ohio River Division because it failed to provide enough warning time for the city to defend itself from rising rivers induced by heavy precipitation. This warning system was unique for the Nashville District in that it was a cost sharing effort that focused on technical and leadership support to the local indigenous resources.

This system is comprised of an inexpensive weather analysis and predictive display system married to a small network of precipitation and streamgage units which were dovetailed into the National Weather Service's Integrated Flood Observing and Warning System (IFLOWS) for Appalachia.

This paper describes a pioneering effort by the Harlan county Director of Emergency Services, the Harlan County Fire Department, the Kentucky State Police, and the Corps of Engineers, to organize itself to design, construct, and implement the system. The paper focuses on the human ingenuity and cooperative effort by all parties to fulfill the county's dream of autonomy in flood control protection and the opportunity to provide a heads up for their downstream neighbors in Bell and Knox Counties.

Note: A short video is available to demonstrate the installation of equipment by county personnel, especially the County Judge's prisoners that provided the labor for the effort to protect itself with limited resources and the help of the United States Government.

¹United States Army Corps of Engineers, Nashville District, P.O. Box 1070, Nashville, TN 37202-1070.

SESSION 1-C

HAZARDOUS WASTE MANAGEMENT

10:30-12:00

Andy Shivas, *Update on the Division of Superfund, Voluntary Cleanup Oversight and Assistance Program (VOAP).*

Barbara B. Pyles, *Update and Recent Happenings With the Dry Cleaner Environmental Response Program.*

Andy Binford, *Comments on the Relevancy of Using the SPLP or TCLP to Determine Whether a Contaminant in Soil May Pollute Ground Water.*

KARST #1

1:00-2:30

Carol Goldinger Ford, Albert E. Ogden, Laura R. Ogden, Stephen Ellis, Jesse Scarborough, *Ground Water Basin Delineation for Sinkhole Flood Prevention, Johnson City, TN.*

Michael W. Hiett, *A Wellhead Protection Study for Cascade Spring in Coffee County, Tennessee.*

KARST #2

3:00-4:30

William J. Wolfe, *Karst Features of the Barrens (Tennessee): Their Hydrologic and Ecological Significance.*

Peter J. Lemiszki, Bruce A. Zerr, Robert J. Sepanski, *A Karst Inventory of the Oak Ridge Reservation, Tennessee.*

Michael D. Guebert, Ph.D., Anne Marie Otis, Nathan Williams, *Karst Vulnerability Assessment for Sinkhole Flooding and Groundwater Contamination in Middle Tennessee: Integrating Hydrology, Education, and Policy.*

**UPDATE ON THE DIVISION OF SUPERFUND,
VOLUNTARY CLEANUP OVERSIGHT AND ASSISTANCE PROGRAM (VOAP)**

Andy Shivas¹

The Voluntary Oversight and Assistance Program is designed for parties who are willing and able to investigate and clean up contaminated sites. The voluntary party may be the person who caused the contamination, a proposed buyer of the property, or a lending institution protecting their security investment. The talk can include a description of the VOAP, requirements for the program entry, comments on program guidance documents, and an overview of the approach used to work a site through the program.

¹ TDEC/Division of Superfund, 4th Floor L&C Annex, 401 Church Street, Nashville, TN 37243-1538.

UPDATE AND RECENT HAPPENINGS WITH THE DRY CLEANER ENVIRONMENTAL RESPONSE PROGRAM

Barbara B. Pyles¹

BACKGROUND

On June 13, 1995 the Tennessee General Assembly enacted a law establishing the Dry Cleaner Environmental Response Program (DCERP). The Act established a fund that is made up of annual dry cleaning facility registration fees and surcharges on dry cleaning solvent. Inactive (former) dry cleaning sites may also register with the program and are subject to an annual registration fee.

GOAL: FEE-BASED REMEDIAL ACTION PROGRAM

The current annual registration fee for a dry cleaning facility with four full time equivalent employees or less is \$500. Fees are higher for larger facilities. The current surcharge fees are \$1 per gallon for hydrocarbon solvents and \$10 per gallon for non-hydrocarbon (chlorinated) solvents. The majority of dry cleaning facilities in Tennessee as well as other states use tetrachloroethylene (also known as perchloroethylene, "perc", or PCE). Because it is a "sinker", removal of PCE (and its breakdown products) can be extremely costly and difficult. Soil and groundwater impacts from PCE can result from spills, discharges of PCE wastewater into sanitary sewers, or disposal of waste material on the ground or in dumpsters.

The dry cleaning industry has supported and encouraged the development of environmental response programs. Other states have recently established such programs; they include Florida, South Carolina, Kansas, Connecticut, Minnesota, and Oregon. Tennessee's program as well as other state programs include Best Management Practices requirements that are aimed to prevent future environmental impacts from dry cleaning operations and solvent use.

HOW THE PROGRAM WILL OPERATE

Applications for use of program funds will be initiated by dry cleaner owner/operators or other eligible parties that are interested in investigating and/or remediating solvent impacts. The DCERP fund will be used to reimburse eligible parties for the investigation and cleanup of sites contaminated by dry cleaning solvent. Facilities will pay a deductible, and the fund can provide reimbursement up to \$200,000 per site, per year.

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The DCERP staff will prioritize sites based on the relative threats to human health and the environment posed at each site. Funds will be committed for investigation and remediation work based on the prioritization schedule and the approval of work plans and cost proposals. At the current time there are over 500 registered dry cleaner sites in the Tennessee program. It is unknown how many applications will be submitted for initiation of work once the regulations go into effect. The program has set up a process for qualifying "Approved Contractors" for inspection, investigation, and remediation work. Work funded by the DCERP is to be conducted by an Approved Contractor in accordance with a Reasonable Rate Schedule.

BOARD OVERSIGHT

A separate oversight Board is in place for the DCERP program. This Board is comprised of representatives of both large and small dry cleaning facilities, a representative of the solvent supplier industry, an impacted third-party representative, an environmental interest representative, a representative of the scientific or engineering community, and the TDEC's Commissioner's designee.

CURRENT EVENTS

During the 1996 year the DCERP program staff developed draft Regulations and the technical aspects of the program. The majority of regulations for the program were approved in draft form by the DCERP Board in September 1996. Public Hearings were held in November 1996.

During the November through February 1997 period the program staff continues to develop remaining sections of the Regulations and address public comments. Following passage of the complete set of final Regulations, applications will be accepted into the program.

**COMMENTS ON THE RELEVANCY OF USING THE SPLP OR TCLP
TO DETERMINE WHETHER A CONTAMINANT IN SOIL
MAY POLLUTE GROUND WATER**

Andy Binford¹

The April 1996 version of the USEPA Soil Screening Guidance: User's Guide and the Technical Background Document derives soil screening levels for the protection of ground water through a partitioning equation approach and alternately through a leaching test approach. The User's Guide also states "to compare the target soil leachate concentration to the extract concentration from the leach test." This process will be evaluated using a mass balance concept. The concentration in soil necessary to cause a specific leachate concentration will be calculated utilizing a volatile organic compound for illustration. This concentration will be compared to both an adjusted and non-adjusted concentration derived from the soil/water partitioning equation. This analysis should demonstrate that there is no correlation between the results of the leachate test and the soil partitioning equation approach. It should also show how sample volume and dilution of the leach test makes this an inappropriate application of the SPLP or TCLP leach test. Time permitting, an alternative methodology, currently under development, which utilizes the SPLP leach test and a totals analysis to calculate a site-specific K_d may be discussed.

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**GROUND WATER BASIN DELINEATION
FOR SINKHOLE FLOOD PREVENTION
JOHNSON CITY, TN**

***Carol Goldinger Ford¹,**

Stephen Ellis²,

Albert E. Ogden and Laura R. Ogden³,

and

Jessee Scarborough⁴

INTRODUCTION

In the spring of 1994, parts of Johnson City, Tennessee and a large portion of east Tennessee received its normal annual rainfall in a period of four months. The rainfall began in December 1993 and finally ceased in May 1994. The large amount of rainfall caused the groundwater table in many areas to rise and inundate low-lying areas (i.e., sinkholes) not previously known to flood. The City of Johnson City was plagued with this problem and initiated an endeavor to conduct a study pertaining to ground water basin delineation for sinkhole flood prevention. The region of largest concern for the City of Johnson City was an area planned for immediate potential growth. The growth area was located in a high density sinkhole area within the northwest quadrant of the city. Very few hydrogeologic studies had been performed in the Johnson City area prior to this study. Four qualitative dye traces were initially conducted by Redman et al. (1993) in Johnson City, and these traces formulated the initial premises regarding ground water flow direction for the study. The ground water (dye) trace studies for this study were qualitative rather than quantitative in that they were conducted to determine where the ground water flow paths are, not how fast the ground water flows through the systems. The ultimate goal of the project is to develop a policy and city ordinance concerning development/drainage in and around sinkholes.

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HYDROGEOLOGY/GEOLOGY

Johnson City, Tennessee is located in the Valley and Ridge Physiographic province of the Appalachian Mountains. Cambrian and Ordovician age rocks are complexly folded and faulted in this geologic province. The nearby Holston Mountain Fault has thrust older rocks over the Knox Group, which are the cavernous rocks underlying the study area. The Knox Group is about 3000 feet thick and has not been subdivided into the individual formations around Johnson City. The other cavernous bedrock types in the study area include the Maynardville Limestone and the Honaker Dolomite, both part of the Conasauga Group. A fault has cut across Indian Ridge on the northeastern end of the study area, and has juxtaposed low permeable beds of the Sevier Shale against the cavernous rocks of the Knox Group. As a result, the large springs involved in the study area are located just up gradient of the contact between the Sevier Shale and the Knox Group. Sixteen springs, three karst windows, four caves, and numerous sinkholes were located and monitored during the ground water (dye) tracing study. Using the orientation of the four caves in the study area, the orientation diagrams of straight cave segments from Washington and surrounding counties (Ogden et al. 1989), and the long and short axes of sinkholes, it was predicted that most of the ground water moves through the karst in Johnson City in a northeast direction towards Knob Creek.

GROUND WATER TRACE STUDY

After the hydrogeologic inventory was concluded and the background tracing agent receptors were installed and analyzed, the ground water tracing activities were initiated. The first ground water tracing event began on 8 April, 1995 and the last event was conducted on 19 October 1995. Where no water existed at the injection point, water from a City of Johnson City water truck or a fire hydrant was used to flush the tracing agent into the bedrock fractures. The following tracing agents were used for this study; fluorescein - acid yellow 73, eosine - acid red 87, rhodamine WT - acid red 388, and tinopal CBS-X - fabric brightening agent 351. A total of seventeen traces were conducted, of which only one trace had no recorded detection in a spring or karst window.

Initially, tracing agents were placed in the three most obvious locations for detection in the potentially down gradient springs. After these tracing agents were detected in the down gradient springs, the next three traces were conducted to provide a positive/negative, broader boundary in either direction. These later three traces also had positive hits in the down gradient springs, intermediate cave, karst window and sinking stream monitoring locations. Up to this point, two ground water basins had been delineated (labeled the Arrowood-Cattail Basin and Todd Lake-Shoe Basin). These two basins were possibly the major ground water basins in the study area. The next six traces were used to better define the two previously mentioned basins as well as delineate two adjacent ground water basins (labeled Indian Ridge Basin and Brush Creek Basin). Each of the trace events in the adjacent basins had positive hits in down gradient springs or creeks. Three of the four other traces had positive hits in the down gradient springs, intermediate cave, karst windows, and sinking stream monitoring points. The remaining four traces further defined the lateral extent of the two main ground water basins and provided positive hits at the resurgence (springs) in the two major basins.

RESULTS

The karst system underlying the study area is a relatively open system. Tracing agents were usually detected at the monitoring points within one week of injection, except in the case of the Todd Lake-Shoe Basin which took almost two weeks for one trace to be detected. It was estimated that the upper end of the Todd Lake-Shoe Basin was clogged. Most of the injected tracing agents probably traveled to the springs in less than one week; however, the detectors were changed and analyzed on weekly intervals.

The predominant type of ground water flow in the study area is described as a conduit flow system. The other type of flow observed is a diffuse flow system. Conduit flow systems consist of openings ranging from solution widened fractures, bedding plane, and joints to irregular pipelike passages many feet in diameter. The diffuse flow system is characterized by the lack of conduit systems or poorly integrated fracture and joint patterns (White 1988). Diffuse flow systems show little response to storm events while conduit flow systems have a flash flood-like response to storm events. Conduit flow systems were most prevalent in the Arrowood-Cattail, Todd Lake-Shoe, and Brush Creek Basins. The upper Indian Ridge Basin was classified as having a more diffuse flow system.

Four subsurface basins separated by three boundaries were delineated within the field of study. The four basins were named Indian Ridge Basin (2 positive traces), Arrowood-Cattail Basin (9 positive traces), Todd Lake-Shoe Basin (4 positive traces), and Brush Creek Basin (1 positive trace). Arrowood-Cattail Basin is the larger of the two main subsurface basins studied, covering an estimated 4.5 miles from the furthest injection point to the resurgence. Todd Lake-Shoe Basin is not quite as large, but its subsurface headwater pathways are believed to be extremely clogged. This basin may also be affected by an adjacent, unstudied subsurface basin named Cobb Creek Basin. It is believed that during base flow, the head waters of Cobb Creek may be diverted underground to the Todd Lake-Shoe Basin; however, this was not examined during this study.

Based on the topographic map for this area, Arrowood-Cattail Basin, Todd Lake-Shoe Basin, and Brush Creek Basin are dotted with sinkholes, caves, sinking streams, and springs, indicating a predominantly karstic region. Indian Ridge Basin has significantly fewer sinkholes and other karst related features, and therefore, appears to be a more intricate diffuse flow system. Interpreted profiles of the subsurface connection of sinkholes, caves, karst windows, and springs along the two major basins are shown on Figures 1 and 2.

CONCLUSIONS

Ground water tracing events conducted for this study were successful in delineating two major and two minor subsurface ground water basins. The basin delineation illustrated the connection between area sinkholes and their potential link to flooding problems along the interpreted ground water flow path. The delineations helped the City of Johnson City locate critical areas within the high potential growth area. A number of karst windows, caves, and sinking streams were identified as being critical in maintaining the ground water system and minimizing flooding in the high growth area.

The basin delineation also illustrated how far up gradient (i.e., four miles away) the ground water actually came from to affect the study area.

Based on Figures 1 and 2 the potential hydraulic gradient of the subsurface is relatively low. The bottoms of sinkholes, particularly in the area near the springs, are near or at the level of the water table reflected by the streams in the karst windows. The cave systems underlying the basins are of limited size and even without the influence of man are dynamic, clogging and unclogging in association with major flood events. With the onset of the human population's need to expand, sinkhole capping for additional land space, siltation from increased runoff, garbage filling sinkholes, and diversion of street runoff into sinkholes all have increased the frequency and severity of flooding from major storm events. These problems may be reduced with the proper treatment and design of drainage systems, groundwater tracing activities, and community awareness. The ultimate goal of this study is to create a policy and city ordinance that is both environmentally friendly and also allows for commercial and residential growth.

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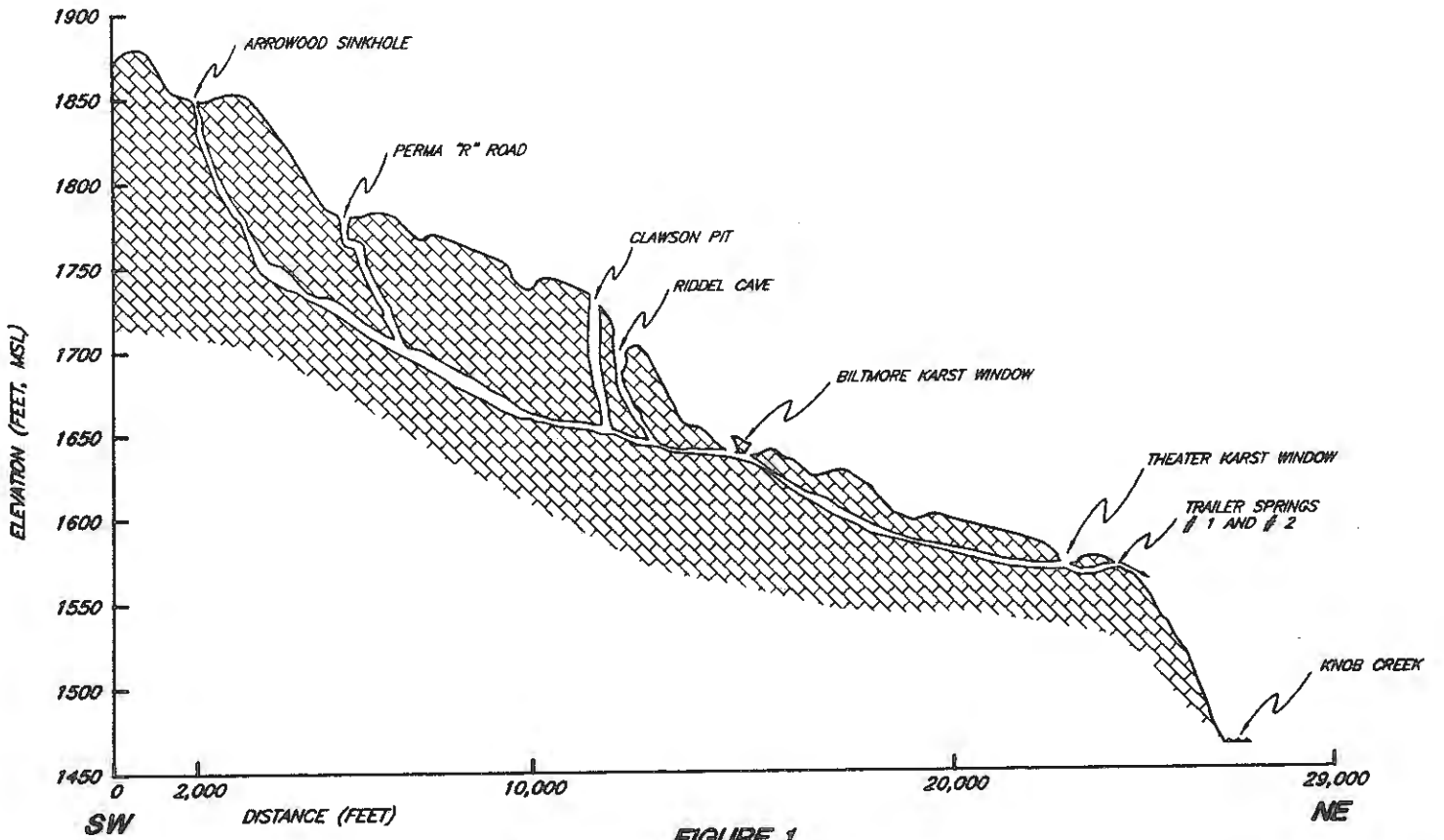


FIGURE 1
PROFILE THROUGH ARROWOOD - CATTAIL BASIN
JOHNSON CITY GROUND WATER TRACE STUDY

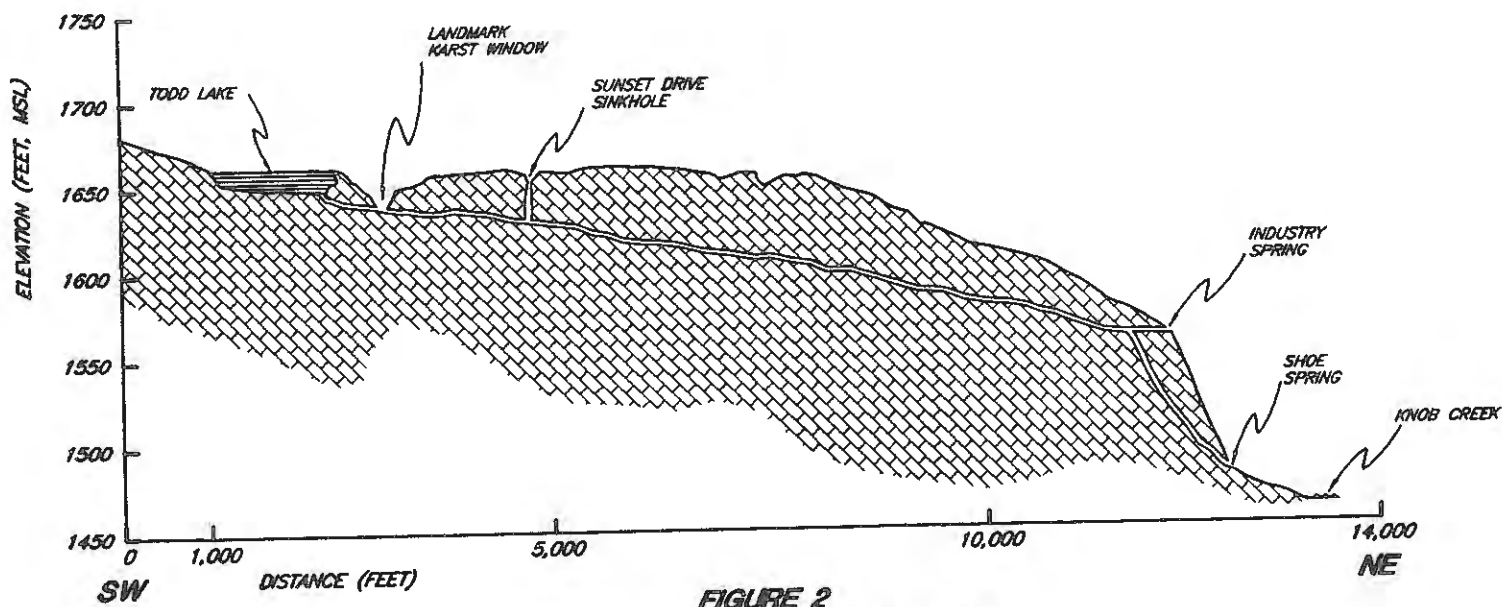


FIGURE 2
PROFILE THROUGH TODD LAKE - SHOE BASIN
JOHNSON CITY GROUND WATER TRACE STUDY

A WELLHEAD PROTECTION STUDY FOR CASCADE SPRING IN COFFEE COUNTY, TENNESSEE

Michael W. Hiatt¹

INTRODUCTION

Cascade Spring furnishes the public water supply for Wartrace, Normandy, and Bell Buckle, Tennessee. This karst spring in Middle Tennessee provides a study site to determine if an adequate Wellhead Protection Area (WHPA) can be delineated by the hydrogeologic mapping method using existing data. The hydrogeologic mapping method uses topographic, geomorphic, geological, geophysical, and/or dye tracing techniques, along with hydrologic data, to map ground water flow boundaries for determination of the recharge area of a well or spring. It is one of the most accurate methods of WHPA delineation, and is well suited for fractured rock and karst settings.

The hydrogeologic mapping method provides a high degree of accuracy for delineation of a WHPA, but it requires a large amount of hydrologic data (such as the location or drilling of wells for obtaining water level measurements, or dye tracing of ground water) to achieve maximum accuracy. Collection of data requires extensive field work, which can be expensive. However, data may already exist that can provide a substantial degree of accuracy without the necessity for expensive means of data collection. This can provide an alternative, less expensive, but potentially equally accurate, means of WHPA delineation, depending on the amount and quality of data available. The goals of this study are to: 1) determine the recharge area of Cascade Spring and delineate its WHPA; 2) identify potential contaminant sources within the WHPA; 3) utilize a personal computer based Geographic Information System (GIS) for data storage, display, and analysis; 4) use readily available, inexpensive sources of data and information to achieve the above.

LOCATION AND HYDROGEOLOGIC SETTING

Cascade Spring is located on an escarpment face of the Eastern Highland Rim. It discharges from a solution opening in the carbonate bedrock of the Fort Payne formation, just above the Chattanooga Shale. Another spring (called East Cascade Spring), also owned by the Wartrace water system which owns Cascade Spring, is located nearby and discharges from several conduit openings and seeps from the same formation. The combined flow rate of the springs is approximately 1.7 million gallons per day (MGD) (Theis, 1936).

Ground water on the Eastern Highland Rim is the source of the water for both springs. The

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Mississippian carbonate formations from which the springs discharge make up a complex aquifer system, especially along the highly dissected escarpment where the springs occur. This aquifer is called the Manchester aquifer (Burchett, 1977) and is composed of a thick series (up to 100 feet) of interbedded clay, cherty clay and chert rubble from the weathering away of the Warsaw limestone, the cherty residue of weathered Fort Payne limestone, and solution cavities found in the underlying Fort Payne bedrock. The Chattanooga Shale provides the base of the aquifer system, retarding vertical flow to the Ordovician limestones beneath. The shale deflects ground water movement laterally, and discharge occurs along the escarpment face of the Highland Rim, producing springs such as Cascade Spring. Due to the complex nature of the aquifer system, it may exhibit confining conditions locally, but the aquifer is hydraulically connected to the weathered regolith (Zurawski, 1978). Precipitation through the regolith is the source of recharge. Near the escarpment, water table conditions exist (Burchett, 1977).

The solution openings and fractures in the Fort Payne bedrock, from which Cascade Spring discharges, transport ground water more rapidly than the weathered regolith, through which slower diffuse flow is predominant. The thick regolith absorbs water from precipitation, holding it in storage and releasing ground water more slowly to the underlying conduits and fractures of the Fort Payne bedrock. This supplies the sustained flow of springs and surface streams originating along the escarpment (Burchett, 1977).

DATA ASSESSMENT AND METHOD OF STUDY

Background literature information of the regional geology and hydrogeology of the study area was adequate, but specific information for the study site regarding these subjects was insufficient. However, the literature was valuable for obtaining information with which to begin the assessment of the study site and for assisting in the determination of its hydrogeologic characteristics.

Aerial photographs, topographic maps, and geologic maps were analyzed for initial determination of surface and subsurface flow boundaries, karst features, and other physical features of the study area. The surface watershed of the springs was determined (Figure 1) from the topographic map and comprises about 0.265 square mile, or 172 acres.

Water quality data, available from the USGS, indicated slight elevated but acceptable concentrations of transdichloroethene and trichloethylene in Cascade Spring. The detectable concentrations of these solvent-based constituents are cause for concern, and closer monitoring of the water quality of Cascade Spring should be a priority.

Ground water level data was available for the Cascade Spring area from records obtained from the Tennessee Division of Water Supply and from the U.S. Geological Survey. There were an insufficient number of wells for the Cascade Spring area noted in the Tennessee Division of

Water Supply records to adequately determine the direction of ground water flow in the area. The USGS Ground Water Site Inventory database provided adequate hydrogeologic information with which to interpret the general trend of ground water flow in the study area.

Water level measurements of wells from the USGS records were used to draw a ground water elevation contour map of the Cascade Spring area (Figure 1). Because of their close proximity to each other, it was not possible to separate the recharge areas (using the available data) of the two springs owned by the town of Wartrace. The recharge area of both springs (Figure 1) was determined from the ground water contours and consists of approximately 1.12 square miles or 717 acres. The Aquifer Recharge and Area of Withdrawal Balance (ARAWB) formula (TDEC, 1994) was used to calculate the estimated size of the recharge area necessary for the combined flows of both Cascade Spring (the water source) and East Cascade Spring. Using 1.7 MGD as the value of the combined spring flow rate (Theis, 1936) and an average annual recharge rate of 0.82 ft/yr (Hoos, 1990) to calculate recharge area size by the ARAWB formula:

$$A = Q / R$$

where A = Area of recharge, square feet

Q = Discharge of the spring, cubic feet per year

R = Annual recharge, feet per year

A = (1.7 MGD) (0.13368 cf/gal) (365 days/yr) / 0.82 ft/yr

A = 101,156,634 square feet or

A = 3.63 square miles or 2322 acres

The recharge area determined from the ground water elevation data (Figure 1) is smaller than the ARAWB formula estimated recharge area, but it is a reasonable approximation based upon the available hydrogeologic data. The recharge area in Figure 1, derived from hydrogeologic mapping of the study area using the available data, maintains a sufficient degree of accuracy so that it can be designated as the WHPA with a substantial amount of confidence. Based upon the potentially larger recharge area required for the spring from the ARAWB estimation, however, the WHPA was expanded. The WHPA of Cascade Spring (Figure 2) was therefore delineated based not only on the ground water contour map but also on the estimated recharge area size of 3.63 square miles. Hydrogeologic factors from the literature and this study indicate that most additional ground water recharge would come from the southeast.

Following delineation of the Cascade Spring WHPA, U.S. Environmental Protection Agency (USEPA) and State of Tennessee guidelines and sources of information were used to conduct a contaminant source inventory. Figure 2 shows the location of potential contaminant sources within the Cascade Spring WHPA.

Storage, display, and analysis of contaminant source (as well as hydrogeologic) data was simplified by using a PC-based GIS program called "ATLAS GIS." GIS was used for this study for the analysis of data by overlaying different forms of the data on each other to assess their

common spatial relationships. Some of these relationships were then displayed in map form. GIS is a useful tool for data analysis, delineation, and mapping of a WHPA. It also provides an efficient method for the storage, display, and updating of the locations and attributes of potential contaminant sources within the WHPA.

CONCLUSIONS

The WHPA of Cascade Spring was delineated using the hydrogeologic mapping method based on the available data (Figure 2). This WHPA provides an adequate and reasonably accurate area for the management of potential sources of contamination within it. A potential contaminant source inventory was conducted, and these sources are noted on the WHPA map. The WHPA is divided into two zones as required by the Tennessee Wellhead Protection Program guidelines.

The

Wellhead Protection Zone (Figure 2) is the area within a 750 feet radial distance around the spring. This is considered the area where direct contamination into the water source may occur (TDEC, 1994). This may be true if a contaminant is injected directly into the spring (for example, into the springhouse basin). For a karst spring, however, the second zone is equally important. The Wellhead Management Zone (Figure 2) is the scientifically derived portion of the WHPA (TDEC, 1994). For Cascade Spring, this zone was determined by the hydrogeologic mapping method of WHPA delineation, using the available data for the study area. Because ground water flow in karst areas is relative rapid with little attenuation of contaminants that may be carried in the water, the Wellhead Management Zone is as important, if not more so, than the previously described Wellhead Protection Zone.

Based upon the results of this study, the recharge area of Cascade Spring could not be determined with complete confidence using the available data for the study area. The determination of the recharge area of a karst spring is important for the reasons noted above. However, this study does show that the hydrogeologic mapping method of WHPA delineation using the available data, depending on the quality and quantity of the data, provides a substantial degree of accuracy for delineating a WHPA. Significantly greater accuracy was attained by this method than that attained from an arbitrary fixed radius method (as depicted by the 750 feet radius around Cascade Spring in Figure 2) or that of using topographic divides to infer ground water divides (the surface watershed depicted in Figure 1). Even if no other hydrologic factors had been considered, the relatively simple task of contouring the water level elevations obtained from the available well data in the study area would provide a substantial amount of accuracy for delineating the WHPA of Cascade Spring.

The WHPA of Cascade Spring (Figure 2) provides an acceptable degree of protection for Cascade Spring at this time. A WHPA should not be static, however, no matter how it is derived.

More wells should be located or drilled towards the southeast to obtain more water level measurements, and dye tracing should be attempted. Accurate discharge measurements of the springs should be obtained also. As more hydrogeologic data become available and as further

study is conducted, the WHPA should be refined to reflect the most current, scientific knowledge that is attained of the area.

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Cascade Springs Ground Water Recharge Area

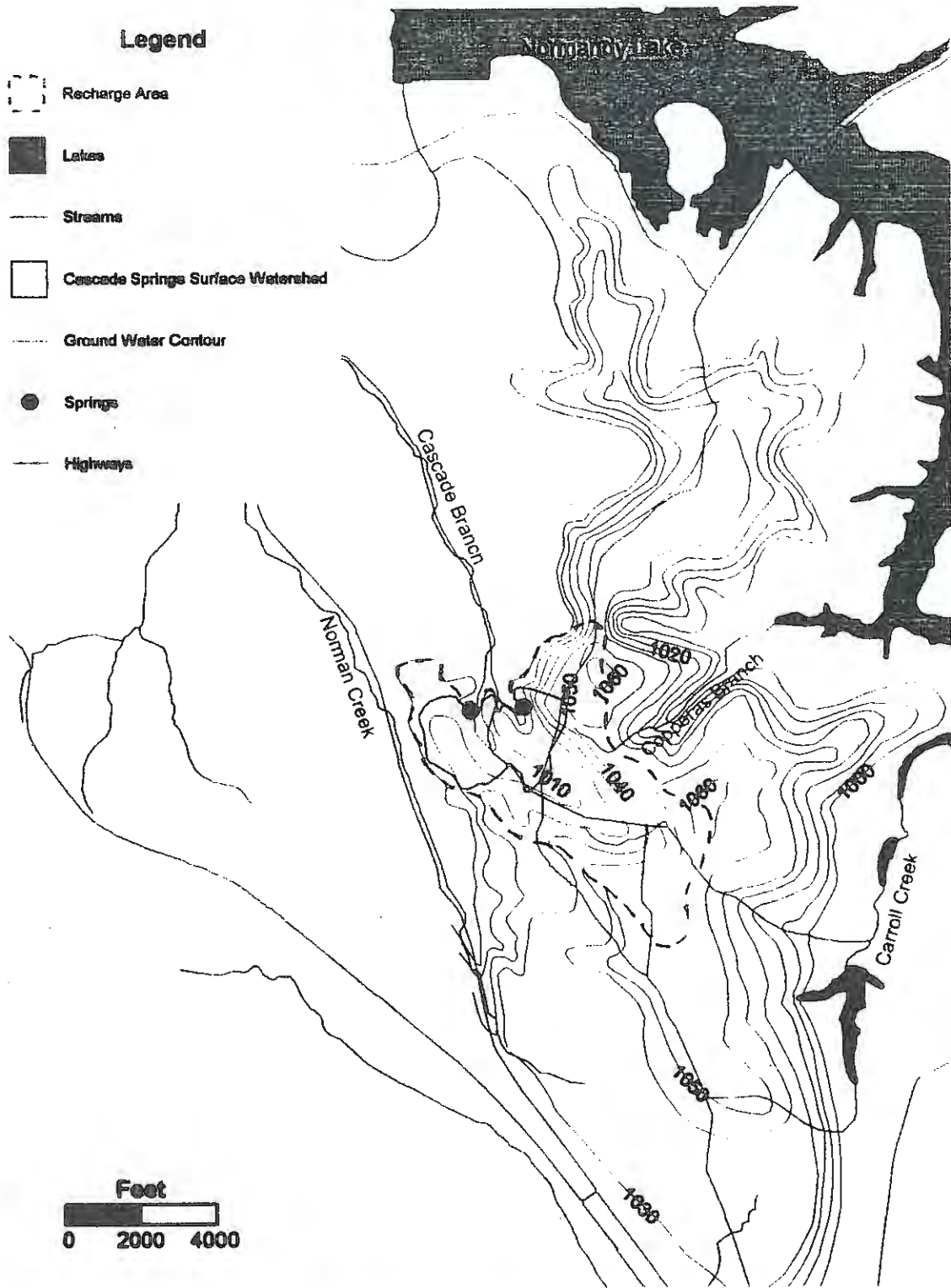


Figure 1. Ground water contours, surface watershed, and recharge area of Cascade Springs.

Cascade Springs Wellhead Protection Area

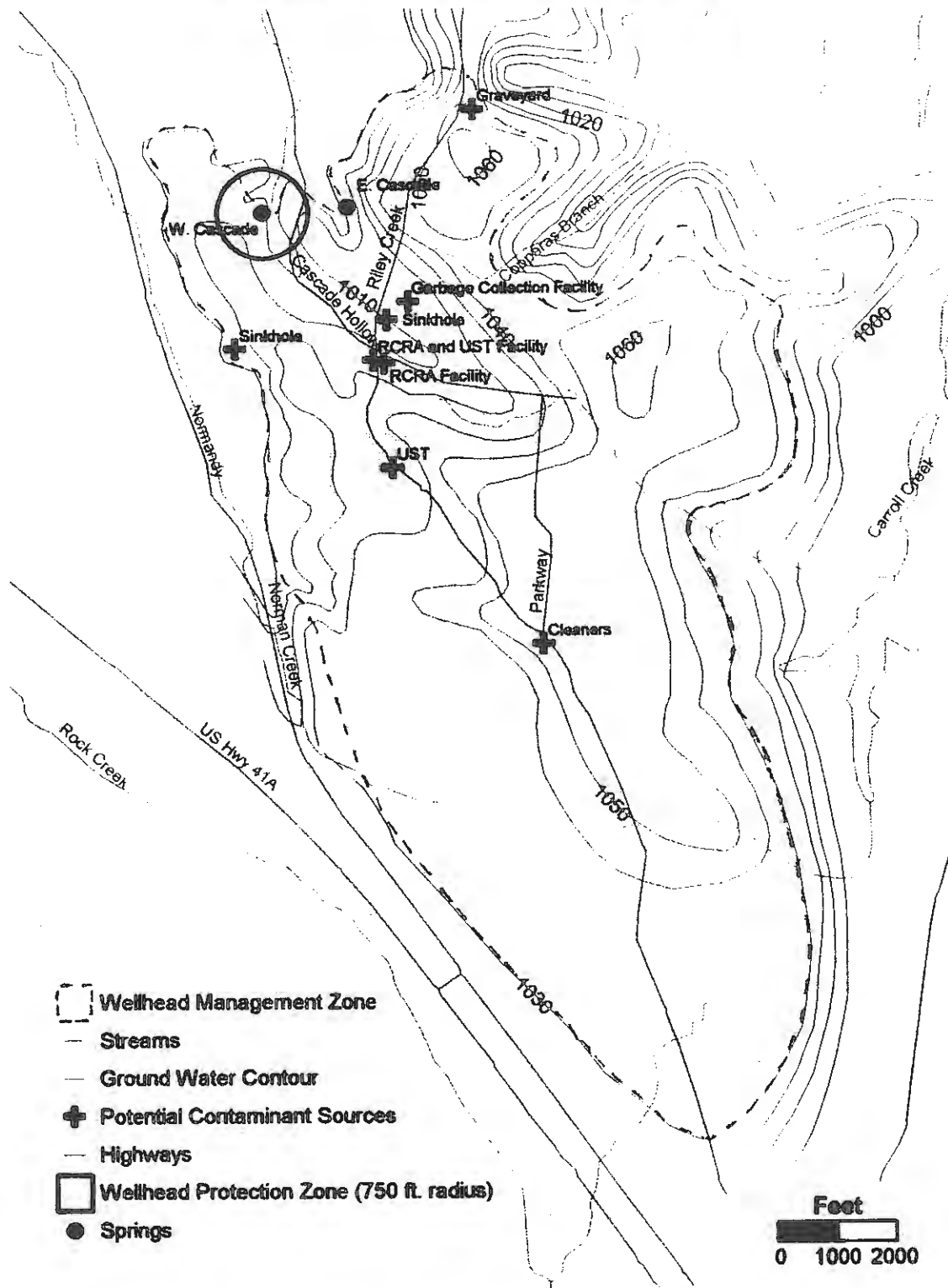


Figure 2. Cascade Springs Wellhead Protection Area.

**KARST FEATURES OF THE BARRENS (TENNESSEE):
THEIR HYDROLOGIC
AND ECOLOGICAL SIGNIFICANCE**

William J. Wolfe¹

The Barrens is a broad band of flat topography that occupies part of the Eastern Highland Rim of Tennessee, from northwestern Franklin County to the Smithville area in DeKalb County. Because of its flat topography, The Barrens is rarely emphasized in discussions of karst development in Tennessee. However, The Barrens contains a variety of distinctive and ecologically significant karst landforms. Two characteristic karst features of The Barrens are shallow (depth <1.5 meters), flat-bottomed karst pans, and larger, deeper (depth >2.5 meters) compound sinkholes. Both types of karst depressions generally flood for at least several months a year.

The ecological significance of these seasonally flooded karst depressions lies in the number and variety of rare and endangered plants and animals they support. Sinking Pond, Goose Pond, and other karst depressions at Arnold Air Force Base near Manchester, Tennessee, illustrate the geomorphic, hydrologic, and ecological characteristics of karst features in The Barrens.

Goose Pond and other shallow pans are isolated from the ground-water system. Depending on drainage basin characteristics and bottom material, pans can support vegetation ranging from common, highly adaptable trees such as *Acer rubrum* (red maple) to specialized wetland plants such as the coastal-plain tree *Nyssa aquatica* (water tupelo). The bottom material of the wettest pans is saturated throughout the year.

Sinking Pond and similar deep compound sinkholes are closely coupled to the ground-water system and are characterized by abrupt seasonal floods and recessions. Most compound sinkholes support forests of water-tolerant oaks. These features are less common than pans.

The general patterns of the water regimes in compound sinks and karst pans observed in The Barrens reflect geomorphic and hydrologic controls that determine the water regimes of sinkhole wetlands in other settings. These controls include sinkhole geometry; connection to the ground-water system; bottom elevation relative to the normal range of the water table; periodicity of water-table fluctuation; and drainage-basin characteristics (basin area, relief, ground cover, and other factors affecting runoff generation).

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A KARST INVENTORY OF THE OAK RIDGE RESERVATION, TENNESSEE

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INTRODUCTION

Our main purpose here is to present a summary of the karst features present within the Oak Ridge area and discuss the techniques used to produce the karst inventory. The discussion will focus on the sinkhole and cave inventory, but the spring inventory will also be discussed in the presentation. This work represents nine months worth of funding, spread out over two years, from the Oak Ridge Reservation Hydrologic and Geologic Studies Group.

The primary goal was to create a comprehensive inventory of the karst features present within the Department of Energy's Oak Ridge Reservation (ORR). The karst features included in the inventory are sinkholes, caves, sinking streams, and springs. The karst features within and surrounding the ORR were mapped and described using the following methods: (1) stereoscopic analysis of 1942 air photo stereo pairs; (2) detailed field mapping of the entire ORR; (3) reviews of old reports, topographic maps, and drilling records; and (4) word of mouth. Besides collecting the data, the secondary goal of this study was to make the information easily accessible and reproducible for those who need it. Therefore the data have been compiled digitally in spreadsheets that are linked to maps that have been created using both MAPINFO™ and ARCINFO™.

The inventory compiled from this study will provide the data necessary to develop a preliminary framework of the karst system within the Oak Ridge area. To date there have been numerous karst studies conducted on the ORR, such as (1) dye tracing tests, (2) airborne and ground-based

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geophysical studies, (3) statistical analysis of cavities intersected while drilling, and (4) cave mapping. The interpretation and extrapolation of the results, however has been affected by the lack of a comprehensive framework of the karst system surrounding the individual study sites. Furthermore, detailed field mapping was without question the most informative of all the techniques used to compile the inventory, because in order to understand the intricacies of a particular karst system, it is necessary to see it in action. Time after time, predictions made based on past experience have been wrong, which emphasizes the inherent complexities associated with most karst systems. This then calls into question the interpretations and models that are developed by studying only a small portion of the system. Finally, understanding the relationship between conduit development and bedrock geology is important on the ORR because the presence of mature karst indicates the potential for rapid transport of contaminated groundwater from waste disposal sites. Information of this type is needed for developing groundwater testing and monitoring strategies, and for characterizing and conceptualizing the base and storm flow response of the karst systems.

GEOLOGIC SETTING

The ORR is located in the northwestern part of the Appalachian Valley and Ridge physiographic province in east Tennessee. In the Oak Ridge area, three thrust faults (Kingston, Whiteoak Mountain, and Copper Creek) imbricate and juxtapose carbonate and noncarbonate sedimentary rock units that range in age from the lower Cambrian to the lower Mississippian (Fig. 1). The carbonate stratigraphic units range in total thickness from 4193 to 5735 ft, and include the Maynardville Limestone in the Conasauga Group (hereby included as part of the Knox Group), the Knox Group, and the Chickamauga Group. Stratigraphic relationships and repetition of units by thrust faulting have produced three northeast striking and southeast dipping carbonate bands bounded to the northwest and southeast by noncarbonate units (Fig. 1). In the Kingston thrust sheet carbonate band northeast of K-25, the strike and dip of bedding averages N50°E/40°SE, and maintains a fairly constant orientation. In the K-25 area, complex bedding orientations are associated with the southwest hinge of the East Fork Ridge syncline and the development of the Whiteoak Mountain fault (Fig. 1). In the Whiteoak Mountain thrust sheet carbonate band, the strike and dip of bedding is also approximately N50°E/40°SE, and maintains a fairly constant orientation across the area. Finally, the gentle dip of bedding (10–15°SE) in the Copper Creek thrust sheet is responsible for the large width of the carbonate band.

The Upper Cambrian to Lower Ordovician Knox Group is the thickest unit within each carbonate band. In general, the stratigraphic characteristics of the Knox Group remain the same within each thrust sheet, which suggests that stratigraphic controls on karst development will be similar within each carbonate band. The Knox Group consists of medium to massively bedded dolostone of various grain sizes, with lesser amounts of limestone, chert, and calcite cemented sandstone. The Middle and Upper Ordovician Chickamauga Group comprises the remaining portion of each carbonate band (Fig. 1). Although composed primarily of limestone, the

stratigraphic characteristics of the Chickamauga Group vary within each thrust sheet, because of sedimentologic facies changes. Within the Chickamauga Group there are a number of formations consisting of thick bedded mudstone, calcareous siltstone, and argillaceous limestone. Because these formations are less soluble, they may separate groundwater flow systems in adjacent units. Although the major carbonate units are the focus of this study, it is important to note that karst features have been documented in carbonate beds of the Rome Formation and Conasauga Group (Moore, 1988). In fact, a thick dolomite sequence does occur in the Rome Formation that is responsible for the development of a large sinkhole blind valley.

The fracture system in the area consists of both systematic and nonsystematic fracture sets comprised of extensional, hybrid, and shear fractures (Hatcher and others, 1992). The systematic fractures in the carbonates are planar, have relatively long lengths, and maintain a fairly consistent orientation with respect to bedding. There are two major systematic fracture sets that are normal to bedding. One fracture set strikes northeast and dips moderately northwest, and the second fracture set strikes northwest and dips steeply to the northeast or southwest. Solutional enlargement of fractures is clearly evident in surface and cave exposures. Furthermore, faults observed in exposures of the Knox Group are often associated with a local increase in the frequency of fracturing, which appear to develop as preferred zones of dissolution.

SINKHOLES

Stereoscopic analysis of 1942 air photo stereo pairs – Stereoscopic analysis of 1:12,000 scale 1942 air photo stereo pairs was conducted to identify closed depressions. The first reason the 1942 air photos were used is because they were taken at a time prior to the construction of the main plant sites and related facilities. As a result, for example, closed depressions that no longer exist were identified underlying buildings at the K-25 plant and X-10 sites. Many of these sinkholes were large enough to also be present on the preconstruction topographic maps of the plant sites. Second, the air photos were taken at a time when the amount of forest cover was less than today. Compared to the recent air photos, the 1942 photos provided a clearer view of the ground surface, which made it possible to identify relatively small closed depressions. Third, the over 50 year old air photos provided a means to compare changes in the landscape with what we see today.

Producing digital maps of the air photo interpretations required a number of steps. First, closed depressions were inked directly on the photos. Two different color inks were used based on how confident we were that the closed depression was "real". Second, mylars at a scale of 1:12,000 were made from the 1942 preconstruction topographic maps of the area. The older topographic maps were used because they contained similar cultural features that existed at the time of the air photos, which allowed them to be easily registered with each other. The circular depressions identified on the air photos were then transferred to the mylar maps. Third, the features on the mylar topographic maps were digitized into ARC/INFO™. Finally, the digital maps were

correctly registered to the present day ARCINFO™ version of the S16-A topographic map of the Oak Ridge area by using the relatively few correlative features, such as benchmarks, present on the old and new topographic maps.

If the closed depressions interpreted from the air photos represent sinkholes, then their abundance clearly attests to the mature karst development in the area. It is important to note here that the air photos covered both the carbonate and noncarbonate rock units, but only a handful of closed depressions were mapped in the noncarbonates. This suggests to us that we were not picking artifacts in the photos which would have been uniformly distributed regardless of bedrock type. More than 90% of the sinkholes occur within the Knox Group and the remaining occur within the Chickamauga Group. Any additional subdivision of the sinkhole data, however, must be considered with caution. For example, subdividing the number of sinkholes per individual formation within the Knox Group (e.g., Copper Ridge Dolomite, Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite) may be misleading, because the amount of cleared area with which to map them varied across the site. In other words, fewer sinkholes may be recorded in the Mascot Dolomite because there was more forest cover on that unit. Finally, although the air photos provided a means to begin assessing the distribution, size and shape of sinkholes in the area, many aspects of the sinkholes were still unknown, such as their depth and activity.

Field Mapping – Field mapping to inventory sinkholes, as well as the remaining karst features (caves, springs, and sinking streams) was conducted during the winters of 1995 and 1996. Mapping during the winter when the leaves were gone allowed for a clear sight over most of the area. Field teams consisting of primarily two to as many as five members mapped at a scale of 1:12,000. Teams worked in a coordinated manner to survey the entire landscape designated for that day. The mapping and inventory strategy changed progressively over the course of the project in 1995, but was fairly well established during 1996, when the majority of the area (two-thirds) was covered. The location of a karst feature was plotted on a topographic map while in the field. In addition, either a Magellan™ or Trimble™ GPS unit was used to determine the latitude and longitude coordinates in order to provide a check on the mapped location of the feature. In most instances the location plotted on the topographic map was accurate and was less time consuming than waiting for the GPS units to fix on the satellites and collect a sufficient number of readings. Besides plotting their location, the following information was collected for each sinkhole: elevation, sinkhole depth, sinkhole size (diameter if circular and long and short axis if elliptical), as well as any other distinguishing characteristics. We also developed criteria to decide if a sinkhole was presently active vs inactive. For example, active sinkholes contained steep (unstable) slopes, exposed bedrock, and a throat (drain). Inactive sinkholes exhibited gentle slopes, no bedrock, no throat, and well developed trees. These criteria may also be used to suggest the difference between subsidence sinkholes vs collapse sinkholes.

As with the air photo results, the majority of sinkholes were located in the Knox Group. A total

of 555 sinkholes were mapped across all of the ORR carbonate units. Numerous others not included in this count also exist, such as breached sinkholes along topographic slopes that are forming drainage ravines. Out of the total number of sinkholes mapped, 16% (86) of the sinkholes appear to be active based on the criteria noted above. There is a fair correspondence between the field and air photo mapped sinkholes. Some of the air photo sinkholes were not found in the field suggesting either that the landscape has modified them over the past 50 years or that they were wrongly identified as closed depressions (Fig. 2). The opposite is true also, many sinkholes mapped in the field were not identified on the air photos. Overall, we conclude that the field sinkhole database best reflects the karst features present today. Sinkhole locations were most abundant along ridge tops and saddles, with much fewer forming within drainage ravines. The sinkholes located within saddles were the most difficult to accurately measure for their size and depth, because some of the rims were formed by the upward sloping topography to the next ridge point. We decided to measure the diameter(s) and depth based on the distance to the lowest rim. With this problem in mind, sinkhole sizes covered a considerable range from less than five to hundreds of feet in diameter.

CAVES

The abundance of sinkholes, and in particular active sinkholes with visible drains, suggests that there exist well developed cave systems that transport the weathered bedrock material. Accurately predicting the geometry of a cave passage that is piping away soil from an active sinkhole is an elusive task considering the complex geology in the area. Only by cave mapping and geological studies in caves can we begin to decipher the stratigraphic and structural controls on passage development (Rubin and Lemiszki, 1992).

Following the criteria of the Tennessee Cave Survey, any enterable opening longer than 50 ft can be reported as a cave. The karst inventory contains a total of 49 caves that plot on the S16-A topographic map of the Oak Ridge area. Approximately half of these caves were previously known, but the rest have been found during the karst inventory project and as a result of the personal efforts of Bruce Zerr. Within the boundaries of the ORR there are twenty caves and a few potential cave leads. In particular, the ORR contains Copper Ridge Cave, which is the second longest cave in the area with a total length of over 1800 ft (Fig. 2). All of the caves occur within the Knox Group or Maynardville Limestone. On Blackoak Ridge and Chestnut Ridge 19 out of 24 caves occur on the scarp slope within the Copper Ridge Dolomite adjacent to the contact with the Maynardville Limestone. The abundance of caves found in these rock units, however, may be related to the fact that bedrock tends to be best exposed along the scarp slope. On Copper Ridge caves are more distributed, but again 19 out of 25 occur within the Copper Ridge Dolomite. On this ridge the shallower dip increases the width of the Copper Ridge Dolomite outcrop and also causes the Maynardville Limestone to form the outcrops along the scarp slope. Mapping in these caves has provided insights into the stratigraphic and structural controls on passage development.

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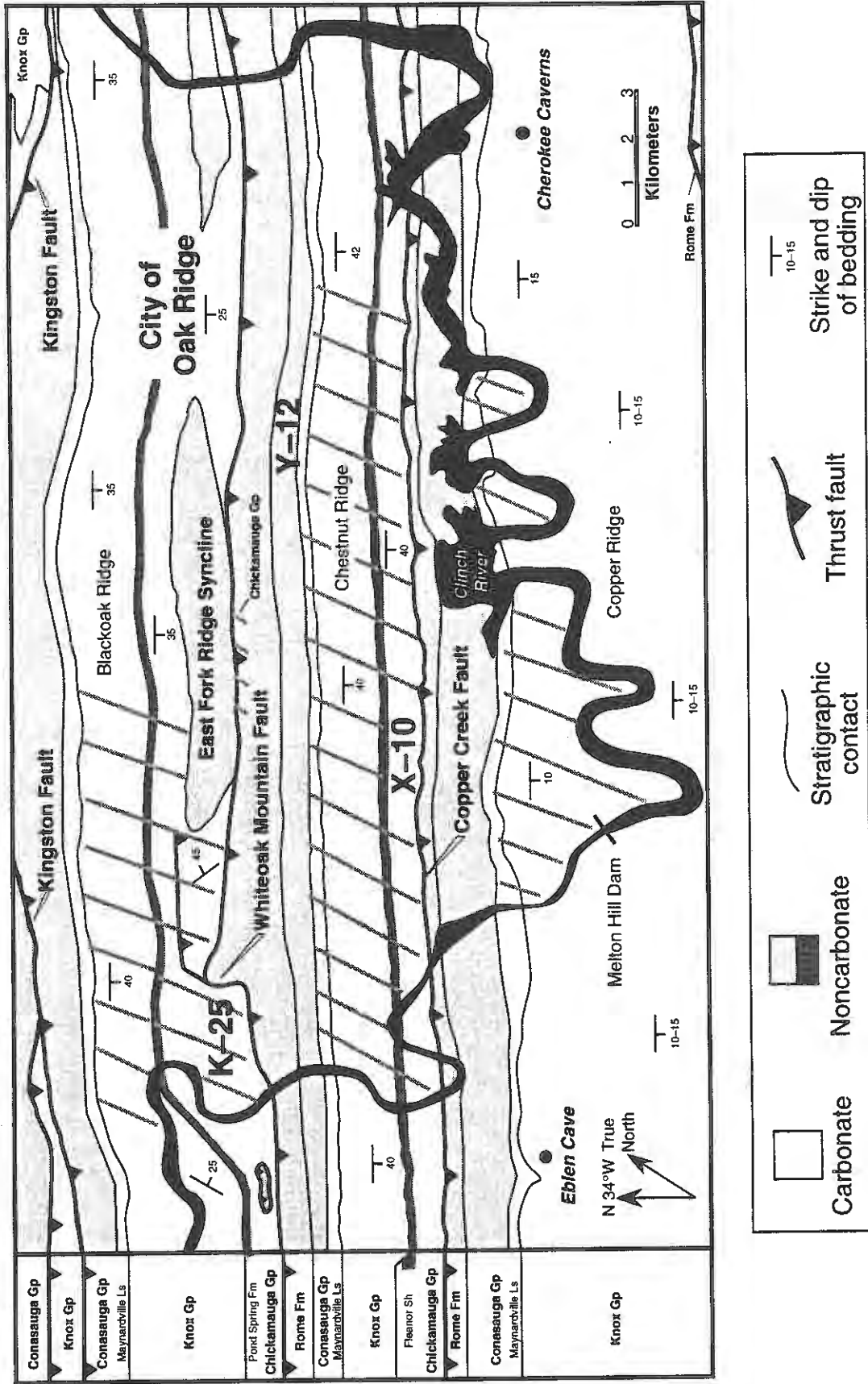


Figure 1. Simplified geologic map of the Oak Ridge Reservation and surrounding area. Cross lines represent the area of the detailed karst inventory.

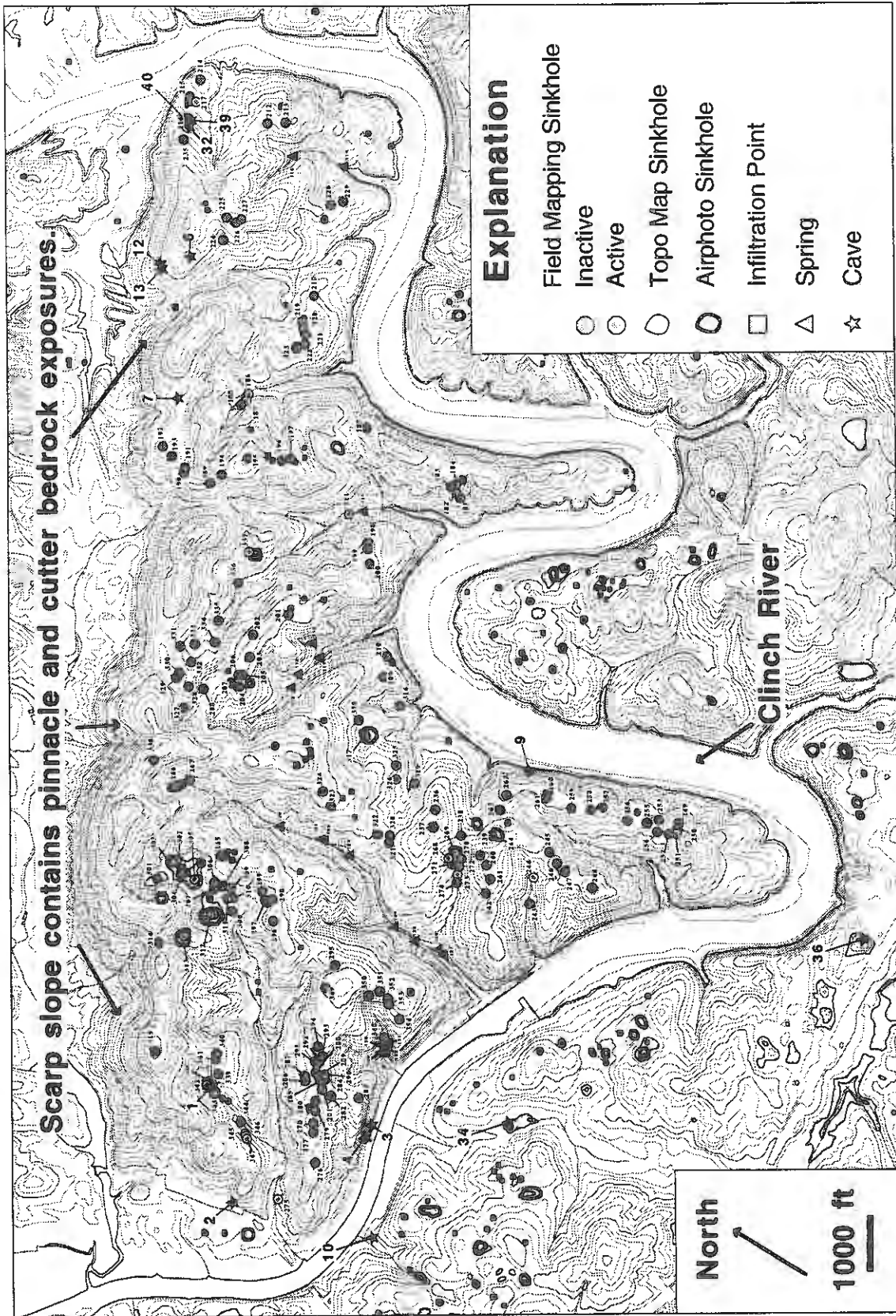


Figure 2. Karst features mapped on the portion of Copper Ridge that lies within the boundaries of the Oak Ridge Reservation. Cave #1 is Copper Ridge cave that is mentioned in the text.

**KARST VULNERABILITY ASSESSMENT
FOR SINKHOLE FLOODING
AND GROUNDWATER CONTAMINATION
IN MIDDLE TENNESSEE:
INTEGRATING HYDROLOGY, EDUCATION, AND POLICY**

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Anne Marie Otis,

and

Nathan Williams

INTRODUCTION AND PURPOSE

The upper Stones River watershed located in Rutherford County, Tennessee, is at the center of the prominent Central Basin karst region of middle Tennessee. The area exhibits thin soils and numerous wide, shallow sinkholes. It is well known that human development in such karst areas is often associated with hazards of sinkhole subsidence/collapse, groundwater contamination, and sinkhole flooding. While sinkhole collapse is rarely a major hazard in Middle Tennessee, groundwater contamination and flooding present significant potential risks. Sinkhole flooding, common in such shallow sinkhole depressions, is often intensified by increased surface runoff rates and altered drainage patterns resulting from urbanization. Potentially polluted surface water receives little natural filtration as it either percolates through the thin soils common in this karst terrain, or as it recharges directly into the aquifer through sinkholes. Once in the subsurface, the contaminated water may travel rapidly through the open conduits.

Rutherford County, located adjacent to Nashville in Davidson County, has experienced tremendous population growth in the past two decades. According to the 1990 U.S. census, Rutherford County was the fastest growing county in Tennessee (41%), and Murfreesboro, the county seat, was the second-fastest growing "exurb" in the U.S. (37%). As the county grows at such a fast pace, the environmental condition has been, and will continue to be, under extreme development pressure. Thus, the assimilative capacity of the subsurface karst aquifer and the surface karst drainage system is pitted against the engineering efforts of the developers. As

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population increases and development continues, surface and subsurface drainage systems in karst regions become increasingly vulnerable to hazards such as sinkhole flooding and groundwater contamination, because of: (1) increased stormwater discharge, (2) leaks, spills and discharges of contaminants from commercial and industrial sources, and (3) high spatial concentration (and failure) of residential septic systems.

However, there is a general lack of understanding of groundwater behavior and potential problems in karst areas by both the general public (due to ineffective public education) and by some decision-making officials (who may unwittingly make inappropriate land-use decisions). Inappropriate land use such as sinkhole dumping present a significant potential for affecting water quality. In addition, the lack of significant land-use restrictions prevents those citizens and planners aware of karst hazards from effectively controlling development in sensitive areas.

Therefore, given the increasing vulnerability of the karst system due to the growth rate of Rutherford County; potential for groundwater contamination, sinkhole flooding and related karst problems will increased. Thus, it becomes imperative for the protection of public and private drinking-water supplies, stormwater drainage, and the general surface and groundwater quality of Rutherford County, that (1) a systematically approached and scientifically based karst vulnerability assessment be prepared as a guide for land-use decisions; (2) the general public and public officials become aware of karst processes and their hazards; and (3) that public policies and regulations be adopted and implemented to improve and ensure the regional water quality.

KARST VULNERABILITY ASSESSMENT

The primary scientific result of this project shall be a comprehensive Karst Vulnerability Assessment of Rutherford County to identify high-risk areas for sinkhole flooding and serious groundwater contamination. The assessment will consist of a series of county-wide maps of geologic and hydrologic features, accompanied by textural explanation, analysis, and interpretation. Themes of the maps and text will include: (1) sinkholes and sinkhole areas (particularly for sinkhole flooding), (2) lineaments and fracture traces, (3) soil suitability for on-site septic absorption fields, (4) wetlands, (5) watersheds for important surface-water supply areas and groundwater recharge areas for important springs, and (6) groundwater contamination vulnerability (a composite of the first five maps). Each map will be accompanied by (a) textual and graphical explanation of the physical characteristics of the features, (b) analysis of the importance of each feature in the context of karst vulnerability, and (c) interpretation of the approach(es) needed to correct and minimize the associated risk.

The development of the Karst Vulnerability Assessment will include: (1) examination of USGS and other topographic maps for major sinkholes and areas of high sinkhole concentration (mapped by percent area), and delineation of surface watersheds; (2) interpretation of multiple date aerial photography for sinkholes, fracture traces, springs, and wetlands, (3) review of the published geologic quadrangle maps and USDA-NRCS Soil Surveys for soil limitations for septic systems and for wetlands delineation, and (4) field mapping. Pending sufficient funding,

the field mapping may include: (a) detailed mapping and verification of areas of high concentration of karst features observed on the previous media, (b) collection of periodic water level data to prepare a water table map for delineation of recharge areas and general groundwater flow directions, (c) dye tracing studies to provide more accurate delineation of flow direction and velocity of significant karst features, and (d) monitoring of rainfall, spring discharge, and streamflow of one or more major springs to determine style of recharge and flow systems and surface/ground water interaction.

Each map will be prepared by sections on a base of 1:24,000 USGS topographic quadrangles (seventeen covering Rutherford County), and will be digitized into a GIS for data management, compilation, and production of the geologic and hydrologic feature maps and the groundwater contamination hazard map. By using the GIS, this work can be used as a starting point for future hydrologic and land-use studies, and new land-use and point data can be added periodically, keeping the product up to date.

Suggestions for additional investigations for subsequent years include: (1) development of a quantified DRASTIC index map modified for the karst aquifer; (2) calculation of the degree of localized sinkhole flooding predicted for specific rainfall events by use of GIS and Stormwater Management Model; (3) completion of an inventory of underground storage tanks and other potential contaminant sources in the county; (4) completion of an inventory of all sinkholes near major highways in the county, including the determination of flow directions (by dye tracing); and (5) associated with these projects, assistance to the county government in establishing an emergency response plan in the event of a detected leak or spill of a hazardous substance.

The maps from this project will provide a general characterization of the county. While as much detail as possible will be included, the maps are intended for general, rather than site-specific, use. When significant developments are planned, it will be necessary to develop site-specific information. This information, coupled with sufficient understanding of karst processes, will lead to more effective and protective land use decision.

KARST EDUCATION

The public often lacks understanding of the basic processes of groundwater flow, especially in karst terrain. Evidence of this is found in the occurrence of widespread sinkhole dumping resulting from the perceived expense and inconvenience of refuse pickup or hauling to convenience centers. Residents must understand the basics of caring for their own watershed, and decision-making public officials must be informed of the hazards and risks associated with decisions of development in karst terrain. Far-reaching public education of karst processes is both dependent upon the reliable research of the karst vulnerability assessment and is essential to the assessments effective use through land-use planning. Education provides the basis for understanding the assessment and the policy.

Environmental education of karst processes and hazards, coupled with the assessment, should

target several specific groups. The results of the assessment will be used primarily by Rutherford County Regional Planning Commission for making land-use decisions and establishing land-use policy. This document will increase their efficiency by allowing them to spend less time on proposals in low-risk areas, and concentrate efforts on proposals in moderate-, and high-risk areas. This project will also benefit developers, who will be more informed in their site selection process by avoiding the high-risk areas, reducing the risk of costly environmental site preparation or remediation. The Chamber of Commerce will be able to attract prospective industries with easier preliminary site selection and will be able to identify "environmentally friendly" prospective industries. Banks and loan agencies can assess risk and value of commercial and residential loans. Insurance companies will be able to identify areas at risk for sinkhole flooding and subsidence. And of course, residents will develop a greater sense of informed ownership and pride in their county.

For a program of environmental education to be effective in accomplishing its goals, a series of necessary components must be present that correspond to appropriate attitudes developed among the public, including citizens and decision-making officials alike. First, an education program must create an initial awareness of the situation in response to a real need. In the case of Rutherford County, the public must become aware of the need to reduce/prevent the occurrence of sinkhole flooding and groundwater contamination. Second, by use of accurate and objective information (the karst vulnerability assessment), the public develops an understanding of the processes creating the need. Third, public involvement in the solution is necessary and is encouraged by moral and practical support of the local public officials. Fourth, the public must develop a change in their behavior toward the environment that will lead to a long-term rather than a short-term solution to the situation. And fifth, an attitude of commitment by the public is necessary to provide a proactive, rather than reactive approach.

An effective environmental education program will consist of several diverse components, each designed to reach a different segment of the public. Education must begin in the school curriculum at all levels. K-12 and post-secondary institutions should include karst as a significant component within their normal earth and environmental science topics. Media releases, periodic newsletters, and informational brochures could be used to reach a large number of people no longer in formal education settings. For those of greater awareness and concern, public informational meetings and project field days could be presented to more thoroughly explain karst care methods. A one-day conference could be offered periodically for decision-making officials such as planners, developers, and representatives from loan agencies, insurance companies and the chambers of commerce. Regardless of the approach, each component must convey, at the appropriate level, the basic processes of karst hydrology, the hazards associated with the terrain, the risks presented by our activity, and the proper care for the environment to limit the risks.

KARST POLICY

The entire karst vulnerability assessment and education program avails little, however, if specific action is not taken in the form of enforceable planning regulations that minimize the risks. The success of the educational programs directly affects the public understanding and acceptance for policy control of land use. At the same time, land use policy is an essential and beneficial key to unlocking educational barriers to residents, developers, policy regulators and other decision making officials. While most planning and zoning offices have developed suitable development ordinances and land-use plans for normal geologic conditions, the presence of karst requires development of a set of special guidelines to protect the environment and the human health and welfare.

Properly established, karst regulations coupled with the karst assessment can produce several desired outcomes. Once established, the presence of ordinances will allow increased efficiency of land-use decisions by the regional planning board. By identifying high-risk areas with the karst vulnerability assessment, planners can use policy guidelines to spend less time approving proposals in low-risk areas and more of their time in areas of concern. Properly implemented policy will protect the economy and the environment. Chambers of Commerce and departments of economic development can more easily screen potential industries that will increase the economic base while presenting a decreased potential for environmental degradation. Similarly, prospective corporations can improve their primary site selection process by use of the assessment and development restrictions. This simple site selection approach to pollution prevention could prevent them from expensive contamination remediation procedures. Smaller developers and loan and insurance agencies can also reduce their risk of loss by restrictions in high vulnerability areas. Finally, when properly enforced, the policy will help inform and guide citizens in responsibly caring for their environment.

Special karst policy, as observed in several other karst areas in the United States, can take several approaches, all aimed at reducing the impact of development on the karst environment. For example, protection of highly vulnerability areas typically requires restriction of nearby development. Rural subdivision ordinances control housing density; particularly important for spacing rural on-site sewage absorption fields in thin-soil areas. Sinkhole buffer zones may be a keystone for karst protection policy by retaining or constructing vegetated buffer zones to limit surface runoff into open sinkholes. For commercial properties, it is important to license potential contaminants, closely monitor their use, and require preparation of an emergency management plan in the case of a spill.

CONCLUSION

Protection of the environmental quality, economic potential, and human health and welfare in a karst terrain requires the intimate integration of science, education, and policy. Accurate and objective information in the form of a karst vulnerability assessment can become useful only when effective public education, integrated with appropriate environmental policy, are properly

implemented. The need for land use planning and regulation increases the importance for education programs both to the citizens and the decision-making officials. Meanwhile, education is effective only when a need is communicated, which may occur through the vulnerability assessment and the enforced regulations. However, both education and policy related to karst environmental risks have no basis without a comprehensive, accurate, and scientifically-based assessment of the karst hazard.

SESSION 1-D

STUDENT SYMPOSIUM #1

10:30-12:00

Clark Cropper, *Investigations of Air and DNAPL Entry and Migration in Large Columns of Fractured Shale Saprolite.*

Kenneth Stewart, *An Extended Study of the Treatment Capability of Three In-Tank Filters for Septic Effluent.*

Stephen M. Long, *Treatment Capability of Commercial Septic Tank Effluent Filters.*

STUDENT SYMPOSIUM #2

1:00-2:30

Jack D. Wall, *An Application of Arc/Info GIS and the USGS Three-Dimensional Finite-Difference Model MODFLOW on a Carbonate Aquifer.*

Katherine Y. Pelren, *Environmental Fate and Transport Modeling Made Possible via the Internet.*

Stacy Nolan, *Comparison of Joint, Sinkhole, Photo-Lineament, Straight Cave Segment, Stream Orientations for Predicting Contaminant Transport Direction in the Central Basin of Tennessee.*

STUDENT SYMPOSIUM #3

3:00-4:30

Philip Storvik, *Fecal Coliform Bacteria and Nitrate Levels of Carbonate Wells and Springs in Rutherford and Cannon Counties, TN.*

John W. Burleyson, *Comparison of Sinkhole Densities for the Carbonate Rocks of Tennessee.*

J.B. Reese, *Determining a 100-year Peak Flow and Associated Errors from Simulated Streamflow.*

INVESTIGATION OF AIR AND DNAPL ENTRY AND MIGRATION IN LARGE COLUMNS OF FRACTURED SHALE SAPROLITE

*S. Clark Cropper¹,

and

McKay, Larry D.

INTRODUCTION

Dense nonaqueous phase liquids (DNAPLs) are often detected at hazardous waste sites, and are among the most common hazardous chemicals found in groundwater (Mackay and Cherry, 1989). When released to the soil, DNAPLs enter and initially move through the subsurface as a distinct continuous fluid phase because of their low solubility in water (Carey et al., 1989). during migration, a discontinuous liquid residual or pools of continuous phase can form which will slowly dissolve in flowing groundwater and create health hazard that can persist for decades (Kueper, et al., 1993). Estimating or predicting the extent and distribution of DNAPL residuals and pools are critical steps in designing measures to clean up or control the spread of contamination. Many investigations in DNAPL migration have been conducted in granular materials, while few studies have been conducted in fractured materials, even though there are many sites where DNAPL contamination has occurred in fractured soil and rock.

THEORY AND BACKGROUND

When present, fractures and macropores can act as rapid migration pathways for DNAPLs (Wills et al., 1992; Kueper et al., 1992). In fractured materials, DNAPLs tend to follow the largest aperture fractures, so their movement and final distribution can be very erratic. This makes them difficult to find and remove. As well, a DNAPL spill in fractured material can spread over a much larger region than the same spill in a granular material because the macroporosity represents only a small portion of the total volume of the material. For a DNAPL to enter a saturated fracture, it must overcome an "entry" displacement pressure controlled mainly by the aperture of the fracture and the interfacial tension between the DNAPL and water. Being denser than water, a DNAPL can displace water and move vertically through a fracture network as long as the pressure at the base of the DNAPL phase (capillary pressure) is greater than the displacement entry pressure present in the fractures. If the displacement pressure is not exceeded, migration will either continue laterally or stop and begin to pool. Interconnecting

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fractures will be invaded only if their apertures are large enough to permit entry of the DNAPL. A DNAPL generally migrates downward through a medium choosing paths determined by the lowest displacement pressure high enough to act as a barrier. Since DNAPL migration in fractured materials is largely controlled by the relationship between the capillary and displacement pressures at the fluid interface within the fractures, it is necessary to quantify this relationship to model DNAPL migration.

In porous materials, capillary pressure is a function of water saturation. The established method for determination of capillary pressure-saturation relationships in porous media consists of establishing a series of equilibria between water in the sample and a body of water at known potential (Klute, 1986). This method has typically been applied to air-water systems where air is the immiscible fluid. Data obtained by this method are most often fit to either the Brooks and Corey (1964) or van Genuchten (1980) model to produce an expression relating the capillary pressure and the water saturation. Capillary pressure-saturation curves are used to graphically depict these relationships.

Experimental work by Lenhard and Parker (1988) has shown that capillary pressure-saturation relationships for air-water systems in granular materials can be scaled to give a good estimate of the capillary-saturation relationship for another fluid pair. A scaling factor is determined from the ratio of the air-water interfacial tension to the interfacial tension between the other fluid pair. This work suggests that differences in capillary pressure-saturation relationships between pairs of immiscible fluids may simply be a function of fluid properties.

Recent models of capillary pressure behavior in fractured materials assume that fractures exhibit capillary behavior very much like granular materials based on an analogy between the distribution of pore throat radii in a porous medium and the distribution of apertures in a rough walled fracture (Firoozabadi and Hauge, 1990; Kueper and McWhorter, 1991). In this case, capillary pressure in fractures is a function of saturation as it is in porous media, and models developed to describe capillary pressure-saturation relationships in porous media would be applicable to fractured media. Although there are few studies in the scientific literature where capillary pressure-saturation relationships have been determined directly in fractures, excellent support for this hypothesis was given in a study by Reitsma and Keuper (1994). They measured capillary pressure-saturation relationships in a single fracture and found that the Brooks-Corey porous media model fit their data well. Also, in a study by Hinsby et al. (1995), entry pressure measurements were made for the injection of creosote into a large scale column of fractured glacial till. Although results contained a large degree of uncertainty because of pressure measurement problems, they estimated fracture apertures based on the measured displacement entry pressure and their estimates were within the range of apertures estimated from hydraulic and colloid transport methods.

PROPOSED INVESTIGATION

If the capillary behavior and scaling principles are applicable in fractured media, DNAPL-water entry and drainage behavior may be predicted based on air-water data and a scaling factor based on differences in the immiscible fluid properties. This would have several advantages including: 1) air-water drainage curves are readily available for many kinds of media, and theoretical and modeling approaches are already developed; and 2) more importantly, air-water drainage curves can be determined in the field without introducing hazardous chemicals into the environment.

In experiments on small scale columns of undisturbed fractured shale saprolite collected from the Melton Valley area of the Oak Ridge Reservation, Oak Ridge, Tennessee, Wilson et al., (1992) found that water saturation decreased markedly when capillary pressure was incremented between zero and -1.0kPa again resulted in relatively large decreases in saturation. It is hypothesized that this behavior represents initial rapid drainage of the fractures at capillary pressures between 0 and -1.0kPa, followed by a period of very little drainage until water occupying the much smaller pores of the matrix begins to drain at a distinctly lower pressure head. This behavior allows the capillary behavior of the fracture and macropore system within this material to be isolated from that of the matrix so long as capillary pressures are always above -25kPa. In the proposed investigations, initial entry pressures and capillary pressure-saturation curves will be measured for air-water and DNAPL-water fluid pairs in a large diameter columns of the same fractured saprolite. The data sets will be compared to examine the relationship between air-water and DNAPL-water behavior in fractured soils. The investigation is expected to give considerable insight into the migration of DNAPLs in fractured materials, and potentially provide a safe method for estimating DNAPL capillary behavior in fractured materials in the field or laboratory.

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**AN EXTENDED STUDY
OF THE TREATMENT CAPABILITY
OF THREE IN-TANK FILTERS
FOR SEPTIC TANK EFFLUENT**

Kenneth Stewart,

Dr. K. Larry Roberts,

and

Dr. Richard W. Lowhorn¹

INTRODUCTION

One of the simplest and most economical methods of improving septic tank effluent quality is an in-tank effluent filter designed to remove suspended solids and BOD. A study conducted at Tennessee Technological University by Treanor [1] showed that the filters reduced the suspended solids and BOD discharged to the absorption field. Treanor's work was a short-term study (approximately 3 months) and is currently one of the few non-biased evaluations of filter performance.

OBJECTIVE

One objective of this current research was to evaluate the filters studied in Treanor's project after they had been in operation approximately 5 months. Filter failure to reduce the suspended solids leaving a tank would define the required filter cleaning interval. The second objective of this project was to produce new short-term BOD and TSS data to compare with that produced by Treanor [1].

EXPERIMENTAL METHODS AND MATERIALS

Phases

In order to meet the objectives, this study was conducted in three phases. Phase I, which began approximately 5 months after Treanor's study terminated, was the long-term phase. This phase included the measurement of BOD and TSS with the filter condition unchanged from Treanor's study. Phase II involved removing the filters and measuring the BOD and TSS with only a

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standard tee on the effluent line. The purpose of Phase II was to produce new baseline data of the septic tanks' operation without the filters. In Phase III the filters were cleaned and reinstalled in the tanks; and, where it was possible, the filters were installed in an order different from that of Phase I.

Filters

Three types of filters were used in Phase I: the Orenco models FT0436 (4" diameter/ 36" height) and FT0848 (8" diameter/ 48" height), and the Zabel model A-100 (12" diameter/ 16" height). In Phase III the Zabel model A1810-1 (4" diameter/ 18" height) was also used. A detailed description of the filters is given by Stewart [2].

Sampling

The sampling sites were located in Putnam County, Tennessee, either in or near the city of Cookeville. The sites and the sampling procedure used were the same as in Treanor's [1] study. Access to each septic tank was provided through a ribbed PVC riser that was covered with a watertight fiberglass lid. During each sampling trip two water samples were taken from each septic tank. One sample was withdrawn from the surface and the other at the 3" depth inside the filter or tee. A hand held vacuum pump was used to withdraw the samples through a plastic tube that was firmly attached to the inside of the filter or tee.

The ambient and water temperatures at various depths and locations in the tanks were recorded during each sampling trip to account for seasonal variations. The ambient temperature was obtained from the Cookeville wastewater treatment plant, and the temperatures in the tanks were obtained using a thermometer mounted inside the tanks.

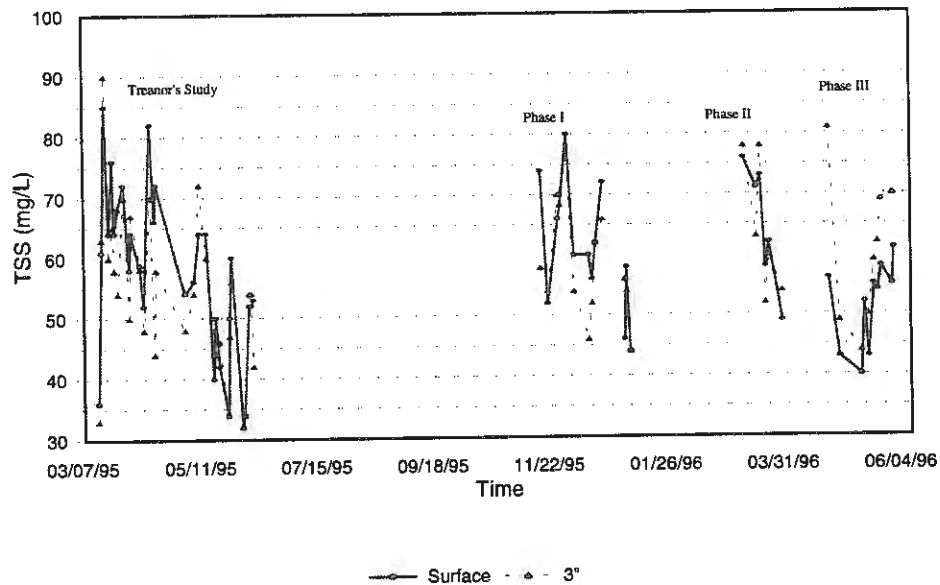
The 3" depth sample collected from each site was analyzed for TSS and BOD. The surface sample was analyzed for TSS only. All of the laboratory testing was performed in accordance with the methods listed in Standard Methods for the Examination of Water and Wastewater [3].

RESULTS AND ANALYSIS

Baseline

The first step in the filter analysis was a comparison of Treanor's baseline data (no filter) to the Phase II (baseline) data. The surface TSS changes were statistically significant only at sites 5 and 6. A similar analysis of the 3" depth TSS data revealed that the changes were significant at sites 5, 6, and 7. The changes in BOD baseline were statistically significant at sites 1, 2, 4, 5, and 7. It should be noted that the asterisks in the tables included in this abstract indicate that the changes in the baseline results of the measured parameter were statistically significant at the sites. Since the baseline had significantly changed for three of the sites, it was decided to use the new baseline established in Phase II in determining the treatment achieved in Phase I (long term).

Figure 1. TSS vs. Time at Site 2.



TSS

As mentioned earlier both the surface and 3" depth suspended solids were measured at each site. A comparison of the data for one of the sites is given in Figure 1 along with Treanor's [1] data. This figure illustrates the variability that was experienced in the data and the time frame of the project. Since the 3" depth solids were more representative of the effluent solids from the tanks, this paper will only present that data. A more detailed presentation of the results and discussion was made by Stewart [2].

TSS Reductions for Phase I (Long-Term). The 3" depth TSS results for the long-term study are presented in Table 1. The extremely large increase at Site 4 was the result of an overloaded 1000 gallon septic tank serving a family of 11 people. During Phase I, the effluent filter became clogged with solids as a result of this overloading condition. Excluding site 4, the highest increase in 3" depth TSS was 8 percent at Site 3. Results at 1, 2, 5, and 7 indicated a reduction in the effluent suspended solids as a result of the filter installation. Comparing these sites to the results produced approximately 5 months earlier (Table 2), indicated that the effluent qualities at sites 1 and 5 had continued to improve while those at sites 2 and 7 had worsened.

Table 1 Phase I 3" Depth TSS % Changes

Site	Phase II Baseline Average (mg/L)	Phase I Filter Average (mg/L)	% Change
1 (8" Orenco)	55	44	-20
2 (4" Orenco)	64	59	-8
3 (4" Orenco)	49	53	8
4 (4" Orenco)	62	489	689
5 (12" Zabel) *	50	47	-6
6 (12" Zabel) *	45	46	2
7 (12" Zabel) *	784	70	-91

Table 2 Comparison of 3" Depth TSS % Changes for Treanor's Study and Phase I

Site	Treanor's Filter Average (mg/L)	Phase I Filter Average (mg/L)	% Change
1 (8" Orenco)	52	44	-15
2 (4" Orenco)	48	59	23
3 (4" Orenco)	52	53	2
4 (4" Orenco)	64	489	664
5 (12" Zabel) *	54	47	-13
6 (12" Zabel) *	47	46	-2
7 (12" Zabel)	40	70	75

The only statistically significant change from the earlier study was the increase in the effluent suspended solids that occurred at Site 2. Even though the filter at Site 7 was not reducing the solids to the concentration experienced in Treanor's study, it was reducing the solids a higher percentage as compared to the new baseline of Phase II.

Taking into consideration the special effects at sites 4 and 7, the results generally indicated that most of the filters maintained or improved their efficiency between Treanor's short-term study and the Phase I long-term study.

TSS Reductions for Phase III (Short-Term). The short-term data generated in Phase III are compared with the short-term data of Treanor's study in Table 3. The filters were changed at all the sites except sites 2, 4, and 7. The filters at sites 1 and 7 out-performed those filters installed at these sites in Treanor's study. Those filters at Sites 2, 3, 5, and 6 did not perform as well as the installations studied by Treanor. The results of the filter at Site 4 were still indicating an overloaded condition.

It should be noted that the tank at Site 4 was pumped just prior to Phase II. It appears that the loading on the system was so large that the accumulation of solids onto the filter quickly caused a failure of the filter. The tank at Site 7 was not pumped during the study and the filter at this site clogged up with solids within 14 days after reinsertion for Phase III. It was re-cleaned and by the end of Phase III appeared to be nearing a point where it needed cleaning again.

Table 3 Phase III 3" Depth TSS % Changes

Site	Phase II Baseline Average (mg/L)	Phase III Filter Average (mg/L)	% Change	Treanor's % Change	Treanor's Filter Type
1 (12" Zabel)	55	20	-64	4	8" Orenco
2 (4" Orenco)	64	60	-6	-19	4" Orenco
3 (4" Zabel)	49	68	39	0	4" Orenco
4 (4" Orenco)	62	186	200	3	4" Orenco
5 (4" Orenco)	50	66	32	-33	12" Zabel
6 (8" Orenco)	45	50	11	-20	12" Zabel
7 (12" Zabel)	784	221	-72	-27	12" Zabel

BOD

The variability of the BOD data was even more pronounced than that for the TSS data. Because of this variability the results were difficult to analyze and were inconclusive.

Temperature

The temperature results indicated the 3" depth temperature was affected more by seasonal temperature trends than the individual daily ambient temperatures. The high and low daily peaks seemed to have little effect on the water temperature. The tanks were at least 1' underground, which provides some insulation against daily temperature changes. The difference in the average temperature inside the tank between Phases I and II was approximately 1° C. With the variability that was experienced in the data, this was considered to be a negligible difference. The change in the average temperature in the tanks between Phases II and III was approximately 8°C. This temperature fluctuation could have had an impact on the settling characteristics of the solids. There was also a general stratification of temperature with depth in Phase III that could have affected the distribution of solids with depth.

pH

The pH throughout the tanks was fairly uniform, especially for Phases II and III. This showed there was little or no zoning in the tanks relative to pH, which may indicate there was some degree of mixing.

CONCLUSIONS AND RECOMMENDATIONS

The long-term study indicated the filters either improved or maintained their efficiency in removing the suspended solids over an eight-month period. One of the seven sites studied indicated that the filter needed to be cleaned. Where comparisons were possible, the 12" Zabel

filters appeared to have better TSS removal efficiencies than the other filters on a short term basis. The filters operated relatively equally on a long-term basis, with the exception that one of the Orenco filters was shown to be approaching its cleaning time cycle.

The results of this study, combined with those from Treanor's [1], reflect the variable conditions within the septic tanks. It is recommended that a similar study be conducted under more controlled conditions. The temperature data suggested that stratification occurred seasonally. This effect and its impact on the solids concentration should be evaluated. It is also recommended that samples be taken inside and outside the filters to establish removal efficiencies in lieu of sampling with and without a filter.

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**TREATMENT CAPABILITY
OF COMMERCIAL SEPTIC TANK
EFFLUENT FILTERS**

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INTRODUCTION

Any technology that improves the quality of the effluent from septic tanks would have a beneficial effect on ground and surface water quality in the United States. Improvements to existing technology include sand filtration, multi-soil-layering, and commercial septic tank effluent filters.

A series of projects evaluating the efficiency of septic tank effluent filters has been conducted at Tennessee Technological University. The overall objective of these projects was to study the treatment capability of commercial septic tank effluent filters. Treanor [1] began the first project, an evaluation of the removal of suspended solids (SS) and BOD by the filters, in the Spring of 1995. The project reported in this paper, an evaluation of the removal of total volatile suspended solids (TVSS) and nitrogen by the filters, started in November, 1995.

OBJECTIVES

The objectives of this project were:

1. To determine if the effluent filters reduced the concentrations of TVSS in septic tank effluents on a short- and long-term basis.
2. To determine what concentrations and forms of nitrogen were present and if there was any reduction in nitrogen due to the effluent filters.
3. To measure temperature, dissolved oxygen (DO) concentrations, and fecal coliform counts to determine if changes in these parameters affected removals or had any interactions with the filters.

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PHASES

This study was conducted in three phases. The first phase was conducted to determine if the filters affected water quality parameters such as TVSS, DO, fecal coliform counts, and nitrogen on a long term basis. Since Treanor (1) installed the filters in March, 1995, and this study was begun in November, 1995, the long-term basis was approximately 8 months. Phase 1 began in November 1995 and ran until the requirement of 15 sampling trips had been completed. The three types of filters used in Phase 1 were the Zabel A-100 Filter, manufactured by Zabel Wastewater Filter Systems, and the FT-0848 and FT-0436 Biotube Effluent Filters, manufactured by Orenco Systems®, Inc [1]. A detailed description of all of the filters used can be found in Long [2].

The second phase was conducted in order to establish a baseline against which to compare the results of the other phases. The filters were removed and tees installed in the tanks where possible. The tanks were left undisturbed for one week to adjust to the lack of filters, and then 6 samples were taken during the period January 1996, to March 1996.

During the third phase, clean filters were reinstalled at different sites and sampling begun immediately in order to determine the effect of the filters on the water quality variables on a short term basis. Site configurations are shown in Table 1. In addition to the three types of filters already mentioned, a 4" Zabel A1810-1 was installed at Site 3 during Phase 3 due to tank constraints. Ten samples were taken in the period April, 1996, to May, 1996.

SITES

The 7 sites used in this study were the same as those used by Treanor [1] with the exception that one homeowner dropped out. All are located in Putnam County, Tennessee, either in or near the city of Cookeville. Table 1 shows the sites and the type of filter installed at each site.

	Phase 1	Phase 2	Phase 3
Site 1	8" Orenco	tee	Zabel
Site 2	4" Orenco	tee	4" Orenco
Site 3	4" Orenco	tee	4" Zabel
Site 4	4" Orenco	tee	4" Orenco
Site 5	Zabel	tee	4" Orenco
Site 6	Zabel	tee	8" Orenco
Site 7	Zabel	tee	Zabel

SAMPLING PROCEDURES

Samples were taken from the tanks using a hand-held vacuum pump and plastic hose fastened to the filter housing at the appropriate depth. During Phases 1 and 3, samples for TVSS, DO, and coliform analysis were taken 2 to 3 times a week from the septic tanks until some minimum number of sampling trips (15 for Phase 1 and 10 for Phase 3) had been completed. During Phase 2, 6 samples were taken over a 6 week period. All samples were taken between the hours of 7:00 and 11:00 a.m., as consistently as possible, to take into account the fluctuations in the wastewater flow throughout the day.

Each septic tank was accessed by a fiberglass riser with a fiberglass watertight lid. At each sampling site in the first and third phases, up to three samples were taken from each tank. The first sample was taken inside the filter 3" below the water surface to avoid any floatable solids. The second sample was taken at the surface of the water inside the filter. The surface samples were for comparison purposes only and will not be discussed in this paper. The data is available in Long [2]. In a limited number of cases, the third sample was taken at the 3" depth outside the filter to analyze for nitrogen.

An Orion model 290A portable temperature and pH probe was used to measure temperature and pH readings at each sample site at water levels 1', 2', and 3' below the water surface outside the filter, given that the septic tank was deep enough to obtain the 3' reading. A Fisher® thermometer which was mounted in each filter was used to measure the temperature inside the filter at approximately 3" below the surface of the water.

SAMPLE ANALYSIS

The sample that was taken from the 3" depth below the water's surface inside each filter was analyzed for TVSS, nitrogen concentrations (when appropriate), DO, and fecal coliforms. The next sample, taken at the water's surface inside the filter leading to the effluent pipe, was analyzed for TVSS only. The third sample, taken at a 3" depth below the water's surface outside the filter, was analyzed for TVSS and nitrogen concentrations. All analyses were conducted in accordance with methods outlined in *Standard Methods for the Examination of Water and Wastewater* [3]. During each sampling trip the samples were stored in a cooler with ice to preserve the samples.

Photographs were taken with a 35mm camera to document the progression of solids accumulating on the effluent filters used in this study. Each photograph was taken after the samples had been taken from the filter so that each sample was not disturbed. In order to understand what is actually accumulating on the effluent filter, solids scrapings were obtained from the filters located at Site 1, Site 6, and Site 7. These particular sites include a lightly loaded system, a normal loaded system, and a failing system, respectively. The photographs of the filters and the scrapings will be referred to in this paper, and can be seen in Long [2].

RESULTS

Figure 1 shows the variation of TVSS data at a typical site over the duration of the project. Figures showing the data at other sites are contained in Long [2]. The TVSS data for each site were averaged and the Phase 1 and 3 (filters installed) data compared to Phase 2 (no filter - baseline) data. The percent changes are shown in Table 2 for Phase 1 (long term) and Table 3 for Phase 3 (short term). The statistical significance of the change percentages were computed using $P=0.05$ and are also shown in Tables 2 and 3.

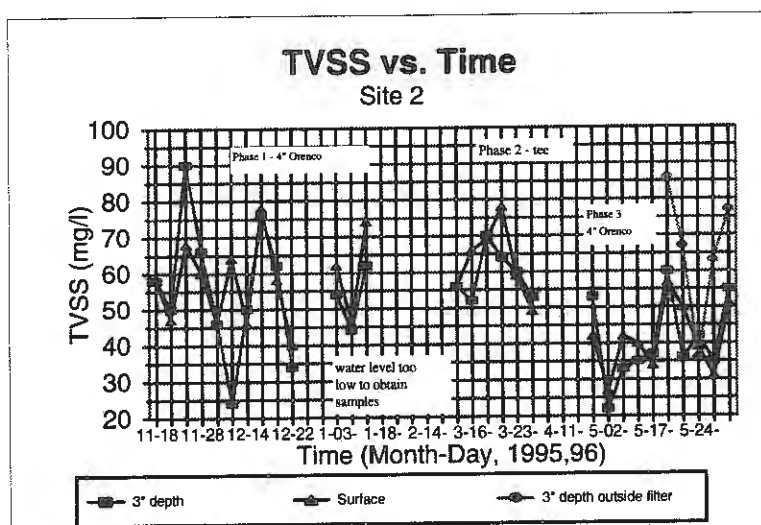


Figure 1 - TVSS vs. Time - Phase 1, 2, and 3

As shown in Table 2, only two of the change percentages (sites 4 and 7) were statistically significant for the long term data because of the high variability of the data (see Figure 1) and only one of these, at site 7, was a reduction. Visual inspection and photographs taken during sampling confirmed that both site 4 and site 7 were overloaded. It was concluded that effluent filters have a negligible effect on TVSS on a long term basis unless the filter is overloaded.

Table 3 shows the effects of the filters when they were cleaned and reinstalled in the tanks. Five of the 7 filters reduced TVSS and 3 of these removals (31-74%) were statistically significant. The reductions at sites 3 and 6 were not statistically significant due to the high variability of the data but were substantial. The increase at site 4 was in a system which was overloaded and the increase at site 5 was small and statistically insignificant. It was concluded that the filters reduce TVSS on a short term basis. If this data is compared to that in Table 2, it appears that the filters clog and lose their ability to remove TVSS some time between zero and 8 months.

Table 2 - Overall Percent Changes in Average TVSS					
	Sample Location	Phase 2 (mg/l)	Phase 1 (mg/l)	% change	Significant (P<0.05)
Site 1	3" depth	45	35	-22	
Site 2	3" depth	59	55	-7	
Site 3	3" depth	67	56	-16	
Site 4	3" depth	65	430	+562	X
Site 5	3" depth	54	63	+17	
Site 6	3" depth	53	60	+13	
Site 7	3" depth	628	72	-89	X

Table 3 - Overall Percent Changes in Average TVSS					
	Sample Location	Phase 2 (mg/l)	Phase 3 (mg/l)	% change	Significant (P<0.05)
Site 1	3" depth	45	15	-67	X
Site 2	3" depth	59	41	-31	X
Site 3	3" depth	67	54	-19	
Site 4	3" depth	65	149	+129	
Site 5	3" depth	54	62	+15	
Site 6	3" depth	53	46	-13	
Site 7	3" depth	628	162	-74	X

The photographic data supported the conclusions above. The photographs of the filters at Sites 4 and 7, for example, showed that the filters were extremely clogged while photographs of the other filters showed that they were accumulating solids but still had capacity left.

Microscopic photographs of the scrapings from the filters showed that much of the solids from the filters was biological in nature. Positive identification of some protozoa indicated that some of the growth was aerobic. Since all DO measurements were zero, this is difficult to explain and should be the subject of a future study.

Nitrogen

Samples were taken at a 3" depth outside and inside each filter to determine any reductions in concentrations of nitrogen species or total mass due to these filters. The major forms of nitrogen that were found in the analysis were ammonia and organic nitrogen, and nitrite and nitrate nitrogen were not found in detectable concentrations. The average concentrations are shown in Table 4.

Site	Nitrogen	Outside Avg Conc. (mg/l)	Inside Avg. Conc. (mg/l)	Site	Nitrogen	Outside Avg Conc. (mg/l)	Inside Avg. Conc. (mg/l)
1	Total	54.93	58.83	5	Total	51.6	60.14
	Ammonia	41.01	38.91		Ammonia	35.85	29.49
	Organic	13.92	19.92		Organic	15.76	30.65
2	Total	52.2	50.62	6	Total	37.88	53.16
	Ammonia	36.54	23.54		Ammonia	25.58	37.13
	Organic	15.65	10.21		Organic	12.31	16.03
3	Total	64.19	74.27	7	Total	65.12	36.61
	Ammonia	51.49	57.13		Ammonia	32.8	25.54
	Organic	12.7	17.14		Organic	32.32	11.07
4	Total	38.57	60.14				
	Ammonia	23.6	29.49				
	Organic	14.96	30.65				

Simple regression was used to compare the means of ammonia, organic, and total nitrogen concentrations outside each filter with the means of the concentrations inside each filter for Phase 1. The only reduction that was significant (P-value < 0.05) as measured by simple regression was the total nitrogen for Site 2.

TEMPERATURE

Temperature measurements were taken at each site at the 3" depth inside the filter, 3", 1', 2', and 3' depths outside the filter in the septic tank. The main objective for taking temperature measurements was to determine if temperature affected certain water quality parameters such as total volatile suspended solids and nitrogen. Also, temperature data taken from the temperature

profiles was used in order to determine if any mixing is occurring in each tank. A typical temperature profile over the life of the project is shown in Figure 2.

As shown in Figure 2, the tank temperatures followed the trend of the ambient temperatures but were moderated by the fact that the tanks were buried in at least one foot of earth and were receiving relatively high-temperature water from the houses. The temperatures at all depths were fairly uniform until Phase 3, at which point significant stratification occurred. This coincided with the improved removals of TVSS that were noted during Phase 3 as compared to Phase 1. Further studies should be conducted to determine if stratification in septic tanks improves removal of solids.

DISSOLVED OXYGEN AND FECAL COLIFORMS

Dissolved Oxygen (DO) was measured at each site on selected sampling trips. The purpose for taking DO measurements was to determine if conditions in the tanks fitted with effluent filters were conducive to the processes of nitrification and denitrification. Almost all measurements produced zero DO.

Fecal coliform counts were taken to obtain general data on septic tanks with effluent filters. The samples used for the counts were taken only from the 3" sample inside the filters.

CONCLUSION AND RECOMMENDATIONS

Based on the data produced during this study it was concluded that:

1. Septic tank effluent filters remove from zero to 74% of TVSS from septic tank effluent on a short term basis (0-2 months).
2. After being installed for 8 months, the filters lose their ability to remove TVSS. This would indicate that the filters must be cleaned regularly.
3. Septic tank effluent contains 35-75 mg/l of total nitrogen in the form of ammonia and organic nitrogen. The amounts and forms of nitrogen are not affected by effluent filters.
4. Uniform temperatures with depth indicate that the tanks are mixed during winter months but a decrease of temperature with depth in the spring indicates that stratification takes place then. This stratification coincided with the increased efficiency of the filters in Phase 3 and may have affected it.

It is recommended that:

1. A study be conducted with side-by-side tee and filter to test the effects of the filters in a more realistic manner than measuring a baseline followed by filter installation.
2. A study be conducted to determine the identity and effect of the biological growth that occurs on the filters.

3. A study be conducted to determine the effect of temperature stratification in the tanks on filter efficiency.

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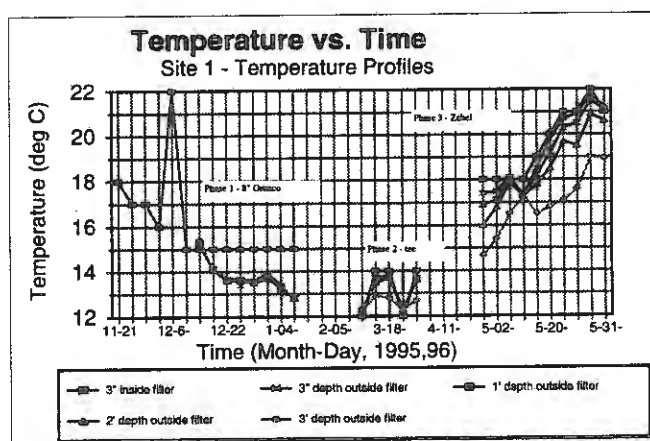


Figure 2 - Temperature Profiles

AN APPLICATION OF ARC/INFO GIS AND THE USGS THREE DIMENSIONAL FINITE-DIFFERENCE MODEL MODFLOW ON A CARBONATE AQUIFER

Jack D. Wall¹

INTRODUCTION

The purpose of using Geographic Information Systems (GIS) linked to a groundwater flow model was to develop a groundwater flow component of a water resources management model that would simulate the interaction of stream flow and groundwater flow. The aquifer analyzed in the study was the groundwater basin associated with the Richland Creek Watershed. Requirements of the model included the ability of the model to accept infiltration from a surface water model, to provide baseflow to a riverine model, and the ability of the model to be portable on other aquifers.

Located on the southern side of the Nashville Basin in Giles, Lawrence, Marshall, and Maury Counties, the Richland Creek basin contains portions of both the Highland Rim and the Central Basin regional aquifer systems. Each aquifer system contains varying geologic and hydrogeologic properties and the systems are separated by the fairly impervious Chattanooga shale formation. The regolith of the Highland Rim is relatively deep and continuous as opposed to the Central Basin which contains thin soil cover. Underlying the regolith are limestone formations ranging in strata from the Mississippian to Ordovician systems. Solution channels, open joints, and bedding planes in the carbonate layers represent secondary porosity and permeability in the otherwise nonporous, impermeable rock mass (Brahana and Bradley, 1986).

MODEL

The justification for utilizing Modflow as the groundwater flow code was its ability to model complex flow systems, its widespread use among the modeling community, its use of finite difference equations for an approximation of head values, and its compatibility on both Unix and DOS platforms. Arc/Info GIS was utilized to facilitate the processing of input and output data for the model and for its ability to graphically view and update hydrogeologic property layers in a model.

Development of the model involved collection of data on the aquifer, storing the data in Arc/Info Grid format, altering a Bureau of Reclamation Arc/Info GIS Grid interface for Modflow, the

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construction of menus to enable a user to directly add grids generated outside the interface for pre-processing of the data, the incorporation of the River and Zonebudget modules into the interface, and the calibration of the model. Data collection involved obtaining well logs from the Tennessee Department of Environment and Conservation to generate an initial potentiometric surface, obtaining initial storage coefficient and transmissivity data from the United States Geological Survey (USGS) and acquiring the digital elevation model to aid in the development of an initial potentiometric surface and for stream generation.

In order to observe the response of recharge to the Richland Creek system, the Zonebudget and river packages were interfaced with Arc/Info. River leakage was determined for subregions in the model by activating the river package and then loading the cell-by-cell flow terms generated by MODFLOW into Zonebudget. The menu system allowed the user to update the model parameters when needed, apply multiple stresses to the model, and to run the model quickly when only one parameter such as hydraulic conductivity was altered.

HYDROGEOLOGIC PARAMETERS

Necessary hydrogeologic parameters for the unconfined, two-dimensional model included the storage coefficient and hydraulic conductivity. The spatial variation in the properties for aquifers in a carbonate basin may be quite large. Thus, general estimates of the aquifer parameters were obtained from Hoos (1990) and applied to the Highland Rim and the Central Basin systems by identifying formations above the location of the Chattanooga Shale formation on digital geologic maps. Areas corresponding to the Ft Payne formation were assigned properties associated with the Highland Rim, while the regions not corresponding to the Ft Payne formation were assigned values associated with the Central Basin.

The initial water surface elevations were determined using well logs obtained from the Tennessee Department of Environment and Conservation. The locations of the static water surface elevations were plotted using the digital elevation model, the depth to the static level from the land surface, and the latitude and longitude of the wells. Using geostatistical techniques associated with Arc/Info, an estimation of the surface of the aquifer was obtained. Far from being an accurate representation of the water surface elevation at any point in time, the starting heads were only an estimate to initialize the model.

BOUNDARY CONDITIONS

The water surface elevation was also utilized in the determination of the boundaries of Richland Creek basin. A delineation of the surface watershed compared to the water surface elevation generated by the static level in wells revealed the topographic highs in the basin corresponded to the regional surface water table elevations. Thus, the boundaries of the model were established at the topographic highs within the basin. The bottom of the aquifer was based on the assumption that water below the stream bottoms was not recharging the streams. The bottom grid of the aquifer was generated by converting the grid of the stream bottoms to a map of points

representing the streams. The points were spatially interpolated to generate a surface.

MODEL CALIBRATION AND APPLICATION

Calibration of the model was based on specified heads throughout the basin and on baseflow records of Richland Creek. Most groundwater models are calibrated by adjusting parameters to match measured and predicted water table surfaces. Due to the limited data in the basin, the baseflow was relied upon to adjust the parameters in the aquifer. Numerous wells throughout the basin that contained water table elevations were utilized to assess the accuracy of the model.

Once the model was constructed, infiltration predicted by the surface water component was directed to the groundwater model of the watershed management tool. The baseflow was predicted by the groundwater component for the individual sub-basins and directed to the instream model HSPF through watershed data management files. The time step of the model was specified to be one day, with the length of a run specified by the surface water model.

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ENVIRONMENTAL FATE AND TRANSPORT MODELING MADE POSSIBLE VIA THE INTERNET

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and

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BACKGROUND

Study Area

The Mississippi River alluvial plain is a fertile delta area approximately 90,000 square kilometers (35,000 square miles) in size, covering portions of Arkansas, Mississippi, Louisiana, Tennessee, Kentucky, Missouri, and Illinois. The valley is used extensively by migratory waterfowl, shorebirds, marsh birds, neotropical migrants, and various species of fish. Habitat is provided for many threatened and endangered species including bald eagle (*Haliaeetus leucocephalus*), pallid sturgeon (*Scaphirhynchus albus*), interior least tern (*Sterna antillarum*), fat pocketbook pearly mussel (*Potamilus capax*), pink mucket pearly mussel (*Lampsilis orbiculata*), and the endangered pondberry plant (*Lindera melissifolia*) (U.S. Fish and Wildlife Service [USFWS], unpublished data, 1996). The USFWS has established numerous refuges throughout the Mississippi valley to preserve and protect habitat for fish and wildlife species. Most of these refuges were established to protect migratory waterfowl as a result of the United States' responsibilities under international treaties for migratory bird conservation as well as legislation such as the Migratory Bird Conservation Act of 1929.

When settlers first arrived in the area, the Mississippi valley was carpeted with over 10 million hectares (25 million acres) of seasonally flooded bottomland hardwoods. Over time, due to the nature of the valley, the majority of the alluvial plain was converted into row-crop production agriculture (Frey and Dill, 1971; Sternitzke, 1976). Currently, there are less than 2 million hectares (5 million acres) of unconverted land in scattered pieces throughout the valley. The conversion of the river valley into agricultural land has led to concern over the introduction of sediments (McHenry et al., 1984) and agrochemicals into the alluvial plain ecosystem (Schmitt

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and Winger, 1980; Winger et al., 1988). Because there is overlap in the distributions of fish and wildlife species and contamination in the Mississippi River alluvial plain, there is concern regarding the exposure of these species to this contamination.

Impaired ecological health has been observed throughout the Mississippi alluvial plain (Cooper, 1996; Mississippi Department of Environmental Quality, 1994). These observations have prompted interest in evaluating environmental conditions at the 27 USFWS refuges throughout the Mississippi alluvial plain and in initiating the use of an environmental model, integrated with a Geographical Information System (GIS), as a management tool for the refuges. This move toward using a GIS as a predictive and management tool is becoming popular in biological survey work. Neldner et al. (1995), and Koutnik and Padilla (1994) demonstrated that a GIS was a useful tool in evaluating the spatial distributions of particular species.

ENVIRONMENTAL MODELS

There are a number of existing predictive models which yield output regarding point and nonpoint source contamination. The models related to surface runoff discussed in literature vary widely in approach, input data requirements, output data quality, complexity, etc. (U.S. Environmental Protection Agency (USEPA), 1992; Donigian and Huber, 1991). Because the Mississippi alluvial valley is primarily agricultural in nature, models that focus on non-point source problems were reviewed for application in this study. A number of surface water models in the current literature emphasize agricultural application. However, because of its availability over the Internet, convenience of input data requirements, and ease of GIS linkage, etc., the Agricultural NonPoint Source (AGNPS) model was selected for implementation.

The AGNPS model was developed by the United States Department of Agriculture (USDA) to evaluate large watersheds to determine the effects of land management practices on physical and chemical characteristics of streams. The current version of this distributed parameter model, 4.03, uses cell sizes of 0.001 to 400 hectares (0.01 to 1000 acres). Because AGNPS is cell-based, spatial variation is maintained throughout the basin as sediment yield and nutrient loading processes are simulated (Perlitsch, 1995). The model is capable of handling point source inputs such as feedlots, waste water treatment discharges, and stream bank gully erosion. Furthermore, the most recent version of this model allows users to perform limited analyses on pesticide movement through a watershed (Young et al., 1994).

The model has been used to link watershed and lake processes to simulate their responses to land management and weather conditions (Summer et al., 1990), and it has been successfully integrated with a GIS (Lee and White, 1992; Needham, 1994). Additionally, GIS linkage provides an ideal data management tool when dealing with large watersheds and small cell sizes. Because of the versatility and the increased accuracy and simulation simplicity of AGNPS, some consider this model to be the most comprehensive and cost-effective watershed-based nonpoint source model available (Evans and Miller, 1988).

METHODS

Description of Geographically-Based Data Availability

The groundwork for the modeling effort in this study consisted of an evaluation of the input requirements for the environmental model, data collection, and data processing for model application. The evaluation of input data requirements yielded a list of parameters that were readily available over the Internet. The data required by the model includes but is not limited to: watershed and flow direction coverages, land use/land cover, soils information, and various chemical databases. Data were formatted to standard ARC/INFO coverages so as to be compatible with the ARC/INFO software selected as the GIS management tool.

Digital Elevation Models (DEMs)

The 1:250,000 scale, U.S. Geological Survey (USGS) DEMs were downloaded by state from the Internet site, http://edcwww.cr.usgs.gov/glis/hyper/guide/1_dgr_demfig/states.html. The 7.5-minute DEM is a standard USGS file format, which contains elevation data that was collected at a constant mesh-point spacing of 30 meters. In order for a DEM to be used in ARC/INFO, a data format conversion must be made. This conversion can be made with ARC/INFO using the `DEMLATTICE` command.

Flow direction maps and watershed boundaries were derived from the DEMs using `GRID` functions in the ARC/INFO software (Environmental Systems Research Institute, Inc. [ESRI], 1994). Once the basic set of digital data, DEMs, were obtained and converted into ARC/INFO format, a series of `GRID` commands were used to develop flow direction maps as well as watershed coverages. The `FLOWDIRECTION` command generates a flow model which describes the flow of surface water over the DEM by routing water in a path of descending elevations. After flow direction was determined for each cell, hydrologic sinks, which may be defects in the data, can be filled using the `FILL` command. Delineation of the watershed was then accomplished. Watershed boundaries were generated when specific user-determined pour points are input with the `GRID` command `WATERSHED`. The watershed was developed from all cells upstream of the pour point that flow toward the pour point.

Digital Line Graphs (DLGs)

The 1:100,000 scale, USGS DLGs were downloaded from the Internet site, <http://edcwww.cr.usgs.gov/pub/data/DLG/2M>. The DLGs are also a USGS standard file format. These files contain information such as roads, railroads, waterways, county and state boundaries, etc. In order for DLGs to be used in ARC/INFO, a data format conversion must be made. Standard DLG files were converted to ARC/INFO coverages by using the ARC/INFO command `DLGARC`. The output coverage created by using this command contains line, polygon, and node features created from nondegenerate line, area, and node records respectively.

Land Use/Land Cover (LULC)

The 1:250,000 scale land use/land cover files were obtained from the Internet as GIRAS files. These files were accessed from <http://edcwww.cr.usgs.gov/pub/data/LULC/250K>. File conversions were necessary to access LULC coverages in ARC/INFO. The ARC/INFO command GIRASARC provides a means to quickly load the digital data into an ARC/INFO coverage. The coverage generated by GIRASARC contains georeferenced polygons that are coded at Anderson Level II. Anderson Level II categories are a further division of Level I categories.

State Soil Geographic Database (STATSGO)

The 1:250,000 soil maps for the STATSGO database were generated by generalizing detailed soil survey data. Each STATSGO map was linked to the Soil Interpretations Record attribute database which gives the proportionate extent of the component soils and their properties for each map unit. The Soil Interpretations Record database included more than 25 physical and chemical soil properties such as water capacity, salinity, interpretations for engineering uses, water table, etc. This product is available on compact disk-read only memory (CD-ROM) at a nominal fee from the National Cartography and GIS Center; details regarding ordering the data are available on the Internet at <http://www.ncg.nrcs.usda.gov/statsgo.html>.

National Wetland Inventory (NWI)

The NWI data is part of the USFWS program to protect the nation's wetland resources. The data is available to the public from the USFWS at <http://www.nwi.fws.gov/maps/nwi.data.gz>. The NWI digital data are digitized and distributed by 7.5-minute quadrangles. The maps have a limited availability. However, as maps are digitized, they are made available. The digital NWI maps were downloaded as DLG files; conversion of digital NWI maps was performed in the same manner as other DLG files obtained from the USGS.

Toxic Release Information System (TRI)

The US Environmental Protection Agency (USEPA) has collected data from facilities that release chemicals from a list of toxic chemicals for a number of years. This information was made available to the public as a searchable database. Data such as facility information, amounts and names of chemicals released to the air, amounts and names of chemicals released via underground injection, amounts and names of chemicals released to surface water, date of release, latitude and longitude of release, etc. are searchable at http://www.epa.gov/enviro/html/tris/tris_query.html. Upon a successful search, the data may be downloaded. The latitude and longitude information of the data is to be georeferenced. If latitude and longitude are obtained for the various data. Then, a point coverage may be generated with ARC/INFO. The coverage can then be linked to the data in such a way that each point location

will be associated with the appropriate data. These point release coverages may then be layered with data such as LULC or watershed coverages.

STOrage and RETrieval of parametric data (STORET)

The STORET database contains information pertaining to the quality of the waterways within the contiguous US. While serving as a repository for water quality data, STORET provides information such as descriptive data concerning sites where data has been collected; measurements of the physical characteristics and chemical composition of water, fish tissue and sediment; biological field survey data, and stream flow data. The data contained in STORET was collected by many agencies and their contractors. Requests for data from STORET may be made to EPA at <http://www.epa.gov/gumpo/storet-email.html>. As with TRIS data, STORET data may be used to generate point coverages with ARC/INFO. These coverages will link data with a geographical location.

SUMMARY AND CONCLUSIONS

The ease of access to models and data available over the Internet makes it possible for environmental scientists or engineers to utilize the GIS as an analytical tool. Not only can a user access current environmental models, but also the input data required to make predictive assessments of areas. This capability will allow environmental scientists to develop more effective environmental fate and transport management tools.

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**COMPARISON OF JOINT, SINKHOLE, PHOTO-LINEAMENT,
STRAIGHT CAVE SEGMENT, AND STREAM ORIENTATIONS
FOR PREDICTING CONTAMINANT TRANSPORT DIRECTION
IN THE CENTRAL BASIN OF TENNESSEE**

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Albert E. Ogden,

and

Kate Martin¹

INTRODUCTION

In carbonate rocks, ground water and contaminants usually move along solution-enlarged joints, fractures, and bedding planes. Predicting the direction of contaminant transport from a landfill, leaky underground storage tank, pipeline break, or highway spill is essential for immediate emergency response and siting monitoring wells. Ground water tracing is the best method for delineating ground water flow paths, but the lack of regulatory pressure to conduct such traces often dictates that other means be utilized. Cave maps provide us with a record of how ground water has actually moved in the past or is presently moving in karst terranes. Unfortunately, few caves have been mapped or caves in a particular area of interest may not be known. Therefore, other tools are needed to help predict ground water and contaminant transport directions. The purpose of this study was to measure the orientations of joints, photo-lineaments, sinkhole axes, and straight stream segments to determine which best compare to actual ground water flow directions as demonstrated by straight cave segment orientations. An analysis similar to this but for the Eastern Highland Rim and Valley and Ridge provinces of Tennessee was previously performed by Ogden and Redman (1993).

HYDROGEOLOGIC SETTING

The study area is situated primarily within Rutherford and Cannon counties of the Central Basin physiographic province which is underlain by limestones of Ordovician age that have been gently upwarped to form the Nashville Dome. Subtle synclines and anticlines occur "superimposed" on the Nashville Dome. These folds have been beautifully exposed for view by the recent opening of the new Interstate 840. Moore et. al. (1969) attempted to delineate some of these folds by

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constructing a structural contour map of the Upper Stones River Basin with the top of Ridley Limestone as a datum. They found that the anticlines are generally dome-shaped and are found in the interstream areas. They found that the synclines are elongated and that their troughs follow the trends of the streams and forks of the streams. In addition to the Ordovician rocks, joint measurements were also made on the Devonian-aged Chattanooga Shale and the Mississippian-aged Fort Payne Chert along the Eastern Highland Rim Escarpment. The oldest rocks exposed in the study area are those of the Murfreesboro Limestone, which is approximately 400 feet thick. Formations involved in the study between the Murfreesboro and Chattanooga Shale include the: Piece Limestone, Ridley Limestone, Lebanon Limestone, Carters Limestone, Hermitage Formation, Bigby-Cannon, and Catheys-Leipers. About 600 feet of stratigraphic section exist in the study area between the top of the Murfreesboro Limestone and the bottom of the Fort Payne Chert.

METHODS

A total of 979 joint measurements were made at outcrops of the various formations using a Brunton compass. Two hundred and sixty photo-lineaments were delineated from 1:20,000, black-and-white, stereo aerial photographs and their orientations measured with a protractor. Proprietary cave maps of the Tennessee Cave Survey were used to delineate the straight cave segments. A straight cave segment was defined for the purpose of this study as a straight passage of 50-foot length. Large caves of particular interest were Snail Shell, Espey, and Pleasant Ridge which contain nearly 20 miles of passage. A total of 247 straight cave segments were delineated in this manner. The long axes of 318 sinkholes were drawn on 1:24,000, U.S.G.S. topographic maps, and the orientations measured with a protractor. Similarly, 101 straight stream segments were delineated and measured throughout the study area. The orientations of the straight cave segments, joints (by formation), sinkhole axes, photo-lineaments, and straight stream segments were then placed in 10 degree classes and plotted as rosette diagrams.

RESULTS

Figures 1 and 2 present the orientation measurements. The straight stream segments showed the widest scatter in most compass directions suggesting that any structural control present is being masked by topographic effects. When grouped together, the cave orientations show a wider scatter than for an individual cave as would be expected. In general, though, both the large and smaller caves showed three dominant cave passage orientations with scatter around the following average trends: N55°W, N40°E, and N5°W. These similar joint trends were observed throughout the Ridley, Carters, Bigby-Cannon/Catheys-Leipers, Chattanooga, and Fort Payne formations. The N55°W and N40°E trends may be a result of compressional forces with N5°W trend a manifestation of extension correlating with the troughs and axes of the folds. Field measurements of synclinal troughs by the authors and the structure contour map of Moore et. al. (1969) show that most of the troughs are oriented in a north/northwest direction.

Possible similarity of the joint and cave orientation data was statistically tested using the Komogorov-Smirnov (K-S) test at an alpha probability level of 0.10. The results of the test indicate statistical similarity of the data sets. The sinkhole and photo-lineament orientations match the N55°W and N40°E trends well, but the N5°W trend is nearly absent. When statistically tested, though, the K-S test showed that the orientation distributions were similar for the sinkhole and joint data, the cave segment and sinkhole data, and the cave and photo-lineament orientations.

CONCLUSIONS

The statistical similarity of the joint, straight cave segment, photo-lineament, and sinkhole axes data shows that a variety of tools are available to help predict the direction of ground water movement. The similarity of the joint data throughout the different geologic formations suggests that inter-formational transfer of ground water and contaminants is easily possible and that any spilled or leaked contaminant will likely move from one formation to another in a similar downgradient compass direction. Close inspection of the cave passage orientation data shows that the main or "trunk" passages are developed along the troughs of the synclines while the tributary or "side" passages are developed along the joints. Within the synclinal troughs, sinkholes are found to be aligned in a similar direction, although this is masked when all the sinkhole orientations are combined on a rose diagram. It is therefore proposed that much of the ground water in the study area moves through large conduits situated in the synclinal troughs, with inputs of subsurface waters moving downdip within the limbs of the synclines. This hypothesis is substantiated by recent dye traces that have been conducted in portions of the Dillton and Walter Hill quadrangles. These results should be quite helpful in developing a monitoring scheme at waste disposal sites and help in emergency response to spills, leaks, and pipeline breaks.

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**FECAL COLIFORM BACTERIA AND NITRATE LEVELS
OF CARBONATE WELLS AND SPRINGS
IN RUTHERFORD AND CANNON COUNTIES, TN**

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and

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INTRODUCTION

In a relatively recent study by the United States Geological Survey (Roman-Mas´ et. al., 1991) homeowner wells were sampled in Bedford and Coffee counties, Tennessee to determine coliform bacteria, nitrate, and sulfate levels, as well as, pH and conductivity. This investigation found that 38% of the wells were contaminated with fecal coliform bacteria and a significant number had higher than expected background concentrations of nitrate. To determine if the problem is more widespread, a total of fifty wells and springs utilized as water supplies were sampled in neighboring Rutherford and Cannon counties. Of particular interest were "roadside" springs that are commonly used for drinking due to the widespread occurrence of hydrogen sulfide in water wells of the region.

HYDROGEOLOGIC SETTING

The study area is situated entirely within the Central Basin physiographic province which is underlain by limestones of Ordovician age that have been gently upwarped to form the Nashville Dome. Although portions of Cannon County occur on the Eastern Highland Rim, no samples were obtained from this area. The oldest rocks exposed in the study area are those of the Murfreesboro Limestone, which is approximately 400 feet thick. The youngest formation within the region of investigation is the Leipers-Catheys Limestone. Approximately 500 feet of stratigraphic section occur between the

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Murfreesboro and Leipers-Catheys. Stratigraphically upward these formations are the: Pierce Limestone, Ridley Limestone, Lebanon Limestone, Carters Limestone, and Hermitage Formation. Most of the sampled wells obtain water from the Murfreesboro and Ridley limestones, but one sample was obtained from a deep well drawing ground water from the Knox Dolomite. Eight of the ten springs sampled are located at the base of the Eastern Highland Rim Escarpment and are in the Lebanon and Carters limestones. The other two springs emerge from the Ridley Limestone.

METHODS

Samples were collected in sterile quart containers, refrigerated, and then tested for fecal coliform bacteria within 24 hours after being collected. The fecal coliform tests took place in the biology department at Middle Tennessee State University (MTSU) using the *Membrane Filter Technique*. The Membrane Filter Technique requires M-FC Broth (the medium) which contains lactose, protein digest, vitamins, and bile salts. The broth was made by mixing 3.7g of M-FC Broth powder with 100ml of sterilized water. One milliliter of Rosolic acid was then added, and the broth was heated until it boiled. When cooled to room temperature, the broth was put into 47mm petri dishes (Millipore, 1992). Once a 100ml sample of the well or spring water was siphoned through a sterile membrane pad, the membrane was placed in the petri dish and turned upside down (to restrict condensation). The petri dish was then put in an incubator at 44.3° C and left undisturbed for 24 hours. After 24 hours, the fecal colonies were counted (Millipore, 1992). The colonies appeared blue because of the aniline blue dye in the broth. The U.S. EPA (United States Environmental Protection Agency, 1982) requirements state that no fecal coliform bacteria should be present in a 100ml sample of water. Any fecal coliform present in a 100ml sample of water is considered contaminated and unfit to drink (Millipore, 1992).

Once the fecal coliform bacteria tests were complete, the water samples were refrigerated again for the next step: the *Cadmium Reduction Method* test or nitrogen-nitrate test. To conduct this test two, 25ml bottles were filled with a sample of spring or well water. The control bottle was put aside while the other was mixed with a Nitra Ver® Nitrate Reagent. The water with the nitrate reagent was allowed to sit for five minutes. After five minutes, the control sample was placed into a Hack DR 2000 Spectrophotometer to calibrate the instrument. Once calibrated, the water with the reagent was placed in the instrument, and the nitrate level was recorded. The maximum level of nitrate that is allowed by health standards is 10 mg/l (Hach, 1984).

RESULTS

Table 1 presents a summary of the results. The fecal coliform bacteria test results show that 15 out of 50 samples (30%) met U.S. EPA standards for drinking water while 35 of the 50 samples (70%) did not. Fifteen of the 35 wells showing fecal contamination had

between 1 and 10 fecal coliform colonies. When broken down into local addresses, Readyville and Murfreesboro wells had the highest fecal counts with 69% and 64% contamination, respectively (30 out of 40 wells). Fifty percent of the wells sampled in Woodland, Woodbury, and remaining areas of the counties showed the presence of fecal coliform bacteria. Three of the 40 wells had greater than 1000 colonies or the level considered too numerous to count (TNTC) in this study. All 10 of the springs sampled were contaminated with fecal coliform. Four springs had between 1 and 10 fecal colonies/100ml while the other 6 springs had >65 fecal colonies/100ml. Two of these springs had fecal coliform levels that were TNTC.

All 50 water samples met U.S. EPA nitrate level standards for drinking water. The nitrate levels ranged between <0.1-9.3mg/l, with the average being 1.4 mg/l. The highest level of nitrate occurred at a dairy barn with a nearby storage area for cow manure. All of the other nitrate levels were below 3.5mg/l which is significantly less than the drinking water standard. The average nitrate values for the springs versus wells are nearly the same (see Table 1).

Table 1. Fecal Coliform Bacteria and Nitrate Ranges and Averages.

Sample Type	# of Samples	Fecal Coliform Bacteria (100ml)		Nitrate (mg/l)	
		Range	% >0	Range	Avg.
Wells	40	0 - >1000	63%	<0.1 - 9.3	1.36
Springs	10	2 - >1000	100%	<0.1 - 2.9	1.53

CONCLUSIONS

Rutherford and Cannon counties have approximately 30% higher levels of fecal coliform bacteria contamination as compared to Bedford and Coffee counties. With spring contamination at 100% and well contamination at 63%, these counties have serious and rampant fecal contamination in their water supplies. There are several likely explanations for this. First, most wells do not have casing below the required 21 feet. Therefore, the open fractures and cavities intersected by the boreholes provide avenues for surface waters containing fecal matter to rapidly enter the wells. Second, many of the sites tested were in agricultural/rural areas that have numerous cattle operations. Wells near cow pastures are therefore very likely to receive an influx of fecal matter, particularly during a storm event. In addition, all of the wells sampled are within close proximity of a septic tank, and certainly there are numerous septic tanks within the recharge area of each spring. The results of this study strongly suggest that a majority of the sampled sites are under "surface water influences" as defined by the Safe Drinking Water Act and thus, stand the risk of being contaminated by *Giardia* and *Cryptosporidium*. Since these organisms are not effectively killed by chlorination, filtration of the waters may be

necessary to insure human health. Pesticides applied to croplands and gardens, as well as petroleum products on streets and parking lots may also endanger the quality of these water supplies.

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COMPARISON OF SINKHOLE DENSITIES FOR THE CARBONATE ROCKS OF TENNESSEE

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and

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INTRODUCTION AND BACKGROUND

A common problem in carbonate rock terranes is subsidence. This may occur at both slow and rapid rates, but both generally result in damaging and costly effects to property owners and the occasional loss of life. Most sinkholes in Tennessee are the result of slow dissolution of limestone along fractures and bedding planes with small scale collapses occurring as a result of piping. Piping of fine grained material downward through a fracture results in a cavity at the soil/bedrock contact. Such soil cavities will continue to enlarge until an eventual collapse occurs. Natural piping rates are greatly enhanced by diversion of drainage associated with growth and development such as from parking lot and building roof runoff. Sinkhole collapse due to drainage diversions from highways also has been shown to occur in Tennessee (Moore, 1981 and 1987). Other region-specific studies of sinkhole occurrence in Tennessee have been made by Kemmerly (1976 and 1982), Mills and Starnes (1983), and Ogden et. al (1989). Kemmerly (1976 and 1982) performed a detailed analysis of some 25,000 sinkholes from 42 quadrangles in the Western Highland Rim of Tennessee and the Pennyroyal Plain of Kentucky which are both underlain by the St. Louis and St. Genevieve limestones of Mississippian age. Mills and Starnes (1983) investigated sinkhole morphometry in the Eastern Highland Rim while Ogden et. al. (1989) compared sinkhole densities of the Mississippian carbonates of the Eastern Highland Rim and the Knox Group (undifferentiated) in the Valley and Ridge Province. The present study calculates and compares sinkhole densities of the Ordovician rocks in the Central Basin and the individual formations of the Knox Group in the Jefferson City/Morristown/Tazwell area. Sinkhole densities were also calculated for the Maryville, Rutledge, and Lenoir/Holston formations in the Valley and Ridge Province and the St. Louis and Warsaw formations of the Clarksville area.

METHODS

As an aid for predicting the possibility of sinkhole collapse, sinkhole densities were calculated for carbonate rocks formations of the Central Basin, Highland Rim, and Valley and Ridge

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provinces of Tennessee using 7½-minute scale topographic maps. Sinkholes smaller than 50 feet in diameter and 10 to 20 feet in depth (depending on map contour interval) were probably not observed using this method. Thus in flatter areas, such as portions of the Central Basin, a number of sinkholes were likely missed. Sinkhole densities were calculated by measuring the area of formation in sinkholes divided by the area of formation times 100. This percentage of sinkhole area per geologic formation was obtained by placing one mile square grids on the geologic maps (Figure 1).

RESULTS

Although sinkhole occurrence is related primarily to rock solubility, it was found that topographic setting was equally important. The Bigby-Cannon and Catheys-Liepers formations, for example, usually occur on the sides of steep slopes and although very soluble, produce few sinkholes at the 20-foot contour interval of the maps. The range in sinkhole density for the Bigby/Cannon is 1.6%-2.9% with an average of 2.2% (Table 1). The range for the Catheys/Liepers is 1.2%-2.3% with an average of 1.9%. In more flat areas, especially near the springs draining the karst aquifers, sinkholes are more abundant. In the Central Basin the Lebanon and Ridley limestones show the greatest abundance of sinkholes with most sinkholes appearing to be occurring near the geologic contact. The percent of square miles underlain by sinkholes/square mile of geologic formation for the Lebanon Limestone ranges from 1% to 16.4% with an average of 5.7%. The Ridley has a range of 2.7% to 6.8% with an average of 5.4%. Formations within the Knox group showed significant variability having the following average values: Copper Ridge Dolomite (1.9%), Chelultepec Dolomite (4.3%), Longview Dolomite (1.6%), Kingsport Formation (3.0%), Mascot Dolomite (9.1%), and Newala (Kingsport and Mascot undifferentiated-12.8%). Other carbonate rocks in east Tennessee have the following sinkhole densities: Rutledge Limestone (1.2%), Maryville Limestone (5.9%), Lenoir/Holston formations (5.4%). On the Eastern Highland Rim, the St. Louis Limestone had the highest average sinkhole density (10.4%) with a similar density on the Western Highland Rim (10.2%). Of the other Mississippian carbonates, the Warsaw Formation had the next highest sinkhole density (7.6%) followed by the Monteagle Limestone with 4.6%.

Table 1. Average sinkhole density per geologic formation.

Catheys/Leipers	1.9%	Mascot	9.1%
Bigby/Cannon	2.2%	Kingsport	3.0%
Lebanon	5.7%	Newala	12.8%
Ridley	5.4%	Longview	1.6%
Monteagle	4.6%	Chelultepec	4.3%
St. Louis	10.3%	Copper Rigde	1.9%
Warsaw	7.6%	Maryville	5.9%
Lenoir/Holston	5.4%	Rutledge	1.2%

CONCLUSIONS

Construction of buildings, parking lots, and roads in karst areas is often affected by slow subsidence and occasional catastrophic collapse. Problems are often the result of drainage diversions that accelerate the piping process. Common failure of tailings and livestock ponds on carbonate rocks attest to this. To help predict which carbonate rock formations in Tennessee will be more prone to collapse, doline densities were calculated for limestones and dolomites of the Central Basin, Eastern Highland Rim, and Valley and Ridge physiographic provinces. In the Central Basin, the Lebanon and Ridley formations are likely to pose the greatest risk to subsidence, particularly near the geologic contact. On the Eastern and Western Highland Rims, the St. Louis and Warsaw limestones have greater potential to show soil subsidence and collapse than the other Mississippian carbonates. In east Tennessee, most of the karst is developed on the Knox Group. The results of this study, show that sinkhole densities are very different among the formations that comprise the Knox Group with the Kingsport/Mascot or Newala showing the highest potential risk for subsidence and collapse. The Maryville Limestone and Lenoir/Holston formations of east Tennessee also have relatively high sinkhole densities. Even for the carbonate rock formations that have lower sinkhole densities, drainage diversions into sinkholes should be avoided to prevent collapse.

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DETERMINING A 100-YEAR PEAK FLOW AND ASSOCIATED ERRORS FROM SIMULATED STREAMFLOW

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and

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INTRODUCTION

Low-level radioactive wastes have been generated and buried in trenches at Oak Ridge National Laboratory (ORNL) since 1943 (Tucci, 1992). Groundwater flow through these waste trenches has resulted in the transport and deposition of contaminants to White Oak Creek (WOC) and its tributaries. The levels of contamination in the creek bed have led to concerns about erosion and off-site transport of contaminated sediment during extreme streamflows.

A streamflow having a one percent probability of being met or exceeded in a given year (100-year return period) was needed for the WOC watershed at White Oak Dam (WOD), near Oak Ridge, Tennessee, in order to understand how contaminant-bound sediments are mobilized and transported and to assist in identifying, selecting, and designing appropriate remedial alternatives that might be taken to ensure their continued control. The principal existing sediment control structures consist of WOD, built in 1943, and renovated in 1983, which impounds White Oak Lake, and a permeable gabion dam constructed in 1992 just downstream from WOD at the mouth of WOC (Frederick et al., 1996).

When an adequate period of streamflow record is available over homogeneous and stationary watershed conditions, a common approach to determine peak flow return periods is to fit a probabilistic distribution to a series of one peak streamflow per each available year of record. In this case, the aforementioned dam construction and renovation have caused uncertainties and interruptions in the streamflow record over time. In any event, only five continuous years (1990-94) of streamflow record were available, and another approach had to be undertaken for analyzing flood frequency.

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METHODS

The approach taken was to simulate a longer streamflow record using a deterministic hydrologic watershed computer model. The model was calibrated using the five-year period when streamflow and other hydrologic data were available. The Environmental Protection Agency's Hydrologic Simulation Program--FORTRAN (HSPF) was chosen for the model. Data from six rainfall gauges was used to develop, calibrate, and validate the model, and a continuous 41-year streamflow record was simulated using the 1953-93 record of precipitation and evaporation available at a single site outside the watershed in nearby Oak Ridge. Annual peak streamflows were extracted from this 41-year simulated record and used for estimating the probability distribution. Attempts were made to identify and to statistically and mathematically account for the random and systematic errors associated with this distribution.

Many possible sources of random and systematic error exist in the estimation of a flood frequency for a watershed. The usual errors encountered with gauged data are only compounded with the use of simulated data. Despite this, useful estimates can be made if the errors are rationally accounted for. Attempts were made to identify each source of error encountered in the estimation of a flood frequency with the use of simulated data. Each of these error sources and their causes are briefly summarized below:

- Model error - random and systematic
- Frequency analysis error- random
- Rainfall spatial distribution error - random and systematic
- Truth error - random and systematic
- Geographic translation of precipitation error - systematic
- Extrapolation error - systematic
- Calibration error - systematic

RESULTS

Variances reflecting random model and random frequency analysis errors were calculated, assumed independent, combined, and expressed as a 90 percent confidence interval to form an overall indication of uncertainty. The systematic model error was examined by comparing a best fit line of observed verses simulated peak streamflows with a line of equality representing a perfect model fit. The rainfall spatial distribution and geographic translation of precipitation errors were accounted for by comparing simulated streamflow results generated using individual rain gauges from among the six available for the five-year calibration and validation period, and the one available for the 41-year simulation period. The extrapolation error remains unknown because of the limited range of gauged streamflow data available for calibration and validation of the model. The calibration error can only be either disregarded if the model is considered "calibrated" or improved through recalibration. Finally, the truth error associated with any misrepresentation of actual hydrologic data (rainfall, streamflow, evaporation, etc.) with gauged data cannot be quantified without testing of the recording mechanisms in question. However,

since no obvious truth error is apparent, gauged data was assumed to be representative of actual data.

CONCLUSIONS

The investigation produced a method for determining the flood frequency of a small watershed in eastern Tennessee along with the uncertainty in the flood frequency. The known shortcomings in the underlying simulations and in the final result for the White Oak Creek Watershed warrant further study and probable revision of the quantitative results. For this reason, although the project has been completed, the results are judged to be preliminary and are not considered to be a reliable representation of the hydrologic system at White Oak Creek. The project has been worthwhile insofar as it has generated an approach to using simulated data to estimate flood frequencies and their uncertainty.

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SESSION 2-A

GROUNDWATER #1

8:30-10:00

Dale D. Huff, John D. Long, Alex Naudts, *Demonstrating the Utility of Grouting for Radioactive Waste Source Control.*

Shabbir Ahmed, David H. Barton, Steven C. Young, Logan Vanleigh, *Groundwater Flow Modeling for Remediation Alternatives at the Brandywine Defense Reutilization and Marketing Office Site, Andrews Air Force Base, Maryland.*

Nicolas Williams, David H. Barton, Steven C. Young, *Comparison of Internodal Transmissivities in a Heterogeneous Aquifer for Difference Schemes.*

GROUNDWATER #2

10:30-12:00

Kenneth C. Black, *Groundwater Modeling of Western Cape Cod, Massachusetts: A Strategy for Large Scale Multi-site Modeling.*

Roger B. Clapp, *Estimating Groundwater Recharge to the Shale Aquifers in Eastern Tennessee Using a Topography-Based, Water-Budget Model.*

David H. Barton, *Groundwater Modeling of Western Cape Cod, Massachusetts: The Interactive Process for the Massachusetts Military Reservation.*

GROUNDWATER #3

1:-2:30

M.A. Khan, S. Ahmed, M. Rahman, D.B. Watson, *Modeling for a Strongly Heterogeneous Porous Medium in Connection with Simulating a Pressure Bulge System at the S-3 Site of the U.S. Department of Energy, Oak Ridge, Tennessee.*

Dudley J. Benton, *Running Large Models on a PC Platform.*

Connor J. Haugh, *Geologic Controls on Ground-Water Flow to the J4 Test Cell at Arnold Air Force Base, Coffee County, Tennessee.*

GROUNDWATER #4

3:00-4:30

Tom D. Byl, Ank Webbers, *Evaluating the Suitability of Natural Attenuation at Sites Contaminated with Chlorinated Solvents.*

Robert Benfield, *Report of a Successful Dye Trace Along Chestnut Ridge, Oak Ridge Reservation, Oak Ridge, Tennessee.*

DEMONSTRATING THE UTILITY OF GROUTING FOR RADIOACTIVE WASTE SOURCE CONTROL

***Dale D. Huff¹,**

John D. Long,

and

Alex Naudts

At Oak Ridge National Laboratory's Solid Waste Storage Area (SWSA) 4, a project to control ⁹⁰Sr sources in radioactive waste trenches by grouting took place during the summer of 1996. Remote sensing methods involving the use of multiple media, including classified imagery, provided a breakthrough for identifying likely contributing waste trenches in late 1994, and led to a focused field investigation during the spring of 1995 (Energy Systems, 1995). The site investigation employed the use of small-diameter wells driven into trenches to sample the contaminant concentration in suspect trenches, and also to selectively observe water level responses to storm events. This information was coupled with measurements of flow and contaminant concentrations in seeps that emerge down slope from trenches, and in the small stream that drains SWSA 4. Studies at seeps and along the stream were used to rank the most important target trenches for remediation and set a baseline for later evaluations. Hydrologic monitoring showed that two of the six contaminated seeps that release ⁹⁰Sr to the surface water system accounted for most of the transport from SWSA 4. Data indicated that about half of the contaminant transport occurs rapidly, via water that enters trenches during storms and overflows to surface seeps. The remainder follows a slower subsurface pathway via groundwater flow and emerges directly in a small stream that drains the site. Investigation of the trenches up slope from the contaminated seeps showed that releases were not uniformly distributed, but instead were localized in a few trenches, based on sampling and analysis of groundwater withdrawn from the suspect trenches. Tracer tests used noble gasses (neon, helium and argon) to label groundwater in the most contaminated trenches, and passive samplers were used at down gradient locations to attempt to identify important flow pathways. The tracer tests were partially successful in linking source locations with discharges to seeps and the SWSA 4 tributary. Based on analysis of all results from the site investigation, portions of four trenches were selected for an interim action project to control the releases.

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Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

Evaluation of possible remedial options resulted in the selection of low-pressure permeation grouting as the preferred approach. The method uses a technology that employs multi-port sleeve-pipes for grout emplacement. The technique also uses on-line real time monitoring of grouting pressures and rates of grout injection for controlling the injection rates and adjusting the grout formulation for conditions specific to the zone being treated. Prior to grouting operations, the sleeve pipes were driven into the target zones using a remotely operated pile driver. Remote operations were necessary because of the potential for explosive reactions if certain types of waste containers were breached. Final confirmation of target trench location came as pipes were driven. During driving operations, blow counts were recorded and the information was used to assess whether or not the pipe was likely to be in a waste trench, and when the bottom of the trench had been reached. Where trench locations were particularly uncertain, adjustments to the planned pipe layout were made in the field with the aid of Geographic Information System images, and blow-count and depth information gathered during installation. Once each sleeve pipe was in place, a weak casing grout was placed around the outside of each sleeve pipe to complete the installation process and seal the pipe into the ground to avoid movement of grout up along the pipe to the ground surface.

Once the weak casing grout had set, ports in each pipe were water-tested. This involved exerting enough pressure to laterally crack the casing grout and allow hydraulic connection between the pipe and the trench volume. This was followed by a permeability test to determine locations of the largest voids and to identify lower permeability zones. This information was analyzed to determine the most effective sequence for grouting and the correct grout formulation to be used. During operations, packers isolate the individual ports for grout injection and sufficient pressure is applied to open the protective sleeve over the grout injection ports and allow movement of the fresh grout into the trench. Multiple ports can be injected simultaneously, although they are selected according to the grout properties of the mix being injected. The sleeve pipes are cleaned after each use and are available for repeated access. Grout emplacement progresses from Portland type III cement-based grout to ultra-fine cement based grout and finally to a polyacrylamide chemical grout as voids become filled. The final product at each trench is a grout monolith of low permeability that is expected to minimize contact between sources and water moving through the trenches. Once grouting was completed, hydraulic testing was conducted in check pipes that had been installed prior to grouting operations. The performance goal for grouting was a hydraulic conductivity that was lower than 1×10^{-6} cm/sec. Although testing was difficult, and there were limits on the lowest hydraulic conductivity measurements that could be achieved in a reasonable amount of time, the results showed that the goal was met.

It is expected that the full effects of grouting will take 10 years to develop, although effects on the more direct pathway should be evident much sooner. The conceptual model for ^{90}Sr release assumes that the waste trenches collect both shallow subsurface stormflow and deeper groundwater discharge along their length, the water comes into contact with wastes that release ^{90}Sr into solution at a fixed concentration, and that the contaminated water then moves to the down slope end of the waste trench where it either moves into the fractured near-surface

weathered shale or, during peak periods of runoff, partially surfaces at seeps and flows over the land surface. Both pathways discharge to the small tributary that drains the site. Evidence exists to confirm both pathways. The trench overflow, called "bathtubbing," is marked by surface contamination that originates at the point where seeps emerge and extends along flow pathways to the tributary. The subsurface pathway is indicated by the field measurements that showed that less than half of all ^{90}Sr observed in the tributary could be captured by seep collection systems that were established during the site investigation and sampled during the wet season. If one assumes complete effectiveness of the source control action, it is possible to estimate the resulting time history of releases using a conceptual model for release processes and a numerical model (Sudicky and Frind, 1982) with parameters derived from tracer studies in comparable geologic settings on the Oak Ridge Reservation (e.g. Sanford, et al., 1996). To quantify expected future releases after completion of the grouting project, it was assumed that the pathways from the source trenches could be represented by a single large fracture in the weathered saprolite between the end of the trench and the tributary. The fracture aperture was set to 0.5 mm, which is larger than physical reality, but is hydraulically equivalent to several small fractures, which is the typical preferred flow pathway for transport that has been observed in controlled tracer tests at similar sites. The approach that was taken was to "turn on" ^{90}Sr sources at about the mid-point of burial ground operations (ca. 1955). Concentrations in trench water were set to approximate those actually observed at the site. The model was run for 40 years, using a specific discharge (i.e. volume of water per unit cross section) of 1.8 m/yr. The simulation was continued for the next 60 years, but the source was turned off for that interval to represent the actual source control action taken. The concentration at the end of a 10 meter flow pathway was taken as the indicator for expected future release. Because ^{90}Sr is sorbed by the material, a retardation factor of 30 was used to represent this interaction, based on typical distribution coefficient values and physical characteristics of the weathered shales. The half-life for radioactive decay that was used for ^{90}Sr was 28.6 years, and the physical diffusion process from the fracture into the rock matrix was considered. Figure 1 shows the model results for simulated concentration over the 100 year period. There is a ten-fold decrease in simulated concentration during the first 10 years, and after 50 years from source control, the concentration is roughly 100 times smaller. If one assumes that the rates and amounts of water moving through the site do not change, then similar fractional reductions in total ^{90}Sr released from the area would be expected. For purposes of comparison, scaled values of concentrations of representative cations (Ca, Sr, Mg, N, Na) observed in Bear Creek following the source control action at the S-3 ponds (Shevenell et al., 1994) are also shown on the graph. The observed 'decay constant' for the decline was 0.16/year. The visual comparison strengthens the modeling results by showing that in a similar geologic setting, roughly comparable declines were observed for the first ten years following source removal and control. It should be noted however, that the model over predicts the decline when compared with the S-3 ponds observations.

ACKNOWLEDGMENTS

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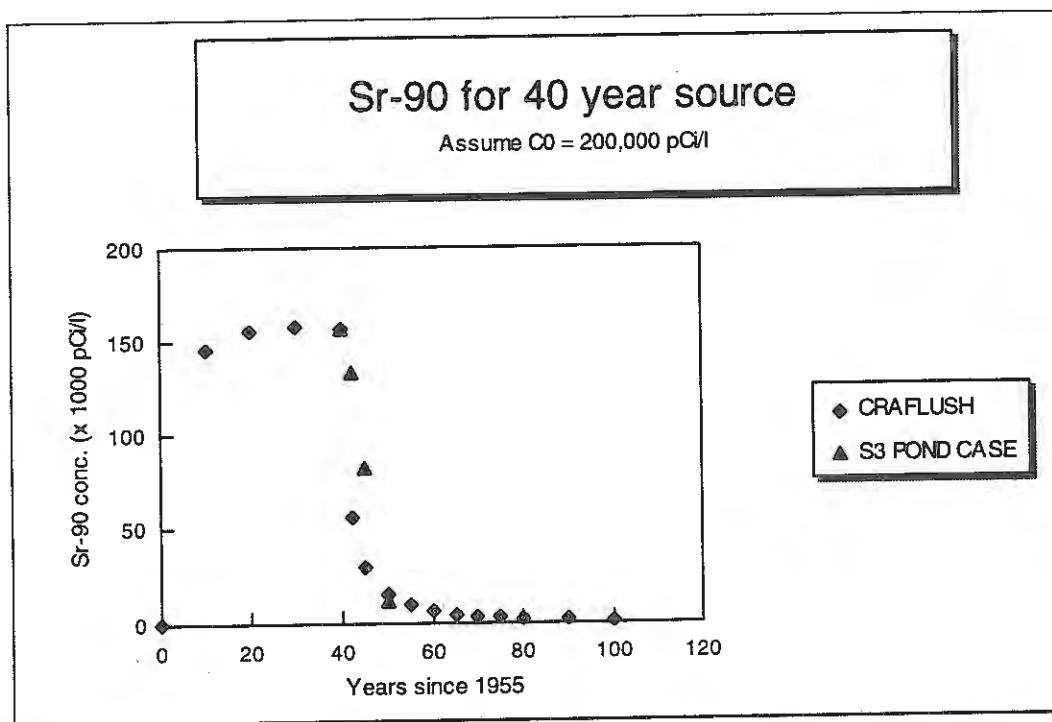


Figure 1. Model and field results used to estimate the ^{90}Sr removal effectiveness of low-pressure permeation grouting of target trenches at WAG 4.

**GROUNDWATER FLOW MODELING FOR REMEDIATION ALTERNATIVES
AT BRANDYWINE DEFENSE REUTILIZATION AND MARKETING OFFICE SITE,
ANDREWS AIR FORCE BASE, MARYLAND**

by

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and

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ABSTRACT

A three-dimensional groundwater flow model was developed for the Brandywine Defense Reutilization and Marketing Office (DRMO) site as part of the removal action effort to control and treat contaminated groundwater. The model simulated nine collection system scenarios (CSS) for capturing a trichloroethylene (TCE)-plume at the site. The modeling study was accomplished using FRAC3DVS, an efficient simulator for three-dimensional unsaturated-saturated groundwater flow and contaminant transport in porous or discretely-fractured porous media. Model calibration was based on matching hydraulic heads and the locations of groundwater divides. CSS 9, consisting of a 120-ft horizontal well, was found to be the most appropriate option for removal of the TCE plume at this site. The simulations indicated that the horizontal well scenarios would deliver a steady flow ranging from 1.8 to 3.3 gal/min from the sand and gravel layer of the aquifer. The capture zone corresponding to each of the collection system scenarios, except for CSS 8, was adequate to contain the entire TCE plume, but the cost effectiveness of CSS 9 lead to its being chosen as the final design for the capture system.

INTRODUCTION

The Brandywine Defense Reutilization and Marketing Office (DRMO) site has been operated by Andrews Air Force Base (AFB) since 1961. The site is located about eight miles south-southeast

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of Andrews AFB, Maryland. As shown in Fig. 1, the site is near the intersection of Brandywine Road and Cherry Tree Crossing Road in Prince George's County, Maryland. On the west side, the site is bounded by an active railroad track operated by Conrail. The site faces a forest on the east and north sides.

The site, with an area of eight acres, was used as a storage yard for excess materials and wastes generated from several facilities, including Andrews AFB, the Navy Research Laboratory, White Oak, Bolling AFB, the Washington Navy Yard, and Indian Head Naval Ordnance Station. As a result of past operations, groundwater contamination exists in the aquifer beneath the DRMO site. Dames & Moore (1992a) conducted a field study to identify the nature and extent of contamination at the DRMO site. The principal finding of the investigation was contamination due to trichloroethylene (TCE) in the unconfined shallow aquifer.

In the present study, a detailed three-dimensional (3D) groundwater flow model was developed that investigates the TCE collection efficiency of different collection system designs. The objective of the 3D model is to quantitatively evaluate and compare the efficiency of any proposed extraction well collection system design.

HYDROGEOLOGIC SETTING

The uppermost aquifer at the Brandywine DRMO site consists of a silty clay unit above a sand and gravel unit, together approximately 13–38 ft thick. These two units are referred to as the Brandywine Formation. The Brandywine Formation overlies the Calvert Formation, which acts as the base of the uppermost aquifer. The Calvert Formation consists of clay deposits that have a thickness on the order of 65 ft.

The hydraulic properties at the site were previously described by Dames & Moore (1992a), who conducted a pumping test at the site (Dames & Moore, 1992b). Assuming a 25-ft saturated thickness, the K values range from 0.9 to 4.8 ft/day. Environmental Consulting Engineers (ECE) conducted a large-scale pumping test. Assuming a saturated thickness of 25 ft, the results indicated that the K values ranged from 0.28 to 0.04 ft/day (ECE, 1995). The K values obtained from the different tests represented spatial heterogeneity in the sand and gravel layer. The initial estimates for the sand and gravel layer K distribution were obtained from this information, and the values were subsequently modified during model calibration.

GROUNDWATER FLOW MODEL

The near-surface (uppermost) groundwater flow system consists of an unconfined aquifer composed of silty clay overlying a sand and gravel layer. This unconfined aquifer lies above the Calvert Formation, which acts as a barrier to downward groundwater flow. The Calvert Formation consists of approximately 65 ft of clay.

The orientation of the groundwater divides and general flow patterns at the north and southwest boundary of the model suggest insignificant flows into the model domain from outside. Therefore, no-flow conditions were used along the north and southwest boundaries of the model.

The model requirements included the ability to simulate a 3D, saturated-unsaturated groundwater flow system in a heterogeneous and anisotropic porous medium. Additionally, flow to extraction wells in heterogeneous porous media must be properly handled. The FRAC3DVS (Therrien et al., 1994) code was selected because of its effectiveness in meeting these criteria.

The finite difference grid for modeling the aquifer was generated using BUILD3D, the FRAC3DVS grid generation preprocessor developed by ECE. The entire 3D grid consists of 76,496 block elements, with a total of 87,984 nodes. A vertical grid spacing of 4.25 ft was used in four element layers above the Calvert Formation to give flexibility in the placement of the horizontal wells in the model to simulate the capture zones more effectively. Summary information on the Brandywine groundwater flow model is given in Table 1.

Calibration of the Brandywine DRMO site model was accomplished by obtaining an agreeable match between observed water levels measured during 1991 and computed water levels during model runs. The calibrated K of the sand and gravel layer was found to be 0.3 ft/day. This corresponds to the pump test measured K. A higher K was used close to the river to obtain topographically consistent groundwater levels and to reproduce observed groundwater divides in the area. The calibration results indicate that the average absolute value of the residuals is 2.9 ft, with a standard deviation of 1.40 ft for the average groundwater level data collected between June 27 and November 26, 1991, by Dames & Moore (1992a).

SIMULATION OF EXTRACTION WELL SCENARIOS

In the present modeling study, nine CSS were simulated to define capture zones for the TCE plume. The CSS 1–6 were simulated as horizontal wells, CSS 7–8 were simulated as collection trenches, and CSS 9 was simulated as a trench backfilled with sand to the ground surface. All the CSS except number 9 were placed approximately 3–4 ft above the Calvert Formation, at an elevation of approximately 198 ft, in the sand and gravel layer of the Brandywine Formation. The CSS 9 was placed at an elevation of about 202 ft in the sand and gravel layer. The simulated capture zones for all the CSS were compared in terms of cost and effectiveness in removing the TCE plume at the site. All the CSS are described in the report submitted by ECE (1996).

The nodes along the CSS were assigned as constant heads. A constant head of 209 ft, about 13 ft below the average groundwater level under nonpumping conditions, was used. Drawdowns were allowed to occur along the horizontal wells. From the simulated hydraulic heads and drawdowns around the horizontal wells, steady-state withdrawal rates were computed by the FRAC3DVS model.

The capture zones for all the CSS were drawn from the fluid particle tracking results for the simulated flow field. A groundwater divide around the collection system was delineated to determine the capture zone. The capture zone corresponding to CSS 9, which was found to be the most effective in capturing the plume, is illustrated in Fig. 2.

The steady-state flow rates for all the CSS vary from 1.8 to 3.3 gal/min, with larger flow rates occurring in simulations having longer screen section lengths. Therefore, the length of the screen will affect the amount of plume capture and, therefore, the volume of contaminated water available for decontamination at the treatment facility.

SUMMARY

All the simulated CSS, with the exception of CSS 8, indicate that complete plume capture can be achieved with a sufficient amount of groundwater available for a treatment facility at the site. The CSS 9 was determined to be the best option for TCE removal based on cost effectiveness and sustained removal of groundwater.

The simulations of the CSS indicate that the flow rates vary between 1.8 and 3.3 gal/min from the aquifer. The flow rates were based on a realistic K field determined by calibrating the model for measured water levels.

The model simulation results for the current condition indicate that groundwater flows to the west toward Timothy Branch and northeast toward the Mataponi branches, thus defining a groundwater divide from north to southeast across the site. Groundwater also flows to the southwest toward Mattawoman Branch, thus defining another groundwater divide from the site to the southwest. The observed groundwater divides were reproduced successfully for the ambient condition by the calibrated model.

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Table 1. Summary information of Brandywine groundwater model

Aquifer properties:

Recharge	0-4 in./year
Hydraulic conductivity (DRMO site)	0.3 ft/day

Numerical grid:

Area	920 acres
Number of nodal layers	9
Number of elemental layers	8
Number of nodes	87,984
Number of elements	76,496

COMPARISON OF INTERNODAL TRANSMISSIVITIES IN A HETEROGENOUS AQUIFER FOR DIFFERENT FINITE DIFFERENCE SCHEMES

Nicolas J. Williams,

David H. Barton,

and

Steven C. Young¹

A concern with applying finite difference schemes to modeling groundwater flow through heterogenous aquifers in the calculation of effective transmissivity between nodes.

A conventional method for representing this parameter with codes such as MODFLOW is to calculate effective transmissivity using a weighted harmonic averaging scheme. The harmonic mean is only exact for steady-state on dimensional flow with no recharge. This approach will lead to different solutions than conventional grid-centered finite difference approaches. In order to investigate efforts associated with both types of modeling approaches, numerical simulations were performed on several different heterogeneous aquifer systems. MODFLOW was used to

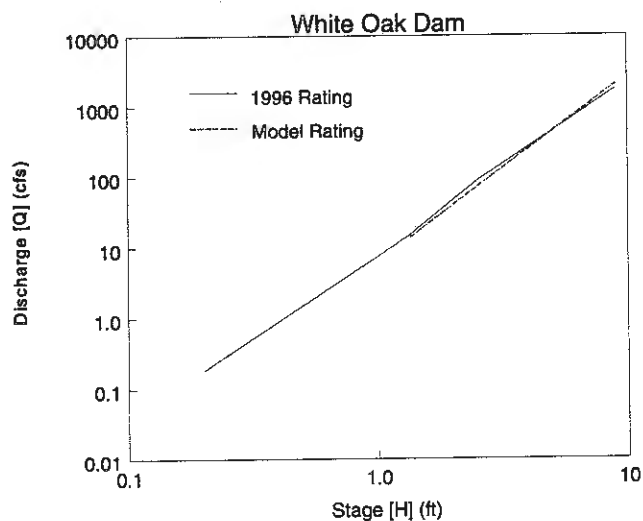


Figure 2. White Oak Dam 1996 rating versus model rating.

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simulate the system using block-centered finite difference with harmonic averaging. FRAC3DVS was used to simulate the same system utilizing a grid-centered finite difference. In each progressive run, the grid was refined. Different averaging schemes were also investigated for the block-centered finite difference method. The results of these modeling simulations showed that although the block-centered and grid-centered models approached the same solution, the grid-centered model with the arithmetic averaging scheme was more accurate for coarser grid spacing. The results of these model runs indicate a need to consider model selection and grid refinement not only as a tool to minimize classical numerical error, but also as a tool to better represent heterogenous aquifers.

GROUNDWATER MODELING OF WESTERN CAPE COD, MASSACHUSETTS: RUNNING LARGE MODELS ON THE PC PLATFORM

Kenneth C. Black, P.G.¹

From April 1995 to July 1996, P-SQUARED Technologies, Inc. supported Operation Technologies Corporation with groundwater modeling for the Massachusetts Military Reservation (MMR) in Western Cape Cod (WCC). The primary goal of this modeling effort was to simultaneously capture six large groundwater plumes emanating from the MMR facility. The large areal extent of both the plumes and the WCC aquifer necessitated the use of large groundwater models. Many more difficulties and frustrations are associated with running large models than one might expect. The 640KB limitation of standard DOS is far too small for any serious modeling. Access to more memory involves software and hardware capability and cooperation. Accessing more than 64MB of physical memory or more than 256MB of virtual memory on a PC is extremely difficult. Many problems associated with the compatibility of various DOS extenders, FORTRAN and C compilers and Windows operating systems were encountered during the MMR modeling effort. In short, only one combination of program compilers and Windows operating systems allows the ability to run all of the necessary programs on a single platform.

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ESTIMATING GROUNDWATER RECHARGE TO THE SHALE AQUIFERS IN EASTERN TENNESSEE USING A TOPOGRAPHY-BASED, WATER-BUDGET MODEL

Roger B. Clapp, Ph.D.¹

Recharge is a critically important descriptor of the groundwater system. For unconfined aquifers, recharge determines the productivity of water supply wells, and it strongly influences the rate of movement of groundwater contaminants; however, it is a difficult variable to evaluate. Model calibration which is traditionally used to back calculate the hydraulic conductivity field cannot yield an unambiguous value. In the groundwater flow equation, the recharge variable, R , is divided by the drainable porosity, θ_n , a parameter subject to considerable uncertainty, thus the quantification of R/θ_n does not yield a useful estimation of R . The conventional methods for quantifying recharge also yield uncertain results. Specification of R via conventional water-budget simulation involves many simplifying assumptions. Because evapotranspiration is itself subject to considerable uncertainty, the resulting recharge estimate is very uncertain. Probably the most common method for determining recharge is graphical hydrograph separation, but the quantification of baseflow involves untestable assumptions about the amount of recharge that occurs during the overland flow and interflow phases of storm runoff, and there is usually some additional uncertainty about groundwater gain or loss in the watershed. New methods of recharge measurement via shallow groundwater dating are very promising although these innovative methods based on tritium-helium-3 dating or chlorofluorocarbon dating can also be ambiguous due to the confounding effects of macropore flow and matrix diffusion. Moreover, these new methods yield recharge estimates at a single point, and future studies may find that recharge is highly variable from point to point within a watershed. Despite its importance, recharge remains an elusive variable to evaluate at the level of certainty that groundwater modelers strive to achieve.

Estimation of recharge in watersheds underlain by weathered shale found in eastern Tennessee poses particular problems. In the valley-ridge geologic province, the karst belts provide the most productive aquifers whereas the shale belts are generally typified by low hydraulic conductivity and low aquifer productivity. Because of their low permeability, groundwater flow in shale aquifers has not been characterized very well. On the Oak Ridge Reservation (ORR) where U.S. Department of Energy facilities are located, the shale soils have been the preferred area for disposal of low-level radioactive waste, leading to the unintentional transport of radionuclides from waste disposal facilities to nearby streams. Reliable estimates of recharge in the shale aquifers would assist in understanding, quantifying, and ultimately remediating the transport of groundwater pollution to surface water at these disposal sites.

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In this study, colleagues at the Oak Ridge National Laboratory (ORNL) and I have modified a topography-based, water-budget model to simulate individual components of the stream hydrograph, and the modified model yields reasonable estimates of recharge that may, in the future, be confirmed by more detailed field measurements. The new model simulates evapotranspirational loss plus overland flow, interflow, and baseflow. The baseflow estimates are assumed to be good approximations of recharge. Because the model is mechanistic and because parameter values are calibrated over a long period of time, the recharge estimates are considered to be more reliable. In essence, the new model combines the benefits of water-budget modeling and conventional hydrograph separation.

In order to model runoff in the shale watersheds of the ORR, we started by using TOPMODEL which was originally developed by Keith Beven and Michael Kirkby at the Institute of Hydrology in Wallingford, England. TOPMODEL is the combination of a conventional water-budget submodel with separate storages for interception, root zone water, unsaturated soil water, and groundwater, plus a unique submodel that identifies the portion of the watershed that becomes saturated during a storm. Rainfall on the variably saturated areas produces the overland flow portion of the hydrograph. Because variable source areas are the primary mechanism for stream flow generation in the hilly terrain of eastern Tennessee, TOPMODEL provided a good starting point for the modeling work reported here.

To apply TOPMODEL, first the modeler has to generate the Topographic Index, identified as $\ln(a/\tan\beta)$, from a digital elevation model of the watershed to be simulated. The index is computed on a pixel-by-pixel basis, and a refers to the contributing area uphill from each pixel, β refers to the local slope of the pixel, and \ln is the natural logarithm. For input, the model does not require the actual map of the Topographic Index, but it does require the frequency distribution of the index. Recent advances in topographic-hydrologic theory have shown the conceptual linkage between the inherent shape of the hydrograph recession following a storm, the distribution of permeability within the "typical" soil column in the watershed, and the topographic index. According to theory, watersheds with different permeability distributions in the soil profile will result in different hydrograph recessions, and these watersheds should be characterized using different topographic indices (i.e., variations similar to $\ln(a/\tan\beta)$). The modified model incorporates different topographic indices in addition to $\ln(a/\tan\beta)$. This extra flexibility allowing the use of alternative topographic indices was very important in our model application.

TOPMODEL is a mechanistic rainfall-runoff model that simulates subsurface drainage and overland runoff. The model assumes that groundwater flows in a shallow aquifer with flow paths that tend to parallel the overlying topography. For instance, the model is very applicable to a watershed where a shallow soil overlies impervious granite bedrock. For our purposes, one key shortcoming of TOPMODEL is that it lumps subsurface drainage processes. It does not differentiate between transient, lateral flow in soils (interflow or stormflow) and discharge from the deeper water-table aquifer (baseflow). For the shale aquifers on the Oak Ridge Reservation, the lateral, subsurface stormflow in the upper part of the soil profile is known to be significant.

This shallow stormflow tends to fill disposal trenches with water leading to contaminant leaching and transport to nearby streams.

In our version of the model, which we call TOPMODEL-PLUS, the groundwater storage is used to represent the stormflow storage, and there are three new components to the model: a new groundwater storage, a vertical drainage function that routes water from the stormflow zone to the groundwater zone, and a method whereby both groundwater and stormflow can cause saturation adjacent to the stream (the variable source area). As mentioned above, there are options for using alternative Topographic Indices. We have applied the modified model to an experimental watershed at the Oak Ridge National Laboratory (ORNL), and the simulation results are encouraging. Parameter values related to evapotranspiration were calibrated by initially simulating hourly flows for an entire year. Subsequently the subsurface parameters were calibrated for a simulation period of 5 months that included 6 storms. Once calibrated, the model was used to simulate flows for 7 years when discharge measurements were available. For those years the average precipitation was 1.092 m and the average simulated runoff was 0.484 m. Annual overland flow, subsurface stormflow, and groundwater discharge respectively constituted 6.2, 46.6, and 47.2% of the total runoff on average. The simulation period was exceptionally dry with annual rainfalls well below the normal precipitation of about 135 cm. Experience with the calibrated model suggests that, for years with more rainfall or more intense storms, the overland runoff component increases, as expected, and that the stormflow and groundwater discharge components also increase but remain about equivalent in magnitude. Correlation between the simulated groundwater state variable and the water levels at 18 monitoring wells in the test watershed indicates that subsurface hydrologic processes are not uniform across the watershed, as assumed in both the original and modified version of TOPMODEL. The modified model does calculate a groundwater discharge that may be used as an estimate of a spatially averaged groundwater recharge. In our investigation, the average annual recharge in the shale aquifer was 23 cm, but it is expected to be greater for years of average and above average precipitation. The local variations in recharge may be significant.

We have made some initial simulations for an experimental watershed underlain by karst. For this watershed, overland runoff is almost negligible for years of average hydrologic conditions. The stormflow component is smaller and the groundwater component is larger, as compared to results from the watershed underlain by shale. There were problems related to groundwater loss and gain, as expected in karst terrain, which required empirical adjustments.

The TOPMODEL-PLUS is applicable to hilly terrain underlain by deeply weathered soils that develop transient, perched water in the soil during storms and where the hydrograph has evidence of three separate flow components. In practice, it may be used advantageously wherever the hydrograph can be separated into three components. More tests of the model are needed to establish its reliability, and ideally we will intensively study other experimental watersheds using both TOPMODEL-PLUS and the new methods for direct measurement of recharge based on groundwater dating in order to validate recharge estimates.

**GROUNDWATER MODELING OF WESTERN CAPE COD, MASSACHUSETTS:
THE INTERACTIVE PROCESS
FOR THE MASSACHUSETTS MILITARY RESERVATION**

David H. Barton, R.G.¹

As part of modeling for the Massachusetts Military Reservation (MMR) in Western Cape Cod (WCC), an interactive process was used. Client and stakeholder involvement was an integral part of the model development and application. Political and public concern about migration of plumes at MMR led to a new approach to address this issue. An expedited action would require all stakeholders to be involved in and reach a consensus agreement on the analysis, design, and remediation process. The stakeholders include the public, Operational Technologies Corporation, the U.S. Geological Survey, the U.S. Air National Guard, the U.S. Army, and various other federal, state, and local regulators. Model development and application was concurrent with field data collection, which led to significant changes in plume positions, ecological impacts, and stakeholder concerns as additional field data became available. Groundwater modeling of WCC included nearly continuous, i.e. weekly or even daily, stakeholder input. The interactive involvement was integral in modification of remedial scenarios on a time-critical basis. Remedial scenarios were often presented by stakeholders, modeled, analyzed, and presented to stakeholders in one to two weeks. This time scale of model development and application required a highly specialized set of efficient and flexible pre- and post-processing tools. The development of the models and tools was essential in the ability to respond rapidly to stakeholder inputs, supplemental field data, and plume containment design changes.

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**MODELING FOR A STRONGLY HETEROGENEOUS POROUS MEDIUM
IN CONNECTION WITH SIMULATING A PRESSURE BULGE SYSTEM
AT THE S-3 SITE OF THE U. S. DEPARTMENT OF ENERGY,
OAK RIDGE, TENNESSEE¹**

M. A. Khan,²

S. Ahmed,³

M. Rahman,⁴

and

D.B. Watson⁵

ABSTRACT

A spatially varying density dependent flow model was used to investigate the effects of a strongly heterogeneous medium in generating a pressure bulge in the subsurface at the Bear Creek valley (BCV) S-3 site of the U. S. Department of Energy (DOE) at Oak Ridge, Tennessee. The model formulation included one-dimensional groundwater flow equation with compatibility and continuity criteria at the interface between adjacent hydraulic conductivity zones. The model was applied to simulate the pressure bulge system at the BCV S-3 site. The simulation included representation of the variation of hydraulic heads in a multilayered porous medium beneath the S-3 site. Hydraulic conductivity data from the previously calibrated BCV regional model (DOE 1996a) were used in this modeling which produced the pressure bulge quite in agreement with field data. A sensitivity analysis was carried out by changing the hydraulic conductivity data in simulating the pressure bulge at the site. Dissipation of the pressure bulge due to application of long-term extractions was also investigated.

INTRODUCTION

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Prediction of flow and contaminant transport in a porous medium becomes complicated due to the presence of geologic profiles with abrupt changes in their characteristics. The specific problems include changes in the magnitude, timing, and direction of flow and contaminant transport across geologic contacts associated with strong heterogeneity in a porous medium. These effects can be studied by the methodologies described by Bear (1972) that deals with flow and contaminant transport in a strongly heterogeneous medium.

In the present modeling study, a one-dimensional density dependent flow (DENSFLOW) model was developed using methodologies related to porous media with discontinuity in properties. The model was applied to simulate a pressure bulge scenario at the DOE's BCV S-3 site in Oak Ridge, Tennessee.

DESCRIPTION OF THE MODEL

The DENSFLOW model was developed by solving the density dependent groundwater flow equation using finite difference method. The methodologies described by Bear (1972), Liggett and Lieu (1983), and Taigbenu (1985) for a strongly heterogeneous and discontinuous medium are incorporated into the governing equation. In this approach, the original domain is divided into subdomains based on the geologic units in a medium. Each subdomain is homogeneous but anisotropic. The governing equation is solved for each subdomain corresponding to each geologic unit. Therefore, the mathematical problem is decomposed into subproblems corresponding to each subdomain.

According to Bear (1972) and Liggett and Lieu (1983), it is required to apply compatibility and continuity criteria at the interface between adjacent subdomain. The compatibility criterion allows a unique solution of the hydraulic head at the interface and the continuity criterion allows inflow/outflow between adjacent subdomains.

The aforementioned conditions at the points of discontinuities and the governing equation for each subdomain are combined to obtain solution for the whole heterogeneous domain. The inclusion of the special conditions of compatibility and continuity ensure stability, convergence, and consistency in the numerical solution for sharply varying aquifer characteristics in a domain.

BACKGROUND

Within the Oak Ridge Reservation, there are four waste disposal ponds referred to as the S-3 ponds, near the western edge of the Y-12 Plant operated by the U.S. DOE. The S-3 ponds received liquid waste until 1983 (DOE 1996b). The S-3 ponds were filled and the area was converted into a parking lot. Four boreholes were drilled west to the S-3 ponds and later equipped with multiport monitoring and sampling system to characterize the subsurface of the region. The data collected from one of the bore holes, GW-134, approximately 600 ft from the center of the S-3 ponds, indicates the existence of a pressure bulge with a maximum nitrate concentration at a depth of about 450 ft.

It was necessary to evaluate the causes of the existence of the observed pressure bulge and concentration at the location of GW-134. A modeling study was conducted by INTERA, Inc. (1995) to evaluate potential scenarios that could produce the observed pressures and concentrations data from GW-134. The specific objective was to understand the hydraulics between the S-3 ponds and GW-134 that would produce the conditions at the locations of GW-134 consistent with the observed data. Three scenarios were modeled with different heterogeneity and anisotropy in the formation having the pressure bulge using SWIFT-III. The general trend of the data observed from GW-134 was reproduced assuming a homogeneous formation with anisotropy of horizontal to vertical hydraulic conductivity of 10 : 1 and assuming a high permeability zone between the S-3 ponds and GW-134.

The subsurface geology at the location of GW-134 consists of unconsolidated regolith, the Maynardville Limestone, and the Nolichucky Shale Formations as shown in Figure 1. The borehole GW-134 extends to a depth of 600 ft by intersecting the Nolichucky Shale Formation at a depth of approximately 300 ft. Detailed description of the BCV geology and hydrogeology can be found in the BCV RI Report (DOE 1996b).

MODEL APPLICATION

In the present modeling study, DENSFLOW model was applied to reproduce the pressure bulge observed at GW-134 using hydraulic conductivity data from the regional flow model. The hydraulic conductivity data of the formation above the Nolichucky Shale was decreased by one order of magnitude during calibration runs to obtain a better match between the observed and simulated results. The simulated results after calibration was used as the base run for further simulations. The model was also run using the hydraulic conductivity data used by Intera, Inc. (1995). A sensitivity analysis was carried out by changing the hydraulic conductivity data of both the Maynardville and Nolichucky Formations.

The model was run for sixty years. It was observed that the pressure bulge will remain at a steady state condition over a longer period of time using the calibrated hydraulic conductivity data from the regional flow model developed by DOE (1996a). Similar results were obtained by running the model for the hydraulic conductivity data used by Intera, Inc. (1995). All these hydraulic conductivity values were varied by one and two orders of magnitude to investigate the sensitivity with respect to the existence of the pressure bulge. Figure 2 demonstrate the results of sensitivity runs by varying hydraulic conductivity in all geologic units.

The model runs were made to investigate the effects of withdrawals on the pressure bulge. Withdrawal was made from the pressure bulge area between depths 350 and 550 ft below ground surface. The effects of continuous withdrawals for twenty and thirty years, predicted by the model are shown in Figure 3. It is observed that the continuous withdrawal for a long period will allow capturing the pressure bulge at the location of GW-134.

A sharp variation of hydraulic head due to pumping is observed at a depth of 550 ft as shown in Figure 3. The hydraulic conductivity below 550 ft is about two orders of magnitude lower than the hydraulic conductivity just above it. The sharp variation of hydraulic head is due to discontinuity of the hydraulic conductivity at a depth of 550 ft.

CONCLUSION

The following conclusions can be made from this investigation:

- The hydraulic heads at the well GW-134 were reproduced by applying the simple one-dimensional DENSFLOW model in the vertical direction. The model results were in close agreement with all the hydraulic conductivity data obtained from previously calibrated models. The model results demonstrated the effects of discontinuity of the hydraulic conductivity in the subsurface beneath GW-134.
- The results of the sensitivity analyses indicate that the calibrated hydraulic conductivity from the regional model for Maynardville Limestone is an order of magnitude.
- The model results indicated that dissipation of the pressure bulge can be achieved by continuous groundwater extraction for 20 to 30 years. However, the effects of withdrawal indicated by the simulations are not definite due to the lack representing the radius of influence and capture zones more appropriately with a one-dimensional model.

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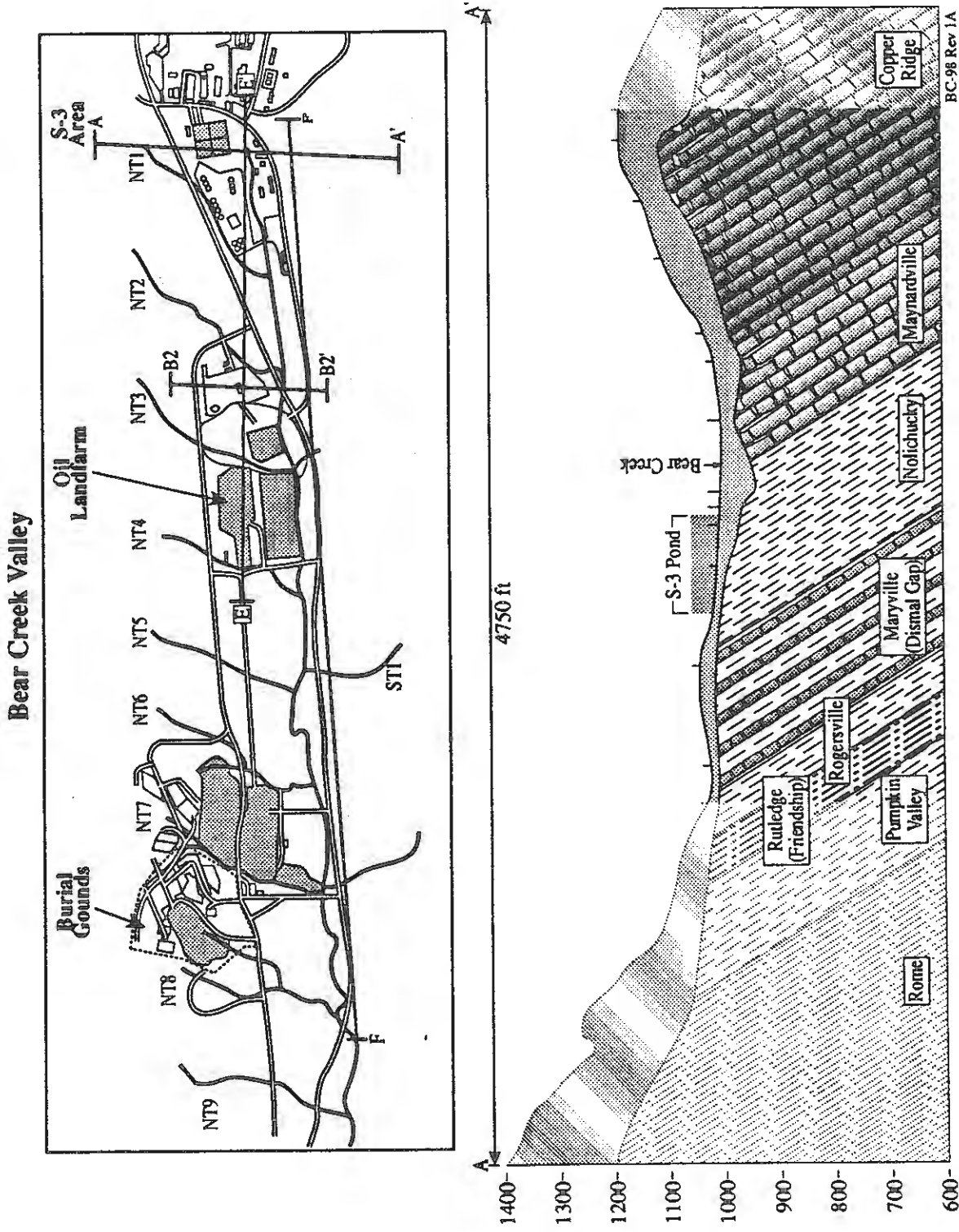
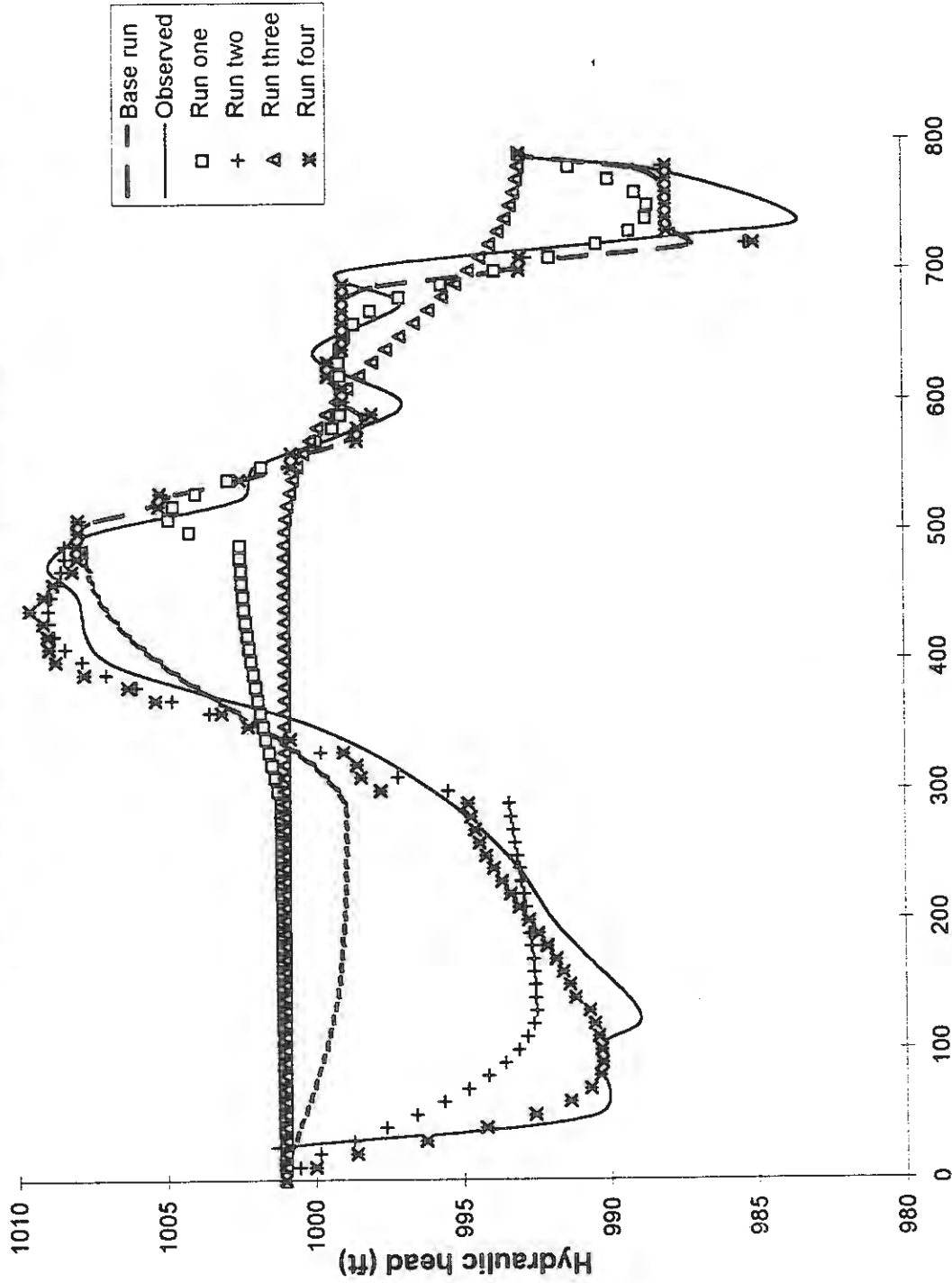


Figure 1. Geological cross section of Bear Creek Valley showing S-3 Site

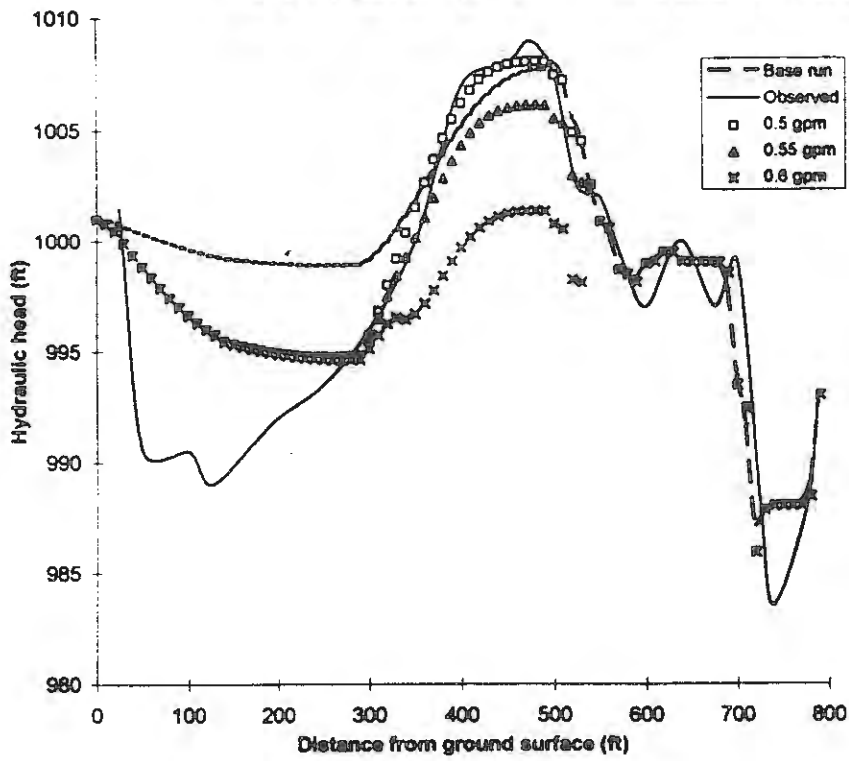
BC-98 Rev 1A

Sensitivity analysis for hydraulic conductivity in all geologic units



Distance below ground surface (ft)
 Figure 2. Effect of pressure bulge near S-3 Site due to variations in hydraulic conductivities.

Effects on pressure bulge due to continuous extraction for 20 years.



Effects on pressure bulge due to continuous extraction for 30 years.

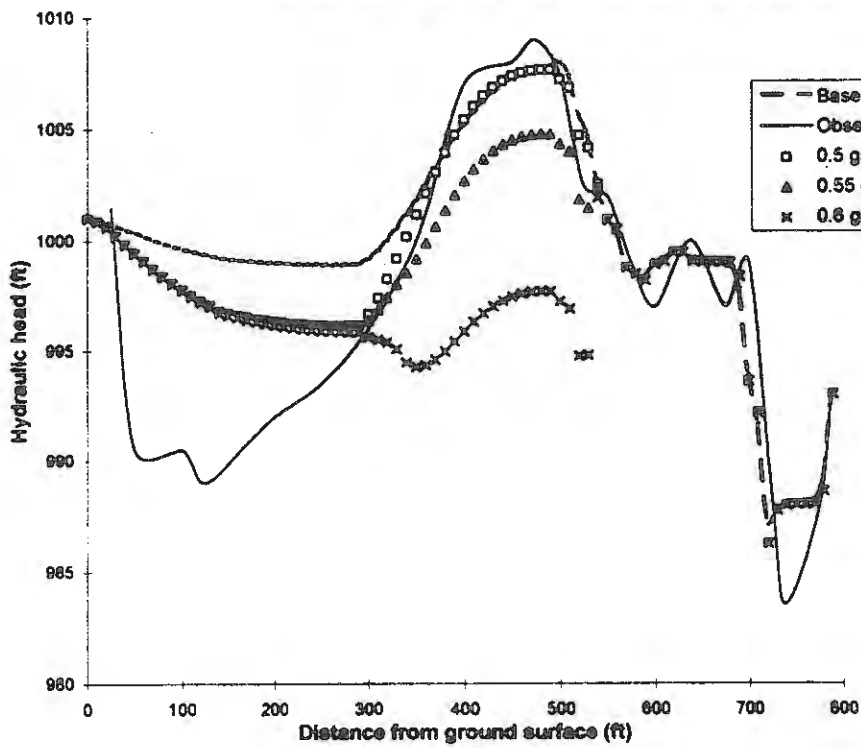


Figure 3. Effect on pressure bulge due to continuous extraction.

RUNNING LARGE MODELS ON A PC PLATFORM

Dudley J. Benton¹

INTRODUCTION

P-Squared Technologies specializes in environmental fluid flow modeling--especially groundwater and surface water systems. These applications are often large models which require large programs. The 640KB¹ memory limitation of standard DOS² is far too small for modeling complex environmental phenomena. Utilizing more than 64MB³ of physical memory or more than 256MB of virtual memory on a PC⁴ is extremely difficult and requires software and hardware capability.

PHYSICAL MEMORY

The most significant increase in PC hardware capability came with the introduction of the 80386⁵. The 80386 and subsequent Intel processors are capable of operating in *real* and *protected*⁶ modes, or 16-bit and 32-bit⁷ operation. In protected mode, these processors

Even if the memory chips can be purchased, and even if they can be inserted into a machine, this does not assure that it will actually recognize any more than 64MB of RAM. Even if the BIOS¹² recognizes the memory above 64MB during boot-up, this does not assure that any available software can utilize this additional memory. Some systems (e.g., Gateway P5-90s) when augmented from 64MB to 128MB actually report less than the original 64MB.

The DOS and Windows¹³ extended memory manager¹⁴, HIMEM.SYS¹⁵, can not report any more than 64MB of extended memory. This is by virtue of its protocol and is not correctable. A different protocol is necessary in order to report more than 64MB. Some machines (e.g., Zeos Pentiums), have a switch which enables Windows-NT to access up to 256MB of RAM by altering the HIMEM.SYS protocol. Enabling this switch causes the BIOS to report up to 256MB. However, this causes non-NT programs which utilize this protocol to report only 16MB of RAM, making this a non-solution to the 64MB RAM ceiling problem.

VIRTUAL MEMORY

Virtual memory, or disk-swapping, is provided by software. Windows-V3, Windows-95, and Windows-NT all provide virtual memory access (VMA). This is done by creating a swap file and placing *hooks* in the protected-mode memory access which will generate an *interrupt*¹⁶ when these phantom memory locations are accessed. The VMA software can then swap in and out of active and inactive memory. This enables the computer to function as if it had more memory than is physically

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present. As this additional processing takes time, and disk drives are much slower than RAM, programs utilizing virtual memory may run much slower than those which can function entirely within the limits of physical memory.

The biggest limitation of VMA is seen with Windows-V3, which will create, but refuses to utilize a swap file larger than four times the physical memory. As HIMEM.SYS is limited to 64MB, this results in a maximum Windows-V3 swap file of 256MB. It would seem only logical that, were a user willing to commit the disk space and runtime, Windows should have no upper limit on the swap file size; however, this is not the case. There is a marginally-documented Windows SYSTEM.INI parameter, *PageOverCommit*, which has a default value of 4 and is said to accept any value between 1 and 20. This would seem to indicate that the 256MB ceiling is linked to this parameter. The *PageOverCommit* parameter can indeed be set in SYSTEM.INI to values between 1 and 20; however, Windows-V3 refuses values above 4; thus, the 256MB limitation remains. Windows-95 and Windows-NT will create any size swap file, limited only by available disk space. Rather than dynamically growing as needed, a Windows-V3 swap file larger than 20MB must be made *permanent*, which results in a dedicated allocation of disk space.

As different compilers (which may be necessitated by the use of several models, pre-processors, and post-processors written in different languages or which depend on compiler-specific features) utilize different virtual memory managers, separate hard disk space must be dedicated to each. When running several models which require in excess of 256MB of virtual memory and may require/produce 512MB of input/output files, available disk space becomes a serious problem. Repeatedly switching from one virtual memory manager and/or operating system to another is not only time-consuming and tedious, it increases the likelihood of hardware failure.

Pharlap sells a DOS extender, TNT, which allows non-Windows programs to run in protected or 32-bit mode. Pharlap also sells a virtual memory manager, VMMDRV, which adds disk-swapping. This software, while expensive and cumbersome, does increase capability, as its virtual memory is limited only by available disk space, unlike the virtual memory provided by Windows-V3. VMMDRV, however, will not provide virtual memory inside any Windows environment. It must be run in DOS, outside Windows. Under DOS-6.22, the Pharlap DOS extender will only access the first 64MB of physical memory. This eliminates any advantage in purchasing more memory. However, running in what might be called DOS-95, or the residual DOS left after a shut-down of Windows-95 and warm boot, physical memory above 64MB can be accessed, provided the hardware and BIOS are compatible.

COMPILERS AND DOS EXTENDERS

Two languages are essential: FORTRAN and C. Large models require that the compilers be able to generate 32-bit code. Running 32-bit code on a PC requires either a DOS extender or a Windows-NT executable (Windows-95 will run Windows-NT programs). The project in which these operating systems and compilers were evaluated required running pre-processors and post-processors written in C and a solver written in FORTRAN. Getting these programs to run on a single platform and in a single configuration is very important.

WATCOM, Lahey, Salford, and Microsoft PowerStation FORTRAN compilers were tested. All but the PowerStation produce extended DOS executables. WATCOM uses the Rational Systems DOS extender. Lahey uses the Pharlap DOS extender. Salford uses the DBOS DOS extender. PowerStation executables will only run under Windows-95 or Windows-NT and will not run in DOS outside of Windows.

Due to an internal limitation of the Microsoft PowerStation FORTRAN Version 1, programs having more than 256MB of static arrays will not run under Windows-NT, but will run under Windows-95. Microsoft indicates that PowerStation programs larger than 256MB should not run on any system. The Microsoft *solution* to this discrepancy, which came out with Version 4 of the PowerStation (there were no versions 2 and 3), was not to repair the problem so that larger programs would run under Windows-NT, but to assure that larger programs would no longer run under Windows-95. Thus, if more than 256MB is required, the old version of PowerStation along with Windows-95 is required.

The Rational Systems and Pharlap DOS extenders supplied with the WATCOM and Lahey compilers, respectively, are *crippled* in that they are limited to a few megabytes. An expanded version of the Rational Systems DOS extender for use with WATCOM FORTRAN, which would provide access to the hundreds of megabytes required for the current project is unreasonably expensive. A network license or a distribution license (required if the executables are to be run by another party) for the Rational Systems DOS extender are quite expensive.

Lahey FORTRAN suffers from a similar problem as WATCOM in that large fees are required for Pharlap support--a situation not made clear when purchasing the compiler. Perhaps the most irritating factor associated with the Pharlap DOS extender is that the versions which support the FORTRAN compilers will not support the C compilers, or vice versa; thus making it necessary to purchase two costly DOS extenders.

C compilers also present an array of frustrations. Microsoft C Version 7.00 is an excellent example of conglomerated problems. The documentation states in many places that compilation can target the 80386 processor family. This capability, however, is not part of the software. The compiler will produce some form of 80386-targeted code if a Windows executable is generated. The problem with this is that a Windows-based executable requires a Windows-based, rather than console-based, interface, as well as many more changes. Building a Windows-based interface for an already-functioning computational model can be an enormous effort. There is a simulated console interface available with several C compilers which can be built into a Windows executable; however, this is limited to small programs. The further limitation of this compiler is that it does not utilize the power of the 80386 and later processors for even simple calculations involving integers. This console interface limitation and processor 32-bit function utilization is not a problem with Microsoft PowerStation FORTRAN.

WATCOM C suffers from the same limitations as WATCOM FORTRAN, arising from a dependence on the Rational Systems DOS extender.

Symantec C (formerly called Zortech) is by far the most impressive 32-bit compiler for the PC platform. The switch from 16-bit to 32-bit compilation is effortless. Symantec C supports several 32-bit options, including DOS, Pharlap¹⁷, and Windows-NT. The Windows-NT option will only run inside Windows-NT, Windows-95, or WIN32s; however, virtual memory is not accessible under WIN32s when compiled with this option.¹⁸ In the case of Windows-NT and Windows-95, a *console interface* is provided internally. No such compatibility is available with WIN32s.¹⁹ Thus the only solution that Symantec C provides for more than 256MB is to produce a Windows-NT executable with the native console interface provided by Windows-95 and Windows-NT. Symantec C does not provide any solution for large models running in a DOS or Windows-V3 environment.

High-C is an expensive and cumbersome compiler which seems to work well with the Pharlap DOS extender; but offers no advantage over the Symantec C compiler; and, was found to be inferior to Symantec C in each of the categories discussed above.

SUMMARY

In summary, many more difficulties and frustrations are associated with running large models on a PC platform than one might expect, based on the claims of compiler vendors. Repeated references to gigabytes of memory are misleading, at best. The availability of memory slots capable of seating many megabytes of RAM are also misleading. For FORTRAN code, only one configuration has been found which can support very large models and at least 256MB of RAM: early versions of Microsoft PowerStation running under Windows-95. For C code, the Symantec compiler with the Windows-NT target operating system, and running Windows-NT or Windows-95 provides access to more than 256MB of physical and virtual memory. Therefore, the combination of Microsoft PowerStation and Symantec C compilers targeting Windows-95 is the only combination found which enables all of the programs to run on a single platform.

ENDNOTES

¹ KiloByte or 1024 bytes

² Disk Operating System - a trademark of Microsoft

³ MegaByte or 1024×1024 bytes

⁴ Personal Computer - a trademark of IBM

⁵ microprocessor and trademark of Intel

⁶ The etymology of the terms *real mode* and *protected mode* arise from the respective memory addressing. In *real mode*, memory addresses correspond directly to *real* locations in physical memory. In *protected mode*, memory addresses are translated within a program context and may not have a literal correspondence to physical memory. In *protected mode*, some areas of memory are *protected* from alteration and/or access.

⁷ 16-bit and 32-bit refer to the size of the integers used to address memory. A 16-bit integer can range from 0 to $2^{16}-1$ (or 65536). Thus, a processor operating in *real mode*, using 16-bit integers to address memory, must use *segmented* addresses, or a combination of two 16-bit integers. Intel

processors overlap these two to form a 20-bit address. As 2^{20} equals 1048576, or 1024×1024 , this is the source of the 1MB memory limitation of DOS. A 32-bit integer can range from 0 to $2^{32}-1$ (or 4294967295); thus, accessing megabytes or memory requires 32-bit operations. are capable of addressing 4GB^8 of memory. Memory above 1MB on these machines is called *extended*⁹. This processor capability is misleading; however, as no currently available PC can contain 4GB of physical memory (often called RAM¹⁰). Furthermore, the top 2GB is reserved for the operating system and is not available for user programs. Thus, no more than 2GB will ever be available on a 32-bit machine--regardless of the claims of software vendors promising access to 4GB. Practically, most PCs, even Pentium¹¹-based machines, are limited to 128MB of RAM and very few single-processor Intel systems are commercially available which can support more than 512MB of RAM.

⁸ GigaByte or $1024 \times 1024 \times 1024$ bytes

⁹ physical memory extended beyond the 1MB 16-bit addressing capability

¹⁰ Physical memory *chips* are often referred to as *RAM* or Random Access Memory. This is to distinguish it from Sequential Access Memory (or *SAM*) devices such as a tape or disk drive.

¹¹ microprocessor and trademark of Intel

¹² Basic Input/Output System, or the lowest level software which supports the operating system. The rolling numbers displayed during the power-up procedure indicate the physical memory recognized by the BIOS.

¹³ Windows is a trademark of Microsoft

¹⁴ An extended memory manager is memory-resident (i.e., ever-present) software which controls access to the memory above 1MB.

¹⁵ HIMEM.SYS is an extended memory manager developed by Microsoft.

¹⁶ An *interrupt* is a notification of the operating system and can be hardware or software generated. Depending on the nature of the interrupt, the processor may suspend the current activity, process the interrupt, and then resume the previous task; or it may save the interrupt in a queue and process it later.

¹⁷ Note that the recent documentation for Symantec C and Pharlap DOS extender do not indicate that these are compatible; however, this option functions quite well through Version 6.11.

¹⁸ There is the further, marginally-documented limitation of WIN32s, that no single array can be larger than 16MB (the practical limit is more like 15MB).

¹⁹ While a program compiled with this set of options will indeed run, no output will be displayed during operation, and it must be launched from FileManager, not from the DOS box.

**GEOLOGIC CONTROLS ON GROUND-WATER FLOW
TO THE J4 TEST CELL
AT ARNOLD AIR FORCE BASE,
COFFEE COUNTY, TENNESSEE**

Connor J. Haugh¹

The potentiometric surfaces in the shallow, Manchester, and Fort Payne aquifers (collectively, part of the Highland Rim aquifer system) have anisotropic water-level depressions centered on the J4 test cell. The anisotropy, particularly in the Manchester aquifer, is the result of features of high permeability such as linear chert-gravel zones in the regolith and fractures, joints, and bedding planes in the bedrock. Surface and borehole geophysical surveys, potentiometric-surface data, and lineations mapped from aerial photographs were used to investigate the occurrence, distribution, and orientation of these features. The high permeability features result in complex flow patterns in the Highland Rim aquifers near the J4 test cell.

The J4 test cell is a part of a major aerospace systems testing facility operated by the U.S. Air Force at Arnold Engineering Development Center (AEDC) in Coffee County, Tennessee. The J4 test cell is approximately 100 feet in diameter, extends approximately 250 feet below land surface, and completely penetrates the Highland Rim aquifers. Ground water is pumped continuously from around the test cell to keep the cell structurally intact. Because of the test cell's depth, this pumping has depressed water levels in the aquifers surrounding the site. The depressed water levels exhibit anisotropy that is controlled by zones of high permeability in the aquifers. The depressions extend out horizontally through the aquifers along the most permeable pathways. Because the aquifers are not separated by distinct confining units, areas in adjacent aquifers above and below the zones of high permeability in the Manchester aquifer are also dewatered.

The effects of dewatering at the J4 test cell were investigated by studying the lithologic and hydraulic characteristics of the aquifers, investigating the anisotropy and zones of secondary permeability using geophysical techniques, mapping the potentiometric surfaces of the underlying aquifers, and developing a conceptual model of the ground-water-flow system within the test cell area.

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**EVALUATING THE SUITABILITY
OF NATURAL ATTENUATION AT SITES
CONTAMINATED WITH CHLORINATED SOLVENTS**

Tom D. Byl,

and

Ank Webbers¹

Natural attenuation, *in situ* bioremediation, is gaining acceptance as an alternative to "pump and treat" methods at contaminated ground-water sites. This acceptance has been generated by past successes in biodegradation of gasoline. However, sites contaminated with chlorinated solvents require different physicochemical conditions for natural attenuation to succeed than do sites contaminated with gasoline. For example, successful biodegradation of gasoline requires an ample supply of electron acceptors in the aquifer, whereas chlorinated-solvent biodegradation requires electron donors and depletion of natural electron acceptors. Nevertheless, the general approaches to site assessment are similar and include: (1) characterizing site hydrology, (2) demonstrating that natural biodegradation has occurred, (3) characterizing the site geochemistry, (4) confirming that microorganisms at the site have the potential to transform the contaminant under expected site conditions, (5) documenting a decrease in contaminant concentration at the site, and (6) ensuring that target receptors are safe from contaminants.

The U.S. Geological Survey, in cooperation with the Tennessee Department of Environment and Conservation, is drafting preliminary guidelines for evaluating the suitability of natural attenuation at sites contaminated with chlorinated solvents. The preliminary guidelines are being tested at several sites in Tennessee.

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**REPORT OF A SUCCESSFUL DYE TRACE
ALONG CHESTNUT RIDGE, OAK RIDGE RESERVATION,
OAK RIDGE, TENNESSEE**

Robert C. Benfield¹,

Donald F. Gilmore,

Sidney W. Jones,

and

Jack D. Wheat²

The Chestnut Ridge East Borrow Area (CREBA) study was initiated to locate groundwater exit pathways across the eastern boundaries of the DOE Oak Ridge Reservation (ORR) and to improve the conceptual model of groundwater flow and contaminant migration in the Knox aquifer under Chestnut Ridge. An effort was made to find the source for suspended sediments which emerged after storm events from a contaminated spring (called "Bootlegger" Spring because of its history) located east of Scarboro Creek in the University of Tennessee Arboretum in Oak Ridge. Recently formed swallets created by soil piping next to bedrock pinnacles were discovered in a large unreclaimed borrow on the ORR approximately 100 meters west of Scarboro Road. The largest of these swallets was used as the point of dye introduction.

Rhodamine WT (Acid Red 338) was selected as the tracing agent after a study to determine background fluorescence and a review of commercially available dyes. Twenty springs, four surface water locations, and one groundwater monitoring well were sampled for dye using charcoal packets as dye accumulators and occasional water samples. In addition, Bootlegger spring water was sampled for dye with a much greater frequency to provide the basis for estimating dye recovery. Quantitative tracing results at Bootlegger spring were desirable because:

- 1) Sampling data and sediment discharge during storms had already identified this spring as the most important discharge from the area on Chestnut Ridge near the CREBA,

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- 2) Accurate estimates of travel time and dye recovery were important to establishing a better conceptual model, and
- 3) Although Rhodamine WT was not found during background studies at any sampling location, past tracer studies and a sewer line leak had resulted in the introduction of large quantities of several dyes commonly used for tracer studies, including Rhodamine WT, into the groundwater in the general area of the trace, and dye recovery curves were considered to be more conclusive proof of a positive trace than accumulation of dye on charcoal.

The dye trace was initiated at 8:20 AM on June 1, 1995 with the introduction of two liters of 20% by weight dye in aqueous solution and approximately 3000 gallons of deionized water. Bootlegger spring water was continuously monitored with a filter fluorometer until June 4 with no definitive detection of dye. Charcoal detectors were exchanged weekly in all of the monitoring locations. The charcoal detector retrieved from Bootlegger Spring on June 6, 1995 tested positive for Rhodamine WT, as did all charcoal packets subsequently retrieved this location. Water samples taken at Bootlegger Spring and at all other monitoring locations continued to yield negative results for dye until June 21, after approximately three quarters of an inch of rain fell between 2 PM and 4 PM. From June 21 to June 24, dye in water samples taken from Bootlegger Spring was recovered in concentrations that could be quantitatively measured on the filter fluorometer.

Throughout the duration of the study, an intense thunderstorm of sufficient magnitude would be followed six to eight hours later by the appearance of muddy water and elevated levels of fluorescence in Bootlegger Spring. Both suspended solids and dye concentrations would reach peak values 8 to 12 hours after the recharge event. Rhodamine WT levels in the spring water were correlated with precipitation over the duration of the study. The rainfall event on September 16-17, 1995 occurred in two peaks, the first between 6:00 p.m. and 7:00 p.m. on the 16th, and the second between 2:00 a.m. and 3:00 a.m. on the 17th. The dye recovery curve displayed similar maxima separated by the same 7-8 hour interval as the peaks in precipitation. Dye recovery at Bootlegger Spring appeared to be correlated with the flushing of suspended matter through the system and to increase with more intense rainfall and wetter antecedent conditions as well as total precipitation.

Closure of the swallet was initiated on September 22, 1995 by DOE and dye recovery on charcoal packets at Bootlegger spring declined throughout the fall of 1995. The dye was no longer detectable by either the filter fluorometer or spectro-fluorophotometer in water samples during October, 1995, even after the rain event of October 5, when the maximum daily precipitation that occurred over the entire duration of the test was recorded by the National Oceanic and Atmospheric Administration station in Oak Ridge. Suspended solids continued to be observed at the spring after rains in October, but at significantly lower concentrations than those measured prior to the closure of the swallet.

Total dye recovery estimates for the duration of the study were not calculated, since dye recovery curves were not available for at least one major storm event, and dye concentrations between

storm events were often below the resolution of the filter fluorometer. However, dye recovery curves after storm events and flow estimates were used to estimate qualitative dye recovery due to single recharge events. For these purposes, Bootlegger Spring flow was taken to be 75 gallons per minute, as estimated using a turbine flow meter near the time of the closure of the swallet. Dye recovery for the rainfall events of June 21 and August 1 was calculated to be 0.4 and 0.25 grams of Rhodamine WT respectively. Duration of dye recovery and peak dye concentrations were similar in four subsequent recovery events, so the percent dye recovery at Bootlegger Spring resulting from a typical summer storm was about 0.1 % of the total dye injected. Dye recovery is usually greater at higher stage, so larger percentages would be anticipated if the test had been run in the winter under wetter conditions, rather than during a dry summer.

In conclusion, this study provides evidence of groundwater flow at velocities in excess of a kilometer per day along strike under Chestnut Ridge from the Y-12 plant to Bootlegger Spring on Scarboro Creek. In addition, sampling indicates contaminant migration from the Chestnut Ridge Security Pits disposal area to Bootlegger Spring. Hence, the groundwater contamination from DOE sources extends off-site and farther to the east under Chestnut Ridge than has been reported to date. Failure to detect Rhodamine WT at springs in Union Valley adjacent to Chestnut Ridge indicates that under low flow conditions, minimal mixing occurs between contaminated groundwater migrating through the Maynardville limestone in Union Valley and that migrating in the Knox dolomite under Chestnut Ridge. Currently, Bootlegger Spring represents the most distant known discharge point of this impacted groundwater and should be included in any program designed to monitor changes in the primary and secondary sources of volatile organic compounds that persist at or near the Chestnut Ridge Security Pits.

Conceptual models of contaminant transport along strike in the Knox must be able to accommodate both the rapid groundwater velocities and low dye recoveries seen in this study. The results of this study indicate that much the source mass may be retarded or retained in the deep vadose zone on Chestnut Ridge, even when dye is injected directly into a swallet. Significant releases from this vadose zone trap can nevertheless result during recharge events, and dye recovery may have been much greater if the test had been run under wetter, high stage conditions. Dye recovery dropped dramatically after closure of the swallet, indicating that in some circumstances, contaminated leachate from buried waste on Chestnut Ridge could experience considerable attenuation by isolation of the waste from recharge.

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SESSION 2-B

SURFACE WATER MODELING #1

8:30-10:00

S. Marshall Adams, K.D. Ham, M.S. Greeley, C.F. Saylor, *Downstream Effects of Paper Mill Effluents on the Ecological Health of the Pigeon River (NC/TN).*

Dennis M. Borders, *Soluble Contaminant Concentration Versus Discharge Relationships for Remediation Performance Assessment at an Oak Ridge National Laboratory Waste Site.*

Douglas A. Hopper, Bernard J. Frederick, Dennis M. Borders, Bradley A. Bryan, *State-Discharge Rating Development for White Oak Dam at Oak Ridge National Laboratory Using an Acoustic Velocity Meter.*

Shabbir Ahmed, Michael A. Eiffe, Mary C. Halley, *Development of a Two-Dimensional Kinematic Wave (2DWAVE) Flow Routing Model.*

SURFACE WATER MODELING #2

10:30-12:00

Katherine F. Lindquist, Paul N. Hopping, Paul J. Wolff, *Strategies to Meet Regulatory Water Temperature Criteria and Minimize Power Generation Losses.*

Charlie Irwin, *Hydrographic Surveying Using GPS.*

Este F. Hollyday, James J. Farmer, Tom D. Byl, *Water-Quality, Discharge, and Biologic Data for Watershed-Based Water Quality Data for Watershed-Based Water-Quality Mangement: An Example from Bedford County, Tennessee.*

Clell J. Ford, *Surface Sediments "Cleaned" by Remediation Project: White Oak Creek Embayment Revisited.*

Cont.

**DOWNSTREAM EFFECTS OF PAPER MILL EFFLUENTS
ON THE ECOLOGICAL HEALTH
OF THE PIGEON RIVER (NC/TN)**

S. Marshall Adams¹,

K.D. Ham,

M.S. Greeley,

and

C.F. Saylor²

The Pigeon River in Western North Carolina and Eastern Tennessee has been significantly degraded since 1908 by effluent discharges from the Canton Paper Mill at Pigeon River kilometer (PRK) 102 and further influenced since 1930 by impoundment for hydroelectric power generation at PRK 61. To determine the effect of these effluent discharges and modifications on the ecological condition of the river, a suite of bioindicators ranging from the biochemical and physiological level to the community-levels of biological organization were measured on fish populations and communities downstream of the paper mill. Downstream gradients in responses were evident in elevated hepatic mixed-function oxygenase activity, several measures of condition and bioenergetic status, growth, the health assessment index, and several fish community-level parameters. A multivariate discriminant analysis procedure, which included many of the individual bioindicators, also demonstrated a gradient in integrated health status of a sentinel fish species in the contaminated river. The relationship between biological effects and contaminant exposure is particularly convincing because of the known gradient in paper mill-related contaminants such as dioxin in the river and the gradient in chlorophenolic metabolites in bile of fish downstream of the mill. These downstream response gradients were probably influenced to a greater degree by contaminant discharges than by natural or anthropogenic nutrient sources downstream. Establishing causal relationships between a specific contaminant source and responses in sentinel aquatic organisms becomes relatively more straightforward when downstream gradients in biological responses are observed at multiple levels of biological organization.

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**SOLUBLE CONTAMINANT CONCENTRATION
VERSUS DISCHARGE RELATIONSHIPS
FOR REMEDIATION PERFORMANCE ASSESSMENT
AT AN OAK RIDGE NATIONAL LABORATORY
WASTE DISPOSAL SITE**

Dennis M. Borders¹

ABSTRACT

Baseline monitoring of soluble contaminant releases from the Solid Waste Storage Area (SWSA) 4 waste disposal site at the Oak Ridge National Laboratory (ORNL) has been completed. A primary objective was to support the evaluation and verification of the effectiveness of remedial actions by establishing baseline characterizations of contaminant transport in the tributary draining this waste site. There are reproducible relationships ($C=aQ^{-b}$, where $0 \leq b \leq 1$) between concentration (C) of soluble contaminants (e.g., ⁹⁰Sr) and discharge (Q) in surface streams that receive contamination from uncontrolled waste sources. These relationships can be determined by collecting water quality samples over a wide range of flow conditions. After determining and verifying these relationships, contaminant mass flux from surface streams can be estimated by measuring discharge only. Characterization of the C-Q relationships, if developed before and after remediation activities, can be used to evaluate the effectiveness of remedial methods to reduce contaminant fluxes. Comparing C-Q relationships before and after remediation tends to remove climatic influence because the analyses are largely independent of individual storms. In the summer and fall of 1996, four waste disposal trenches, identified by site investigation activities as contributors of approximately 70% of all ⁹⁰Sr releases from SWSA 4, were subjected to multi-grout source stabilization using low-pressure permeation grouting to achieve physical and chemical binding of the wastes and to reduce ⁹⁰Sr releases to the surface-water system. Post-remediation characterization will begin in the winter wet season with the pre-remediation characterization serving as the performance assessment model. Results from a previously remediated site indicate that this method provides a relatively quick indication of improvement as opposed to monitoring groundwater which may not show significant improvement for years.

INTRODUCTION

Surface water is the ultimate receptor of the majority of contaminant releases from waste sources in the White Oak Creek (WOC) watershed at ORNL and the primary pathway for contaminant transport and migration to the off-site environment. The vast majority of groundwater travels to nearby streams through the shallow groundwater zone in the WOC watershed. Therefore, nearly

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all contaminated groundwater from waste areas is discharged to local tributaries (Solomon et al. 1992). These tributaries can serve as integrators of contaminant releases from their respective subbasins and can be used to identify and quantify sources of contaminant input to the ORNL surface-water system.

Between 1951 and 1959, SWSA 4 was used as a disposal site for low-level radioactive waste at ORNL (Melroy and Huff, 1985). The wastes were disposed of in unlined trenches and auger holes. Cowser et al. (1961) reported that groundwater came in contact with the radioactive wastes, and that contamination could be detected in area wells and seeps at the time disposal operations ceased in 1959. Therefore, contamination, notably ^3H and ^{90}Sr , has been leaching out of the SWSA 4 disposal area into the WOC surface-water system for at least 37 years.

A monitoring program was initiated in 1992 to characterize contaminant transport mechanisms in tributaries, including the tributary draining SWSA 4, responsible for significant contaminant fluxes to WOC. Accurate contaminant flux determinations are necessary to evaluate potential risk to the public and to evaluate mitigative measures aimed at reducing contaminant mass flux. In addition, determination of the individual contribution to total off-site releases is important in order to prioritize sites for future remediation. The tributary draining the waste disposal areas in SWSA 4 was included in this program.

CONCEPTUAL MODEL OF TRIBUTARY DISCHARGES

The conceptual model of tributaries that drain waste disposal areas into the main streams at ORNL is presented in Figure 1 (Clapp and Watts, 1993). Soluble contaminants migrate from buried waste trenches to surface streams via subsurface flow paths. Three regimes or components of streamflow can be defined for surface streams. Under baseflow (1) conditions, streamflow is generated entirely from groundwater contributions (primarily from the shallow water table interval). During moderate precipitation events, rainwater infiltrates the surface soil layer and reaches the stream via the shallow subsurface stormflow zone (lateral flow in the upper 2 m of the soil) (2). During extreme storm events, the precipitation rate exceeds the capacity of the surface soil layer to infiltrate rainwater, and overland flow (3) occurs.

The three flow regimes define the conditions that transport contaminants into tributaries and their subsequent release to the off-site environment. Under baseflow conditions, tributary discharge, contaminant concentration, and contaminant flux are relatively constant. As precipitation begins, increased flow mobilizes contaminants by subsurface pathways causing partial dilution. Therefore, as discharge increases, concentration decreases while contaminant flux increases, up to a certain point. After that point, when overland flow is generated and discharge increases further, there is essentially complete dilution from uncontaminated surface runoff. Concentration decreases significantly while flux remains nearly constant because no further contaminants are being mobilized. As the precipitation event ends and discharge begins to recede, the flow regimes succeed in the reverse order, returning the tributary back to baseflow conditions and steady-state parameters.

Contaminant concentration (C) can be plotted against discharge (Q) on a logarithmic scale (Figure 2). This allows the relationships representing the three flow regimes to be plotted as straight lines. For ORNL tributaries receiving soluble contaminant releases from uncontrolled waste sources, the C-Q relationships ($C=aQ^{-b}$, where $0 \leq b \leq 1$) are reproducible and can be defined as follows: a) under baseflow conditions concentration is nearly constant ($b \approx 0$), b) increased flow mobilizes contaminants by subsurface pathways ($b < 1$) under wet conditions, up to a certain point, causing partial dilution, and c) after that point there is essentially complete dilution ($b \approx 1$) from uncontaminated surface runoff. These relationships can be determined by collecting discrete water quality samples over a wide range of streamflow conditions.

HISTORICAL BASIS FOR C-Q EVALUATION

In 1987, multiple discrete water quality samples were collected from a tributary draining a portion of SWSA 6 in the WOC watershed (Clapp 1992). Samples were analyzed for ^3H , a soluble contaminant released from waste trenches into the SWSA 6 tributary. In addition, continuous discharge measurements were made to support the development of the C-Q relationship for ^3H . Figure 3 shows the data for site MS2 plotted as lines A and B, corresponding approximately to the relationships for partial dilution and complete dilution, respectively.

In 1989, an interim corrective measure (ICM) was completed in WAG 6 (SAIC, 1993) in an effort to limit the migration of contaminants to the off-site environment. The ICM consisted of the installation of approximately 4.2 hectares (10.4 acres) of plastic membrane caps over the waste trenches to enhance hydrologic isolation of buried hazardous wastes. The goal was to reduce the total mass flux of contaminants from SWSA 6 by limiting the transport and migration of contaminants to the surface-water system.

In 1990, surface-water sampling was reinitiated on the SWSA 6 tributary. Again, discrete water quality samples were collected over a wide range of discharge conditions and samples were analyzed for radionuclides, including ^3H . Line C in Figure 3 shows the C-Q relationship for ^3H at the SWSA 6 MS2 monitoring station based on the data collected in 1990. The fitted curve is parallel to and lies below line B from the 1987 data.

The 1987 C-Q data can be divided into two flow regimes. The slope of line A (the b exponent in the equation $C=aQ^{-b}$) is less than 1, which suggests that with increased flow, increased mobilization of contaminants is occurring. Hence, ^3H flux is increasing with discharge. The slope of line B (b exponent) is approximately 1, which conforms to the complete dilution model. The two line segments, representing the 1987 data, before the installation of the ICM, conform to the conceptual model of tributaries draining uncontrolled waste sources. The three flow regimes are represented, although there is uncertainty regarding the baseflow component due to lack of data, and ^3H flux at MS2 is controlled by subsurface pathways that mobilize contaminants until complete dilution occurs from uncontaminated surface runoff.

The 1990 C-Q data, collected after the ICM caps were installed, indicate different behavior. Line C, in addition to being downwardly displaced from line B, has a slope (b exponent) of approximately 1. There appears to be an absence of the relationship representing partial dilution; that which would correspond (b exponent) to line A. In 1990, the ^3H concentration appears to be dominated by dilution from uncontaminated runoff, presumably largely attributable to runoff from the caps. Mass flux over the range of measured flows remains nearly constant. The downward displacement of the relationship from line B to line C represents a reduction in concentration by a factor of approximately 2. The outliers in the 1990 data suggested a need for more sampling to resolve the uncertainty. However, the change between the pre-cap and post-cap data is deemed to represent a significant change in the ^3H mass flux relationship attributable to the ICM remedial action.

PERFORMANCE ASSESSMENT MODEL

Baseline monitoring of soluble contaminant releases from the SWSA 4 waste disposal site at ORNL has been completed. An important objective of the tributary monitoring and characterization program was to support the evaluation and verification of the effectiveness of future remedial actions by establishing baseline characterizations of contaminant transport from key tributaries draining waste disposal sites at ORNL. The characterization of C-Q relationships, if developed before and after remediation activities, can be used to evaluate the effectiveness of remedial methods to reduce contaminant fluxes. The C-Q relationship provides a time-independent measure of release conditions that can be readily compared to results of previous or future characterizations. The comparison of pre- and post-remediation C-Q relationships tends to remove the climatic influence because the relationships incorporate variations caused by changes in meteorological conditions and individual storms. Therefore, this method is intended to provide an immediately useful indication of whether remediation has been effective, and a relative measure of effectiveness, as opposed to observing groundwater conditions that may not show significant changes for decades.

In order to provide a relatively simple "model" for comparison to future (post-remediation) conditions, ideally, a single C-Q relationship would be developed for a contaminant at a given site. Such was the case for the SWSA 6 site discussed previously. However, for site MS1 in SWSA 4, C-Q relationships for individual storms, for both ^{90}Sr and ^3H , show distinct and significant seasonal differences. Systematic changes, due to hydrologic influences, occur between storms where concentrations during the wet season are greater than those during the dry season for a given discharge. However, there is more variability in the ^3H data than in the ^{90}Sr data and the timing of the cycle is different for the two radionuclides. Tritium concentrations are highest in the early wet season but decrease relatively rapidly through the course of the wet season into the early dry season as the source is depleted. Concentrations begin rising again during the dry season when the source is not being depleted by precipitation generated processes. The source is replenished during the dry season. Strontium-90, on the other hand, appears to be available according to how wet the system is, perhaps because during the wet season the source has greater contact with groundwater and therefore greater availability. The ^{90}Sr source does not

appear to be depleted and replenished in an annual cycle because the concentration remains nearly steady over the course of the wet season.

The difference between the annual response cycle of ^3H and that of ^{90}Sr reflects the dominant mechanisms of transport for each. The transport of ^3H , a purely soluble contaminant, is dominated by diffusion, whereas for ^{90}Sr , a contaminant whose chemical characteristics make it subject to dissolution, transport is likely to be dominated by sorption-desorption processes. In addition, evidence suggests that the two contaminants originate from different sources.

The simplified model chosen to represent response for ^{90}Sr at MS1 is composed of wet (winter) season and dry (summer) season relationships. Figure 4 presents the dual-curve C-Q performance assessment model for ^{90}Sr at MS1. It was developed by combining sample results from seasonal storms (in each case) and fitting C-Q curves to the data. The individual storm C-Q relationships for ^{90}Sr at MS1 show less uncertainty (lower 95% confidence limits) and greater seasonal stability than for ^3H . Therefore, expected reproducibility and confidence in the use of a dual-curve performance assessment model for ^{90}Sr at MS1 is relatively high.

CONCLUSIONS

A site investigation at SWSA 4 identified four trenches that appear to contribute approximately 70% of the ^{90}Sr being released from SWSA 4. Relationships between discharge and concentration, stream transect sampling, continuous discharge measurements, and direct observations of contaminants in trench water (from drivepoints) were used to quantify releases from specific seep areas and identify the primary source area targets. During the summer and fall of 1996, multi-grout source stabilization inside the target trenches was completed using low-pressure permeation grouting. The objective of the source grouting was to chemically and physically isolate contaminants (^{90}Sr) in the source trenches from hydrologic transport mechanisms. Ultimately, the success of the source stabilization (remedial action) will be determined by demonstrating significant reductions in the release of ^{90}Sr from SWSA 4.

To estimate and illustrate the degree of improvement that must be achieved in order to show a statistically significant reduction in fluxes, potential sources of error (uncertainty) must be considered. The 95% confidence interval (error bars) must be calculated for each of the seasonal performance assessment C-Q models and for each individual C-Q relationship developed for post-remediation conditions. The uncertainty analysis will be utilized to determine the approximate reductions in concentrations, and hence flux, required of the remedial action to indicate statistically significant improvement. The relative flux of a given storm (post-remediation) must be less than the lower limit of uncertainty on the appropriate performance assessment model. In addition, a comprehensive statistical evaluation of the factors contributing to uncertainty can be utilized to estimate the level of effectiveness (reduction in flux) of the remedial action at various post-remediation periods.

Baseline characterization of contaminant transport from the SWSA 4 tributary clearly shows the partial dilution of soluble contaminants that occurs during storms; that is, reduced concentration but increased flux of contaminants that occurs in surface streams as discharge increases during precipitation-generated runoff events. In addition, the data show seasonal changes from storm to storm, where concentrations during the wet season are generally higher than those during the dry season. Post-remediation sampling will commence with the onset of the 1996/97 wet season. In order for the post-remediation results to be comparable to the pre-remediation performance assessment characterization, multiple discrete samples must be collected over a wide range of discharge conditions. In addition, multiple storm events must be characterized to identify the seasonal variations in the C-Q relationships, or the lack thereof. Possible remediation impacts include the abatement of the post-remediation C-Q model to a single dry season-type model with reduced fluxes primarily in the wet season, when the majority of contaminants have historically been released from SWSA 4.

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Discharge and Soluble Contaminant Fluxes Draining ORNL Disposal Sites

Hydrologic components:

Baseflow - Lateral flow at the water table interval plus minor groundwater from the intermediate interval

Subsurface Stormflow - Lateral flow in upper 2 meters of soil

Overland Flow - Surface runoff from contributing areas, typically uncontaminated

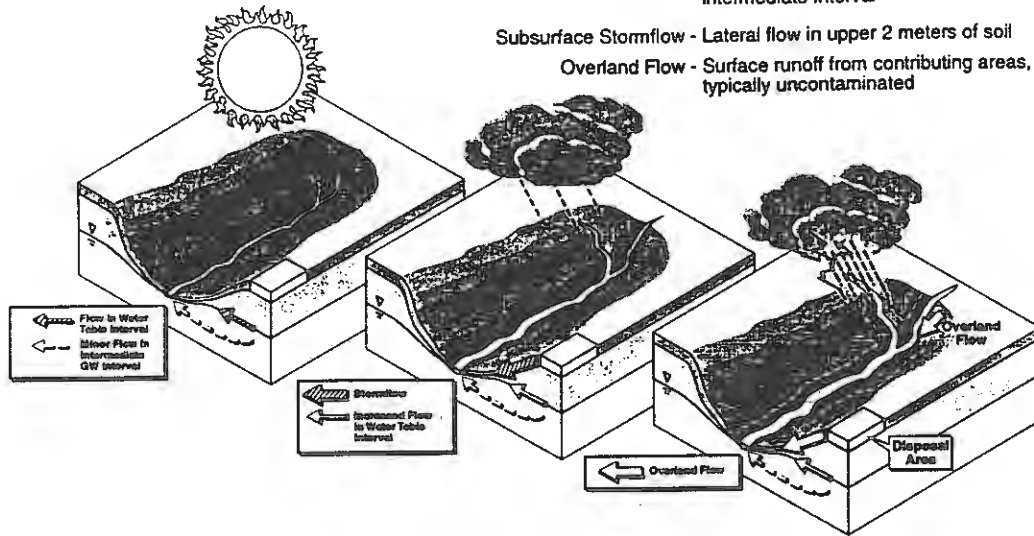


Figure 1. Conceptual model for tributaries draining ORNL waste disposal sites.

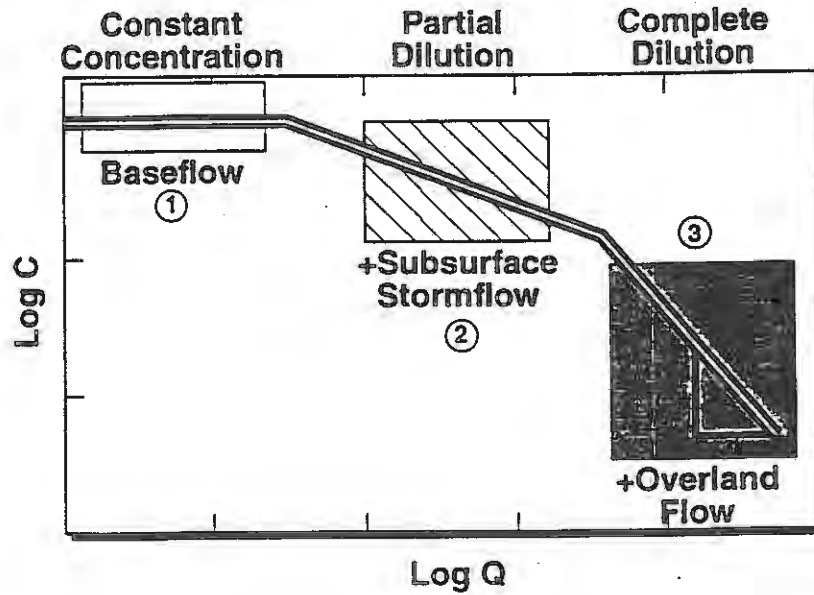


Figure 2. Contaminant concentration (C) versus Discharge (Q). Numbers refer to the flow regimes in text.

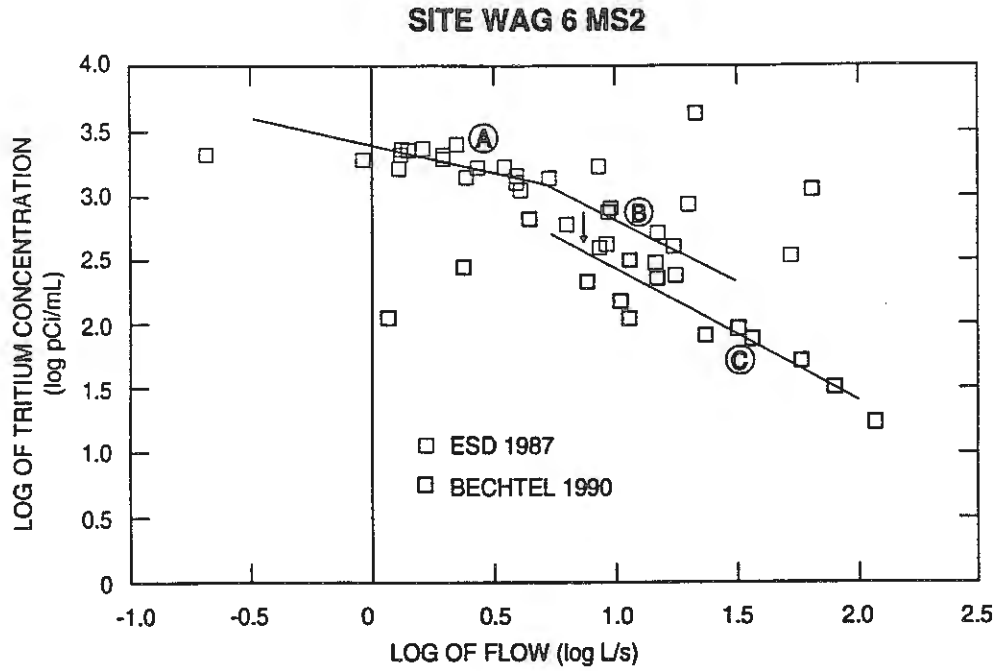


Figure 3. SWSA 6 site MS2 ³H concentration (C) versus Discharge (Q) plots.

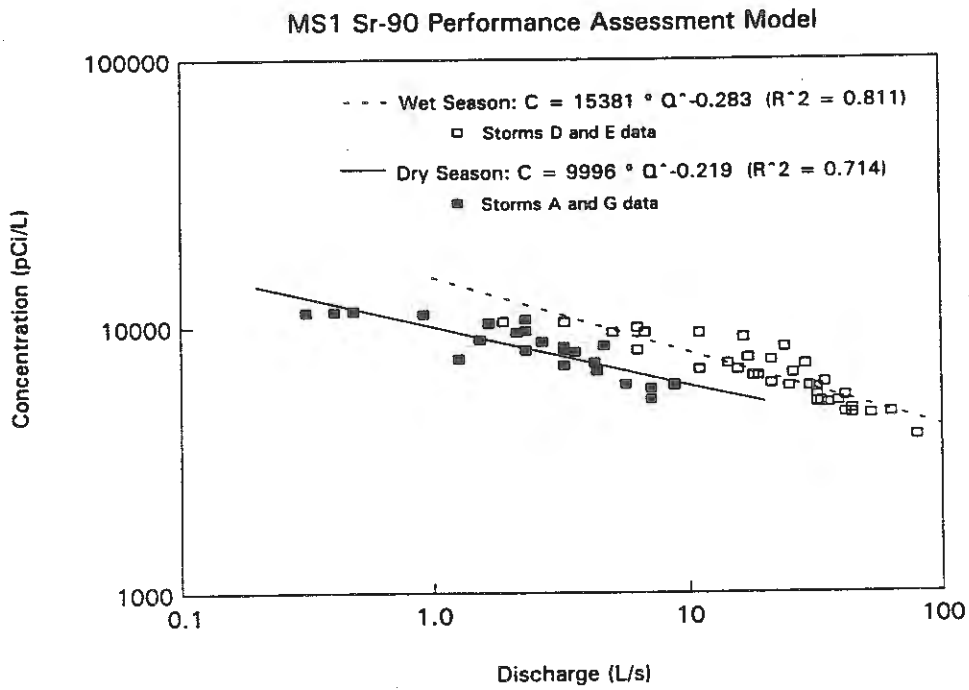


Figure 4. Strontium-90 performance assessment model for SWSA 4 site MS1.

**STAGE-DISCHARGE RATING DEVELOPMENT FOR WHITE OAK DAM
AT OAK RIDGE NATIONAL LABORATORY
USING AN ACOUSTIC VELOCITY METER**

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and

Bradley A. Bryan⁴

ABSTRACT

White Oak Dam (WOD) is the final controlled point of release of water-borne contaminants from Oak Ridge National Laboratory (ORNL). As an indicator of programmatic success, the Environmental Restoration Program tracks reduction in releases at WOD. Therefore, accurate discharge records are essential in order to quantify individual contaminant sources within the watershed and prioritize them for future remediation. Since the completion of the dam upgrade in 1983, discharge through the dam has been determined from stage-discharge relationships for a trapezoidal weir (low flows) and a triangular broad-crested weir (high flows). The rating for the trapezoidal weir is well established for free flow conditions. However, the rating for the broad-crested weir, which was based on a scale model rating, had never been verified. The purpose of this paper is to present how the model rating and the recently revised rating were developed and to discuss how the revised rating has improved contaminant mass and water balance calculations within the watershed.

INTRODUCTION

White Oak Creek (WOC) is the principal carrier of precipitation runoff, process releases, and

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leachate from buried waste in the Oak Ridge National Laboratory (ORNL) area. State Highway 95 crosses the creek approximately 1 km (0.6 mi) upstream from the mouth of the creek at its confluence with the Clinch River. During road improvement work in 1941, the road surface was raised, and a concrete box culvert was installed under the road to carry the creek flow. In 1943, when generation of radioactive waste began at ORNL, a sheet pile dam and a vertical sliding gate, to assist in regulating flow in the creek, were installed directly upstream from the road culvert, creating what is known as White Oak Lake (WOL). From 1943 to 1983, the WOL outlet consisted of this simple configuration, although in 1959 the gate structure was renovated to prevent inflow of backwater from the Clinch River.

The present dam structure and outlet, completed in 1983, consists of two vertical gates at the entrance to the discharge channel, a broad-crested triangular weir, and a sharp-crested trapezoidal weir. Figure 1 shows the location of WOD on the WOC watershed. Since completion of the 1983 upgrade, flow from the lake has been determined from stage-discharge relationships for the two weirs. The trapezoidal weir has been utilized for flows less than 14.6 cubic feet per second (cfs), the capacity of the weir, and the broad-crested triangular weir has been used for flows greater than 14.6 cfs. The rating for the trapezoidal weir was determined from on-site volumetric measurements in 1984-85, and is well established and reliable for free-flow (i.e., non-submergence) conditions. The rating for the broad-crested triangular weir was based on the rating of a scale model of the weir. Field verification of the high-flow weir rating was not done prior to 1995 because conventional methods, including standard Price-type current meters, were inappropriate due to the configuration of the hydraulic control structures and prohibitively low velocities, both upstream and downstream from the weir, under a significant range of flow conditions.

In April 1992, a sediment retention structure (SRS), a permeable gabion dam, was constructed downstream from WOD at the mouth of WOC (Borders et al., 1992). The structure has resulted in higher water surface elevations that impact the performance of the WOD trapezoidal weir. The elevated water levels have caused the trapezoidal weir to be submerged to some degree most of the time, rather than for infrequent, short periods as occurred prior to the construction of the SRS. Therefore, more computational adjustments to the low-flow record were required. Since the computational adjustments are theoretical in nature (not field tested), the uncertainty of low-flow discharge records was increasing. Flow through the broad-crested weir is also affected infrequently by submergence, but if the submergence does not exceed 80%, the effect is insignificant. When submergence exceeds 80%, a drowned-flow reduction factor (Bos, 1990) is applied. The reduced performance of the trapezoidal weir, together with the need for field verification of the WOD rating at high flows, prompted the effort to collect the field discharge measurements to allow revision and improvement of the rating.

DEVELOPMENT OF MODEL RATING

The original stage-discharge relationship for the broad-crested weir was developed from a scale model test conducted by Alden Research Laboratory (ARL) (White and Larsen, 1981). The weir was calibrated for flows ranging from 40 to 2000 cfs utilizing a 1:8 scale model. Flows less than 40 cfs

were not tested because of scale effects, which introduce errors estimated to be on the order of 5-8%. The model calibration resulted in a single power curve relationship, $Q = 6.2 * H^{2.63}$, where Q is discharge in cfs and H is head over the broad crest in feet. The model rating differs significantly with respect to the new rating, as described in the following section. Among factors likely to be responsible for the difference is the configuration of the approach channel. The model approach channel featured an abrupt 45° change (turn) in alignment approximately 60 feet (equivalent) upstream from the broad-crested weir. This caused the flow approaching the weir to be skewed and could have a significant effect on head measurement, particularly at high flows. The approach channel, as constructed, is straight and uniform with no turns. Another factor potentially contributing to the difference between the model and new rating was high approach velocities induced by limited cross-sectional channel area in the model. Velocity effects become more pronounced at high flows, resulting in over-estimation of discharge. A later evaluation of the ARL model study (Chaudhry and Lin, 1981) recommended increasing the approach channel depth to decrease the velocity of approach.

DEVELOPMENT OF REVISED RATING

In 1993, the U.S. Geological Survey (USGS), Knoxville Office, obtained a Neil Brown acoustic velocity meter from the Altamonte Springs, Florida, USGS office for the purpose of field rating a number of unconventional sites at ORNL, including WOD. The Neil Brown meter was chosen because it provides reliable velocity measurements down to 0.1 foot per second and also compensates for non-horizontal water movement. In 1995, the USGS made multiple discharge measurements at WOD. Some were made with the Neil Brown meter lowered into the discharge channel between the upstream face of the broad-crested weir and the gates used to regulate outflow from WOL, and some were made with a standard current meter in the throat of the weir. It was determined that the current meter measurement location was inappropriate and produced unreliable results; therefore, it was abandoned.

Five discharge measurements ranging from 52.6 cfs to 193 cfs were made at WOD with the Neil Brown meter between May 3 and November 3, 1995. No measurements in this discharge range had been made previously. These measurements, together with free-flow discharges from the field-rated trapezoidal weir and a stage-stage relationship between the trapezoidal weir pool and the broad-crested weir pool, were used to develop a new stage-discharge relationship based on the stage for the broad-crested weir. This stage-discharge relationship can be used for the entire range of free-flow discharges at WOD. Comparison of discharge obtained from the trapezoidal weir rating and the new broad-crested weir rating for ten discharges between 0.2 cfs and 14.6 cfs showed an average difference of less than 1% and a maximum difference of less than 5%.

The stage-discharge relationship for the new WOD rating can be defined mathematically by a series of four equations relating stage (H), in feet (for the broad-crested triangular weir), to discharge (Q), in cfs. The four equations are as follows:

$$Q = 7.462 * H^{2.304} \quad \text{for } H = 0 \text{ to } 1.34,$$

$$\begin{aligned}
 Q &= 6.451 * H^{2.801} && \text{for } H = 1.35 \text{ to } 2.50, \\
 Q &= 9.781 * H^{2.347} && \text{for } H = 2.51 \text{ to } 4.30, \text{ and} \\
 Q &= 9.597 * H^{2.360} && \text{for } H = 4.31 \text{ to } 9.00
 \end{aligned}$$

The first equation, for stages (H) from 0 to 1.34 feet, coincides with the trapezoidal weir range of discharges. The intention is to use the trapezoidal weir rating under free-flow conditions, but when it becomes submerged, under applicable flow rates, to use the first broad-crested weir equation in its place. Since the equation is derived from a stage-stage correlation with the trapezoidal weir, the trapezoidal weir is considered to be somewhat more reliable.

Figure 2 presents a graphical comparison of the 1996 White Oak Dam rating and the previously used model rating. At discharges between 14.6 and 250 cfs, the model rating differs considerably from the new rating. In this range, discharges from the model rating are from 6% to 16% less than the discharge from the new rating. For the five measurements between 52.6 cfs and 193 cfs, made with the Neil Brown meter, the average difference of the new rating from the measurements is +1%, and the maximum difference is +4.9%. The model rating shows an average difference of -12.9% and a maximum difference of -17.1%. Above 250 cfs, the difference in the model rating versus the new rating varies from -6% at 250 cfs, to essentially 0 at 430 cfs, to +17% at 1700 cfs. However, both ratings are of questionable accuracy at discharge greater than 500 cfs (a relatively infrequent occurrence).

CONCLUSIONS

White Oak Dam is the final controlled point of release of water-borne contaminants from ORNL. The Environmental Restoration Program bases a significant measure of programmatic success on the evaluation of reduction in releases at WOD. The performance and impact of individual removal actions in the WOC watershed is verified, in part, by reductions at WOD, and the impact of multiple removal actions in the watershed is quantified at WOD. Therefore, accurate discharge records are critical in order to define and quantify these individual sources and prioritize them for future remediation.

By calculating contaminant flux at WOD and other gauging stations upstream, a mass balance approach is used to identify sources responsible for significant contributions to total contaminant release at WOD. Historically, mass balance calculations at WOD, based on unrevised discharge data generated with the model rating, have indicated a loss of ^3H , a conservative, water soluble contaminant, in the lower WOC/WOL reach. However, there are known sources of ^3H in this reach. Therefore, the mass balance calculations were known to be in error. Mass balance calculations using updated WOD data, based on the new rating, generally indicate a gain of ^3H in this reach. Thus, the new results are consistent with other data and represent a substantial improvement over previously reported results.

Updates to the discharge record at WOD, based on the 1996 rating, have resulted in annual increases in total discharge of approximately 7%. This has improved water balance calculations in the

watershed. For example, with the revised rating, the local inflow to WOL is approximately equal to the inflow to Melton Branch on a per area basis, which is reasonable because they are in the same valley and have similar geology and land cover. Specifically, when averaging the WOL local area inflows (WOD discharge minus the sum of WOC and Melton Branch) from the six wettest months of 1995 (January, February, March, May, November, and December), the ratio (0.72) of this value to Melton Branch discharge is virtually the same as the area ratio (0.72) between the two. This is reasonable for wet months when losses to evapotranspiration and deep groundwater flowpaths are negligible and because each area receives little imported water. Conversely, the water balance calculations with unrevised WOD data (based on the model rating) result in a ratio of WOL local area inflow to Melton Branch discharge, for the same six months, of 0.37. These results also support the mass balance approach previously discussed.

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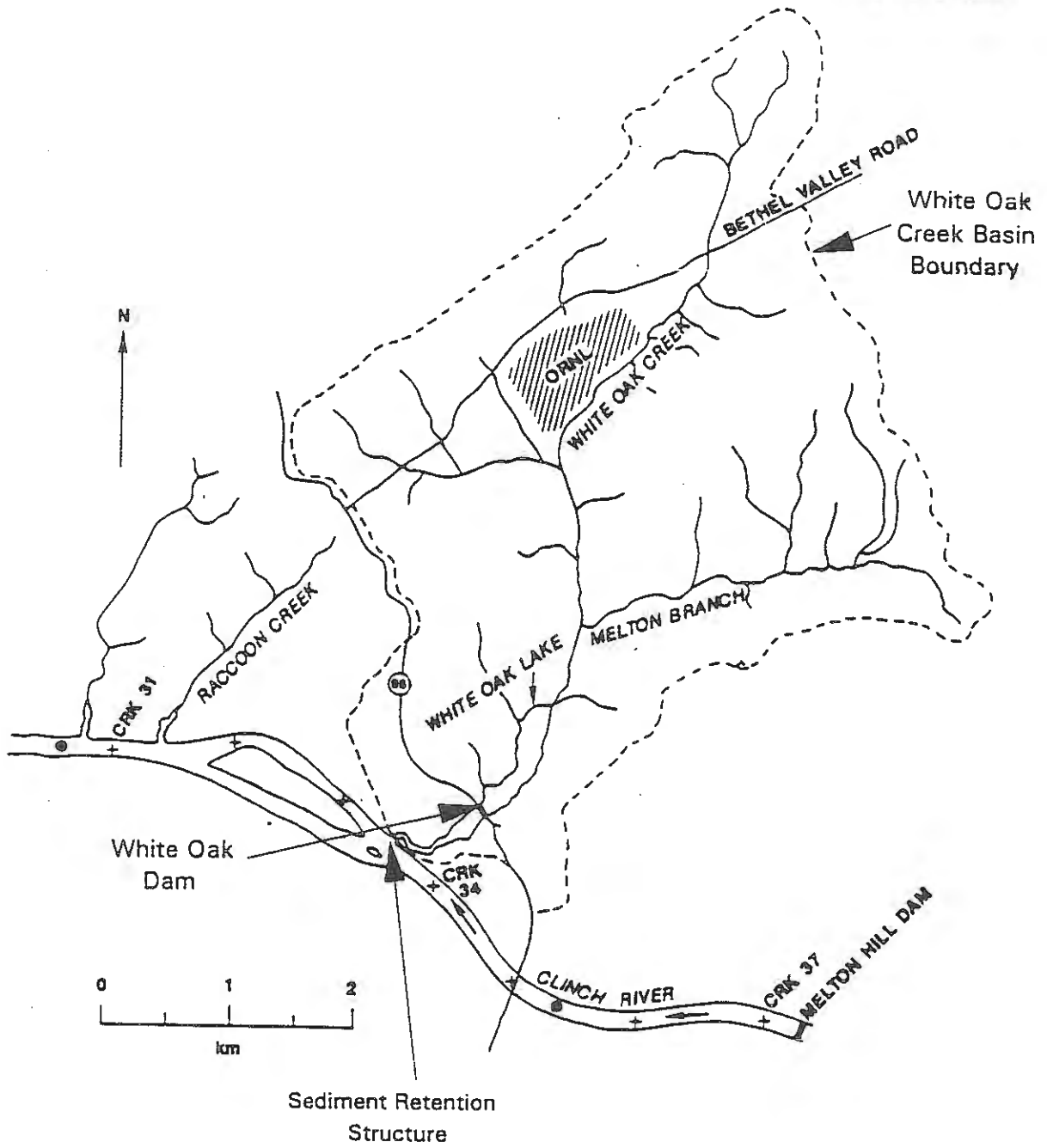


Figure 1. Map of White Oak Creek watershed showing location of White Oak Dam.

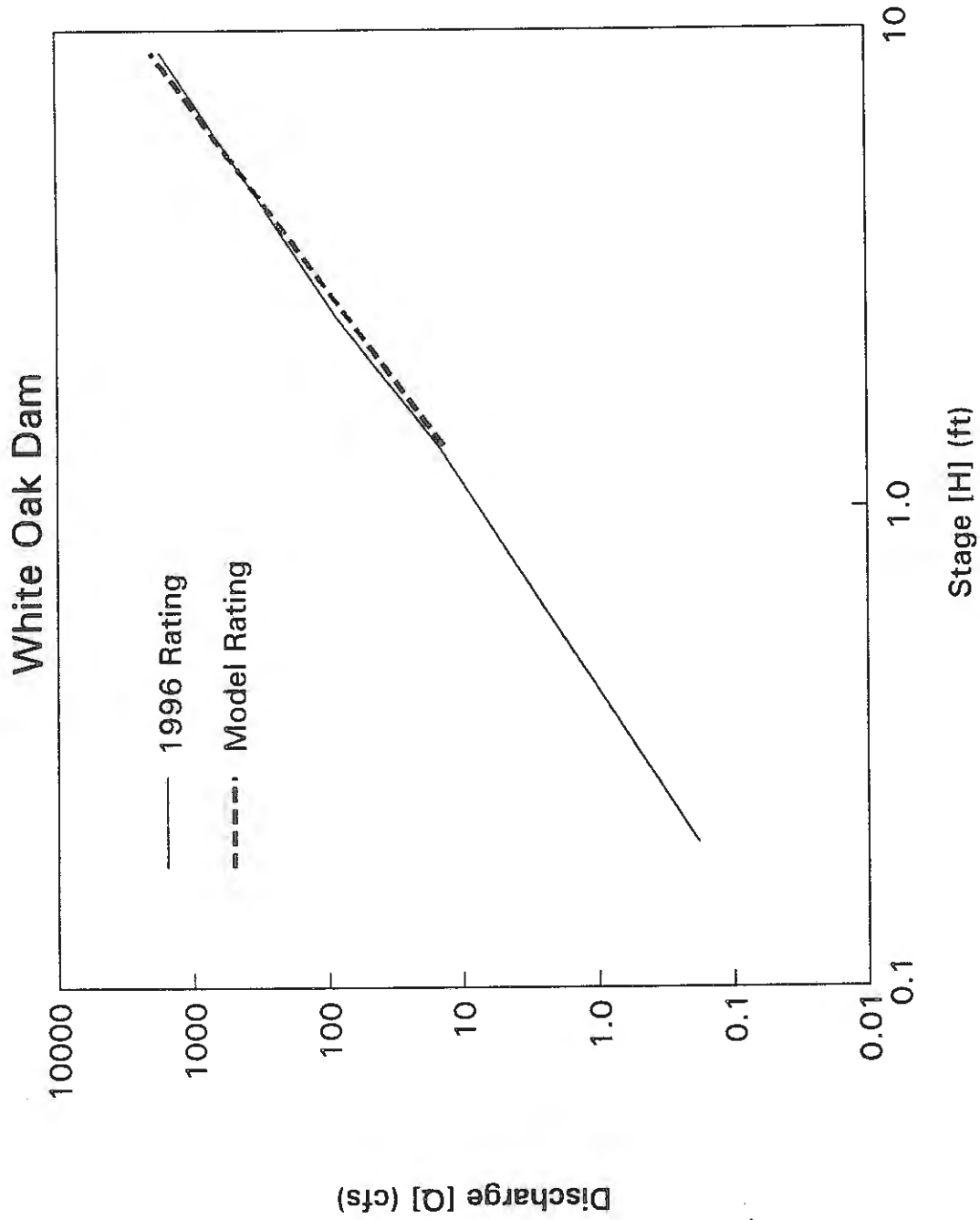


Figure 2. White Oak Dam 1996 rating versus model rating.

**DEVELOPMENT OF A TWO-DIMENSIONAL
KINEMATIC WAVE (2DWAVE)
FLOW ROUTING MODEL**

by

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and

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ABSTRACT

A two-dimensional kinematic wave (2DWAVE) overland flow routing model was developed to investigate the hydrologic response of a drainage area due to rainfall. The two-dimensional form of the kinematic wave equation was solved to compute spatially and temporally varying depth, velocity, and discharge. The model considers spatially varying slope and surface roughness parameters in the kinematic wave solution. The finite-difference numerical technique was used to obtain the algebraic expression for the kinematic wave equation. 2DWAVE model results compared favorably with simulations of one-dimensional flow planes using HEC-1 (developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center) and SWMM (developed by the U.S. Environmental Protection Agency). Finally, the model was applied to determine the flood potential due to the 10,000-year rainfall event for one of the several hexafluoride cylinder storage yards (Yard B) of the K-25 Site of the U.S. Department of Energy, Oak Ridge, Tennessee. The model simulation results included location and magnitude of the highest flood depths and velocities for the cylinder storage yards.

INTRODUCTION

The hydrologic response of drainage areas is generally investigated using currently available rainfall-runoff models such as the Storm Water Management Model (SWMM) developed by Huber and Dickinson (1988), the Hydrologic Engineering Center (HEC-1) flow routing model developed by U.S. Army Corps of Engineers (1990), and the Water Erosion Prediction Project (WEPP) model developed by Laflen and Foster (1991). Simplified hydrologic methods such as Curve Number or Rational Formula are used to understand rainfall-runoff processes. Infiltration

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equations are also used to estimate rainfall excess that can cause surface runoff or overland flow. The currently available overland flow routing models simulate hydrologic processes based on the surface roughness, slope of the area, and infiltration capacity of the surface soil. To avoid complexity in the numerical solution, the models are based on the assumption of one-dimensional flow and are developed by averaging the spatial variations of the characteristics of the drainage areas.

In the 2DWAVE model, the two-dimensional form of the kinematic wave equation was solved for a drainage area. The model considers spatially varying slope and surface roughness in solving the kinematic wave equation. The finite-difference numerical technique was used to obtain an algebraic expression for the partial differential kinematic wave equation. Two methods based on Muskingum-Cunge (Cunge, 1969) and Bras (1990) were employed to obtain the finite-difference expressions for solving the kinematic wave equation. The simulation results included variations of depth and velocity of flows in both space and time on a two-dimensional drainage basin.

THEORETICAL BASIS OF THE 2DWAVE MODEL

The kinematic wave equation is developed using conservation of mass and Manning's equation in a segment of an overland flow field. The one-dimensional form of the kinematic wave equation described by Chow et al. (1988) and Bras (1990) can be extended to two-dimensional form in x,y-coordinates by applying the continuity equation and Manning's formula in both x- and y-direction. The resulting two-dimensional kinematic wave equation for overland flow can be expressed as (Yu and Schwartz, 1995):

$$\frac{\partial h}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = q \quad (1)$$

where,

- Q_x = flow in x-direction;
- Q_y = flow in y-direction;
- h = depth of flow;
- q = rainfall excess for overland flow;
- x,y = space coordinates; and
- t = time.

NUMERICAL SOLUTION SCHEMES

Application of numerical solution techniques convert equation (1) into algebraic equations that can be solved for depth of flow and velocity at finite locations of (x,y) for a finite incremental value of t. In the present model, two finite difference schemes are employed to solve the

kinematic wave equation for overland flow for different Courant conditions. The finite-difference scheme proposed by Cunge (1969) was employed using the Muskingum-Cunge method. The second scheme was based on the finite-difference scheme described by Bras (1990).

MODEL VERIFICATION AND APPLICATION

To establish the credibility of the 2DWAVE model and gain confidence in the application for predictive simulations, it was important to verify the model by comparison with the other widely used and generally accepted models. The models selected for comparison were SWMM and HEC-1. All three models were applied to a test drainage area of rectangular shape, 500 ft by 1000 ft, with a slope of 1 percent across 1,000 ft width and a Manning's roughness coefficient of 0.1. Five different rainfall patterns were used to investigate the model response to time-varying rainfall intensities. The rainfall patterns included a constant rainfall intensity of three inches/hr with a total rainfall of three inches in one hour; a triangular distribution with a peak rainfall intensity of six inches/hr; a gradually increasing and a gradually decreasing rainfall patterns with a total rainfall of six inches in three hours; and a constant rainfall intensity of three inches/hr with a total rainfall of nine inches in three hours.

The magnitude and timing of peak flow rates for five different storms simulated by 2DWAVE, SWMM, and HEC-1 are shown in Table 1. The simulation results for peak flow rates obtained by 2DWAVE, SWMM, and HEC-1 are agreeable for all five storms as shown in Table 1. The time-varying simulation results for all three models were in close agreement for all of the five storms. The comparison for storm one is illustrated in Fig. 1. Note that the HEC-1 discharge hydrograph is at the downstream end of the hypothetical channel receiving runoff from the simulated overland flow plane.

To demonstrate the performance of the 2DWAVE model, a real world problem was simulated for the 10,000-year rainfall event. The model was applied to simulate the flood potential for a hexafluoride cylinder storage yard (Yard B) located at the K-25 site of the U.S. Department of Energy, Oak Ridge, Tennessee. Yard B slopes to the northwest at a low to moderate grade, ranging from about 0.5 to 1.0 percent. Manning roughness values range from 0.2 in the grassy areas to 0.1 within the paved yard. The simulations for all hexafluoride cylinder storage yards at K-25 are described by P-SQUARED Technologies (1996).

Maximum computed flood depths vary in the 10,000-year rainfall from 0.8 to 3.5 inches. The two-dimensional velocity vectors for the 10,000-year storm event were simulated by the model. The streamlines obtained from the velocity vectors for the peak flow condition for the 10,000-year storm are shown in Fig. 2. The stream lines indicate that the flow passes through the model domain from the southwest to the north and northeast directions.

SUMMARY

2DWAVE represents hydrologic variations more realistically using the spatially varying characteristics of a drainage area. The 2DWAVE model simulates spatial variation of depth and velocity of flows due to changes in slope and surface roughness on a drainage area. These results are useful in simulating average and peak overland flood levels due to rainfall.

The model was applied to simulate five example rainfall patterns. The simulation results for five example rainfall patterns have been presented. The model results were compared with HEC-1 and SWMM. The 2DWAVE model results were in close agreement with those of HEC-1 and SWMM.

A successful application of the model was made by simulating a real world problem. The model results were useful in understanding the development of an overland flow wave on a two-dimensional plane. The model results were used to determine the flow paths and flood levels in both space and time.

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Table 1. Comparison of peak flow rates simulated by 2DWAVE, SWMM, and HEC-1.

Rainfall pattern	2DWAVE		SWMM		HEC-1	
	Q_p	t_p	Q_p	t_p	Q_p	t_p
1	33.16	38.5	33.09	43.0	34.20	46.0
2	46.32	34.5	43.26	34.7	47.00	47.0
3	33.60	137.5	34.52	139.8	34.10	146.0
4	33.16	38.6	33.09	43.0	33.90	46.0
5	33.67	40.0	34.79	48.8	34.00	48.0

Q_p : Peak flow rate (cfs).

t_p : time to 90 percent of peak flow rate (minutes).

STRATEGIES TO MEET REGULATORY WATER TEMPERATURE CRITERIA AND MINIMIZE POWER GENERATION LOSSES

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INTRODUCTION

The Tennessee Valley Authority (TVA) currently has fourteen operating thermal powerplants, all of which use large quantities of water from nearby rivers to dissipate waste heat. To avoid permit violations of the National Pollutant Discharge Elimination System (NPDES), TVA is required to curtail generation at a given facility if the water temperature of the plant discharge exceeds allowable river limits. At nuclear facilities, similar action is required by the Nuclear Regulatory Commission (NRC) if the water temperature at the intake threatens the safe shutdown of the plant. To prevent NPDES and NRC violations, which are seasonally threatened at roughly half of TVA's thermal plants, the agency has developed a number of innovative techniques to monitor, forecast, optimize, and control instream water temperature and plant thermal discharges. This paper highlights a number of the techniques that have been highly effective in helping TVA minimize power losses which can occur as a result of maintaining thermal compliance.

MONITORING

At all TVA facilities, river temperature and other quantities (e.g., flows, water elevations, wetbulb and drybulb temperatures) are monitored at strategic locations chosen depending on site-specific requirements. At nuclear plants, this includes upstream control points, the plant intake, and the plant discharge structure. A good example is TVA's Sequoyah Nuclear Plant (SQN), located near Chattanooga, Tennessee, at Tennessee River Mile 484.5. Upstream, the monitoring system for SQN includes continuous monitoring of temperature at Watts Bar Dam and at the plant intake. Downstream, temperature is monitored at the plant discharge diffuser and in the river at the edge of the mixing zone. Flow is monitored continuously at the diffuser and the upstream and downstream hydroplants (i.e., Watts Bar and Chickamauga Dams). Data from all the temperature and flow sensors, along with that from meteorological sensors, are sent via radio links to an environmental data station on the plant site, which relays the information by satellite to a central system in Knoxville.

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In Knoxville, data from SQN and other powerplants are collected automatically by a central decision support system, called TERRA (TVA, 1996). TVA developed TERRA to help coordinate power and reservoir operations while protecting water quality, meeting water supply needs, and managing reservoir levels. The system integrates tracking, display, and modeling tools into a computer system accessible at widely dispersed decision-making locations. TERRA provides a common set of historical, current, and forecast data to assist in resolving problems in operating, forecasting, and planning power and reservoir systems. The system automatically compares water temperatures with threshold limits established to signal the need for remedial action. If any threshold limit is exceeded, the computer notifies personnel responsible for thermal compliance by a pre-recorded telephone message. TERRA also displays schedules for operations at the hydroplants and weather forecasts from the National Weather Service satellite WIRE system.

NUMERICAL MODELING AND CONTROL

Temperature data are used in numerical models developed by TVA to predict water temperatures and discharge flows. These predictions are used to adjust the operation of the TVA power system to minimize power losses. Special releases from upstream and downstream hydroplants can be scheduled to control water temperatures at thermal plants, if such releases comply with requirements for flood control, navigation, recreation, water quality, and power demand. TVA's Bull Run Fossil Plant (BRF) located near Claxton, Tennessee, at Clinch River Mile 47 provides an example. The plant, which is situated downstream of Norris Dam and upstream of Melton Hill Dam, has an NPDES discharge water temperature limit of 31.1 °C. Calculations based on the thermal efficiency of the plant indicate that this limit will be exceeded if the intake water temperature exceeds 20.0 °C. Hydrothermal studies have shown that the intake temperature at BRF is highly dependent on the discharge temperature from Norris Dam. When Norris and Melton Hill hydroplants are not generating, or when discharges from the two dams are not properly synchronized, back-flow also will occur in the river, recirculating the warm BRF discharge water into the plant intake. This is particularly problematic when the discharge from Norris is curtailed to fill the reservoir in the spring.

To assist BRF, a one-dimensional reservoir flow and temperature model was developed to evaluate the effect of various hydropower-operations on the intake water temperature. When the intake water temperature exceeds a threshold limit of 18.3 °C, the model is used to estimate the temperature in the upcoming week, based on scheduled operations at the Norris and Melton Hill Dams. If the NPDES limit is predicted to be exceeded, additional flows are requested from the dams to prevent BRF from derating. Normally, a day or two of strategic hydro releases will dissipate recirculation and prevent a permit violation.

Four of TVA's powerplants contain cooling towers. To forecast exactly when towers are needed, several numerical models have been developed. These are used to minimize overuse of the towers, which consume substantial power and require high maintenance costs. TVA's Browns Ferry Nuclear Plant (BFN), located near Decatur, Alabama, utilizes an unsteady, one-dimensional flow and temperature BFSCH (TVA, 1983) to evaluate the impact of the plant thermal discharge on river temperature. The model is imbedded within the TERRA decision

support system and includes modules that automatically upload boundary conditions required for the computations (i.e., upstream water temperatures, scheduled discharges at upstream and downstream hydroplants, meteorological data, and forecasts). A graphical user interface allows the user to provide other relevant information, such as BFN power generation, number of condenser cooling water pumps in operation, and number of tower lift pumps in service (see Figure 1). The model subsequently provides the BFN discharge and downstream river temperatures. Times for starting and stopping tower operations, or adjusting river flows, are recommended based on the model results to prevent violation of the NPDES temperature limits.

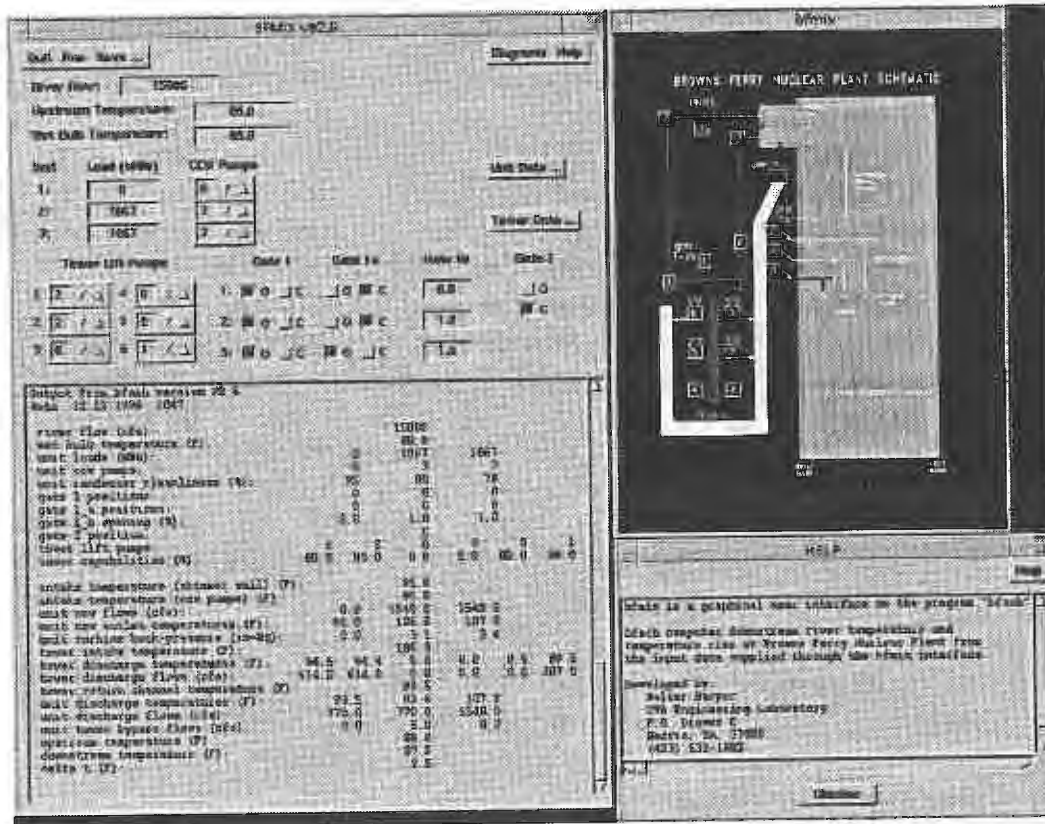


Figure 1. Graphical User Interface for Browns Ferry Nuclear Plant Scheduling Model

To provide long-range (90-day) water temperature forecasts for the Tennessee River, from Watts Bar to Kentucky Dams, TVA developed SYSTEMP, a two-dimensional, system-wide flow and temperature model. If a SYSTEMP forecast indicates that a water temperature problem may occur, operational changes can be planned for the hydro system in an attempt to alleviate the situation. In 1987, SYSTEMP forecasts showed that the summertime water temperature at SQN might exceed the intake limit for safe shutdown of the plant. The model subsequently was used to plan a special release of cold water from Norris Dam, including operational procedures to route the flow through the Melton Hill, Watts Bar, and Chickamauga Reservoirs, to arrive at Sequoyah at the time relief was needed. As a result, water temperatures remained below the NRC limit and SQN was spared from plant shutdown (see Ostrowski et al., 1991; Alavian and Ostrowski, 1992).

SPECIAL STUDIES

Both physical and numerical models are used by TVA to evaluate the benefits of power plant improvements, such as channel modifications to withdraw cooler intake water from the bottom of the river. A recent study was performed for TVA's Kingston Fossil Plant located near Kingston, Tennessee. A physical model was constructed at the TVA Engineering Laboratory to examine alternatives for redistributing flow in the cooling water intake to mitigate excessive accumulation of sediment. The physical model was used to design cylindrical baffles for the approach channel and inner bay to eliminate a recirculation zone in front of two of the units. Dredging and widening the approach also were recommended (Hoover and Hadjerioua, 1993).

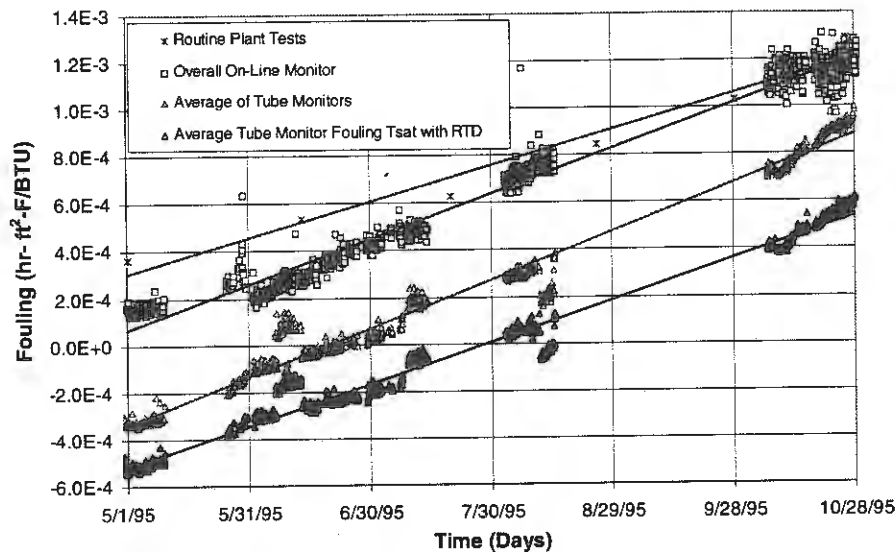
To avoid violating the NPDES discharge temperature limit at TVA's Colbert Fossil Plant located near Florence, Alabama, one or more units were routinely removed from service during off-peak demand hours for 28 days in 1995, resulting in 83,500 MWh of lost generation. In response to this problem, TVA used a three-dimensional, finite-element unsteady heat and mass transport model, PHOENICS (CHAM, 1993), to evaluate the feasibility of dredging the intake channel to allow cooler bottom water to flow into the plant. Model results indicate that dredging the channel to its original depth may improve intake temperatures by 0.5 C° during periods of recirculation when the reservoir is stratified by 4 C°. In 1995, an improvement of 0.5 C° would have reduced the duration of reduced generation to only 11 days, increasing the plant output by 23,500 MWh.

CONDENSER MONITORING

Cooling water discharge temperatures are strongly affected by condenser macro-fouling and to a lesser extent by condenser micro-fouling. Macro-fouling is caused by relatively large objects (e.g., mussels, fish, debris) adhering to the face of the condenser tube sheet, thereby reducing the cooling water flowrate. Micro-fouling is typically caused by biological growth, siltation, or scale formation that reduces the heat transfer effectiveness of the condenser tubes and decreases unit efficiency. Both forms of fouling lead to increased cooling water discharge temperatures.

TVA has developed on-line monitoring techniques and systems (Almquist and March; 1987, Wolff et al., 1996), optimization tools (Wolff and March, 1996), and on-line cleaning systems (Almquist and March, 1986) to maximize condenser performance while minimizing cleaning costs. Two general types of on-line monitoring systems have been developed and implemented: (1) an overall monitor that measures a macro-fouling and micro-fouling level for the entire condenser, and (2) a monitoring system that measures the performance of individual condenser tubes. Both monitors measure the required parameters to compute fouling rates (i.e., inlet and exit water temperatures, cooling water flowrate, and steam pressure). Figure 2 presents fouling rates measured by an overall monitor, fouling rates measured by individual tube monitors, and fouling rates measured by routine plant tests. All systems predict fouling rates that agree reasonably well. The condenser monitoring strategy best suited for a plant depends on several factors, including the size of workforce and the condenser fouling characteristics.

These fouling rates are then used in an optimization program that computes a condenser cleaning schedule which minimizes the cost of increased fuel usage due to poor condenser performance while minimizing condenser cleaning costs. The optimization program provides a



clear and concise link between condenser performance measurements and the actions plant personnel must take to increase plant profits through improved condenser performance.

Figure 2. Comparison of Fouling Rates From Individual Tube Monitors, Overall On-Line Monitor, and Routine Plant Tests

CONCLUSION

TVA has developed a number of techniques for hydrothermal compliance, including monitoring, a decision support system, numerical and physical modeling, and optimization procedures for reservoir releases and condenser cleaning schedules. This suite of services has been successfully used by TVA to meet regulatory water temperature criteria and minimize power generation losses.

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HYDROGRAPHIC SURVEYING USING GPS

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INTRODUCTION

Global Positioning System (GPS) is a NAVigation Satellite Timing and Ranging (NAVSTAR) based system that is all-weather, continuously available and provides world-wide coverage. This system provides accurate and efficient positioning for navigation and land-based surveying. With the introduction of Differential Global Positioning System (DGPS), it is possible to apply this same system to hydrographic surveying. DGPS provides continuous horizontal positioning as a vessel traverses across a survey path taking depth measurements. The Nashville District Corps of Engineers (COEN) recently switched to DGPS for positioning hydrographic survey vessels. The first project to utilize the system was the sediment resurvey of Lake Cumberland, which is located in Southeastern Kentucky. Prior to this sediment resurvey, horizontal positioning was obtained with a distance meter that utilized piano wire under tension. DGPS promises improved accuracy, cost savings and safer operation when compared to the previously used positioning method. The purpose of this paper is to describe DGPS and to discuss the system configuration and operational procedures used by COEN.

DGPS DESCRIPTION

Over the last decade, operational procedures and technology have been enhanced so that two GPS receivers can be operated simultaneously. Doing so allows 3-D line vectors to be computed between the two receivers. Thus, it is possible to compute x, y, and z differences between the two receivers. A minimum of four satellites must be observed simultaneously at each receiver for the process to work. This technique is collectively termed "differential positioning" (i.e. DGPS).

A base station receiver remains stationary on a reference position and monitors the movements of satellites in orbit. Position corrections are computed at the base station receiver and transmitted via a radio link to the other receiver. The other receiver is free to move around, thus it is often called the rover receiver. The rover receiver uses the generated corrections in conjunction with satellite observations that it receives to compute delta x, y, and z values. With the horizontal and vertical coordinates of the base station known, position coordinates are computed for the rover receiver location. The rover receiver's position coordinates are known as "real time coordinates" because they are computed as the survey proceeds and do not require post-processing. If need be, more than one rover receiver can be used together with a single base station.

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This same technique applies to hydrographic surveying with the exception that the z-value computed for each rover receiver position is discarded. The water surface elevation in conjunction with depth readings received from a echo-sounder are used to determine the z-value for each point.

Reported position accuracy for hydrographic surveying using DGPS is in the sub-meter range. Vertical accuracy will depend upon the depth-sounding equipment and depth of measurement, but should be significantly better than the horizontal accuracy. The horizontal accuracy is acceptable for most, if not all hydrographic surveying work. Certainly, the accuracy is equal to, if not greater than, those achieved by previous survey methods.

SYSTEM CONFIGURATION

A vast array of equipment is required to perform a hydrographic survey using DGPS. There are two primary facets that encompass a DGPS hydrographic surveying system, a survey vessel and a bank station. These two components are essentially the same for every type of hydrographic survey application. The following is a description of the system configuration used by COEN to perform hydrographic surveying in conjunction with sediment resurveys.

The survey vessel contains all essential hardware and software required for the rover receiver configuration. Installed on the COEN survey vessel are a Trimble 4000SE GPS receiver, Trimble TRIMTALK rover radio, Trimble geodetic antennae, VHF radio antennae, Pentium laptop computer, Trimble Hydronav software and a Ratheon echo-depth sounder equipped with an Odom digitrace. A Honda generator is used to supply auxiliary power to the electronic devices.

The computer functions as a data collector and is necessary to run Trimble's Hydronav software. A depth is recorded, at user-defined locations along the survey path, from the digitrace to the computer via a PCMCIA card. The software then inputs a corresponding horizontal position for each depth. The position is recorded as an easting and northing (x and y) value.

Within the Hydronav software is a Helmsman display that provides continuously updated information on the progress of the survey and related parameters. The pilot of the survey vessel is kept on-line as the vessel travels along the survey path by viewing a 14" monitor connected to the laptop computer. The pilot can see the intended survey path and the location of the survey vessel as it traverses across the path.

The bank station setup used by COEN consists of a Trimble 4000SE GPS receiver, Trimble TRIMTALK 25-watt radio modem, Trimble geodetic antennae and a VHF radio antennae. Power is supplied to the receiver and radio via a 2-cycle marine battery. The modem allows communications between the base station and GPS receiver on the survey vessel. COEN personnel have performed DGPS hydrographic surveys at distances up to 2.5 miles between the

base station and survey vessel. This distance will vary depending on the terrain and ground clutter. However, there need not be a direct line of sight between the two receivers.

SYNOPSIS OF THE 1996 LAKE CUMBERLAND SEDIMENT RESURVEY

Lake Cumberland is a multipurpose reservoir that winds through hilly and mountainous terrain. The lake is bounded by steep, rocky bluffs in some instances. It has a surface area of 50,300 acres at the maximum power pool elevation of 723 feet MSL. Maximum reservoir depth is 180 feet at an elevation of 723 feet MSL. The sediment resurvey of 1996 was a partial resurvey consisting of 22 of the 49 total sediment ranges.

Prior to beginning the hydrographic surveying, COEN personnel had to establish reference control points. Each sediment range has two monuments, one on each bank. The left bank monument, oriented in the downstream direction, being station 0+00 and the right bank monument being the end of the range. Previous hydrographic surveying methods required only stationing along the range to maintain horizontal positioning. However, with DGPS, an x and y coordinate system must be used. State plane coordinates in the North American Datum of 1927 (NAD '27) were used for the survey. GPS static surveying methods in conjunction with traditional surveying methods were used to establish coordinates on monuments with no horizontal control. This was a time consuming process that will not have to be done prior to the next resurvey. The NAVSTAR satellites use the World Geodetic System (WGS '84) spherical datum, therefore the NAD '27 coordinates had to be converted to WGS '84 prior to input into the base station. Trimble's GPTrans software was used to make the conversion.

Traditional survey methods were then used to profile the overbank areas from the survey monuments down to the water's edge. In the future, GPS equipment in a mobile backpack unit will be used for this portion of the survey. The survey vessel was then used to continue the section from the left bank water's edge to the right bank water's edge.

Start of line and end of line coordinates must be specified at each range prior to beginning the hydrographic survey. The Hydronav software uses these values to compute a straight line between the two monuments. This is the line that the pilot uses to navigate the vessel across the range. Depth measurements were recorded at distances of every 10 to 20 feet along the range depending on the total length of the section. The user also has the option of taking readings at specified intervals of time instead.

After the completion of the field surveying, the data was brought into the office for processing. The raw data on the laptop computer was downloaded to a file for plotting and volume calculations. The volume program and plotting program currently used by COEN requires that the data be output in the station-elevation format. However, data can be output in x, y and z format for import into a 3-D CADD file. Some of the data points had to be edited for "spikes" in the data resulting from false readings received from the depth-sounding equipment. Previously,

hydrographic survey data had to be digitized from fathometer charts or entered manually by hand. This was a time consuming method with a higher probability for error.

There are several benefits that can be realized by switching to using DGPS for hydrographic surveying. With previous hydrographic surveying methods, four to five personnel were required. If DGPS methods are used, only two to three people are needed to perform the work. This results in direct savings in labor costs. Increased safety is also a benefit of using DGPS versus the previous hydrographic surveying method. The previous tag-line survey method required stretching a high-tension cable across the survey range. There was always the potential for the cable to be struck by boat traffic or to break and whiplash.

Because this was the first hydrographic surveying job attempted by COEN, there were many problems that arose. The primary problem initially was that the system was new and personnel needed time and experience to become proficient in its operation. GPS and DGPS are complicated and require that personnel be adequately trained on the theory and equipment operation. Performing a hydrographic survey requires vast amounts of equipment that must work in unison. Because of this, the possibility of not performing a survey due to a equipment malfunction is great. As mentioned previously, there is a minimum of four common healthy satellites that must be observed at both receivers. The availability of satellites is determined primarily by the orbit of the satellites and the terrain surrounding the receiver. The geometry of the satellites, in the sky relative to the rover receiver, determines the Position Dilution of Precision (PDOP) of the rover receivers position. The higher the PDOP, the greater the error in the position. Trimble recommends not accepting the positioning if the PDOP is greater than seven. This caused many problems during the Lake Cumberland resurvey because there are several areas on the reservoir where the water surface is surrounded on both sides by steep bluffs. At these locations it was nearly impossible to perform the hydrographic survey using DGPS unless there were four or more satellites directly overhead. Trimble's Quick Plan program was used to determine the number of satellites that would be available and the PDOP that could be expected on a given day and time for a survey. This allowed for careful planning and selection of the optimum time to perform a hydrographic survey at a particular location.

**WATER-QUALITY, DISCHARGE, AND BIOLOGIC DATA
FOR WATERSHED-BASED WATER-QUALITY MANAGEMENT:
AN EXAMPLE FROM BEDFORD COUNTY, TENNESSEE**

Este Hollyday,

James J. Farmer,

and

Tom D. Byl¹

In 1996, the Tennessee Department of Environment and Conservation, Division of Water Pollution Control, began a procedure to issue new, and renew old, NPDES permits simultaneously within a single watershed. This watershed-based approach to permitting will be accomplished in five steps: planning, data collecting within the watershed, assessing and allocating, drafting a watershed plan and permits, and implementing the plan and issuing the permits. The scope of data collection within the watershed could vary depending upon the complexity of the geology, land use, and existing point and nonpoint sources of pollution. One example of data collection within a watershed was performed by the U.S. Geological Survey, in cooperation with the Bedford County Solid Waste Authority. The effects of the Quail Hollow landfill on water quality in nearby aquifers and streams draining the Duck River in southeastern Bedford County were investigated.

From November 1994 through April 1995, streams and springs in 9 watersheds, each having a drainage area of about 2 square miles, were observed and sampled during base flow at 176 sites. Reconnaissance data from the streams and springs were collected to establish regional baseline conditions. Water samples from 26 seepage sites were analyzed for major dissolved solids, nutrients, selected dissolved metals, and the occurrence of organic compounds. During reconnaissance, the discharge at the most downstream site on each stream ranged from 0.01 to 6.0 cubic feet per second; the specific conductance of water from all sites ranged from 17 to 617 microsiemens per centimeter ($\mu\text{S}/\text{cm}$). The baseline specific conductance values were less than 50 $\mu\text{S}/\text{cm}$ at, and upstream from, the outcrop of the Chattanooga Shale. Conductivity increased downstream and was between 150 and 300 $\mu\text{S}/\text{cm}$ at the confluence with a receiving stream (fig. 1). Conductivity of water in tributary streams draining the landfill differed markedly from this regional pattern. Data at sites 3090 and 3173 that are adjacent to the toe of the landfill indicated anomalously high conductivities which coincided with anomalously high concentrations of chloride, dissolved iron, dissolved manganese, and detectable concentrations of synthetic organic solvents. The biologic diversity of most streams had a unimodal distribution of the number of

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orders per site. The biologic diversity of one naturally acidic stream and the stream draining the east side of the landfill lacked a mode or were polymodal.

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**SURFACE SEDIMENTS "CLEANED" BY REMEDIATION PROJECT -
WHITE OAK CREEK EMBAYMENT REVISITED**

***Clell J. Ford¹,**

Chuck Swinney,

Dan Levine,

George Houser,

Mike Morrissey,

and

Mike Smith

Surprisingly elevated ¹³⁷Cs levels (<40,000 pCi/g) were found in the surface sediments of White Oak Creek Embayment (WOCE) of Watts Bar Reservoir by phase 1 of the Clinch River Remedial Investigation (1990). An accelerated site characterization performed to determine the extent of contamination (Blaylock et al., 1993), concluded that highly contaminated sediments, released from upstream sources in the mid 1950s to early 1960s, were being eroded out of the embayment by the combination of winter storms and routine reservoir operations. Additionally, Blaylock et al. revealed the potential for a significant risk to human health from exposure to contaminated sediments, exposed during the winter draw down of Watts Bar Reservoir. A sediment retention structure was constructed at the mouth of White Oak Creek in 1991 - 1992 in order to 1) create a trap for relatively cleaner sediments transported from upstream sites, and 2) prevent exposure of the public to contaminated sediments (CDM Federal Programs, 1992; Leslie and Kimmel, 1992; Ford and Wefer, 1993).

The purpose of this investigation is to determine whether or not the coffer cell structure is being effective in preventing the erosion of highly contaminated sediments out of WOCE. More specifically, it was to determine whether the highly contaminated surface sediments in the embayment have been covered by deposition of relatively cleaner sediments. If the sediment retention structure is functioning as designed, it is estimated that roughly 4 to 5 cm of additional sediment per year may be accumulating within lower WOCE based on total suspended particle levels from WOD, for a total of 20 to 25 cm of new sediment covering the highly contaminated sediments since the completion of the structure.

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White Oak Creek, in eastern Tennessee, flows through the Oak Ridge National Laboratory complex, draining into the Clinch River at approximately Clinch River Kilometer (CRK) 33.5. White Oak Creek has received radiologically and chemically contaminated flows from nuclear and waste disposal operations on the Oak Ridge Reservation since the mid 1940s. White Oak Creek is relatively free flowing until it reaches White Oak Lake (WOL), ~2 km upstream from its mouth. White Oak Lake was formed in 1943 by the construction of White Oak Dam (1 km upstream from the Clinch River). WOL served as a settling pond for activities occurring during and after the Manhattan Project (Blaylock et al., 1993). However, in the mid 1950s, WOL was drawn down. During the draw down, heavy rains eroded large quantities of sediments highly contaminated with ^{137}Cs and other radionuclides downstream. These contaminated sediments, estimated to contain 300 Ci or more of ^{137}Cs (Olsen et al., 1992) were deposited both in lower WOCE and downstream in the Clinch River, near the source.

Clinch River flow conditions changed dramatically following the completion of Melton Hill Dam, located at CRK ~ 39, in 1963. Melton Hill Dam (MHD), used for hydropower generation by the Tennessee Valley Authority (TVA), releases water at times of peak demand on the TVA system. During the summer, the dam generally operates on a 12 hour cycle, being turned on for 12 hours and then off for 12 hours (Fig. 1.3 in Blaylock et al., 1993), creating sudden, large changes in flow rates and elevations, both within the Clinch and WOCE. These operations moved deposited sediments from former seasonal depositional areas in the 5 to 10 km reach of river downstream from the dam, to depositional areas nearer the Clinch River mouth, where the flow slows considerably. However, since the coffer cell structure at the WOCE mouth was completed, the water levels and flows behind the structure have been much more stable.

METHODS

Five sediment cores were collected at mid channel from the portion of WOCE immediately upstream from the coffer cell structure. Cores were collected from a small boat using a light-weight, short barreled gravity core device. Samples, identified as AB, BC, CD, DE and EF, were collected from mid channel at points between lateral transects in WOCE. Samples were labeled sequentially, with core AB being closest to the coffer cell structure and EF being furthest upstream. Sediment core lengths were limited to ~20 to 30 cm due to sampling logistics. Each core was sectioned by 2 cm increments by siphoning off the overlying water and vertical extrusion of the sediments, following standard techniques. All samples were sealed in aluminum cans, labeled and returned to the laboratory for gamma spectrometry.

A second field excursion was conducted to survey longer cores in the field. These cores were collected using a longer barreled, light-weight gravity core device. These cores were surveyed using a sodium iodide (NaI) detector, shielded in a lead sleeve to minimize gamma shine. Results were recorded in the field logbook.

Sediment samples were submitted for gamma spectrometric determinations on germanium-lithium (GeLi) detectors. Randomly selected samples were also surveyed using a NaI detector to

establish a relationship between laboratory-measured and field-measured values. Sample wet and dry weights were determined for calculation of percent moisture and dry mass concentration of ^{137}Cs (pCi/g); percent moisture and dry mass concentrations were directly compared with historic data. ^{137}Cs inventory values (pCi/cm²) were estimated by dividing the gross picocuries of ^{137}Cs per sample by the lateral surface area of that core section (19.62 cm²); values were used for a direct comparison with the wet measured field screen values.

RESULTS

Sediment ^{137}Cs levels ranged from a peak of 611 pCi/g dry weight for the 0 to 2 cm depth in the most downstream core to 217 pCi/g dry weight for 16 to 18 cm depth in the most upstream core, with the mean for all core sections of 356 pCi/g dry weight. Though highest values tended to be observed near the top of each core, there were no apparent trends in contaminant levels with depth in the cores (Fig. 1). The highest mean ^{137}Cs values tended to be observed for the most downstream core location, with an average concentration of 496 pCi/g dry weight. Mean concentration values for the other cores ranged from 309 to 388 pCi/g dry weight. These values are in the range of suspended ^{137}Cs values (~1000 pCi/g) observed at WOD (Kornegay et al., 1994, Ford and Wefer, 1993). Surface sediment moisture contents ranged from 56 to 73% (Fig 2).

Core section inventories for ^{137}Cs increased with depth in all cores, though values tended to plateau as the moisture content dropped to 50% or less. The maximum ^{137}Cs inventory (477 pCi/cm²) was recorded for the most downstream core, the minimum (311 pCi/cm²) recorded for a more upstream core, with no clear distinction possible among the remaining cores (range 373 to 413 pCi/cm²).

The ^{137}Cs inventory for individual sections of each field surveyed sediment core was estimated based on the significant ($F < 0.005$) relationship between field screen (NaI) and laboratory (GeLi) techniques. While inventory values for the top 10 to 20 cm of the field screen cores were within the range of those measured quantitatively, the estimated ^{137}Cs inventory values below 20 cm increased to roughly twice that of surface values.

DISCUSSION

Contaminant inventory and concentration values were inversely related over depth in the current samples. This disparity, commonly observed in sediments from depositional areas, is related to the moisture content of each core section. For all current core sections, percentage moisture initially was relatively high, dropping with depth in the sediment. Given similar contaminant activities in WOCE sediments, a higher moisture content dilutes ^{137}Cs inventories, but will yield relatively higher concentrations per unit dry mass than sections with lower moisture percentages

Sediments collected in 1990 and 1991 differed greatly from those collected in 1996. The first difference is in sediment moisture content (Fig. 2). Cores collected in 1990 and 1991 from

WOCE had relatively uniform and low sediment moisture contents over the top 40 cm of the core (range 30 to 40% water) while the moisture contents of the 1996 cores ranged from 56 to 72% water at the sediment surface; values ranged down to ~ 40% by 20 cm deep (Fig. 2). The moisture content of historic WOCE sediments are consistent with more riverine systems in which sediments are not accumulating and may be eroding. By comparison, the 1996 values reflect values from lake-like, quiescent systems where sediment accumulation is taking place.

The most striking difference between the sets of samples lies in the 0 to 40 cm deep ^{137}Cs levels. Contaminant levels in the 1990 - 1991 cores ranged from ~2000 to 59,000 pCi/g dry mass, with a peak of 45,000 pCi/g at the sediment surface (Fig. 1). As presented above, current ^{137}Cs levels over these depths ranged from 200 to 600 pCi/g, ~ 100 times lower than for pre-coffer cell samples (Fig. 1).

Field screen values indicate that, for both screened cores, ^{137}Cs inventory increased with depth, following the pattern observed for laboratory analyzed cores. This indicates that the field screens of sediment cores accurately represented laboratory-derived values. Peak values for 1996 cores were at best at the low end of the historic cores. Estimated values from field screened cores did increase by two to three times with depth in the sediments. The failure to detect values in the range of historic data may be due to a very high sedimentation rate.

There does appear to be a relatively clean layer of sediment, at least 20 cm thick, covering the heavily contaminated sediments in WOCE. In this respect, the coffer cell, sediment retention structure appears to have created a sediment deposition zone in lower WOCE and is functioning as designed. Evidence in support of this conclusion includes 1) current ^{137}Cs levels in the same range as recorded on suspended solids from White Oak Lake (Kornegay et al., 1994), 2) physical measurement of sediment moisture reflective of sediment deposition zones, 3) surface sediment ^{137}Cs values approximately 100 times less than from pre-coffer cell sediments, and 4) a marked increase in ^{137}Cs inventory values below 30 cm in field screened sediments. Further, the data presented indicate that the sediment deposition rate is similar to that observed in depositional environments.

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Fig. 1 Values for Cs-137 on WOCE sediments, old collected 1990-1991, new collected 1996.

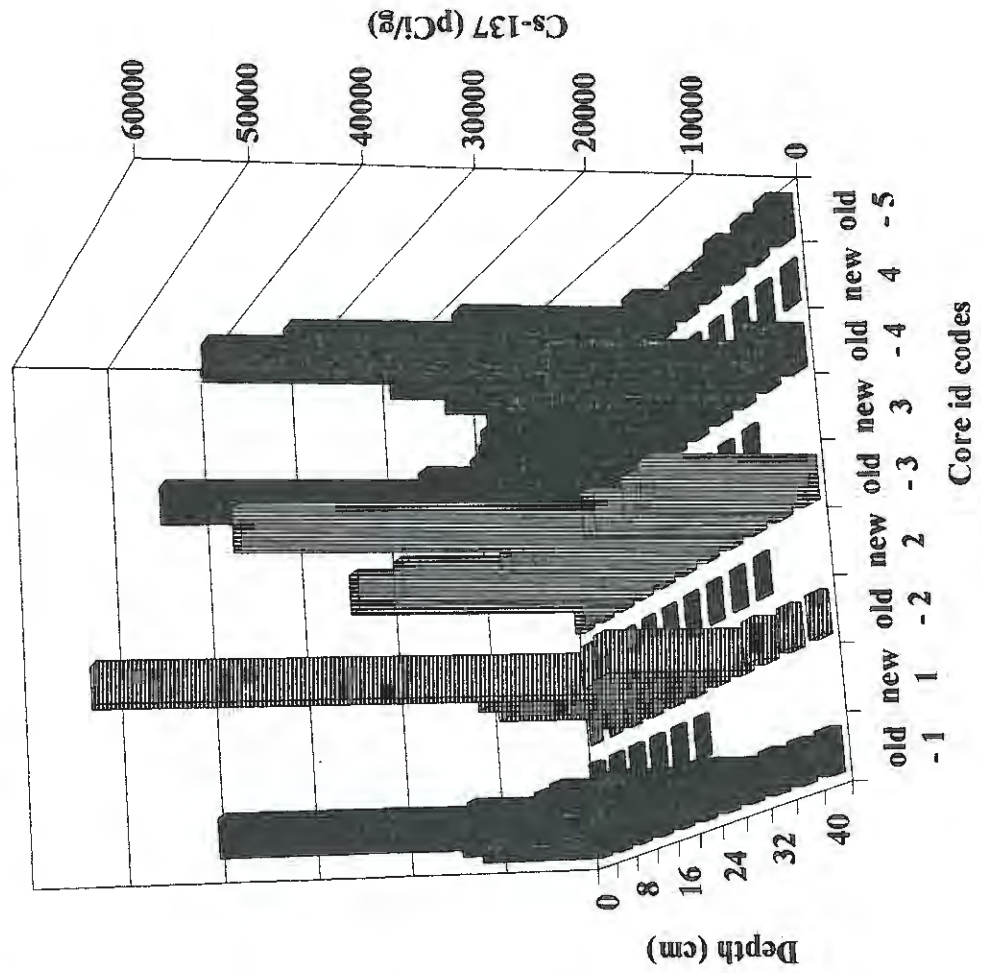
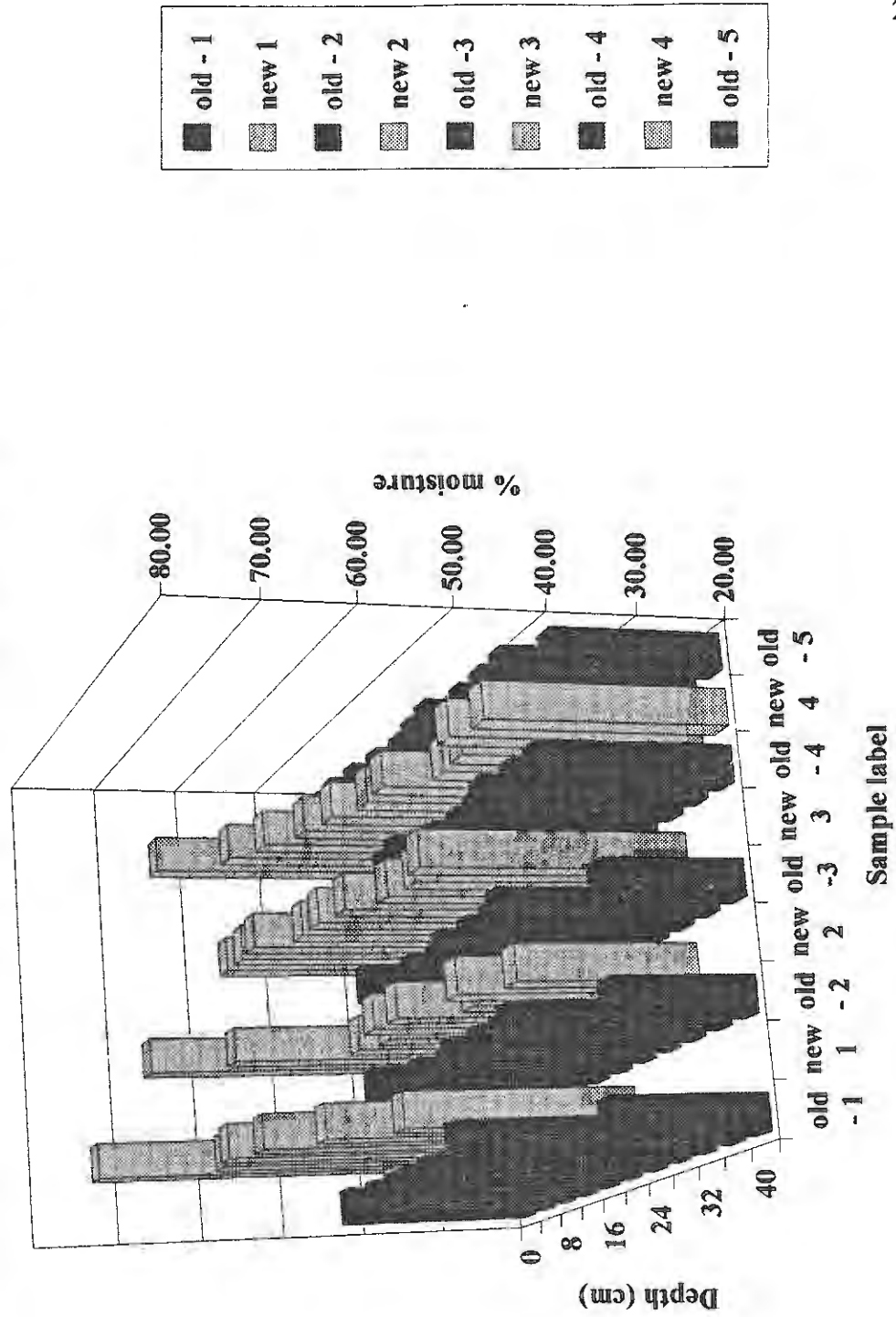


Fig 2. Percent moisture in WOCE Sediments, old collected 1990 - 1991, new collected 1996.



SESSION 2-B, continued

URBAN HYDROLOGY/STORMWATER #1

1:00-2:30

George E. Kurz, W. Reid Adams, Arthur C. Newby, *Combined Sewer Overflow Control in Nashville, A Water Quality-Based Strategy.*

Bruce A. Tschantz, *Performance Analysis of Constructed Urban Stormwater Detention Ponds.*

Paul C. Cate, *Maximizing the Use of the Sanitary Interceptor System for Combined Sewer Flow.*

URBAN HYDROLOGY/STORMWATER #2

3:00-4:30

Wayne H. Schacher, *Biomonitoring Used as a Water Quality Assessment Tool in Urban Streams.*

Michael J. Sale, Craig C. Brandt, Daniel A. Levine, *Development of an Environmental Data Management System for Urban Storm Water Management.*

W. Reid Adams, Arthur C. Newby, D. Scott Woodard, *A Watershed Study of Nashville's Urban Streams.*

**COMBINED SEWER OVERFLOW CONTROL IN NASHVILLE:
A WATER QUALITY-BASED STRATEGY**

George E. Kurz, P.E., DEE,

W. Reid Adams, E.I.T.,

and

Arthur C. Newby, C.H.M.M.¹

Under EPA's National CSO Control Policy and a Tennessee Commissioner's Order, Nashville is required to modify its combined sewer system. CSOs must be controlled to a degree that any discharge point remaining in service after 1 July 2001 must satisfy requirements for an NPDES Permit. Initially, the Policy requires the implementation of "Nine Minimum Controls" by 1 January 1997. These controls represent "minimum technology-based controls that can be used to address CSO problems without extensive engineering studies or significant construction costs prior to the implementation of long-term control measures." (EPA, 1995) This paper describes how each of the controls was interpreted, on a site-specific basis, to improve operation of the combined sewer system. Coupled with changes to the overall sewer system configuration:

- More than two-thirds of the CSO locations will be eliminated.
- CSO duration is expected to be reduced by one half.
- Conveyance and treatment capacity will be increased.
- Floatable materials will be captured using low-tech netting systems.
- Selected tributary basins will be separated.
- Public participation and notification will be improved as a result of the CSO Advisory Group established by Metro.

Intensive water quality studies in the Cumberland River and tributary streams in the Nashville area indicated that the impact of CSOs on water quality was much less than originally expected. Therefore, this plan represents a significant departure from the storage tank system contemplated in 1988. The initial findings from the system characterization and monitoring should be helpful for other cities in planning their control strategy.

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PERFORMANCE ANALYSIS OF CONSTRUCTED URBAN STORMWATER DETENTION PONDS

Terry E. Romans, E.I.T.¹

and

Bruce A. Tschantz, P.E.²

INTRODUCTION

The management of stormwater runoff becomes a very important concern to a community as urban development increases. Runoff volumes increase as previously natural areas are replaced with impervious surfaces such as asphalt, concrete, and buildings. Natural depressions, sinkholes, and marshy areas that previously captured stormwater are being filled in for development. Urbanization generally increases the peak flows while reducing the time of concentration. The peaks are increased because there is less pervious surface to infiltrate the rainfall and because of the concentrating effects of engineered pipes and channels. Time of concentration is decreased, because efficient manmade conveyance systems often replace natural channels, resulting in accelerated runoff. Left unchecked or unmanaged, these accelerating effects and increased runoff volumes can produce an increase in downstream flooding depths, erosion and sedimentation, flooding frequency, property damage, and lawsuits.

Many municipalities have adopted stormwater policies or ordinances that require or allow some type of stormwater detention. The purpose of a detention pond is to regulate or limit the peak flow from a specified rainfall event to some specified lower discharge. Typically, a detention pond will provide adequate storage volume and outlet control to temporarily store enough post-development runoff for releasing the water at a peak flow rate no larger than existed during pre-development conditions. Common practice is to limit the post-development condition peak flow to the pre-development peak for a single rainfall event, such as a 10-year storm. However, many local governments are beginning to adopt ordinances that require post-development discharges not exceed present-condition discharges for multiple storm frequencies. Some community policies require that the maximum release rate from a developed site not exceed the 10-year pre-development peak flow, for an assumed larger (i.e. 50-year) storm event.

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The methods used by engineers for sizing detention pond volume vary; however, the Soil Conservation Service's TR-55 Urban Hydrology for Small Watersheds approach appears to be the most favored method in Tennessee. TR-55 provides two methods, Graphical and Tabular, for design engineers to compute peak flows from a drainage basin of known size and hydrologic conditions. TR-55 then allows the engineer to estimate required detention volume from computed peak outflow discharge to peak inflow discharge ratio. However, the TR-55 technical manual warns users to apply the method with caution. Its principal use should be for developing preliminary estimates of storage for small detention ponds and where storage volume errors of 25 percent are acceptable. The TR-55 graphical procedure for storage routing is not sensitive to a particular type of outlet structure (i.e. weir or orifice or pipe). Therefore, a specific outlet structure and pond configuration can greatly affect the shape of the outflow hydrograph and, hence, the amount of storage required to control the outflow discharge. The limitations of the TR-55 method, coupled with inadequate as-built inspections, can combine to produce either expensive over-designed/over-constructed or deficient under-designed/under-constructed ponds. This study compares field conditions with design intent and discusses the subsequent hydrologic effects on pond performance.

OBJECTIVE AND SCOPE

This study has two main objectives. The first objective is to determine if detention ponds in the Knox County area are generally built according to the intended design plans and specifications submitted to the regulating agency. Improperly built ponds will not perform the way they were designed. Many municipalities do not have the staff to adequately inspect all constructed detention ponds. Outlets are designed around specific flow, head, and storage requirements. If an outlet facility is configured to operate at 3 feet of design head for a given flow and storage, but the pond is *constructed* to operate at 4 feet, the discharge will be more than intended and the pond will fail to perform as assumed. Many problems can arise from improperly built spillways and outlet structures. Larger or smaller than designed outlet structures and spillways will affect the discharge rates. The second objective is to evaluate the design assumptions, methods, and computations used in sizing detention ponds and outlet facilities for meeting the designer's intent and the regulatory requirements.

A minimum of 20 stormwater detention ponds in the Knoxville area will be analyzed. The dimensions of about 10 newly constructed and 10 older ponds will be documented through extensive field work. Ponds of varying sizes and volumes for residential and commercial developments are included in the study. The work involves hydraulic and hydrologic analysis of field data and comparison of the "as-built" storage and flow reduction performance of each detention pond with (1) the intended engineered storage and peak flow reduction performance characteristics, and (2) the required regulatory storage and performance criteria. Pond characteristics to be examined include pond geometry, emergency spillway, outlet structure, stage vs. storage and stage vs. discharge relationships, and general maintenance.

METHODS

The field work involves taking photographs, measuring and documenting existing conditions, and doing an "as-built" survey of the ponds and outlet structures. Surveying is being done with a Topcon total station EDM and an HP 48GX data collector. The ponds are digitally computed using AutoCAD 12 and Softdesk 7.2.

Original pond design information was obtained from the City of Knoxville, Knox County, and the Town of Farragut. The designer's computations are checked, using the same method that the designer used. If any mistakes are found, corrections are made before proceeding further.

HEC-1 was used to route the inflow hydrographs through the ponds using the actual, as-built pond and outlet conditions, to determine required storage. If the original designer did not compute an inflow hydrograph, but used the TR-55 Graphical method to determine peak inflow, HEC-1 was used in conjunction with the designer's drainage basin parameters to produce the inflow hydrograph before routing through the actual pond. However, if the original designer computed an inflow hydrograph, HEC-1 was used only to route that hydrograph through the actual pond. The intent in this study is to try to match what the original designer intended.

SUMMARY OF FINDINGS

Preliminary results for nine inspected ponds, as of November 1996, show some significant differences between what was designed or intended and what actually exists in the field as follows:

I. Detention Ponds

- Table 1 shows that the volumes of all inspected ponds differ significantly between the computed design volume and the actual volume in the field for the 10-year storm event.
- One of the newly constructed ponds has accumulated a large amount of silt due to poor erosion control practices on the surrounding construction site. The result of decreased storage volume will decrease the performance of the pond to reduce peak flow.

II. Outlet Structures

- One outlet structure was designed for a circular orifice diameter of 9 inch, but a 9 inch by 9 inch *square* opening was installed, an increase in area of 27%. This will result in discharge flows greater than intended for any pond depth.
- Emergency spillways are placed in different locations than intended or shown on plans. Spillway invert elevations are set higher than intended. One pond calls for a concrete

spillway, and there is none. One emergency spillway was specified to be 30 ft. long and 1 ft. deep, but the actual spillway is only 3 ft. long and 0.2 ft. deep.

- One pond will overtop the dam before the emergency spillway is utilized.
- One control outlet was sized for a 12-inch CMP, but a 10-inch orifice plate was installed.

III. Dam

- The measured dam heights are smaller than the intended heights for all nine dams by 4 to 60 percent, with most being about 50 percent.

IV. Computational Method

- Many design computations are difficult to read, follow, or review.
- Assumptions are unclear and unstated in some of the design documents.
- Spillway and outlet control computations are often confusing and unclear. Unreasonable weir and orifice discharge coefficients are frequently used.

Pond Number	Calculated Design Volume (acre-feet)	Actual Volume (acre-feet)
POND 1	2.90	1.70
POND 2	1.05	0.76
POND 3	0.19	0.32
POND 4	0.40	0.55
POND 5	0.20	0.08
POND 6	0.10	0.07
POND 7	0.09	0.05
POND 8	0.23	0.06
POND 9	1.1	0.54

Table 1. Comparison of calculated and actual detention volumes for 10-year frequency storms.

CONCLUSION AND RECOMMENDATIONS

The findings based on preliminary inspection and analysis show that detention ponds are not being constructed according to the indicated design plans and specifications. Some of these differences are significant, and may have a profound effect on pond performance. Findings to date show a need for inspection of detention ponds during construction. Close attention to design computations and details needs to be given by reviewers. There should be guidelines on how drainage calculations should be submitted so that the reviewers can better follow the designer's assumptions and intent.

Field data of nine ponds has been analyzed to date. The hydraulic and hydrologic data will be reviewed and analyzed. At least eleven more ponds will be analyzed by February 1996.

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**MAXIMIZING THE USE
OF THE SANITARY INTERCEPTOR SYSTEM
FOR COMBINED SEWER FLOW**

Paul C. Cate, P.E.¹

The City of Chattanooga is under a mandate from the Tennessee Department of Environment and Conservation (TDEC) to eliminate or control overflows from the combined sewer portion of its wastewater collection system before the end of this century. The combined sewer portion of the system consists of 17 individual drainage basins which together cover an area of slightly over four square miles. Most of these basins are located in what is generally referred to as the central business district.

In April 1994, after several years of preparation, the United States Environmental Protection Agency (EPA) issued its final Combined Sewer Overflow Control Policy. This policy provides the first definitive guidance for controlling combined sewer overflows (CSOs). The policy identifies a number of possible control options and outlines procedures for their evaluation. The City retained Consolidated Technologies, Inc. (CTI) to identify the "best" control option for two of its combined sewer service areas (Areas C1 and C2) and to obtain acceptance of the identified option from TDEC prior to detailed design.

Areas C1 and C2 cover approximately 868 acres; of these, 834 acres are served by sewers. Flows from Areas C1 and C2 are conveyed into the Chattanooga Creek Interceptor via two regulators. Normal sewage flow from these areas is transported by the interceptor system to the City of Chattanooga wastewater treatment plant through the 23rd Street Pump Station. Wet-weather flows above the capacity of the connector pipes between the interceptor and the regulators enter Chattanooga Creek as overflows.

EPA's Combined Sewer Overflow Control Policy requires that the maximum storage capacity of the wastewater collection system be incorporated into a community's CSO control strategy. CTI's work has resulted in the development of a systematic method of dealing with this requirement. Evaluations of flows within the Chattanooga system indicate that peak combined sewer flows and peak interceptor sewer flows do not typically occur simultaneously. Generally, the peak combined sewer flows occur within minutes of the beginning of a rain, but even during major rainfall events, it takes several hours, or even days, for interceptor flows to reach their peak. CTI developed a program to take advantage of this "phase differential." The program resulted in a substantial reduction in the size of the proposed CSO facility.

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Steps in this program are as follows:

- Step 1 is the collection of 25 years of stream (Tennessee River) level and rainfall data for the Chattanooga area.
- Step 2 is the collection of available actual flow data for the sanitary interceptor which receives normal flow from the combined sewer area.
- Step 3 is the development of an empirical formula for the interceptor flow using the actual interceptor flow data and corresponding rainfall and stream level data.
- Step 4 is the development of a simplified hydrologic model for the combined flow from the combined sewer area.
- Step 5 combines the 25-year database with the interceptor flow model and the hydrologic model to predict and rank CSO events.

This approach takes full advantage of the available interceptor capacity to handle combined sewer events and, consequently, significantly reduces the size of the CSO control facility. EPA's requirement to maximize the amount of combined flow handled by a sanitary sewer system mandates that this available capacity be used to its full extent.

The first step in the "phased differential" approach was the assembly of a coordinated database, which included:

- Daily rainfall data.
- River gauge data for the Tennessee River at Chattanooga.

The river gauge was calculated as the river elevation above Elevation 633.0. Rainfall data was for the weather service station at Lovell Field, the Chattanooga municipal airport. Lovell Field is located several miles from the combined sewer area.

The second step of the "phased differential" program was the collection of available data for flows in the sanitary system which receives the normal flows from the combined sewers.

Only limited flow data was available for the Chattanooga Creek Interceptor, and all of this data was taken from a metering station approximately 5,950 feet upstream of the junction of the C1 and C2 combined service areas. This intermediate monitoring station is identified as Station CH9 in the City of Chattanooga's network of flow metering stations.

The assembled database covered a period from January 1, 1991, through September 30, 1994; however, because of meter problems at CH9, there were significant gaps in the data. The usable periods consisted of a 20-month period from January 1, 1991, through September 19, 1992, and a 5-month period from May 1, 1994, through September 30, 1994. The selected approach for developing the model was to use the 1991-92 period to create the model and the 1994 period to test its predictive accuracy.

In order to fully use the interceptor's available capacity, it is necessary to have a predictive tool or empirical model to forecast the flow in the interceptor contributed by its non-combined service areas. With the model, it becomes possible to predict the average flow for the interceptor for

each day in the 25-year database created for this study and, consequently, to forecast the system capacity available to handle combined flow each day.

The third step of the "phased differential" program was the development of the model for the flow in the sanitary system. The development of empirical models has a long history in civil engineering. CTI applied this approach to allow the examination of a very long period and thereby avoided the many statistical problems normally involved in hydrologic analyses.

Once the coordinated database of sanitary flows, river level, and rainfall was available, an incremental process was used to develop the empirical sanitary flow model. The first step was to assign a rainfall code to each day's data: "dry" days had no significant rain that day or the preceding three days, "rain" days had significant rain that day but no significant rain the preceding three days, and "antecedent" days were days following days with significant rainfall. For these identifications, "significant" rainfall was considered to be at least 0.1 inch in one day.

The next step was to sort the data by rainfall code to produce three distinct data sets. Attention was then focused on the dry data set. The dry day flows were plotted against the corresponding river gauge, and a linear regression analysis was performed on the data set. During this analysis, it became obvious that the flow data for the period December 31, 1991, through February 28, 1992, was erroneous, and this period was excluded from further study. The regression analysis identified two critical variables for the model. The first was the base dry weather flow (the flow at "zero" gauge) and the second was the flow multiplier for infiltration related to river level.

Attention then focused on the rain day data set. First, the daily inflow amounts were calculated by subtracting the previous day's monitored flow from the current day's flow. This approach eliminated the need to separately estimate daily and seasonal flow variations. The computed inflow amounts were then plotted against the daily rainfall amounts, and a linear regression analysis was made of the data. For this analysis, the Y-intercept was set to zero and the resulting coefficient describes the flow multiplier for direct inflow.

Next, attention focused on the antecedent day data set. First, "net" antecedent flow was calculated by subtracting calculated base flow, river gauge-related infiltration, and current day inflow from the monitored flow for each day. The computed antecedent flows were then plotted against the previous day's rainfall amount and a linear regression analysis was performed. In this analysis, the Y-intercept was also forced to zero and the resulting coefficient describes the flow multiplier for the antecedent effect.

The following equation is the mathematical model for flow at Monitoring Station CH9, which resulted from the analyses described above:

$$\text{Equation 1} \quad Q = 11.457 + 1.329G + 8.890R + 10.977P$$

Where:

Q = Interceptor flow (mgd).

G = River gauge (depth in feet above Elevation 633.0).

- R = Daily rainfall (inches).
P = Previous day rainfall (inches).

As a test of the model, it was then applied to the 1994 data set. This test is illustrated on the following figure. On this figure, one line is the actual flow measured at Monitoring Station CH9, and the other line is the model's estimate. It is clear from the figure that the model tracks the actual flow very closely and that in only a very few cases does actual flow exceed the adjusted model's estimate. From this comparison, it is clear that the adjusted model can be used with a high level of confidence for predicting CH9 flows over any time period for which rainfall and river gauge data are available.

The relative size of the service areas, the relative lengths of the interceptor sewers, and previous assessments of the base flow for the entire service area above the combined sewer junctions were then used to adjust the CH9 flow model to reflect the overall sanitary service area. The modified model was then run with the 25-year rainfall and river level database to estimate the expected daily flows in the sanitary interceptor if these conditions were repeated in the future.

Step 4 of the "phase differential" program was the derivation of a CSO runoff model for Areas C1 and C2. This effort relied on the synthetic hydrograph method developed by the Soil Conservation Service (SCS) and explained in their Technical Reference No. 55 (TR55). The TR55 method considers the topography, vegetative cover, and land development patterns of a given drainage area. This method also uses 24-hour rainfall amounts to estimate runoff volumes.

The calibrated runoff data developed during previous analyses was used to select the appropriate system coefficients or curve numbers used in the TR55 approach. The selected curve numbers were 85 and 92 for Areas C1 and C2, respectively. Composite runoff coefficients were then determined from the TR55 synthetic hydrographs for rain events in 0.1-inch rainfall increments for Areas C1 and C2. These were then applied to the 25-year rainfall database to estimate the runoff volume for each storm.

Step 5 of the "phase differential" approach compared the predicted interceptor flows and the predicted CSO runoffs to the available capacity of the sanitary interceptor system. For each rain event, comparing the runoff volume to the available interceptor capacity allowed the identification of predicted overflow events. This evaluation indicated that for the 25 years of data there would be 800 separate runoff events from Areas C1 and C2; however, because of available interceptor capacity, only 584 events would actually result in overflows if the interceptor were fully used and if no detention capacity were constructed within the system.

The overflow listing was then sorted by overflow volume to produce an ordered listing (largest to smallest) of the predicted overflows. This ordered listing provided the basis for selecting the "design event" for the CSO control facility.

Method TR55 proved to be a very valuable tool in rapidly assessing the overflow problem for Areas C1 and C2. However, this method is not sufficiently sophisticated to be used as the basis for the final design of a major detention/treatment system. The TR55 method did make it possible to identify a limited range of potential design events. With this identification complete, it is possible to apply more advanced runoff modeling methods to the specific design events.

The EPA CSO control policy does not mandate sizing the control facility for a particular overflow recurrence interval. The policy does recommend the capture of at least 85 percent of the uncontrolled overflow volume, but anticipated water quality impacts are the final determinant. Because of concerns about the impacts on Chattanooga Creek (the receiving stream for the CSO's), a decision was made to size the control facility to limit overflows to one per year. Under the EPA policy, an overflow is considered to be any release which does not receive the equivalent of primary treatment.

Review of the ordered list of overflow events indicated that the 25th largest, or "one per year," event occurred on February 16, 1990. This event resulted from a daily rainfall amount of 2.2 inches and the estimated overflow volume was 25.08 mg. Because a number of events which fall on either side of the February 16, 1990, event in the ordered list had similar estimated overflow volumes but larger daily rainfalls, it was decided to examine a range of events to identify the most critical. The selected range extended from the 22nd event (April 15, 1994) to the 28th event (March 15, 1973). The most critical event was assumed to be the single event with the highest ratio of overflow volume to receiving stream flow.

A separate hydrologic examination of the Chattanooga Creek drainage basin had to be conducted in order to estimate the flows in the creek which coincided with the candidate design events. This analysis identified the April 15, 1994, event as the most critical, and this event was used for the design of the control facility.

Having identified a single design storm event, a more in-depth hydraulic analysis of the design event was necessary to size the detention/treatment facility. Review of the available hydraulic modeling programs led to the selection of the HEC1 software package for this analysis.

The capacity of the CSO control facility for the design storm was determined by trial and error.

1. A "smart" regulator system will be installed which will divert the maximum amount of combined sewer flow into the Chattanooga Creek Interceptor in order to fully use the hydraulic capacity of the interceptor system.
2. CSO control facility is empty at the beginning of the simulation.
3. The control facility acts as a storage tank until it is filled to the level of the outflow weir.
4. When the water overflows the weir, the facility acts as a primary clarifier.
5. The control facility should intercept at least the first hour of runoff resulting from the design storm.
6. The outflow weir shall be approximately 9 feet, 4 inches above the bottom of the control facility.

7. The facility shall have a peak surface overflow rate of 3,000 gallons per day (gpd) per square foot (TDEC's maximum permitted flow rate for a primary clarifier).

The HEC1 simulation predicted a peak inflow of 551 cubic feet per second (cfs) into the facility and a peak outflow from the facility of 466 cfs (300 mgd). For this outflow with a surface overflow rate of 3,000 gpd per square foot, a surface area of approximately 100,000 square feet is required. This surface area can be provided by a square tank 320 by 320 feet. This tank with an average depth of 9 feet, 4 inches provides a base storage volume of slightly over 7.0 mg. Flow above this amount is provided with primary treatment.

The total and diverted flow quantities predicted by the HEC1 simulation agreed closely with the predictions of the TR55 approach. This close agreement confirms that the TR55 approach can be used with a high level of confidence as a screening tool in CSO evaluations.

Based on detailed hydraulic analysis of the system, a 7.0-mg storage tank was recommended for the combined sewer control facility for Areas C1 and C2. This facility will provide primary treatment to the "one per year" and all smaller events and will reduce the total number of combined sewage releases to less than 5 per year (120 in 25 years).

An earlier evaluation of a CSO facility to serve Areas C1 and C2 had concluded that a 17-mg facility would be required to reduce the number of overflows from these areas to 12 per year. Complete utilization of the available interceptor capacity and the "phase differential" approach, as described above, allowed a much smaller facility to reduce this number of expected overflows to only one.

BIOMONITORING USED AS A WATER QUALITY ASSESSMENT TOOL IN URBAN STREAMS

Wayne H. Schacher¹

INTRODUCTION

In May of 1990, General Plan 2005, a program adopted by the respective administrations of Knoxville, TN, and surrounding Knox County, released a document entitled "Environment: Issues, Goals, Objectives and Strategies.. This master plan established goals, set objectives and prescribed policies and actions intended to facilitate improvement and development of the city's waterfront property along Fort Loudoun Reservoir (Tennessee River).

Plan goals included the identification of point source and non-point source water quality issues and problems along the city's reservoir waterfront and within the watersheds of Knoxville's tributary streams. Both surface water and groundwater issues were to be addressed. Resulting from this initiative, the Knoxville Water Quality Forum (WQF) was created, teaming federal and state agencies with municipal governmental departments, the University of Tennessee, and other entities to investigate and address water quality problems present within the watersheds of tributary streams.

According to the Tennessee Department of Environment and Conservation (TDEC) 1994 report, "The Status of Water Quality in Tennessee," several water bodies present in the Upper Tennessee River basin fail to fully support their designated use. Fort Loudoun Reservoir is listed as "not supporting" its designated use, due to PCB contamination, urban runoff, and municipal and industrial discharges. Within the city of Knoxville, Goose Creek, First, Second, and Third Creeks, and East Fork of Third Creek are listed as "not supporting" their designated use due to a variety of point source and non-point source perturbations, and are posted against body contact recreation due to elevated coliform levels. Similarly, the Sinking Creek embayment of Fort Loudoun Reservoir is listed as "not supporting" its designated use and is posted against body contact recreation due to elevated coliform levels. Baker Creek and Sinking Creek are listed as "partially supporting" their designated uses.

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METHODS

The Upper Tennessee River basin, including Fort Loudoun Reservoir, the city of Knoxville, TN and surrounding Knox County, falls within the Central Appalachian Ridges and Valleys ecoregion (Omernick, 1993).

An early decision of the WQF established that biomonitoring of the tributary fisheries and benthic macroinvertebrate communities would be used to evaluate the benefits of any tributary watershed management activities implemented. A literature search and a review of historical records revealed that there was an absence of published information on the biota of the tributary streams present in Knoxville and Knox County, TN. The necessity to conduct baseline biological assessments on the seven City of Knoxville tributary streams (First, Second, Third, Fourth, Baker, Goose and Williams Creeks), selected Knox County streams, and reference streams became a priority (Schacher, 1992).

The biomonitoring tool chosen by the WQF to establish benchmark assessments of the status of the fisheries communities for the selected Knoxville-area streams, was Karr, et al.'s (1986) Index of Biotic Integrity. This methodology was further refined by Charles F. Saylor of TVA to incorporate consideration of factors such as respective stream length, watershed drainage area, geographical region and specific fish community (Holdeman 1993). For the tributary benthic macroinvertebrate communities, the biomonitoring tools chosen were qualitative and quantitative analyses conducted to assess total taxa, organism density and sensitive (E-P-T) taxa. Concurrent with the biological surveys, Tennessee Valley Authority (TVA) Physical Characterization/Water Quality Field Data Sheets and Stream Habitat Assessments were completed for each survey site.

RESULTS

1990

In late September of 1990, an IBI survey was completed in lower Third Creek. The IBI score of 28 placed the result in the "Poor" classification. No benthic macroinvertebrate community analyses were conducted.

1992

During May, June and July of 1992, IBI surveys were completed for seven city of Knoxville tributaries (9 stations), and one reference station (Fisher Creek, Hawkins County, TN) (Holdeman, 1993; Gardner, 1993). These surveys yielded IBI results as follows: First Creek - 44 (Fair); Second Creek, lower site - 40 (Fair), intermediate site - 32 (Poor), upper site - 36 (Fair/Poor); Third and Fourth Creeks - 32 (Poor), Baker Creek - 36 (Poor/Fair), Goose Creek - 32 (Poor) and Williams Creek - 40 (Fair). On Fisher Creek, the reference stream, the IBI score was 58 (Excellent).

The benthic macroinvertebrate assessments conducted on each City of Knoxville tributary stream resulted in greatly reduced total taxa (range: 5 - 23), severely depauperate EPT taxa (range: 0 -

3), low percent EPT taxa (range: 0 - 15.4%) and domination by tolerant organisms. On Fisher Creek, the reference stream, the benthic macroinvertebrate community analysis yielded 64 total taxa and 30 EPT taxa (47%) (Holdeman, 1993; Gardner 1993).

1995

During April and May of 1995, results from IBI surveys (TVA, unpublished data) conducted on city of Knoxville streams resulted in scores of 30 (Poor) at an intermediate site on First Creek; 32 (Poor) at lower, intermediate and upper sites of Second Creek; 24 (Very Poor/Poor) on East Fork of Third Creek; and 36 (Poor/Fair) on the lower site and 38 (Poor/Fair) on the upper site of Third Creek.

Results (TVA, unpublished data) of the benthic macroinvertebrate analyses were similar to those from 1992, though identification was only taken to the family taxonomic level. At the sites on First Creek (12 total taxa, 1 EPT) and East Fork of Third Creek (6 total taxa, 0 EPT) the benthic macroinvertebrate community was dominated by tolerant oligochaeta and chironomid taxa, exhibited greatly reduced total taxa and was completely or nearly devoid of EPT taxa. At the two Third Creek sites, improvement within the proportion of EPT taxa present in the benthic macroinvertebrate communities (family-level identification) was indicated. At the lower site, 10 total taxa and 2 EPT taxa were recorded, while at the upper site, 19 total taxa and 8 EPT taxa were found.

At the three Second Creek sites, benthic macroinvertebrate identification (family-level) resulted in greatly reduced total taxa (range: 2 - 16), depauperate EPT taxa (range: 0 - 3), low percent EPT taxa (range: 0 - 18.8%) and domination by tolerant organisms.

1996

During June of 1996, IBI surveys conducted on the lower and intermediate sites of Second Creek resulted in scores of 32 (Poor) and 28 (Poor) respectively (TVA, unpublished data). Benthic macroinvertebrate data for these sites are not yet available.

TRENDS AND CONCLUSIONS

Bioassessments of the fisheries and benthic macroinvertebrate communities present within streams in the city of Knoxville indicate a significant degree of impairment in water quality and/or physical habitats. Though reflective of degraded stream conditions, some degree of biotic community recovery should be realized through ongoing programs to improve watershed, riparian and in-stream habitats; implementation of Knoxville's stormwater NPDES program; upgrading city sewage delivery system infrastructure; and expansion of city and county greenways development.

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DEVELOPMENT OF AN ENVIRONMENTAL DATA MANAGEMENT SYSTEM FOR URBAN STORM WATER MANAGEMENT¹

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Water quality problems associated with urban runoff have been highlighted as a national problem in publications including the Wall Street Journal and in studies by environmental activist organizations including the National Resources Defense Council. For example, a 1995 epidemiological study of Santa Monica Bay in the Los Angeles area identified elevated human health risks near storm drains. State and local governments, such as Los Angeles County, are required to develop effective and enforceable controls on the sources of this pollution, including tightening controls on storm water runoff, better water quality monitoring, and closure programs that adequately protect the public in accord with requirements of the Clean Water Act. To help address such problems, LA County requested assistance from Oak Ridge National Laboratory (ORNL) through a cooperative agreement between the American Public Works Association (APWA) and Lockheed Martin Energy Research Corporation, manager of ORNL.

ORNL and Los Angeles County's Department of Public Works (DPW) signed a Cooperative Research and Development Agreement in September 1996 to address storm water environmental concerns of Los Angeles County. A team from the Environmental Sciences and Computational Physics and Engineering divisions of ORNL are working with LA County staff to create a conceptual design for a new environmental data management system by January 1997. The environmental information system then will be used by Los Angeles county, in cooperation with the 85 municipalities in the County, to acquire, to analyze, and to report environmental data on the storm water systems of the County as an element of the County's response to and compliance with a recently issued National Pollutant Discharge Elimination System permit

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governing storm water management for LA County. The ORNL-LA County team also will conduct an inventory and evaluation of existing environmental data and information systems applicable to storm water management, and will develop long-term recommendations to advance computing applications and data acquisition technologies in environmental management.

This cooperative initiative is one of the first efforts to bring science and technology from one of the National Laboratories to address environmental problems in urban areas. It is the objective of APWA and ORNL that cooperative projects like this initial project with Los Angeles County might evolve to serve as a models for adaptation by other communities, including those in Tennessee.

A WATERSHED STUDY OF NASHVILLE'S URBAN STREAMS

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INTRODUCTION

The term watershed is becoming a topic of national discussion these days. The "Watershed Management Approach" to controlling point and non-point source pollution is endorsed by the EPA as well as many states. Tennessee has recently adopted a watershed-based approach to controlling pollution, and will be targeting priority watersheds in the next few years. This paper describes how the City of Nashville adopted the watershed framework to assess impacts from point and non-point source pollution on the water quality of the Lower Cumberland River watershed, and incorporated the data into the sewage system improvement programs currently underway.

Well before there was a national or even state-wide discussion about watershed-based management strategies, Metro Nashville Department of Water and Sewer Services (Metro) and CTE Engineers realized there was a need to implement this type of global study to accurately determine the real impacts of the City's sewer discharges on the resulting water quality of the Cumberland River downstream from Nashville. In 1990, The commissioner of the Tennessee Department of Environment and Conservation (TDEC) issued an order to Nashville requiring specific sewer line improvements, and elimination of unpermitted Combined Sewer Overflow discharges. Metro and CTE subcontracted with Vanderbilt University to develop and calibrate a mathematical water-quality model capable of simulating the effects of stormwater runoff, CSOs and wastewater discharges on the Cumberland River. The primary goal was to determine the real water-quality impacts from the City's discharges and to assess various water-quality improvement scenarios resulting from construction projects designed to reduce the sewage discharges.

DATA COLLECTION

From 1991 to 1994, a multi-agency collaborative effort was conducted to collect data for model calibration through participation in river surveys and share resources and information to jointly

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develop strategies to improve the river's water quality. Participants included the Tennessee Department of Environment and Conservation, U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (COE). Using the combination of intensive data collection and computer modeling efforts, many concerns about the overall water quality of the Cumberland River have been eliminated.

Modeling and monitoring efforts revealed that proposed CSO abatement projects had little impact on conventional pollutant (BOD, nutrients) loadings and did not improve the dissolved oxygen concentrations. Sampling of tributaries, CSOs, and wastewater treatment plants during wet weather for toxics showed that there were only a few heavy metals detected, and concentrations in storm water vs. CSOs were comparable. Mathematical models showed that CSOs account for less than 1% of the annual heavy metals loadings on the Cumberland River watershed, as compared with storm water runoff and wastewater treatment plant loadings. The remaining water-quality parameter of concern was fecal coliform bacteria.

FECAL COLIFORM BACTERIA STUDIES

Combined sewer overflows have been shown to contain high concentrations of the bacteria which are typically used as indicators of domestic sewage=2E. During rain events (approximately 0.25" or greater), Nashville's combined sewer system can discharge large quantities of bacteria into the Cumberland River, resulting in violations of TDEC's water-quality standard of 1000 colonies/100 ml. However, there are other significant sources of bacteria in the watershed.

In order to calibrate the water-quality model to compare predicted results during a rain event with actual sampling data in the river, CSOs and the larger tributaries were sampled in 1994 for fecal coliform bacteria. During the times of high flows, the levels in the tributaries were sometimes very high, exceeding the water-quality standards. They too had a significant impact on the quality of the Cumberland, and even if Metro treated their CSO discharges (via physical/chemical treatment or flow containment), there would still be violations of the recreational water-quality standards due to the tributaries upstream and downstream of the City. Metro is using this data to relate the relative benefits by spending tens of millions of dollars to provide CSO disinfection versus water quality benefits in developing their long term CSO control plan.

Part of the original Commissioner's order of 1990 required significant sewer line improvements in the separated sewer system areas. This was an action to reduce the sanitary sewer overflows (SSOs) from the separate sewer system. These documented overflows typically occur along Metro's large trunk sewers which parallel many of the tributaries to the Cumberland, the same streams found to contain high levels of fecal coliform bacteria=2E Therefore, these SSOs become potential point sources of fecal coliform bacteria.

STREAM STUDIES

In 1995, Metro Nashville decided to assess ten of Davidson County's streams using a watershed-based approach. Urban runoff studies have shown that high levels of fecal coliform bacteria are present in urban and rural stormwater due to runoff from yards, streets, agricultural areas, septic tanks and industrial/commercial areas. The studies have two primary purposes: to determine sources and levels of fecal coliform bacteria during wet weather, and to determine where and when Metro's SSOs occur and the relative impact on stream fecal coliform levels as compared to the other non-point sources. SSOs are illegal and Metro will have to address them in the future, according to TDEC, and provide some type of sewer line improvements to remove excess I/I. However the overall impact the tributary streams have, as compared with CSOs, on the Cumberland River is an area where negotiation should take place, and a watershed-based approach, assessing all sources of fecal coliform pollution, provides the most beneficial and cost-effective technique.

Ten watersheds were studied in the Nashville-Davidson County Area, five of which will be described in this paper. These are Richland Creek, Whites Creek, Mill Creek, Browns Creek, and Mansker Creek. They are five of the larger basins and are currently monitored by the USGS under a Metro contract for flow and stage. In addition, past sampling and modeling data has focused primarily on these five basins, due to the number of sanitary sewer problems and potential overflows within each one and the wide mix of land uses within each basin. The following Table describes the characteristics of each basin:

WATERSHED	DRAINAGE AREA (MI ²)	STREAM MILES	% URBAN	AGRICULTURAL	% UNDEVELOPED	RUNOFF FACTOR
Richland	28.8	25	81	8	11	.33
Whites	63.4	60	30	15	55	.16
Mill	71.8	75	73	10	17	.32
Browns	15.8	15	91	6	3	.47
Mansker	20.7	25	36	12	52	.16

Note: Drainage areas are within Davidson Co. only: Mill and Mansker Creeks extend beyond the county borders (Metro Public Works). Stream miles are distances walked during dry weather surveys.

DRY AND WET WEATHER FIELD SURVEYS

Each stream was surveyed during dry and wet weather. Dry weather surveys consisted of teams walking each mile of the streams—including sub-tributaries—collecting DO, temperature, pH and conductivity measurements, fecal coliform samples, assessing the macroinvertebrate populations, surveying the sewer lines adjacent to the stream, and documenting the data with photographs and videotape. Suspected sewer overflow locations were identified, as well as

potential sources of fecal coliform bacteria or toxic pollutants (i.e. industrial discharges). Baseline fecal coliform data was interpreted to determine sources not related to stormwater runoff (leaking sewer pipes, cattle feed lots, illegal discharges). Macroinvertebrate samples were collected at selected locations to determine the overall health of the stream, and to assess impairment caused by excessive organic and toxic loadings.

Once the dry weather data was compiled, teams sampled the streams at accessible locations during large rainfall events. Fecal coliform samples were collected hourly before, during, and after the peaks in stream flows, and suspected sewer overflow locations were checked periodically to determine if/when the sewers overflowed. Changes in land use areas, and locations of sewer overflows were bracketed by stationary sample locations during wet weather to determine "background" levels of fecal coliform versus levels impacted by overflowing sewers. Using the actual flow and fecal coliform data for the mouths of the streams during specific rainfall events, the information was incorporated into the mathematical model to simulate impacts on the Cumberland River. Also, documented sewer overflow data was assimilated into Metro's sewer inspection program to determine areas to be rehabilitated.

The map located on Figure 1 shows the locations of the five basins in relation to Davidson County, and ranges of wet weather sample results and rainfall amounts from near the mouths of each tributary beginning in 1994. As expected, the data is highly variable, and the peak values are dependent upon flows, time of year, and dry periods prior to the rain events. However, the data does support the fact that urban runoff is a significant contribution to bacterial pollution, and the streams with the most development generally have the higher fecal coliform levels. In addition, for the two streams that have historically been known to have numerous sewer problems, Richland and Browns Creeks, the sampling data indicates much higher levels of fecal coliform bacteria than the other streams.

Richland Creek, in particular, has been sampled extensively and is one stream that has shown a dramatic improvement in water quality after substantial sewer line improvement projects were completed.

RICHLAND CREEK WATERSHED

The basin is almost totally urban, draining approximately 29 square miles in southwest Davidson County. Dry weather sampling occurred during July 1995, when the base stream flows were low. The map shown on Figure 2 displays the features of the basin, and locations of commercial/industrial areas, suspected sewer overflow locations, and macroinvertebrate sample locations. The survey data indicates that the stream is impacted by urbanization (trash, debris, impaired macroinvertebrate habitats), and fecal coliform data ranged from 10 col./100 ml to a high of 20,000 col/100 ml, just below a herd of cattle. The map shows approximately 26 suspected sewer overflow points: some showed previous overflow signs during the dry weather survey, and others were known or historical locations from Metro's records. There were no dry weather sewer overflows.

Macroinvertebrate samples were collected at eight locations along the main branch, and a statistical analysis was performed using a modified version of EPA's Rapid Bioassessment Protocol II. A few locations were reported to be severely impaired due to an inability to support pollution-intolerant species, and these were downstream of some heavily commercialized areas. However, the stream communities showed signs of recovery further downstream. Overall, the data suggests that Richland Creek is moderately impaired.

Several wet weather events have been sampled since 1994, ranging from 0.63" to 2.00" of rain. Figure 2 shows a fecal coliform versus flow profile for a sampling event on September 27 1996, during a 1.85" rain. As shown on the map on Figure 2, the two sampling locations (mile 1.4 and 3.3) bracket an area where sewer overflows occur. The data at mile 1.4 show an increase in fecal coliform concentrations due to the overflows. At mile 3.3, upstream of the overflows, the levels are still high, and tend to follow the flow profile. Sample result at mile 3.3 suggest levels typical of background concentrations in the watershed.

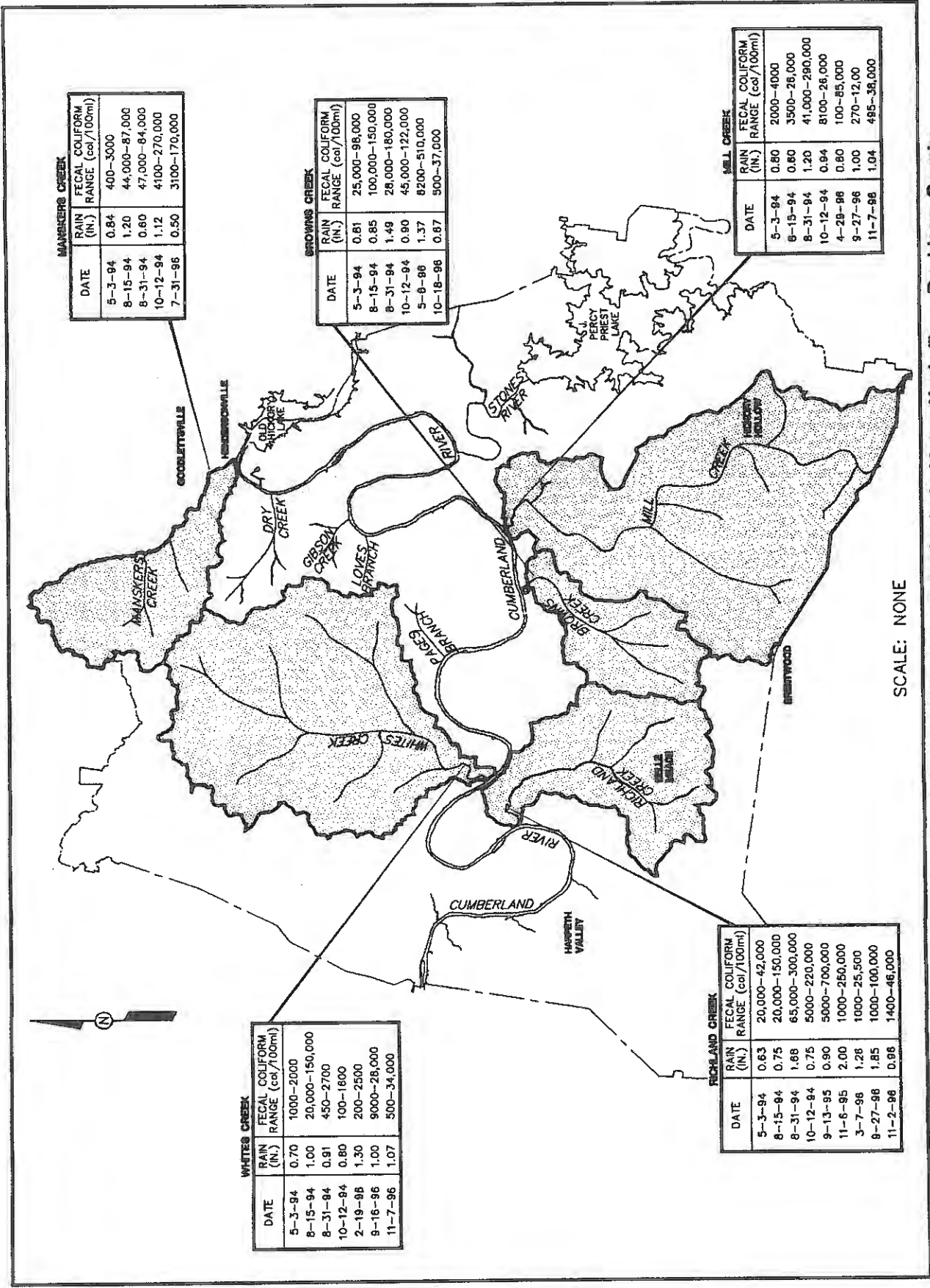
In 1994, a major sewer trunk was constructed along Richland Creek, replacing the older, undersized line. Sampling and sewer monitoring during 1996 has shown a reduction in overall fecal coliform levels and narrowed the overflow locations from the 26 shown on the map to four (numbers 1-4) confirmed. Over \$45 million dollars in capital expenditures were spent in the Richland Creek area, and more are budgeted for the next few years, to take care of the four remaining. Once these projects are complete, further reduction in fecal coliform levels will have to be a part of a watershed management project, promoting best management practices.

CONCLUSIONS

Total watershed management is being successfully implemented in the Lower Cumberland Basin near Nashville. Specific monitoring, computer modeling, and sharing of data and resources has helped to refine management strategies to target the real water-quality issues. The integrated approach of the dry and wet weather stream surveys may serve as a model Tennessee can use in future watershed studies. The stream studies have provided insight into the impact from point and non-point source pollution, and targeted methods by which Metro and other agencies can develop future watershed management strategies to improve the water quality of the Lower Cumberland Watershed.

REFERENCES

Metro Department of Public Works, Metropolitan Nashville - Davidson County Storm Water NPDES Permit Part 1, November 1991.



MANAGERS CREEK

DATE	RAIN (IN.)	FECAL COLIFORM RANGE (col/100ml)
5-3-94	0.84	400-3000
8-15-94	1.20	44,000-87,000
8-31-94	0.60	47,000-84,000
10-12-94	1.12	4100-270,000
7-31-96	0.50	3100-170,000

GRROWINGS CREEK

DATE	RAIN (IN.)	FECAL COLIFORM RANGE (col/100ml)
5-3-94	0.81	25,000-96,000
8-15-94	0.85	100,000-150,000
8-31-94	1.49	28,000-180,000
10-12-94	0.90	45,000-122,000
5-8-96	1.37	8200-510,000
10-18-96	0.97	500-37,000

MILL CREEK

DATE	RAIN (IN.)	FECAL COLIFORM RANGE (col/100ml)
5-3-94	0.80	2000-4000
8-15-94	0.60	3500-26,000
8-31-94	1.20	41,000-290,000
10-12-94	0.94	8100-26,000
4-29-96	0.60	100-85,000
9-27-96	1.00	270-12,000
11-7-96	1.04	485-36,000

WHITES CREEK

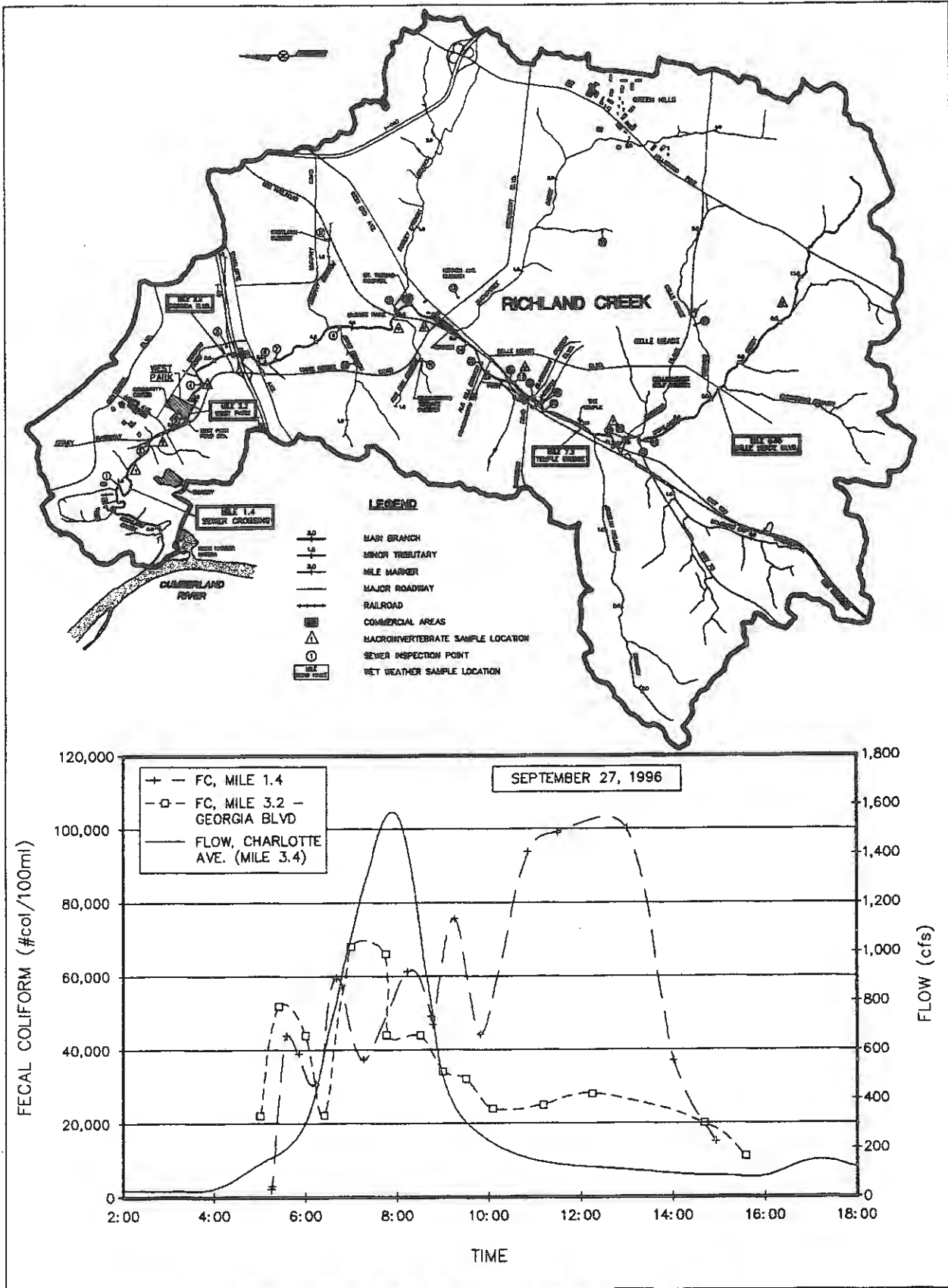
DATE	RAIN (IN.)	FECAL COLIFORM RANGE (col/100ml)
5-3-94	0.70	1000-2000
8-15-94	1.00	20,000-150,000
8-31-94	0.81	450-2700
10-12-94	0.80	100-1600
2-19-96	1.30	200-2500
9-16-96	1.00	9000-28,000
11-7-96	1.07	500-34,000

RICHLAND CREEK

DATE	RAIN (IN.)	FECAL COLIFORM RANGE (col/100ml)
5-3-94	0.63	20,000-42,000
8-15-94	0.75	20,000-150,000
8-31-94	1.66	65,000-300,000
10-12-94	0.75	5000-220,000
9-13-95	0.90	5000-700,000
11-6-95	2.00	1000-250,000
3-7-96	1.28	1000-25,500
9-27-96	1.85	1000-100,000
11-2-96	0.96	1400-46,000

SCALE: NONE

FIGURE 1 - Wet Weather Sampling Results from Five Watersheds in Metro Nashville - Davidson County



**FIGURE 2 - RICHLAND CREEK WATERSHED
Dry and Wet Weather Survey Results**

SESSION 2-C

RESERVOIR MANAGEMENT/NPS

8:30-10:00

Julia Burr Avera, John A. Gordon, Kimberly Keen Hargett, *The Correlation of Land Use to Oxygen Demanding Material Loadings Engering Eight of TVA's Reservoirs During 1992, 1993, and 1994.*

Robert E. Yager, *Modeling of Suspended Sediments in Lake Cumberland.*

Julia Burr Avera, John A. Gordon, Alison O. Langley, Janet L. Putnam, *Tracing of Bromide Entering Reservoirs for Nonpoint Pollutant Effect Assessment.*

WETLANDS

10:30-12:00

C.B. Coburn, Jeff Bindas, John Oster, *Wetland Mitigation Based on a Succession of Functions.*

Timothy C. Wilder, Thomas Roberts, *Development of Hydrogeomorphic Models for Wetland Functional Assessment in Western Tennessee.*

C.B. Coburn, Jeff Bindas, John Oster, *"Education": A Value-Added Component Designed into Mitigation Wetlands Functions.*

ECOLOGICAL RESOURCES/MANAGEMENT

1:00-2:30

Timothy H. Diehl, *Channel Evolution in Jarrell Bottoms, Tennessee.*

Wendy E. Sabin, N.S. Nicholas, *Kentucky Lake Embankment Protection Plantings: A Historical Overview.*

Gary E. Mullaney, *Westvaco's Ecosystem-Based Multiple Use Forest Mangement Systems: The State of the Art in Water Quality Protection on Industrial Forest Lands.*

Ruth Anne Hanahan, Clifford C. Amundsen, *Comparison of Forest Stand Edges in Riparian and Mesic Habitats Along Watts Bar Reservoir Shoreline.*

Cont.

SESSION 2-C, continued

ADVANCED WASTE TREATMENT TECHNOLOGY

3:00-4:30

Dave Turner, Gerald W. Longnecker, William C. Cantrell, *Passive Treatment of Acid Mine Drainage: A Mine Wastewater Treatment Alternative.*

L. Behrends, F.J. Sikora, H.S. Coonrod, E. Bailey, C. McDonald, J. Clayton, M. Higgins, *Reciprocating Subsurface-Flow Constructed Wetlands for Treating Domestic and Municipal Wastewater.*

F.J. Sikora, L.L. Behrends, H.S. Coonrod, W.D. Phillips, D.F. Bader, *Phytoremediation of Explosives-Contaminated Groundwater Using Innovative Wetlands-Based Treatment Technologies.*

**THE CORRELATION OF LAND USE
TO OXYGEN DEMANDING MATERIAL LOADINGS
ENTERING EIGHT OF TVA'S RESERVOIRS
DURING 1992, 1993, AND 1994**

Julia Burr Avera, PhD, PE,

***John A. Gordon, PhD, PE,**

and

Kimberly Keen Hargett, MSCE¹

INTRODUCTION

Natural processes in a watershed as well as the use of the land by man produce significant pollution loadings which are transferred via streams and rivers to lakes and reservoirs. These sources of pollution are referred to as nonpoint sources. Novotny and Chesters (1981) stated that nonpoint sources accounted for more than 50 percent of the total water quality problems which exist in lakes and reservoirs. Some of the land uses which are known to contribute to this nonpoint pollution are crop land, urban storm water, strip mining, and runoff from construction sites. Cooke *et al* (1993) determined that the water quality of lakes and reservoirs is a direct result of what enters from their watersheds. Therefore, the quality of a receiving body of water such as a stream, river, lake, or reservoir can be related to the characteristics of its watershed.

Cole *et al* (1990) reported that better estimates of NPS contaminants would result if sampling was conducted during the rising limb, base flow, and falling limb portions of the rainfall-induced runoff hydrograph. Hopefully, the rising limb would get the first flush of contamination while the falling limb would better represent later runoff. Better regressions between contaminant concentration and flow were reported to exist due to this stratified sampling.

OBJECTIVES

Point source pollution loads in the TVA region have been significantly reduced over the past fifteen years due to efforts by TVA, EPA, and the States. This leaves nonpoint sources as the main contributors to water quality problems within the region. Therefore, the focus of TVA,

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EPA, and the States has shifted to producing reductions in nonpoint loadings. This study was designed to estimate NPS organic and nutrient loadings entering eight of TVA's reservoirs and correlate the loads to the land use within the respective watersheds. A trial of stratified sampling based upon hydrologic events was a further objective.

The reservoirs included in the study were Blue Ridge, Chatuge, Cherokee, Douglas, Norris, Nottely, South Holston, and Watauga. The rivers sampled were the Toccoa, Hiwassee, Shooting Creek, Holston, South Fork Holston, Middle Fork Holston, Nolichucky, French Broad, Pigeon, Clinch, Powell, Nottely, and Watauga. During the spring and summer of 1992, 1993, and 1994, the streams and rivers, which run into the aforementioned reservoirs, were sampled about biweekly with special emphasis on hydrologic events to estimate loadings entering each reservoir.

The parameters included in the data collection procedure were designed to estimate organic and nutrient loadings which could cause dissolved oxygen depletion in the reservoirs. Blue Ridge and Watauga Reservoirs were used as controls since minimal DO depletion existed previous to and during the study while the remaining reservoirs were observed to have hypolimnetic DO levels less than 2 mg/l during the summer months. In summary, the objectives for this study were as follows:

1. Estimate the nutrient and organic loadings from each river or stream based on hydrologic events and field samples.
2. Determine the percent of each of six land use categories present in the watersheds.
3. Estimate loadings per unit area for the various types of land uses.
4. Develop equations which may be used in the future to predict loadings based on hydrology and land use in a watershed.
5. Compare the estimated loadings per unit area to published values.
6. Compare the equations for predicting loadings based on land use to published values.

RESULTS

Table 1 shows the estimated loadings for each river for each parameter along with the standard deviations of the loadings for the most recent samples taken in 1994. The loadings are based upon regressions between flow and concentration and upon daily flows from nearby gauging stations.

Unfortunately, hydrologically stratified sampling did not help eliminate uncertainty in these thirteen rivers based upon three years of data. Only 11 out of 351 linear regressions and 13 out of 351 natural log regressions had R^2 values greater than 0.75. This was most unfortunate, but indicates that the extra expense and effort of stratified sampling does not seem to be warranted.

Table 2 shows the loadings normalized by drainage area for 1994 which allowed the NPS loadings to be compared and ranked. It is also the basis for the comparison of land use to

loadings, the results of which are shown in Table 3. Regression equations developed for estimating loadings based upon land use are shown in Table 4.

CONCLUSIONS

Loadings

1. Three years of sampling at 13 stream sites did not produce the desired linear or logarithmic relationships between concentrations and flow having R^2 values greater than 0.75 based upon hydrologically stratified sampling. Only 11 out of 351 linear regressions and 13 out of 351 natural log regressions had R^2 values greater than 0.75.
2. The mean and standard deviation values calculated from three years of hydrologically-based sampling presented the only useful values with which to calculate loadings from the watersheds according to hydrological events (rising limb, falling limb, and base flow). This did improve the estimates and somewhat justifies stratified sampling.
3. Clinch and Watauga Rivers ranked the lowest in export loadings per hectare.
4. The Holston, Pigeon, and Hiwassee Rivers ranked the highest in export loadings per hectare. The Holston and Pigeon Rivers were expected to rank high, but the Hiwassee River ranking is unexpected.
5. Rivers which flow into the same reservoir tended to have similar average loadings.

Loading Versus Land Use

1. Based upon multiple regression analyses of loadings versus land use, agricultural land use has a significant impact on the loadings for all parameters except total and dissolved organic carbon.
2. Pasture land has a treatment effect which removes total phosphorous, ammonia, and 5-Day BOD from the runoff.
3. The elimination of the four North Georgia Rivers resulted in better R^2 values; therefore, it appears that geography/geology has a significant impact on the loadings.

REFERENCES

- Cole, R.A., T.J. Ward, and S.M. Bolton. 1990. Estimating Intermittent Runoff Concentrations of Organic Matter and the Allochthonous Organic Loading of New Mexico Reservoirs. *Lake and Reservoir Management* 6(2):187-196.
- Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1993. *Restoration and Management of Lakes and Reservoirs*. 2nd Edition. Lewis Publishers, Boca Raton, Florida.
- Novotny, V. And G. Chesters. 1981. *Handbook of Nonpoint Pollution Sources and Management*. Litton Educational Publishing, New York, New York.

Table 1. March 1 - September 30 1994 Loadings in Kilograms (determined by using daily flows and estimating daily concentrations)

	Total Phosphorous		Ortho Phosphorous		Ammonia		Nitrite + Nitrate		Total Nitrogen		5-Day BOD		50-Day BOD		Total Organic Carbon		Dissolved Organic Carbon		
Notlichucky	100322	47166	1429430	2744098	2809126	7533676	7230357	5278140											
	(95378)	(30880)	(259319)	(706285)	(1883908)	(3669347)	(4813195)	(2824637)											
French Broad	155978	105678	1330243	2999245	3052025	9161505	7835750	6942270											
	(82013)	(48971)	(385917)	(1070835)	(1419004)	(2589156)	(4528314)	(4024368)											
Pigeon	52961	34189	522326	1181141	1552179	4367658	6012156	5342872											
	(33745)	(16163)	(156045)	(276083)	(886127)	(1347964)	(5329361)	(3374927)											
Holston	330182	195956	3392013	7150169	11477154	31075410	20646109	15239349											
	No Data Available																		
Middle Fork Holston	7257	5715	211311	311182	273214	737931	475135	411986											
	(4743)	(3346)	(47439)	(68077)	(140028)	(167533)	(246632)	(194426)											
South Fork Holston	7474	3777	161377	328119	444370	1093717	800457	648925											
	(3941)	(2920)	(36639)	(83003)	(164312)	(289000)	(439714)	(350701)											
Watauga	4553	1817	67877	155110	188506	511330	469590	250452											
	(3062)	(1126)	(22648)	(48400)	(126927)	(290131)	(317244)	(171071)											
Clinch	31540	16080	545199	1347227	1756595	4811041	4873934	3530837											
	(20626)	(15068)	(289512)	(467368)	(991772)	(1494317)	(2483307)	(1940227)											
Powell	25309	14624	546261	1068197	1116107	3066082	2622928	2268011											
	(19221)	(11080)	(160511)	(326504)	(614032)	(985606)	(1361319)	(1242659)											
Notteley	4492	3240	36018	113482	144279	426999	403283	306437											
	(3797)	(3164)	(12698)	(41030)	(86479)	(154291)	(260232)	(206558)											
Toccoa	10109	4341	37387	207197	436573	1195283	1023155	760985											
	(8953)	(4069)	(40014)	(91689)	(277859)	(586336)	(818600)	(656932)											
Hivassce	2475	1757	10623	80183	123852	383485	270463	228869											
	(1424)	(1340)	(4846)	(30129)	(62493)	(176742)	(164880)	(124743)											
Shooting Creek	1972	1267	15153	71592	88789	274488	246645	208659											
	(1425)	(1228)	(8909)	(31699)	(56564)	(137172)	(133226)	(129147)											

Note: Numbers in Parentheses are Standard Deviations

Table 2. Loadings per hectare for March through September 1994 (kg/ha)

	Total Phosphorous		Ortho Phosphorous	Ammonia	Nitrite + Nitrate	Total Nitrogen	5-Day BOD	50-Day BOD	Total Organic Carbon		Dissolved Organic Carbon
	Phosphorous	Phosphorous							Organic Carbon	Organic Carbon	
Nolichucky	0.2318	0.1090	0.1522	3.3026	6.3400	6.4902	17.4058	16.7050	12.1946		
French Broad	0.3264	0.2212	0.2209	2.7839	6.2767	6.3872	19.1728	16.3983	14.5285		
Pigeon	0.2963	0.1913	0.2357	2.9220	6.6076	8.6832	24.4337	33.6334	29.8893		
Holston	0.4243	0.2518	0.2995	4.3587	9.1878	14.7479	39.9313	26.5299	19.5823		
Middle Fork Holston	0.1152	0.0907	0.0862	3.3530	4.9376	4.3352	11.7090	7.5392	6.5371		
South Fork Holston	0.0919	0.0465	0.1216	1.9847	4.0355	5.4652	13.4514	9.8446	7.9810		
Watauga	0.1152	0.0460	0.1134	1.7166	3.9228	4.7674	12.9317	11.8761	6.3340		
Clinch	0.0830	0.0423	0.0965	1.4352	3.5464	4.6241	12.6646	12.8302	9.2946		
Powell	0.1270	0.0734	0.1142	2.7414	5.3607	5.6011	15.3869	13.1630	11.3819		
Notely	0.2607	0.1880	0.2965	2.0903	6.5858	8.3731	24.7806	23.4042	17.7839		
Toccoa	0.1680	0.0722	0.1337	0.6215	3.4441	7.2570	19.8687	17.0075	12.6495		
Hiwassee	0.2101	0.1491	0.3406	0.9015	6.8044	10.5102	32.5429	22.9517	19.4220		
Shooting Creek	0.2004	0.1287	0.2040	1.5396	7.2741	9.0214	27.8895	25.0605	21.2009		

Table 3. Defined Multiple Linear Regression Results (excluding Georgia Rivers)

Constant	Estimate	Total Phosphorous	Ortho Phosphorous	Ammonia	Nitrite + Nitrate	Total Nitrogen	5-Day BOD	50-Day BOD	TOC	DOC
Pasture	p-value	-0.0034		-0.0017						
	Estimate	0.0030		0.0309						
Agriculture	p-value	0.0536		0.0259		0.5187				
	Estimate	0.0016	0.0097	0.0194	0.5770	0.0013				
Forest	p-value	0.0011	0.0154	0.0009	0.0000	0.0198	0.0355	0.0981	0.0978	0.0788
	Estimate	0.0004		0.0005		0.0002	0.0000	0.0000	0.0002	0.0009
Urban	p-value		0.0310							
	Estimate		0.0005							
Strip Mines	p-value									
	Estimate									
Wetlands	p-value									
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Table 4. Equations for Determining Loadings in Watersheds
(March 1 - September 30)

$$\text{Total Phosphorous (kg/ac)} = (-0.0034 \bullet P) + (0.0536 \bullet A) + (0.0011 \bullet F)$$

$$\text{Ortho Phosphorous (kg/ac)} = (0.0097 \bullet A) + (0.0310 \bullet U)$$

$$\text{Ammonia (kg/ac)} = (-0.0017 \bullet P) + (0.0259 \bullet A) + (0.0009 \bullet F)$$

$$\text{Nitrite + Nitrate (kg/ac)} = (0.5770 \bullet A)$$

$$\text{Total Nitrogen (kg/ac)} = (0.5187 \bullet A) + (0.0198 \bullet F)$$

$$\text{5-Day BOD (kg/ac)} = (0.0355 \bullet F)$$

$$\text{50-Day BOD (kg/ac)} = (0.0981 \bullet F)$$

$$\text{Total Organic Carbon (kg/ac)} = (0.0978 \bullet F)$$

$$\text{Dissolved Organic Carbon (kg/ac)} = (0.0788 \bullet F)$$

Where:

P = % Pasture

A = % Agriculture

F = % Forest

U = % Urban

MODELING OF SUSPENDED SEDIMENTS IN LAKE CUMBERLAND

Bob Yager¹

INTRODUCTION

Lake Cumberland is located on the Cumberland River in South Central Kentucky. It is operated by the U.S. Army Corps of Engineers (COE) for flood control, water quality, water supply, hydroelectric power production, and recreation. The lake is impounded by Wolf Creek Dam at Cumberland River Mile (CRM) 460.9 with the upper end at Cumberland Falls at CRM 562.3. The reservoir is deep, with a hydraulic residence time varying from a few months to approximately one year. Temperature stratification is strong and persistent during the summer, but the reservoir is completely mixed during the winter.

Lake Cumberland experiences influxes of high concentrations of suspended sediment into the upper portions of the lake during periods of heavy rainfall and runoff into the reservoir and tributary streams. These sediments originate both from the tributary stream beds and the areas of the watershed that have been strip mined. Subsurface plumes of high concentrations of suspended sediment are formed and often move downstream where they are discharged through the hydroelectric turbines. The COE model CE-QUAL-W2 was applied to the reservoir using the suspended solids algorithm in CE-QUAL-W2 to simulate suspended sediments. The major purposes of the modeling effort were to evaluate the suitability of CE-QUAL-W2 for simulating suspended sediment dynamics in Lake Cumberland, and to improve understanding of the suspended sediment dynamics.

MODEL CONSTRUCTION

Wolf Creek dam is located at Cumberland River Mile (CRM) 460.9 and the upstream end of the reservoir is at Cumberland Falls, CRM 562.3. The drainage area is 5,789 square miles at the dam and 1,977 square miles at Cumberland Falls. Flow is gauged at the dam and the upper end of the lake. Local inflows explicitly included in the model are listed below. Inflows from ungauged tributaries were estimated from gauged tributaries and drainage area ratios. The water budget was closed by assigning flow to distributed tributaries along the Cumberland River and the South Fork. Inflow temperatures and suspended sediment concentrations were estimated from available data. Meteorological data from Bowling Green were used.

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A branched version of CE-QUAL-W2 was developed for Lake Cumberland. The only constituents modeled were temperature and suspended solids. The suspended solids algorithm was used to simulate suspended sediments. The model grid consists of six branches, with a total of 101 segments and 34 layers. The Cumberland River is Branch 1 and the South Fork is Branch 2. Segment lengths are 3,000 m in branches 1 and 2 and 5,000 m in branches 3–6. Segment orientation was assigned by measuring the orientation at each segment midpoint on an AutoCad drawing of the reservoir.

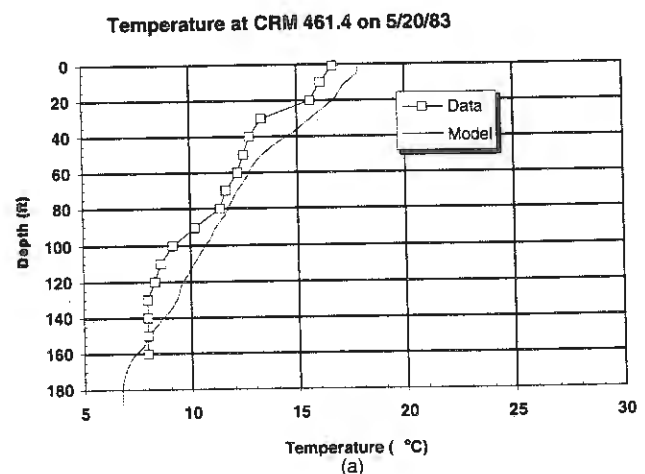
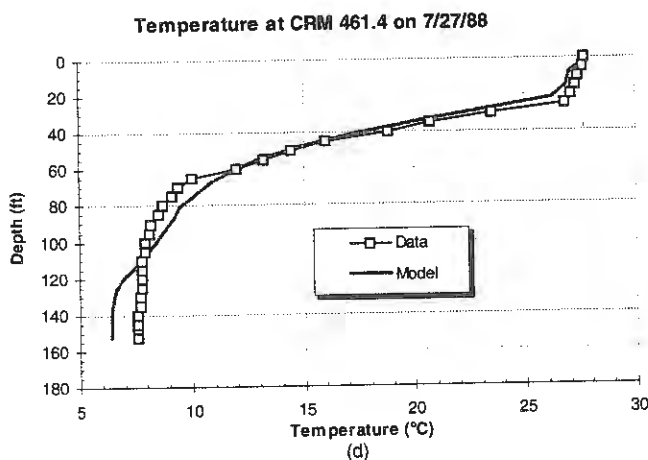
Table 2-1. Drainage Areas of Cumberland River Tributaries

Stream	CRM at Mouth	Drainage Area at Mouth (square miles)	Drainage Area at Gauge (square miles)	Ratio of Total Area to Gauged Area
Laurel River	552.1	289.0	—	—
Rockcastle River	546.4	763.0	604.0	1.26
Buck Creek	533.8	294.0	165.0	1.78
South Fork Cumberland River	516.0	1,382.0	954.0	1.45
Fishing Creek	508.2	179.0	—	—
Wolf Creek	476.2	95.8	—	—
Beaver Creek	466.8	234.0	43.4	5.39
Indian Creek	462.7	48.7	—	—
Total		3,285.5		
<i>Unaccounted For</i>		<i>526.5</i>		

Note: All drainage areas from TVA, 1962.

CALIBRATION

Temperature data were available for 1983 and 1988 and suspended sediment data were available for 1983. The simulated temperatures agreed well with field data using default parameters in the model. Typical examples are shown below.

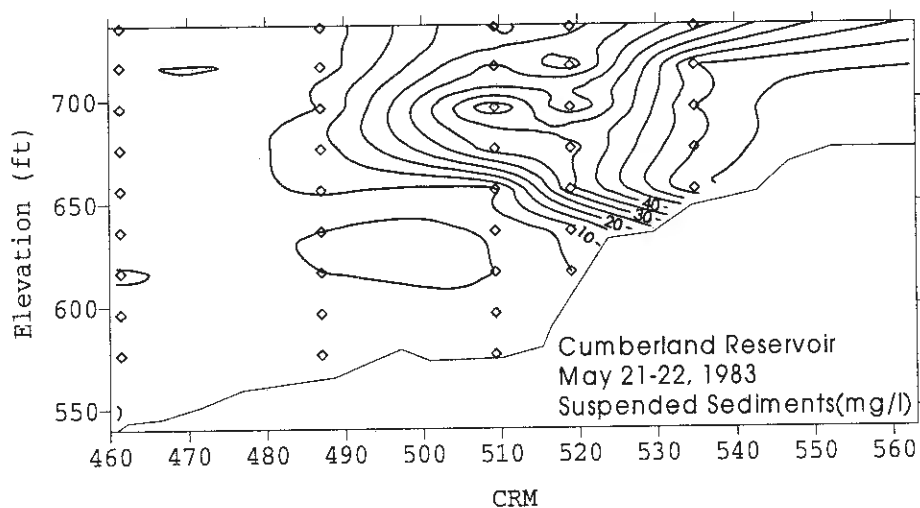


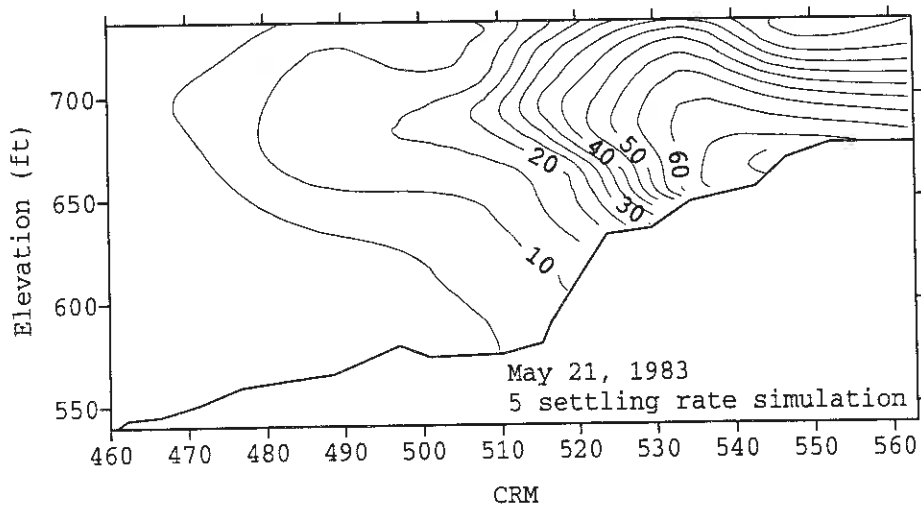
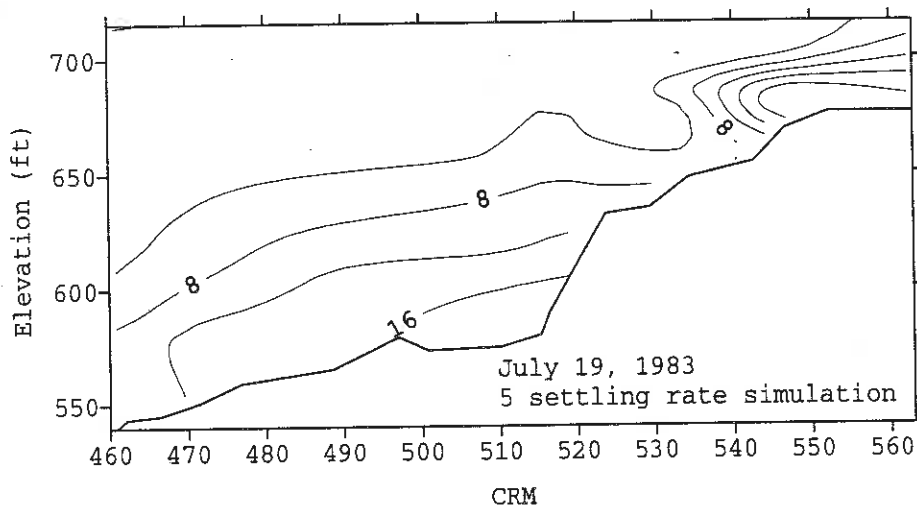
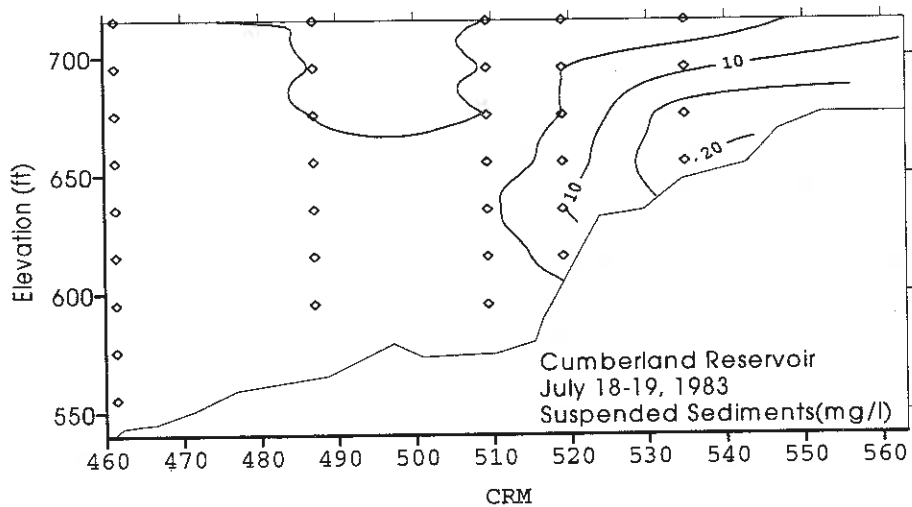
Initial simulations of suspended sediments yielded predicted concentrations in the lake an order of magnitude greater than measured concentrations. The concentrations in inflow to the lake were reduced by a factor of 10 but the agreement with field data was still poor.

MODEL MODIFICATIONS AND ADDITIONAL SIMULATIONS

Since suspended sediments consist of a continuum of grain sizes and the suspended solids algorithm in CE-QUAL-W2 allows only one suspended solids component with one settling, the code was modified to allow for a user-defined number of components. This was accomplished by dividing the inflowing suspended sediments among a user-defined number of fractions, each with its own settling rate. The maximum number of fractions is set with a parameter in the control file. The number of fractions, the partitioning of the suspended sediments among these fractions, and the associated settling rates are also assigned in the control file. The concentration of each fraction is included in all processes that affect the movement of suspended solids throughout the code including inflow, settling, advection, and diffusion. For model output, the fractions are summed to report a single suspended solids concentration.

While this modification allowed simulations which more closely matched the field data, the results were still unsatisfactory. Further refinements to the code allowed more precise definitions of the locations of suspended sediment inflow to the model. Examples of comparison of model output with field data are shown in the following figures.





The model shows suspended sediments being advected downstream and overpredicting concentrations in the downstream portion of the reservoir. The data indicate a slow settling and dilution of the suspended sediment plume with very little movement toward the dam. A plausible explanation for the lack of success in simulating the observed suspended sediment concentrations is the nature of the suspended solids compartment in CE-QUAL-W2. While the addition of the ability to partition the suspended solids into several size fractions and associated settling rates has improved the model, critical processes are not included.

Suspended sediments consist of a continuum of particle sizes with different settling rates and chemical and physical properties. The distribution of particles is affected by advection, diffusion and settling of particles, and by the agglomeration of particles to form larger ones with higher settling rates. In addition, organic material may grow on particles to modify their size and settling rates. (Data from Gordon indicate an organic content of about 20% for suspended sediments in Lake Cumberland during 1983.) These latter processes are influenced by the physical, chemical, and biological environment. The agglomeration of particles could be included in the CE-QUAL-W2 model by incorporating these processes into the suspended solids subroutine. The formulation would consist of additional terms to add and subtract particles of each size fraction and would be of the form;

$$\frac{\partial n_k}{\partial t} = 1/2 \sum_{i+j=k} \alpha_p \lambda(i,j) n_i n_j - n_k \sum_{i=1}^{\infty} \alpha_p \lambda(i,k) n_i$$

where $\lambda(i,j)$ is a collision frequency depending on Brownian motion, fluid shear, and differential settling; α_p is a collision efficiency which parameterizes the fraction of collisions that will result in agglomeration; and n_k is the concentration of particles of size k . $\lambda(i,j)$ depends on the hydrodynamics, and α_p is a function of particle composition and water chemistry.

This process of agglomeration could reduce the difference between the model results and the field data. Particles enter the upstream portion of the reservoir with a certain size and settling rate distribution. As they are advected downstream, smaller particles would form larger particles as time passed, leading to a more rapid settling of suspended sediments in the downstream portion of the reservoir. This process would reduce the simulated suspended sediment concentration, particularly in the lower reaches of the lake, and help explain the depletion of suspended sediments with very little downstream advection, as indicated in the field data from May, June, July, and August of 1983.

The data collected by Gordon indicate that the process of agglomeration is possible. The zeta potential was found to be generally between -10 and -20 millivolts, which is in a range for which agglomeration may occur (Gordon, 1985). Without further model development, it will not be possible to accurately simulate suspended sediments in Lake Cumberland with the CE-QUAL-W2 model.

TRACING OF BROMIDE ENTERING RESERVOIRS FOR NONPOINT POLLUTANT EFFECT ASSESSMENT

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INTRODUCTION

Nonpoint source water pollution remains the predominant degrader of this nation's streams, lakes, and reservoirs. NPS contaminants are responsible for 73 percent of the oxygen demands, 84 percent of nutrient loadings, 98 percent of bacterial concentrations, and 99 percent of suspended sediment in waters of the USA (Rogers and Rosenthal, 1988). Therefore, nonpoint pollution is the dominant source of degradation of the nation's surface waters, especially lakes and reservoirs, at the present time (Foran et al., 1991).

Sound, economically-based water quality management requires that the planning of remedial measures include the identification, measurement, and quantification of the NPS contaminants followed by an evaluation of water quality effects. Since NPS contamination originates over broad non-homogeneous regions and pollutant fluxes are intermittent, the mode of conveyance is not often entirely understood. Therefore, the fate of the contaminants and their effects on water quality are not amenable to analysis by conventional hydraulic techniques (Marsalek, 1991). A typical problem involves proving a direct linkage between contaminant loadings and water quality degradation. A method for tracing continuous and slug-dose nonpoint contaminant inputs into reservoirs is needed to link sources, fates, and effects of these pollutants and allow for cost effective remediation measures.

GOALS

The goal of this project was to develop methods for tracing nonpoint sources of contaminants directly from their source into lakes and reservoirs. The exact effects of nonpoint loadings on a

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reservoir depend upon the placement of stream flows into the often stratified reservoir and the response of biological systems to the chemical and physical environment incurred. Reservoir surveys can usually show the effects on water quality, but cannot link such changes directly to the inflowing stream's NPS.

The basic idea is that a tracer should be able to be placed on the ground at a suspected NPS site where it will remain until a storm event picks up the tracer and transmits it along the stormwater runoff path to a stream which then provides inflow into a storage reservoir. In the reservoir or lake, the tracer can be detected using cost-effective analysis techniques. If detection needs to be backed up, there should be laboratory procedures available for the tracer material. Any additional low cost field and laboratory measurements should also be used to back up the tracer movements.

Bromide ions and conductivity appear to be promising tracers which should allow NPS tracing. Bromide concentrations are very low throughout the natural environment and are typically less than one percent of the chloride concentrations (Bowman, 1984). It can be measured with a combination electrode system in the field at an equipment cost of about \$2000 per system. Conductivity can be remotely monitored and easily measured in the field with conductivity meters costing less than \$1000. Despite the uncertain nature of conductivity, it can be used to back up the bromide traces.

METHODOLOGY

Conductivity and/or bromide were thusly used as tracers in four streams entering Watauga and South Holston Reservoirs and Flint Creek which flows into Wheeler Reservoir. Watauga River and Roan Creek were traced via conductivity into Watauga Reservoir along with the South and Middle Forks of the Holston River into South Holston Reservoir. Bromide was injected into the South Fork of the Holston River and traced into South Holston Reservoir and into Flint Creek for an embayment trace.

Conductivity traces began by deploying a Hydrolab H₂O sonde unit which measured conductivity time series of the inflowing streams at locations upstream from the reservoirs. The Watauga deployment was at WRM 57 at the Highway 321 bridge. The sonde was deployed for a 24-hour period on July 20, 1994 and for a three-day period beginning on June 18, 1995. Roan Creek data measurements were taken at RCRM 10.5. The deployment locations for the South and Middle Forks were at SFRM 77.2 and MFRM 3.0 with the first on July 27, 1994 for three and a half hours and the second on June 11, 1995 for five days.

The H₂O sondes were used to continuously measure and record conductivity, temperature and pH in the reservoir feeder streams. During 1994 deployments, the readings were taken every half hour and during 1995 readings were taken every 2 hours. The units were checked daily to minimize problems. Water samples were taken during sonde deployment and analyzed for cation/anion balances which were used to confirm the trace results. Alkalinity, metals and non-

metals data were used to confirm the characteristics of the inflowing stream at the locations traced within the reservoirs.

The bromide trace for South Holston Reservoir was performed by injecting a slug dose of bromide into the South Fork of the Holston on September 16, 1994, from 3:00 to 7:00 pm, and then following the bromide "cloud" through the reservoir on September 17 and September 24, 1994. A 1400 pound dose of potassium bromide, (85 percent pure), was injected into the stream at SFRM 77.2. The flow of the stream as recorded by the nearby U.S.G.S. gage was 138 cfs giving a calculated bromide concentration of 11.3 mg/L in the stream.

Tracing of the South Fork Holston River inflow began just 12 hours later at 7:30 am on September 17, 1994. A bromide ion specific probe was calibrated in the lab and in the field prior to use. Bromide measurements were taken at incremental distances and depths in the reservoir. A Hydrolab Scout 2 was used to determine depth, pH, DO and conductivity in the reservoir and water was pumped into a bucket so the bromide concentration could be measured with the electrode. A second reservoir bromide search was conducted one week later on September 24, 1994. Water samples from the bromide plume location were analyzed for cation/anion balances. These laboratory data were used to confirm that the plume located in the reservoir was indeed the South Fork Holston River.

The second phase of this project was to determine whether bromide could be used as a tracer in a more hydrodynamically complex system such as the embayment of a mainstem reservoir. This required that tracing be performed under three reservoir hydraulic conditions which included a rising, falling, and steady reservoir surface. Bromide tracing was used to describe the embayment hydrodynamics and relate it to water quality problems in the embayment. Flint Creek watershed of Wheeler Reservoir was chosen as the study site because hydrodynamic information could help explain the poor water quality which has been observed within the Flint Creek Embayment.

The Flint Creek bromide traces were conducted with slug doses placed in the creek during three reservoir surface conditions. For the steady reservoir surface condition, the tracer studies were conducted on July 31 and on August 14, 1995. The trace for the falling reservoir surface condition was performed on October 14-16, 1995. The trace for the rising reservoir surface condition was conducted during March 28-29, 1996. A 300 pound dose of potassium bromide, which was 85 percent pure, was injected into the inflow end of the embayment. The first dose was injected at the Highway 67 bridge, FCM 6.0, and subsequent injections were later moved to the Red Bank bridge, FCM 9.0. The flow into the embayment was determined from the U.S.G.S. stations on Flint Creek and West Flint Creek using drainage areas to ratio the flow to either the Highway 67 or Red Bank bridge. After each injection, the bromide "cloud" was followed through the embayment using a combination electrode calibrated in the lab and in the field prior to use. At Flint Creek, water was pumped through a flow-cell equipped to accommodate the bromide probes.

APPLICATION RESULTS

Both tracing techniques employed in the first phase exhibited good and bad qualities. Conductivity, as a tracer, was easy to use as the Hydrolab sondes could record and measure conductivity *in-situ*, did not require chemical addition and were economical. Tracing with conductivity worked well in all Watauga River and Roan Creek applications. Conductivity was successfully used to trace a rain event into Watauga Lake. The trace of the Middle Fork of the Houston River into South Houston Reservoir on July 28, 1994 with conductivity was not as successful because of a mixing zone created by a bridge immediately downstream from the confluence of the South and Middle Forks of the Houston River. This mixing zone made it impossible to trace either river singularly into the reservoir. However, the conductivity trace did show the mixing zone created at the bridge, an important factor when applying tracing studies.

Conductivity should be considered as a tracing mechanism for streams which do not encounter mixing zones in their paths prior to entering strongly stratified reservoirs; however, it will not provide as exact a trace as other tracing methods.

The bromide trace of the South Fork of the Houston River through South Houston Reservoir on September 17, 1994, verified the existence of the mixing zone that was created immediately following the confluence of the South and Middle Forks at SFRM 72.3. If the mixing regime were not present at SFRM 72.3, the bromide cloud would probably have remained more "intact," traveling into the reservoir in a more confined layer. The position of the bromide plume one week following the initial application of bromide was in a deep layer near the dam. The plume had moved considerably during the week due to fall drawdown of the reservoir. Figure 1 shows the position of the bromide cloud in South Houston Reservoir during the trace. Based on this application, bromide appeared to be a good tracer to use when slow moving water, such as an inflowing stream, moves through a stratified storage reservoir at quite low velocities.

The second phase of this project was to determine whether bromide could be used as a tracer in a hydrodynamically complex system such as the Flint Creek embayment of Wheeler, a mainstem reservoir. The first Flint Creek trace was during July 31-August 1, 1995. After the 300 pound dose of KBr was injected, the bromide cloud was located at nine positions over a 6.5 hour time interval. The average embayment velocity was 460 feet per hour and the flow in the embayment was initially upstream before turning downstream for the remainder of the trace. The second trace was during August 14-15, 1995. After injection, the bromide cloud was located at 12 points over a 9 hour period. The average embayment velocity was 316 feet per hour and included almost equal periods of upstream and downstream flow. Figure 2 shows the path of the bromide for this trace.

The third trace was during October 14-16, 1995. The bromide cloud was injected and subsequently located at 7 points over a 52 hour period. The average velocity was 242 feet per hour and included mostly downstream flows. Two periods of reverse flows were encountered. The fourth trace was during March 28-29, 1996. The embayment flowed strongly downstream

and the cloud was detected 5 times over 24 hours. The cloud covered a total distance of 6.6 miles at velocities ranging from 385 to 3160 feet per hour.

While the rapid in and out movement of embayment waters was very interesting and has some important water quality ramifications, the goal was to evaluate the bromide tracing technology. While there is promise for bromide tracing of reservoir flows, several problems became evident. In the laboratory, the response time of the bromide electrode systems ranged from 20 seconds to 10 minutes, and was normally about 30 to 60 seconds. In the low velocity environment of stratified South Holston Reservoir, this was adequate. However, in fast moving Flint Creek, response is entirely too slow and an adequate trace with an appropriate mass balance is impossible. Some modification of the detection system or sampling system is needed for this method to be entirely effective.

CONCLUSIONS

Bromide has potential for tracing non-point contaminants into and through reservoir systems. The best applications are at stratified reservoirs having long retention times and low horizontal velocities. Fast response systems like a mainstem embayment act like estuaries with back and forth flushing related to main lake generation/storage operations. In these systems, the response time of the current electrode measurement system is too slow to accomplish a reliable trace.

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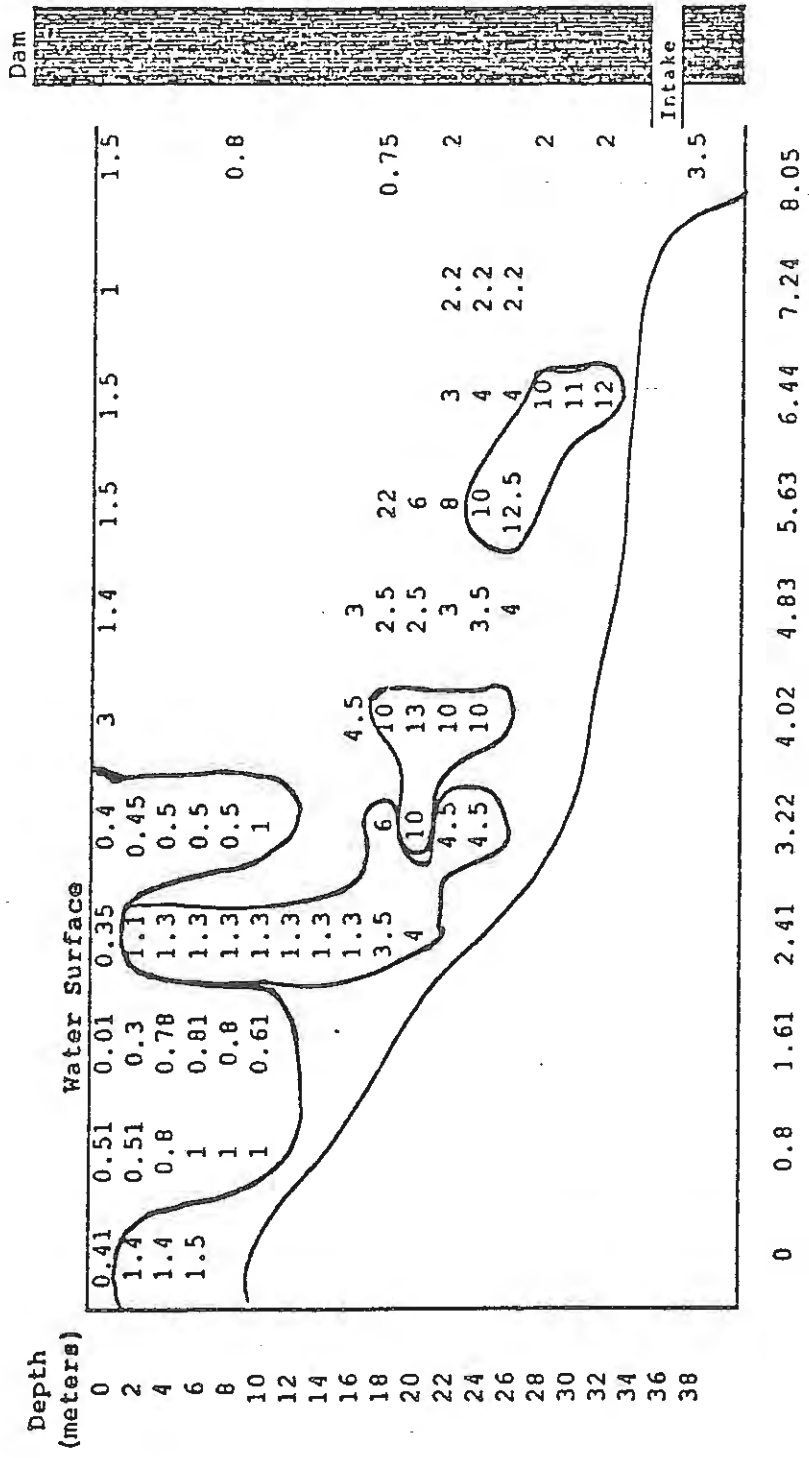


Figure 1. September 24, 1994, bromide trace of the South Holston Reservoir

Bromide concentration in ppb

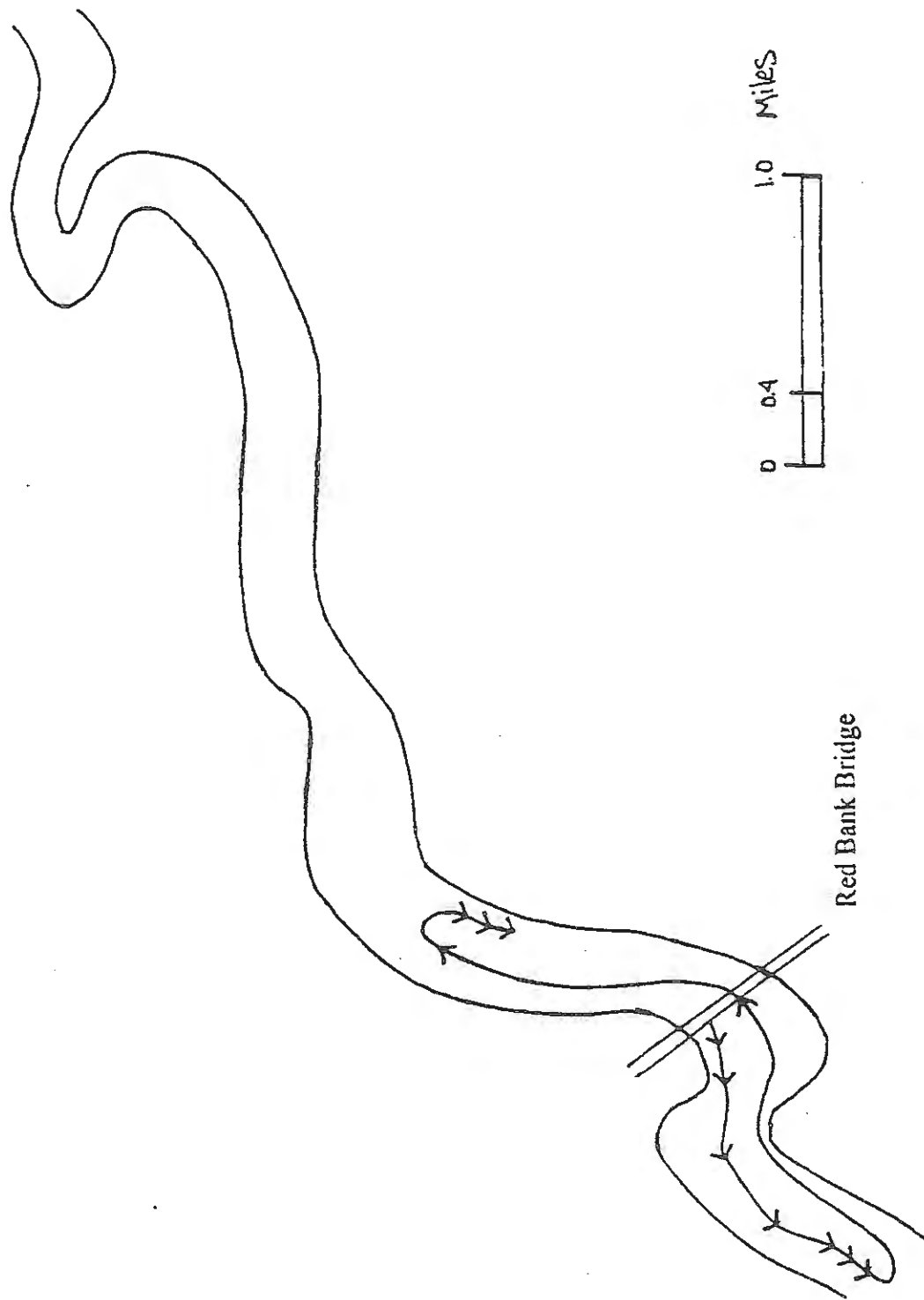


Figure 2: Movement and Location of Bromide Cloud for Field Study No.2.

WETLAND MITIGATION BASED ON A SUCCESSION OF FUNCTIONS

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and

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Historically, wetland mitigation between owners and regulatory agencies has been based on a multiplier of acreage. Regulatory agencies guidelines typically call for mitigation plans based on wetland acreage. North Star Steel and Broken Hill Proprietary (NSS/BHP) recognized their responsibility as owners in perpetuity and desired to base their wetland mitigation on quality of function as well as quantity of wetland.

NSS/BHP planned to build a mini steel mill at the junction of Ohio State Route 2 and Fulton County Route 109 Fulton County, Ohio. The Delta (Ohio) National Wetland Inventory Map does not indicate the presence of a wetland on the property; however, the local Soil Conservation Service had classified a portion of a ten-acre woodlot as being "wet forest land." The area was nearly level with poorly defined drainageways. The woodlot was surrounded by open fields used for row crop agriculture drained by subsurface drainage tiles. Approximately two acres of wetlands were delineated in the woodlot. The Buffalo District of U.S. Army Corps of Engineers required mitigation by replacement of the two acres with three acres. NSS/BHP decided to replace the two acres with approximately eight acres.

The principal objective of mitigation was to replace the wetlands with wetlands that would serve equal, although different, functions and would become a forested wetland through succession. Other mitigation objectives included: establishment of wetland bank for future use, net gain of wetlands for Fulton County, increasing quality of wetland functions in the region, and enhancement of ecological diversity in the region.

The soils in the wetland to be replaced were in the Hoytville Series and Nappanee Series of lacustrian origins on glacial till. Hoytville Soils are considered to be hydric soils in Fulton

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County, Ohio. Hoytville Soils are deep, very poorly drained clay loams that are gleyed in the upper 8 inches. The Nappanee Soils are deep, poorly drained loams with slow permeability. Both are on heavy clay more than 120 feet deep.

The natural vegetation of the region was deciduous forest dominated by basswood (*Tilia americana*), a facultative tree (FAC). Other trees included silver maple (*Acer saccharum*) [FAC], sugar maple (*Acer saccharinum*) [FAC+], red maple (*Acer rubrum*) [FACW], ash (*Fraxinus*) [FAC, FACW-], cottonwood (*Populus deltoides*) [FAC], red oak (*Quercus rubra*) [FAC], pin oak (*Quercus palustris*) [FACW], and shagbark hickory (*Carya ovata*) [FACU]. The wetland was in a young forest with approximately 80% of the trees being less than 6 inches in diameter. The estimated canopy was approximately 50 percent and there was no structured understory and sparse ground cover .

The wetland bordered a drainage way that had been dredged approximately 50 years ago with the spoils being deposited along its left bank descending. This formed a hydrologic barrier resulting in seasonal hydrology that supported the wetland. The wetland hydrology was comparable to *Zone IV* (Seasonally flooded) and *Zone V* (Temporarily flooded).

The wetlands served the following limited functions.

- Wildlife support - The wetlands were a portion of a woodlot surrounded by agricultural fields. Most of the trees, sparse understory, and ground cover provided little wildlife support.
- Habitat - The homogeneous woodlot was composed of young trees and a sparse floor cover. Deer were transient. Rodents, rabbits, and birds tended to be dependent on edge effect and agricultural fields for habitat.
- Recreation - There was some hunting of squirrel, rabbit, and deer in the woodlot.

Short-term and long-term functional objectives were established and the site plans were engineered to accomplish the objectives. These functions included:

- Flood attenuation - Temporary storage of surface and vadose water draining from agricultural fields.
- Sediment deposition - Velocity attenuation and filtering actions of water draining from agricultural fields would extract sediments.
- Nutrient retention, transformation, and release - Physical and biological processes will transform soil and commercial nutrients from surrounding farms into biological tissues or bind them in soil sediments. They will be released slowly into receiving waters.
- Removal, transformation, and deposition of pollutants - Biodegradation, chemical, and physical activities within the wetland will remove much of the chemical pollutants in water from surrounding farms, roads, and urban sources entering the wetland.
- Aquatic food chain support - Slow leaching on nutrients into receiving waters will provide nutrient expansion of the Law of the Minimum during periods that would

normally be low in nutrients. It would also serve as a feeding ground for mobile animals that would return nutrients to water courses.

- Wildlife support - The wetland will transition from open water to upland, thus providing diverse habitat support for wildlife. The site was seeded with marshland species and planted in Obligate and Facultative Wet trees. The early years will support marshland type wildlife and the mature wetland will support hardwood bottomland wildlife.
- Habitat - Habitat diversity ranging from the permanent standing water to uplands was designed into the mitigation. Brush piles provide early shelter and foci for increasing rate of succession. A variety of den boxes and bird houses will also provide habitat for the early years.
- Recreation - A trail around the perimeter and boardwalks that extend over a portion of the wetland provide observation opportunities. A parking area provides access.
- Education - Interpretative plaques in the parking area and along the trail inform visitors of wetland functions and values. A partnership was established with the local school system to use the wetland as an outdoor classroom.

The site chosen for the new wetland was a fallow agricultural field with Haskins and Nappanee soils. Boring indicated the deep soils were colluvium over a clay layer greater than 130 feet thick. At 8-10 feet there was a layer of stiff, gleyed silty clay indicating a historical wetland. The topsoil was removed and stockpiled to be returned as the final surface layer. The remaining colluvium and a portion of the clay layer were removed and used as fill at other locations of mill construction. The bottom was graded with a 2 percent fall toward the outfall end thus making an impermeable basin. A series of deeper depressions was dug with interconnecting channels to form ponds. The stockpiled Nappanee/Haskin surface soils were returned to the basin to serve as an 18-24 inch deep soil substrate for the new wetland. Several loads of topsoil excavated from the original wetland were also spread on the surface to "seed" the new wetland with plants from the natural wetland.

A low head dam was created by soils rip-rapped with stone greater than 4 inches in diameter to regulate high water levels. Four-inch diameter stand pipes were also placed in ponds to regulate the low standing water levels. The latter would slowly release water and provide capacity for future flood attenuation. By adding and removing sections of the standpipes, the hydrology of the wetland can be managed to meet objectives. For example, water saturation in the first year can be kept low to enhance early growth of Facultative to Facultative Wet trees and can be increased in subsequent years to limit upland forbes and grasses.

Native wetland species were planted. Obligate and Facultative Wet nursery stock were strategically placed to best serve the functions of a mature wetland. Native forbes in commercial wildlife mixes recommended by the Soil Conservation Service provide ample cover to protect disturbed soils during the first year. These stabilized the soils and provide protection for the newly planted trees. This rapid establishment of ground cover also prevented encroachment of monotypic noxious plant domination. Topsoil from the original wetland provided natural "seeding" for the new wetland. Succession is also being accelerated by a couple of well

established techniques. For example, rows of string were stretched across the site to create a "fence row effect" by providing roosts for birds that in turn accelerate seed dispersal.

Undesirable and nuisance plants (such as cattails [Typhaceae], giant reed [*Phragmites australis*], purple loosestrife [*Lythrum salicaria*], etc.) often upset the ecological balance in young constructed wetlands and will be discouraged by selective mowing or removal of plants. In extreme cases the area from which these are spreading will be cultivated with a tiller and reseeded with more competitive desirable species. Buttonbush (*Cephalanthus occidentalis*) may be planted at these location to rapidly shade the ground, thus preventing growth of the undesirable plants, with a plant having wildlife value. These areas will receive additional monitoring attention. Otherwise, long-term wetland stabilization will be ensured through natural succession to an eventually reforested state.

Hydrology will be maintained by passive drainage of runoff from farmland on the westerly side of the site into the wetland. The basin will be imbedded into the heavy clays with the surface level being regulated by lowhead dam and stand pipes. If the water level is not adequate, the stand pipe will be elevated. Other water sources are available from storm water management if necessary.

A monitoring program was designed to assess the condition of the wetlands and to determine if they are serving these functions at any given time. The monitoring plan in turn drives the management program to help the wetland develop the designed functions. All vegetative treatments for the project require monitoring on the following schedule:

- The site will be inspected at least twice the first growing season to evaluate stability of the site and coverage, germination, and growth of the vegetation. Spot reseeded and selected mowing are planned to limit invasion of upland species. Appropriate adjustments in hydrology will provide wetland species competitive advantages.
- Inspections were designed for the second growing season to determine if adequate hydrology is being provided and whether the vegetation was successful in reseeded. The monitoring program considers that natural processes will selectively eliminate some vegetation types from some areas as dictated by local conditions and vegetation requirements thus leading to long-term succession. The invasion and selection of undesirable plants will be detected and the appropriate actions will be taken. Trees will be measured to determine their growth rates and decisions can be made relative to a need for fertilizing selected trees.
- In the fifth year inspections will determine whether the vegetational succession is continuing to provide soil stability and erosion control, as well as providing habitat suitable for wildlife characteristic of the region. The soils will be evaluated to determine their stabilization and progression toward hydric soil characteristics.

The major success criteria will be the wetlands' ability to support hydrophytic vegetation that is progressing, by natural succession, toward a bottomland hardwood wetland community. Ninety

percent ground cover during the growing season composed of 80 percent Facultative or wetter species with no monotypic populations would be acceptable. Survival of 85 percent of the planted tree species will denote success. In addition to surviving, these trees are expected to double their mean diameter at breast height.

**DEVELOPMENT OF HYDROGEOMORPHIC MODELS
FOR WETLAND FUNCTIONAL ASSESSMENT
IN WESTERN TENNESSEE**

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and

Thomas Roberts²

Bottomland hardwood forests (BLH) are the dominant type of wetland in western Tennessee. Estimates of the exact acreage of BLHs that existed historically in the state are not available, although it is clear that a substantial portion has been cleared and converted to other uses. Dahl (1991) estimated that Tennessee lost nearly 60 percent of its wetland acres between the 1780s and the mid-1980s. More precise figures on Tennessee's original wetland base and the amount remaining will be available during the next few years as digitization of National Wetland Inventory (NWI) and hydric soils data bases are completed and integrated using GIS technology. Precise figures on the acreage of BLH wetlands that have been lost in Tennessee are not needed to demonstrate that the drainage and clearing that has occurred during this century has had significant environmental costs.

The Tennessee Wetlands Conservation Strategy (TWCS) highlighted that many of Tennessee's wetlands have been altered or lost, thereby eliminating their potential to perform many of their natural functions (Governor's Interagency Wetlands Committee, 1994). Some of the major problems identified with the loss and alteration of BLH systems include excessive and prolonged flooding, unwanted sediment deposition, water quality degradation, and loss of wildlife and fish habitat. The degree to which wetlands have been impacted varies widely among regions of the state and among wetland types, but generally the most significant alterations have occurred in the BLH communities of western Tennessee. There, all major drainages except two, the Hatchie River and part of the Wolf River, have been drastically altered by channelization and the BLH forests remaining have been highly fragmented.

In 1987, The Conservation Foundation convened the National Wetlands Policy Forum. One recommendation of the Forum was that all states undertake the preparation of State Wetlands Conservation Plan for wetland management issues. In 1989, Governor Ned McWherter

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appointed an Interagency Wetlands Committee (IWC) to advise him (Governor's Interagency Wetlands Committee 1994), and in July of 1990, the state of Tennessee was awarded a grant by EPA to develop a Wetlands Conservation Plan. A subcommittee, the Technical Working Group (TWG), produced the Tennessee Wetlands Conservation Strategy which was endorsed in February 1994 by Governor McWherter as an official instrument of state wetlands policy. As a result of this policy, and grants from the EPA, Tennessee is developing a method for assessing wetland function.

Several agencies have been involved with the development of a new generation of assessment techniques. The most promising of these advances made in recent years is related to development of the Hydrogeomorphic Classification System for wetlands (Brinson, 1993). The Hydrogeomorphic (HGM) system is designed to group functionally similar wetlands based on (1) geomorphic setting, (2) water source and its transport, and (3) hydrodynamics. Geomorphic setting is the topographic location of the wetland within the surrounding landscape. Five geomorphic settings are described; depression, slope, flat, riverine, and fringe. Three primary water sources are given: precipitation, surface or near surface flow, and ground water discharge. Hydrodynamics refers to the direction of flow and strength of water movement within the wetland. Using geomorphic setting, water source, and hydrodynamics, Brinson (1993) identified the following five major hydrogeomorphic wetland classes: (1) slope, (2) depression, (3) fringe, (4) riverine, and (5) flat. Each of these classes can be subdivided into regional hydrogeomorphic subclasses based on factors at the landscape and ecosystem scale.

The U.S Army Corps of Engineers Waterway Experiment Station (WES) is coordinating the development of procedures that can be used to evaluate the functions of various HGM wetland categories. Working groups composed of wetland ecologists and scientists from many disciplines have worked to develop guidebooks for the HGM classes. These are intended to serve as a starting point for the development of models for various functions with application at the regional, state, and/or local levels. It is intended that these templates be evaluated, tested, and refined to improve their ability to perform at the desired scale (Smith et al., 1995). The guidebook appropriate for use in the bottomland hardwood wetlands (BLH) of western Tennessee is A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands (Brinson et al., 1995).

The HGM functional assessment method is refined regionally in stages. The first phase of the HGM procedure is classification. An interdisciplinary group familiar with BLHs of western Tennessee was formed. This group is known as an Assessment Team or "A-Team." The wetland class and subclass of interest, riverine lower perennial in this case, is defined, and a functional profile of those wetlands is developed. The region in which the models will be applied to an HGM subclass is known as a reference domain. Also in this phase, wetlands (reference wetlands) which serve to represent the range of conditions for that class within that region (reference domain) are chosen by the A-Team. Wetlands which exhibit the highest level of sustainable functions (i.e. the least disturbed) are known as the reference standard wetlands. In the next phase, the development phase, the guidebook models of function are modified for

application to a specific reference domain, and reference wetlands are sampled so that the models may be calibrated. The final phase is the actual application of the method in wetland regulatory or management activities. A more complete description of the program for assessing the functions of HGM categories of wetlands can be found in Smith et. al. (1995).

Wetlands perform numerous valuable functions that have been described thoroughly in the literature (Sather and Smith, 1984; Adamus et al., 1987). Functions specified by the Governor's Interagency Wetlands Committee for wetlands in Tennessee are found in the TWCS. These include four broad categories and are listed in Table 1. along with those given by Brinson et. al. (1995) for riverine wetlands.

TABLE 1. Lists of wetland functions in the literature.

Brinson et al. (1995)

1. Hydrodynamics
dynamic surface water storage
long-term surface water storage
energy dissipation
subsurface storage of water
moderation of groundwater flow
2. Water quality
nutrient cycling
removal of imported elements & compounds
retention of particulates
3. Ecosystem
organic carbon export
maintain characteristic plant community
maintain characteristic detrital biomass
maintain spatial structure of habitat
maintain interspersions and connectivity

TWCS (1994)

1. Water quality enhancement
sediment/toxic substance retention
nutrient removal/transformation
2. Flood impact mitigation
flood peak reduction
erosion potential reduction
3. Biological productivity
aquatic species
semiaquatic species
wetland wildlife species
vegetation
food chain support
4. Ground water influence
ground water recharge
flow augmentation
ground water discharge buffering

maintain distribution and abundance of invertebrates
maintain distribution and abundance of vertebrates

In addition to these functions which correspond closely with those identified by Brinson et al. (1995), Sather and Smith (1984), Adamus, et al. (1987), and others, the TWCS listed several direct human benefits that can be derived from wetlands. These include recreation, education, timber production, and agricultural production. It is important to differentiate between these latter benefits or values and the previously mentioned functions that wetlands perform. The two concepts are not interchangeable.

METHODS

The Assessment Team (A-Team) met in December 1994 to discuss potential reference sites in the reference domain and to list the conditions that could be expected. In April of 1995, the A-Team met in Jackson, TN, to investigate potential reference wetland sites and to familiarize themselves with the Hydrogeomorphic (HGM) functional assessment method (Smith et al., 1995). During this meeting, there was consensus that sites on the Hatchie River represented the least disturbed riverine wetlands in the reference domain. The Hatchie National Wildlife Refuge near Brownsville and sites on the Wolf River were chosen as reference standards. Also during this meeting, criteria were discussed for selecting sites that would represent more disturbed conditions within the HGM subclass. An aerial reconnaissance was made that month of the Wolf, Loosahatchie, Hatchie, Forked Deer (and its 3 forks), and Obion (and its 4 forks) Rivers of most of their entire length. Sites were chosen on the Forked Deer River and the Obion River systems to represent conditions more disturbed than the reference standard. Data collection began in May of 1995 and continued through the summer of 1996.

Vegetation was sampled using 20 m² plots (0.04 ha), divided into four equal subplots of 10 m² (0.01 ha). At the 0.04 ha scale, trees and snags greater than 10 cm diameter at breast height (DBH) and vines greater than 1.25 cm DBH, were measured using a Biltmore Stick at a point approximately 1.2 m from the ground. If a tree forked below this point, it was measured and recorded as two trees. Species and DBH of each were recorded. Also recorded at the 0.04 ha scale were the species and number of trees, and number of snags between 2.5 cm and 10 cm DBH, although the DBH of these were not measured. Trees less than 2.5 cm DBH and vines less than 1.25 cm DBH, but taller than 1.5 m, were counted and species recorded in the southwestern subplot only.

Other variables measured at the 0.04 ha scale were: the number of canopy gaps, the number and type of log decomposition categories, number and type of vertical vegetation strata, a visual estimate of percent of the plot covered by microtopographic depressions that may pond water, an estimate of microtopographic deviations, and evidence of water dynamics (scouring, sediment deposition, etc.). At the 0.01 ha scale, large woody debris (including limbs, logs, and stumps), greater than 2.5 cm in diameter were sampled in the southwestern subplot only. The length of each log and limb, and the diameter of each stump, was estimated using the Biltmore Stick.

Vegetation at ground level was sampled in each of the four subplots using the point intercept method (Floyd and Anderson, 1987; Mueller-Dumbois and Ellenberg, 1974; Raelson and McKee, 1982). Ground level vegetation was defined as any living plant 1.5 meters above the ground. A point on the southern edge of each subplot was selected randomly, then a compass bearing was generated to give direction. The compass line was paced until a boundary of the subplot was encountered, whereupon a new compass bearing was generated to give a new direction. One sample point was made at each step; twenty-five points were taken in each subplot for a total of 100. At each point, a hit or miss was recorded for leaf litter, small woody debris, vegetation, and canopy. The leading edge of the Biltmore Stick was used to determine

hits and misses, except for canopy data. Canopy cover was measured using a sighting point similar to methods described by Mueller-Dumbois and Ellenberg (1974) and Johansson (1985). The height of any vegetation and its species and the depth of any leaf litter also were recorded.

In May of 1996, WES sponsored a workshop in Cadiz, KY, to refine the models found in the Riverine Guidebook for use in the Coal Fields of western Kentucky and the Gulf Coastal Plain of western Tennessee. Experts in hydrology, biogeochemistry, ecology, and soils were brought together to evaluate and refine the models. The models that were developed at that three-day workshop are the most current. The models will be calibrated using the data collected from the reference wetlands in western Tennessee, and these calibrated models will then be taken to the field and applied and assessed for consistency, usability, and accuracy.

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**“EDUCATION:” A VALUE-ADDED COMPONENT
DESIGNED INTO MITIGATION WETLANDS FUNCTIONS**

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and

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North Star Steel and Broken Hill Proprietary (NSS/BHP) built a mini steel mill in Fulton County, Ohio. The construction required filling approximately two acres of wetland and required mitigation by constructing a new wetland. Since NSS/BHP would own the wetland in perpetuity, the wetland was designed to have many functions. NSS/BHP requested education be added to the conventional functions.

The wetland function was designed to serve two segments of the community: visitors and local schools. Interpretative plaques have been placed along the trails to inform people of the characteristics and values of wetlands in general and the specific functions in this wetland. Local organizations (such as garden clubs, bird clubs, etc.) have cooperated in production of timely interpretative displays and pamphlets of natural history of the site.

The school administration and teachers were brought into the planning of the educational functions from the outset of mitigation design. Physical attributes having direct educational functions include school bus parking, trails, observation decks, and interpretive signs. Teachers and administrators were supplied technical drawings of the site plans.

Teacher training related to the site was identified as a key element in effective use of the resource, thus a series of teacher workshops has been conducted based on such curricular resources as *Project Wet*, *Wonders of Wetlands*, *Aquatic Wild*, and *Project Wild*. The approach is across the curriculum from grades K through 12. Vocational Technology students are involved in building houses for birds, bats, etc. and building a functional model of a wetland. In addition

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to class activities the wetland is available for long-term science fair projects and class projects that progress with that group of students through high school.

Cargill, North Star Steel's parent company, awarded Delta Schools a grant to initiate utilization of the wetland by science teachers of the Pike, Delta, York Local School system, to purchase books and equipment, to conduct teacher workshops, and to connect the schools to National Geographic Kids Network. The teachers have formed an organization that established and maintains a Wetland Resource Center, coordinates curriculum requirements, develops grant proposals, and seeks additional training through workshops.

Classes of elementary school students participated in field trips to the site to learn the characteristics of wetlands and see the plan being put into place. Following the concepts "across the curriculum - throughout the schools," a mentoring program has been established in which high school students work with classes of elementary students on select projects. For example, the Delta Future Farmers of America provided leadership to three fifth grade classes in planting trees, shrubs, and other wetland plants in the wetland.

To protect the fragile ecosystems, the use will be restricted to certain locations and activities dependent on the season, successional stages, wear, etc. Visitors will be restricted to trails. At present, only the Pike, Delta, York Local School system is permitted to use the wetland. Each student must have parental permission for each visit to the site.

CHANNEL EVOLUTION IN JARRELL BOTTOMS, TENNESSEE

Timothy H. Diehl¹

Jarrell Bottoms is the reach of the South Fork Obion River (SFO) and its associated wetlands from U.S. Highway 79 to just downstream from Christmasville Road, in Carroll County, Tennessee. Channelization of the river isolated sections of the original channel from the newly constructed drainage canal. Drift and sediment filled the SFO drainage canal in two reaches, first at the mouth of Reedy Creek and, later, just downstream from the Louisville and Nashville Railroad bridge. These two blockages created a valley plug and diverted the flow of the SFO across the valley bottom and into sections of its previous meandering channel. The SFO is gradually establishing a single main channel through this valley plug, with most sections of the new channel containing the base flow of the river.

The flow pattern around the more recent upstream blockage includes ponded areas and multiple channels. Just upstream from the railroad bridge, most base flow leaves the canal and flows southwest in the ditch between the railroad and U.S. Highway 79. The remainder of the base flow exits the ditch just downstream from the railroad and flows through a small channel leading northward toward the original channel. At the south edge of the valley bottom, the main flow passes through a relief bridge under the railroad. Sand passing under the relief bridge is building a delta that presently extends about 600 feet westward from the bridge. Below this delta, the SFO flows through a large ponded area, then through a sinuous channel that reenters the drainage canal between the two blockages.

Flow in the reoccupied natural meandering channel bypasses the second, less recent blockage. At the upstream end of the blockage at the mouth of Reedy Creek, several small channels flow northward from the canal to a meandering channel in the open marsh. This channel rejoins the natural channel at the mapped location of the Todd Creek drainage canal, which is filled with sediment. The SFO follows its natural channel from the former location of the Todd Creek ditch to Christmasville Road. Just downstream from Christmasville Road, most flow reenters the canal through a short cutoff that has formed since 1991.

All the sand carried into Jarrell Bottoms by the SFO accumulates within a short distance downstream from the railroad. As a result, the SFO has excess bedload transport capacity in the two short multiple-channel reaches downstream. It will likely widen and deepen the largest of the multiple channels in each of these reaches. The smaller channels may remain open, because little

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sediment enters them, or woody debris may block them. Throughout Jarrell Bottoms, the apparent trend is toward the formation of a well-defined channel conveying the base flow.

The depth of the re-established main channel is adequate for small boats even during summer low flow. Hunters and fishermen maintain a boat trail passable by canoes and johnboats through most of Jarrell Bottoms by cutting small gaps in drift that blocks the dominant channel. In multiple-channel reaches, these gaps concentrate flow in the deepest channel. Boat-trail maintenance is contributing to the re-establishment of a single main channel throughout Jarrell Bottoms.

THE KENTUCKY LAKE EMBANKMENT PROTECTION PLANTINGS: A HISTORICAL OVERVIEW

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SUMMARY

The Tennessee Valley Authority (TVA) planted over two million trees from 1942 to 1946 along the embankments and dikes of Kentucky Lake, the reservoir formed by Kentucky Dam. Twenty bottomland species were planted to serve as an inexpensive and attractive means of wave erosion protection for relocated road and railroad embankments, as well as dewatering area dikes. The purpose of this study is to perform a detailed examination of the history of the plantings. It will provide information about historical TVA planting practices, reservoir embankment protection plantings, and the history of Kentucky Lake. Many of the planting sites may have now become functioning wetlands. Knowledge of their planting history will be crucial in evaluating the success of the species planted in those sites.

INTRODUCTION

The Tennessee Valley Authority (TVA) built many high dams, such as Kentucky Dam, to create large capacity reservoirs to hold surcharge water and prevent large river-stage fluctuations. Kentucky Dam, located in Marshall and Livingston counties (Kentucky), was built to control flooding at the mouth of the Tennessee River. The dam's reservoir, Kentucky Lake, is located on the Tennessee River in Western Kentucky and Tennessee between the Kentucky Dam (river kilometer 36) and Pickwick Landing Dam (river kilometer 332). The reservoir is located in five Kentucky counties (Livingston, Marshall, Lyon, Calloway, and Trigg) and ten Tennessee counties (Humphreys, Benton, Decatur, Hardin, Wayne, Henry, Henderson, Perry, Stewart, Houston and Carroll) (Tennessee Valley Authority, 1951). It has a total of 3258 kilometers of shoreline (excluding islands) at normal pool level (elevation 119 meters). Kentucky Lake covers both the riverine area that was once the main channel of the Tennessee River, as well as adjacent

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mesic land. In the early 1940's, due to the pending inundation of Kentucky Lake, TVA relocated some of the area roadways to roadbeds atop newly constructed, elevated embankments located on the reservoir, its shorelines and dewatering areas. Areas at the base of the new embankments were expected to be flooded during flood storage operations and seasonal water level changes. Since flooding would place the embankments in danger of water erosion by wave action, it was necessary to take protective measures. TVA foresters and engineers used belts of bottomland trees as a method of erosion protection for these areas, with the expectation that the tree boles and branches would effectively dissipate waves. TVA planted over two million trees using 20 water-tolerant bottomland forest species along the base of these embankments from 1942 through 1946. A complete, detailed description of the history of the plantings has not yet been published.

METHODS

The existence of the Kentucky Lake embankment protection plantings was virtually unknown until their rediscovery in the 1980's by a TVA forester. His interest led to the discovery of much of the original planting records. Most of the original planting records were found in the TVA Forestry Building in Norris, Tennessee, including planting forms and maps, original photographs, correspondence, and project reports. Additional reports and correspondence were obtained from the National Archives in Georgia. The Archives' original documents were examined, and copies filed at TVA in Norris for future access. Planting record information was recorded in database and polygon maps, accessible through GIS systems, from the original planting maps for many of the plantations (Emerson, 1994). Attempts were made to contact surviving TVA foresters who were involved in the original project for informational interviews. When this proved unsuccessful, living relatives and colleagues were contacted and interviewed.

RESULTS

TVA raised, relocated, and protected 543 kilometers of road, as well as many miles of railroad. Many of these roadways were relocated onto earth embankments that were susceptible to water erosion from wave action. Since rock was not readily available for riprapping, protective tree belts were used along the base of these embankments. Some dewatering area dikes were also expected to experience wave erosion, and the protective tree belt method was applied to them as well. Some of the areas surrounding the embankments and dikes were treeless, primarily due to former agricultural use (Tennessee Valley Authority Planting Records, 1941-1946). TVA designated 66 of these sites for the establishment of embankment protection planting belts. The belts were located on marginal land between the normal pool shore line and 17 m from the toe of the embankments or dikes (Tennessee Valley Authority, 1951).

Each potential planting site was given an identification number. A general reconnaissance of each site was made, in which the number of seedlings needed, acreage of land to be planted, potential costs, and a general work schedule were estimated. A detailed evaluative reconnaissance of each planting site was then made. Site characteristics such as acreage, soil

type, slope, and existing erosion were evaluated and recommendations made for the planting of "water tolerant species, mixtures, and spacing best suited to the various sites" (Allen, 1944). Each planting site spanned from one to five tracts. Tracts were individually evaluated for planting. These tracts ranged in size from 0.08 to 9.92 hectares (Tennessee Valley Authority Planting Records, 1941-1946).

A total of twenty tree species were planted. Species were selected according to their ability to survive in existing site conditions with water tolerance qualities being of key importance. Seventeen species often found in southern bottomland hardwood forests were selected for planting, including two softwood species (*Taxodium distichum* L. and *Pinus taeda* L.). Three softwood species not typically found in southern bottomlands, *Chamaecyparis thyoides* L., *Thuja occidentalis* L. and *Pinus strobus* L., were also planted. All planting was performed using either sapling transplants or cuttings, and took place during the dormant season. As each tract was planted, information such as planting dates, weather conditions, species planted, spacing, and source and condition of transplants was recorded. In some cases, the desired species was unavailable and substitutions of other water tolerant species were made. If no water tolerant trees were available, the planting was postponed (Silker, 1943). Most transplants were provided by the TVA Wilson Dam, Alabama and Clinton, Tennessee nurseries, however, some seedlings and cuttings were imported from other geographic areas including Wisconsin and Kansas (Tennessee Valley Authority Planting Records, 1941- 1946). Planting maps were drafted which showed plantation locations and recorded various plantation landmarks, such as the location of highways or bodies of water (Tennessee Valley Authority Planting Maps, 1941- 1946). In some cases, photographs were also taken of the site or planting process.

The tree belt planting took place from February 26, 1942 to April 2, 1946. A total of 66 plantings were established on over 490 hectares of land, including eleven on disturbed sites such as borrow pits. Between one and four foremen and 35 to 100 laborers were hired each fiscal year to serve as planting crews. Each crew was overseen by technical foresters (Allen, 1944). At various times during the year, survival reconnaissance missions and general reports on the condition of the plantings were made (Allen, 1944). If seedling survival appeared to be low on any given tract, the tract was reevaluated and later replanted. At least one tract on 35 of the 66 total plantings was replanted.

In order to insure the survival of the planted saplings, protection measures were taken against damaging agents such as fire and livestock. Reports containing recommendations for fire and grazing control for many tracts in the embankment protection plantings were produced. Thinning tests were performed on four sites in 1960 according to established guidelines (Allen, 1960). Three of the four sites were reexamined in 1965, which resulted in the recommendation of the systematic thinning of other sites to alleviate tree competition. This thinning was never carried out. General survivorship reconnaissance was performed throughout the planting to determine the necessity of replants (Allen, 1944). A discussion of survivorship sampling plans can be found in various TVA Forestry correspondence of the mid-1950's, however, sampling was continually postponed in favor of other projects. In 1947, the survivorship of eight species in 445

hectares of drawdown and surcharge zone plantings that had reached five years of age was examined (Silker, 1948).

TVA published a brief general history of the first nine years of the plantings (Tennessee Valley Authority, 1951). A few TVA reports and correspondence were produced in the 1960's, and the plantings were then essentially abandoned and forgotten until their rediscovery in the 1980's by a TVA forester. Both the plantings and roadway embankments still exist, and many of the planting sites may have become functioning wetlands. The historical planting records and reports should prove invaluable when examining the success of these plantings as erosion deterrents, as well as evaluating some of the species in terms of their use in wetland restoration.

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**WESTVACO'S ECOSYSTEM-BASED MULTIPLE USE
FOREST MANAGEMENT SYSTEM:
THE STATE OF THE ART IN WATER QUALITY PROTECTION
ON INDUSTRIAL FOREST LANDS**

Gary E. Mullaney¹

INTRODUCTION

Throughout our history, Westvaco's forest management systems have changed and evolved as our forest researchers and land managers have developed new approaches to produce the wood fiber needed by our customers while protecting the other values of the forest. As the intensity of our management has increased, so has the need to maintain a balance between economic, environmental, and social concerns. We reached an important milestone when we formalized our System for managing company forestlands. We call it Ecosystem-based Multiple Use Forest Management. This comprehensive System enables us to provide the wood and paper products people need and the forests they want.

Our objective is to meet our fiber supply mission targets while, through good stewardship, maintaining the other benefits of the forest for present and future generations. Specifically, the Ecosystem-based Multiple Use System is designed to meet those objectives in a manner that:

1. Maintains water quality in lakes, rivers, and streams;
2. Provides diverse wildlife habitat;
3. Maintains the visual quality of our forestlands; and
4. Protects areas of special significance.

In addition, we use the System, its written Guidelines, and an internal forest practices audit as means of ensuring that our forest management adheres to state and federal regulations, state Best Management Practices (BMPs), the American Forest and Paper Association's Sustainable Forestry Initiative, and Westvaco's own internal Forest Management Principles.

To apply Ecosystem-based Management, we classify company forestland into one of six zones, each having a primary and numerous secondary functions. The six zones have as their primary management objectives: timber or fiber production, water quality, protection of special areas, wildlife and habitat diversity, visual quality, and lastly the ongoing management of non-forest areas. In laying out the six zones over the landscape, our forest managers use their personal knowledge of Westvaco's land base and our computerized forest information system to consider all of these factors. This illustration of our management system, shown on the screen, was developed to explain Westvaco's ecosystem management to our customers and the general public. I want to emphasize that in practice about 75 percent of our land is classified for

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intensive fiber production and the other five zones comprise the remaining 25 percent. Due to oversimplification for illustrative purposes, this artwork tends to suggest that a larger portion of our land is in non-timber production than is actually the case on the ground.

WATER QUALITY ZONES

Water Quality Zones are the first planning layer we identify because they are fixed on the landscape (we can't move them) and maintaining high water quality standards is an essential objective of our forest management. Water is both an important product of the forest and a measure of ecosystem health. Water Quality Zones are forestlands where water quality protection and enhancement are emphasized over other values. These areas are generally adjacent to rivers, streams, or lakes that function as water collectors or water conduits. State BMP guidelines normally require some degree of Streamside Management Zones, or SMZs. These are usually stated as a minimum width of vegetated cover to be left on each side of a stream, and are usually only required on perennial streams. We normally expand them to much wider corridors to provide an extra measure of stream protection and to enhance wildlife habitat. In addition to the required SMZs, we extend our Water Quality Corridors further upstream to include intermittent streams to provide even more water quality protection and habitat diversity. Table 1. shows the width standards that we apply in Tennessee.

SPECIAL AREAS

Special Areas are sites of unique or unusual biological, geological, or historical significance. They are managed to protect those special qualities. Examples include historic sites, endangered species habitat, nature trails, and cemeteries.

NON-FOREST ZONES

Non-Forest Zones are areas where it is not possible or desirable to grow a crop of trees. Examples include roads, utility rights-of-way, lakes, non-forested wetlands, rock outcrops, and building sites.

TIMBER MANAGEMENT ZONES

Timber Management Zones are the areas where wood fiber production is our primary objective. They are the reason we own forestlands. They represent close to 75 percent of our total ownership and consist of both natural stands and high yield plantations of both pine and hardwood. Plantations comprise 40 percent of our land base and are managed very intensively through the application of technology, such as genetic improvement, site preparation, fertilization, and competition control to maximize fiber production. Because our plantations are grown specifically to produce fiber under intensive management systems, they are all harvested by clearcutting followed by replanting with even more genetically advanced seedlings.

In natural stands of mixed species, which represent 35 percent of our Timber Management Zones, we use several systems of harvesting. Clearcutting to remove all stems followed by natural regeneration predominates because the unmanaged forest on much of the land we bought does not contain the stocking we desire in terms of species mix, age distribution, or quality. In those cases, we prefer to remove the existing stand and start over from the ground up with sprouts and natural seedlings.

Clearcutting has other positive aspects and when measured against other harvesting systems, it is often economically and ecologically the best approach. Clearcutting mimics natural events such as windstorms and wildfires without the associated destruction of valuable wood fiber. The sites are quickly reforested, and a new forest cycle of growth begins. For many important tree species the even-aged regeneration process is a natural part of their life cycle. When the dense canopy of older growth is removed, species that cannot grow without full sunlight, like loblolly pine, are given optimum growing conditions. Low growing vegetation that cannot grow in dense forests provides important browse for wildlife. With today's harvesting technology, the use of BMPs, and proper planning, it is possible to extract wood fiber by clearcutting while leaving forest ecosystem functions intact. However, we are using and experimenting actively with a variety of other systems that do not remove the entire timber stand at harvest, and we are extending the use of these systems as we increase the area of forest with suitable conditions.

Timber Management Zones vary somewhat in size depending on topography and geographic area, but normally do not exceed 500 acres in size. Each Timber Management Zone is made up of several smaller stands of timber of varying age classes. Harvesting and cultural treatments are normally carried out at the stand level. We limit the size of our clearcut harvests to 40 acres in Appalachia, and last year the average size of our pine plantation harvest unit in South Carolina was only 57 acres. Division-wide our average stand size is less than 60 acres, so there is a lot of diversity within a single Timber Management Zone. Furthermore, a period of time must elapse and newly regenerated stands must achieve a minimum height before adjoining stands can be harvested.

Our harvests are, therefore, dispersed throughout the forest landscape I have described, and in no circumstances do we employ the immense and highly visible harvests of hundreds of contiguous acres that give clearcutting its bad reputation with the public and environmental groups. You may be familiar with the proposal in the state of Maine to regulate clearcutting. Our system of small, dispersed cuts as part of Ecosystem-based Forest Management has not generated opposition.

HABITAT DIVERSITY ZONES

Where natural landscape features do not already limit our Timber Management Zones to less than their maximum allowable size we establish Habitat Diversity Zones. They are managed less intensively for wood fiber production and more intensively for wildlife habitat and biodiversity. The real emphasis is on providing more mature forests and habitat than is available in our Timber Management Zones. That type of habitat is critical to certain wildlife species. We also use

Habitat Diversity Zones to connect other Zones so that we form a web of continuous, mature forest habitat interspersed with our younger, vigorous stands.

VISUAL QUALITY ZONES

There are areas where we need to preserve aesthetic quality or soften the visual impact of forestry operations. In these situations, we create Visual Quality Zones. These are often established along ridge lines or well traveled public roads that border or bisect our lands. Timber harvesting in a Visual Quality Zone can only be done in a manner that protects visual quality and integrity. These areas are often temporary visual buffers that can be harvested when the adjoining younger stands become more mature and visually attractive.

CONCLUSION

The overall result of our Ecosystem Based Forest Management System is a mosaic of stand types and habitat conditions that is visually pleasing. But, we don't own the entire landscape. For that reason we seek opportunities to explain our management concept to non-industrial private landowners that join Westvaco property. We hope that they will want to extend Water Quality and Habitat Diversity Zones on to their lands.

Westvaco's style of ecosystem management as shown here, along with the technology we are applying, allows us to meet our wood needs in a manner that satisfies the social and environmental concerns of our customers and the public.

It also allows us to manage 75 percent of our forestland very intensively for fiber and the remainder for a variety of purposes including water quality protection and lower intensity fiber yields.

Our System is unique and has allowed Westvaco to maintain its position of environmental leadership in forest management. It has been well received by environmental organizations, our customers, and even other forest products companies who have come to see and emulate our management practices. The system has won recognition from state and national organizations. Since 1980 we've been recognized more than 50 times for our environmental performance in forest and wildlife management. Since 1994, most of the awards have cited our Ecosystem-based Management.

We consider this a "work in progress." In cooperation with government, academic, and environmental organizations, we are conducting wildlife and ecosystem research to enhance and refine our system. Here in Tennessee, and throughout our North American woodlands, we participate in the research and monitoring programs of the Partners in Flight Initiative, which seeks to address concerns about declining populations of certain neotropical migratory songbirds. In West Virginia, we have established the Westvaco Wildlife and Ecosystem Research Forest. The mission of the research forest is to provide an outdoor laboratory to study both the

immediate and long-term interactions of forest management activities with landscape-level ecological processes. Other cooperative ecosystem research studies are being conducted on our lands in the South Carolina Coastal Plain.

Table 1. Width of Streamside Management Zones

Type of Waterway	Minimum Width on Each Side
Major rivers and reservoirs	330 feet
Secondary rivers and large creeks	165 feet
Smaller perennial streams with terraces less than 1/4 mile in total width	165 feet
Smaller perennial streams in terraces or floodplains wider than 1/4 mile	66 feet

Water Quality Zones (minimum width 100 feet each side) are established along:

Intermittent streams in narrow "V" or "U" shaped landforms. Intermittent streams have well-defined banks and natural channels, but typically have flowing water from a headwater source for only a portion of the year.

Some ephemeral "drain" landforms with are longer than 1/4 mile, or where, because of slope and soil characteristics or other factors, intensive silviculture may be inappropriate.

**COMPARISON OF FOREST STAND EDGES
IN RIPARIAN AND MESIC HABITATS
ALONG WATTS BAR RESERVOIR SHORELINE**

Ruth Anne Hanahan, M.S.,

and

Clifford C. Amundsen, Ph.D.¹

INTRODUCTION

Approximately fifty years ago, the landscape upslope from the riverine position banks of the Tennessee River was inundated by the closing of Watts Bar Dam. Land primarily forested or farmed became a part of the newly formed shoreline (Olsen, 1938). In low-lying areas that bordered the reservoir, TVA cleared much of the vegetation in preparation for the impoundment (TVA, 1949). Studies of subsequently established forest communities in these areas have been conducted (Amundsen, 1994; Loy, 1994). Results show that stands located in shoreline habitats influenced by subsurface lateral pool inflow are compositionally similar to unmanaged southern bottomland forests. Results also show that not all of Watts Bar shoreline is predisposed to such riparian habitat conditions. Sections of the shoreline that are topographically elevated and thus minimally influenced by subsurface pool inflow contain a mesic habitat. The purpose of this research was to determine how edges of mature forest stands established in riparian and mesic habitats along Watts Bar Reservoir shoreline structurally and compositionally differ.

These habitats defend against shoreline degradation; enhance water quality by sequestering excess nutrients, chemicals, and sediments; provide allochthonous input as a base food for the reservoir's trophic web; provide faunal habitats; and contribute aesthetic, recreational, and resource values (Lowrance et al., 1984; Gregory et al., 1991; Malanson, 1993; TVA, 1996). As the Watts Bar forested shoreline continues to be lost to erosion, (Amundsen, 1994) and as development increases, conserving these ecological and socioeconomic functions increases in importance (TVA, 1996).

STUDY SITE

Watts Bar Reservoir is located in Roane, Rhea, Meigs, and Loudon Counties and has an approximate area distribution by county of 60, 20, 12, and 8%, respectively. The reservoir covers approximately 15,783 ha, which is about four times the area of the original river bed (4,186 ha).

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At summer pool, the total length of the reservoir shoreline is 1,241 km (Amundsen, 1994). TVA currently maintains Watts Bar pool levels at two principal elevations. During the growing season from spring to late summer, the pool is maintained at approximately 225.9 m (741 ft) msl. During the winter months, the level is drawn down to a minimum of 224 m (735 ft) msl. Erosion has been estimated to occur up to two meters per year along certain summer shoreline segments, with waves generated by recreational boats the primary cause (Amundsen, 1994).

METHODS

Thirty shoreline sites were selected for sampling by quadrats between May and August, 1996. Fifteen quadrats were located in a riparian habitat and 15 in a mesic habitat. Riparian and mesic habitats were distinguished by the hydric influence of the depth-to-subsurface lateral pool inflow (incursion). A habitat was identified as riparian if pool incursion at the summer pool level was estimated to be less than 0.5 m to soil surface (i.e., a low-lying area) and mesic if equal to or greater than 0.5 m (a topographically-elevated area) (Figure 1). Shoreline sites were selected using biotic and abiotic criteria. These criteria included a shoreline that: (1) contained ostensibly mature forest stands that showed minimal signs of post-impoundment disturbance; (2) was not rock-defended; (3) could categorically be classified as a riparian or mesic habitat (i.e., could not contain both types of habitats); (4) was fully exposed to wave impacts from unrestricted boat traffic on the channel sail line; and (5) had a slope less than 50%.

Each quadrat was 4 m wide x 25 m long and was located along the pool with the lengthwise edge the summer pool line. Slope and scarp height was measured at five points along the scarp edge. Scarp form was described and categorized. Canopy and edge closure was estimated from five quadrat midpoints and canopy height was measured. Vegetation data were acquired for canopy, subcanopy and sapling/shrub/liana (i.e., low profile) strata. Canopy data included species identification and diameter at breast height (DBH) measurement of trees (defined by a DBH \geq 12.5 cm). Subcanopy data included number of poles by species. Data for these two strata were collected over the entire quadrat. Low-profile vegetation was sampled by species percent coverage in three 1 m² subplots and by species presence/absence over the entire quadrat.

Characteristics of stands in mesic and riparian habitats were compared by structure (e.g., basal area, canopy height, canopy and edge closures) and composition (e.g., diversity, richness, importance values (IV) 200). Descriptive analyses (e.g., Sørensen Coefficient of Community (CC) similarity index and Shannon Index of General Diversity) and nonparametric statistics (e.g., Mann-Whitney U test) were employed for these comparisons. Canopy data were also described using Two Way Indicator Species Analysis (TWINSPAN), a polythetic divisive clustering technique. Detrended Correspondence Analysis (DCA), an indirect ordination technique, was employed to determine whether any predominant underlying environmental gradient could be detected among and within mesic and riparian habitats based on canopy species distribution. This technique uses hypothetical environmental gradients to explain principal patterns of variation in vegetation data. The possibility that the primary gradient was related to depth-to-reservoir pool incursion was analyzed qualitatively by quadrat distribution in ordination space and

quantitatively by statistical correlation. TWINSpan, DCA and correlations were performed with the PC-ORD Software Package (McCune and Mefford, 1995). Depth-to-pool estimates were calculated for the back edge of the quadrat (four meters slopedward from the pool) using shoreline geometric configuration measurements (i.e., slope and scarp height). Five estimates were calculated and then averaged for each quadrat.

RESULTS

Riparian habitat quadrats had a mean estimated depth-to-pool incursion of 0.23 m, with a range from 0.03 m to 0.49 m. Those located in the mesic habitat had a mean estimated depth of 2.7 m, with a range from 1.9 m to 4.1 m. Mesic scarp forms were broadly characterized under four categories and riparian under three (Figure 2). Vegetation data analysis results showed that sampled stands in riparian and mesic habitats were similar in productivity based on basal area, but differed significantly in their structure and composition. Stands in the mesic shoreline habitat exhibited characteristics typical of the central portion of the Ridge and Valley Province hardwood stands (Martin, 1971; Bailey, 1995). Twenty-nine hardwood taxa were represented in the canopy with oaks and hickories predominating (*Quercus* spp. IV 200 = 72.4; *Carya* spp. IV 200 = 18.8). Dominant species were *Quercus rubra* (IV 200 = 42.7), *Liriodendrum tulipifera* (IV 200 = 17.7), *Liquidambar styraciflua* (IV 200 = 13.5), and *Quercus muehlenbergii* (IV 200 = 10.8). Stands in the riparian shoreline habitat were compositionally similar to regional bottomland forests and were limited to 16 canopy species with *Acer saccharinum* predominating (IV 200 = 82.0). Other dominant species were *Platanus occidentalis* (IV = 29.5), *Betula nigra* (19.1), and *Liquidambar styraciflua* (IV 200 = 13.6). Riparian sites' anaerobic soil profiles very likely contributed to the limited species richness by selecting against taxa that were physiologically less adaptable to these conditions. An assessment of similarity in canopy species of the two habitats yielded a CC of 0.33. Only nine species were common to both habitats. The arboreal community in the mesic habitat was also significantly richer ($\alpha = 0.01$) and more diverse ($\alpha = 0.005$) than the community in the riparian habitat.

As in the canopy strata, the similarity in species in the riparian and mesic habitat stand canopies was low (CC = 0.34). Subcanopy species in the mesic stands with the highest relative density were *Ostrya virginiana* and *Cercis canadensis* and those with the highest relative frequency were *Cercis canadensis* and *Quercus rubra*. Subcanopy species in the riparian stands with the highest relative density were *Alnus serrulata* and *Ligustrum sinense* and those with the highest relative frequency were *Acer saccharinum* and *Alnus serrulata*. Diversity in the subcanopy species of the mesic stands was significantly greater than the diversity in the riparian stands ($\alpha = 0.003$).

An analysis of similarity in subcanopy and canopy species internal to riparian and mesic habitat stands resulted in CC indices of 0.78 and 0.73. These levels are sufficiently high to indicate canopy replacement and, therefore, some semblance of stand stability. Notably, in the mesic stands, *L. tulipifera* was not found in the subcanopy or the low-profile strata. This suggests that *L. tulipifera*, a pioneer species, is not reproducing in these mesic habitats and is being displaced by other species.

The low-profile strata of the two habitat stands had many more species in common than was found in the canopy and subcanopy strata comparisons. A comparison of species found within the m^2 samples in the two habitat stands resulted in a CC of 0.52, while a comparison of the species that were present across the $100 m^2$ quadrat resulted in a CC of 0.64. Species with the highest cover-frequency indices in the mesic habitat stands were *Acer rubrum*, *Lonicera japonica*, and *Rhus radicans* while those in the riparian stands were *Ligustrum sinense*, *Rhus radicans*, and *Lonicera japonica*.

There was no significant difference in bole basal area (m^2/ha) of sampled riparian and mesic habitat stands ($\alpha = 0.42$) (Figure 3). Since mesic stands were selected to be at least equivalent in age or greater, it appears that over the last 50 years basal areas of the sampled riparian stands are approaching that of their mesic shoreline counterparts. Comparisons showed a significant difference in understory density between quadrats in the mesic and riparian habitats ($\alpha = 0.02$). The riparian habitat stands had a much denser understory, often composed of *L. sinense*, *A. serrulata* and *C. amomum*. Edge closure also significantly differed between habitats ($\alpha = 0.001$). The three species most common to the riparian understory generally created a dense curtain-like cover, with bowed branches dipping into the pool edge. Canopy height ($\alpha = 0.001$) and closure ($\alpha = 0.001$) also significantly differed between habitat stands. Canopies of the stands in the mesic habitat were higher and more closed than those in the riparian habitat.

TWINSPAN results, as shown in Figure 4, confirmed compositional dissimilarity in sampled habitat stands. TWINSPAN partitioned mesic and riparian quadrats into two separate clusters on the first division of the TWINSPAN dendrogram. The only exception to this was a riparian quadrat (2R) which was placed in the mesic cluster. This quadrat was primarily composed of *A. rubrum* and *L. styraciflua*, species which have broad hydric amplitudes and are commonly found in both types of habitats. TWINSPAN also identified indicator species (Figure 4). These are species that show the highest fidelity to a cluster (i.e., are true to a single cluster), making them the best species to differentiate one cluster from another. Results from the DCA analysis segregated quadrats by habitat along a predominant underlying environmental gradient (axis). Pearson and Kendall tau-b's correlations between quadrats' species scores along this axis and depth-to-pool incursion estimates were 0.67 and 0.48, respectively. Although moderate, these correlations do support the premise that among habitats species distribution was related to reservoir subsurface inflow. Separate DCA analyses of mesic and riparian quadrats showed no predominant environmental gradient within either habitat.

APPLICATIONS AND CONCLUSIONS

Results of this study may prove useful to managing and conserving natural resources along reservoir shorelines in three ways. First, results demonstrated the importance of the relationship between shoreline geomorphology and its influence on established vegetation. This relationship should be incorporated into future shoreline inventories. Second, the finding that productivity (as indicated by basal area) was approximately equal in sampled riparian and mesic shoreline

reinforces the importance of nearshore habitat contribution to the allochthonous resource input required for sustaining reservoir aquatic life. Third, structural and compositional data provided by this research may assist the shoreline manager in better depicting the shoreline vegetation to the public.

Results also prompt two additional research questions. First, as shoreline development continues and forests become increasingly fragmented, how does fragmentation affect their overall composition and structure? Second, substantial erosion was observed along channel frontage supporting otherwise undisturbed, relatively stable forest stands. How effectively does vegetation prevent erosion in areas that are severely impacted by waves? And, at what point and under what conditions is vegetation insufficient to minimize shoreline loss?

In one-half century or less, a compositionally and structurally distinct reservoir riparian forest community has succeeded and become established along the pool-influenced shoreline of Watts Bar. Habitats along the shoreline that are elevated enough to avoid the direct influence of rhizosphere pool incursion contain forest stands similar to mesic stands described across the region. Recognition and interpretation of the differences and similarities in these contrasting shoreline communities may benefit those assessing, monitoring and managing reservoir shoreline resources and should be encompassed in future management plans.

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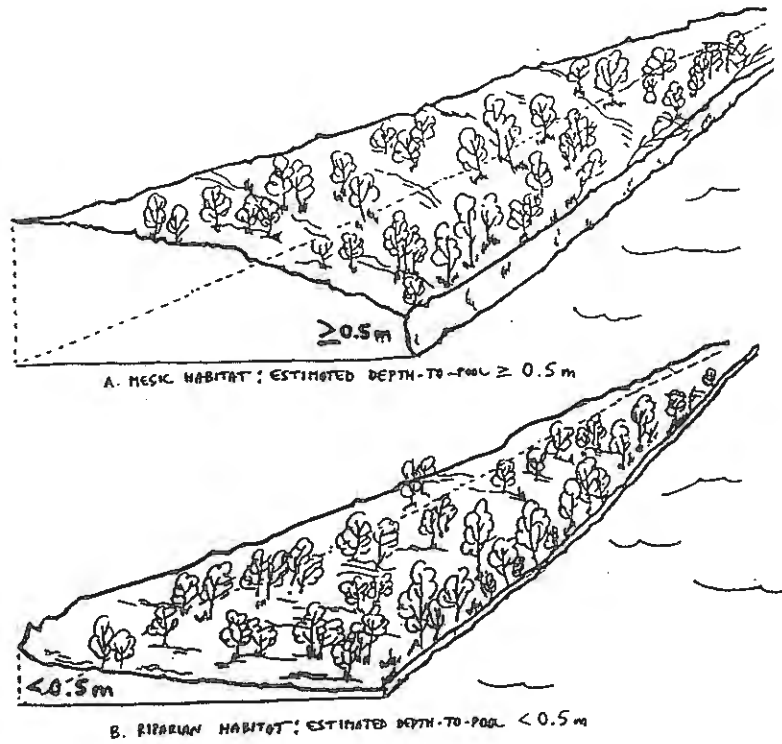
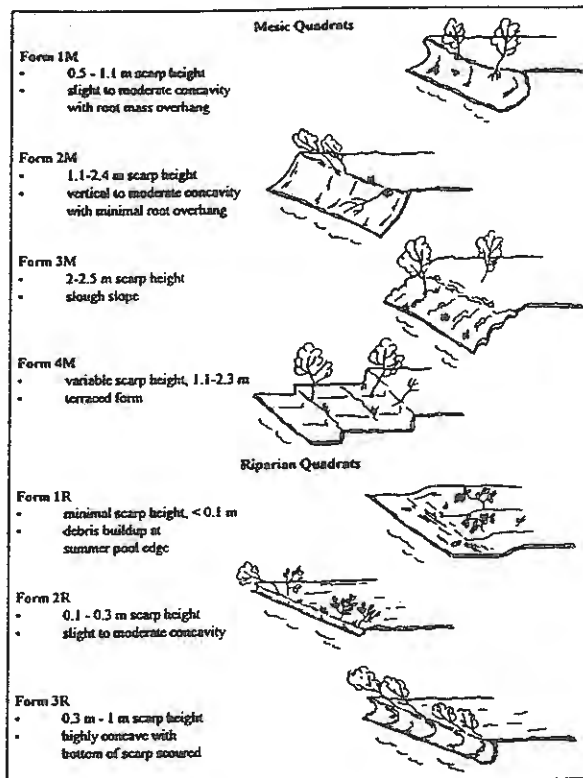


Figure 1. Graphic Depiction of Mesic and Riparian Shoreline Habitats.



*Scarp height measured from base.

Figure 2. Mesic and Riparian Quadrat Scarp Forms¹.

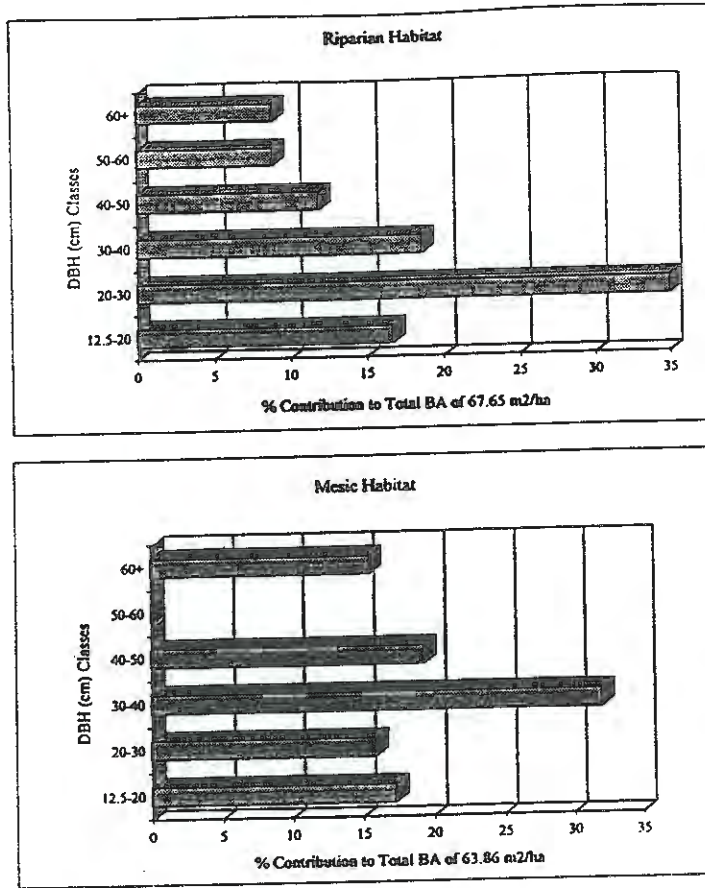


Figure 3. Basal Area Distribution by Size Class of Forest Stand Edges in Shoreline Habitats.

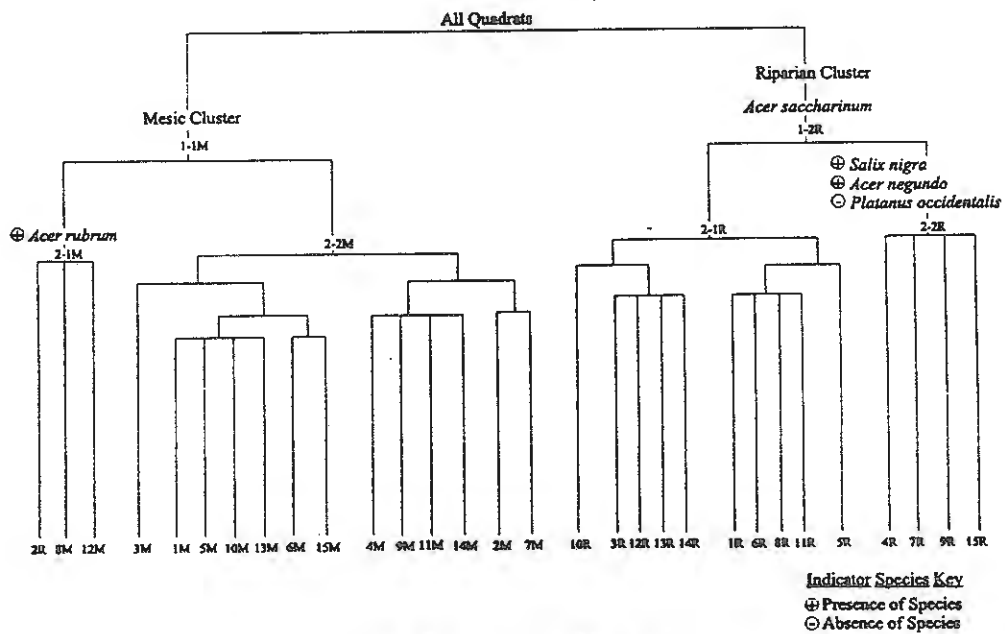


Figure 4. TWINSpan Classification of 30 Quadrats using PC-ORD.

**PASSIVE TREATMENT OF ACID MINE DRAINAGE:
A MINE WASTEWATER TREATMENT ALTERNATIVE**

Dave Turner,¹

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and

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In 1995, Sequatchie Valley Coal Corporation (SVC) implemented a passive treatment of a severe acid mine drainage condition at their reclaimed surface coal mine in Van Buren County, Tennessee. This passive treatment included a five-thousand ton high calcium carbonate Anoxic Limestone Drain (ALD), Oxidation basins, and wetlands. SVC conducted pre-installation tests for proper sizing of the ALD and wetlands. Through proper planning and field installation, the mine wastewater treatment system has produced very consistent treatment and has resulted in the improvement of water quality in both the NPDES discharge monitoring point and adjacent receiving streams (Baltimore Branch and Rocky River). SVC has worked with the Division during the entire process. With the implementation of this passive treatment, conventional chemical treatment has been eliminated with a significant economic savings.

SVC mined and reclaimed this coal mine under the regulatory authority of Surface Mine Reclamation Control Act (SMRCA) Public law 95-87. The Division of Water Pollution Control Mining Section issued NPDES permits to discharge treated mine wastewater. In 1995, the Division issued a modification of the NPDES permit to SVC. These approved plans included the implementation of a complex passive treatment system. This system included a five-thousand ton Anoxic Limestone Drain (ALD), oxidation basins and ditches, and constructed wetland treatment areas.

PROJECT PLANNING

This paper describes the planning necessary for successful treatment using passive treatment technologies. Plan development includes a comprehensive knowledge of the mine wastewater quality and hydrology. SVC documented relationships of the surface water influences as a recharge source to the mine backfill water. SVC conducted hydrologic studies of the mine area.

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These included surface water, groundwater and receiving streams near the mine area. SVC installed backfill monitoring wells that provided access to the ambient mine groundwater. This data is essential to plan development.

The planning of this project included working within the scope of federal rules that involved several federal and state environmental agencies. The Federal Office of Surface Mining and the Division were the primary reviewers of the modification of the wastewater treatment plan. These permit modifications for the SMRCA and NPDES permits required several years to obtain.

Before installation of the passive treatment, the Division and SVC had documented numerous water quality concerns that included depressed pH and elevated concentrations of metals in the mine wastewater treatment structures. SVC established and maintained conventional chemical treatment systems to field treat acid mine drainage that seeped from the mine area to treatment structures.

The approved permit modification plans allowed for the construction of a 5000 ton Anoxic Limestone Drain (ALD), two oxidation ponds with oxidation channels and a constructed wetland at SVC's Mine Area 1. Completion of the project occurred in summer of 1996. The following sections discuss project details.

ANOXIC LIMESTONE DRAIN

The design and performance expectations of the proposed anoxic limestone drain (ALD) were based on published design and performance reports as the performance of a small on-site test ALD system. The technology has been particularly reliable for the treatment of waters containing ferrous iron. The alkalinity-producing potential for ALD's is limited by the relatively low solubility of calcium carbonate, so the method is not recommended as final treatment for waters with more than 200 mg/l iron. Because groundwater discharges at SVC's Mine Area 1 contain primarily ferrous iron at concentrations less than 180 mg/l, the use of an ALD as a primary source of alkalinity was warranted.

PREDICTED ALD PERFORMANCE

In order to better evaluate the performance of the proposed ALD, two methods have been used to simulate ALD conditions at Area 1. In July 1993, groundwater from the site was incubated with limestone in a manner described by Watzlaf and Hedin at a minor drainage task force symposium in April 1993. This "cubitainer" study was intended to determine the concentration of alkalinity that would likely be produced if the mine wastewater contacted limestone in an anoxic environment. Watzlaf and Hedin reported that the alkalinity in a cubitainer after 48 hours correlates well with the concentration produced by anoxic limestone drains with detention time of at least 12 hours. Results of a cubitainer test on Area 1 groundwater indicated that 340-360 mg/l alkalinity could be expected (48 hour concentration was 340 mg/l, plateau concentration was 360 mg/l).

In January 1995, a test ALD was constructed at SVC Area 1 so that the performance of the proposed system under a variety of flow conditions could be studied. The test ALD consisted of

65 tons of limestone placed in a trench that was 58 feet long by 6 feet wide by 4 feet deep. The limestone was wrapped in plastic and buried under 1-2 feet of spoil (soil). The test ALD received water from the dewatering system. Because the influent pipe was valved, the flow rate of water through the ALD could be controlled. The test trench used a limestone tonnage:gallon per minute (gpm) of flow ratios of greater than 15. The test ALD discharged water with an average 369 alkalinity (a value in good agreement with the cubitainer test). At limestone:flow ratios less than 10, the concentration of alkalinity decreased. At a limestone flow ratio of 8 tons per gallon per minute, the effluent contained 330-335 mg/l alkalinity. This concentration of alkalinity can buffer the acidity resulting from the oxidation and hydrolysis of 185 mg/l iron. At a limestone: flow ratio of 5 tons per gallons per minute, the test ALD discharged water containing 290 mg/l, or enough alkalinity to buffer acidity associated with 160 mg/l iron.

SPECIFIC ASPECTS OF THE FULL-SCALE ALD

The full-scale ALD was designed to hold 4000 tons of 93% calcium carbonate limestone. However, an additional one thousand tons of crushed limestone was added at the bottom of excavation based on field observations and professional judgment of SVC's Mine Manager. At an average flow rate of 200 gallons per minute, the ALD provides 20 tons of limestone per gallon per minute of flow (approximately 20 hours of retention) and discharges water containing an average of 340 mg/l alkalinity. This alkalinity is 70-160 mg/l in excess of the amount of alkalinity necessary to buffer the expected iron concentrations of 100 to 150 mg/l.

OXIDATION/SETTLING PONDS

Water discharges from the ALD dropped vertically four feet for aeration before entering the settling basin. The mine wastewater is aerated by turbulent flow between the ALD and Pond A and by turbulent flow between Pond A and Pond B. Within the ponds, solids form and settle as designed. The principal solid in the ponds is iron hydroxide. Under alkaline conditions provided by the ALD pretreatment, ferrous iron readily oxidizes and hydrolyzes to form iron hydroxide.

The sizing of aerobic ponds and wetlands for the precipitation of iron from alkaline water has been approached from two directions. The U. S. Bureau of Mines used a surface area approach for constructed wetlands that measured iron removal in terms of grams of iron removed per square meter of wetland per day. Studies document an iron removal from 10 to 40 grams squared per meter squared per day. When the influent water to the SVC Area 1 settling ponds contains 150 mg/l and flows at 200 gallon per minutes, the iron loading is 17.2 grams squared per meter squared per day.

The Tennessee Valley Authority recommends that aerobic settling ponds positioned downstream of the ALD's should be sized to provide 1-2 days of retention time. Empirical studies indicate that this time period is normally necessary to precipitate dissolved iron from alkaline, aerated water. The constructed treatment ponds have 11.0 days retention time. Thus, the proposed settling ponds are sized in a manner consistent with recommendations of both the surface area method and the retention time method.

CONSTRUCTED WETLANDS

To further improve the quality of the discharge and to buffer against extreme weather events, a wetland downstream of the settling ponds was constructed. Although not critically necessary to meet discharge standards, wetland treatment is valuable in several ways. Wetlands are especially effective filtrates of suspended solids. Organic substrates contact in the wetland also results in a reduction of dissolved metals that are already present in trace concentrations. Lastly, the wetlands provide the potential for wildlife habitat.

The wetland area was designed to provide approximately 2 acres of surface area which is sufficient to remove the suspended particles yet maintain a 100-foot buffer distance from Rocky River. The average depth of the wetland is approximately two feet.

WATER QUALITY IMPROVEMENTS

In 1987, the Division conducted a watershed water quality survey and documented degraded water quality in Rocky River and Baltimore Branch. This survey showed degraded water quality upstream of the SVC mine area and similar water quality downstream of the mine area. The Division documented poor water quality in the receiving streams. These degraded conditions were related to water elevations within the mine area and dip of the coal pit bedding plain. In 1990, the Division listed Rocky River for 11.0 stream miles of 23.0 stream miles as not supporting use classification in the "The Status of Water Quality in Tennessee 305(b) Report".

SVC ground water sampling and analyses of mine wastewater demonstrate an acid mine drainage with a maximum total acidity of 403 mg/l with an average of 226.25 mg/l. Other parameters sampled that demonstrate acid mine drainage conditions include total iron with a maximum of 191.5 mg/l and an average of 154.53 mg/l. Sulfate concentrations from this ground water source had a maximum of 1790 mg/l and 714 mg/l average. The pH of the water had an average of 5.35 standard units. The ground water source from the mine back fill had a very low dissolved oxygen of less than one mg/l. Low dissolved oxygen indicates a reducing environment. The ground water source pH changed upon exposure to atmospheric oxygen with pH dropping to below 3.0 standard units. The Division documented mine wastewater as seeps and springs with similar acid mine drainage water quality.

Recent water quality data collected from the final discharge monitoring point from the constructed wetland and Rocky River indicate compliance with water quality criteria standards for the most stringent designated use: fish and aquatic life. The passive treatment system complex demonstrates remarkable treatment effectiveness with a neutral pH and total iron of 0.277 mg/l and excess alkalinity. In addition, SVC biomonitoring tests measured no toxicity in 100% wastewater concentrations.

CONCLUSIONS

The Sequatchie Valley Coal Corporation Mine 1 passive treatment project has improved water quality in both the discharge and the receiving stream. SVC anticipates cost recovery within two calendar years compared to chemical treatment costs. Successful results are a result of project planning and successful implementation by SVC personnel.

RECIPROCATING SUBSURFACE-FLOW CONSTRUCTED WETLANDS FOR TREATING DOMESTIC AND MUNICIPAL WASTEWATER

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and

Mitch Higgins²

INTRODUCTION

Constructed wetlands designed for treating domestic and municipal wastewater have been shown to be effective for removal of suspended solids (SS), biological oxygen demand (BOD₅), fecal coliform bacteria, and certain heavy metals. However, in organically rich wastewater many of the oxidative treatment processes, such as nitrification, are rate limited due to chronically low dissolved oxygen concentrations. The passive wetland designs in use today, both free water surface and subsurface-flow, rely on two limited sources of oxygen: 1) oxygen derived from aquatic plants and their associated root transport system (Armstrong et al., 1990 and Steinberg and Coonrod, 1994) and 2) oxygen diffusion from the atmosphere into the water at the air-water interface (Behrends et al. 1993). Both sources are meager at best, and are usually not sufficient to meet the high respiratory oxygen demands in wastewater treatment wetlands. Air to water diffusion is a very slow and inefficient process, and can only meet oxygen demands when the surface area of the wetland is large relative to the BOD and ammonia loading rates. Furthermore, at low D.O. concentrations (< 2.0 mg/L), nitrifying bacteria are not able to oxidize ammonia as fast as it is produced, and thus ammonia accumulates to unacceptably high concentrations, often exceeding 20-30 mg/l. Such high concentrations pose potential legal problems for municipal wetland treatment systems because they are often above mandated N.P.D.E.S. permit limits.

Within the past decade, design criteria have been developed for passive constructed wetlands (free water surface), to treat ammonia in domestic wastewaters. However, to reduce ammonia to compliance levels requires a large wetland area, often 10-12 times as large as the area

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required for adequate removal of BOD₅ and suspended solids (Knight and Iverson, 1990). Thus, designing free water surface wetland systems for ammonia removal may dramatically increase capital costs, bringing into question their utility and cost-effectiveness.

This paper will present information on a demonstration-scale subsurface-flow constructed wetland system in which vastly improved wastewater treatment is possible. Improvements are brought about by coupling anaerobic and aerobic environments within and between wetland cells via *recurrent reciprocation* (patent application filed), whereby adjacent wetland cells are alternately drained and filled on a defined and recurrent basis. This sequential and recurrent fill and drain technique provides for control of microbially mediated processes such as nitrification and denitrification. A continuum of redox-specific reactions can be controlled via system design and operation.

BACKGROUND INFORMATION

TVA's Engineering Services (ES) and the Environmental Research Center (ERC) have been involved in the design, monitoring and modification of a subsurface-flow constructed wetland designed for treating municipal wastewater. The system is located in Benton Tennessee. The original wetland design consisted of a passive subsurface flow system including 4 lined (30 mil plastic liner), quarter acre cells each @ 50' x 220'. Each lined-cell was back-filled with 18-24" of limestone gravel (45% void space). Domestic wastewater was pretreated in a large (100,000 gal. capacity), above ground septic tank. Beginning in 1992, the four cells were operated as two independent pairs with each pair operated in series. Design hydraulic loading for the 4-cell system is 50,000 gpd although actual loading has averaged approximately 23,000 gpd. Wastewater effluent from the septic tank was distributed to the wetland cells via PVC-plastic header pipes, with adjustable turn-down tees. The headers were positioned across the width of each cell rather than the length; thus cells were operated at a very low aspect ratio equal to 0.23. Figure 1 illustrates a plan view of the facility and details the direction and sequence of wastewater flow through the paired cells to a combination sump for final disinfecting and aeration. The system was designed to accommodate gravity flow of wastewater from the septic tank through the paired series of wetlands to the discharge sump. Water leaving the sump passes by gravity through a v-notch weir and into a small receiving stream.

Within two years of start-up, the subsurface flow wetland system was completely anaerobic and emitting noxious gases, i.e., hydrogen sulfide. Based on weekly and monthly samples, the facility was occasionally out of compliance with respect to state mandated effluent guidelines including five-day biochemical oxygen demand (BOD₅), dissolved oxygen (D.O.) and fecal coliform bacteria (F.C.). Ammonia levels, although not currently regulated, were often in excess of 20 mg/l, and the State of Tennessee has recently indicated that it would begin imposing ammonia limits in 1997 of 4 mg/L in the summer months and 10 mg/L during the winter months.

In 1995, the State of Tennessee's Division of Water Pollution Control requested that the treatment system be brought into compliance. Subsequently, TVA developed a contract with Benton to allow

field testing of the novel recurrent reciprocation technique. The reciprocation retrofit for each pair of wetlands consists of a series of corrugated plastic pipe underdrains connected to 200 gallon sumps, each sump with a 1 horsepower pump (3 pump sumps/ wetland cell). The frequency and duration of pumping is controlled by a programmable digital timer.

FIG. 1 BENTON, TENNESSEE CONSTRUCTED WETLANDS

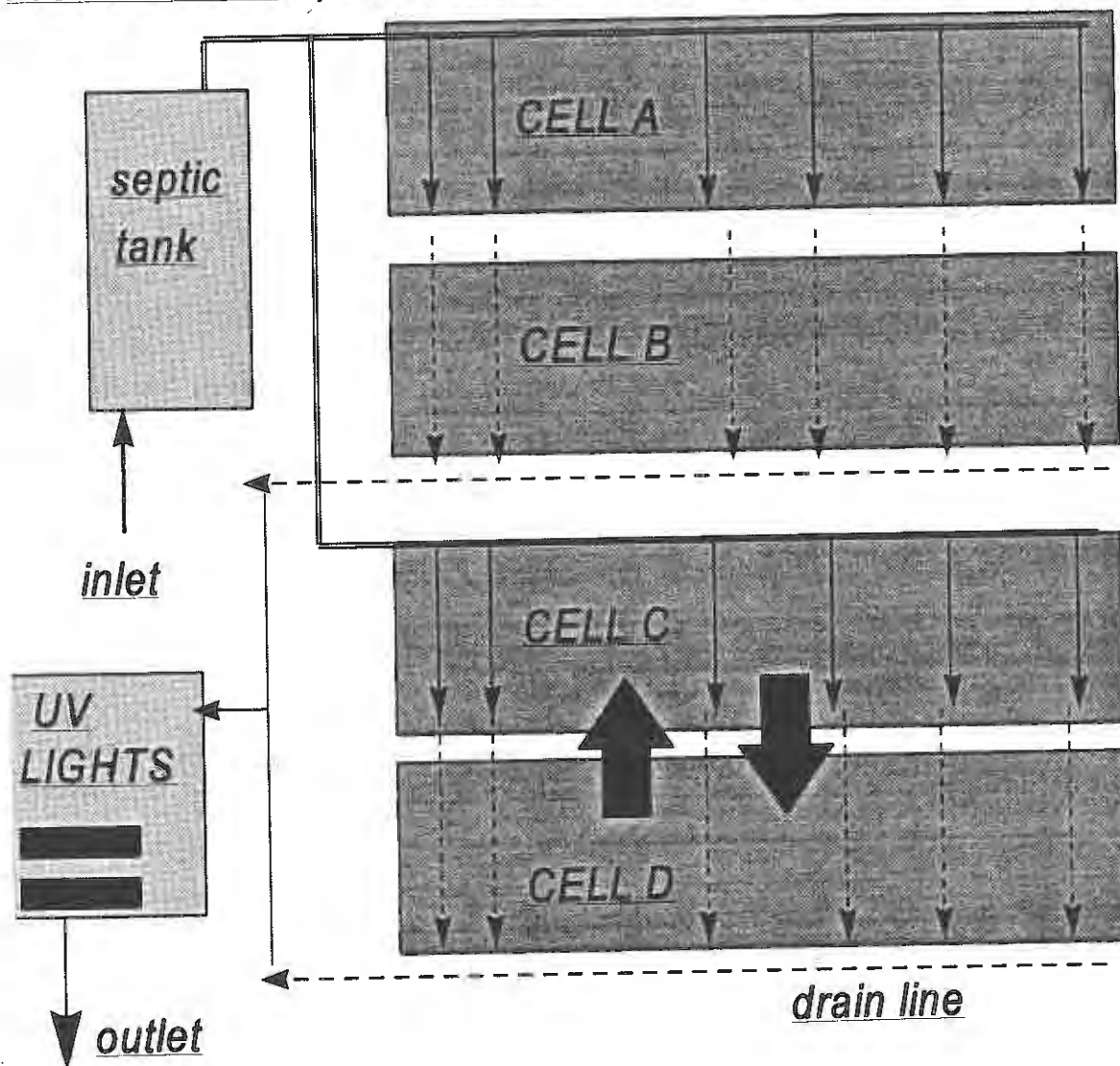


Figure 1. Plan view of Benton, Tennessee, subsurface-flow constructed wetland for treating municipal wastewater. The figure illustrates the relationship of the wetland cells to the supply and drain lines, the flow of water through the system, and the discharge of effluent to a UV light system for pathogen control. The two large arrows illustrate the reciprocal movement of wastewater between cells C and D.

The wetland system discharges treated effluent to a small natural stream, and as such must meet discharge limits as imposed by the NPDES (National Pollution Discharge Elimination System), which is under the control of each State's Water Quality Commission. The specific limitations as imposed by NPDES permit TN0067334 includes monthly averages for the following parameters: CBOD₅, not to exceed 25 mg/l; suspended solids not to exceed 25 mg/l, fecal coliform not to exceed 1000/100 ml grab sample on a daily basis, dissolved oxygen not to be less than 1 mg/l on a daily basis.

After evaluating the data and discussing options, it was mutually decided that an experimental reciprocating system would be installed in each of the two series of treatment wetlands. The experimental system was installed and operational by November of 1995. The goal of the large scale experimental reciprocating system was to determine optimum operating and management requirements to remove odor and to improve removal of CBOD₅, fecal coliform, and nutrients, specifically total ammonia nitrogen.

RESULTS AND DISCUSSION

The system has been successfully operated under various experimental guidelines for the past 12 months. Currently, reciprocation is practiced such that water is pumped between contiguous cells at a rate of 600 gpm for periods of up to 2 hours, and then pumps are turned off for a period of 4 hours. Under current operating conditions, the 12 pumps operate for a total of 8 hours per day at a system cost of approximately \$130/month.

Within a week of turning on the experimental retrofit system, the strong smell of hydrogen sulfide was reduced dramatically. Results of weekly monitoring also revealed continuous improvement of dissolved oxygen concentrations and reductions in CBOD₅, ammonia and ortho-phosphorus (see Figures 2a b and c). It should be noted that during the period Nov. 95 to April 96, cells A and B were operated as controls, i.e., no reciprocation, while cells C and D were operated as reciprocating units. Also, starting in April, all units were operated as reciprocating units and values for cell D actually represent effluent values for the combined effluent of all four cells (see Figure a and b).

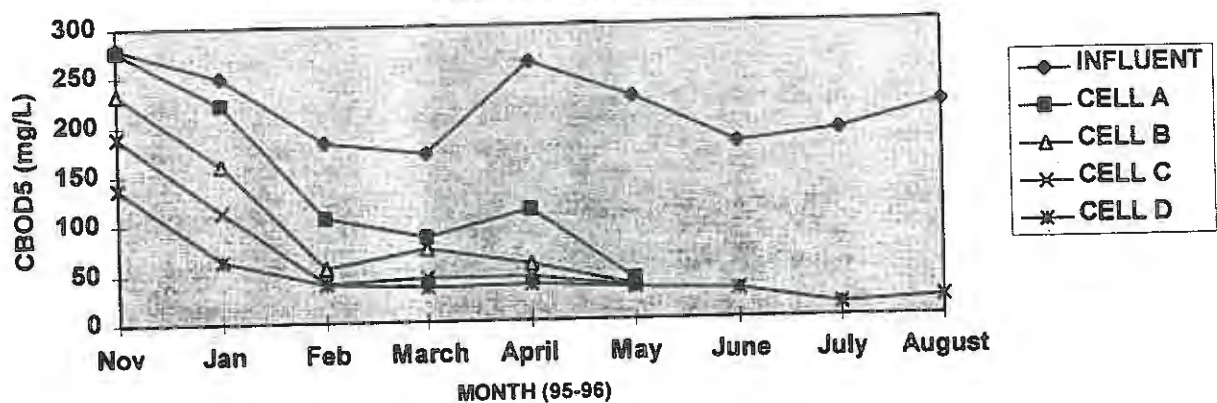
The most recent monthly report for November 1996 revealed that the experimental reciprocating wetland system was in compliance with respect to all NPDES limits.

The monthly averages for November 1996 were: ammonia 4.6mg/l, CBOD 15.9 mg/l, and fecal coliform bacteria 7.2 colonies /100 ml. The significant improvement in fecal coliform numbers is thought to be due to both 1) the direct impact of reciprocation (alternating aerobic and anaerobic environments), and 2) the improved clarity of the water passing the UV light system. Prior to reciprocation, the water had a gray-water coloration, and fecal coliform numbers were "too numerous to count".

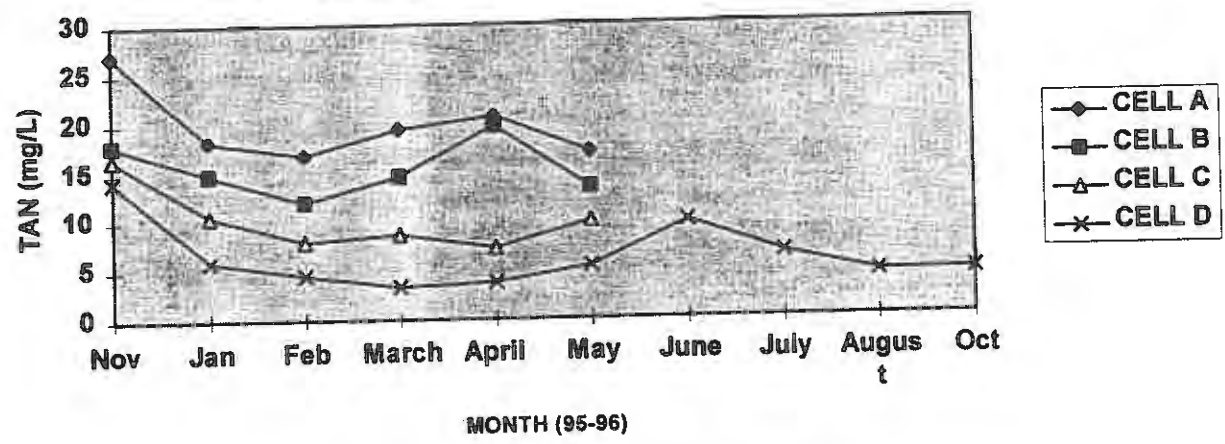
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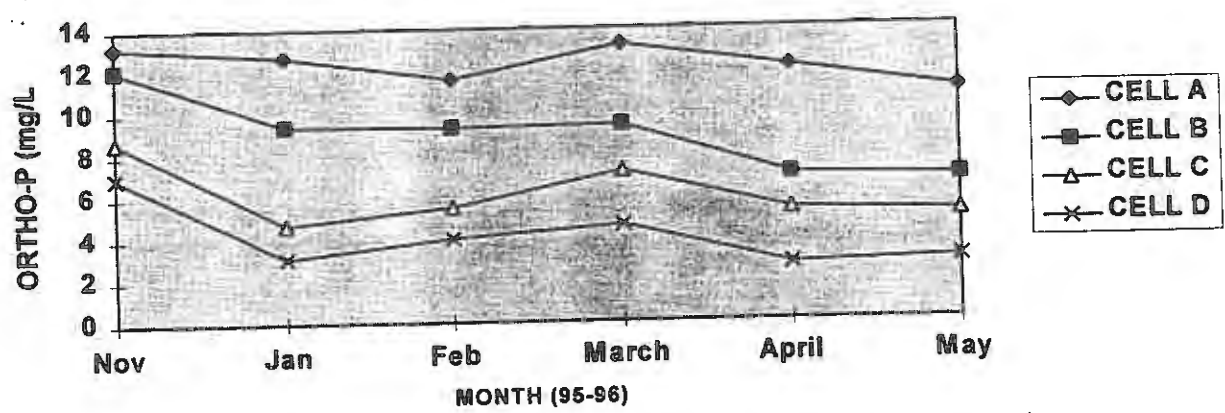
**FIGURE 2A. CBOD5 CONCENTRATION
BENTON, TENNESSEE
CONSTRUCTED WETLANDS**



**FIGURE 2B. TOTAL AMMONIA NITROGEN CONCENTRATIONS
BENTON, TENNESSEE CONSTRUCTED WETLANDS**



**FIGURE 2C. ORTHO-P CONCENTRATIONS
BENTON, TENNESSEE CONSTRUCTED WETLAND**



PHYTOREMEDIATION OF EXPLOSIVES-CONTAMINATED GROUNDWATER USING INNOVATIVE WETLANDS-BASED TREATMENT TECHNOLOGIES

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INTRODUCTION

Constructed wetlands have been successfully used to treat a wide variety of wastewaters. Municipal wastewater and acid mine drainage encompass most of the water treated by constructed wetlands (Hedin and Narin, 1993; Kadlec and Knight, 1996). Other wastewaters treated with wetlands include petroleum industrial effluents, pulp and paper wastewater, and landfill leachates (Litchfield, 1993; Marten et al., 1993; Thut, 1993). The main advantage of constructed wetlands is that the technology is inexpensive compared to conventional treatment options. There are capital costs associated with building the wetland, but the minor operation and maintenance costs makes constructed wetlands a cheaper alternative to conventional treatments that include yearly labor and chemical costs.

Many army ammunition plants across the country have problems with groundwater contaminated with explosives. A demonstration was initiated at the Milan Army Ammunition Plant near Milan, Tennessee early in 1996 to test the feasibility of treating contaminated groundwater with constructed wetlands.

MATERIALS AND METHODS

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The design for the demonstration was developed from information obtained from two preliminary microcosm studies conducted in 38 L aquaria and are reported in Sikora et al. (1995) and Behrends et al. (1995).

The demonstration involves a comparison of two wetland types including a lagoon system with submergent plants and a subsurface flow gravel-bed wetland with emergent plants. A lagoon system consists of two cells in series with each cell having dimensions of 24 x 9.4 x 0.6 m (L x W x H) containing 137 m³ water. A gravel-bed system has a first cell with dimensions of 32 x 11 x 1.4 m (L x W x H) containing 205 m³ water and is kept anaerobic by adding 114 kg of powdered milk to the water every two weeks. The second cell in the gravel-bed treatment system has dimensions of 11 x 11 x 1.4 m (L x W x H) containing 43 m³ water and is kept aerobic by reciprocating water back and forth from one interior partition to another (patent application filed). Gravel used in the gravel-based wetlands had 42% porosity. For the purpose of the demonstration, effluent from both wetland treatments goes through granular activated carbon bed canisters before being discharged to the sewer system. The lagoons were planted with sago pond weed (*Potamogeton pectinatus*), water stargrass (*Heteranthera dubia*), elodea (*Elodea canadensis*), and parrot feather (*Myriophyllum aquaticum*). The gravel-bed wetlands were planted with canarygrass (*Phalaris arundinacea*), woolgrass (*Scirpus cyperinus*), sweetflag (*Acorus calamus*), and parrot feather. Water began flowing to each of the wetland treatment systems at 19 L min⁻¹ starting on June 17, 1996. The design hydraulic retention time is 10 days through the lagoon system and 9.1 days through the gravel-bed system. The retention time in each of the lagoon cells was 5 days. The retention time in the first anaerobic gravel-bed wetland was 7.5 days. The retention time in the reciprocating gravel-bed wetland was 1.6 days.

Influent and effluent water samples were collected every 2 weeks. Intensive sampling of water at interior locations in the wetlands occurred every 2 months. Interior water samples were collected at equal distances between the inlet and outlet at 4 locations in the lagoon cells and first gravel-bed wetland cell and 2 locations in the reciprocating gravel-bed wetland. The demonstration and the scheduled sampling is planned to continue until August, 1997. Data will be presented for biweekly water samples collected from July 1, 1996 to October 8, 1996 and intensive water sampling that occurred on August 13 and October 8, 1996.

Water samples were analyzed for explosives via HPLC. A photodiode array detector with a range of 190 to 367 nm was used for analyte qualification and confirmation. A fixed wavelength detector at 254 nm was used for analyte quantification. Total organic C (TOC) was analyzed via Dohrmann DC 190 TOC analyzer. Total Kjeldahl N (TKN) and ammonium N (NH₄-N) were analyzed with LACHAT flow-injection analysis. Biological oxygen demand (BOD) was analyzed via standard methods (Greenberg et al., 1992). Chemical oxygen demand (COD) was determined via HACH digestion and colorimetric analysis. Dissolved oxygen (DO), temperature, and pH were determined with hand-held YSI probe at time of sampling.

Disappearance rate of TNT, RDX, and HMX was analyzed using first-order kinetics (Kadlec and Knight, 1996). Assuming plug-flow hydraulics, the first-order equation for the reduction of a pollutant in a wetland is:

$$\ln (C/C_i) = -y (k/q) \quad [1]$$

where k is the first-order rate constant with units of m/yr , q is the hydraulic loading rate with units of m/yr , y is the fractional distance from inlet to outlet (ranging from 0 to 1), C_i is the influent concentration of pollutant, and C is the concentration at y . The k value for removal of TNT, RDX, and HMX in the lagoon and gravel-bed systems was determined from average influent and effluent concentrations for the two cells of the lagoon system and the first anaerobic cell of the gravel-bed system using:

$$k = -q/y \ln (C/C_i) \quad [2]$$

In the instances where effluent concentrations were above detection limits, C was the concentration in the effluent and $y=1$. In the instances where effluent concentrations were below detection limits, C was the concentration at y closest to the outlet that was above the level of detection.

With the calculated rate constants, first-order models were plotted for C versus time of treatment (t) in wetlands using:

$$C = \exp [(-t-i) k / (RT q) + \ln C_i] \quad [3]$$

Equation [3] is a rearrangement of Eq. [1] with $y = t/RT$ where t is time of treatment and RT is the design hydraulic retention time for the wetland cell analyzed, and i is the time of treatment from a previous cell. For the first gravel-bed and first lagoon cell, $i=0$. For the second lagoon cell, $i=5$.

RESULTS AND DISCUSSION

Average influent concentrations into the wetland systems were 1.28, 1.74, and 0.10 mg/L for 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), respectively (Table 1). The first anaerobic gravel-bed wetland did a good job removing TNT, RDX, and HMX with effluent concentrations below the detection level. The lagoon system did nearly as well at removing TNT in the water but did a poorer job at reducing RDX and HMX. Concentrations of RDX and HMX leaving the lagoon system were 0.93 and 0.08 mg/L, respectively, with removal efficiencies of 47 and 20%, respectively.

The rate of explosives removal in the wetlands was determined by first-order kinetic analysis. The rate of TNT removal in both the anaerobic gravel-bed and first lagoon cell was rapid with k values ranging from 437 to 891 m/yr (Table 2 and Fig. 1). The rates of RDX and HMX removal in the gravel-bed wetland was not as rapid as TNT but was still high with k values of 316 m/yr for RDX and 129 m/yr for HMX (Table 2 and Fig. 1A). The rates of RDX and HMX removal in

the lagoon wetlands was a lot slower than corresponding removal rates in the gravel-bed wetlands with k values of 10 m/yr for RDX and 2 to 5 m/yr for HMX (Table 2 and Fig. 1B).

The reciprocating gravel-bed wetland follows the anaerobic gravel-bed wetland in order to remove nutrients and carbon that is released in the first wetland from continual feeding with powdered milk. Reciprocating water in a gravel-bed wetland allows for aeration of microbial biofilms on the gravel, which hastens ammonium and BOD removal via aerobic microbial activity. The average dissolved oxygen concentration increased from 1.6 mg/L going into the reciprocating wetland to 4.4 mg/L exiting the wetland indicating improved aeration of the water (Table 1). Ammonium and BOD removal efficiencies were greater than 90 % in the reciprocating wetland and were fairly rapid since the retention time in the reciprocating wetland was only 1.6 days.

In addition to the primary explosives, TNT byproducts analyzed in the water samples were 2-amino-4,6-dinitrotoluene (2A), 4-amino-2,6-dinitrotoluene (4A), and 2,4-diamino-6-nitrotoluene (2,4-A), and 2,6-diamino-4-nitrotoluene (2,6-A). 2,6-A was below the detection limit of 0.006 mg/L in all samples. The byproducts of TNT were observed in the gravel-bed wetlands at the retention time of 1.5 days at concentrations at approximately 10% of the influent TNT concentration (Fig. 2A). The degradation of TNT in the anaerobic gravel-bed wetland is believed to have occurred via reduction of the molecule to amino derivatives to ultimately form triammonium toluene (TAT) which may be further polymerized to harmless humic-like substances (Rieger and Knackmuss, 1995). The increased concentration of all the amino derivatives was about 25% of the initial TNT concentration and is comparable to results from a batch study with microcosm wetlands in aquaria where 25% of

Table 1. Water analysis results for water entering wetlands (INFLOW), exiting the first cell in each wetland system (OUTLET 1), and exiting the second cell in each wetland system (OUTLET 2). Percent efficiencies (% EFF) shown for removal of explosives from inflow and removal of nutrients in effluent of anaerobic gravel bed. Data averaged for samples taken every 2 weeks from July 1 to October 8.

	Gravel-bed wetland			% Eff #
	INFLOW †	OUTLET 1 †	OUTLET 2 †	
TNT, mg/L	1.32 ± 0.27	<0.002	<0.002	100
RDX, mg/L	1.73 ± 0.32	<0.008	<0.008	100
HMX, mg/L	0.10 ± 0.02	<0.012	<0.012	>88
TKN, mg/L	0.7 ± 0.2	20.6 ± 12.5	2.2 ± 2.2	89
NH ₄ -N, mg/L	0.6 ± 0.1	19.7 ± 11.8	1.5 ± 1.5	92
TOC, mg/L	3.4 ± 1.5	59.2 ± 59.2	3.4 ± 2.0	94
TSS, mg/L	2.9 ± 2.9	45 ± 45	9.9 ± 9.9	78
BOD, mg/L	0.2 ± 0.2	119 ± 119	1.4 ± 1.1	99
COD, mg/L	0.4 ± 0.6	174 ± 174	3.6 ± 3.5	98
pH	5.8 ± 0.6	6.4 ± 0.5	7.3 ± 0.7	

<i>DO</i> , mg/L	3.8 ± 2.8	1.6 ± 0.4	4.4 ± 3.1	
<i>TEMP</i> , °C	18.0 ± 1.0	21.6 ± 4.8	23.3 ± 5.0	
—— Lagoon wetland ——				
	<i>INFLOW</i>	<i>OUTLET 1</i>	<i>OUTLET 2</i>	<i>% Eff</i>
<i>TNT</i> , mg/L	1.23 ± 0.25	0.11 ± 0.11	<0.002	100
<i>RDX</i> , mg/L	1.74 ± 0.28	1.25 ± 0.36	0.93 ± 0.41	47
<i>HMX</i> , mg/L	0.10 ± 0.02	0.09 ± 0.02	0.08 ± 0.02	20
<i>TKN</i> , mg/L	0.7 ± 0.2	0.9 ± 0.4	0.6 ± 0.6	
<i>NH₄-N</i> , mg/L	0.6 ± 0.1	0.3 ± 0.2	0.1 ± 0.1	
<i>TOC</i> , mg/L	2.3 ± 1.5	3.6 ± 1.7	2.2 ± 2.2	
<i>TSS</i> , mg/L	1.7 ± 1.7	3.8 ± 3.8	<2	
<i>BOD</i> , mg/L	0.3 ± 0.3	1.3 ± 0.8	1.6 ± 1.1	
<i>COD</i> , mg/L	1.0 ± 1.0	4.0 ± 4.0	5.0 ± 2.4	
<i>pH</i>	5.8 ± 0.7	6.7 ± 0.7	7.2 ± 1.2	
<i>DO</i> , mg/L	3.1 ± 3.5	4.7 ± 5.6	4.1 ± 4.9	
<i>TEMP</i> , °C	18.9 ± 1.6	23.2 ± 5.9	24.5 ± 5.9	

† Average is shown before ± and standard deviation is shown after ±.

‡ Percent removal efficiencies (% Eff) shown for TNT, RDX, and HMX refers to difference in concentration between inflow and outlet 2. Percent removal efficiencies shown for TKN, NH₄-N, TOC, TSS, BOD, and COD in gravel-bed wetland system shown for difference in concentration between outlet 1 and outlet 2.

Table 2. First-order rate constants (k values with units of m/yr from Eq. [2]) for removal of TNT, RDX, and HMX in wetland treatment systems.

	<i>TNT</i>	<i>RDX</i>	<i>HMX</i>
1st GRAVEL-BED	891	316	129
1st LAGOON CELL	457	10	2
2nd LAGOON CELL	437	10	5

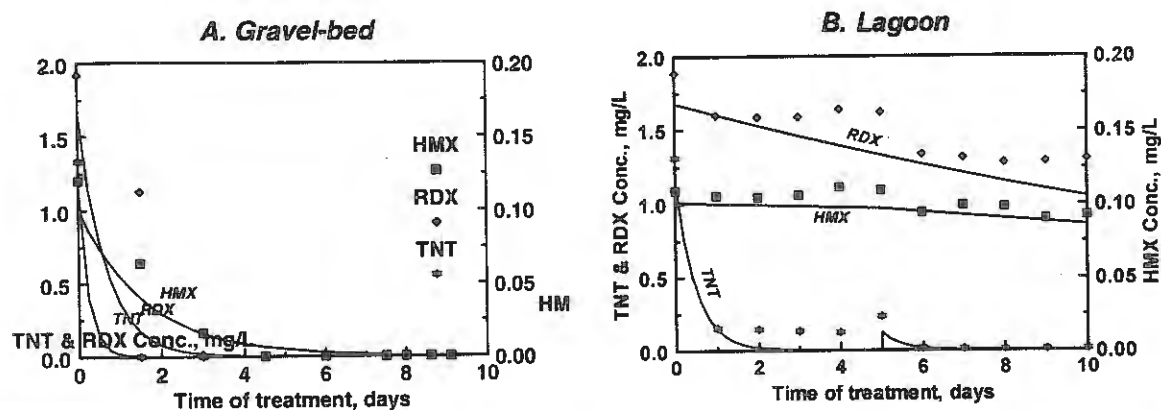


Figure 1. Transect data for TNT, RDX, and HMX concentrations in the gravel-bed and lagoon wetland systems. Data points are average data for two sampling events on August 13 and October 8. Lines are first-order models using Eq. [3] with appropriate rate constants in Table 2.

the initial TNT concentration was observed to form 4-A (Sikora et al., 1996). The absence of any increase in TNT degradation products in the lagoon system was puzzling (Fig. 2B). TNT is believed to be degraded by submergent plant species via production of nitroreductase enzymes (Wolfe et al., 1994) which should have yielded amino derivatives in the aqueous phase with decrease TNT concentrations as observed with parrot feather (Sikora et al, 1996).

Byproducts of RDX analyzed were mononitroso-RDX (m-RDX) and trinitroso-RDX (t-RDX). m-RDX was observed at 1.5 and 3 day retention time in the anaerobic gravel-bed system (Figure 2C). t-RDX accumulated to a maximum concentration of 0.5 mg/L at 3 day retention time and was persistent with 0.13 mg/L in the effluent of the anaerobic gravel-bed at 7.5 day treatment time. The concentration of t-RDX was reduced to 0.06 mg/L after passing through the reciprocating gravel bed at a 9.1 day total treatment time. m-RDX and t-RDX are believed to be degradation products of RDX undergoing anaerobic reduction. As with TNT byproducts, the RDX byproducts were not observed in the lagoon system (Figure 2D). The lack of RDX byproducts was not surprising since there was only a very small decrease in RDX concentrations in the lagoon system.

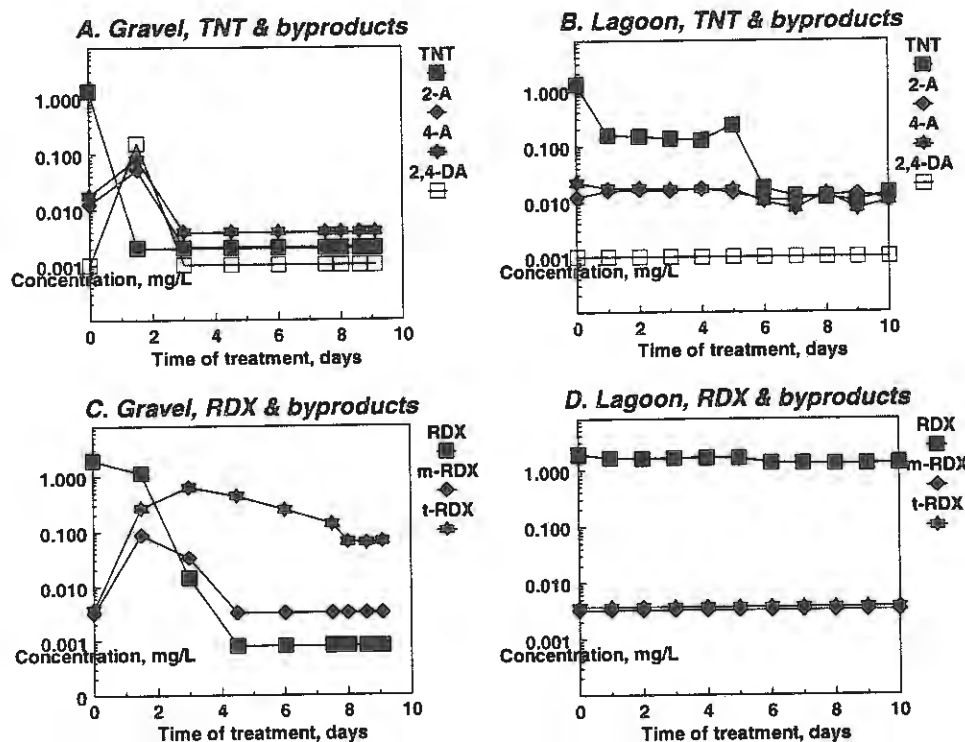


Figure 2. TNT and RDX byproducts observed in water samples taken from gravel-bed wetlands. Data points are average data for two sampling events on August 13 and October 8. Detection limits for TNT, 2-A, 4-A, 2,4-DA, RDX, m-RDX, t-RDX, were 0.002, 0.002, 0.004, 0.001, 0.001, 0.003, and 0.004 mg/L, respectively.

The data presented for explosives removal using wetland systems is preliminary data describing removal in newly constructed wetlands in operation for only 3 months. The project is continuing at least for one year so seasonal effects on explosives removal can be observed. Longer term observation of these systems is also desirable to determine removal of explosives in matured constructed wetlands. In addition to sampling water, sediment, gravel, and plants samples are being taken and analyzed for explosives to determine if explosives and byproducts are sorbing onto or into various components of the wetlands.

SUMMARY

Influent concentrations of TNT, RDX, and HMX averaged 1.28, 1.24, and 0.10 mg/L, respectively. Both the lagoon and gravel-bed wetlands are reducing TNT below 0.002 mg/L. The gravel-bed wetland removed RDX and HMX in the groundwater, whereas the lagoon wetland was not as effective. The demonstration is planned to operate until August 1997. The collected data will be used to recommend design and operational parameters for implementing the technology to other sites.

ACKNOWLEDGEMENTS

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POSTERS

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ARE MUSSEL COMMUNITIES SELF-ORGANIZED?

B. L. Rashleigh¹

and

J. A. Drake

INTRODUCTION

The theory of self-organizing criticality (SOC) assumes that pattern, structure, and ultimately organization in ecological communities arise in excess of that which can be predicted based on a detailed knowledge of initial conditions as a result of a system's evolution to a critical state. The critical state is often thought of as the "edge of chaos" (Langton, 1991). Patterns characteristic of self-organized systems are power laws of frequency vs. magnitude in time and frequency vs. distribution in space (Bak and Chen, 1991). These patterns are expected to be scale invariant in SOC systems (Hastings and Sugihara, 1993). Pattern in an SOC community is thought to be generated by simple rules, which would result in similar power law exponents (assuming interval widths are equal) and correlations between characteristics. Force structuring SOC communities may be underlying hierarchical structure (Kolasa, 1989), simple rules (Sole and Manrubia, 1995), underlying fractal structure of the environment (Huston, 1994).

Here we have sought to examine the patterns of ecological characteristics in freshwater mussel communities in the context of the SOC hypothesis. We have examined the community patterns of 5 ecological characteristics at 5 different scales. We have asked the following questions:

(1) *Do the observed patterns fit power law distributions, i.e., are coefficients significantly different from random?*

(2) *What are the scales of interaction, i.e., at what scales do the power laws fit best?*

(2) *How do the power law exponents change as a function of scale?*

We hypothesize that mussel communities will exhibit patterns of SOC (good power law fits, scale-invariance), and we propose that the underlying rule is patterning on fish hosts, on which mussels are parasitic.

METHODS

We have put together databases of 5 ecological characteristics (phylogeny, resource use, abundance and distribution, and conservation status) at 5 different scales (one site, one river

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reach, one river system, several tributaries in a region, one region) for the Upper Tennessee River basin. Phylogeny, abundance, and distribution data sources were Dennis (1984) for a single site (Kyle's Ford on the Clinch River), Ahlstedt (1991) for a small stream (Copper Creek in the Clinch River drainage), Ahlstedt (1984) for a river (Clinch River in Tennessee/Virginia), and a compilation of available sources for the collection of tributaries and regional basin (Ahlstedt and Rashleigh, in review). At the scale of the Upper Tennessee River drainage, distribution was calculated by U.S. Geological Survey hydrologic units. Host resource use information was put together from several sources: Watters (1994), and references therein, Hove (1995), Hove et al. (1995), and Layzer and Madison (1995). Conservation status data source was Williams et al. (1992), who recognize 5 categories of increasing seriousness: currently stable (CS), Special Concern (SC), Threatened (T), Endangered (E), or Extinct (EX).

Our analysis included plotting frequency vs. magnitude as log-log plots for each of the characteristics at each of the scales and calculating the spectral coefficient, standard error, and the goodness of fit of the regression line through these points. A spectral coefficient significantly different from random is indicative of organization (Hasting and Sugihara, 1993)--we considered the spectral coefficient to be significantly different from random if a range bounded by two standard deviations did not include zero. We determined scales of interaction as the scales with highest overall goodness of fit of power laws. We regressed spectral coefficient vs. scale and compared standard deviations of individual points in order to look for trends and break points, respectively, in scale.

RESULTS

Power law exponents for graphs of species frequency vs. ecological characteristics ranged from -0.08 to -1.94 for all analyses combined, although most of the spectral coefficients fell between -0.5 and -1.5. All of the values for phylogeny, number of hosts, and abundance, and all but one of the values for distribution (excepting Upper Tennessee distribution) were significantly different from zero. However, none of the values for conservation status were different from zero.

In general, phylogeny gave excellent power laws ($r^2 > 0.90$), except for Kyle's Ford; number of hosts, distribution, and abundance gave fairly good power laws ($r^2 > 0.50$), except for distribution in the Clinch River and the Upper Tennessee; and conservation status gave generally poor power law curves ($r^2 < 0.35$) except for the collection of tributaries. The best fit as a function of scale is the collection of tributaries, followed by Copper Creek and Kyle's Ford.

There was essentially no trend in spectral coefficients across scales. There was a significant break between the scale of the Clinch River and the collection of tributaries for two characteristics (hosts and distribution). There were also significant breaks in phylogeny between Kyle's Ford and Copper Creek and between the collection of tributaries and the Upper Tennessee region.

DISCUSSION

We interpret our finding of non-zero spectral coefficients for all ecological characteristics except conservation status in freshwater mussel communities examined as evidence of self-organized complexity. Power law signals have been found in several aspects of ecology by other researchers (e.g., Kolasa et al., 1996) so this is not a surprising result.

Patterns in conservation status indicate that collapses in freshwater mussel communities are not internally-driven. Power law signals were relatively poor for conservation status at all points. This may be because status is a national ranking which may not apply to regional and local levels. However, we suggest that this finding is a result of mussels undergoing a mass extinction as a result of external forces, such as pollution and loss of habitat.

Power law goodness of fit indicates that ecological patch size is on the scale of a medium sized tributary. These results are similar to genetic data (Berg et al., 1995, found a patch size between 20 and 50 stream miles), and cluster analysis data (Ahlstedt, 1984, found tight clusters of species composition on the order of 40 stream miles). We suggest that patch size reflects the fish host range of activity. We suggest that the peak at Copper Creek represents ecological scale, and the peak at the level of tributaries represents the evolutionary scale. The breaks between Clinch River and collection of tributaries supports this hypothesis.

Because there was no clear trend across scales for any of the characteristics, we conclude that essentially the same processes operating at one scale determine the processes at each successive scale. This scale-invariance is characteristic of an SOC system.

It is possible that mussels are patterned on fish hosts, because mussel diversity and fish diversity are highly correlated (Watters, 1992) and fish also exhibit power law signatures. Patterns in fish may be explained by hierarchical structure of the environment (Kolasa, 1989; Pyron and Taylor, 1993).

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ECOLOGICAL ASSESSMENT OF STREAMS NEAR A LANDFILL 1994 THROUGH 1996

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The U.S. Geological Survey, in cooperation with the Bedford County Solid Waste Authority, is conducting an aquatic ecological assessment on streams draining an active sanitary landfill. The landfill is located in the karst terrane of southeastern Bedford County, Tennessee. A preliminary biological assessment of streams around the landfill indicated lower diversity and decreased abundance of benthic macroinvertebrates at selected sites near the landfill. Also, chemical analyses of landfill-draining streams found elevated concentrations of chloride, manganese, iron, and nickel compared to reference streams. Data from these tests imply exposure of aquatic communities to landfill-associated chemicals. Additional quantitative biomonitoring, laboratory toxicity tests with *Ceriodaphnia dubia* using water collected from eight monitoring sites, and chemical monitoring of local wells are underway. The first round of quantitative biomonitoring and *Ceriodaphnia* tests indicate some local effects from the landfill. There was less abundance and diversity of macroinvertebrates at some of the monitoring sites draining the landfill. Also, *Ceriodaphnia* exposed to water collected from these sites were detrimentally affected, suggesting a toxic effect. However, there was no observable toxicity several hundred yards downstream, perhaps due to dilution and natural removal of chemicals from the water during base flow. In 1996, we measured a rise in specific conductance in the stream draining the landfill during storm flow. This is contrary to the usual rain-dilution effect and decrease in specific conductance observed in the reference streams during storm flow. Because of this paradoxical increase in specific conductance, additional *Ceriodaphnia* tests are being done under storm-flow conditions.

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INNOVATIVE USES OF TIME DOMAIN REFLECTOMETRY**N. Randy Rainwater,****Ronald E. Yoder,****Wesley C. Wright,****Eric C. Drumm,****and****Glenn V. Wilson¹****ABSTRACT**

Time domain reflectometry (TDR) has been used for several years as an in situ soil moisture measurement technique. TDR measures the propagation time of a signal as it travels through a transmission line (probe) imbedded in soil. For a known length of transmission line, this propagation time is indicative of the dielectric constant and volumetric water content of the soil.

Researchers in the Agricultural Engineering and Civil Engineering Departments of The University of Tennessee are using TDR to monitor subgrade water content below asphaltic concrete pavement. The objective of the research is to demonstrate the seasonal variation in water content and temperature in pavement subgrades, and to measure the effects of these variations on pavement performance. This information will be used to incorporate environmental factors in flexible pavement design resulting in pavement systems with lower life-cycle costs. This research project is funded by a grant from the Tennessee Department of Transportation. Multiple segment TDR probes are placed horizontally in the soil subgrade, stone subgrade, and asphaltic stabilized base layer at three test sites in Tennessee. Single segment probes are placed in the asphaltic concrete. Eight probes are combined in a multiplexed TDR monitoring system at each test site using Moisture Point² soil moisture measurement instrumentation by Gabel Corporation and dataloggers and multiplexers by Campbell Scientific Incorporated (CSI). The multiple segment probes will allow monitoring a wetting front moving laterally in the subgrade. Placing the probes horizontally during the respective stages of

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²The use of brand names does not imply endorsement of these products by The University of Tennessee.

construction will prevent unnecessary destruction of roadway integrity and will avoid causing unnatural conditions in the pavement. The poster presentation illustrates existing TDR technology that is available for monitoring subsurface hydrology.

TIME DOMAIN REFLECTOMETRY

Time domain reflectometry (TDR) is a method for measuring the high-frequency electrical properties of materials. In soil applications TDR is used to measure the dielectric constant (Topp and Davis, 1985). TDR has been commonly used by professionals and technicians in the electrical field to locate breaks in transmission lines by monitoring the reflection of a voltage pulse signal along the transmission line. The reflected signal's propagation velocity and amplitude are dependent upon the electrical properties of the materials making up the transmission line and dielectric medium surrounding the transmission line. Since 1980 the use of TDR to measure soil water content has been thoroughly explored and documented (Topp et al., 1980; Topp et al., 1983; Dasberg and Dalton, 1985; Topp and Davis, 1985; Ledieu et al., 1986). Parallel transmission lines are usually used for measuring soil water content. The parallel conducting rods serve as wave guides. The soil around the wave guide serves as the dielectric medium. The signal propagates as a plane wave in the soil surrounding the wave guide. TDR measures the time between sending and receiving the reflected signal. For a known length of transmission line, this transit time is indicative of the dielectric constant and volumetric water content of the soil. The relative dielectric constant K , is calculated from the measured transit time t of the voltage pulse through the length L of soil material (wave guide length):

$$K = [ct/2L]^2 \quad (1)$$

where c = velocity of light in free space (3×10^8 m/s). An empirical relationship between relative dielectric constant and soil volumetric water content W was derived by Topp et al. (1980):

$$W = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}K - 5.5 \times 10^{-4}K^2 + 4.3 \times 10^{-6}K^3 \quad (2)$$

Baran (1994), found that Topp's equation was valid for loosely compacted crushed rock (1.5 g/cm^3) and for clay subgrade material, but unsuitable for high density samples of crushed rock. Baran adopted a new relationship between dielectric constant and moisture content for high density crushed rock:

$$W = -6.2164 \times 10^{-2} + 2.3831 \times 10^{-2}K - 5.98 \times 10^{-4}K^2 + 6.0 \times 10^{-6}K^3 \quad (3)$$

(for $5 < K < 25$).

Hook et al. (1992) reported improved TDR measurements of soil water using remotely switched shorting diodes in combination with differential detection techniques. Their technique increased the effective amplitude of reflections and significantly reduced background noise. The effective amplitude of a reflection from a point on a transmission line can be increased by placing a

switching diode at that point. When the diode acts as a short circuit, a strong negative reflection is created at that point; when the diode acts as an open circuit, the electromagnetic pulse is unaffected and continues to propagate down the transmission line. The reflection waveform obtained with the diode shorted is identical to that obtained with the diode open until the time the reflection from the diode reaches the TDR instrument. Segmented probes can be fabricated using a switching diode at the beginning and end of each segment. The TDR instrument can be used to determine the propagation time of the voltage pulse in each segment.

The MP-917 instrumentation by Gabel Corporation uses TDR, remote diode shorting, and processing techniques to solve signal quality problems specific to soil applications of TDR. The MP-917 measures the round-trip propagation time of a pulse along a probe segment by measuring the round-trip time to the beginning of the segment and the round-trip time to the end of the segment. Switching diodes are used to define segment boundaries (Young, 1995a). The MP-917 can be used as a component of a larger instrumentation system including datalogging, probe multiplexing, environmental monitoring, and custom data collection (Young, 1995b).

TEST SITES

Three sites are being instrumented to measure subgrade moisture below asphaltic concrete and to monitor climatologic conditions. The three test sites should represent the range of environmental and geotechnical conditions that exist across the state of Tennessee. The Blount County Site is located in East Tennessee along a new section of I-141 (Pellissippi Parkway), in

Alcoa. The Overton County Site is located inside of the Highland Rim along a section of State Route 42 near Rickman. The McNairy County Site is located along a new section of US-45 near Henderson. Each site is being instrumented during specific phases of road construction.

MATERIALS AND METHODS

TDR probes and temperature sensors were installed horizontally beneath the outer wheel path of the roadway from a trench constructed in the shoulder (Figure 1). Installation in this manner limited the amount of subgrade and pavement disturbance and will allow lateral monitoring of subgrade moisture content using segmented TDR probes. Three 5-segment probes were installed in the soil subgrade, two 5-segment probes were installed in the stone base, one 5-segment probe was installed in the asphaltic stabilized base layer, and two single-segment probes were installed in the asphaltic concrete layer. One of the single segment probes at the Blount County Site was omitted after a defect was discovered during installation. Probes placed in the asphaltic stabilized base and asphaltic concrete were placed during construction before the material cooled. The five-segment probes were manufactured by Gabel Corporation and purchased through Environmental Sensors Incorporated. Each segment is 300 mm long. The single-segment probes were fabricated in the laboratory using two 400-mm, 1/8" stainless steel rods, a nylon terminal block, and a Motorola MPN 3404 PIN switching diode. Cable to probe connections were enclosed in electrical junction boxes equipped with 3/4" conduit connections. The junction

boxes were filled with silicone caulk. Temperature sensors will be placed in the asphaltic concrete through a core hole. The core hole will not penetrate the bottom of the pavement and will be sealed after the sensors are placed. Two 1-m² pan lysimeters were installed below the asphaltic stabilized base material at the Overton County and McNairy County sites before the base material was placed. The bottom of each pan is sloped toward a 3/8" I. D. opening where infiltrated water runs through tubing to a tipping bucket rain gauge. The back of each pan lysimeter is 76 mm deep and the front of each pan, where the outlet is located, is 102 mm deep.

Climatological data will be collected to quantify the effects of seasonal variations in subgrade water content and temperature on pavement performance. Each site will be instrumented to monitor rainfall, air temperature, relative humidity, wind speed, and solar radiation. Climatological sensors will be measured every 60 seconds and hourly averages or totals placed in final storage. Initially, TDR probes will be scanned three times at six hour intervals.

Nondestructive Falling Weight Deflectometer (FWD) tests will be periodically performed at each site to correlate pavement performance with environmental conditions. This will permit the direct observation of the effects of subgrade water content variations on pavement performance.

An MP-917 (multiplexed) datalogging system is being installed at each site to collect data from the TDR sensors, subgrade and pavement temperature sensors, tipping buckets, and climatologic sensors (Figure 2). Dataloggers and other instrumentation are contained in a NEMA IV enclosure inside of a concrete vault located outside of the roadway shoulder. The instrumentation utilizes a CSI DC1765 Cellular Phone Package to allow off site downloading by telephone. The CR10X will be downloaded by telephone using PC208 software by CSI. The input/output lines of the CR10X datalogger will be filled to capacity. Thus, a CR500 datalogger will be included in the instrumentation to monitor wind speed, one pan lysimeter tipping bucket, and to power the cellular phone transceiver at specific time intervals. The CR500 will be downloaded monthly on site.

RESULTS

Automatic datalogging has not started at the time of this writing. Due to weather conditions, the asphaltic concrete placement may not be completed at the Overton County and McNairy County sites until 1997. The instrumentation at the Blount County and Overton County sites is planned for power up by January 1, 1997. Preliminary data will be presented in the poster presentation.

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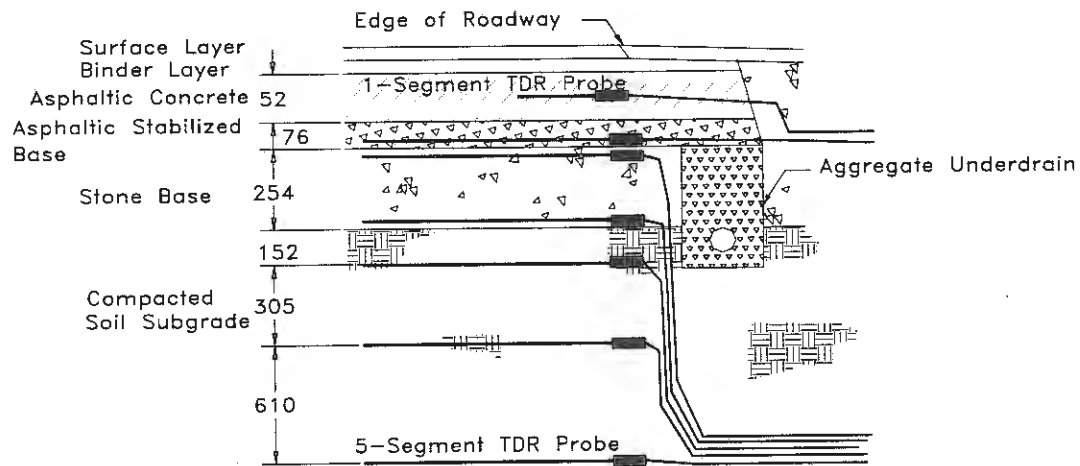


Figure 1. Roadway cross section showing TDR probe placement. Dimensions are in mm.

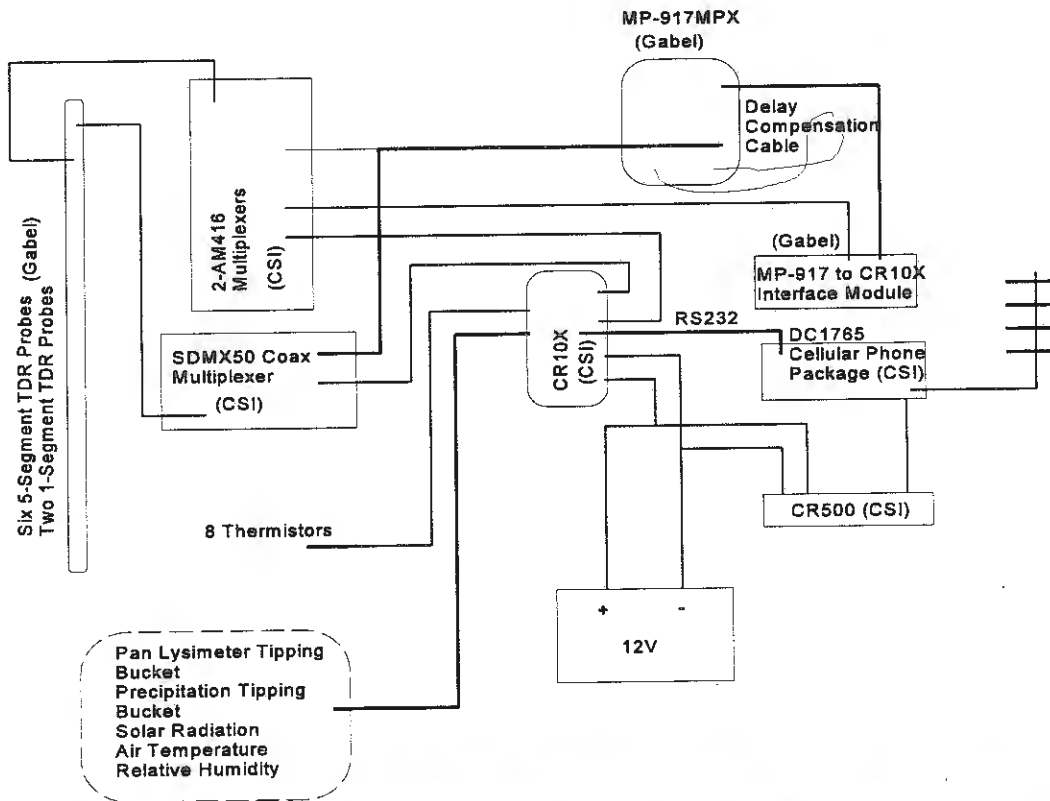


Figure 2. Block diagram of MP-917 multiplexed datalogging system used to monitor subsurface moisture and climatological conditions.

MAPPING OF PREFERENTIAL WATER FLOW PATHS
IN WEST TENNESSEE
USING GROUND PENETRATING RADAR

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and

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ABSTRACT

Vadose zone studies are being conducted in the loess soils at Ames Plantation, which is located near Memphis, TN. The vadose zone beneath two agricultural production fields at this site (one a tilled field and the other a no-tilled field) is very heterogeneous. The soil profile consists of two or more parent materials, varying soil textures, and lamella formations. These heterogeneities govern solute migration throughout the vadose zone, having an impact on the off-site transport of agrichemicals. To assist the ongoing vadosezone well-monitoring studies at Ames Plantation, an interdisciplinary team of scientists from The University of Tennessee are developing innovative applications of Ground Penetrating Radar (GPR) technology. Preliminary studies have shown that GPR will provide an accurate and nonintrusive means of mapping and studying these heterogeneities. Research has focused on the development of near-surface survey methodologies for identifying and mapping subsurface hydrogeological features. Subsurface features of primary interest included loess/alluvium interfaces, perched water tables, and preferential flow paths. Successful identification of such features include (1) the location of saturated soil layers, (2) evidence of fingering in the soil profile, and (3) any major or influential subsurface features that might be identified within the soil profiles.

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INTRODUCTION

Many rural and urban communities use groundwater wells as a primary source of drinking water. As society's environmental awareness increases, the actual offsite impacts of agrichemicals are being questioned and debated. Challenges to traditional farming practices, coupled with farmers' economic concerns, have spurred an increase in vadose zone research and monitoring. The monitoring of the vadose zone has proven to be a formidable challenge, and it is sometimes alluded to as a "hit and miss science." This is due to the many unseen and unpredictable variables that govern the transport of solutes in the vadose zone. Some variables that influence solute transport include perched water tables, differing soil layers, and macropores.

Identifying these parameters in the past has been both time-consuming and labor intensive. Backhoes, hand augers, drill rigs, and picks have been the primary tools available for such research (Doolittle, 1987). Although these tools have been proven effective for identifying heterogeneities in the soil profile, they may physically alter the many parameters governing soil water movement (i.e., hydraulic conductivity, total porosity, and soil structure). Thus, measurement methodologies that do not physically alter soil water movement are essential for vadose zone investigations (i.e., noninvasive). One such remote surveying technique that has been traditionally employed by geologists and archeologists is GPR.

GPR images are formed by electromagnetic reflections that are influenced by the dielectric contrasts of differing subsurface media and features. Sharper contrasts between the dielectric properties of the media provide stronger reflections. A medium with low conductive properties (i.e., dry, non-saline, high-sand content) provide better images when surveyed. In contrast, a medium with higher conductive properties such as wet clay materials will reduce radar penetration (The Finnish Geotechnical Society, 1992). Diverse soil horizons and parent materials often produce sharp reflective images.

Preliminary GPR research has been conducted at geologically similar locations to Ames Plantation (Bouldin, 1996). These investigations have shown that GPR has the potential of providing researchers with a tool that will identify the parameters listed above without physically altering the soil profile. The application of GPR technology will allow researchers the ability to monitor vadose zone water movement in its natural state.

CONTRASTING GEOLOGICAL FEATURES IN WEST TENNESSEE

The soil profile at Ames Plantation is very heterogeneous, consisting of aeolian-deposited loess overlying an alluvial paleosol, which is in turn underlain by coastal plain sediments. Whenever a wetting front (moving in response to the matrix potential of the loess and the combined gravitational potential) reaches the alluvium interface, ponding of the wetting front should occur (Miller and Gardner, 1962). The wetting front enters the smaller pores of the alluvial material and finally reaches the coarser textured coastal plain sediments. If the pores of the coarse-textured sublayer are too large to be entered at the suction of the wetting front, the wetting front will pause temporarily at the

interface. The increasing head at the interface will cause the suction to fall below the threshold of water entry into the smallest pores in the sublayer, and the wetting front will begin to enter the sublayer in distinct, randomly distributed streams (i.e., fingerings) (Hillel and Baker, 1988). Kung and Donohue (1991) were able to locate such distinct soil horizon boundaries using GPR imaging, thus allowing the team of researchers to increase substantially solute concentrations of a KBr tracer in their vadose zone samples.

Since water has a dielectric constant of 81 while dry soil has a dielectric constant of approximately four, the situation discussed above provides an ideal situation to detect moisture regimes in the vadose zone using GPR imaging. The distinct boundary conditions at Ames Plantation caused by differing depositional environments also provide a good situation to detect soil horizons with GPR imaging.

CONVENTIONAL MONITORING

GPR imaging is providing insight into the data obtained from conventional monitoring wells that have been installed at the site. A KBr tracer was applied to the field sites at Ames Plantation. Both 10-ha field sites are part of the 994-ha watershed within Ames Plantation. The geology of Ames Plantation is representative of much of West Tennessee, in that it consists of aeolian-deposited loess covering the Tertiary-aged Claiborne and Wilcox formations.

The two sites are separated by an ephemeral stream. Since 1990, the 10-ha field site north of the stream has been under a conservation tillage practice while the 10-ha field site south of the stream has been under conventional tillage practices. Each of the field sites contains a 0.4-ha square test plot to measure runoff, which are bounded by an earthen berm to prevent surface runoff. A KBr tracer was broadcasted to each of the test plots to aid in the development of vadose monitoring equipment and sampling methodologies.

To obtain samples from the upper 1.20 m of the vadose zone, pan lysimeters and solution samplers were installed. In each 0.4-ha plot, three tension-free pan lysimeters were installed at a depth of 1 m to collect integrated water samples over a surface area of 0.25 m². On two sides of each of each pan lysimeter, a cluster of five solution samplers were installed to collect soil water through porous ceramic cups at depths of 0.15, 0.30, 0.60, 0.90, and 1.20 m. In total the two field sites contain 60 vacuum operated solution samplers and 6 tension-free pan lysimeters (Yoder, 1996).

Shallow wells were installed with 0.23-m length of well screen at the loess alluvium interface to collect perching water. The shallow wells were installed at 24 locations surrounding the 0.4-ha tillage test plot and at 23 locations surrounding the 0.4-ha no-till test plot. To sample possible solute migration in the aquifer underlying the field plots, 12 groundwater wells were also installed (Rainwater, 1996).

PRELIMINARY RESULTS

The research involving the shallow wells and the KBr tracer has produced surprising data. The KBr tracer first appeared in shallow wells located along the outer realms of the concentric well configuration, bypassing many preliminary shallow wells. The results from the sampling well data have led to much speculation pertaining to the migration of the KBr tracer through the vadose zone.

CONCLUSION

Preliminary GPR research conducted at geologically similar sites have produced images of heterogeneities in the subsurface that may provide researchers with answers for the erratic movement of the KBr tracer. Some of these images include perched water tables (Fig. 1), fragipans (Fig. 2), and varying depths to the coastal plain sediments (Fig. 3). These preliminary results will be compared to actual images obtained at the two field sites. The images obtained in the future should provide researchers with a better understanding of the heterogeneities governing the flow of vadose zone water in West Tennessee. This research is providing an innovative, nonintrusive means of identifying these parameters without disturbing the soil matrix, thereby reducing the uncertainty and cost associated with vadose zone research.

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83 m

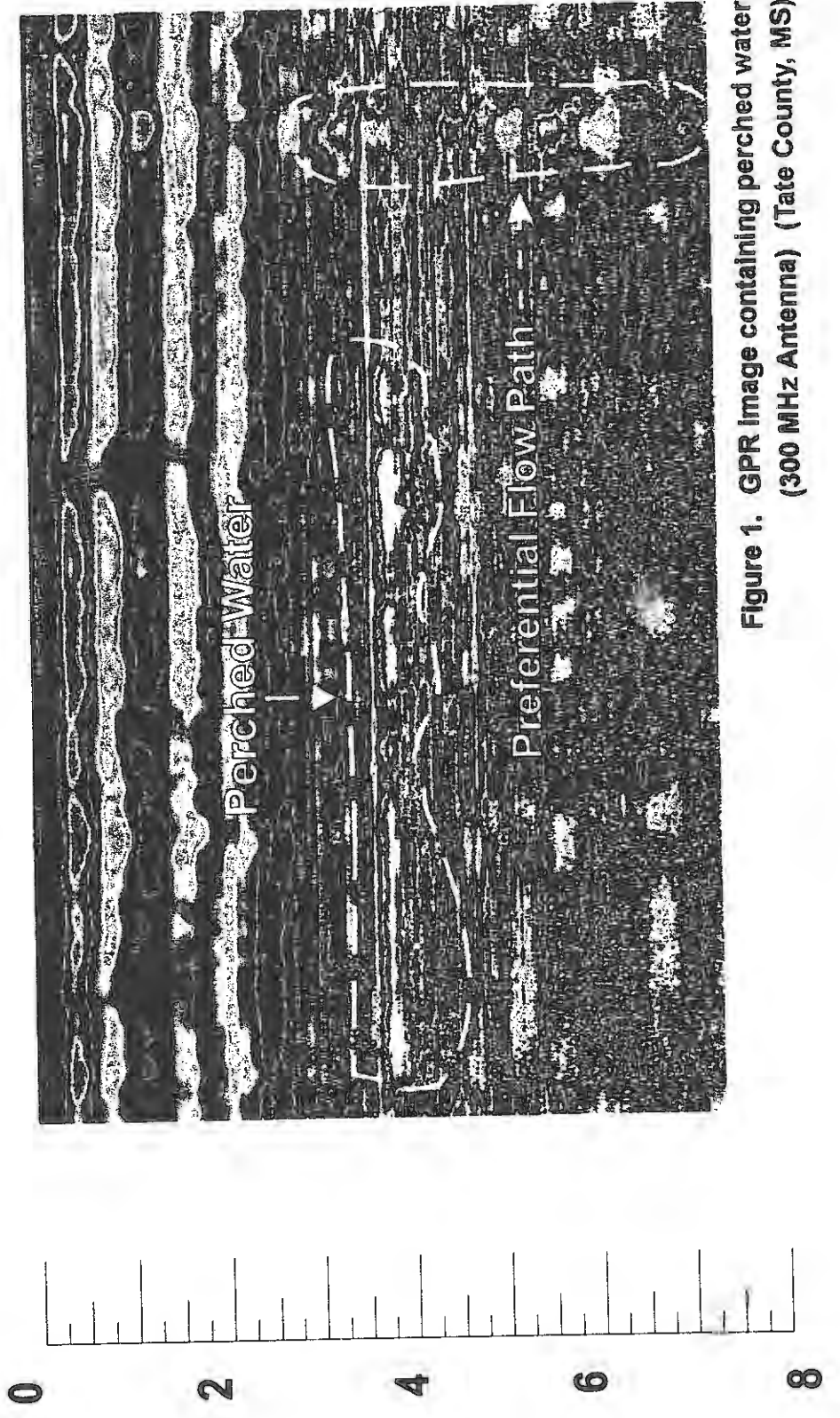
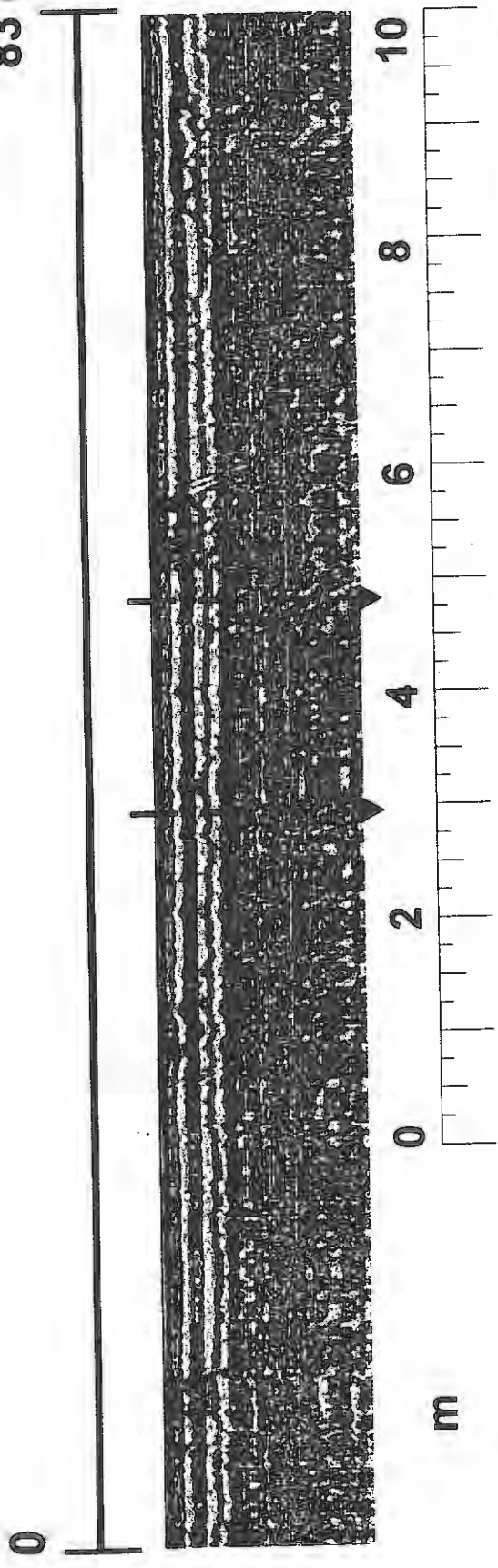


Figure 1. GPR Image containing perched water (300 MHz Antenna) (Tate County, MS)

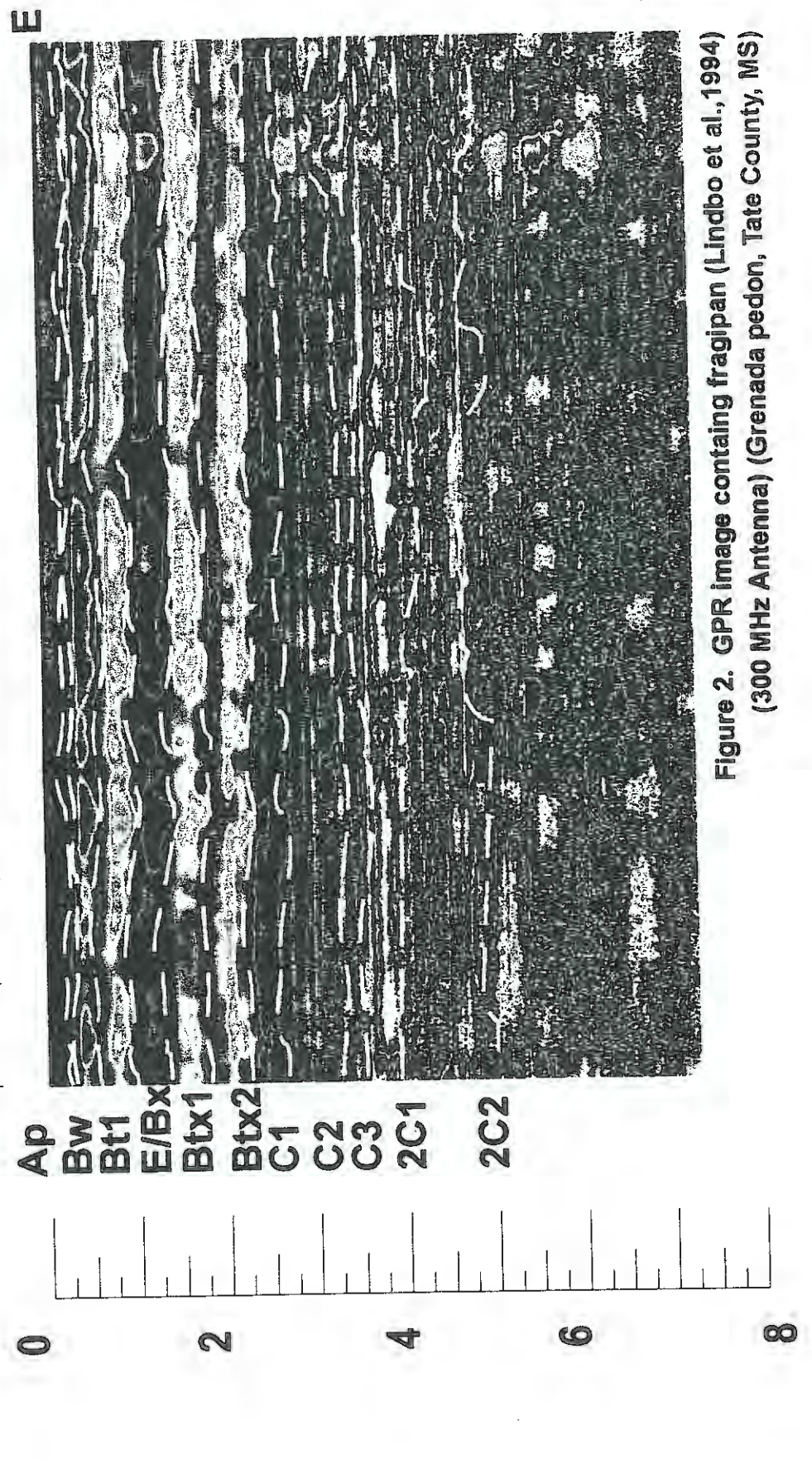
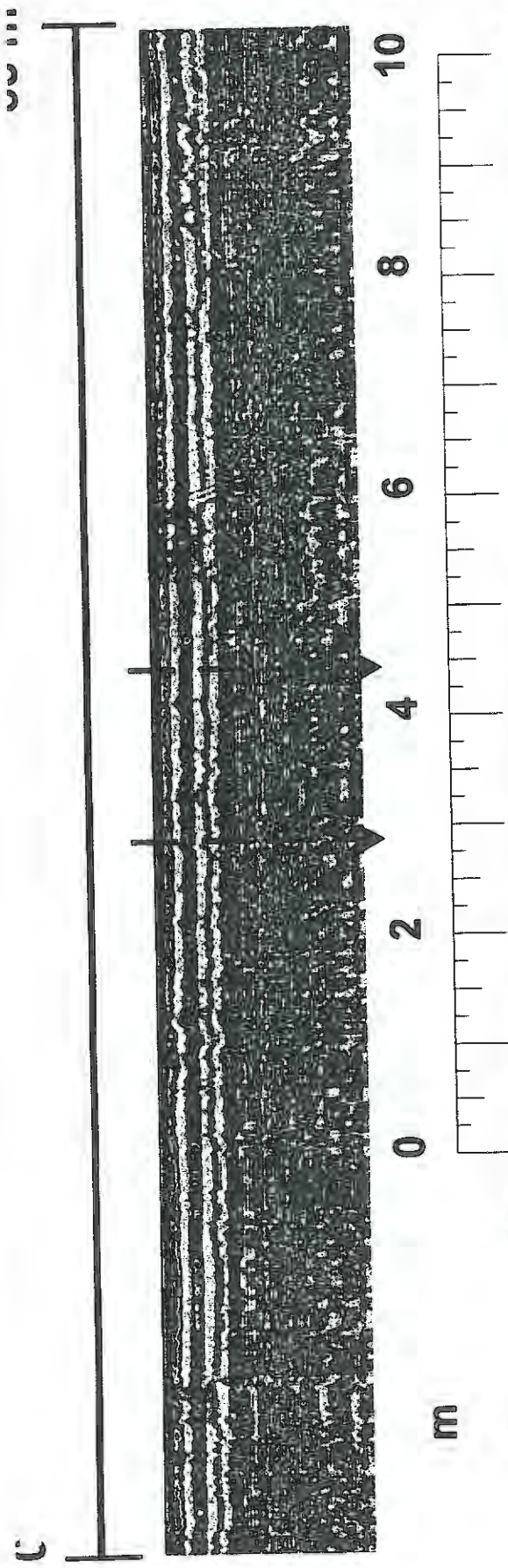


Figure 2. GPR image containing fragipan (Lindbo et al., 1994) (300 MHz Antenna) (Grenada pedon, Tate County, MS)

69.5 m

0

0

1

2

3

4

5

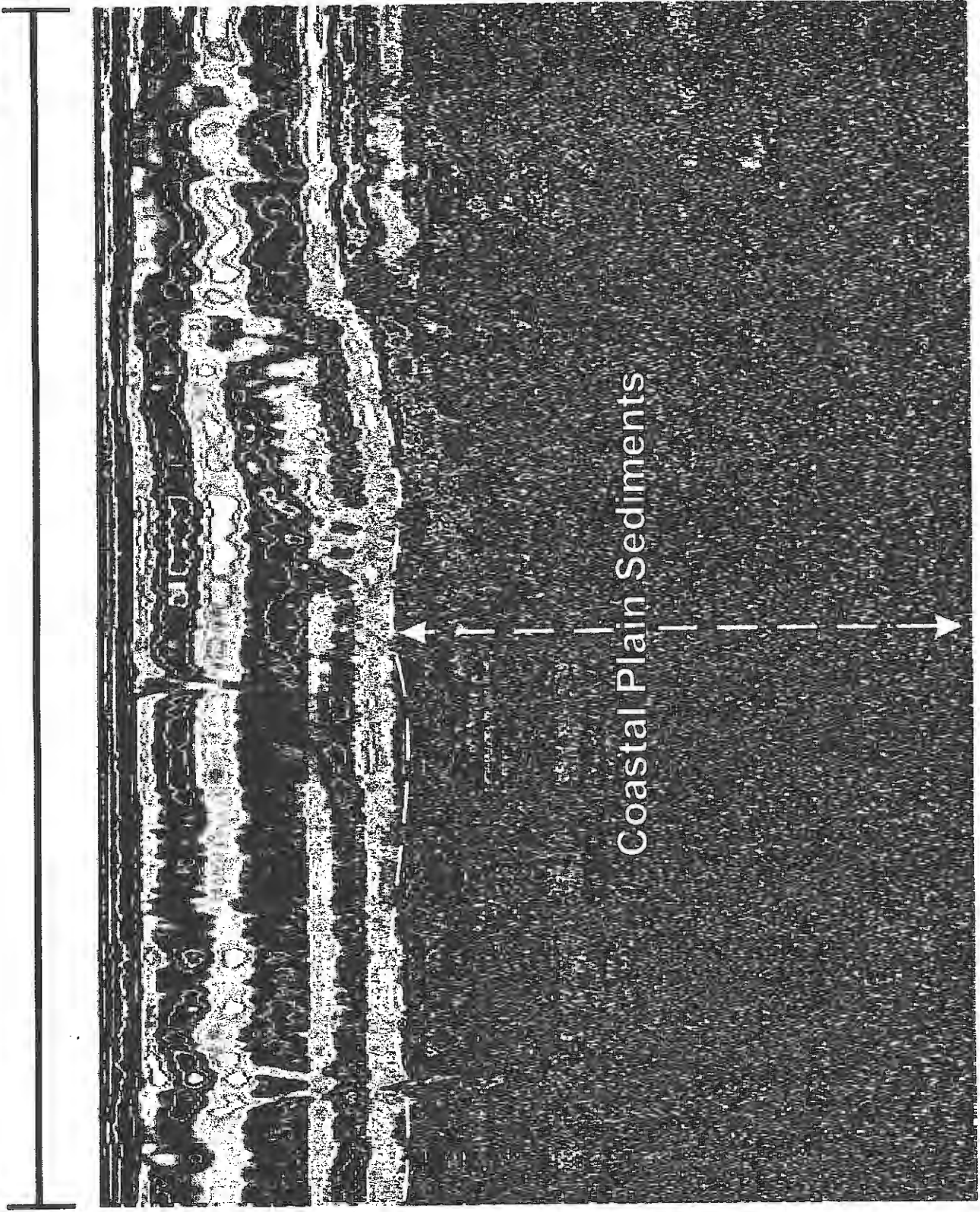


Figure 3. GPR image illustrating variation in soil horizon depth (300 MHz Antenna) (West TN Exp. Station)

**PREDICTING THE WATER QUALITY IMPACTS
OF ENERGY CROPS
USING A GEOGRAPHIC INFORMATION SYSTEM¹**

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INTRODUCTION

Changes in land use patterns may impact many social and environmental factors within a watershed. Quantifying the effects of these changes in a predictive manner allows evaluation of alternatives to present land uses. This project is an attempt to quantify the impacts of converting

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some agricultural lands from production of traditional row crops to bioenergy crops, in particular hybrid poplar trees, might have on the water quality of the Minnesota River Basin (MRB). It is part of a multi-group effort to examine the effects, both environmental and socio-economic, of planting large blocks of bioenergy crops in the region.

Recent research has indicated many possible environmental benefits of switching from conventional agricultural crops to short rotation woody crops (SRWC) such as hybrid poplar (Tolbert and Schiller, 1995). Several factors related to management and timing of fertilizer and pesticide application and the physical properties of SRWC show promise for improving overall water quality by minimizing soil erosion and chemical movement (Tolbert and Downing, 1996).

A net reduction in fertilizer and pesticide use is anticipated for hybrid poplar and SRWC in general. Projected annual nitrogen application is comparable to wheat, and application is not recommended until the second or third growing season (McLaughlin et al., 1985; Ranney and Mann, 1994). If nitrogen is used during hybrid poplar establishment, nitrogen-leaching rates may be high, although ground cover may offer a significant reduction (McLaughlin et al., 1985). Projected phosphorous application rates are considerably lower than most conventional agricultural crops (Ranney and Mann, 1994). Herbicide application is high during the establishment phase (approximately two years), but tapers off significantly and is relatively low when averaged over the life of the crop (Clay, 1992; Ranney and Mann, 1994).

Soil erosion and runoff quantity are expected to decrease dramatically after SRWC establishment. While sediment loss is high during establishment, tree canopy closure and leaf litter accumulation may substantially reduce soil loss compared to conventional row crops (Thornton et al., 1996). Longer cultivation cycles would also reduce soil loss by maintaining a soil cover over an extended period (Pimental and Krummel, 1987). Both canopy closure and litter accumulation are also expected to decrease runoff (Thornton et al., 1996).

While several studies have looked at the economic and physical properties of sites in determining where to plant, very few have examined the potential water quality impacts relative to variability in the magnitude of plantings on a watershed scale. This study is an attempt to address this issue by modeling nonpoint-source pollution and water quality in the MRB. The modeling is being done using a common water quality model integrated with a Geographic Information System. While it is understood there is a lack of quantitative field data to verify modeling predictions, both the need for professional guidance in deciding where to plant and the value of assessing relative impacts of these planting decisions justifies a modeling exercise of this type.

METHODS

SWAT (Soil and Water Assessment Tool) was the model chosen to evaluate water quality in the MRB. It is a physically based water quality/hydrology model that predicts agricultural chemical yields (nutrients and pesticides), sediment loads, and water flow for large basins from varying land use and management schemes (Arnold et al., 1996). Predictions of these parameters can be

made for up to 100 years at daily intervals. SWAT can be run with readily available input data and has been linked with the Geographical Resources Analysis System (GRASS), a public domain Geographic Information System (GIS). The model has been verified over a variety of spatial scales (basins from 17 km² to 25000 km²), and is used and supported by the United States Department of Agriculture (USDA), through the Agricultural Research Service (ARS) station in Temple, Texas.

The GIS interface (SWAT-GRASS) was developed by Srinivasan and Arnold (1994) to simplify application of the model. There are modules in the interface for input data extraction and preparation, and model output visualization in both tabular and map form. The interface requires four raster (grid cell) map layers: a subbasin map, elevation map, soils map, and land use map. All of these layers are publicly available for the entire U.S. at a scale of 1:250,000. Elevation and land use maps were obtained from the U.S. Geological Survey (USGS), and general soils information from the Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO). The database assembled for this project also included other layers necessary for site selection, data preparation, and data visualization. Data layers are stored in an ARC/INFO database, and converted to GRASS as needed for model runs.

SWAT was parameterized for hybrid poplar using values obtained from researchers involved in modeling using the Erosion Prediction Impact Calculator (EPIC). Nitrogen fertilization is assumed minimal, as yields from three nine-year-old plantations in Minnesota have been at expected levels with no nitrogen fertilizer application. Harvest cycles are assumed to be between 7 to 10 years based on current growth curve expectations. Ongoing communication with the model developers has been necessary as SWAT was not developed for multi-year harvest cycles.

The model is being run initially on the Cottonwood watershed (hydrologic unit code 07020008), a subbasin within the Minnesota River Basin. The basin is dominated by agricultural land use, primarily soybean and corn production. The model was calibrated through modification of curve numbers and soil available water content, and comparison with measured water quality and flow data obtained from various federal and state agencies. Both calibration methods were recommended by model developers in the USDA-ARS.

Planting scenarios include planting hybrid poplar in riparian zones and on former Conservation Reserve Program (CRP) lands, in varying amounts. As the project progresses, additional scenarios will be explored.

DISCUSSION

We are still in the process of running the model for the CRP and riparian zone planting scenarios. The model output from these scenarios, particularly fertilizer yields, runoff, and sediment, will be compared to both measured water quality data and other model runs assuming conventional crop production. The results will be used to evaluate relative changes in water quality resulting from a change in land use, rather than representing expected water quality parameter values.

A question raised early in the study was whether spatial location of plantings on a finer scale, such as riparian versus upland planting, might also have an important impact on water quality. Earlier modeling efforts with the Agricultural Nonpoint Source Pollution Model (AGNPS) have indicated this possibility (Sears, 1996). SWAT is not appropriate for modeling hydrology at the field scale, as it averages land use and soil parameters over subbasins many square kilometers in size. SWAT does, however, accept output from field-scale models such as EPIC and AGNPS, which are appropriate for addressing riparian or erosion-prone areas. Other researchers have used EPIC for modeling bioenergy crops (Downing and Graham, 1996), and the integration of this model into our modeling efforts is anticipated.

Regional economic studies have demonstrated the viability of bioenergy crops in Tennessee, particularly in the central and western portions of the state (Downing and Graham, 1996). The methodology presented here has the potential for application by Tennessee managers and planners, as it relies on a water quality model that has been verified over a wide geographic range, was developed for regionally based studies, and is reliant on publicly available databases covering the conterminous United States. An additional benefit of integrating GIS with this model is the potential for better communication of model results.

There is a decided lack of measured quantitative data on the effects of biofuel crops on water quality. At least one study has been initiated examining the effects of SRWC versus conventional row crops (Thornton et al., 1996; Tolbert and Schiller, 1996); initial results support the hypothesis that water quality will improve with conversion to SRWC. Due to the long harvest cycle of these crops, it will be several years before conclusive results can be presented. However, land use decisions, especially those that might affect water quality and agricultural nonpoint-source pollution, still need to be made. Modeling efforts alone and in conjunction with field studies aid in this planning process for the Minnesota River Basin and ultimately provide guidance for other basins.

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**THE ELKTON AQUIFER OR WESTERN TOE AQUIFER
OF THE BLUE RIDGE MOUNTAINS:
REGIONAL PERSPECTIVE FOR A LOCAL TENNESSEE AQUIFER**

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By the mid-1980's, the Elkton aquifer, herein named for its development in the Elkton area, Rockingham County, Virginia, had been recognized as a major, local source of water within only six counties in the Valley and Ridge Physiographic Province in Pennsylvania, Virginia, Tennessee, and Alabama. Before 1994, this aquifer was unrecognized as a regional resource, probably because it occupies less than one percent of the area of the province and is geographically discontinuous. In 1994 during a U.S. Geological Survey regional study of ground-water resources, the authors analyzed well records for statistical significance of the Elkton aquifer and recognized the aquifer's regional extent.

The Elkton aquifer, formerly known as the western toe of the Blue Ridge Mountains (western toe), is a karst-bedrock aquifer that underlies a discontinuous apron of colluvium and alluvium less than 3 miles wide at the toe of the western slope of the Blue Ridge Mountains. The colluvium consists of stony material shed from outcrops of resistant, siliciclastic rock of Cambrian age that in many places caps the Blue Ridge Mountains. The apron overlies fine-grained residuum and dolomite bedrock at more than 36 places at the southeastern edge of the Valley and Ridge Physiographic Province. In parts of the western toe, the combined thickness of colluvium, alluvium, and residuum exceeds several hundred feet. In Augusta, Rockbridge, and Rockingham Counties in Virginia, the Elkton aquifer has public and industrial supply wells that individually may produce in excess of 1,000 gallons of water per minute, and that together produce more than 20 million gallons of water per day from dissolution openings in the dolomite that underlies the thick regolith. The geomorphic conditions that define the western toe exist in isolated parts of 36 counties from Harrisburg, Pennsylvania, to Anniston, Alabama, including

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Carter, Cocke, Greene, Johnson, McMinn, Polk, Unicoi, and Washington Counties, Tennessee.

The statistical analysis of the specific capacity of 44 wells in Virginia and West Virginia (28 "in-toe" and 16 "out-of-toe" wells) showed that the ranges of the middle 90 percent of specific-capacity values overlapped, and each range spanned about three orders of magnitude. The median specific-capacity value for "in-toe" wells (26 gallons per minute per foot) is more than three times the median value for "out-of-toe" wells (7.2 gallons per minute per foot). A Mann-Whitney test indicated a statistically significant difference between these median values where the p-value is 0.05. Public and industrial supply wells in dolomite of the Elkton aquifer had significantly greater specific-capacity values than comparable wells in dolomite elsewhere in Virginia and West Virginia. From late 1993 through 1996, the Elkton aquifer was being developed with wells for water supplies in Carter and Unicoi Counties, Tennessee.

**WHITE OAK CREEK EMBAYMENT SEDIMENT CONTROL STRUCTURE:
COOPERATIVE EFFORT YIELDS RESULTS,
AN EXAMPLE OF THE OAK RIDGE MODEL IN ACTION**

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White Oak Creek, the major surface drainage through the Oak Ridge National Laboratory, contains sediments which have been contaminated with Cesium-137, Cobalt-60, and various metals. Releases of these contaminants into the Clinch River from the uncontrolled White Oak Creek Embayment, especially during power generation periods at a nearby upstream hydroelectric power plant, created community concern for health safety. The sediment control project which corrected this situation was completed in 1992 and involved the effective utilization of the professional and managerial talents of many individuals from diverse organizations, both public and private, and is an excellent example of the effectiveness of a partnering approach to the solution of a complex environmental problem.

The design of the sediment control structure at the mouth of the White Oak Creek Embayment addressed not only the long-term objective of minimizing or eliminating releases of contaminated sediments into the Clinch River, but also considered the short-term effect of the construction on water quality. To minimize sediment releases during construction, special methods and sequencing were used to construct the facility, and the success of these measures was determined by real time and laboratory test monitoring.

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**ZINC ADDITIVE IN ONCE-THROUGH COOLING WATER
IDENTIFIED AS CONTRIBUTING TO TOXICITY
OF EFFLUENT DISCHARGED FROM THE OAK RIDGE Y-12 PLANT.¹**

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and

Bradley Skaggs³

The National Pollutant Discharge Elimination System (NPDES) permit for the Oak Ridge Y-12 Plant, issued in April 1995, contains a biomonitoring permit limit at an ambient location (Outfall 201) in East Fork Poplar Creek. Effluent at Outfall 201 consists of treated process wastewater, treated groundwater, groundwater that infiltrates the storm sewer system, cooling water, condensate water, sump water, cooling tower blowdown, and storm water. Prior to the 1995 NPDES permit, a biomonitoring limit did not exist; however, historical data demonstrated that effluent from Outfall 201 would not routinely meet the permit limit, a no-observed-effect concentration (NOEC) of 100%. A toxicity assessment of effluent from Outfall 201 began in December 1994. Following procedures similar to those described by the U. S. Environmental Protection Agency for toxicity identification evaluations, approximately 30 toxicity tests with *Ceriodaphnia* have been conducted. During 1995, the general physical and chemical characteristics of the toxicants in the effluent were determined. Using a variety of effluent treatments and sampling scenarios, researchers found that (1) grab samples tended to reduce survival and reproduction of *Ceriodaphnia* more frequently than composite samples, (2) toxicity was reduced by the addition of a metal-chelating agent (EDTA) and by filtration at pH 11, (3) the response of *Ceriodaphnia* to the effluent varied with pH, and (4) zinc contributed to the toxicity observed in at least one sample.

During 1996, the effluent treatments focused on the possibility that zinc was a major contributor

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to the intermittent toxicity observed. Four primary treatments were used on effluent samples: (1) pH 6 adjustment, (2) pH 9 adjustment, (3) addition of EDTA, and (4) filtration at pH 11. In these tests, the pH 9 adjustment increased toxicity in 80% of the grab samples and 40% of the composite samples. The EDTA addition (metal-chelator) decreased toxicity in 40% of the grab samples and 55% of the composite samples. Because zinc is one of the few metals that is more toxic at higher pH, the trends from the 1996 tests showed that zinc clearly contributed to toxicity at Outfall 201. A major source of zinc in the effluent was traced to a zinc additive used as a corrosion inhibitor in potable water, which is subsequently used as once-through cooling water. Toxicity tests with zinc, the zinc additive, and potable water confirmed that the concentrations of zinc in the potable water were also sufficient to reduce survival and/or reproduction of *Ceriodaphnia*.

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