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The Thirteenth Annual Tennessee Water Resources Symposium

Proceedings of

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April 9-11, 2003

Montgomery Bell State Park

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The Thirteenth Annual Tennessee Water Resources Symposium

Montgomery Bell State Park
Burns, Tennessee

April 9-11, 2003

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AWRA

PREFACE

Since the first symposium sponsored by the Tennessee Section of the American Water Resources Association (TN AWRA) in 1998, the organization has continued to provide a forum for practitioners, regulators, educators, and researchers in water resources to exchange ideas. The 13th TN AWRA Symposium consisted of 65 presentations and over 20 posters on a broad range of policy, technical, and outreach issues of interest to water resource professionals in Tennessee. The 13th Symposium would not have been possible without the efforts of the planning committee, session moderators, speakers, exhibitors, and sponsors.

AWRA

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AWRA

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REGIONAL WATER SYSTEMS IN GENERAL…
THE WATER AUTHORITY OF DICKSON COUNTY SPECIFICALLY

D. Elmo Lunn[1] and George Garden, P.E. [2]

WATER AUTHORITY OF DICKSON COUNTY
CUMBERLAND RIVER PROJECT STATUS

Since we reported to this Symposium two years ago the Cumberland River Project and the dream of a long term drinking water source for Dickson County has moved from the planning and funding stage to construction. Of the $29.4M budgeted $28.6M has been contractually obligated to date and $17.3M or approximately 59% spent. Physical construction progress is about 1 month behind the two year schedule primarily due to the extremely wet fall of this year. All transmission lines are in the ground and tested, all tanks are erected and awaiting spring painting season, and the Water Treatment Plant, Raw Water Intake and the two booster pump stations are on track to meet an August 2003 production target.

Funding for the project came from the combined efforts of the utilities involved, the State Revolving Fund loan program and the Federal Governments Rural Development Agency. Initial engineering feasibility studies, land acquisition and project design was financed via a $0.25/1000 gallon surcharge collected by the City of Dickson Water Department, Turnbull-White Bluff Utility District, Sylvia-Tennessee City-Pond Utility District (STCPUD) and Harpeth Utility District for almost three years. A private sector bond for approximately $17M was held for approximately 15 months until the consolidation of three of the utilities into the Water Authority of Dickson County to start the construction project. Final financing includes $12M from Rural Development in the form of two $4M loan-$2M grant packages, and a public bond for $23M which provided not only project funding but covered the consolidated debt of the merging entities. Water rates for WADC customers were raised to rates comparable to area larger utilities to cover the debt service and required reserve funds to maintain a AAA bond rating and satisfy Tennessee Regulatory Agency requirements for the transfer of debts to the larger entity.

The magnitude of the project is impressive for a community of this size:

- 33 miles of water transmission line:
  30" diameter raw water line
  24" diameter main transmission line (32 miles)
  12" diameter transmission line to STCPUD (1 mile)
- The first major membrane filtration plant in the State of Tennessee with 1,800,000 six-foot long submerged ultrafiltration membrane fibers with 192,000 square feet of filtration surface area capable of producing 5 million gallons of high quality drinking water each day

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[1] Chairman, Water Authority of Dickson County, Dickson, Tennessee

[2] Barge Waggoner Sumner & Cannon, Inc., Nashville, Tennessee

- 2.5 million gallons of water storage (2 Mgal at the water treatment plant, 500,000 kgal in intermediate transmission system storage)
- Four major pumping facilities:
  5.75 MGD raw water from the intake
  5 MGD from the high service pumps at the water treatment plant
  5 MGD from the Rock Church Road Booster Pump Station
  1 MGD from the STCPUD Booster Pump Station

EVOLUTION OF THE WADC INTO A FULL OPERATING UTILITY

In 1990, the Dickson County Water Authority was created by Private Act and Ratified by the Dickson County Commission with one vote to spare. It's mission was to develop a water source on the Cumberland River and deliver finished water to participating utilities in the County, who were expected to purchase water at a fair wholesale rate. The concept gained enough support for passage and approval because the Authority was conceived as a wholesale supplier only, and would not be a threat to any utility or their customer base.

It was not only desirable, but absolutely necessary, that the County Water Authority establish a large water source to meet the growing needs. In 1990 there were two (2) municipal water systems and five (5) Utility Districts in Dickson County. City of Dickson and Turnbull Utility were the only water systems with surface water supplies and filtration plants. Harpeth Utility District and the Town of Vanleer both had small spring sources that were considered non-viable for coming water treatment rules. The other three- (3) utilities were water purchasers only. TDEC/WPC had placed withdrawal limits on both Dickson and Turnbull intakes. Dickson County was in a desperate need for additional water to serve new residential and industrial growth.

So the first meeting of the new Authority Board was held in July 1990. I had two shocks:

1. The group wanted me to serve as the Chair.
2. All seven (7) utilities said they would not support the regional project. All said they were happy with current arrangements, and were content to use springs and small streams. Not a one had vision of future needs. It simply did not matter to them.

Over the next 6 years, the Board dutifully met each month, and along the way developed various financial models for project financing directed at the Authority being a wholesale water supplier for the other independent water utilities. Additionally, during this 6-year period all potential sources were evaluated, and one by one eliminated. It was determined that only the Cumberland River would satisfy the needs for the 40-year planning window.

In 1996, the first utility became a project supporter. The Chairman of Turnbull Utility retired; leadership of Turnbull's Board changed. The City of Dickson and Turnbull Utility District discussed merger of the two water utilities. Crucial errors were made at critical times, and the merger failed.

In 1998, 4 very important events occurred:

1. White Bluff merged with Turnbull Utility District forming TWBUD.
2. Dickson merged West Piney Utility District into the City Water Department.
3. STCP Utility District changed views and became a project supporter and participant.
4. The County Executive replaced one of the Harpeth Utility District Commissioners with one of great vision, who understood what needed to be done.

At the end of the year, the number of opposing utilities was reduced to only 3 remaining.

In 1999, the County Executive replaced a second commissioner of Harpeth Utility with a project advocate, and then Harpeth Utility District became fully supportive. At this time, all of the Utility Districts were aboard; only the two municipals disfavored the Regional project. At this time the three utility districts deemed the project feasible with some downsizing to serve their needs without the two municipals. The Water Authority pursued two avenues of financing……one, a combination grant and loan by Rural Development, and second, a private bond issue.

In 2000, engineering designs were virtually complete for a project to serve the three utility districts, leaving aside the municipals. The combined customer base of the three utilities was 8,200. If the City of Dickson became involved, its added 4,800 would bring the total customer base to 13,000. There was an additional problem with what was being planned…. an excessive residence time in the transmission line. We all deemed it urgent to talk to the City of Dickson, who was in a capacity dilemma of its own. Talks proceeded with the City throughout the year. At the year's end, a tentative agreement was reached that would bring the City aboard. Based on this very tentative agreement, the Authority directed its engineers to revise project scope with larger plant, larger line and hydraulic modifications.

In 2001, construction started on the Cumberland River Water Project. The deal with the City of Dickson included Private Act Revisions that would restructure the Authority Board. These revisions, after passing the General Assembly, were contested by some County Commissioners and only gained approval by one vote to spare.

The primary basis for the agreement was consolidation of Harpeth, Turnbull-White Bluff and the City of Dickson Water Department, all into the Water Authority, which was renamed the Water Authority of Dickson County. STCP Utility declined to be a part of the new utility structure, but remains a purchaser.

Special legislation in 2002 led to changes in the SRF requirements that enabled WADC to assume SRF loans in place by the City of Dickson. This was necessary for a complete merger of all assets.

On May 20, 2002, the Water Authority changed character to a full operation utility service provider for water and wastewater. Consolidation was complete.

TECHNICAL ISSUES IMPACTED BY THE POLITICAL CHANGES

Since the early 1980's when source water quantity was identified as the long term limitation on the Dickson County's potable water supply, the identification of a source or sources has defined the debate. Regulations have made smaller treatment systems on springs and small streams less and less cost effective and resulted in inevitable consolidation of treatment to two large plants by the turn of the century. As predicted in the '80's, growth in water demand has continued unabated in Dickson County, although somewhat less rapidly during the economic downturn of the 2000-2003 time period, and will exceed the 80% capacity of the two main existing water treatment plants by 2005. Each existing plant is designed to treat and pump at the stream-quality mandated maximum withdrawal rate.

Wisely in 1998 the then Dickson County Water Authority set forth the following goals for the long term water solution:

1. Provide a system which will result in a long term (30-50 years) solution to the source water delimna,
2. Meet long term drinking water quality objectives while reducing the impact of withdrawal from the scare surface water resources of the County, and
3. Be fiscally far-sighted but prudent.

These goals resulted in a feasibility report which demonstrated that the concept of withdrawal from the Cumberland River and utilization of recent treatment technologies could meet the Authority's supply objectives while not saddling rate payers with excessive water rates. In addition the placement of the plant near the River provided the future opportunity to support growth in the proposed SR 840 corridor without promoting urban sprawl. The vision at this time was for a 2 MGD system capable of growth to 5 and eventually 10 MGD operated by the Water Authority in a wholesale producer mode.

Technical objectives for the system evolved while utility politics moved toward a more consolidated approach. Design objectives shifted in a six month period from a wholesale entity selling to 4 utilities, to a wholesale entity selling to 3 with the capacity to expand back to 4, to a consolidated entity of two or three utilities selling to the remaining utilities at wholesale rates, to, finally, a consolidated entity of three selling to the fourth utility, STCPUD. Fortunately the Water Authority's technical objectives did not need to change extensively during this process because they always kept the long-term County-wide perspective in view:

1. Provide an easily expandable system for the long term.
2. Provide a system which could replace one of the existing plants in the short term or long term if necessary due to regulatory changes, economies of scale, water source degradation, or material damage.
3. Meet long term treatment requirements anticipated and foreseen, specifically the competing and evolving requirements of the surface water treatment rules and the disinfectant/disinfection by-products rules.
4. Provide expansion capability to eventually serve all four utilities seemlessly. This was interpreted to mean that each utility delivery requirements for flow and pressure would be met through the period of time that the initial plant capacity of 5 MGD was sufficient for County-wide needs and that transmission line and raw water pumping capacity would be sufficient to meet 30-50 year projections for the individual utilities.

This combination of objectives resulted in a system with the following characteristics:

1. An intake line capacity to withdraw and transmit to the treatment plant 5-15 MGD; 5 MGD initially, 10 MGD without any equipment modifications; and 15 MGD with only pump change out.
2. A Water Treatment Plant utilizing membranes to meet the pathogen-driven surface water treatment rules, in combination with the pre-treatment objectives to reduce total organic carbon, disinfection by-product precursors, and chlorine usage to meet disinfectant/disinfection by-product rule trends.
3. A Water Treatment Plant capable of 5 MGD initially with expansion to 10 MGD and 15 MGD with minimal structural changes to the treatment process building. Raw water storage, administrative spaces and residual treatment would not have to be altered for the growth.
4. A distribution system capable of meeting 15 MGD county-wide delivery objectives with only pump upgrades, while conserving energy consumption in all phases, and without the construction of structures with limited life spans or hydraulic usefulness.

The design team to implement this plan included Water Authority representatives, City of Dickson Water Department and Turnbull-White Bluff Utility operationg personnel as well as the design engineering firm in a collaborative design effort. Because this group and the Water Authority itself were so focused on integrating customer needs, consolidation of the utilities not only did not result in the requirement to conduct expensive redesign but resulted in significant cost savings:

1. Direct service of STCPUD could be accomplished through the former City of Dickson system rather than through a separately constructed and dedicated line. The less expensive additional connection will provide a much larger and therefore meet STCPUD's needs for a considerably longer period of time for less money.
2. The larger customer base reduced overall individual rates.
3. Consolidation will provide the opportunity for future overhead reductions in staff.
4. Individual system expansions which would have had to occur in non-participating utilities were shelved.

Water quality issues due to the initial low usage, and, therefore, low flow rates and long residence times in the transmission system designed for the future, were also resolved by the consolidation.

STRATEGIC SIGNIFIANCE OF FINANCIAL/TECHNICAL PLANNING

This segment will deal with difficulties created by regulatory agency decisions throughout our 13-year adventure. This is a plea to State policymakers to better define water supply objectives; create a strategy that recognizes that many communities across the State will meet their needs only though the formation of regional plans; and directing agency decisions that are consistent with these regional plans. And if these plans are to work, the funding agencies at both the State and Federal level must direct their funding away from proposals that are inconsistent with the regional plan.

First, consider the posture of the City of Dickson. TDEC/WPC very correctly placed a limitation on the water withdrawal from the Piney River and Turnbull Creek. The City likely would never have joined in with the Regional effort, except for the tenacity of WPC/Paul Davis. But the project financial feasibility depended on everyone.

During this time, the City drilled wells in an attempt to avoid being part of the solution. This engineering was approved by DWS.

Even in the face of the TDEC/WPC limitation, the City installed a pumping system designed for more than twice the limit and constructed it with the approval of DWS.

Even in the face of the TDEC/WPC limitation, the City designed an expanded filtration plant, and the plans were approved by DWS. Funding plans included a $0.5 million CDBG by the Tennessee Department of Economic and Community Development. City strategy was to accept the CDBG and force the issue to the State's Water Quality Control Board on appeal, saying "if you won’t allow the additional capacity we need, we will lose the grant offer". Fortunately, consolidation came about, and this effort went away.

Had this strategic direction of the City been completed, the prospects for meeting the water needs of all the other utilities would have been extremely dismal.

Next, consider the small Dickson County Town of Vanleer. With around 1,000 customers and no desire to grow, the town still faces a regulatory obligation to upgrade its system to comply with new rules.

The Authority is positioned to furnish water to Vanleer for about $0.5 million in design and construction costs. In fact, the Authority has a 24-inch finished water transmission line that crosses part of Vanleer's service area.

Vanleer has proposed a project to develop a new surface water source, abandon its spring, and install a raw water pumping station and transmission line to an upgraded filtration plant. The entire project has been designed and bid at $2.4 million. All of this is very current.

Vanleer has been approved for a CDBG grant by the Tennessee Department of Economic and Community Development.

Vanleer has been approved for a grant by Rural Development of the US Department of Agriculture.

The project has the approval of TDEC, both WPC and DWS.

With all of these approvals, it appears that about $1.9 million will be unnecessarily expended and lost to the needs of other communities across the State.

Yes, people across the State are begging for water policy definition and commitment by TDEC and the funding agencies to the concept of Regional planning. This could solve issues and needs in Cumberland County, Hawkins County, Carter County, Giles County, Lawrence County and many more. We in Dickson County were lucky, but sound policy would have saved much of our time. If the Regulatory and Funding Agencies would have locked onto the County-approved regional plan, as the Division of Water Pollution Control did, it would have been much easier to deal with the City's posture. All the utilities, including the City, would have benefited and the Cumberland River Projected would have been completed sooner.

WAYNE, LEWIS, AND LAWRENCE COUNTIES, TN – REGIONAL WATER SUPPLY STUDY
"A REGIONAL APPROACH TO RURAL WATER SUPPLY"

Cindy Popplewell,P.E.[1] and Todd Boatman[2]

The *Wayne, Lewis, and Lawrence Counties, TN - Regional Water Supply Study* is a unique project in both the regional methodology and cost share funding. Typically, water supply studies are performed by an individual utility district in search of an adequate water supply source for their respective district needs. This regional study is a preliminary study of the existing water supply conditions of Wayne, Lewis and Lawrence Counties and a preliminary investigation of water supply alternatives to supplement the existing water supply of these Counties.

The first step in this study was the preliminary Needs Assessment. Water distribution for Wayne, Lewis, and Lawrence County residents is provided by 14 utility districts. Field visits were made to Wayne, Lewis, and Lawrence Counties to interview and collect historical water usage data from each of the 14 utility districts. Three possible growth scenarios were assumed which provide growth patterns based on (1) historical growth, (2) a moderate increase to the historical trend (median growth), and (3) an unlimited increase to the historical trend. The intent of this estimated range of the future demand is to provide a perspective of the feasibility of several different alternatives to supply additional water to the Counties.

The second step was the selection of a variety of water supply alternatives. This step included data collection and a minimum level of field work with respect to topographic surveys, and soil and geologic investigations. Six water supply alternatives were investigated including (1) water conservation; (2) groundwater – natural springs and groundwater wells; (3) large scale pipelines; (4) storage impoundments – new and improvements to existing; (5) water harvesting – to existing and excavated reservoirs; and (6) no action. Preliminary benefit-cost and financial analyses and environmental screening of the various identified solutions were also included in this study.

This *Regional Water Supply Study* is intended to aid the communities in planning for the long-term regional water supply needs of the Wayne, Lawrence, and Lewis Counties region.

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USING GEOGRAPHIC INFORMATION SYSTEMS TO SUPPORT WATER SUPPLY POLICY DEVELOPMENT

Emily N. Heinrich[1], Robert Freeland, Ph.D.[2], David Feldman, Ph.D.[3], and Forbes Walker, Ph.D.[4]

The Southeast's historically abundant water supply provides the basis for agriculture, transportation, energy production, and recreation. However, in Cumberland County, Tennessee and many similar communities, these multiple uses and the increasing demands of rapid population growth, development, and urbanization stress this precious resource. Our study uses ArcIMS to develop the Cumberland County Water Resource Atlas, a tool for planning and managing the county's increasingly scarce water supply. The Atlas gives local, state, and federal decision makers online access to the hydrological, infrastructure, biophysical, and social data necessary to formulate water supply policy. It also facilitates public dissemination of these data by enabling online mapping and data analysis. This encourages public participation in water policy issues.

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TENNESSEE'S WATER SUPPLY AGENDA—UNDER NEW MANAGEMENT

G. Dodd Galbreath[1]

The presentation will highlight past water supply policy initiatives of previous administrations and the federal government and possible policy proposals for the current administration and United States Congress. The presentation will address current challenges to water supplies in Tennessee and current gaps in public policy needed to protect it. Tennessee is surrounded by eight southeastern states and shares more water with other states than any state in the south. Tennessee's water supply policy needs will also be contrasted and presented in the context of regional drought, regional population growth, regional water use and growing water needs of states bordering Tennessee that may affect Tennessee now and into the future.

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FRANKLIN TENNESSEE URBAN STORMWATER PROGRAM

Don Green[1]

Over the last 10 years, the population of Franklin has nearly doubled, and with it impervious surface area and the amount of pollutants have increased and so grows the potential for further degradation of our streams and rivers. Because of this potential for water quality degradation, coupled with the new NPDES Municipal Separate Storm Sewer System (MS4) Phase II permit requirements from Tennessee Department of Environment and Conservation, the city of Franklin assembled a Stormwater Management Task Force in July 2000. It was comprised of citizens, city aldermen, and Franklin employees with Camp Dresser & McKee Inc. facilitating the meetings. The purpose of the Task Force was to evaluate and make recommendations in regards to stormwater management policies established by the Long Range Plan, Zoning Ordinance, Erosion and Sedimentation Control Regulations.

The task force recommendations:
1) a stormwater management document should be prepared to accommodate the City's existing stormwater provisions and incorporate the new Phase II Permit requirements.
2) New ordinances needed to be established and existing regulations would have to be modified to avoid conflicts.
3) Create a Best Management Practices Manual.
4) The task force recommended that the City consider a User Fee Utility to create a funding source to implement the Stormwater Management Program.
5) The city needs more information on water quantity/floodplain on its major subwatersheds

Major tasks accomplished so far:
· Began a subwatershed modeling/infrastructure mapping process: 3 subwatersheds finished
· Began stormwater infrastructure survey
· A Stormwater Management Ordinance passed April 9, 2002 with next
stormwater quality and quantity requirements for all development
· Developed a Best Management Practices Manual
· Stormwater Management Coordinator hired March 2002
· New Stormwater Management Permit, Residential Home Builder Erosion and Sediment Control Permit and updated Grading and Erosion Control Permits for all development
· New Franklin Stormwater web site:
http://www.franklin-gov.com/Departments/engineering/STORMWATER/stormwater.htm
· A Developers/Builders/Contractor information workshop was held July 24, 2002.
· Worked with Williamson County and Brentwood stormwater programs to develop regional organization
· Develop mechanism to tract permits and regulatory communication
· Stormwater User Fee Ordinance 2002-14 past final reading
· Develop a new Forest Riparian Buffer policy
· Stormwater User[1] Fee to begin January 1, 2003

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SOMETIMES IT TAKES MORE THAN A VILLAGE: THE CONTINUING RESTORATION AND RECLAMATION OF CITICO

J. Douglas Fritz [1]

The Citico Creek watershed encompasses a highly urbanized 17.2 km2 area within the City of Chattanooga. Citico Creek runs from Missionary Ridge north to the Tennessee River. As a result of the significant physical alterations and illicit discharges into the stream, Citico Creek does not meet current State of Tennessee water quality standards for temperature, dissolved oxygen, bacteria, biological integrity or habitat assessment. Currently, the segment of Citico Creek, flowing through Carver Recreation Center is posted against human contact due to high bacteria levels.

The City's efforts to restore and reclaim Citico Creek as an important natural resource for the community necessitated the solicitation of services from numerous agencies including local, state and federal governments, non-profit groups, corporations, academic institutions, and even the local airport. Collaborative efforts, concentrated on the Carver Recreation Center segment, have resulted in the restoration of 3,000+ feet of a natural stream channel, a 25% reduction in water temperature during summer months and a reduction of over 50% in the geometric mean of fecal coliform since 1998.

The City continues to monitor Citico Creek in order to document water quality improvement resulting from these and other projects. Additional projects have increased public awareness of the creek's importance to the community. Anticipated projects continue to build upon the importance of fostering partnerships and consensus on how to improve urban watersheds.

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A BETTER APPROACH TO STORM WATER MANAGEMENT BY MAINTAINING SURFACE- AND GROUND-WATER INTERACTION

Michael S. Lighthiser, P.E.[1]

Introduction

As water resources professionals, we work toward improving our aquatic systems and strive to ensure healthy water resources for future generations. Phase II of the National Pollutant Discharge Elimination System (NPDES) has helped make water quality and storm water a high priority for local communities. It presents an opportunity to take a close look at how we manage storm water and to implement more effective and innovative techniques.

Storm Water Management Today

Typically, today's storm water management consists of channeling all storm water as quickly as possible into a detention area at the lowest point on the site. This approach has numerous problems. First of all, by concentrating storm water management where the storm water leaves the site, the site is then left unprotected. Nothing exists to intercept the increased runoff quantity and intensity that typically occurs when a site is developed. As a result, natural drainage ways are degraded. The channel in Figure 1 was a grassy swale that adequately conveyed runoff from the pre-existing agricultural field. Now that the site has been developed into a subdivision, the increased runoff has eroded the channel to bedrock and widened it into homeowners' backyards. Water quality is negatively impacted, and the overall value of the subdivision has decreased. Much energy is now spent trying to grapple with a problem that could have been prevented through better design.

Figure 1

Experience has also shown another problem with detention basins – they do not necessarily protect the channel downstream. Due to their design, discharges that can cause significant erosion are allowed to pass through, degrading the channel. In addition, conservative engineering design may further exacerbate stream-stability problems by releasing even higher flows.

This approach of rapidly draining a site into a central detention basin is part of a storm water management system that focuses on surface-water runoff while ignoring sub-surface processes. Such a narrow focus precludes natural hydrologic functions such as infiltration and evapo-transpiration. As a result, today's storm water management has led to increased runoff and flooding and has degraded water quality. Is there an alternative approach that more effectively deals with storm water while maintaining the benefits of natural systems?

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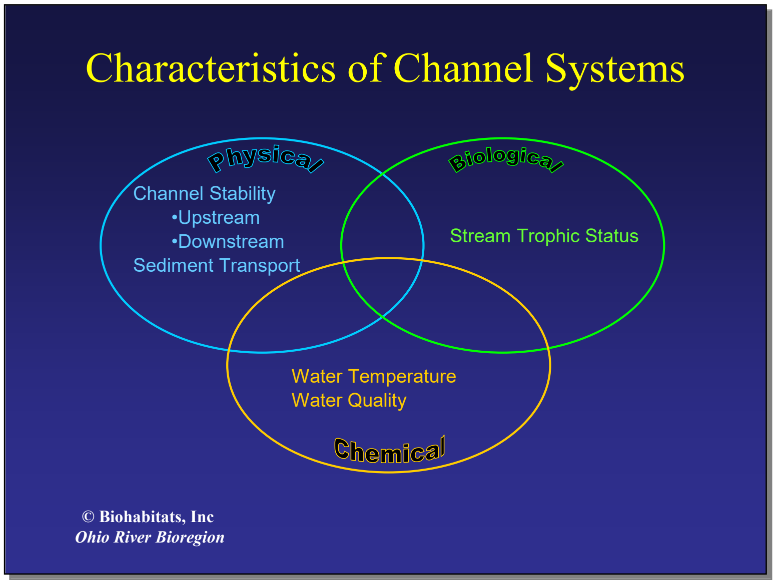
Characteristics of Channel Systems

Physical

Channel Stability
- Upstream
- Downstream

Sediment Transport

Biological

Stream Trophic Status

Water Temperature
Water Quality

Chemical

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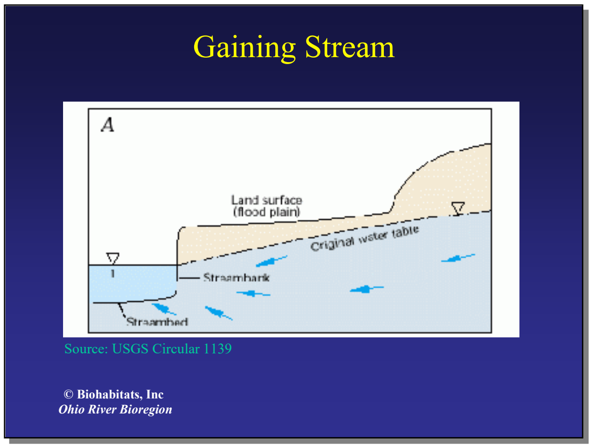
Numerous physical, biological, and chemical characteristics exist that are of concern to water resources professionals (Figure 2). These characteristics overlap and influence one another. Natural systems provide a model of how to deal with storm water without degrading these characteristics. An important feature of natural stream systems is the floodplain.

Figure 2

Floodplain Processes


Gaining Stream

Source: USGS Circular 1139

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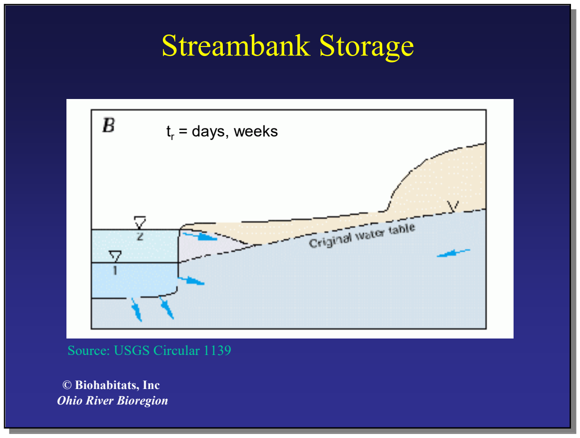
A natural stream channel consists of a bed, bank, and floodplain (Figure 3). During low flow, practically all of the water in the stream comes directly from ground water. The stream is called “gaining” since it is gaining water from the ground.

Figure 3

When a storm occurs, surface water flows into the channel, raising the water level in the stream. Water movement is then reversed, flowing from the stream into the ground (known as a “losing stream”). In Figure 4, runoff has increased the water level to the top of the bank. The water infiltrates into the bank, where it mixes with ground water and eventually returns to the stream. This water that is held in the banks is referred to as “streambank storage.” The duration of storage can be from days to weeks.


Streambank Storage

Source: USGS Circular 1139

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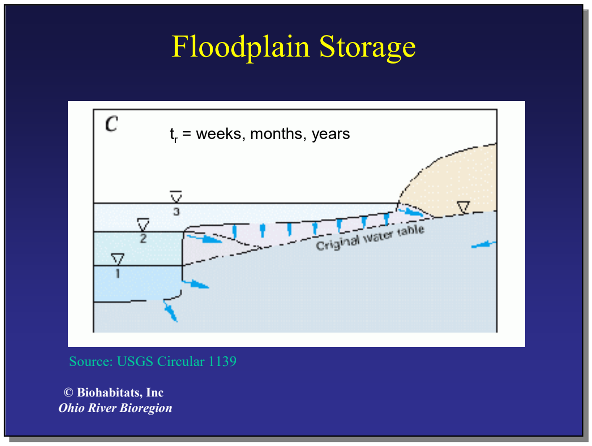
Figure 4



Floodplain Storage

Source: USGS Circular 1139

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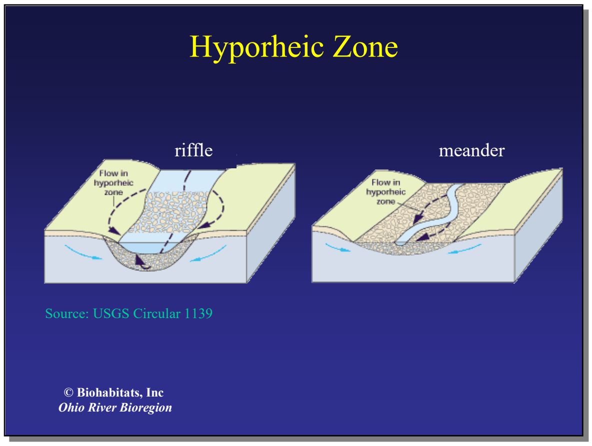
Figure 5

In Figure 5, enough precipitation has fallen to raise the water level above bank height, inundating the floodplain. The flooding water then slowly infiltrates into the ground, mixes with the ground water, and eventually flows back to the stream. This cycle is very important for healthy, natural stream channels, from both a water quantity and water quality standpoint. First of all, the time to complete this cycle of flooding, infiltration, and return can take from weeks to months and even years, depending on the floodplain and extent of inundation. The resulting storage time (or "floodplain storage") can significantly lower water level during peak flows while increasing water during low flows. From a water-resources-management perspective, functioning floodplains lessen floods and also help maintain water in the stream during dry times.

In terms of water quality, the physical and chemical processes that occur during flooding, infiltration, and mixing with ground water actually treat the water. As a result, the water returning to the stream is cleaner than the water that initially floods the floodplain. So floodplains, which are an integral feature of natural streams, provide water storage and quality benefits.



Hyporheic Zone

Source: USGS Circular 1139

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Figure 6

In addition to floodplains, other natural stream features include riffles and meanders. Both of these features have an important common characteristic: they force surface water to flow underground through the streambed and banks. This subsurface zone, or "hyporheic zone," provides another location where surface and ground water interacts. As a result of this interaction, the chemical character of the water in the hyporheic zone is significantly changed (e.g. cooler temperature, higher dissolved oxygen), resulting in water quality and biological benefits. It is no coincidence that the productivity of the stream centers around its riffles, which is also a significant hyporheic zone. The unique conditions found here provide a ripe environment for biological activity.

Alternative Approach to Storm Water Management

The features of natural stream systems – floodplains, riffles, and meanders – demonstrate important water quantity and quality benefits. Consequently, an effective alternative approach to managing storm water is through stream corridor restoration. While today's storm water management typically breaks the system into separate drainage and detention features, I propose an integral system of streams, floodplains, and riparian wetlands that allows surface- and ground-water interaction and that holds and treats storm water. A more natural system has the added benefit of increase stability, thus requiring less maintenance. Also, natural systems are more aesthetically pleasing than highly engineered structures. They have the capacity to add value to human environments.

The following example from Louisville, Kentucky demonstrates the possibilities of stream restoration. Biohabitats, Inc. was contracted to restore a segment of stream that was illegally filled and channelized (Figure 7). A developer had straightened the channel and lined it with large rock. A floodplain was not provided. The impacts of this modification include increased flood levels, sediment transport problems, and high erosion potential.

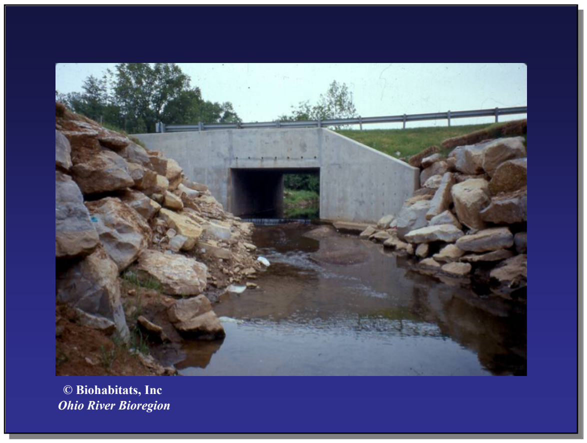
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Figure 7

Using principles of natural channel design, Biohabitats, Inc. designed a channel that would naturally handle the water and sediment from the watershed in a stable manner. Such designs are based on relationships between a channel's plan, profile, and cross-section geometry that have been developed for different, natural stream types. By basing the design on natural, stable streams, we can develop channels that are self-maintaining over the long term. Typical features include floodplains (Figure 8, during construction) and native riparian vegetation (Figure 9, post-construction). This particular restoration has resulted in a stable stream segment that is an amenity to the community.

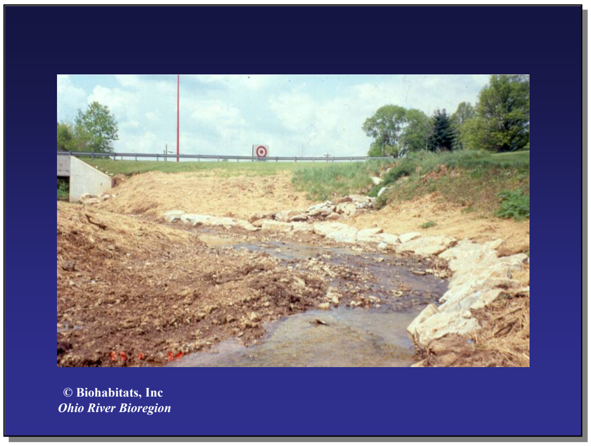
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Figure 8

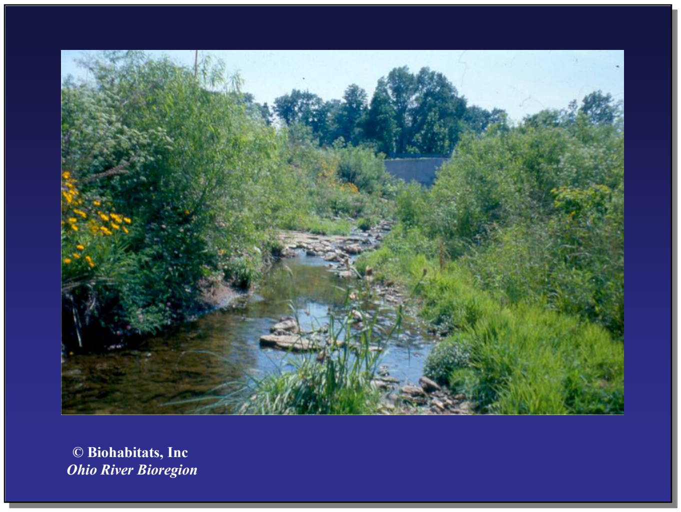
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Figure 9

In addition to stream corridor restoration, bioretention and wetland creation are important components of a natural approach to storm water management that improves surface- and ground-water interaction. Bioretention takes advantage of natural ecological processes of native terrestrial forests to allow evapo-transpiration and to infiltrate and treat storm water. Wetlands, with their inherent complexity, are effective at removing, taking up, breaking down, and burying pollutants.

In conclusion, by incorporating techniques that promote surface- and ground-water interaction and other natural processes, we can provide a storm water management alternative that effectively deals with flooding and water quality while restoring our water resources and increasing the value of our communities.

AUTOMATION FOR FIELD DATA COLLECTION

Stephen Noe, P.E.[1] and Andy Clevenger, P.E.[2]

As budgets are reduced in several agencies and FEMA's budget increases, a renewed interest in the national floodplain-mapping program has evolved. FEMA's map modernization program will require information to be collected faster than the traditional methods to keep up with the goals of the program. New ideas and technological advances are being discussed to provide services on a broader scale. These needs and techniques may set the standards for data collection of other water resource services. Data collection efforts absorb a significant percentage of water resource projects. Technological advances are being investigated and incorporated into the field data collection process to increase accuracies, reduce cost, and provide dynamic data sets. These new tools include the use of LIDAR, ground-based LIDAR, Hyper-spectral imaging, sector-scan sonar, GPS, GIS, PDAs, and digital cameras. Tool integration provides data that can be manipulated and used in automated modeling. This paper discusses the field collection methods and costs to provide data for the modeling in an automated fashion.

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FLOOD FREQUENCY OF UNREGULATED STREAMS OF TENNESSEE, 2000

George S. Law[1] and Gary D. Tasker[2]

Abstract

Up-to-date flood-frequency prediction methods for unregulated, ungaged rivers and streams of Tennessee have been developed. Prediction methods include the regional-regression method and the newer region-of-influence method. The prediction methods were developed using streamgage records from unregulated streams draining basins having from 1 percent to about 30 percent total impervious area. These methods, however, should not be used in heavily developed or storm-sewered basins with impervious areas greater than 10 percent. The methods can be used to estimate 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence-interval floods of most unregulated rural streams in Tennessee. A computer application was developed that automates the calculation of flood frequency for unregulated, ungaged rivers and streams of Tennessee.

Regional-regression equations were derived by using both single-variable and multivariable regional-regression analysis. Contributing drainage area is the explanatory variable used in the single-variable equations. Contributing drainage area, main-channel slope, and a climate factor are the explanatory variables used in the multivariable equations. Average deleted-residual prediction errors for the single-variable equations ranged from 32 to 65 percent. Average deleted-residual prediction errors for the multivariable equations ranged from 31 to 63 percent. These equations are included in the computer application to allow easy comparison of results produced by the different methods.

The region-of-influence method calculates multivariable regression equations for each ungaged site and recurrence interval using basin characteristics from 60 similar gages selected from the study area. Explanatory variables that may be used in regression equations computed by the region-of-influence method include contributing drainage area, main-channel slope, a climate factor, and a physiographic-region factor. Average deleted-residual prediction errors for the region-of-influence method tended to be only slightly smaller than those for the regional-regression method and ranged from 27 to 62 percent.

Introduction

Planners and engineers require reliable estimates of the magnitude and frequency of floods to design bridges, culverts, embankments, dams, levees, and buildings near unregulated streams and rivers. Flood-plain management needs up-to-date information and techniques for predicting floods to protect the public and minimize flood-related costs to government and private enterprise. Standardized techniques for the measurement and analysis of hydrologic data, especially through regionalization of streamflow and basin characteristics, are essential for understanding and predicting the magnitude and frequency of floods on unregulated streams of Tennessee.

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The U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Transportation (TDOT), developed and tested a computer application that automates the complex calculations necessary to predict flood magnitude and frequency. The computer application allows planners and engineers to compare flood-frequency predictions for unregulated rivers and streams in Tennessee produced with regional-regression equations and the newer region-of-influence method.

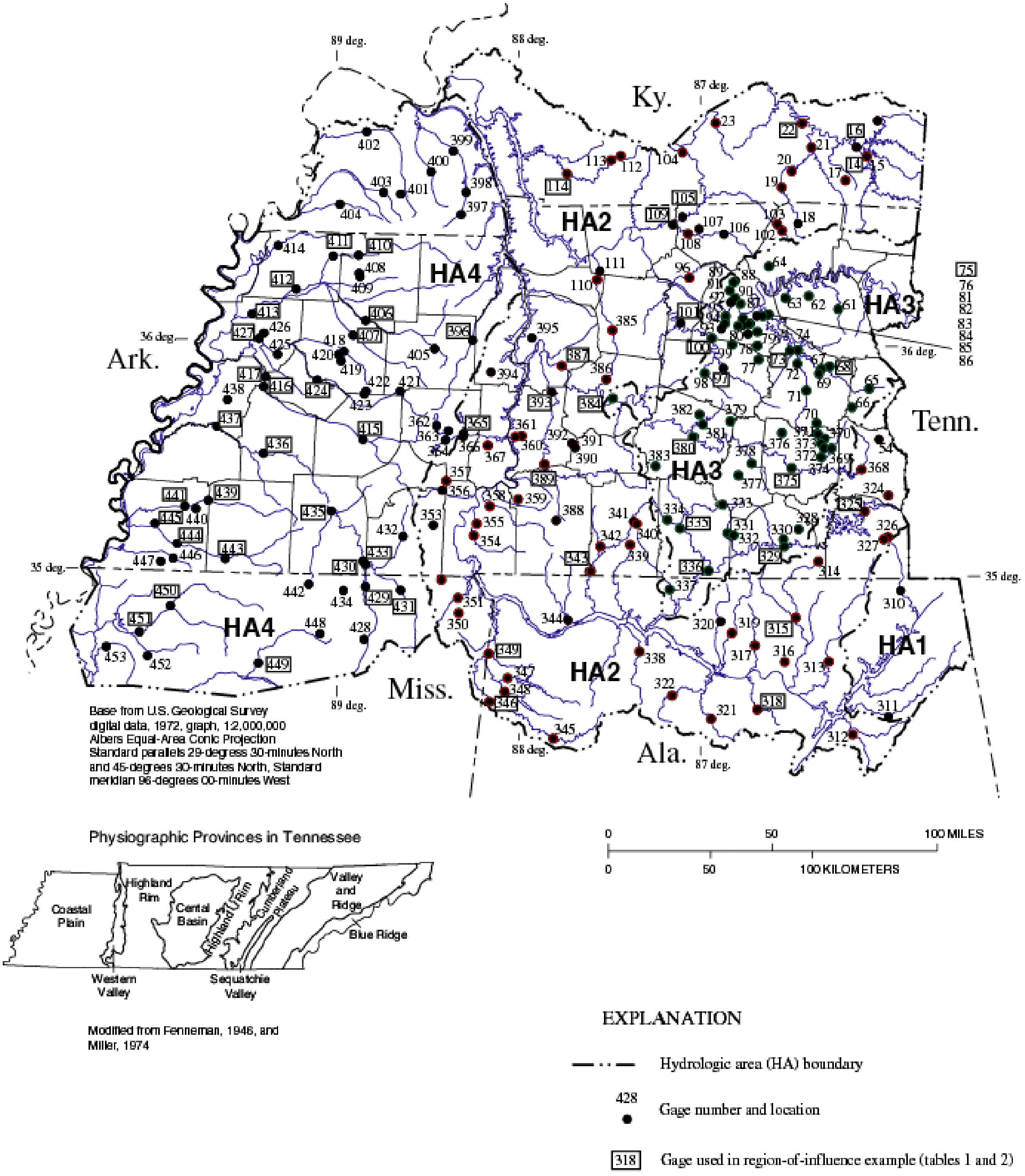
This paper describes the application of flood-frequency prediction methods in Tennessee based on statistical and hydrologic techniques and data developed by various Federal, State, and local government agencies that work cooperatively with the USGS. These agencies include the Federal Highway Administration, U.S. Army Corps of Engineers, National Weather Service, Tennessee Valley Authority, Tennessee Department of Environment and Conservation, TDOT, Metropolitan Government of Nashville and Davidson County, and other State and local agencies.

Prediction Methods

Flood discharges and basin characteristics for 453 gaging stations located in Tennessee and six adjacent States (fig. 1) with 10 or more years of record through water year 1999 were merged to form the database that was used to develop the regression methods presented in this report. Water year refers to the period of record beginning October 1st and ending September 30th. The regional-regression equations (Weaver and Gamble, 1993) were updated using generalized least-squares regression (Tasker and Stedinger, 1989) to develop new regional-regression equations that relate recurrence-interval flood discharges at gaging stations to basin characteristics in the hydrologic areas of Tennessee, which are based on physiographic provinces.

Flood discharges for gaging stations on unregulated streams in the four hydrologic areas (HA) that make up the study area (fig. 1) were computed by fitting the peak streamflow data and supplemental historic information for each gage to the log-Pearson Type III distribution as described in Bulletin 17B of the Interagency Advisory Committee on Water Data (1982). The flood discharges were related to contributing drainage area (*CDA*), main-channel slope (*CS*), and a climate factor (*CF*) to produce the regional-regression equations. The regional-regression equations, in particular the single-variable regression equations, which are easy to solve manually, are an alternative that can be used to obtain estimates of flood frequency at unregulated, ungaged sites in Tennessee if the computer application, and therefore the region-of-influence method, are not available.

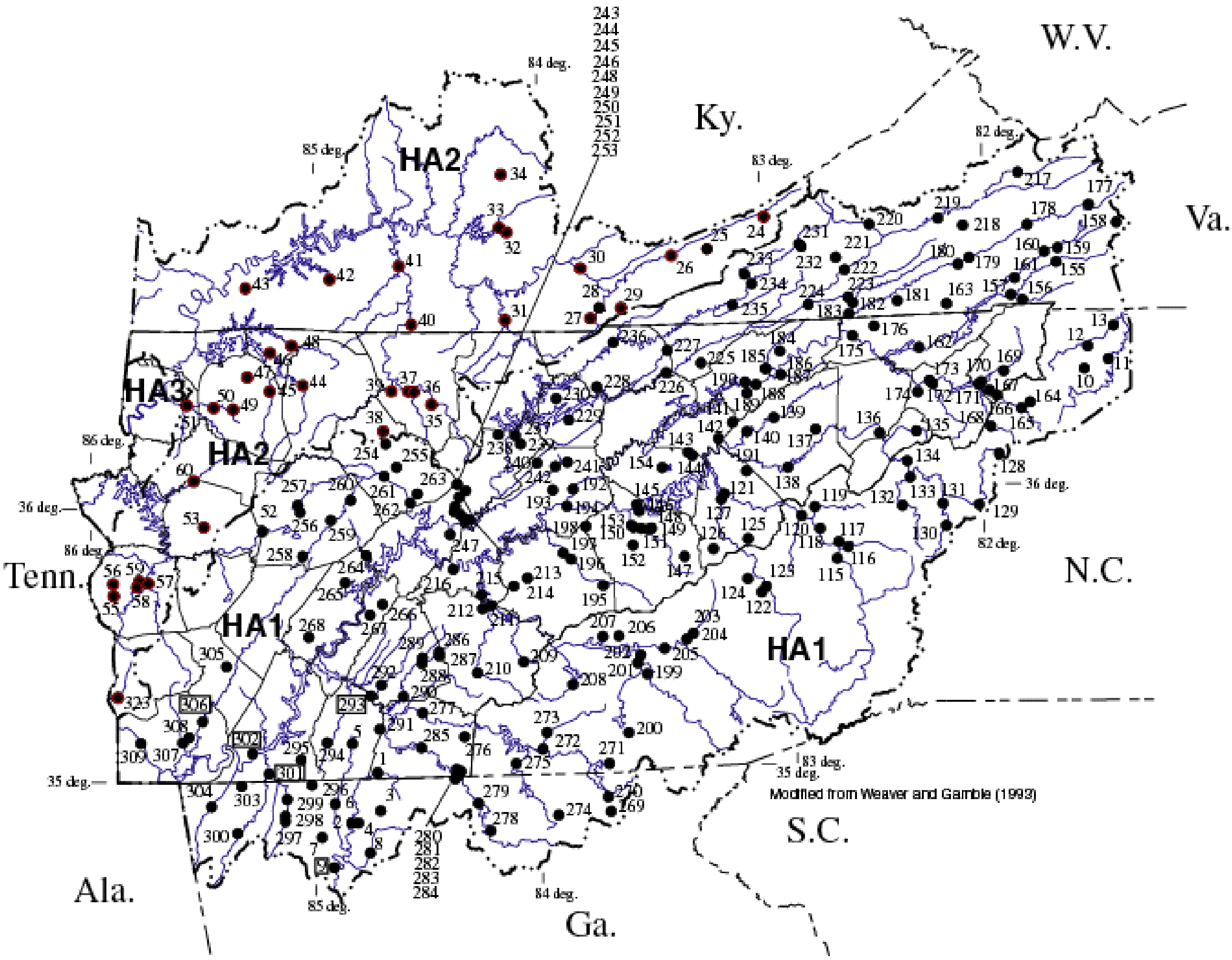
HA1 contains 211 gages and includes most of the Cumberland Plateau physiographic province and all of the Valley and Ridge and Blue Ridge physiographic provinces of East Tennessee. Although these areas are distinct physiographically, their flood statistics are similar. These three regions are therefore treated as a single hydrologic area. HA2 contains 115 gages and includes almost all of the Highland Rim physiographic province, which is a dissected limestone plateau with karst features. In addition, HA2 includes parts of the Cumberland Plateau and Western Valley physiographic provinces. HA3 contains 65 gages and closely conforms to the Central Basin physiographic province, which is a less karstic area underlain by limestone that has less relief than the Highland Rim. HA4 contains 62 gages and includes all of the Coastal Plain physiographic province, and the western part of the Western Valley physiographic province (Weaver and Gamble, 1993).



Base from U.S. Geological Survey digital data, 1972, graph, 1:2,000,000 Albers Equal-Area Conic Projection Standard parallels 29-degrees 30-minutes North and 45-degrees 30-minutes North, Standard meridian 96-degrees 00-minutes West

Modified from Fenneman, 1946, and Miller, 1974

Figure 1. Gages, hydrologic areas, and physiographic provinces in the study area.



Modified from Weaver and Gamble (1993)

Figure 1. Gages and hydrologic areas in the study area--Continued.

The newer region-of-influence method by Tasker and others (1996), required the development of a computer application to derive prediction equations that relate recurrence-interval flood discharges for gaging stations, computed using Bulletin 17B of the Interagency Advisory Committee on Water Data (1982) to *CDA*, *CS*, *CF*, and a physiographic-region factor (*PF*). The physiographic-region factor allows the region-of-influence method to capture the uniqueness in flood-magnitude potential inherent in the four hydrologic areas in Tennessee, which are based on physiographic provinces. Similar to the regional-regression method, the region-of-influence method uses generalized least-squares regression to compute flood-frequency prediction equations. However, the region-of-influence regression analysis is applied to the 60 most similar gages chosen from the database of 453 gages, rather than the four hydrologic-area groupings of gages (fig. 1). Of the 453 gages, 297 are located in Tennessee, 21 in Georgia, 37 in North Carolina, 28 in Virginia, 20 in Alabama, 36 in Kentucky, and 14 in Mississippi.

The flood-frequency computer application predicts flood magnitude and frequency at unregulated, ungaged sites in Tennessee using the regional-regression method and the newer region-of-influence method for easy comparison by the user. The *CDA*, *CS*, latitude (LAT), longitude (LNG), and HA of the site of interest must be specified by the user. The *CF* and *PF* variables are automatically computed using the LAT, LNG, and HA. The computer application automatically adjusts flood discharges for streams draining two hydrologic areas.

The computer application produces on-screen summary results and generates two output files containing the results of flood-frequency calculations at unregulated, ungaged sites in Tennessee. The first output file (table 1), which summarizes the results of each prediction method, contains flood-magnitude predictions, negative (-) and positive (+) standard error (*SE*) departures for the predictions, and 90-percent prediction intervals for each recurrence-interval flood discharge. The second output file contains detailed information for the region-of-influence method including a listing of the gages, basin characteristics, and streamflow characteristics that compose the region of influence for the ungaged site (table 2). The second output file also contains the regression-equation coefficients, residuals and influence statistics for the gages in the region of influence including standardized residual, leverage, *Cook's D*, and regression-equation quality measures for each recurrence-interval flood. An example of this output for the 25-year recurrence-interval flood for a 2,000-square-mile ungaged site is given in table 2.

Comparison of Methods

When comparing accuracy estimates for the regional-regression method and the region-of-influence method at a particular ungaged site of interest, the following points should be considered. Occasionally, the scatter of data about a regional-regression equation has a subtle downward curving appearance. This slight curvature can be overcome by manually fitting a piecewise regional-regression equation to better fit the observed data (fig. 2). This is essentially what the region-of-influence method does by placing the ungaged site of interest as near the center of a regression equation as possible. The *-SE* and *+SE* departures for a prediction are calculated assuming that the scatter about the fitted regression equation is uniform throughout the range of the data for every recurrence interval, which may not always be the case. In such cases, the regional-regression method, which uses the average scatter for the entire range in the calculation, may produce a relatively poor estimate of the *SE* departures for a particular ungaged site.

The region-of-influence method takes advantage of the non-uniform distribution of standard error (scatter), limiting the data used to develop regression equations and associated error estimates to a small range around *CDA* for the particular ungaged site (fig. 3). Thus, in some hydrologic areas, the region-of-influence method can be expected to provide a better “local” estimate of the peak at the ungaged site. Further, the region-of-influence method also may provide a better estimate of the “local” accuracy of that peak than the regional-regression method, even in those instances where the estimates of the *SE* departure for predictions from the computer application are smaller for the regional-regression method.

A comparison of the regional-regression method and region-of-influence method based on the average predictive ability of the methods and site-specific accuracy for a variety of ungaged site conditions indicates that the region-of-influence method is the better of the two methods tested for predicting flood magnitude and frequency in Tennessee.

Table 1. Summary output file produced by flood-frequency computer application for unregulated, ungaged sites in Tennessee

[HA, Hydrologic area; LAT, latitude; LNG, longitude; RI, recurrence interval; SE, standard error; PRED. INTERVAL, prediction interval; cfs, cubic feet per second, ft/mi, feet per mile; %, percent]

```
 SINGLE-VARIABLE REGIONAL-REGRESSION EQUATION (SRE) METHOD FOR TENNESSEE
 Flood frequency estimates for:
 Big River at Centerville, TN
 Hydrologic Areas (percent): HA 3 ( 80.0) HA 2 ( 20.0)
 LAT:   35  50  10    LNG:   87  25  30
 Explanatory variable:
 Contributing drainage area: 2000.00 square miles
 RI       DISCHARGE    - SE (%)    + SE (%)        90% PRED. INTERVAL
            (cfs)
      2        39500.0       -24.4       32.2     24900.0     62900.0
      5        59400.0       -24.4       32.2     37400.0     94400.0
     10        73500.0       -25.3       33.9     45300.0    119000.0
     25        92300.0       -27.1       37.3     54600.0    156000.0
     50       107000.0       -28.7       40.3     61000.0    188000.0
    100       122000.0       -30.4       43.6     67000.0    223000.0
    500       160000.0       -34.3       52.3     79700.0    322000.0


 MULTIVARIABLE REGIONAL-REGRESSION EQUATION (MRE) METHOD FOR TENNESSEE
 Flood frequency estimates for:
 Big River at Centerville, TN
 Hydrologic Areas (percent): HA 3 ( 80.0) HA 2 ( 20.0)
 LAT:   35  50  10    LNG:   87  25  30
 Explanatory variables:
 Contributing drainage area: 2000.00 square miles
 Channel slope:   2.50 ft/mi
 RI       DISCHARGE    - SE (%)    + SE (%)        90% PRED. INTERVAL
            (cfs)
      2        39700.0       -24.8       33.0     24700.0     63700.0
      5        59200.0       -24.9       33.1     36800.0     95100.0
     10        73100.0       -26.0       35.1     44400.0    121000.0
     25        91900.0       -28.1       39.0     53200.0    159000.0
     50       107000.0       -29.5       41.9     59600.0    191000.0
    100       122000.0       -31.3       45.5     65400.0    227000.0
    500       160000.0       -35.4       54.8     77600.0    331000.0


 REGION-OF-INFLUENCE (ROI) METHOD FOR TENNESSEE
 Flood frequency estimates for:
 Big River at Centerville, TN
 Hydrologic Areas (percent): HA 3 ( 80.0) HA 2 ( 20.0)
 LAT:   35  50  10    LNG:   87  25  30
 Explanatory variables:
 Contributing drainage area: 2000.00 square miles
 Channel slope:   2.50 ft/mi
 Climate factor:   2.38
 Log(Physiographic Factor):   0.152( HA 3 )     0.133( HA 2 )
 RI       DISCHARGE    - SE (%)    + SE (%)        90% PRED. INTERVAL
            (cfs)
      2        38800.0       -19.7       24.6     26900.0     55900.0
      5        56300.0       -20.2       25.4     38700.0     82000.0
     10        68500.0       -21.0       26.6     46300.0    101000.0
     25        89200.0       -22.4       28.9     58500.0    136000.0
     50       102000.0       -23.4       30.5     65400.0    158000.0
    100       115000.0       -24.4       32.4     71900.0    182000.0
    500       146000.0       -27.2       37.4     85900.0    247000.0
```

Table 2. Partial output for region-of-influence method produced by flood-frequency computer application for unregulated, ungaged sites in Tennessee

[Q2-Q10 and Q50-Q500 omitted for simplicity; ID, gaging station number; HA, hydrologic area; MAP NO., gage number on fig. 1; LOG, log base-10 transformed value; CDA, contributing drainage area, in square miles; CS, main-channel slope, in feet per mile; PF, dimensionless physiographic-region factor; CF, dimensionless climate factor; OBS, flood discharge, in cubic feet per second, computed using Bulletin 17B of the Interagency Advisory Committee on Water Data (1982); PRED, regression-predicted discharge, in cubic feet per second; STD RES, standardized residual]

```
-------------------------------------------------------------------------------------------------------
DATA FOR REGION-OF-INFLUENCE (ROI) METHOD FOR:
 SITE ID: Big River at Centerville, TN
     ID       HA    LATITUDE    LONGITUDE   MAP NO.    LOG(CDA)    LOG(CS)    LOG(PF)    LOG(CF)
  3602000.    3.    35.78800    87.46600     384.      3.31130     0.32634    0.15187    0.37672
  3584500.    3.    35.02700    86.94800     336.      3.25140     0.45484    0.15332    0.37970
  7026000.    4.    36.25100    89.19200     412.      3.26760     0.34635   -0.19877    0.37246
  3599500.    3.    35.61800    87.03200     380.      3.08210     0.43616    0.15741    0.37447
  7026300.    4.    36.13700    89.42900     413.      3.30810     0.26951   -0.20500    0.37281
  7028000.    4.    35.86200    89.34800     417.      3.00130     0.41497   -0.15776    0.37741
  7027800.    4.    35.81700    89.35600     416.      2.96940     0.43297   -0.15285    0.37780
  7029100.    4.    36.03000    89.38700     427.      2.97270     0.45484   -0.15335    0.37548
  3603000.    2.    35.93000    87.74300     387.      3.40770     0.27875    0.13713    0.37085
  3582000.    3.    35.13400    86.54000     329.      2.91750     0.53403    0.16139    0.37678
  7031700.    4.    35.20200    89.92300     445.      2.88710     0.41497   -0.14016    0.38106
  3604500.    2.    35.81300    87.79700     393.      2.84940     0.61172    0.11741    0.37730
  7029500.    4.    35.27500    88.97700     435.      3.17030     0.10037   -0.18377    0.38174
  3434500.    2.    36.12200    87.09900     101.      2.82410     0.45332    0.11652    0.36950
  7029400.    4.    35.05700    88.80100     433.      2.92270     0.39270   -0.14566    0.38794
  7031650.    4.    35.11600    89.80100     444.      2.84450     0.44716   -0.13361    0.38683
  7025500.    4.    36.40000    88.99500     411.      2.68120     0.56229   -0.10847    0.37101
  3430100.    3.    36.15800    86.62000      75.      2.95040     0.61278    0.16060    0.36543
  7027500.    4.    35.59400    88.81400     415.      2.69460     0.63043   -0.11053    0.37995
  7030000.    4.    35.52300    89.34900     436.      3.29560    -0.04096   -0.20307    0.38011
  7030050.    4.    35.63700    89.60400     437.      3.36320    -0.05061   -0.21349    0.37925
  7277500.    4.    34.72100    89.98900     451.      2.80210     0.50515   -0.12708    0.38828
  7030500.    4.    35.05400    89.54100     443.      2.70160     0.48144   -0.11160    0.38643
  3571000.    1.    35.20600    85.49700     306.      2.58430     0.51720   -0.05113    0.37086
  7029000.    4.    35.85100    89.06700     424.      2.56700     0.58659   -0.09089    0.37825
  7024500.    4.    36.11800    88.81100     406.      2.58320     0.58092   -0.09338    0.37216
  3592500.    2.    34.65600    88.12200     349.      2.82410     0.57978    0.11652    0.38919
  3433500.    3.    36.05400    86.92800     100.      2.59440     0.50786    0.16920    0.36780
  3604000.    2.    35.49600    87.83300     389.      2.65030     0.70586    0.11038    0.37904
  7025400.    4.    36.40600    88.85600     410.      2.57050     0.62325   -0.09143    0.37085
  3436100.    2.    36.55500    87.14200     109.      2.69720     0.62634    0.11203    0.36604
  7030280.    4.    35.28100    89.76600     441.      2.70330     0.77305   -0.11187    0.38106
  3598000.    3.    35.48000    86.49900     375.      2.68210     0.78604    0.16708    0.37469
  3429000.    3.    36.00000    86.46000      73.      2.75660     0.70757    0.16528    0.36566
  3567500.    1.    35.01400    85.20700     301.      2.63140     0.74663   -0.04818    0.37128
  3584000.    3.    35.21400    87.10100     335.      2.56350     0.72591    0.16995    0.37866
  3579100.    2.    35.28600    86.10600     325.      2.43930     0.62325    0.10292    0.37523
  7029275.    4.    35.04100    88.78700     430.      2.49140     0.38202   -0.07924    0.38798
  3314500.    2.    37.00100    86.43100      22.      3.13420     0.41497    0.12743    0.35540
  7269990.    4.    34.59700    89.35000     449.      2.55020     0.53148   -0.08830    0.38991
  3606500.    4.    36.03900    88.22800     396.      2.31180     0.57171   -0.05158    0.37369
  3435500.    2.    36.58900    87.08900     105.      2.49000     0.64738    0.10471    0.36545
  7029300.    4.    34.93100    88.59800     431.      2.44400     0.59106   -0.07195    0.38807
  7029270.    4.    34.94400    88.78600     429.      2.43460     0.64345   -0.07049    0.38826
  7025000.    4.    36.05300    88.87800     407.      2.30320     0.67761   -0.05026    0.37249
  3313000.    2.    36.89500    86.13400      16.      2.93700     0.56820    0.12050    0.35491
  3568000.    1.    35.08700    85.27900     302.      4.33040     0.64836    0.05826    0.37094
  3432350.    3.    35.92100    86.86600      97.      2.24550     0.59106    0.17763    0.36863
  3592000.    2.    34.44400    88.11500     346.      2.42000     0.60206    0.10224    0.39071
  7030240.    4.    35.31000    89.64000     439.      2.41830     0.83251   -0.06799    0.38129
  3588500.    2.    35.02400    87.57900     343.      2.54160     0.91169    0.10654    0.38087
  2387000.    1.    34.67000    84.93000       9.      2.83700     1.04140   -0.03530    0.37404
  7276000.    4.    34.84100    88.82700     450.      2.32840     0.62325   -0.05414    0.38868
  3575000.    2.    34.81900    86.48100     315.      2.53400     0.90309    0.10627    0.38439
  3427500.    3.    35.91800    86.33400      68.      2.41830     0.80346    0.17346    0.36568
  3438000.    2.    36.77800    87.72200     114.      2.17610     0.55630    0.09362    0.36685
  3312500.    2.    36.85200    86.07700      14.      2.71100     0.63347    0.11252    0.35496
  3566000.    1.    35.28800    84.75200     293.      3.36140     1.06070   -0.00245    0.36423
  3594445.    4.    35.62400    88.27300     365.      2.06070     0.57519   -0.01292    0.37929
  3576148.    2.    34.41400    86.68800     318.      2.13350     0.49136    0.09212    0.38727
```

Table 2. Partial output for region-of-influence method produced by flood-frequency computer application for unregulated, ungaged sites in Tennessee--Continued

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```
SUMMARY OF REGION-OF-INFLUENCE (ROI) REGRESSION FOR:
 Big River at Centerville, TN
    25   YR-PEAK

 REGRESSION COEFFICIENTS
  VARIABLE       COEFFICIENT   STANDARD ERROR   T FOR H0:BETA=0    PROB>|T|

  CONSTANT             3.00279        0.11629       25.82217
  LOG(CDA)             0.56059        0.03995       14.03295         0.0001
  LOG(PF)              0.65515        0.15895        4.12166         0.0001

 Residuals and influence statistics
   ID           LOG(OBS)    LOG(PRED)   STD RES     LEVERAGE    COOKS D

   3602000.     4.78620     4.95858    -1.54152     0.07049     0.10306
   3584500.     4.91710     4.92595    -0.07693     0.07595     0.00023
   7026000.     4.74780     4.70436     0.41553     0.10546     0.01075
   3599500.     4.68680     4.83372    -1.32347     0.04818     0.06318
   7026300.     4.69300     4.72299    -0.27864     0.09051     0.00480
   7028000.     4.58420     4.58194     0.01903     0.03097     0.00001
   7027800.     4.50570     4.56728    -0.50423     0.02675     0.00819
   7029100.     4.37370     4.56880    -1.69756     0.02686     0.10520
   3603000.     4.92760     5.00297    -0.68096     0.08468     0.02156
   3582000.     4.56280     4.74406    -1.42026     0.03074     0.05054
   7031700.     4.52810     4.52946    -0.01194     0.03556     0.00000
   3604500.     4.71810     4.67707     0.37459     0.02763     0.00362
   7029500.     4.72110     4.65964     0.58282     0.07950     0.01841
   3434500.     4.67460     4.66230     0.11371     0.02287     0.00034
   7029400.     4.61640     4.54581     0.61534     0.03631     0.01322
   7031650.     4.42960     4.50987    -0.66383     0.05550     0.01297
   7025500.     4.44380     4.43479     0.08204     0.04031     0.00022
   3430100.     4.77760     4.76198     0.13541     0.04297     0.00057
   7027500.     4.44360     4.44095     0.02383     0.02630     0.00002
   7030000.     4.74670     4.71724     0.25595     0.07306     0.00348
   7030050.     4.70520     4.74831    -0.39483     0.08669     0.01004
   7277500.     4.74910     4.49037     1.86567     0.04332     0.07563
   7030500.     4.41490     4.44418    -0.25992     0.02662     0.00211
   3571000.     4.42160     4.41804     0.03233     0.04631     0.00003
   7029000.     4.27670     4.38229    -0.94215     0.01925     0.02752
   7024500.     4.31990     4.38974    -0.64403     0.03391     0.01372
   3592500.     4.55770     4.66230    -0.94219     0.03787     0.02202
   3433500.     4.43350     4.56805    -1.26241     0.04344     0.05873
   3604000.     4.71190     4.56085     1.37769     0.02729     0.04763
   7025400.     4.40600     4.38390     0.18855     0.02867     0.00101
   3436100.     4.66330     4.58822     0.65034     0.03381     0.00950
   7030280.     4.54020     4.44495     0.83115     0.01912     0.02090
   3598000.     4.67230     4.61582     0.49692     0.04003     0.00774
   3429000.     4.71450     4.65641     0.52187     0.03993     0.00879
   3567500.     4.41110     4.44637    -0.31461     0.04028     0.00235
   3584000.     4.75790     4.55122     1.80937     0.04734     0.10671
   3579100.     4.34910     4.43768    -0.76202     0.03939     0.01473
   7029275.     4.30580     4.34754    -0.28836     0.01380     0.00157
   3314500.     4.87180     4.84329     0.23811     0.04626     0.00157
   7269990.     4.35880     4.37457    -0.12334     0.02770     0.00036
   3606500.     4.16280     4.26498    -0.95279     0.06113     0.03452
   3435500.     4.51570     4.46727     0.43832     0.03921     0.00516
   7029300.     4.39140     4.32574     0.55504     0.03092     0.00885
   7029270.     4.31320     4.32143    -0.07099     0.02919     0.00015
   7025000.     3.93970     4.26102    -2.69563     0.03704     0.22518
   3313000.     4.91820     4.72820     1.46167     0.03008     0.04132
   3568000.     5.53130     5.46856     0.71043     0.36184     0.09635
   3432350.     4.25960     4.37798    -0.98416     0.07472     0.03696
   3592000.     4.20930     4.42641    -1.82498     0.04666     0.08210
   7030240.     4.38420     4.31393     0.59436     0.05433     0.01029
   3588500.     4.73990     4.49740     2.18717     0.02868     0.12315
   2387000.     4.46550     4.57007    -0.93629     0.03846     0.01802
   7276000.     4.43760     4.27261     1.28128     0.03301     0.04274
   3575000.     4.76370     4.49296     2.46147     0.03210     0.15926
   3427500.     4.48090     4.47212     0.07914     0.06265     0.00024
   3438000.     4.27290     4.28403    -0.10367     0.07388     0.00043
   3312500.     4.79110     4.59628     1.56697     0.02387     0.04753
   3566000.     4.75700     4.88557    -1.05041     0.06406     0.02808
   3594445.     4.16450     4.14954     0.11759     0.05469     0.00048
   3576148.     4.20440     4.25917    -0.40432     0.05181     0.00438


 AVERAGE SAMPLING ERROR VARIANCE      0.0013
 AVERAGE REGRESSION ERROR VARIANCE    0.0106
 PRESS/N                              0.0149
 MAXIMUM SAMPLING ERROR VARIANCE      0.0045
 1.SITE SAMPLING ERROR VARIANCE       0.0015
 2.SITE SAMPLING ERROR VARIANCE       0.0015
```

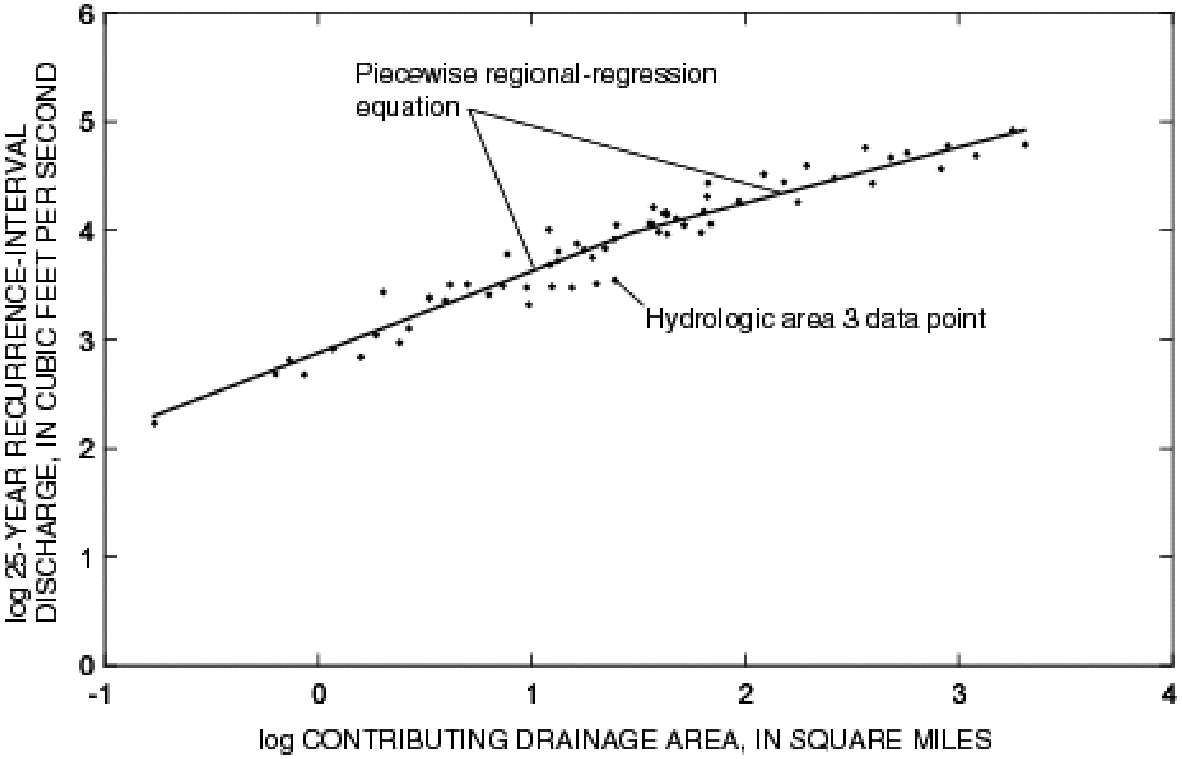

Figure 2. A piecewise regional-regression equation used for hydrologic area 3.

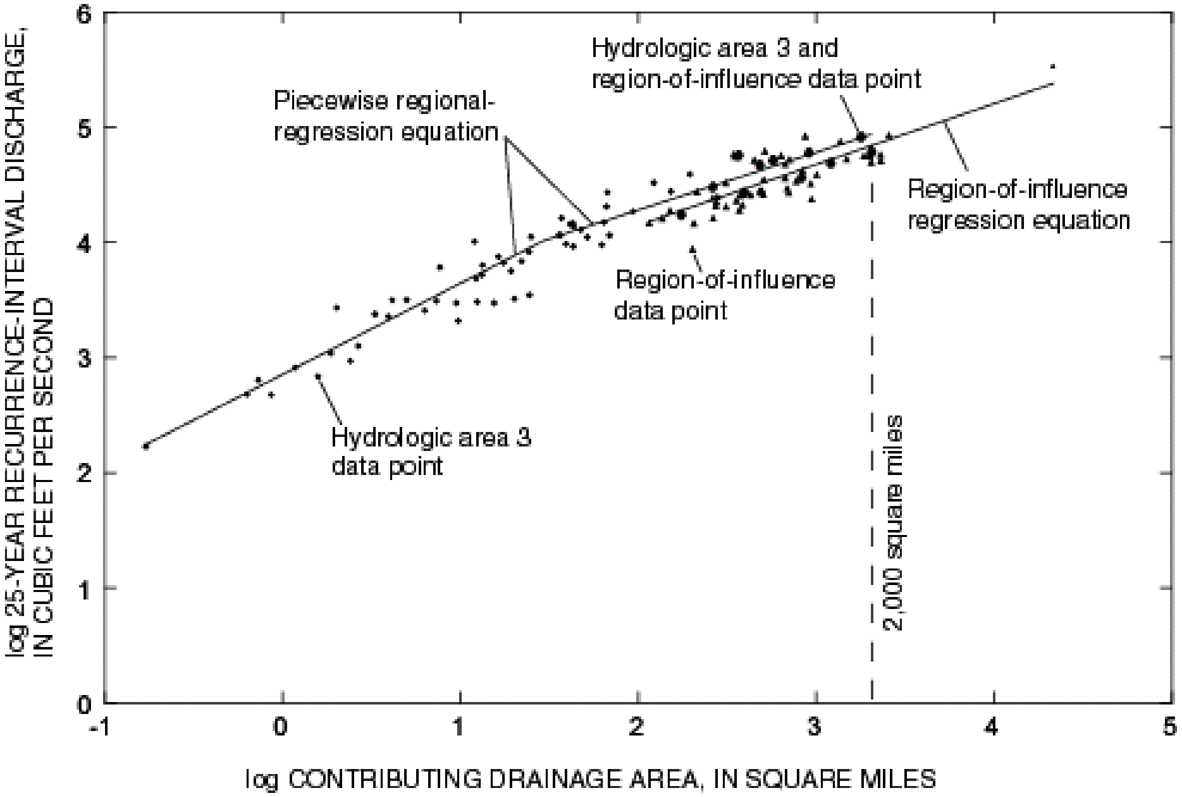

Figure 3. Piecewise regional-regression equation and region-of-influence regression equation for the 25-year flood at a 2,000-square-mile ungaged site in hydrologic area 3.

Summary

Reliable and accurate estimates of the magnitude and frequency of floods are needed for the design of bridges and culverts, the delineation and management of flood zones, and the management of water-control structures. The U.S. Geological Survey, in cooperation with the Tennessee Department of Transportation, developed the region-of-influence method to estimate flood frequency at unregulated, ungaged streams and rivers in Tennessee. As an alternative to the region-of-influence method, the regional-regression method for estimating flood frequency at unregulated, ungaged sites was updated and expanded to include single-variable and multivariable regression equations. The prediction methods are part of an interactive computer application used to estimate flood frequency at unregulated, ungaged sites in Tennessee. The computer application allows for easy comparison of results from both the regression methods.

Annual-peak streamflow records, historical flood information, and selected basin characteristics for streamgages in the study area with 10 or more years of record through water year 1999 were combined to form a database that was used to develop the prediction methods for use at sites in Tennessee. These gages measure the flow in streams draining basins with 1 percent to about 30 percent total impervious area; these methods should not be used in heavily developed or storm-sewered basins with impervious areas greater than 10 percent. Flood frequency at each of the gages was computed by fitting the peak streamflow data and supplemental historic information for each gage to the log-Pearson Type III distribution as described in Bulletin 17B of the Interagency Advisory Committee on Water Data (1982).

Basin characteristics and flood-frequency estimates for 453 gaging stations located in Tennessee and six adjacent States were merged to form the database that was used to develop the regional-regression equations described in this paper. Of the 453 gages, 297 are located in Tennessee, 21 in Georgia, 37 in North Carolina, 28 in Virginia, 20 in Alabama, 36 in Kentucky, and 14 in Mississippi. For the regional-regression method, generalized least-squares regression was used to develop single-variable and multivariable regression equations for the hydrologic areas of Tennessee. The regional-regression equations estimate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence-interval flood discharges at unregulated, ungaged sites using contributing drainage area, main-channel slope, and a climatic factor.

The region-of-influence method was developed in Tennessee using the same 453 gages used to develop the regional-regression equations. For an unregulated, ungaged site, the region of influence is defined as the 60 most similar sites selected from the database. The region of influence for an ungaged site is determined by comparing the contributing drainage area, main-channel slope, and climate factor of the gaged sites to the ungaged site. The region-of-influence method uses generalized least-squares regression to estimate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence-interval flood discharges at unregulated, ungaged sites using contributing drainage area, main-channel slope, a climatic factor, and a physiographic-region factor as explanatory variables. The physiographic-region factor allows the region-of-influence method to capture the uniqueness in flood-magnitude potential inherent in the four hydrologic areas in Tennessee that are based on physiographic provinces.

The regional-regression equations, in particular the single-variable regression equations, which are easy to solve manually, are an alternative that can be used to obtain estimates of flood frequency at unregulated, ungaged sites in Tennessee if the computer application, and therefore the region-of-influence method, are not available. A comparison of the regional-regression method to the region-of-influence method, based on average predictive ability of the methods and site-specific accuracy for a variety of ungaged-site conditions, indicates that the region-of-influence method is the better method of the two methods tested for predicting flood magnitude and frequency in Tennessee.

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EVALUATING POTENTIAL CHANGES IN REGULATED FLOW FREQUENCY IN THE TENNESSEE VALLEY

Michael A. Eiffe, P.E.[1]

ABSTRACT

A comprehensive flood risk evaluation is being conducted by the Tennessee Valley Authority (TVA). The evaluation is part of a larger study, designed to determine whether changes in TVA reservoir operating policy can provide greater overall value to the public. The primary focus of the flood risk study is the determination of potential changes in regulated flow frequency curves at a large number of locations in the Valley. Results of the analysis will be presented at the Symposium.

INTRODUCTION

The Tennessee Valley Authority (TVA) is conducting the Reservoir Operations Study (ROS), a comprehensive evaluation of its reservoir operating policy to be completed by October 2003. This evaluation will form the basis of a new operating policy for the TVA reservoir system. The study is being performed within the framework of the National Environmental Policy Act (NEPA) and will be an Environmental Impact Statement (EIS). The scope of the ROS includes an evaluation of the effect of TVA reservoir operations on multiple benefits which include: navigation, flood damage reduction, power generation, water quality, water supply, recreation, land use and related objectives.

As a part of the ROS, TVA is conducting a flood risk evaluation, the purpose of which is to evaluate the change in flood risk that could occur as a result of proposed operational changes. The flood risk evaluation will establish base-case conditions against which each operational change will be compared. Changes in flood risk with respect to this base case will primarily be established for each proposed operational change by comparing 1) annual and seasonal regulated flood frequency at each of a series of critical locations, including immediately downstream of selected dams and at major flood damage centers; and 2) the expected change in flood damages for discrete events at those major flood damage centers where information is available to support such computations.

Annual and seasonal flood frequency curves will be based on hydrologic simulations including continuous simulations of 99 years of observed inflow data and additional simulations of discrete design storms, including the MPF and PMF events. This approach will allow investigation of a wide range of potential flood events at each critical location. Flood damages for discrete events at selected damage centers will be based on economic models currently being developed.

There are a total of 36 dams below which changes in flood frequency must be established. Of these, 35 are located in the Tennessee River watershed. The single exception is Great Falls Dam

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[1] Tennessee Valley Authority

on the Caney Fork River in the Cumberland River watershed. Not all of the dams are owned by TVA, and not all of the dams in the TVA system are being evaluated. In addition, there are a total of 14 major damage centers to be included in the flood risk evaluation.

The flood risk evaluation is being conducted in four separate phases, which are briefly described in the following sections.

PHASE I

Phase I involves the development of a continuous hydrologic inflow data base. TVA has prepared from existing data a continuous time series of average 6 hour local inflows for the 99-year period of record (POR) from October 1, 1902, through September 30, 2001. Local inflows were determined for a total of 56 locations: these local inflow time series are referred to as Estimated Local Flows or ELFs.

In general, ELFs were computed by first determining total flow at the appropriate downstream location, and then subtracting the routed total flow at the appropriate upstream location. For those locations where the entire contributing drainage area can be represented by a single sub-basin (such as Norris Dam on the Clinch River, and all other such “headwater” projects), total inflow was computed.

The data used to support the computation of the ELFs included average daily USGS stream gage data at various locations throughout the Tennessee Valley, and TVA reservoir operations data such as headwater elevations, elevation-storage characteristics, and observed discharges.

Most of the dams of interest for this study were constructed between 1936 and 1979. Other dams, built in the pre-TVA era by others, were subsequently acquired by TVA. Therefore, the effect and the degree of reservoir regulation on stream flow in the Tennessee River basin have varied continually over a long period. However, in general, the TVA system of reservoirs was essentially completed by the mid-1940’s. From that perspective, the Phase I task can be generally described as the development of local inflow data during: 1) the “pre-TVA-regulation” period of about 40 to 45 years, and 2) the “post-TVA-regulation” period of about 55 to 60 years.

The ELFs represent a continuous time series for the POR; these inflows are intended to closely approximate inflow to the current reservoir system. Only one set of inflows was developed; these inflows will be used to drive both the “unregulated conditions” and the “regulated conditions” continuous hydrologic simulation models that are described later. No attempt has been made to make these data homogeneous.

For that portion of the POR prior to reservoir regulation, total unregulated discharges were converted into local inflows for each sub-basin. For a given sub-basin, this was accomplished by routing the total discharge at the upstream sub-basin boundary through the sub-basin channel, and subtracting it from the total discharge at the downstream sub-basin boundary. Routing techniques used include simple hydrologic methods such as lag routing and a modified Muskingum routing procedure called the Auto-Regressive Moving Average (ARMA) methodology. The total discharge at a given location was either observed or estimated.

For those locations for which stream gage data are sparse or missing (frequently the case for the earliest 20 to 30 years of the POR), total unregulated discharges were estimated where required using a variety of techniques, most commonly drainage area ratios and the Maintenance of Variance Extension procedures first developed by the USGS (Hirsch, 1982).

Total inflows into reservoirs were computed using a mass balance approach (inflow = outflow plus change in storage). For locations subject to upstream regulation, local inflows were computed by first computing total inflows and then subtracting routed discharges from the upstream dam or dams.

All Phase I inflow data were developed using appropriate data-handling techniques, including preservation of mass at all points, and longer term averaging of flows where computational methodologies produce negative local inflows. Ultimately, the ELF time series developed as described herein represent 6-hour average local inflow data. Daily average flows were disaggregated into 6-hour flows using a disaggregation technique first proposed by Ormsbee for rainfall analysis (Ormsbee, 1989).

PHASE II

Phase II involves the development of unregulated flow frequency curves at all of the critical locations of interest. Using the 6-hour average ELFs developed in Phase I, continuous total flows were computed for the POR at all critical locations assuming unregulated conditions using an unregulated hydrologic model developed by TVA. The output of this model provides the basis for the development of unregulated flow frequency curves at all critical locations. Where appropriate, historic flood data prior to October 1, 1902, has been included in order to improve the reliability of the unregulated flow frequency curves.

TVA's unregulated hydrologic model reads the ELF time series and routes and combines them in an appropriate fashion. For the 39 tributary sub-basins, flow routing is accomplished using the ARMA channel routing methodology referred to in the description of Phase I. For the 16 main river sub-basins, flow routing is performed using TVA's Simulated Open Channel Hydraulics (SOCH) 1-D unsteady flow model with no regulation. The SOCH model has already been calibrated for unregulated conditions, and can provide detailed information (elevation, discharge, etc.) at discrete cross sections within each simulation reach.

Calibration efforts involved comparison of Simulated Total Flow (STF) vs. Observed Total Flow (OTF) at various locations throughout the Valley. The output from the calibrated unregulated model simulations is the STFs at all critical locations for the continuous 99-year period. From these simulations, the annual maximum total discharge was extracted at each critical location. Discharge frequency curves were developed using procedures recommended by the Hydrology Subcommittee (IACWD, 1982), and incorporating any additional pre-1903 historic data as appropriate.

PHASE III

Phase III involves the development of unregulated flow frequency curves at all of the critical locations of interest for base-case ("no action") conditions. The 99-year record of ELFs, adjusted as described in Phase II, is being used to perform a continuous simulation under regulated conditions. Regulated conditions refer to the existing configuration of TVA dams and reservoirs including their associated physical properties (elevation-volume curves, turbine operating characteristics, etc.) and operational policies. The hydrologic model being used is RiverWare, developed by the Center for Advanced Decision Support for Water and Environment Systems (CADSWES) at the University of Colorado.

TVA has developed a formalized representation of detailed policies for flood and flood storage recovery operations, and efforts to validate simulations against actual operations are ongoing. Operating policy for "normal" or "non-flood" conditions are defined through simulation rules or operating targets derived from other TVA models. Results of the simulation are continuous regulated average discharges and end-of-time-step headwater elevations (6-hour time step) at each location of interest.

Simulated operating policy is based in part on inflow forecasting capability. In actual practice, reservoir operational decisions are largely based on weather forecasts. Since the hydrologic model is driven entirely by flow data, a simple methodology has been developed that allows "less than perfect" knowledge of future inflows. Simulation results are providing a basis for acceptance or rejection of the operating rules using a comparison of applicable historic operations against the simulated results at several locations.

The POR continuous simulations support the construction of graphical regulated flow frequency curves, using the Weibull plotting position formula, with the result that the largest event in the 99 year POR will be assigned a recurrence interval of 100 years. Because TVA is interested in determining potential changes in flood risk for less frequent events, the continuous simulations described above are being supplemented with simulations of hypothetical design storms.

PHASE IV

Phase IV involves the establishment of conditions for each proposed alternative. For each alternative, all Phase III tasks will be repeated. The total number of alternatives to be evaluated in detail has not yet been established.

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RE-EVALUATING THE ADEQUACY OF WATER SUPPLIES IN THE DUCK RIVER

Brian J. McCrodden[1]

Background

The following brief history of Normandy Dam and the abandoned mainstem dam at Columbia, Tennessee, has been excerpted largely from TVA's Future Water Supply Needs in the Upper Duck River Basin (Programmatic EIS, December 2000) and the references cited therein.

In the mid-1960s, leaders in Maury, Marshall, Bedford, and Coffee Counties formed the Upper Duck River Development Association to promote economic growth in the region. The development of water supply infrastructure was seen as critical to their success. In 1965 the Tennessee Legislature established the Tennessee Duck River Development Agency to be the executive agent for the effort. Using federal grants and municipal bonds, a four-county water supply grid connecting Columbia, Lewisburg, Shelbyville, Tullahoma, and Manchester was planned and partially constructed.

The group sought TVA assistance in the development of major water resources projects. TVA undertook several reconnaissance and feasibility studies and, in 1968, presented the Upper Duck River Project consisting of two reservoirs on the mainstem of the Duck River, one at Columbia and the other at Normandy. Congress began appropriating money for construction of the project in 1969. The $16 million local share of the cost of construction was to be repaid by the Duck River Development Agency from a 5 cent per thousand gallon fee on water use to be collected from the participating utilities.

Construction of Normandy Dam was begun in 1972 and completed in 1976. Columbia Dam was begun in 1973, but in 1976, with the project approximately one-half complete, the U.S. Fish and Wildlife Service listed as endangered two species of freshwater mussel found in the Duck River. Work was allowed to continue on some of the ancillary portions of the project until 1984, but after a lengthy regulatory history, the project was ultimately abandoned in 1995.

At the time the project was abandoned, approximately 12,000 acres had been acquired for the Columbia Reservoir and were in public ownership. One recommendation of the environmental impact statement evaluating the possible future uses of the property was to set aside that portion of the property in the Fountain Creek watershed (a tributary of the Duck River) for possible use as a future water supply source for Columbia and Maury County. The presumption was that a reservoir would be built when the local demand reached a level not available from the releases made from Normandy Reservoir. This presumption was reinforced by a 1998 Needs Analysis undertaken by TVA, in conjunction with a number of other agencies and the local utilities, to determine how much water might be needed and by when. That report concluded that shortages in Columbia might begin to appear as soon as the year 2015.

In 2001, as it began the process of reviewing the available options to forestall the expected shortages, the Duck River Development Agency contracted with Dr. William W. Wade, an economist, to conduct a review of the studies and reports prepared to date. Dr. Wade, among others, pointed out the extremely conservative assumptions underlying the basic conclusion of the Needs Analysis and suggested that a more in-depth analysis might reveal a less costly alternative than those evaluated in the Programmatic EIS

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(Fountain Creek Reservoir; a pipeline to pump water back to Columbia from further downstream; raising Normandy Dam; and a pipeline to transfer water from Tim's Ford Reservoir to the Duck River during periods of drought).

The three Needs Analysis assumptions in question related to (1) the demand projections, (2) the operation of Normandy Reservoir, and (3) tributary inflows below Normandy Dam. The demand projections used were for peak day consumption, which are typically one and one-half to two times as large as longer-term averages. The use of peak day estimates is appropriate for designing distribution systems and storage tanks that need to accommodate short term fluctuations in demand but may be overly conservative when evaluating larger components of the system that can buffer the effects of the fluctuations.

The Needs Analysis also assumed no change in the method of operation of Normandy Reservoir. Shortly after closure of the Normandy dam, the Tennessee Department of Environmental Conservation (TDEC) established a flow target of 165 cubic feet per second (cfs) at Shelbyville – 10 cfs for water supply and 155 cfs to maintain water quality. TVA agreed to operate Normandy to meet these targets. (After acquiring some operational experience and as a direct result of the 1980-81 drought, the water quality target was adjusted downward to 120 cfs during the winter months (December through May) to preserve lake levels in the Reservoir.)

In 1996, following the decision not to complete the Columbia Dam, TDEC established a water quality target of 100 cfs at Columbia, but there was no agreement that Normandy Reservoir would be operated to meet the target. It was assumed that flows of 165 cfs at Shelbyville would be sufficient to maintain the target at Columbia, at least for a while. The Needs Analysis concluded that this might not be the case beginning in the year 2015, but no evaluation was done to determine whether or not Normandy could be operated in such a way as to preclude these occurrences.

Finally, the Needs Analysis assumed that there was no tributary inflow to the Duck River below Normandy Dam. This was viewed as a safe side assumption because it had long been known that the reach of the river between Shelbyville and Columbia actually loses water at certain times of the year.

For good reason, water supply planners err on the side of safety. In this case, in part because there was no readily available analytical tool with which to evaluate the interaction of the large number of factors at play, several "worst case" assumptions had been applied with a potentially compounding effect. This led Dr. Wade and the DRDC and its Technical Advisory Committee and Water Resources Council to conclude that additional analysis would be prudent.

Normandy Reservoir and the upstream (above Normandy Dam) and downstream demand centers constitute a system that can not be disassembled for analysis. Each component affects the others. The traditional safe yield analysis is not applicable because there are upstream as well as downstream demands, and the location of the demand affects system yield. (Safe yield is normally measured at the face of the dam, which means that it pertains to withdrawals from the reservoir only. Whereas demand above the dam can only be met from the water that flows into the reservoir, demand downstream can be met either by water released from the reservoir or, to the extent that it is available, local inflows to the river below the dam.) Safe yield analysis is also not applicable because Normandy Reservoir is a multi-purpose reservoir operated for flood control, recreation, and environmental benefits as well as water supply. The method of operation reflects tradeoffs among the various objectives. A different method of operation might improve water supply reliability but might also diminish the benefits associated with some other objective. What was needed was a way to evaluate the range of possible tradeoffs.

At about the same time, the Tennessee Chapter of The Nature Conservancy, a member of the Water Resources Council, was beginning to evaluate the ecological impacts of the altered flow regime associated with the operation of Normandy Dam. It, too, needed to understand the dynamics of the system. TNC acquired funding from the Tennessee Environmental Endowment and contracted with HydroLogics, Inc. to develop an interactive computer model of the system to be used both by TNC and the Water Resources Council.

Analysis

The model developed is known as the Duck River Model. It is an application of HydroLogics' OASIS modeling system to the Duck River. The system schematic is shown in Figure 1. The Duck River Model is of a class known as mass balance models. They are designed to keep track of water at every node at every time step (in this case daily) to insure that mass (i.e., water) is preserved and not created or destroyed. These models are principally used to evaluate different operating policies by comparing alternative, user-specified, policies over the same period of hydrologic input. Model output consists of daily lake levels and flows at any point in the system or summary information that can be derived from these basic data.

Schematic of Duck River System as Modeled with OASIS

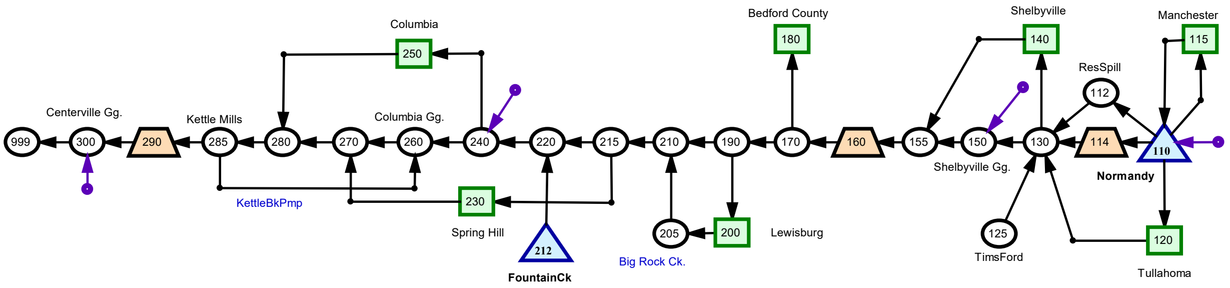

Figure 1.

For the Duck River Model, the hydrologic input consists of daily inflow to the Reservoir and gains between Normandy and Shelbyville, Shelbyville and Columbia, and Columbia and Centerville from January 1, 1934 through September 30, 2000, a total of 24,381 days. For any given run, demands and operating policies are held constant over this period of record. This allows the comparison of different policies in a variety of hydrologic conditions ranging from the most severe drought to the most extreme flood in the nearly 67 years of record.

The purpose of the study for the Water Resources Council was to evaluate the water supply risk associated with relying solely upon Normandy Reservoir for supplies in the lower part of the basin. The evaluation is described more completely in the final report entitled An Assessment of the Water Supply Reliability of Normandy Reservoir (HydroLogics, Inc., October 15, 2002, as revised). A number of demand scenarios were evaluated. The constituent demands for three of the scenarios are shown in Table 1. Originally, it was anticipated that different methods of operating Normandy Reservoir would also be investigated, but early runs indicated that the system is relatively unstressed, and this effort was not pursued. Thus, the only change to current Normandy operations (rule curve, flood control policy, and minimum release) was to force enough water to be released to meet all downstream demands and flow targets at Columbia[2] as well as Shelbyville.

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[2] Whereas the current flow-by requirement at Columbia is 100 cfs, the Columbia wasterwater treatment plant discharge permit is based on 130 cfs. The higher, more conservative, target was used in the analysis.

Given the multiple objectives for the system, the most relevant measures of the impact of increased demands are the minimum Normandy lake levels and the number of days at the minimum flows downstream. (Because water is released from the Reservoir to meet all demands and downstream flow targets, flows are never below the targets. The number of days at minimum flow represents the number of days that minimum flows are just met at the specified site.) The more stressed the system, the more days that flows will be at minimum levels. Table 2 shows the results for current demands, Year 2050 demands, and the currently-contracted demands.

Table 1. Demand Projections (mgd)

	Current	Year 2050	Contracted	% Returned
Manchester	2	5	6	63
Tullahoma	3	6	14	0
Shelbyville	4	7	9	45
Bedford County	1	2.4	0	0
Lewisburg	3	6	8	72
Spring Hill	0	6	0	60
Columbia	10.5	21	18	60
TOTAL	23.5	53.4	55	

Table 2. Summary Results

	Current Demands	Year 2050 Demands	Contracted Demands
Normandy minimum elevation Date of minimum elevation	862.93 11/3/88	860.76 11/3/88	857.82 11/3/88
Days Normandy release at 40 cfs	3320	3631	4156
Days Shelbyville flow between 120 and 130 cfs	618	732	931
Days Shelbyville flow between 155 and 165 cfs	7088	6695	7668
Days Columbia flow between 130 and 140 cfs	337	1656	749

The effects of the increased demand anticipated by the Year 2050 are reflected in slightly over two feet of additional drawdown in Normandy Reservoir and in more days at minimum flow at the dam, at Shelbyville, and at Columbia. The Contracted Demands run points out how the location of the demands affects system performance. Whereas the aggregate projected demands for the Year 2050 and the Contracted Demands are nearly the same, the Reservoir is drawn down over five additional feet with the Contracted Demands because the bulk of the demand is concentrated above the Reservoir. This points up the inherent uncertainty associated with long-term projections and the need for a cyclical planning process to deal with that uncertainty.

Another measure of system performance is how closely the rule curve can be followed given the demands and requirements to release water downstream. (Because of the natural variability of inflows to the Reservoir, it is not possible to follow the rule curve exactly even under the best of conditions.) Figure 2 shows the rule curve and the simulated Normandy elevation for the three runs in 1988, which is the critical year in the record for this level of demand.

Table 3 presents the percentage of days on which the simulated Normandy elevation is two or more feet below the rule curve. (Because of the nature of the flood control operations, the number of days above the rule curve is virtually identical in all runs.)

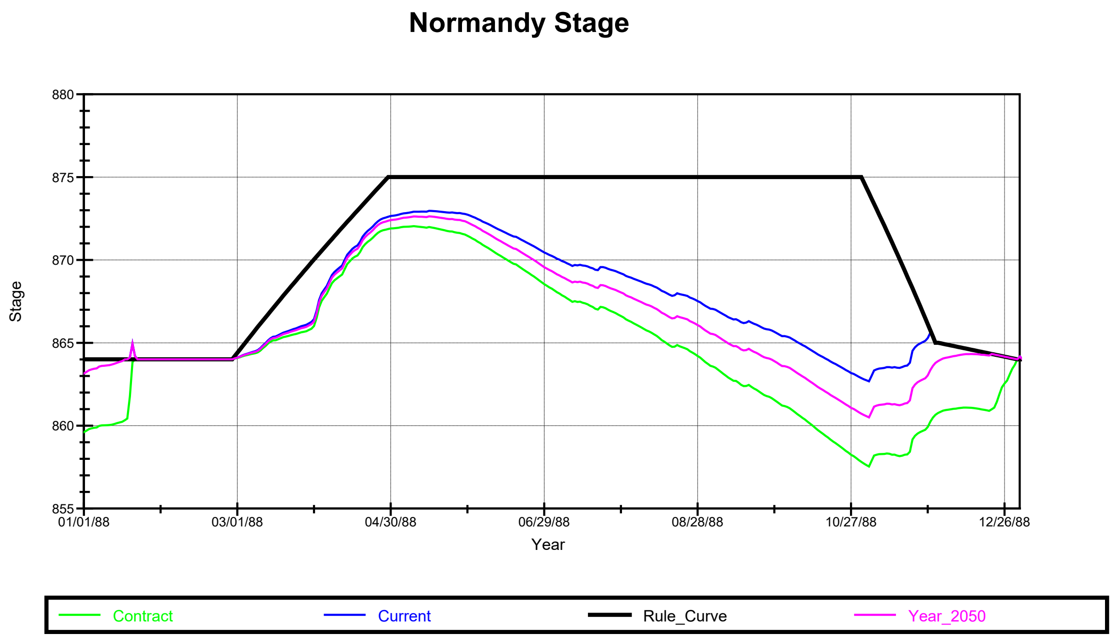

Figure 2.

Table 3. Adherence to Rule Curve

	Current Demands	Year 2050 Demands	Contracted Demands
Percent of days Normandy elevation 2 or more feet below rule curve	13.1	16.6	21.0

Conclusions

It was evident from this analysis that the system can meet the projected system demands, including downstream flow targets, with very high reliability 50 years into the future. Unless climatic conditions change significantly from what they have been for the past 67 years, given current system operations there is less than a two percent chance that Normandy Reservoir will be drawn down below elevation 860 throughout the planning horizon. That is, the probability of falling below elevation 860 does not reach two percent in any year until demands exceed those projected for the year 2050. Until that time, the probability of falling below elevation 860 in any given year is even smaller.

A number of additional runs were conducted to assess the sensitivity of this basic conclusion to changes in demand levels and flow targets, but even with demands in all parts of the Basin 50 percent above current projections and an allowance of 25 cfs to account for operational uncertainty in making releases (a contrived set of circumstances), Normandy Reservoir falls below elevation 859 (the originally-established winter rule curve elevation) only about once every ten years, to an absolute minimum elevation of 855.39 feet over the 67 years of record. For reference, at elevation 855 there are over 50,000 acre-feet of water remaining in the Reservoir, or about 55 percent of the storage available below elevation 875.

This is not to say that the Basin is free of water supply problems. Most notable is the fact that the quality of the water withdrawn from the Reservoir by the Duck River Utilities Commission (DRUC) is such that higher-than-desired treatment costs are incurred on a fairly frequent basis. Having additional water in the Reservoir would ameliorate this problem. But DRUC's problem is not a raw water problem. Rather, it is an issue of cost and equity that can best be cast in the form of a question thus "Is it appropriate for DRUC customers to incur additional treatment costs to benefit interests downstream of the Reservoir?" This is a question that can best be answered by the parties involved.

There are a number of potential solutions that warrant investigation, including the re-evaluation of the Normandy rule curve; the transfer of water from Tim's Ford Reservoir during periods of drought; adding an increment of dry storage to Normandy Reservoir so that the winter rule curve could be raised without jeopardizing flood control benefits; reconfiguration of the DRUC intake structure; and refinement of the downstream flow targets to, for example, be more responsive to temperature or actual water quality than is the current winter season/summer season Shelbyville target. With the exception of modifications to the intake structure, all of these alternatives would have the effect of keeping more water in Normandy Reservoir, thereby reducing DRUC's treatment costs. Of course, any of these policies that alters the quantity and timing of downstream releases has the potential to inflict unacceptable harm to downstream users.

The Duck River Model was designed specifically to assist in this type of evaluation by allowing stakeholders to interactively assess the tradeoffs associated with different types of reservoir operation. It displays both the magnitude and frequency of "good" and "bad" events from the perspective of every party and, thereby, facilitates the planning process.

LOWER MISSISSIPPI RIVER RESOURCE ASSESSMENT

Clarice Sundeen[1]

Public Law 106-541, Section 402 of the Water Resources Development Act of 2000 authorized the Secretary of the Army, in cooperation with the Secretary of the Interior and the States of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee to conduct a Lower Mississippi River Resource Assessment (LMRRA). Once this project receives Federal funding, it will be a unique opportunity to form a large water resource partnership and to view holistically the Lower Mississippi River system. The scope of the investigation will include the Lower Mississippi River and adjacent floodplains within the alluvial valley having commercial navigation channels on the Mississippi main stem and tributaries south of Cairo, Illinois, as well as the Atchafalaya basin floodway system. The three assessments will include: a description of what data gaps exist in information needed for river-related management, a listing of natural resource habitat needs, and the need for river-related recreation and access. Stakeholder information exchanges, public participation, partnerships, education programs and shared responsibility are critical to the success of this project. This presentation will discuss the US Army Corps of Engineers and Department of Interior LMRRA implementation strategy for this important initiative, the proposed project delivery team, roles and responsibilities, project outputs, cost, schedule, mechanisms for public involvement, and the potential for continued Federal interest after the assessments are complete.

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CONCEPTS FOR NATIONAL ASSESSMENT OF WATER AVAILABILITY AND USE WITH IMPLICATIONS FOR TENNESSEE

W. Scott Gain[1]

Will there be sufficient freshwater resources in the future to sustain economic growth and the quality of life? In many parts of the country, competition for water to meet the needs of homes, cities, farms, and industries is increasing. At the same time, requirements to leave water in the streams and rivers for environmental and recreational uses are expanding. Water-resources information is needed at many levels to help shed light on overall changing conditions of water scarcity, use, and competition and to help inform discussions about potential changes in water-resource policies and investment plans.

The U.S. Geological Survey (USGS), in response to a directive from Congress, prepared a report describing the scope and magnitude of the efforts needed to provide periodic assessments of the status and trends in the availability and use of freshwater resources. That report describes efforts needed to develop and report on indicators of the status and trends in storage volumes, flow rates, and uses of water nationwide. It also would propose regional estimates of recharge, evapotranspiration, interbasin transfers, and other components of the water cycle to support studies of water availability and changes in the national and global water cycle that are undertaken by many other agencies. The effort is analogous to the task of other Federal statistical programs that produce and regularly update indicator variables that describe economic, demographic, and health conditions of the Nation.

The effort described would require coordination among many organizations, Federal and non-Federal agencies, and universities to ensure that the information produced can be aggregated with other types of water-availability and socioeconomic information. Information concerning flows, storages, and uses of water would be used with water-quality information from existing programs to provide a more complete national picture of water availability.

The assessment would build on existing data collected by the USGS and by others to create indicator variables. Data gaps identified by the program would be addressed by improvements in data-collection networks for surface water and ground water defined by USGS plans for the National Streamflow Information Program and the Ground-Water Resources Program, and as part of the Cooperative Water Program of the USGS. Water-use estimation would be strengthened from existing efforts along the lines suggested by the National Research Council. The design and development of the entire effort would be coordinated through the Federal Advisory Committee on Water Information.

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RESOLVING WATER DISPUTES: CITIZEN AND DECISION-MAKER PERSPECTIVES

Aaron S. Routhe[1] and Emily N. Heinrich

Water disputes challenge policy-makers' and citizens' efforts to provide both a sustainable economy and environment. The Southeast Water Policy Initiative (SEWPI) employs a holistic approach to identify the factors driving water disputes. Established in 2001, its research agenda is to develop practical tools for resolving and averting water supply conflicts in the region. This presentation describes how SEWPI is testing this approach in Cumberland County, Tennessee. Like many communities, technical solutions exist for resolving conflict, however, social factors constrain the efforts of local officials to implement these. Two projects are exploring an ongoing dispute by comparing perspectives of decision-makers and the general public. One project examines factors influencing decision-maker attitudes about how to meet water supply needs. A second project, using the Theory of Planned Behavior, explores factors affecting the public's concern about and support for water resources and meeting water supply needs. Project results provide baseline data for constructing Internet-based graphical maps using Geographic Information Systems (GIS) software and educational materials for decision-makers, water users, and the general public. Preliminary results suggest that a greater understanding of the social and political drivers of water disputes may provide policy-makers with clearer directions for navigating the treacherous waters of these conflicts. They suggest that when water resources are limited, decision-makers must move beyond simply considering technical or engineering solutions and contend with social factors driving the dispute. Lessons from our investigation, as applied to interstate and intrastate conflicts, show the need for better defining the boundaries and issues comprising these disputes.

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HUNTSVILLE UTILITY DISTRICT
RAW WATER IMPOUNDMENT

Steve Bostic, P.E.[1]

The Huntsville Utility District provides water service to approximately 4,300 customers in rural Scott County, Tennessee. The District originally retailed water bought from neighboring Oneida, Tennessee. As the District continued to grow and extend water lines into various areas of the County during the 1970's, the supply of water available from Oneida became a limiting factor to growth within the District.

The results of a 1980 Engineering Report addressing the District's long-term needs were far reaching and outlined the means for water service in the long-term future of the District. Phase III of the plan was far-reaching and very ambitious for a Utility with a relatively small number of customers. It included expansion of the existing raw water impoundment from 23 to 200 acres to provide maximum storage within the drainage basin where the original lake was located. The basin chosen for construction of the impoundment was previously strip-mined for coal.

Geotechnical investigations performed at the site were utilized to verify the availability of soils necessary to construct the dam. Permitting concerns for the project included a wide range of State and Federal Agencies.

The final design of the impoundment included construction of a dam approximately 1,100 feet in length and 80 feet high from bedrock elevation to the top of the dam. The core of the dam consists of low permeability compacted soils ranging from 40 feet in width at the crest to over 450 feet in width where the core material interfaces with the underlying bedrock. The project includes excavation and placement of over 1.7 million cubic yards of material.

Based on projections of future water demands, the impoundment can provide raw water in sufficient quantity to serve the Huntsville Utility District's customers for a period of over 50 years. The District has developed a strategy to address its water needs for many years into the future and has not been short-sighted in its goals to provide a safe, reliable water supply to its customers.

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COMPARISON OF THE EPA GROUNDWATER CLASSIFICATION SYSTEM AND THE TENNESSEE GROUNDWATER CLASSIFICATION SYSTEM AT A RCRA CORRECTIVE ACTION SITE

Jeffrey L. Pintenich, P.E.[1]

Introduction

Section 3004(u) of the Resource Conservation and Recovery Act (RCRA) requires owners/operators of permitted Subtitle C (hazardous waste) treatment/storage/disposal (TSD) facilities to take corrective action for continuing releases to the environment from solid waste management units, regardless of the time at which wastes were placed in such units. The RCRA Section 3004(u) requirement applies only to facilities seeking a RCRA permit or undergoing closure, including operating permits for existing and new facilities, and post-closure permits. All permit applicants must: 1) identify all solid waste management units at the facility; 2) identify any releases that have occurred or are occurring from the units; 3) if warranted, evaluate and implement appropriate corrective measures to clean up those releases; and 4) demonstrate financial assurance for corrective measures. The universe subject to these regulations is estimated to consist of approximately 6,500 facilities in the U.S. which contain 60,000 to 80,000 solid waste management units (SWMUs). The ultimate total cost of the program has been estimated to range to as much as $400 billion.

A case history for a recent industrial site corrective action project demonstrates one of the flexibilities in the concepts available to the regulated community for selecting remedies which protect human health and the environment, but do so in a cost-effective, rational manner. The EPA's groundwater classification system was applied to this site during the RFI to subsequently guide the evaluation of potential corrective measures.

The site is an inorganic chemical manufacturing facility. The corrective action permit for the facility identified 7 SWMUs which were investigated during the RCRA Facility Investigation or RFI. These included a closed landfill, previous fill areas, and wastewater ponds. The principal constituents of interest were heavy metals. The site is characterized by minimal topographic relief and adjacent industrial properties.

The RFI included, after review of historical information and aerial photographs and work plan preparation, surface geophysical surveys (terrain conductivity and earth resistivity) to help delineate fill/disposal areas; surficial soil sampling and analyses; piezometer and staff gage installations to identify groundwater flow patterns; soil borings, sampling, and chemical analyses; the installation of 13 shallow and 5 bedrock monitoring wells to evaluate groundwater quality; geochemical evaluations; hydraulic conductivity tests; and surface water and sediment sampling and analyses.

Upon receipt and review of the RFI Report, EPA set action levels for soils, groundwater, and surface water at the site and required that the owner conduct a Corrective Measure Study or CMS. A work plan for the CMS was prepared to focus the engineering feasibility study through establishment of preliminary corrective action objectives. The CMS included preparation of an updated health and environmental risk assessment; development of corrective action objectives; preliminary identification, screening, and selection of corrective measure alternatives; a comparative analysis of corrective measure alternatives; and recommendation of one of these alternatives for implementation. This approach is described in general in the RCRA Corrective Action Plan (EPA 1994).

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RFI Results

Geologic conditions at the site correlated quite well with regional reports. Groundwater was found to exist in two zones beneath the site: (1) an unconfined water table zone within the fill material and glacial till (low hydraulic conductivity) and within the deeper unweathered glacial till; and (2) a confined water-bearing zone within the lower hydraulic conductivity shale bedrock. The water table zone groundwater was mounded around the ponds and overall flow directions radiate outward from the site. The horizontal flow direction in the shale was determined to be toward the nearby lake. The drainage ditches on the property are shallow and do not intercept any groundwater.

The quality of the groundwater in the water table zone was somewhat affected by two of the SWMUs as compared to background conditions. For two metals, the action levels were exceeded in groundwater from some of the wells. However, there was rapid attenuation as a function of distance from the SWMUs. Geochemical evaluation techniques were useful in verifying the lack of downward migration of contaminants (ion ratios, Stiff graphs, and Piper trilinear diagrams). The saline shale groundwater was found to be unaffected by the SWMUs.

At most of the SWMUs, shallow soils contained heavy metal concentrations which exceeded background levels based on statistical comparisons and in several locations EPA's actions levels were exceeded. At one SWMU, soils to a depth of 2 m were impacted. However, none of the soils were determined to be characteristic hazardous wastes. The closed landfill contained inorganic wastes, some of which may be hazardous by today's standards. One surface water sample exceeded the EPA action level (based on the state water quality standard), due to erosion of soil from a nearby SWMU. The risk assessment included extensive evaluations of the physicochemical nature of the metals of concern, such as partitioning/sorption, retardation factors, and chemical equilibria calculations, incorporating chemical activities in solution. Properties and behavior compared favorably with actual measurements at the site.

EPA Groundwater Classification

The EPA issued its Groundwater Protection Strategy in August 1984. The core of the strategy is a differential protection policy that recognizes that different groundwaters require different levels of protection. A three-tired classification system was established as the vehicle to implement this strategy (EPA, December 1986):

- Class I: Special groundwater (irreplaceable sources of drinking water and/or ecologically vital).
- Class II: Groundwater currently a source of drinking water (Subclass IIA) or potentially a source of drinking water (Subclass IIB).
- Class III: Groundwater not a source of drinking water due to insufficient yield, high salinity, or contamination that cannot be reasonably treated. Subclass IIIA groundwaters exhibit an intermediate to high degree of interconnection to adjacent groundwater units or surface waters or have insufficient yield. Subclass IIIB groundwaters exhibit a low degree of interconnection to adjacent groundwater units or surface waters.

Based on the final draft of "Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy" issued by the EPA in December 1986 (EPA, 1986), it was proposed that the uppermost water-bearing zone (or that in the glacial till deposits) in the vicinity of the site be classified as Class IIIA groundwater on the basis of insufficient yield. The steps taken to arrive at this classification are described below.

Subdivision of Classification Review Area. The first step in the classification process was to delineate a Classification Review Area (CRA). A two-mile radius is typically used to delineate the CRA according to EPA guidelines (EPA, 1986).

According to EPA guidelines (EPA, 1986), groundwater units are delineated on the basis of three types of boundaries: 1) permanent groundwater divides, 2) thick, laterally-extensive, low permeability geologic units, and 3) permanent fresh water-saline water contacts. Water within a groundwater unit is inferred to be highly interconnected, and therefore, a common use, value, and protection strategy can be determined.

In addition, boundaries separating waters of different classes must coincide with boundaries of groundwater units.

The CRA for this site was subdivided into two groundwater units on the basis of the "Type 3" boundary (fresh water-saline water contact): the uppermost water-bearing zone in the unconsolidated glacial till deposits and the underlying bedrock water-bearing zone in the shale. Although a sandy till zone had been identified in the unconsolidated till deposits underlying the site, this zone forms gradational contacts and is likely to be highly interconnected with the surrounding till. None of the boundaries discussed above are present to separate the sandy till zone from surrounding unconsolidated till deposits and, therefore, the sandy till zone cannot be subdivided into a separate groundwater unit.

The site and surrounding areas are underlain by glacial till. Beneath the till is a Devonian shale which may be up to 1,200 ft thick. It in turn is underlain by Devonian limestone and the Silurian Salina Formation which is composted of carbonates, shale, and evaporates. Because of the great thickness and low hydraulic conductivity of the shale, it is unlikely that any aquifer below the shale would be affected by activities at this site. The amount of open fractures present in the shale would likely decrease with depth because of increasing pressure exerted on the bedrock as depth increases.

The presence of brackish water in the shale was well documented. Saline water may be encountered as sallow as 50 ft into the shale. In fact, analytical data for samples collected in monitoring wells screened from 8 to 25 ft into the shale at the site show total dissolved solids (TDS) levels in excess of 10,000 mg/L. Well logs for the few wells that are located in the CRA (all of which withdraw water from the shale) often note that the water encountered is salty.

Major ion data indicate that the chemical make-up of the water within the shale is distinct from that of the shallow water bearing zone. Also, TDS levels in the bedrock water-bearing zone are much higher that background levels in the shallow water-bearing zone. It is highly unlikely that the high TDS levels found in the bedrock water-bearing zone are due to activities at the site.

Therefore, the shallow water-bearing zone in the glacial till deposits and the bedrock water-bearing zone can be sub-divided into two groundwater units. The units are separated by a "Type 3" boundary or one that is characterized by permanent fresh water-saline water contacts. Because only the uppermost unit (i.e., the glacial till zone) would be potentially impacted by activities at the site, a classification decision was made for this unit only, per EPA guidance (EPA, 1986).

Preliminary Surveys. A well survey was performed for the CRA. Four wells are located within the CRA. All of these wells withdraw water from deep parts of the shale bedrock. There are no domestic or municipal wells screened in the shallow, glacial till groundwater unit. Therefore, no groundwater in the CRA is withdrawn from the shallow groundwater unit and used as a source of drinking water.

The presence of habitats for listed or proposed federal endangered or threatened species, as well as federal lands managed for ecological values, were surveyed for the CRA through the Natural Heritage Program database. The results of the survey indicated that no such species or managed lands are present in the CRA. There are also no existing or proposed state nature preserves or scenic rivers in the CRA. However, a park in the area was noted as an ecologically significant site because of the presence of several state-listed threatened plant species. However, this area, located across a major river from the site, is not a candidate for groundwater discharge originating from this site and is not affected by site activities.

A survey for public water supply reservoirs within watersheds designated for water quality protection was also conducted for the CRA. Although a large lake is located within the CRA and is used for public water supply, a watershed protection area for the lake had not been designated.

Class III Criteria. In this situation, once the preliminary process described above has been completed, the following conditions must also be met to satisfy the Class III criteria (EPA, 1986):

- There would be insufficient yield at any depth within the groundwater unit to provide for the needs of any average-size household (yield must be greater than 150 gpd).
- There are no wells or springs in the CRA used as a source of drinking water regardless of well yield.

The CRA has been described by others as a poor area for developing even minimal domestic supplies. Because there are no wells installed in the CRA in the shallow groundwater unit, well yield data were not available from state or local sources of information. Therefore, an estimated well yield was calculated using data from monitoring wells installed at the site.

Hydraulic conductivity data are available only for monitoring wells installed in the upper, weathered till and such data for the lower, unweathered till zone are not available. However, a number of wells at a nearby site (approximately ½ mile away) are screened in the lower, unweathered till zone. This till has been observed to be very similar to the till at the subject site. Hydraulic conductivity data for these wells were used to represent the lower, unweathered till zone at this site.

Using these hydraulic conductivity data and appropriate estimating techniques (Walton, 1970), an estimated well yield for a six-inch diameter well was calculated for each of the till zones. By adding the yield of the two till zones, a total yield of 117 gpd was calculated for the entire glacial till unit. Therefore, well yield in the glacial till meets the first Class III criterion of well yield being less than 150 gpd.

There are no springs used as a source of drinking water in the CRA. As discussed above, no groundwater in the CRA is withdrawn from the uppermost groundwater unit and used as a source of drinking water. Therefore, the second Class III criterion is met in that there are no wells used for a source of drinking water that withdraw water from the shallow groundwater unit and there are no springs used as a source of drinking water.

Once the groundwater unit has met the Class III criteria, it must be further categorized as Subclass IIIA or Subclass IIIB. The groundwater unit in question may be categorized as Subclass IIIA on the basis of insufficient yield.

Tennessee Groundwater Classification System

Tennessee protects groundwater resources pursuant to the Tennessee Water Quality Control Act. Rule 1200-4-3-.07 establishes 5 classifications for State groundwaters: 1) Special Source, 2) General Use, 3) Limited Use, 4) Site-Specific Impaired, and 5) Unusable.

The characteristics and conditions of the corrective action site examined herein suggest that the uppermost aquifer would be either a Limited Use Groundwater or a Site-Specific Impaired Groundwater. Tennessee rules would require that a 24-hour pump test be performed to demonstrate the low yield of the aquifer (less than 1 gallon per minute/gpm) if a Limited Use classification were sought. For the Site-Specific Impaired classification the facility would need a successful application per Rule 1200-4-3-.09 including a feasibility study of potential clean-up alternatives for the site groundwater.

As for the quality criteria for the site groundwater, as a Limited Use Groundwater, the applicable standards are provided at Rule 1200-4-3-.08 (3). These call for the water to comply with the Tennessee criteria for Water Uses (Rule 1200-4-3-.03) for industrial water supply, irrigation, livestock watering and wildlife, and navigation, excepting naturally-occurring levels. Further, Limited use Groundwaters shall not contain substances which pose an unreasonable risk to the public health, other than those of natural origin. Site-Specific Impaired Groundwaters must meet the latter requirements, and not affect the ability of adjacent groundwater from complying with the criteria for those waters beyond the point of classification change.

Conclusions

The state in which the site is located has not yet adopted any sort of groundwater classification system, and while the classification was useful for evaluating the importance of the water table zone at this site, a formal classification could not be granted. However, the regional EPA office concurred that the shallow water-bearing zone was a Class IIIA groundwater and did not require the evaluation of low benefit, costly groundwater extraction and treatment systems in the corrective measures study (CMS). For comparative purposes, under Tennessee rules, the same outcome would have been possible only after the formal classification process as a Site-Specific Impaired Groundwater via the detailed protocol in Rule 1200-4-3-.09.

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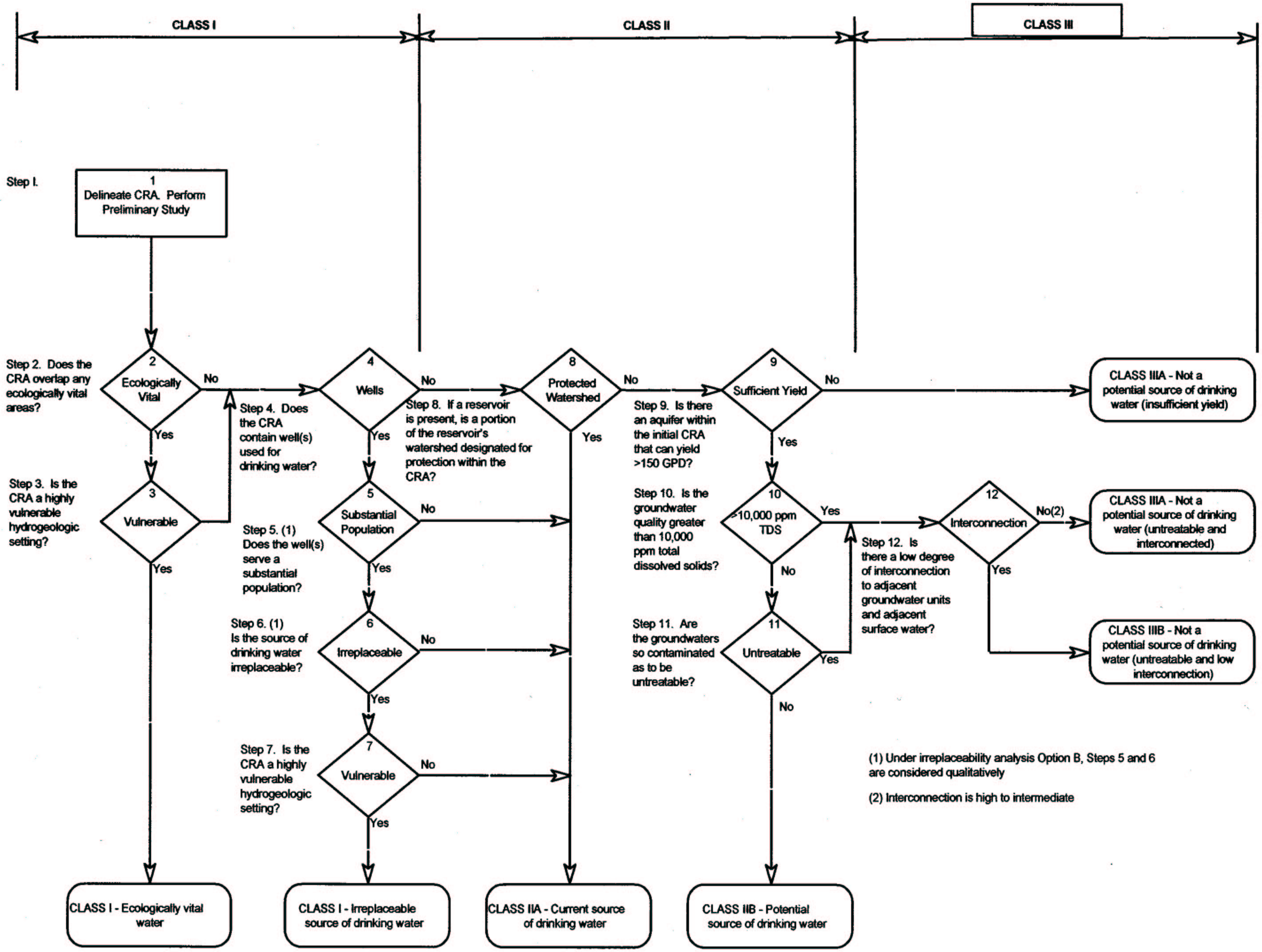

(1) Under irreplaceability analysis Option B, Steps 5 and 6 are considered qualitatively

(2) Interconnection is high to intermediate

FIGURE I USEPA PROCEDURAL CLASSIFICATION CHART FOR GROUNDWATERS

LONG-TERM ROAD CONSTRUCTION IMPACTS ON WATER QUALITY AND FISH COMMUNITIES IN SOUTH INDIAN CREEK[1]

T.D. Holt, P.R. Scheuerman, and K.J. Maier

Abstract

Nonpoint source pollution associated with roadway construction is exacerbated when construction occurs through steep landscapes. The expansion of highway I-181 from Erwin, TN to the North Carolina border began spring 1990 and was completed in 1996. Monitoring studies, conducted to assess construction impacts on the South Indian Creek ecosystem, concluded that several sections of the stream were degraded. The objective of this research is to evaluate the ecological recovery of selected reaches of South Indian Creek to determine the long-term effects of road construction. Habitat assessments and evaluations of water quality and fish communities at 7 impacted and 3 reference sites were conducted quarterly and used to determine if previous road construction activities continue to affect South Indian Creek. Habitat assessments were conducted using standard EPA methods. All water quality samples were analyzed using established methods, with appropriate QA/QC. Fish communities were evaluated using established quantitative methods. The median habitat score for the control sites was 139 while that for impacted sites was 125. Total solids, suspended solids, chloride, hardness, alkalinity, sulfate, and iron were significantly higher at the impacted sites compared to the control sites. Fish diversity and density were significantly different when comparing the impacted sites to the control sites. However, comparison of the 1996 and 2002 fish surveys showed lower fish diversity at sites 3 and 10 in 2002 compared to 1996. Based on the water quality and habitat data collected in spring, summer, and fall it is concluded that the South Indian Creek ecosystem has not recovered and remains degraded probably due to the construction impacts, which include habitat alteration and road runoff.

Introduction

The expansion of highway I-181 (now US 23) from Erwin, TN to the border of North Carolina began in 1990, and was completed in 1996. Intense modifications to steep mountainous terrain occurred during road construction and introduced suspended solids and toxic materials into South Indian Creek and its tributaries (Scheuerman et al., 1997). Watershed habitats were altered through streambed rechannelization and removal of riparian vegetation. Several published studies reported that road construction activities have had negative impacts on aquatic ecosystems (Cline et al., 1982; McNeil, 1996; Stout III and Coburn, 1989; Taylor and Roff, 1986; Lenat et al., 1981; Duck, 1985). The Tennessee Department of Transportation was interested in determining if the I-181 construction affected the South Indian Creek ecosystem. East Tennessee State University (ETSU), in collaboration with Arkansas State University, Virginia Tech, and the Tennessee Department of Transportation implemented a monitoring program conducted from April 1991 through June 1997 to determine of road construction impacts (Scheuerman et al., 1997). They determined that road construction had negatively impacted aquatic invertebrate communities, habitat, and water quality. As a result, additional aquatic invertebrate surveys were performed on October 15, 1998 and April 29, 1999 to evaluate ecological recovery after construction had been completed. The studies showed that many sites had not recovered (Scheuerman et al., 1999). The Tennessee Department of Transportation contracted with Fish and Wildlife Associates, Inc., a consulting firm, to evaluate the effect of the construction activities on the fish communities and populations. The final report, based on qualitative results of a one-year study, stated that construction activities apparently had minimal impacts on the fish communities (Bryan et al., 1995).

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[1] Long-Term Road Construction Impacts on Water Quality and Fish Communities in South Indian Creek
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The primary objective of this research was to evaluate the ecological recovery of selected reaches of South Indian Creek and its tributaries to determine the long-term effects of road construction. The research will also establish the current status of the fish communities, habitat and water quality of South Indian Creek and its tributaries.

Materials and Methods

South Indian Creek is located in Unicoi County, TN, and is a third order stream that is fed by several spring fed first and second order streams. It originates in Flag Pond, TN (elevation: 2,038 ft) with the convergence of Upper Higgins Creek and Sams Creek and tends to parallel old highway 81 and highway 19 until it empties into the Nolichucky River south of Erwin, TN (elevation: 1,675 ft.). Habitat assessments and evaluations of water quality, and fish populations were used to determine if previous road construction activities continue to impact the South Indian Creek ecosystem. The watershed was divided into three reaches (lower, middle, and upper) based on the varying stream characteristics that occur with varying elevation. A control site for each reach of the watershed was included in the experimental design for appropriate comparisons. For the ten experimental sites (Table 1) habitat assessments, water quality evaluations, and fish populations were determined seasonally (spring, summer and fall). Habitat assessments were based on standard EPA protocols (US EPA, 1999). Water quality parameters measured included total solids, suspended solids, chloride, hardness, alkalinity, and sulfate and iron concentrations (Greenburg et al., 1995; Hach, 1993). Fish populations were measured quantitatively using a standard three pass electro-fishing method. Fish were identified to species, and length and weight were recorded. Fish populations were estimated using the Moran Zippen regression formula (Moran, 1951). Abundance and diversity were calculated from the collected fish data. All water samples were measured using established methods with appropriate QA/QC including standards, duplicates, blanks, and spiked samples. A one-way ANOVA was performed on parametric data followed by an LSD multiple comparison test and a Kruskal-Wallis test was performed on nonparametric data with an LSD multiple comparison test.

Results

Water Quality

The control sites were grouped together and compared to the grouped impacted sites. The control sites were significantly lower than the impacted sites for total solids, suspended solids, chloride, hardness, alkalinity, and sulfate and iron concentrations ($p<0.001$). Table 2 provides the median concentrations for the water quality parameters at the control and impacted sites.

Habitat Assessments

The habitat assessment scores were also grouped into control and impacted sites. The control sites habitat score was significantly higher than the impacted sites ($p = 0.001$). The median habitat score for the control sites was 139, and 125 for the impacted sites (Table 2).

Fish Communities

Diversity, number of fish species, and density, number of fish per square meter, were compared between control and impacted sites. Diversity ($p = 0.446$) and density ($p = 0.417$) were not significantly different when comparing the control to the impacted sites in 2002 (Tables 4 & 5). However, when comparing the fish diversity data collected in 2002 to previous fish diversity data collected in 1996 there were differences (Table 4). The differences were not significantly different, but some species were missing in 2002 that were present in 1996. The most obvious differences occurred at sites 3 and 10. At site 3 central stonerollers, long nose dace and northern hogs suckers were not present in 2002 during the spring sampling period. Central stonerollers and northern hog suckers were not present in spring and summer sampling periods, but all three species were collected in fall. Also, river chubs and swannanoa darters were colleted in 1996 in the fall, but were not collected in 2002. In 1996, Site 10 had a median diversity of 25 while in 2002 the median diversity was 18.

Discussion

Water quality in the South Indian Creek watershed has most likely been degraded by altered habitat and road runoff. When comparing the habitat assessment scores for the control sites to the impacted sites the impacted sites had significantly lower habitat scores. The primary disturbances to the impacted sites were channelization and inadequate riparian zones. Channelization occurs when streams are straightened to make way for anthropogenic activities such as road construction. In particular, sites 2 and 10 were rechannelized during the construction of US 23. The median habitat assessment scores at these two sites were 102 and 120 out of a possible 200 points. Site 2 had the lowest habitat assessment score and site 10 had the third lowest score. Site 4 had the second lowest score of 118 and was also heavily channelized from past road construction of old US 81 and had a very poor riparian buffer zone.

When the sampling sites were grouped into control vs. impacted sites, the impacted sites had significantly higher concentrations for all seven water quality parameters. Table 1 shows the median concentration for each water quality parameter for the control and impacted sites. Also, Table 2 provides the median concentrations for all seven water quality parameters. Site 4 is of particular concern, because it has the highest concentration for total solids, chloride, hardness, and sulfate. Site 4 was also second highest in suspended solids and third highest in alkalinity. Site 4 drains several small tributaries that originate at the top of the watershed. One particular tributary flows underneath a retaining wall at the head of the watershed. This location is at Sam's Gap on the border between North Carolina and Tennessee. The elevated concentrations for the water quality parameters at the impacted sites are most likely a response to habitat degradation and runoff from previous road construction activities.

The comparison of control sites to impacted sites for fish diversity and density did not result in significant differences. This could indicate that the fish communities are not showing long-term impacts from road impacts. This could also be caused from selecting site 7 as a control site. Using Site 7 as a control stream for Sites 8, 9, and 10 may have introduced bias into the results and enabled the impacted sites to have apparently higher diversity and density. Site 7 (Spivey Creek) is a smaller and colder creek than South Indian Creek. Table 3 shows that site 7 has a lower average water temperature and smaller stream width than sites 8, 9, and 10. The smaller size and colder water could have limited site 7's ability to support a more diverse and abundant fish fauna. Site 7 was chosen as a control site, because it was used in a previous 1996 study for long-term comparisons. However, when comparing the 1996 study to the 2002 study, diversity differences were recognized. In 2002, central stonerollers, long nose dace, and northern hog suckers were not collected in the spring at site 3, however they were collected in the spring during the 1996 study. Also, at site 3 central stonerollers and northern hog suckers were not collected in the summer during the 2002 study, but they were during the 1996 study. Site 10 was another location that had diversity differences between the 1996 study and the 2002 study. In the spring and summer five less species were collected at site 10 in 2002 compared to 1996. In the fall only 10 species were collected at site 10 in 2002, compared to 25 species collected in 1996. Some of this variation could be caused by unusually high stream discharge during the late fall sampling. The 2002 study shows that fish populations have not been impacted, however this may be caused be the inadequacy of site 7 as a control site for the lower impacted streams. When comparing the 1996 study to the 2002 study, there are distinct differences in diversity for sites 3 and 10. The completion of winter sampling in 2003 will provide more insight into the long-term effects of habitat destruction and road runoff on the fish communities of the South Indian Creek watershed.

Conclusions

Based on the water quality and habitat assessment data collected in the spring, summer, and fall it is concluded that the South Indian Creek ecosystem has not recovered and remains degraded probably due to the construction impacts, which include habitat alteration and road runoff. The 2002 study shows that the fish communities in the impacted sites have not been degraded. However, this could have been biased by the use of site 7 as a control site for sites 8, 9, and 10, which are larger and warmer. The comparison of the 1996 study to the 2002 study did provide diversity differences at sites 3 and 10. This supports that there may be long term impacts occurring in the fish communities that was not detected in the comparison of control and impacted sites. It is difficult to find an appropriate control stream that matches the impacted streams in flow, size, and temperature. This is why the comparison of the 1996 study to the 2002 study is extremely important. It can remove the bias of the inadequate control streams and allow better evaluation of the long-term fish community changes that could be occurring from habitat degradation and road runoff. Sampling in the winter of 2003 will complete sampling and more conclusions can be made into the long-terms impacts of road construction on water quality, habitat, and fish communities of the South Indian Creek watershed.

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Tables and Figures

Table 1 Sample Site Descriptions

Site Number	Site Description
Upper Sites	
1	Upper Higgins Creek, adjacent to Higgins Baptist Church on the left hand side of the road (CONTROL)
2	Upper Higgins Creek, behind Higgins Baptist Church on the right side of the road, section of stream that was relocated during road construction
3	Upper Higgins Creek, below the Flag Pond Exit, below the box culvert constructed underneath the road. Iron gate on left side of road. ~3/10 of a mile above the confluence of Higgins Creek and Sams Creek.
4	Sams Creek, ~0.5 miles above the confluence of Higgins Creek and Sams Creek. Telephone pole # 309.
Middle Sites	
5	Upper South Indian Creek, immediately downstream of the confluence of Carter Branch and South Indian Creek. Below Tilson Mountain Rd. Below a small waterfall below a white double wide trailer.
6	Rocky Fork, up Rocky Fork Rd. and just past the red gate into the Wildlife Management Area. (CONTROL)
Lower Sites	
7	Spivey Creek, ~ 0.5 mile above its confluence with South Indian Creek. Gravel pull off to right side of road with room for three vehicles. On Highway 19. (CONTROL)
8	South Indian Creek, above Temple Hill Exit, adjacent to transfer station and immediately below the confluence of Lower Higgins Creek.
9	South Indian Creek, below Temple Hill Exit, take
10	South Indian Creek, just above Jackson Love Bridge and the confluence with the Nolichucky River. The site contains wooden structures built by TWRA to create habitat. This section of stream was relocated during road construction.

Table 2 Median Water Quality Concentrations (mg/L) and Habitat Assessment Scores for Control and Impacted Sites.

	Total Solids	Suspended Solids	Chloride	Hardness	Alkalinity	Sulfate	Iron	Habitat Assesm.
control	43	1	1	18	13	0	0	139
Impacted	78	5.5	5.4	33	26	1	0.01	125

Table 3 Average Concentrations for Field Water Quality Data.

Site	PH	Conductivity (µS)	Dissolved oxygen (mg/L)	Water temp. (^{0}C)	Air temp. (^{0}C)	Width (m)	Depth (cm)	Flow (m/s)
1	7.22	43.53	10.26	13.3	18.9	3.5	14.8	0.33
2	7.17	70.13	9.91	16.0	21.9	2.2	21.3	0.26
3	7.06	83.43	10.79	11.5	14.0	6.2	16.4	0.72
4	7.06	215.43	10.54	11.4	14.8	3.3	9.9	0.35
5	7.1	109.4	11.03	14.9	18.0	6.5	20.4	0.62
6	6.82	21.45	10.39	12.6	17.1	4.7	28.2	0.43
7	7.24	82.73	9.73	12.5	14.0	7.1	33.2	0.26
8	6.88	75.8	10.12	13.2	13.7	12.4	23.2	0.55
9	6.82	89.93	10.18	12.9	14.8	16.0	36.5	0.40
10	7.15	87.2	10.33	13.3	17.1	9.1	42.6	0.50

Table 4 Fish Diversity for 1996 and 2002.

	2002 Fish Diversity			
Site Number	Spring	Summer	Fall	Average
1	3	3	3	3
2	4	3	4	4
3	4	5	7	5
4	3	3	4	3
5	8	7	6	7
6	4	5	4	4
7	18	16	15	16
8	13	16	N/A	15
9	14	17	N/A	16
10	20	18	10	16
	1996 Fish Diversity			
Site Number	Spring	Summer	Fall	Average
1	4	4	4	4
2	4	4	4	4
3	7	7	9	8
4	3	3	3	3
5	8	8	7	8
6	7	7	8	7
7	16	17	19	17
10	25	23	25	24

Table 5 Fish Density (fish / m^2) for all Sampling Sites.

	Fish Density (fish / m^2)			
Site Number	Spring	Summer	Fall	Average
1	0.618	0.454	0.29	0.454
2	0.549	0.262	0.101	0.304
3	0.338	0.213	0.343	0.298
4	0.636	0.798	0.747	0.727
5	1.030	1.188	0.401	0.873
6	0.271	0.29	0.048	0.203
7	1.029	2.84	0.641	1.503
8	1.260	3.829	N/A	2.545
9	0.436	0.579	N/A	0.507
10	0.543	1.355	0.737	0.878

WATERSHED LAND USE AFFECTS PRIMARY PRODUCTION, COMMUNITY RESPIRATION, AND NUTRIENT CYCLING IN STREAMS: RESULTS OF A COMPARATIVE STUDY OF STREAMS AT FT. BENNING, GEORGIA

Jeffrey N. Houser[1], Patrick J. Mulholland, and Kelly Maloney

Because watershed characteristics affect the inputs of sediments and nutrients into streams, natural or anthropogenic disturbance of upland soil and vegetation can affect in-stream processes. Spatial variability in the intensity of military training (infantry and tank maneuvers) at the Ft. Benning military base (Columbus, GA) results in the uplands of some stream catchments being highly disturbed while others remain relatively undisturbed. We used this disturbance gradient to test the hypothesis that upland disturbance reduces in-stream metabolism due to reduced stability of stream substrata and reduced organic matter content of the stream bottom. We selected 11 headwater streams located in 11 different catchments: 3 reference sites, 4 sites of low to moderate disturbance, and 4 sites of high disturbance. During storm events, larger increases in inorganic suspended sediments (standardized to the magnitude of the increase in stream flow and baseflow concentrations) occurred in the disturbed sites compared to the reference sites suggesting that disturbed catchments export more inorganic sediments to their streams. This increased input of organic matter reduced the percent benthic organic matter in streams in highly disturbed catchments. Associated with this reduced organic matter content were reduced rates of in-stream respiration in disturbed streams during the summer and spring seasons (but not in fall or winter). Algal production was also lower in the highly disturbed streams in the spring, but not in other seasons. In addition, watershed disturbance affected the stream nutrient concentrations. Streams in highly disturbed catchments generally had lower concentrations of PO_4, and dissolved organic carbon (DOC). These results add to our growing understanding of the important connections between watershed characteristics, land use and in-stream processes.

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SHORT-TERM RESPONSES OF EASTERN AND MIDDLE TENNESSEE WARMWATER STREAM FISH COMMUNITIES TO CULVERT AND BRIDGE CONSTRUCTION

Robert B. Nichols[1] and S. Bradford Cook[2]

Impacts to stream ecosystems occur throughout watersheds in differing orders of magnitude and time. Impacts can be classified as those that occur over a short (pulse) period in which species persist and communities rebound, and those disturbances, which occur over a longer period (press) and have sustained affects upon stream fish communities. Adverse land use practices have shaped stream community species over time, thus persistent species have remained, and intolerant species have become restricted to relatively un-disturbed areas. Culvert and bridge construction impacts within watersheds can have variable effects on stream fish communities, depending on the magnitude and type of the construction project. Seven Tennessee streams were evaluated that were designated for culvert/bridge construction. Surveys were conducted from Spring 2000 to Summer 2002 and were sampled through three different phases of construction: pre-construction, during-construction, and post-construction. Single pass backpack electrofishing was used to assess the fish community. Analysis of fish community data was conducted using ANOSIM (Analysis of Similarity) and SIMPER (species percent contributions); both of which are “Change in Community Analyses”, included in Primer software. Results include proliferation of tolerant and pioneering species in the post construction phase, shifts in community composition and abundance, and disruption of seasonal community patterns. Communities were mainly affected on a small scale; however, cumulative impacts may occur after several population turnovers, and consequently cause long term changes in fish community patterns.

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Application of Compound-Specific Stable Isotope Analysis (CSIA) to Environmental Problems

Maria Uhle, Ph.D.[1]

Stable isotopic measurements of total organic matter have been used extensively to identify sources and sinks of carbon, nitrogen, sulfur, oxygen and hydrogen in many natural and contaminated environments. Total organic matter however, is a complex mixture of proteins, carbohydrates, lipids and lignin, which all have distinct isotopic compositions relative to the original source materials. These values are an integrated signal from both allochthonous and autochthonous sources and record the isotopic history of all components from production to alteration and diagenesis. While bulk values provide insight into the dominant sources, the isotopic composition of biological markers, such as amino acids, carbohydrates and lipids yield a more detailed picture of individual sources and provide a means to trace these compounds along various diagenetic pathways.

Using a state-of-the-art analytical instrument (GC/IRMS), which consists of a gas chromatograph interfaced to an isotope ratio mass spectrometer, we can determine the isotopic compositions of individual compounds to document intrinsic bioremediation of organic contaminants such as TCE and other chlorinated solvents and to apportion sources of polycyclic aromatic hydrocarbons from atmospheric and sediments samples. We can also determine the diagenetic pathways involved in contaminant degradation and identify which microbial communities are involved in contaminant degradation. Phospholipid fatty acids (PLFA) are derived from active microbial communities and distribution of certain PLFA are diagnostic of certain microbial communities. The isotopic values of PLFA reflect the incorporation of carbon derived from the contaminant during degradation, therefore we can identify which communities are utilizing the contaminant as a carbon source.

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Fate and Transport of Coal Tar Contaminants in Chattanooga Creek Floodplain

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Introduction

Coal coking operations at an industrial site (Chattanooga Coke Plant) in south Chattanooga, TN resulted in the release of large volumes of coal tar, pesticides, PCBs, and other dense non-aqueous phase liquids (DNAPLs) between 1918 and 1987. This has led to extensive contamination of soils and bedrock at the coke plant site, as well as in nearby Chattanooga Creek and the surrounding floodplain. Deposits of immiscible coal tar up to 4 feet thick were found in the creek and were apparently caused by runoff from the site through ditches and a storm drain system. Groundwater samples from subsoil and bedrock wells (up to 100 ft below ground surface) at the coke plant site and the vicinity indicate that the groundwater quality has been significantly degraded by coal tar constituents (PAHs, VOCs, SVOCs, NSO-compounds, etc.), PCBs, chlorinated solvents, and heavy metals. Similar chemicals were also measured in the creek sediment and water samples.

The Chattanooga Creek and its floodplain, downstream of the coke plant, were placed on the National Priorities List and in 1997, US EPA initiated a remedial action program, which included dredging of coal tar and contaminated sediments from a 1.0 mile long stretch of the creek. Another 1.5 miles of contaminated creek sediments are scheduled for future cleanup. The main objective of this study at the Chattanooga Creek site is to develop and test methods for assessing contaminant concentrations and downstream fluxes in the creek, and relate these to seasonal variations in flood stage, flow rate and turbidity. This research is expected to prove very useful for assessing the effectiveness of excavation methods for removal of coal tar compounds from creek bottoms, and the influence of such methods on water quality and the ecology of streams. Initially, we are using conventional chemical concentration (dissolved and suspended) monitoring in the stream and the sediments, but we also propose to test the applicability of molecular-based microbial ecology monitoring as an indicator of the effectiveness of dredging as a remediation method. We expect this to be a valuable supplement to contaminant concentration monitoring, which can be strongly influenced by dilution and short-term changes in flow rate, and it may prove to be less expensive and more sensitive than other types of ecological monitoring.

A research program is also currently underway to assess processes influencing coal tar fate and transport at both the Chattanooga Coke Plant site and along the creek and floodplain. One of the main objectives of this study at the Chattanooga Coke Plant is to determine whether immiscible coal tar is capable of penetrating fractures and macropores in the clay-rich unconsolidated soils and subsoils and to investigate its subsequent dissolution and migration into the underlying groundwater. This is an important step in predicting long term behavior and in assessing the likely performance of clean up methods for the site. Other objectives are to determine what fracture or macropore types are susceptible to invasion, to determine the depth to which contamination has occurred, to identify the composition of coal tar present in fractures/pores, and to test methods for assessing coal tar source zone geometry and mass distribution (i.e., mass of immiscible coal tar per unit mass of soil). We extracted several continuous soil core samples from the approximately 15 foot thick clay zone which overlies the carbonate bedrock and then

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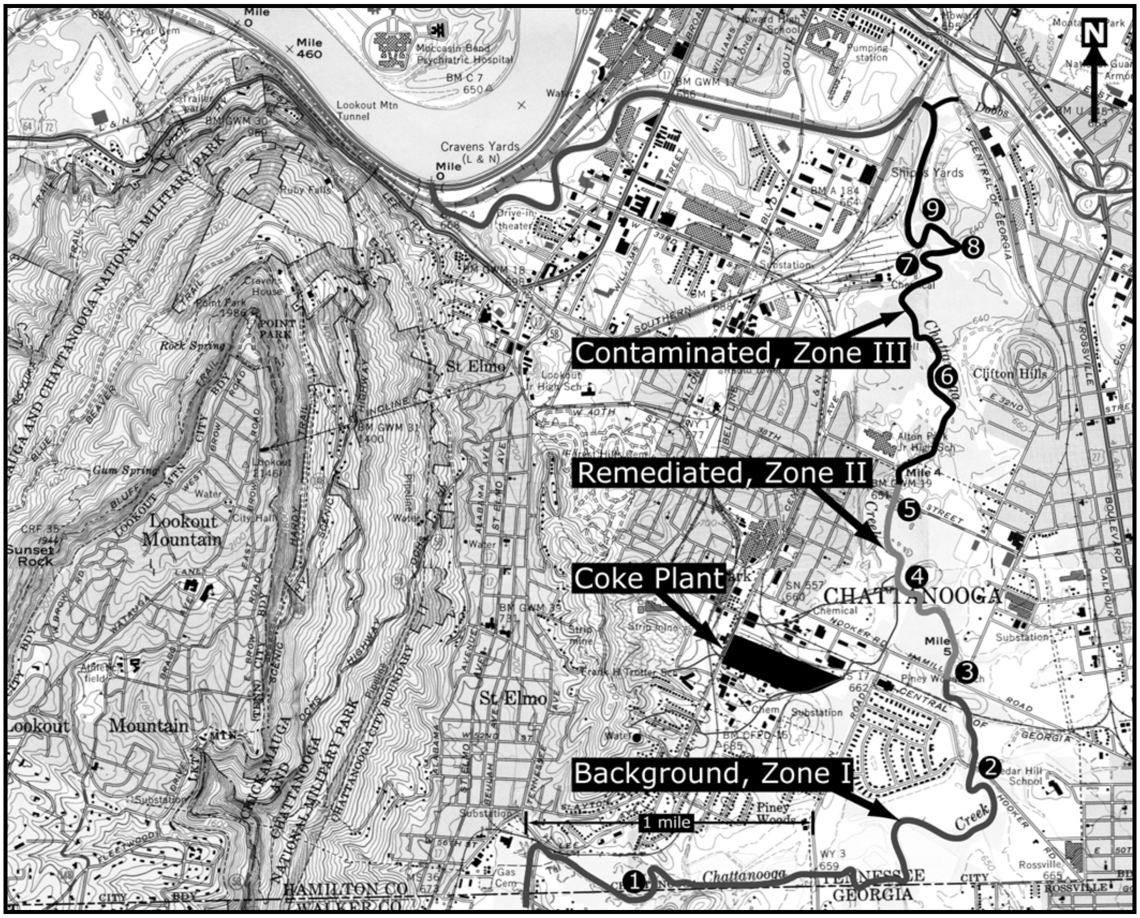
compared pore structure and contaminant distribution. Thin sections were prepared to examine the geomorphology and physical distribution of immiscible coal tar from the soil cores. In addition, coal tar constituents were extracted from the sub-samples to construct a profile of the vertical distribution of coal tar contamination at the coke plant.

Materials and Methods

A preliminary survey of the water and creek bottom sediment quality was conducted along Chattanooga Creek. Grab samples of water and bottom sediments were also collected from several locations along the creek (see Figure 1). These samples were collected from three areas of the creek – (Zone I) upstream of the coke plant (considered to be background), (Zone II) remediated portion of the creek just downstream of the coke plant, and (Zone III) downstream of the remediated section up to the Dobbs Branch (see figure). The US EPA has recently issued a Record of Decision to initiate dredging in Zone III. Only the top sediments were collected in all cases – note that in most areas along the creek that have not been remediated, coal tar contaminated sediments are present up to the bedrock (3–5 m below ground surface). The water and sediment samples were brought back to UT Knoxville for further analysis.

Figure 1: Chattanooga Creek and Coke Plant in southern Chattanooga. The affected creek is marked into three zones (different shades of gray) with several environmental sampling locations.



Five boreholes were advanced in the unconsolidated subsoils up to the bedrock at the southern part of the Chattanooga Coke Plant using Direct Push Techniques (DPT). Continuous undisturbed soil core samples (1.5″ sample diameter) were collected using clear acetate liners. These core samples were examined in the field to determine whether immiscible coal tar or creosote mixtures are present, and were then brought back to UT Knoxville for detailed examination. The soil cores were extruded from the acetate liners and split open to describe the lithology of the samples. Thin sections were prepared from soil cores at various depths to determine micromorphological distribution of coal tar within various soil zones above the bedrock. Hot solvent extractions were performed on sub-samples from the soil cores to determine presence of coal tar constituents at various depths. Sub-samples from each soil core were also subjected to X-ray fluorescence microscopy to determine the bulk inorganic chemistry of the soil.

Hot solvent extractions were performed on the sediment and soil core samples to extract PAHs and PCBs. The extractions in all cases were performed according to EPA standard methods 3545A and 3545A for PAHs and PCBs respectively, using an accelerated solvent extractor (Dionex, ASE 300). The chemical concentrations were determined using a gas chromatograph equipped with either a mass spectrometer or an electron capture detector for measuring PAHs and PCBs respectively. Only 16 PAHs that US EPA considers as high priority carcinogenic compounds were analyzed for in all samples.

Results and Discussion

Chattanooga Creek Sediment Quality:

Samples collected in Zone I (sampling locations 1 and 2) indicated little or no presence of PAHs (see Table 1). Three locations (3-5) were sampled in Zone II of the creek (dredged by US EPA) – (i) at the start of the section (location 3), (ii) in the middle portion near the confluence of two tributaries that pass along the Chattanooga Coke Plant (location 4), and (iii) near the end of the section, at a location where the weathered limestone bedrock was visible in the creekbed (location 5). Of these three locations, extremely high concentrations of most PAHs were measured in sampling location 4 followed very closely by the sampling location 3. No PAHs were measured in the sampling location 5. In Zone III, most sampling locations (6-9) exhibited moderate to very high concentrations of most PAHs of concern (see Table 1).

Table 1: PAH concentrations in Chattanooga Creek sediment samples. Note: All concentrations are averages of all samples measured and are expressed in mg/kg.

Sampling locations	1	2	3	4	5	6	7	8	9
PAHs	**Zone I**	**Zone I**	**Zone II**	**Zone II**	**Zone II**	**Zone III**	**Zone III**	**Zone III**	**Zone III**
Naphthalene	ND	ND	255.85	327.96	ND	28.41	56.57	ND	1.01
Acenaphthylene	ND	ND	253.62	327.09	ND	158.60	219.02	16.32	9.24
Acenaphthene	ND	ND	ND	ND	ND	40.41	ND	ND	ND
Fluorene	ND	ND	ND	ND	ND	97.01	1872.83	ND	0.97
Phenanthrene	ND	ND	4062.14	5312.73	ND	261.10	6969.06	11.72	12.53
Anthracene	ND	ND	983.52	1311.68	ND	197.92	1545.09	18.02	8.74
Fluoranthene	0.29	4.18	3212.97	4305.32	ND	1517.87	4015.38	20.19	60.75
Pyrene	0.06	4.13	2518.23	3378.24	ND	1388.70	2996.94	19.65	35.14
Benzo[a]anthracene	4.05	5.96	1091.43	1466.08	ND	689.50	1069.41	90.01	82.16
Chrysene	ND	0.27	784.25	1053.36	ND	484.92	794.33	12.28	17.57
Benzo[b]fluoranthene	ND	1.88	1265.57	1687.23	ND	1211.75	1049.28	30.34	16.58
Benzo[k]fluoranthene	ND	ND	384.14	513.89	ND	392.22	297.73	1.98	15.27
Benzo[a]pyrene	ND	ND	994.18	1341.94	ND	986.18	712.54	20.90	11.17
Indeno[1,2,3-c,d]pyrene	ND	ND	769.99	1029.13	ND	648.09	409.70	48.77	25.33
Dibenz[a,h]anthracene	ND	ND	ND	3.79	ND	83.67	54.86	2.23	1.79
Benzo[g,h,i]perylene	ND	6.01	503.61	674.74	ND	456.89	362.65	55.56	13.97

The presence of some PAHs in Zone I indicate that either contaminants entered the creek from sources further upstream than originally expected, or that some contaminated sediments may have migrated upstream of the Chattanooga Coke Plant. Such migration may be possible when the flow direction in the creek is reversed due to fluctuating levels in the Tennessee River, into which the creek joins about 2.5 miles downstream of the Coke Plant.

The sediments in Zone II seemed to receive significant influxes from various coal tar sources in the recent years resulting in rather high measured concentrations of PAHs in sampling locations 3 and 4. During US EPA's remedial action on the creek, most of the sediments in Zone II were dredged up to the bedrock – but fresh sediments have now covered most of Zone II. Sampling location 3, located at the beginning of Zone II, probably received PAH inputs from pockets of coal tar contaminated sediments upstream of Zone II that were not dredged. The second location is present roughly in the center of Zone II at the confluence of two small tributaries (which pass through the Coke Plant) and the creek. These tributaries are generally believed to have been amongst the primary pathways for coal tar waste disposal from the Coke Plant to the creek. However, these tributaries were not addressed by the US EPA during the remedial action for the creek. Hence, these tributaries may still be contributing coal tar contaminated sediments, which could explain the high concentrations of PAHs measured in sampling location 4. No fresh sediments were present in the sampling location 5, located near the end of Zone II – weathered limestone bedrock is clearly visible from the surface. Consequently, the sediments collected were actually weathered limestone fragments and these samples did not contain any PAHs. Sediments in Zone II may also have received PAH inputs from several areas that US EPA was unable to completely dredge. These areas include sinkholes within the creek bed, fractures and other macropores present along the banks of the creek that have been infiltrated with coal tar over several decades. The floodplain itself, which was likely contaminated from by flood events, is expected to continue to contribute contaminated sediments to the creek.

All four sediment samples from Zone III (sampling locations 6-9) were collected from upper surface of the sediments. Our sampling surveys which also included extracting cores from bottom of the creek indicated that coal tar contaminated sediments were present up to the bedrock. In addition, surface sediments are constantly turned over and “diluted” with fresh sediments constantly. Hence, much higher PAH concentrations are expected below the surface sediments at the bottom of the creek in Zone III.

An important feature of the PAH concentrations measured in Zones II and III is the composition of various PAH compounds. The 16 compounds in the Table are listed in the order of decreasing solubility, i.e., the more soluble compounds (e.g., naphthalene and acenaphthylene) are usually present in lesser concentrations in older coal tar contaminated sediments. Conversely, less soluble PAH compounds may be present in the same concentrations regardless of weathering and aging. This pattern is clearly visible in the PAH data. The ratio of more-to-less soluble compounds (e.g., naphthalene-to-fluoranthene concentrations) in Zone II is higher than that in Zone III. This clearly implied that Zone II received fresh inputs of coal tar contaminated sediments, whereas the sediments in Zone III may have been in place for much longer times.

Chattanooga Coke Plant core samples:

The preliminary lithological description of the core samples indicated that the soil matrix is primarily composed primarily of clay interspersed with angular chert fragments of varying sizes (see description of one soil core in Table 2).

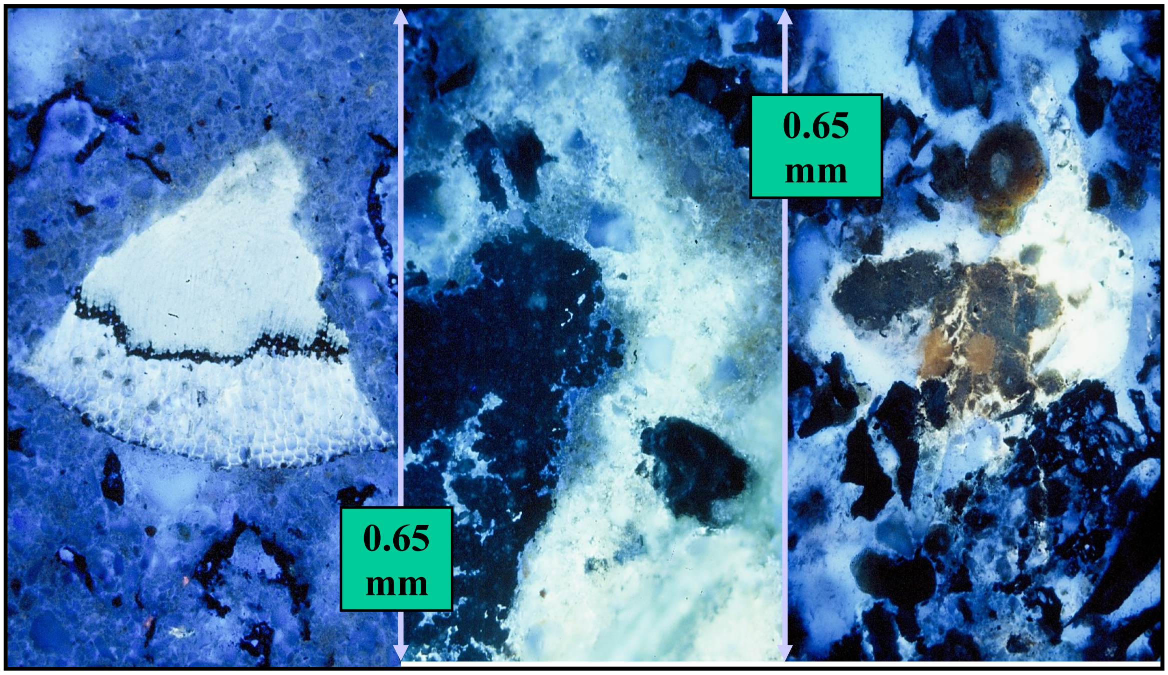
Table 2: Soil core description of one core (UT-2) extracted from Chattanooga Coke Plant. Note: All depths are in cm.

Depth b.g.s.	Description of soil sample	Color of matrix
0-10	Gravel, angular, less than 1.5 cm diameter, limestone.	Gray
10-38	Sand-sized grains, coal or coal slag.	Very dark gray
38-47	Sand and silt soil matrix, weakly cohesive, slightly tarry odor. Includes ~ 40% peds of clay, up to 2 cm diameter.	Matrix - black, clay peds - reddish brown 5YR 4/3
47-72	Sand and silt soil matrix, increasing amounts of clay peds with depth, slight odor, clay, some chert pebbles (~ 2 cm dia.) at 70 cm.	Dark reddish brown 5YR 3/4
72-78	Stiff clay, some gravel-sized fragments, slight odor, moist. Contains a large vertical fracture filled with black substance, ~ 5% small (~ 1 mm dia.) black spots.	Olive brown 2.5Y 4/3
78-86	Clay and granular slag, friable, strong coal tar odor.	Dark gray to black
86-96	Clay, few chert pebbles, stiff, moist.	Light olive brown 2.5Y 5/3
96-104	Sand, gravel, and clay, strong coal tar odor.	Dark gray to black
122-138	Clay, one large chert pebble, small amounts of fine chert granules, strong coal tar odor, ~ 5-10% of matrix covered with dark spots (coal tar or Mn oxides).	Dark olive brown 2.5Y 3/3 at top of interval to olive brown 2.5Y 4/4 at bottom of interval
138-155	Clay, scatterred chert granules with larger pebbles at bottom of interval, strong coal tar odor, ~ 40-50% of matrix coverered with dark spots (coal tar or Mn oxides).	Dark grayish brown 2.5Y 4/2
155-162	Gravelly clay, ~ 20-50% chert gravel, strong coal tar odor.	Dark grayish brown 2.5Y 4/2
162-173	Clay with dark spots (coal tar or Mn oxides), small amounts of chert gravel, strong coal tar odor.	Olive brown 2.5Y 4/4
173-175.5	Clay silt, no visible contamination, small chert granules, strong coal tar odor.	Light olive brown 2.5Y 5/4
175.5-182.5	Clay with several large angular chert fragments, strong coal tar odor, ~ 50% of matrix covered with dark spots.	Olive brown 2.5Y 4/3
244-262	Clay, several angular chert fragments, ~ 50% dark staining on matrix, very strong coal tar odor, very stiff.	Matrix - olive brown 2.5Y 4/3, dark spots - 2.5Y 2.5/1
262-275	Clay, sparse chert fragments, strong odor, some streaks of black material (coal tar or Mn oxides).	Primary - light olive brown 2.5Y 5/4, secondary (~ 25%) - yellowish red 5YR 4/6
275-284	Clay, few chert pebbles, very stiff or hard, moderate to high plasticity, horizontal band ~ 0.8 cm thick gley across core	Primary - light olive brown 2.5Y 5/6, secondary - grayish brown 2.5Y 5/2
284-306	Clay - finely mottled with other colored clays, moderate odor, several small chert pebbles, moderate plasticity.	Matrix - light olive brown 2.5Y 5/4 with ~ 10% light yellowish red 5YR 4/6 and ~ 10% light yellowish brown 2.5Y 6/4 mottles
306-320	Clay with mottling as above, very stiff, black streak near surface between 306 to 324 cm - looks like macropore coated with coal tar or Mn oxides, moderate coal tar odor.	Matrix - light olive brown 2.5Y 5/4 with ~ 5-10% light yellowish red 5YR 4/6 mottles
320-330	Clay, very stiff, no mottling, faint coal tar odor.	Light olive brown 2.5Y 5/4
330-367	Clay with 10-30% dendritic black Mn oxide impregnations and coatings, root cast (~ 1 mm dia.) at 335 cm with black coating and cuts across the core, another (0.5 mm dia.) at 345 cm depth. At 350 cm depth mottles or thin zones - remnants of macropores? Presence of hard Fe nodules below 350 cm depth	Matrix - light olive brown 2.5Y 5/4, mottles - light grey 2.5Y 7/2, Fe nodules - yellowish red 5YR 4/6
367-	Auger refusal	

Judging by the strong odor and presence of black mottling and scarring, coal tar compounds may have diffused into clay matrix and invaded the macropores and fractures. Thin sections of the soil cores indicate that macropores persist to maximum depth cored and consist of root pores, slickensides, and soil fractures and are coated with coal tar. Black veins caused either by coal tar or by Mn oxides penetrate 1-2 mm into soil matrix adjacent to macropore surfaces. Vertic properties in these soil cores, such as slickensides and clay matrix birefringence fabrics, indicate seasonal wetting and drying to depths of up to 250-350 cm. Fe oxide and siderite concretions, and redoximorphic matrix depletion/enrichment features formed around macropores, indicate seasonal cycles of saturation and unsaturation related to water table perching. When the thin sections were viewed under a fluorescent source, several bright spots or steaks were observed (see Figure 2). Typically organic compounds fluoresce very brightly under fluorescent light - indicating that the macropores and the matrix itself have been penetrated by coal tar compounds.

The visual evidence provides sufficient clues that coal tar can indeed penetrate the clay matrix despite conventional belief that clay may be relatively impermeable for contaminants. The presence of macropores, fractures, and other lithological features in the subsurface can easily contribute to movement of contamination to great depths. Currently, the soil core samples are being processed for chemical extractions from which depth profiles of various contaminants can be observed – this data will provide a more definitive evidence of presence of coal tar compounds deep in the subsurface.

Figure 2: Thin sections of soil core from Chattanooga Coke Plant, UT2 (92-96 cm) as seen under fluorescent light: (A) Brightly fluorescing plant fragment, (B) macropore with brightly fluorescing organic compounds, C) brightly fluorescing spot of concentrated organic compounds.



Conclusions

There are two major conclusions that can be reached from this study: (i) while excavation of sediments as a remedial measure does indeed reduce the gross contamination present in the Chattanooga Creek, post-remedial monitoring of the creek quality is required to assess the fate of the residual contaminants and the potential for future human health effects and ecological risk and (ii) despite the common belief that dense clay soils act as impenetrable layers preventing downward movement of DNAPLs, our study indicates that macropores and fractures are present at the Chattanooga Coke Plant and likely act as pathways for downward migration of coal tar contaminants.

EVALUATING STRUCTURAL BMP'S AT TDOT REGIONAL FACILITIES WITH REFERENCE TO THE PHASE II STORM WATER REGULATIONS

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ABSTRACT

The purpose of this paper is to provide preliminary information on a project initiated by the Tennessee Department of Transportation (TDOT) to evaluate commercially available stormwater treatment systems regarding their capability to function as structural Best Management Practices (BMP's) to support future TDOT stormwater regulatory compliance needs. The paper will describe the units that have been installed to date, provide preliminary information from the completed installations, and outline the plans for evaluation of the units and other future work planned to be performed.

INTRODUCTION

Compliance with the impending Phase II Stormwater regulations will require significant upgrades to stormwater systems across the state. Near term actions will be required by many municipalities with separate stormwater sewers; construction sites disturbing greater than 1 acre in size, and state controlled roadways in certain urbanized areas, to develop and file a stormwater discharge permit application with the Tennessee Department of Environment and Conservation (TDEC) by March of 2003. The March 10th compliance deadline for permit application includes a requirement for a stormwater management plan that outlines what actions will be taken to improve discharge standards. One of the components of many stormwater management plans will be the use of structural BMP's to treat stormwater prior to discharge to surface water. TDOT and its consultant, Science Applications International Corporation (SAIC), is working with TDEC, US EPA, the University of Tennessee (Knoxville and Jackson) and Tennessee Technological University to evaluate, select, install and test structural BMP units at TDOT's four regional facilities in Knoxville, Chattanooga, Nashville and Jackson.

Each of the selected units will be evaluated for treatment effectiveness, cost effectiveness, ease of installation, treatment capacity, applicability to actual and projected site conditions at TDOT facilities, and cost of operation and maintenance. To date, five units have been installed as a part of this project, three at the Nashville regional facility and two at the Knoxville facility. The selected units were retrofitted to capture and treat the discharge from the existing stormwater drainage systems existing at each of the TDOT facilities. A sixth unit that was previously installed at the Nashville facility will also be evaluated during the project.

BMP STORMWATER TREATMENT UNITS

1 Tennessee Department of Transportation
2 Science Applications International Corporation
3 Tennessee Technology University

The stormwater treatment currently units installed at the Nashville TDOT facility include:

- Advanced Drainage Systems (ADS) Water Quality Unit[1];
- Royal Environmental Eco Sep Oil and Water Separator[2];
- Baysaver Separation System[3]; and
- Continuous Deflective Separation (CDS)[2].

The CDS system had been installed prior to the initiation of this project as part of stormwater management for a recent addition to the TDOT facility.

The units installed at the Knoxville TDOT facility include:

- Crystalstream (PBM) Oil/Grit Separator[4]; and
- Aquaswirl Concentrator[5].

All of the units were purchased by TDOT from the local distributor and installed by SAIC and its construction subcontractor with technical guidance and assistance from the distributor and/or manufacturer. Detailed documentation of the installation process for each unit was maintained by SAIC and an evaluation and comparison of the installation requirements for each unit will be part of the project final report.

Treatment Unit Selection

At the initiation of the project an extensive literature and internet search was conducted to identify all of the commercially available systems that had potential application to TDOT stormwater management needs. Over fifty potential vendors and stormwater treatment unit designs were originally examined. Criteria for selection of the units included:

- suitability for given stormwater flow conditions – since all of the installations were retrofit conditions, the in-flow rate and potential contaminants could not be controlled and the unit must have been able to adapt to the situation. The requirement for the treated flow rate was based on a rainfall intensity of 2.54 inches/hour over the drainage area;
- suitability for site physical conditions – the units were installed at an existing stormwater outfall, thus the units had to be able to be installed at a given location regardless of elevation differences between inlet and outlet, depth to existing stormwater pipe, distance from paved access, depth to groundwater, and presence of hazards (eg. overhead power lines, buried pipelines);
- uniqueness of system design and construction - the selection process attempted to identify units which were representative of the major design philosophies and materials of construction currently available; and
- cost – cost of the units was not a primary consideration, but if two units represented essentially the same design and materials of construction, the less expensive unit was selected.

A summary of the units installed is provided in Table 1.

Units Distributed by:
1 Advanced Drainage Systems, Franklin, TN
2 Sherman-Dixie Concrete Industries, Hermitage, TN
3 Viking Products, Mt. Juliet, TN
4 Practical Best Management Inc., Stone Mountain, GA
5 AquaShield, Inc., Hixson, TN

TABLE 1 TDOT STORMWATER TREATMENT SYSTEMS

Location	Unit	Installation Date	Description	Treated Flow Capacity	Floatables Storage Capacity	Capital and Installation Cost
Nashville outfall 0-2	ADS	Oct. 2002	89 ft. long, 60 in I.D HDPE pipe with weir near midpoint to trap sediment and baffle over outlet to capture floatables	18.5 cfs	4000 gal.	$77,586
Nashville outfall 0-3	CDS	July 2001	Consists of three circular precast concrete chambers stacked on top of each other. The upper chamber provides initial separation, the middle chamber includes filter baskets for solids separation and the lower chamber is a collection sump.	2.8 cfs	400 gal.	Not Available
Nashville outfall 0-4	BaySaver	Sep. 2002	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device.	22 cfs	1110 gal.	$68,623
Nashville outfall 0-6	Ecosep	Aug. 2002	Three separate precast concrete manholes, first chamber is grit chamber for solids separation, other two are oil separators.	2.72	1200 gal.	$68,385
Knoxville outfall SW0-3	PBM	July 2002	Precast concrete box using baffles to control flow and increase gravity separation. Trash basket on front end for debris and adjustable weir with “oil bucket” to skim off floating oil.	6.2 cfs	200 gal.	$25,353
Knoxville outfall SWO-2	Aqua-Swirl	Sept. 2002	Single HDPE tank using vortex action and baffle to separate solids and floatable	14 cfs	1000 gal	$46,833

SAMPLING AND ANALYSIS PROGRAM

The primary objective of this sampling and analysis program is the collection of monitoring data to support TDOT's evaluation of stormwater runoff treatment devices for their potential future use in meeting environmental compliance program requirements. The secondary objective is to provide site-specific performance data on a variety of BMPs whose long-term use can yield significant environmental benefits to receiving waters of the State.

Specific questions that will be addressed in the data analysis include the following:

- How does the BMPs efficiency, performance and effectiveness compare to other BMPs tested?
- Does the BMP help achieve compliance with water quality standards?
- Does the BMP cause an improvement in or protect downstream biotic communities?
- Does the BMP have potential downstream negative impacts?
- What degree of pollution control does the BMP provide under typical operating conditions?
- How does effectiveness vary from pollutant to pollutant?
- How does effectiveness vary with various input concentrations?
- How does effectiveness vary with storm characteristics such as rainfall amount, rainfall intensity, and antecedent dry conditions?

Questions <u>not</u> addressed in this analysis include:

- How do design variables affect performance?
- How does effectiveness vary with different operational and/or maintenance approaches?
- Does effectiveness improve, decay, or remain stable over time?

Site Characteristics

Common characteristics of the Regional facilities include the presence of large impervious (paved) areas for vehicle traffic and parking, vehicle maintenance operations such as fueling, vehicle cleaning, painting and repair, and road maintenance functions, such as salt, sand and gravel storage, sign painting, and road-striping. A higher stormwater runoff flow rate (i.e., high runoff coefficient) is expected from parking lots and other the impervious areas than from vegetated areas at these sites. Common potential pollutants for all sites include petroleum products (oil & grease), heavy metals, sediment, bacteria and eroded sediment. The regional facilities may have additional pollutants characteristic of vehicle maintenance, including solvents and other synthetic organic compounds.

Storm Events to be Monitored

Storm events will be selected to yield the best quality data for the technology evaluation. A qualifying storm event will be one where the pollutant concentrations are measurable, the composite sample is representative of the complete runoff hydrograph, and the difference in the influent and effluent EMC and EML can be calculated for each site-related pollutant. Qualifying storm events must meet the following criteria:

a. the storm event must be >0.1 inches in magnitude.

b. the storm event must occur at least 7 day (168 hours) after the previously measured (>0.1inch) storm event.

Ideally, there would be an opportunity to obtain samples from 15 qualifying storm events for each technology tested. However, considering the probable practical limitations for the duration of evaluation, it is unlikely that each monitoring site will have 15 storm events resulting in completed sampling and analysis.

The results of this field demonstration and evaluation project will be used to aid in the selection and design of structural BMPs for future new construction and potential retrofits at the existing stormwater outfalls along the highways in “urbanized” areas, as well as other facilities and locations impacted by the Phase II regulatory requirements.

DATA ANALYSIS

Validated stormwater monitoring data will be analyzed to determine the efficiency of each technology in removing pollutants from stormwater runoff at TDOT facilities. Both the reduction in stormwater runoff pollutant concentrations and the reduction in loading (pollutant mass) are relevant to this evaluation. Samples will be collected using flow-proportional composite sampling to allow calculation of the Event Mean Concentration (EMC) and Event Mass Load (EML) for each pollutant and each storm event.

The EMC is the arithmetic average concentration of a specific pollutant in the total runoff volume from each storm event. The EML is the total constituent mass of a specific pollutant transported during a particular storm event. The EML is calculated for each pollutant using the measured EMC and the total runoff volume for the event.

Pollutant Load and Event Mean Concentration

The mid-sample method (Charbeneau & Barrett 1998) will be employed to derive the volume to be associated with each aliquot concentration, where load and event mean concentration (EMC) are calculated as

$$L = \sum_i C_i V_i \tag{1}$$

$$EMC = \frac{\sum_i C_i V_i}{\sum V_i} \tag{2}$$

and C_i is the concentration of the i^{th} sample and V_i is the storm volume associated with the i^{th} sample. The EMC, calculated using the mid-sample method, should be within 20% of the concentration of the composite sample.

First Flush Response (Influent Aliquot Samples Only)

The general assumption that the first part of the runoff is the most polluted will be evaluated by plotting curves of cumulative influent load versus cumulative influent volume for each constituent. A first flush event has occurred, at least qualitatively, if the cumulative load curve falls above the 45° slope. The cumulative load curve can also be used to determine whether a quantitative criteria first flush has been met. For example, Saget et al. (1995) have proposed the 30/80 rule; the criteria that the first 30% of runoff transports at least 80% of the total event load. Parameters like antecedent dry days, intensity, and catchment area and slope are known to be important factors that affect the degree of first flush response.

BMP Removal Efficiency

Two methods for evaluating BMP removal efficiency will be employed: *The Efficiency Ratio Method* and *The Effluent Probability Method*.

The Efficiency Ratio Method is the most commonly used method for evaluating BMP removal efficiency. The Efficiency Ratio is defined in terms of the average EMC of pollutants over some time period,

$$ER = 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} = \frac{\text{average inlet EMC - average outlet EMC}}{\text{average inlet EMC}}$$

Where the arithmetic average EMC is calculated as,

$$\text{average EMC} = \frac{\sum_{j=1}^{m} EMC_j}{\text{number of events measured}}$$

This method weights EMCs from all events equally regardless of the relative magnitude of the storm. A high concentration/high volume event has equal weight in the average EMC as a low concentration/low volume event. However, for the purpose of comparing removal efficiencies among several BMPs it is a valid method

The Effluent Probability Method is the method recommended by EPA-ASCE (EPA-ASCE 2002) for evaluating BMP removal performance because it provides a statistical measure of influent and effluent quality. In this method, a normal probability plot (Frequency of Occurrence vs. EMC) will be generated of the log transform of both influent and effluent EMCs for all events. If the log transformed data deviates significantly from normality, other transforms will be explored to determine if a better distribution exists. Probability plots will be supplemented with standard statistical tests that determine if the data is normally distributed; including the Kolmogorov-Smirnov one-sample test and the chi-square goodness of fit test. These are paired tests comparing the data points from the best-fitted normal curve to the observed data.

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A WEB ENABLED WATER MANAGEMENT PROGRAM DESIGN FOR WATER QUALITY AND QUANTITY ISSUES

Vic Young, Fisher & Arnold, Inc.[1]
Bob Ori, Planning Technology, Inc.

Storm water considerations are some of most costly and high profile decisions that municipalities and counties face. While property flooding (quantity) accounts for many calls to the city they are followed closely behind by citizens reporting blockages, chemical and sediment pollution (quality).

Storm water quantity events require city personnel to quickly respond to flooding whether it is stopped up drains, overgrown ditches, or, just too much rainfall. Managing these incidents and response personnel can be time consuming, expensive, and often not quick enough for the person with a flooded garage.

The implementation of Storm Water Phase I and the Upcoming Phase II (Quality) will put a further strain on personnel and time. Sampling of outfalls and managing construction sites are the major obstacles (components) for Phase II cities, while managing permits and sites, plus achieving all six minimum control measures. Under the current guidelines it is estimated that the average cost for a typical Phase II MS4 could range to several dollars per capita per year.

Developing a comprehensive and cost effective storm water implementation program involves examining the Phase I or Phase II requirements and understanding how tasks can be streamlined. Identifying the physical components of the program is essential. During implementation the MS4 must identify all waterways and drainage areas, outfalls, and other drainage conveyances. Complying with the illicit discharge component will demand creating a detailed storm sewer map and the identification of discharge sources. The logistics of managing the construction and post construction component of Phase II will require locating all sites with a high degree of accuracy. The most practical method of managing storm water implementation is the use of GIS. Concurrently, while display and communication of the data can best be managed through the Intranet and Internet.

Our team has developed a web enabled application that allows the MS4 to streamline their Phase I and Phase II tasks while also more efficiently addressing their storm water runoff issues. The web enabled application allows one client to customize and streamline Phase I sampling issues, another client to better identify exactly where potential pollution would drain, and another to better manage all aspects of the Phase II storm water implementation program. Our ability to host the site, provide the client access to the necessary software, and the ability to update data remotely provides a key to efficiently and cost effectively managing storm water Phase I and II issues.

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TESTING THE CHEMICAL PERTURBATION INDEX IN AN MIXED LAND-USE KNOXVILLE STREAM

Brooks Alan Jolly[1]

Introduction

Landscape change within the United States has resulted in the significant physical and chemical alteration of our nation's surface waters. The effects of watershed disturbance (i.e., landscape change) are controlled by many factors including rainfall intensity, antecedent hydrologic/climatic conditions, local anthropogenic activities, underlying geology, and a myriad of surface characteristics (Pitt et al., 1995). Many research projects demonstrate that land use is a significant landscape feature that moderates or impacts observed surface water quality. One rapidly growing form of land use change in the United States is urbanization; which ranks second to agriculture as a major cause of stream degradation (USEPA, 2000). A major landscape change associated with urbanization is an increased amount of impervious surface. Hydrologic effects of increased impervious cover include a higher frequency of flooding, greater peak flow volumes, greater sediment loadings, loss of aquatic and riparian habitat, changes in the stream's physical and chemical characteristics, and decreased base flow (USEPA, 1997). Studies indicate that the amount of impervious surface is an accurate predictor of urbanization and urban degradation of surface waters (Paul and Meyer, 2001). In addition, several studies suggest that the extent of impervious cover is a useful criterion for classifying the health of streams.

Understanding the effects of urbanization and impervious cover on surface waters is but one component of the larger issue of restoring and maintaining the physical and ecological integrity of urban streams. Effective watershed management is a social process that requires the inclusion of local citizens and community alliances. When a community is involved in the monitoring of streams and watershed management decisions, citizens are more likely to understand water issues associated with urbanizing and comply with good management practices (Rhoads et al., 1999). To this end, communities need the tools to gather useful and interpretable data about water quality. Equipping community organizations with the tools for the chemical monitoring of streams requires tests that are inexpensive, produce scientifically meaningful results, and do not require a scientific or engineering background.

The Chemical Perturbation Index (CPI), developed by Dr. Stewart of the Oak Ridge National Laboratory, is an inexpensive and easily interpretable index of nonspecific water quality that may potentially be able to detect both spatial and temporal changes in stream chemistry resulting from urbanization. Based on the typically strong correlative relationships between alkalinity, hardness, and specific conductivity, the CPI assesses deviations among these constituents (Stewart, 2001). The three parameters used to compute the CPI are primarily controlled by geological and climatological conditions; however the strength of the relationship between these three variables can be significantly altered by inputs of ion-rich wastewaters. Computed from measurements made at a monitoring site over time, the CPI is the sum of the three pairwise Spearman's rank correlation coefficients between alkalinity, hardness, and specific conductivity. Spearman's rank correlation coefficient varies between –1 and 1, with positive 1 indicating a perfect linear relationship between the two variables. Summing the three coefficients used to compute the CPI

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results in an index that varies from +3 to –3. Non-perturbed systems would be expected to exhibit a high degree of correlation between the parameters resulting in positive CPI values. The primary purpose of this study is an initial assessment of the parameters used to calculate the Chemical Perturbation Index as tools for water quality monitoring in an urban environment.

Objectives

The CPI is based on statistical correlations between three water quality parameters; as such, a fairly large number of time-matched observations ($n>20$) should be used for computation of the index. Gathering the number of samples necessary to compute the CPI from multiple sites along a stream requires a significant investment of time. Before investing the resources necessary for computation of this index I will investigate the possibility of differentiating between locations within an urbanized watershed using values of alkalinity, hardness, and conductivity. I will assess the ability of the individual parameters to demonstrate differences in water quality using a smaller number of samples taken from multiple sites. I will also explore possible linkages between the tested constituents and land surface characteristics.

Study Site

Third Creek, the second largest drainage basin in the Knoxville urban area, is a mixed-use watershed encompassing land uses from forest to industrial/manufacturing. Currently the creek is classified as non-supporting along much of its length, for many of its designated uses, which include fish and aquatic life, recreation, irrigation and livestock watering, and wildlife (Borders and Wang, 1998). Third Creek drains an area of 48.17 km^2 and is a geologically tight catchment confining most of the surface and groundwater to the basin. The catchment is characterized by moderate slopes (<12%) although slopes of greater than 25% are found along ridges within the watershed (Kung , 1980). Except in areas with high elevation or steep slope, soil depth is greater than 1.83 meters (6') with infiltration rates of greater than 15.24 mm (0.6") per hour. These permeable soils that are underlain by relatively impermeable geologic formations are a factor in the large groundwater contribution Third Creek receives.

Methodology

I collected data for this study from seven sites within the Third Creek watershed. The main objective of site selection was to characterize water quality across a variety of watershed conditions. Monitoring was done at five locations along the main stem of Third Creek, and two sites on the East Fork; Third Creek's only major tributary. These sites extend from the upper reaches of the creek to near its mouth and follow the stream through a range of land use and landscape conditions. I sampled each site four times during the period from 12/10/02 to 12/19/02, taking a total of 28 grab samples and in situ measurements that resulted in 84 observations. Daily samples and measurements at each site were taken within two-hours of each other during base flow conditions after at least a 72-hour antecedent dry period. I used a 330i Cond (WTW) conductivity meter to measure specific conductance through in stream measurements and performed the chemical analysis for alkalinity and hardness in the lab using the direct titration method. During data analysis I included an additional 27 samples[2] that I had collected from four of the test sites during previous research.

To describe the land use and landscape characteristics of the watershed I used both ArcView and ArcInfo software. I downloaded the 1992 National Land Cover Dataset (NLCD) and Digital Elevation Models (DEM) from the USGS seamless distribution website. KGIS provided me with a land use dataset based

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[2] In the case of these samples, from the Webb, Lonas, Sullivan, and Painter sites, specific conductance was not measured in stream but in the lab.

on zoning classifications from KGIS. I scanned and geo-referenced maps of soil permeability and depth produced by Kung for visual analysis through overlays with GIS (Kung, 1980). Using ArcInfo Hydrologic tools I divided Third Creek into 76 sub-watersheds. Then using the NLCD, I estimated the percent of impervious cover for each of these sub-watersheds with the Analytical Tools Interface for Landscape Assessments (ATtILA) extension in ArcView. This analysis showed that only three of the sub-watersheds have an estimated percent impervious cover of less than 10% a common threshold value for determining stream impairment (Paul and Meyer, 2001). Thirty-five of the sub-watersheds have estimated impervious cover of greater than 30%, the great majority of these sub-watersheds are found in the lower half of the catchment (See Fig. 1). In general a trend towards increased total impervious area (TIA) can be seen moving from the headwaters to the mouth of the creek.

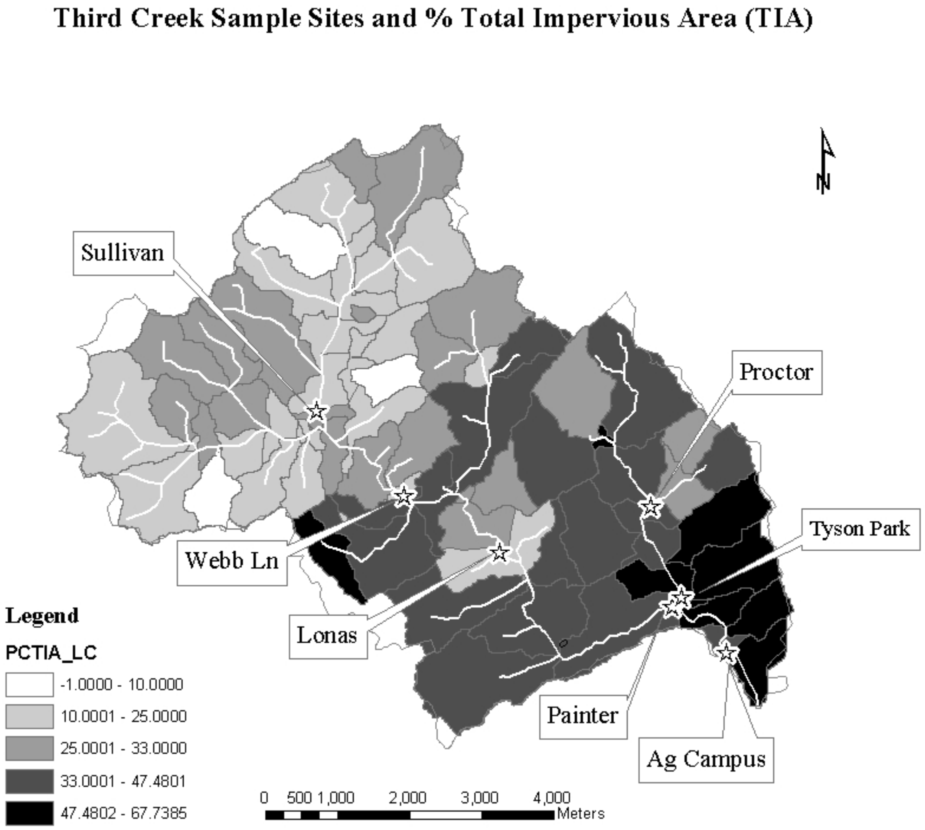

Figure 1

Results

I graphically and statistically analyzed the chemical data to determine any spatial differences within the observations. Boxplots of the individual parameters grouped by site location showed a clear separation between the two East Fork sites and the five main stem sites. This difference is most pronounced when observing conductivity readings. Hardness observations from the Proctor site (upper East Fork) do not deviate as significantly from the other sites as the alkalinity and conductivity measurements. Mean values for samples from the East Fork sites are higher than those sites along the main stem, in most cases significantly so. A scatterplot of conductivity and the ratio of alkalinity to hardness (A:H) also shows distinct groupings for the Tyson and Proctor sites and some grouping for the other sites. A scatterplot of the 28 samples taken between 12/10/02 and 12/19/02 shows fairly distinct groupings for all sites though Tyson and Proctor are more clearly separated than the rest (See Fig. 2).

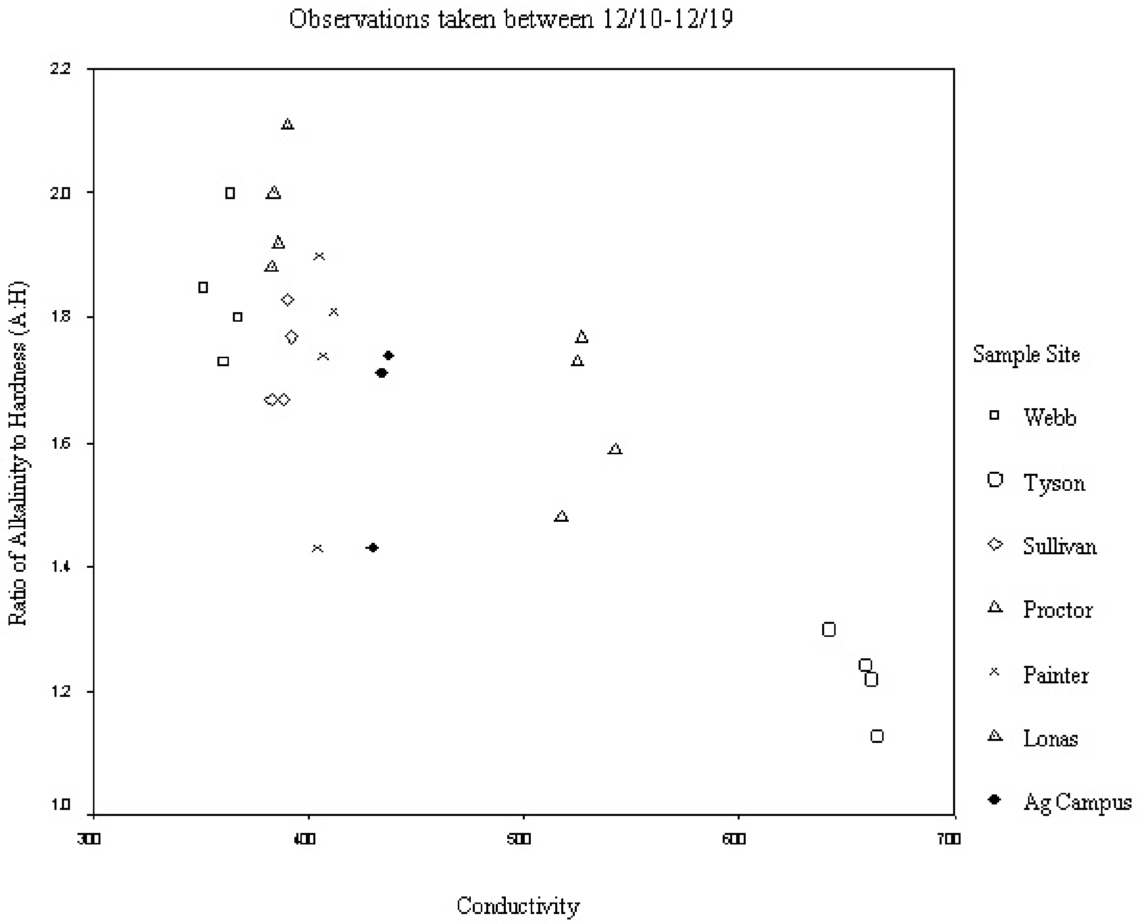

Figure 2

Hierarchical Cluster Analysis (HCA) of both non-standardized and standardized (z-scores) data reinforces the graphical separations observed in the boxplots and scatterplots. A dendrogram of the non-standardized data broke the observations into six first order clusters with a distinct cluster for Proctor and Tyson respectively. Observations from the three upper main stem sites - Webb, Sullivan, and Lonas - comprise one large first order cluster and observations from the lower main branch sites - Ag Campus and Painter - make up the majority of the other large first order cluster. Two other small first order clusters were formed with three and four observations from varied main stem site locations. A dendrogram of the standardized data provides similar clustering and once again shows distinct groupings for the Tyson and Proctor sites. K-Means cluster analysis with seven clusters provides similar results as the HCA.

Discussion and Conclusions

The chemical effects of urbanization are highly variable and depend on factors such as the type of land use, presence of water treatment facilities (such as the one in Third Creek), combined sewer overflows, and stormwater drainage networks. Urbanization consistently results in increased conductivity and generally results in elevated levels of calcium, sodium, potassium, and magnesium, which are among the constituents measured by hardness and alkalinity (Paul and Meyer, 2001). Due to the limited number of samples available for analysis, concrete assertions about the ability of the CPI to characterize water quality in an urban watershed would be premature. However, the data do suggest the possibility that parameters used to compute the CPI differ between sites within the catchment. The clear distinction between the sites located on the East Fork tributary and the main branch may indicate the ability of the CPI's chemical parameters to distinguish between regions with different intensities of urbanization.

Headwaters for the East Fork lie entirely within sub-watersheds of over 25% TIA, and at no time does this tributary flow through any area with a TIA of less than 25%. In fact, along most of its length the East Fork flows through regions of greater than 33% TIA. By contrast, the upper half of the watershed through which the main stem flows has no sub-watersheds over 33% TIA and more than half the region is comprised of sub-watersheds with less than 25% TIA. Not only does the area drained by the East Fork have a higher TIA, it has a larger percentage of its total land area zoned as industrial or commercial than the upper region of the watershed. Comparing the chemical data from the Sullivan, Webb, and Lonas sites in the upper part of the watershed to the Proctor and Tyson sites on the East Fork shows in all cases that mean values for the East Fork sites are significantly higher. Geology and soil characteristics of the Third Creek watershed are similar throughout the basin, though the East Fork does drain an area of less permeable soil. These results seem to support the possibility that increased ion levels in surface waters may be the result of increased urbanization.

Separation of the sites along the main branch of Third Creek is not as clear as the separation between sites along the main stem and its tributary. However, there is some evidence that with a higher sample count a statistical distinction could be made, at least between sites from the upper and lower portions of the watershed. Two large clusters immediately emerge in the HCA. These clusters tend to be composed of sites from either the upper or lower portions of the catchment. Interestingly, the cases for the Lonas site, which is situated between the upper and lower sites, are divided evenly between both clusters. In addition, a scatterplot of just the 28 samples taken from 12/10/02 to 12/19/02 indicates clustering by sample site. Scatterplots of all the data indicate two samples that are definitely statistical outliers and clearly deviate from normal observed conditions. Such outliers may be a 'red-flag' indicating an influx of waste water. The small number of samples used in the statistical analysis make it difficult to tell if these observed values represent actual conditions. However, I am encouraged by the results of this study and plan to expand this research in number of sample sites, watersheds, and observations per site in an effort to more rigorously test the usefulness of the CPI in urban water quality monitoring.

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GETTING TO THE SOURCE
Microbial Source Tracking in an Urban Stream

Tom Lawrence[1]

The City of Memphis worked with Dr. Mansour Samadpour to conduct Microbial Source Tracking using the two-enzyme ribotyping method in the South Cypress Creek watershed (Segment ID TN08010211007_1000) in Memphis, TN. The project was composed of several phases, including the following:

> Collecting 130 water samples for analysis (10 samples approximately 3-5 minutes apart during each of 13 site visits at one site to be located near the downstream end of the watershed).
>
> Analyzing the samples for Fecal Coliform by a local testing laboratory.
>
> Shipping the Fecal Coliform plates to Dr. Samadpour's laboratory in Seattle, WA overnight.
>
> Analyzing the Fecal Coliform plates by Dr. Samadpour using the two-enzyme ribotyping method.
>
> Collecting fecal source samples from in and around the South Cypress Creek watershed for development of the library for the watershed.
>
> Shipping the fecal source samples to Dr. Samadpour's laboratory in Seattle, WA overnight.
>
> Analyzing the fecal source samples by Dr. Samadpour. He added the results determined locally to his existing extensive library, in order to better identify possible sources of Fecal Coliform found in the Creek.
>
> Preparing the Final Report.

Past Fecal Coliform samples collected from this creek have provided results ranging from <10 to the 10s of thousands, often from samples that were collected at the same site a few days apart or from tributaries with no identifiable source of bacteria contamination. As a result of this project, we expect to be able to use the information to be able to identify possible sources of the bacteria results found and thus, to address these sources.

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SOURCE WATER PROTECTION

Larry Lewis

A recent survey found that over 1/2 of people surveyed did not think our water systems and/or water supplies are safe. In 1974 Congress passed the Safe Drinking Water Act that established regulations for Public Water Systems and also developed standards to help water systems provide safe and reliable drinking water to their customers. In 1996 the Source Water Protection Program was authorized by the Amendments to the Safe Drinking Water Act.

What is Source Water?

Source water is defined as the streams, lakes, rivers and aquifers that are used as drinking water sources for water systems in the State of Tennessee. There are two types of source water used by water systems in Tennessee. There are approximately 250 community water systems that use groundwater as their source for potable water. Approximately 150 community water systems in Tennessee use surface water to supply water to their water plants. Both groundwater and surface water have characteristics that require different treatment techniques.

Most of the water systems in West Tennessee use true groundwater as their water source. The water quality of true groundwater is very consistent. Most Non-Community systems use groundwater taken from shallow wells that require very little treatment processes. Community water systems use groundwater that is typically found in a deeper aquifer than is used by Non-Community systems and this water usually requires more treatment.

Most of the water systems in East Tennessee use surface water to supply water to their water plants. Water systems in Middle Tennessee are typically supplied by surface water or groundwater under the direct influence of surface water. Surface water or water that is influenced by surface water is usually more difficult to treat than groundwater and the cost of treating the water is greater.

Wellhead Protection

For water systems using groundwater as their water source, each system was required to develop a Wellhead Protection Plan. Water systems were required to locate each of their wells on a map and then to delineate the area that would supply their source water for the next ten years. Once this area of delineation was established, systems were required to develop a Potential Contaminant Source Inventory. By evaluating the possible sources of contamination water systems could compile a written plan that would help them establish a contingency plan for handling an emergency situation.

Source Water Protection

The goal of the source water protection program is to achieve protection of the streams, lakes, rivers and aquifers that are used as drinking water sources for water systems in the State of

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Tennessee. States were required to conduct assessments of the sources used by water systems that provide potable water to their customers. Tennessee contracted with TAUD to work with water systems to determine their assessment area and the inventory of the potential sources of contamination. This assessment located both the groundwater sources and the surface water intakes in the watershed. Interviews were conducted to help determine if there were potential sources for contamination of the water supply and the location of these sites in relation to the raw water source of the water system. Once the water system had developed the potential contaminant source inventory, the protective area was established and a map of the protection area was used to determine the protective measures that would be needed by the water system. Two zones were established for use in the Source Water Protection Program. The criteria for the Critical Source Water Protection Zone was 5 miles upstream from the intake and along tributaries, 1000 feet on either side of the stream and ½ mile downstream from the intake on lakes in case backflow conditions occurred. The criteria for the Source Water Management Zone established a Zone A as well as a Zone B. Zone A consists of 5-15 miles upstream from the intake and Zone B consists of 15-30 miles upstream from the intake. Once the assessment was completed, the map prepared by the SWAP contract was used by the State of Tennessee to determine the susceptibility of the water system to the contamination sources within the protection area. This is called the Susceptibility Analysis and is defined as the potential to draw contaminated water into the drinking water supply. The State of Tennessee designated criteria for the determination of the susceptibility analysis and submitted these criteria to EPA for their approval. Systems were classified as being highly susceptible to contamination, moderately susceptible or have a low susceptibility to contamination.

Steps for Source Water Protection

In October 2002 EPA authorized TAUD to establish a Source Water Protection Program in Tennessee. The program targets systems that are classified as either highly or moderately susceptible to contamination. A meeting was held using stakeholders that would benefit from this program and the criteria for source water protection was established. The source water assessments were used to develop the protection area within the watershed. Public meetings are being held to involve the various entities that have the authority to take preventative within the protection area. Each entity's area of authority was defined and the purpose of the meetings is to determine the preventative measures that may be initiated by each entity to help the water systems establish a contingency plan in case of a man-made or natural disaster that would affect the water system's source of water. Each protection area is asked to establish a steering committee to review, update and follow through on the plan that was developed.

ANALYSIS OF TENNESSEE PUBLIC WATER SYSTEMS' SUSCEPTIBILITY TO CONTAMINATION

Tom Moss[1]

Source water protection has a simple objective: to prevent the pollution of the lakes, rivers, streams, and ground water (wells and springs) that serve as sources of drinking water. This objective requires locating and addressing potential sources of contamination to these water supplies. There is a growing recognition that effective drinking water system management includes addressing the quality and protection of the water sources.

Tennessee is blessed with an abundance of high quality ground water and surface water. Prevention of contamination is a critical element in the protection of these waters if Tennesseans are to continue to benefit from these high quality waters. There are certain natural and man-made factors which make certain water sources more susceptible to contamination. All water sources should be considered to have some susceptibility to contamination since no water source is completely immune. There are specific geologic and hydrologic settings that make the water source more vulnerable due to natural conditions. There are also certain man-made processes and activities that put the water sources more susceptible to contamination due to the proximity of these potential contaminant sources.

Source water protection is not a new concept, but an expansion of existing wellhead protection measures for public water systems relying on ground water to now include surface water. This approach became a national priority, backed by federal funding, when the Safe Drinking Water Act amendments (SDWA) of 1996 were enacted. Under this Act, every public drinking water system in the country is scheduled to receive an assessment of both the sources of potential contamination to its water source of the threat these sources may pose by the year 2003 (extensions are available until 2004).

Determining the relative potential risk of contamination for each water system intake and well or spring allows EPA and the states to prioritize resources in the protection of water sources and also gives the water system information to better manage the water supply. Tennessee has developed a susceptibility analysis based on a series of yes/no potential contamination factors to keep the susceptibility evaluation as objective as possible. These factors are then incorporated into a pie chart, with each factor as a separate "slice." The size of the slice has been assigned a percentage according to concern (e.g., contamination detected at an intake is a high concern and a larger slice) and will not change from evaluation to evaluation. The key to Tennessee's Susceptibility Analysis Method is whether the slice is a yes (shaded dark) or no (unshaded).

Intakes, wells/wellfields or springs that have more slices filled in on their susceptibility diagrams are considered more susceptible to contamination. Diagrams with more than

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40% filled in are considered highly susceptible, 20 – 40% are moderately susceptible and <20% are a low susceptibility. There are separate sets of factors for surface water and ground water. Susceptibility diagrams for surface water intakes and ground water withdrawal points are given below.

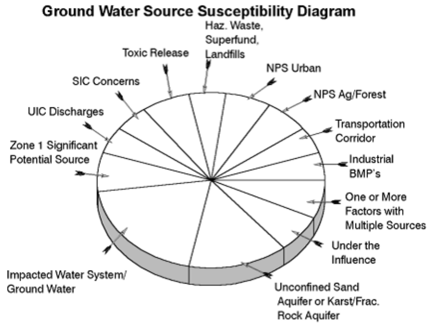

Figure 1

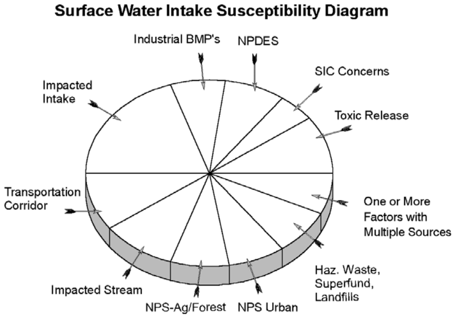

Figure 2

The key areas for scoring for surface water intakes are:

- Impacted intake or stream: 30%
- Potential Contamination from Industrial/Commercial Activities: 20%
- Potential NonPoint Source Issues: 15%
- Reported Industrial Release: 10%
- Transportation Corridor: 10%
- Permitted Discharges: 8%
- Multiple category: 7%

Key areas for scoring ground water sources are:

- Geologic factors: 21%
- Ground Water Contamination: 20%
- Potential Contamination from Industrial/Commercial Activities: 13%
- Potential NonPoint Source Issues: 13%

Reported Industrial Release: 7%
Permitted Underground Discharges: 5%
Transportation Corridor: 5%
Multiple category sources, significant source adjacent to well or spring: 14%

The individual source water assessments with susceptibility analyses are available to the public at www.state.tn.us/environment/dws as well as other information regarding the Source Water Assessment Program and public water systems.

To date, over half of the susceptibility analyses for the water supply withdrawal points in Tennessee have been finalized. Approximately 45% of these scored as high susceptibility, 37% moderate and 18% low. There is some difference in the percentages for the moderate and low susceptibilities when you look at ground water versus surface water sources, but the highs are nearly identical. The higher level of moderate susceptibilities for ground water systems (39% versus 32%) is probably a function of the geologic factors that are used for ground water systems and are not used for surface water systems.

The susceptibility analyses required for the Source Water Assessment Program have significant implications. This determination of susceptibility to contamination from significant potential contamination sources will be a driving force for future management, funding and prioritization of resources in the protection of public water supplies.

ASSESSING THE SUSCEPTIBILITY OF THE WATER TABLE TO CONTAMINATION IN TIPTON COUNTY, TENNESSEE

Merrie Embry[1], Randall Gentry, Ph.D.[2], Daniel Larsen, Ph.D.[3], Jerry Anderson, Ph.D.[4]

Introduction

The assessment of ground water quality in rural areas is often overshadowed due to the necessity of ground water quality control in surrounding urban areas. Land use and the application of herbicides and pesticides have the potential to significantly impact ground water resources in rural or agrarian areas. Unlike some public water supply (PWS) systems that derive their drinking water from ground water, rural domestic wells (RDWs) are not governed by federal regulations and, therefore, are not required to have wellhead protection plans. Approximately ten percent of the residents in Tipton County, Tennessee, rely on rural domestic well water, but delineating wellhead protection zones for every domestic well screened in the water table would require a vast amount of resources unavailable to a rural county. Research at The University of Memphis is being conducted to evaluate the use of the DRASTIC (Aller, et al., 1987) technique for assessing the risk to shallow ground water resources. The technique incorporates hydrogeologic and anthropogenic data in the development of a generalized vulnerability map that will provide a method for determining areas in which RDWs are most in need of protection, without delineating wellhead protection zones for every domestic well. Overlaying features contributing to the susceptibility of the PWS systems, as defined by the Tennessee Department of Environment and Conservation (TDEC), with the vulnerability maps generated for the RDWs in the same area will provide a qualitative assessment of the susceptibility of the RDWs to contamination.

Background

Tipton County is located in the southwestern region of the State (See Figure 1), immediately north of Shelby County, which contains Memphis, Tennessee. According to the South Tipton County Chamber of Commerce (STCCC), Tipton County is the fastest growing county in West Tennessee, and the fifth fastest growing county in the entire State (STCCC, 2002; Bridges, 2003). There are seven PWS systems in Tipton County; however, only five of the seven PWS systems operate their own wells, while the remaining two systems purchase water from one or more of the five self-supporting systems (EPA, 2002a). All of the five PWS systems are considered to have a high degree of susceptibility based upon the factors established for assessment of all PWS systems in the State of Tennessee by the TDEC (TDEC, 1999). Although Tipton County is rapidly growing, the County is home to only 51,271 residents as of 2002 (U.S. Census Bureau, 2002). While most of the citizens obtain drinking water through public utilities, approximately ten percent rely on RDWs as their sole source of potable water (U.S. Census Bureau, 2002; EPA, 2002a). Because the population of Tipton County is rapidly growing, and due to the known susceptibility of the PWS wells that are screened in deeper, semi-confined areas within the Mississippi Embayment aquifer system, an awareness of areas within the water table that are susceptible to contamination may be beneficial for the residents who rely on the RDWs. Also, contamination of the water table in Tipton County may prove to have broader implications for the deeper aquifer units that have not yet been studied in as detailed a manner as the confined aquifer system in the urban Shelby County area.

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The concern of residents within the Beaver Creek watershed, predominately located in Tipton County, in part prompted the United States Geological Survey (USGS), along with the Tennessee Department of Agriculture and the University of Tennessee Agricultural Extension Service, to study water quality within the watershed. The residents in the agrarian areas of the Beaver Creek watershed feared that agricultural activities might adversely affect the quality of their RDW water (Fielder, Roman-Mas, and Bennett, 1994). One hundred and thirty RDWs were sampled in Tipton County during the Beaver Creek watershed study, and, of those wells, four samples (3%) (Fielder, Roman-Mas, and Bennett, 1994) had levels of nitrate (measured as total nitrate) that exceeded the Environmental Protection Agency (EPA) mandated level for nitrate concentrations (measured as nitrate-nitrogen) in public drinking water systems of 10 milligrams per liter (mg/l) (EPA, 2002b). Analyses were conducted to associate elevated levels of nitrate (in excess of 3 mg/l as nitrate-nitrogen) with a statistically significant source of contamination (Williams, 1994). The results of statistical tests performed on sampling data (wells less than 45 meters deep) did indicate a higher average nitrate concentration associated with wells located in the vicinity of septic tanks and/or confined animal pens relative to wells located only by croplands (Williams and Roman-Mas, 1995). It was noted that conditions within the vicinity of the well appeared to be the determining factors for the detection of elevated concentrations of nitrate within the RDW water (Williams, 1994).

Vulnerability Mapping

Because delineating wellhead protection zones for every RDW in Tipton County was not feasible, general vulnerability maps illustrating areas of the county, which have a greater relative sensitivity to potential contamination, were developed using various data sources contained within a Geographic Information System (GIS) database. The DRASTIC scheme, developed by the EPA in 1987 (Aller, et al., 1987), was used to generate a vulnerability map for the water table in Tipton County based strictly on the hydrogeologic characteristics of the aquifer region in question. The authors of the DRASTIC scheme intended the method to provide an assessment of the potential for ground water pollution to occur in any area of the United States, as long as the area subject to the vulnerability assessment was at least 100 acres (Aller, et al., 1987). DRASTIC stands for the following hydrogeologic parameters:

- Depth to ground water (D)
- Net recharge (R)
- Aquifer media (A)
- Soil media (S)
- Topography (T)
- Impact of the vadose zone media (I)
- Hydraulic conductivity of the aquifer (C) (Aller, et al., 1987).

The authors of the DRASTIC scheme assigned each parameter an importance weight from one to five based upon the likelihood of a particular parameter facilitating the entrance of a contaminant into the aquifer system (See Table 1). A weight of five denoted the parameter(s) most capable of accepting pollutants into the system (Canter, 1997). Within each DRASTIC parameter, a range of values was listed for a particular hydrogeologic setting and assigned a numerical rating from one to ten, with ten being the parameter(s) most likely to allow contaminants into the system (Aller, et al., 1987). Once the appropriate rating is chosen from the ranges listed for each DRASTIC parameter, the potential for aquifer contamination is determined by incorporating the ratings and parameter weights into the following equation (Aller, et al., 1987):

$$D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W = \text{Pollution Potential}$$

Where: R = rating, W = weight

When the DRASTIC vulnerability map was generated for the water table in Tipton County, the parameters of "Net recharge (R)" and "Hydraulic Conductivity (C)" were not incorporated into the final map due to a lack of available data.

Although the DRASTIC scheme is one of the most widely used vulnerability mapping tools in the United States, vulnerability maps developed through the DRASTIC scheme have often not correlated closely to real-world contamination data (Merchant, 1994). For this reason, numerous modifications have been developed in an effort to produce a map that has a stronger correlation between predicted areas of vulnerability and proven areas of contamination. Anthropogenic factors such as septic density, land use (Evans and Myers, 1990), and soil drainage (Rupert, 1999) have been suggested as potential modifications to the DRASTIC scoring system. However, incorporating the anthropogenic factors into a vulnerability-mapping scheme requires a strictly additive assessment of each parameter rating, without the weight associated with each parameter, which was developed specifically for the DRASTIC numerical scheme. For the Tipton County water table vulnerability assessment, both a DRASTIC map and a modified DRASTIC map were created using data maintained in a GIS database in an effort to determine which map produced a more realistic illustration of likely areas of vulnerability. A lack of available sampling data prevented verification of either map through actual contamination data. The interaction between the streams and water table in Tipton County was clearly illustrated in the DRASTIC vulnerability map, while the stream-water table interaction was less defined within the modified DRASTIC map. In addition, the modified DRASTIC vulnerability map was skewed towards the highest pollution potential score while the DRASTIC vulnerability map had a more even distribution of pollution potential (See Figure 2). Therefore, the DRASTIC vulnerability map was chosen for use in the susceptibility analysis of the water table.

Susceptibility Analysis

The definition for susceptibility as applicable to raw water sources in the State of Tennessee is "*the potential for contamination of a public water system's raw water source at levels above drinking water standards or other health-based concerns; based on the likelihood and character of releases from potential contaminant sources and human activities within areas hydrogically upgradient of the raw water source*" (TDEC, 1999). Tennessee's Source Water Susceptibility Analysis for PWS systems using ground water lists the following factors as potential sources of contamination:

- Facilities who have released toxic chemicals to land or water
- Facilities with hazardous waste, superfund, or landfill permits
- Facilities with priority standard industrial classification (SIC) codes
- Non-point source areas of agricultural and urban activities
- Facilities with underground injection control (UIC) discharges such as septic tanks
- Transportation corridors
- Facilities with poor waste management practices
- Impacted water systems (i.e. contaminants above MCL such as nitrate and coliform) (TDEC, 1999).

Using the chosen vulnerability map, areas of varying vulnerability were identified and a qualitative susceptibility analysis was performed for each area of vulnerability. Data obtained from the Beaver Creek watershed study was used to define an "impacted system" (Fielder, Roman-Mas, and Bennett, 1994; Williams, 1996). Completing a susceptibility analysis for the water table in Tipton County provided an illustration of those areas of the County, which were predicted to have a high vulnerability to contamination, yet also had a number of factors that would lead to a high susceptibility score. Therefore, according to the vulnerability maps and susceptibility analysis, areas with a high score in both circumstances may have the potential for significant contamination to occur within those areas of the water table, suggesting that such areas should be monitored more closely than areas of predicted low vulnerability. However, no prediction map should be deemed wholly accurate until real-world data is available to ascertain the validity of the map.

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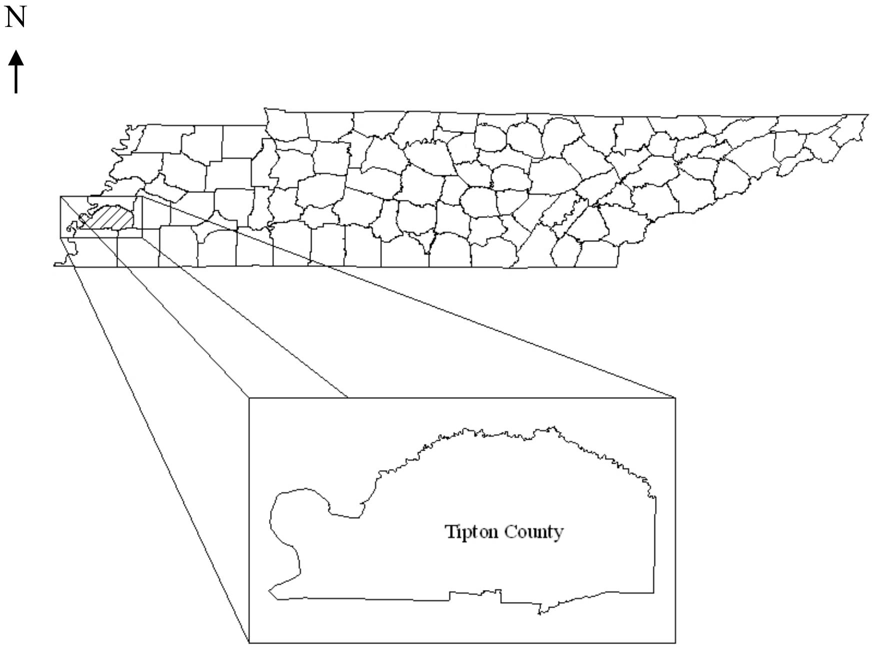

Figure 1. Location of Tipton County, Tennessee

Table 1. Assigned DRASTIC Parameter Weights

Parameter	Relative Importance Weight
Depth to groundwater (D)	5
Net recharge (R)	4
Aquifer media (A)	3
Soil media (S)	2
Topography (T)	1
Impact of the vadose zone (I)	5
Hydraulic conductivity of the aquifer (C)	3

*Source: Aller, et al., 1987

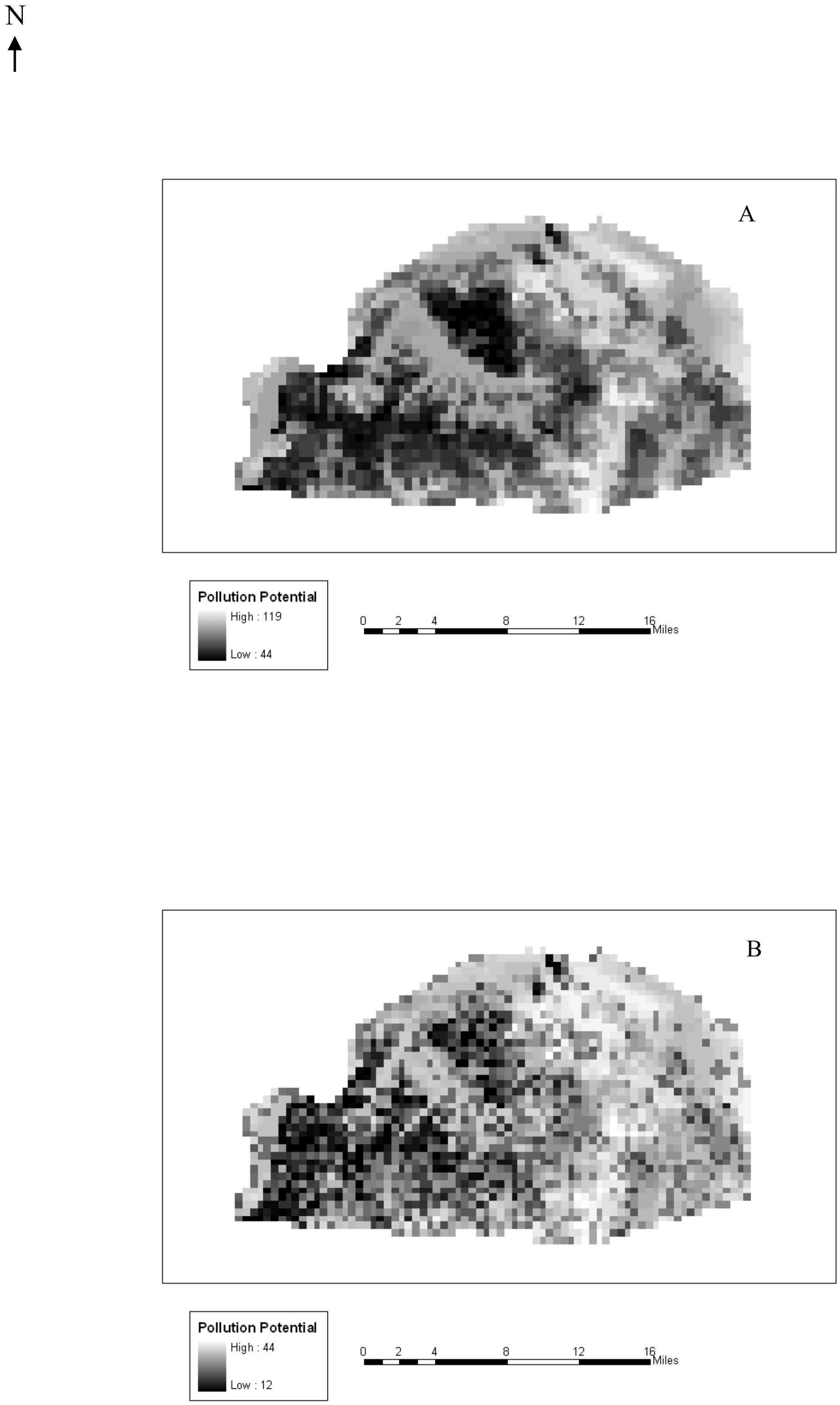

Figure 2. DRASTIC Vulnerability Map (A) and Modified DRASTIC Vulnerability Map (B)

USE OF RADAR-RAINFALL DATA FOR HYDROLOGIC MODELING IN MIDDLE TENNESSEE

Emad Habib [1], Vincent Neary [2], Matt Fleming [3], James B. DeLony [4]

Recent advances in the area of radar hydrology have generated increased interest in the use of radar-rainfall data for hydrological applications. In contrast with traditional rain gauges, radars provide detailed real-time rainfall observations with relatively high spatial and temporal resolutions. The current study examines the use of radar-rainfall information for hydrological modeling in the area of Middle Tennessee. Rainfall-runoff simulations are performed using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). The study catchment is the Dale Hollow Reservoir drainage located within the Cumberland River Basin. This study makes use of an extensive dataset of radar data in the period of 1997-2001 developed by the National Weather Service Ohio River Forecast Center. Given the recognized uncertainty of radar rainfall information, the study performs careful evaluation of the radar data using rain gauges located inside the catchment. Rigorous statistical analysis is performed to assess the accuracy of the mean areal radar-rainfall data before being used as input to the hydrologic model. Simulations based on radar data are evaluated in comparison with the use of traditional rain gauges. The results of the current study will help to assess the potential benefits of using the radar-rainfall products that are becoming increasingly available for the hydrologic community.

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DOWNSCALING PARAMETERS FROM A LARGE WATERSHED TO ITS SUBWATERSHEDS: MODELING THE HYDROLOGY OF EMORY RIVER, CROOKED FORK, AND DADDY'S CREEK USING THE LOADING SIMULATION PROGRAM C++

Ben Arthur[1]

Introduction

Studies show that it is frequently valid to transfer hydrological model parameters developed at one spatial scale to models at other scales. Upscaling moves from a small scale to a larger scale, while downscaling moves from a large scale to a smaller scale. Wood et al. (1988) and later studies showed that model parameters representing the average topography, soils, and precipitation for a small (often less than 2 km^2) representative subcatchment can adequately represent these characteristics for a larger catchment. On a much larger scale, parameters from large watersheds have been upscaled to continental scales (Nijssen et al., 2001; Arnell, 1999).

Hydrological models can downscale characteristics of large watersheds to predict the hydrology of subwatersheds. One downscaling method is using distributed models. These models subdivide a watershed into its constituent parts and use unique parameter values in the subwatersheds. Distributed models allow analysts to easily transfer parameters from the scale of the watershed to its large subwatersheds when appropriate subwatershed parameters are unknown, but the validity of this transfer is not well documented. The demonstrated success of upscaling, however, suggests that the approach holds promise. In this paper I discuss a watershed calibration in a distributed model and how its quality may influence the success of the downscaling process. The downscaling is a work-in-progress.

My study assesses the transfer of parameters from the 2,250 km^2 Emory River watershed in East Tennessee to Daddy's Creek and Crooked Fork, two of its subwatersheds.[2] The first step in this process is to achieve an acceptable calibration of the Emory watershed. The calibration is simplified by the fact that many macroscopic model parameters are based on a fairly complete set of measurable input data (weather), land use, and topography. It is important to recognize, however, that these data do not characterize the watershed completely. Indeed, most of the state variables that define the hydrodynamics are unmeasurable because they describe subsurface processes. These variables include upper and lower zone storage, interflow storage, and active groundwater capacity. Effectively, they are "measured" indirectly using a semi-empirical model to link the response of stream flow to precipitation events over time. Because of the number of variables involved, a substantial data history is required. The subwatersheds do not have a substantial history, but may be able to use the "measurements" from the larger watershed.

Procedures and Results

I used the Loading Simulation Program C++ (LSPC) to create a model of the Emory River watershed. LSPC replicates the algorithms of the popular Hydrological Simulation Program FORTRAN (HSPF), and it is gaining favor as a TMDL modeling tool. LSPC predicts stream

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[2] Crooked Fork is impaired by siltation and is on Tennessee's 303(d) list. The total maximum daily load (TMDL) section of the Clean Water Act requires states to prepare this list of their impaired waterways. Listed streams require models that predict the effects of alternative remediation strategies. Transferring hydrological parameters from the larger Emory watershed to Crooked Fork would simplify the creation of a Crooked Fork model.

discharge using watershed characteristics including weather, land use, soils, and topography. The model predicted mean daily discharge at the United States Geological Survey (USGS) gage on the Emory River near Oakdale, which is near the river's outlet. I used 1980 to estimate subsurface initial conditions, and then calibrated for the years 1981-1995. I verified the model in the years 1996-1998. In the calibration I adjusted parameters that are not spatially explicit, including the soil infiltration index, evapotranspiration rate, subsurface hydrology, and groundwater behavior. The final calibration was generally favorable on a seasonal basis and generally met TMDL modeling standards. It was frequently unable to predict the effects of storm events, however, and it performed poorly on several quality tests – Nash-Sutcliffe R^2, autocorrelation of stream flow residuals, and the stability of the parameter set over multiple years. Figure 1 shows the modeled and measured Oakdale discharge in 1991, a fairly representative year.

I applied the calibrated parameters from this model to Daddy's Creek, the subwatershed physically most like the overall watershed. The Daddy's Creek model predicted mean daily discharge at the USGS gage near Hebbertsburg. Model performance was unacceptable by TMDL standards as well as the other model quality tests. At issue is the reason for the deficiency and how it may be corrected. At this point in the research, I do not know if the deficiency is best addressed by better articulating the input data for the subwatershed or improving the quality of the Emory watershed calibration. Of course, it is also possible that it is invalid to downscale Emory's parameters to Daddy's Creek. My goal is to replicate the Emory model in a software environment that enables me to perform reality checks on the hidden state variables that cannot be inspected in LSPC. I will use these checks to improve my calibration, and then apply these parameters to a new model of Daddy's Creek and to Crooked Fork.

Quality of the Emory Watershed Model Calibration

The LSPC model (currently only a beta version is available) is based on HSPF, a model with a good track record over 20 years. Typically, when the models are applied, few watershed-specific measurements are used besides weather, land use, and topography. Input parameters such as infiltration indices, ground storage capacities, and other physical processes are indirectly "measured" by stream response to precipitation events. The representativeness of the weather data is always uncertain and the stream flow measurements are of variable quality depending on the instrumentation, flow rates and temporal averaging. Taken together, these challenges mean that a substantial data history is required for the "indirect measurements" of the complex interactions to yield reliable parameters.

The Emory River has such a substantial data history. I calibrated the model using fifteen years of hourly weather and daily stream discharge measurements. Nevertheless, there are signs that the calibration is not as good as a one-year snapshot of daily flows or a summary of seasonal performance would indicate. Jacomino and Fields (1997) reported that good multi-year calibrations sometimes require periodically resetting parameters. Moreover, a model that represents phenomena on an hourly time scale should be able to represent stream flow at the daily level. Mine did not, and other modelers have had similar experiences. My hypothesis is that I have failed to identify the best set of parameters. If I can reproduce the Emory model in another software environment, I will be able to inspect modeled subsurface storages unreported by LSPC. This would limit the feasible parameter sets and enable a better calibration.

Heterogeneity of Hydrological Characteristics

My difficulty in calibrating the Emory model may be due to heterogeneity of hydrological characteristics inside the watershed. The Emory watershed spans five level IV ecoregions. Daddy's Creek and most of the rest of the Emory watershed lie in the Cumberland Plateau ecoregion, but much of Crooked Fork lies in the Cumberland Mountains ecoregion. The variability in soils and topology throughout the Emory watershed affect its hydrology. Calibrated parameters that homogenize hydrological characteristics of the entire Emory watershed may not represent hydrological conditions very accurately *anywhere*. This would complicate downscaling these parameters to the subwatersheds.

The most significant cause of heterogeneity in the Emory watershed is precipitation variability. Precipitation drives hydrological predictions in LSPC, so a valid calibration requires precipitation data to be representative of conditions throughout the watershed. This representativeness can be difficult to establish even in highly instrumented watersheds. EPA's example TMDL excuses a large discrepancy between modeled and measured discharge by speculating that a large recorded storm covered only a small area around the rain gauge (USEPA, 2000). Such differences do not compromise the TMDL analysis if the calibration period is long enough to demonstrate that occasional deviations are outliers in a statistical sense.

There is only one National Oceanic and Atmospheric Administration weather station inside the Emory watershed, but there are several additional stations that ring the watershed. My calibration used precipitation data from the Monterey station, which is about 45 km to the northwest of the watershed center. LSPC requires hourly data, and Monterey is closest station to the watershed that provides these.

Precipitation data from all of the weather stations are generally similar on an annual scale, but deviations are more significant at shorter time scales. This suggests that my difficulties in calibrating individual storm events arise because the Monterey data cannot perfectly represent conditions for the watershed as a whole. Even on an annual scale there can be significant variation in rainfall throughout the watershed. Although the Crossville Airport is only about 7 km from the Experimentation Station, the stations sometimes show significant annual differences. Additionally, stations on the Cumberland Plateau consistently get about 20% more rain than stations at lower elevations.

There is even greater variability on shorter time scales. Precipitation correlation coefficients between pairs of weather stations from 1980-1998 are typically much less than 0.5 on a daily basis. A linear model relating precipitation at the Crossville Airport to that at the Crossville Experimentation Station explains only about 13% of the variance. Figure 2 shows a fairly representative annual history (1998) for these stations. In a typical year, a few major storm events will appear at one location but not the other. Correlation coefficients between weather stations near the watershed for hourly rain data are near zero. This is significant because hourly data drive LSPC hydrological predictions. Shifting precipitation measurements by several hours to account for the movement of weather fronts improves correlations somewhat, but such shifts still do not explain much variation. Model calibration both at the watershed and subwatershed level cannot count on representative precipitation data at daily and hourly time scales.

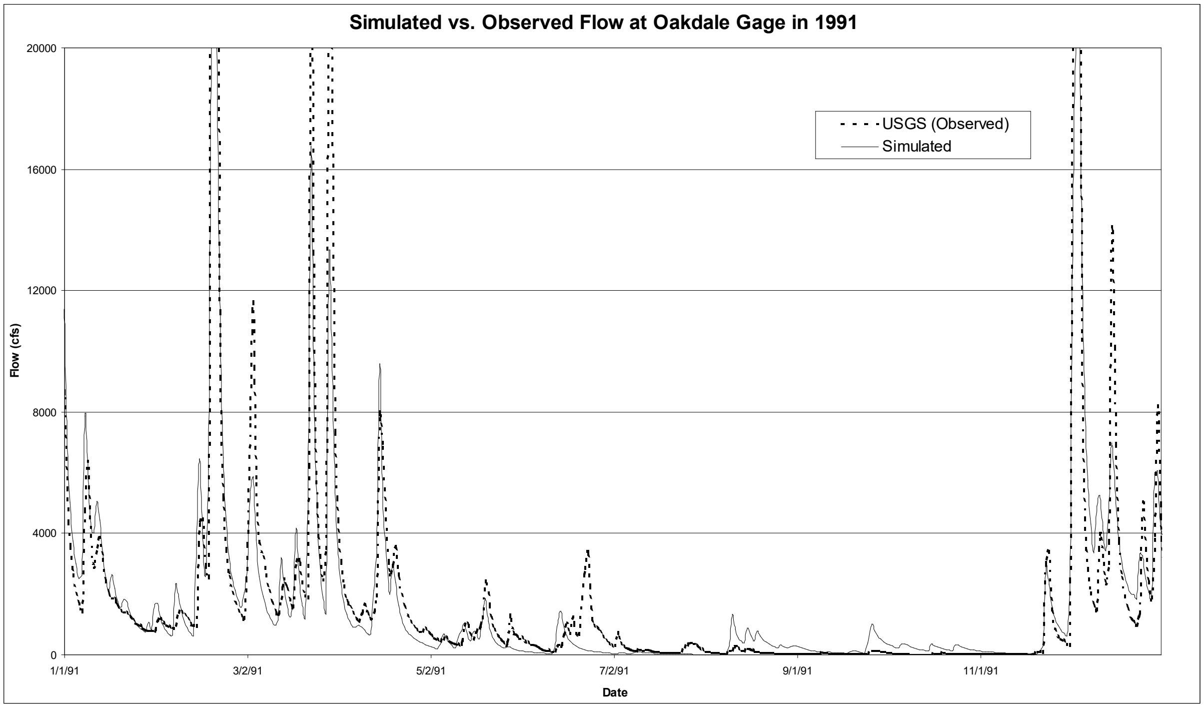

Figure 1.

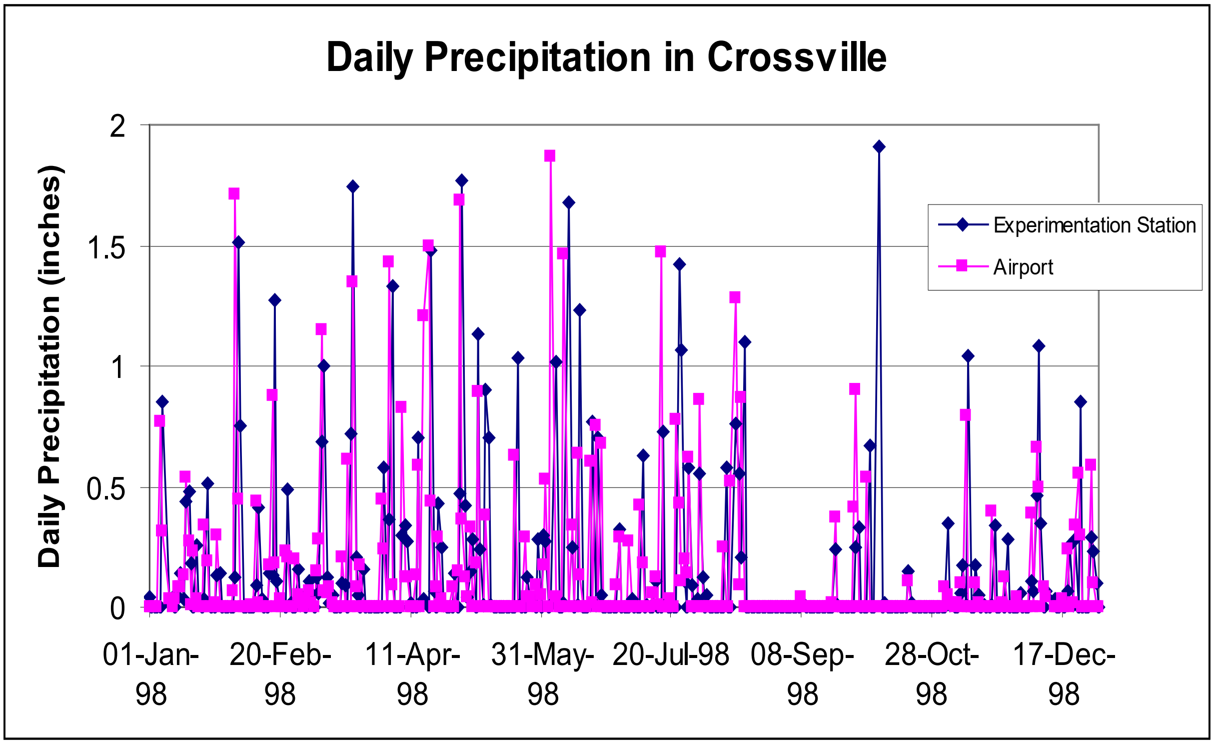

Figure 2.

An encouraging fact is that the frequency distributions of rainfall events among reporting stations show approximately the same shape. It is primarily the timing of the events and the altitude variation that are problematic. As mentioned above, this means that adequate calibrations require long data histories for both input and output data. These factors limit the usefulness of fragmentary discharge data. If the precise timing and amount of rainfall are unknown, then short, isolated discharge data in a watershed may mask a good calibration. More specifically, assessing predictions of several temporally isolated stream discharge measurements will be at best anecdotal evidence of model adequacy. This is a challenge when modeling subwatersheds because instantaneous measurements are frequently all that are available. What is needed is a coherent history over at least a season in which both daily weather and stream flow data are available. Furthermore, seasonal differences in hydrologic behavior make data from all four seasons warranted. This sets the data requirement at a coherent one-year history, but more data are warranted if there is uncertainty in other inputs and initial conditions.

My evaluation of the Daddy's Creek model used mean daily discharges over a two-year period. My difficulty in calibrating the Emory model suggests that a longer time period is necessary for an adequate evaluation. I will try to increase the evaluation period to ten years using data from the 1950-60s. My hypothesis is that the uncertainties about surface variables (such as land use) in these earlier periods will not eliminate the benefits of a longer time series for analysis of model predictions. The findings will be important in the evaluation of the Crooked Fork model. Recent data there include only instantaneous discharge measurements. Despite the uncertainties of changing hydrological characteristics, assessing the model with daily average discharges from the 1960s may provide a more thorough evaluation than the modern data.

Conclusions

My calibration in the Emory watershed met minimum standards, but the derivative calibration of Daddy's Creek did not. Quality standards for the watershed calibration may have to be higher than normal to permit downscaling to a subwatershed. Alternatively, better and more complete data for both the watershed and subwatershed may lead to an acceptable subwatershed calibration. I am continuing to research this issue to find the best data and to find the most appropriate model assessment criteria.

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APPLICATION OF UNET AND HEC-RAS COMPUTER MODELS BIRDS POINT-NEW MADRID FLOODWAY OPERATION PLAN

L. Yu Lin[1], Ph.D., P.E, Roger H. Smith[2], Ph.D., P.E., and Robert L. Hunt[2], Ph.D., P.E.

ABSTRACT

This paper presents flood simulations of the operation plan for the Birds Point-New Madrid Floodway (NMF) using UNET model (4.0 Version) and HEC-RAS model (3.1 Version). The NMF is located just below the junction of the Upper Mississippi and Ohio Rivers at Cairo, IL. The NMF is a major flood control feature of the Mississippi River and Tributaries Project and is used to provide additional storage and conveyance along this reach of the Mississippi River during extreme events equal to the project design flood (PDF) level. In order to examine how the current authorized operation plan for the NMF would be affected by various proposed alternatives related to the levee closure and outlet pump station project, UNET and HEC-RAS unsteady flow models were developed. The water surface profile analyses were conducted using unsteady state frequency flow events and for the PDF conditions. Based upon the comparison of the predicted flood elevations and sensitivity analysis to assumed hydraulic parameters, the results indicated that there was some divergence between the UNET and the HEC-RAS models.

INTRODUCTION

The Birds Point-New Madrid Floodway (NMF) located on the right bank side of the Mississippi River in Missouri was authorized by the Flood Control Act of 1928. The NMF extends from Birds Point to New Madrid, MO and lies between the Birds Point-New Madrid Setback Levee and the Mississippi River Frontline Levee (Figure 1). The floodway drainage basin created by the surrounding levees has an area of approximately 183 square miles and the land is primarily used for agricultural purposes. The NMF has an approximate length of about 30 miles from northeast to southwest and a width of 10 miles from northwest to southeast. The NMF is designed to convey part of the Mississippi River flow during the PDF flood event, thereby reducing main stem stages and potential flood damages at Cairo, Illinois, Hickman, Kentucky and other locations upstream of New Madrid. It has been operated only once, during the flood of 1937. The NMF system under existing conditions is quite different from system conditions in 1937. However, the internal area is still subject to backwater flooding from the Mississippi River. Levees completely surround and protect the NMF area, except at the floodway outlet at New Madrid. A 1500 ft. wide gap opening at New Madrid serves as a drainage outlet. The 1954 Flood Control Act provided authorization for a closure levee and gated outlet structure. In connection with the St. Johns-New Madrid Flood Control Project a 1500 cfs pump station will be installed to evacuate impounded water during high Mississippi River stages. The normal start and stop pump elevations will be 278 and 275 NGVD, respectively. During the 1 December to 31 January waterfowl season the start and stop pump elevations will be 285.4 and 284.4 NGVD, respectively.

In order to identify and assess the differences in the computed stages and flows within the NMF and main stem reaches of the Mississippi River, the UNET and HEC-RAS models were developed. The UNET model had previously been developed by the Memphis District Corps of Engineers to assess the effects of the proposed closure levee alternatives (locations, levee crest elevations, etc.). The primary purpose of the comparison study was to assess the advantages/disadvantages, manpower/experience necessary, relative accuracy, applicability of use, etc. of the Corps new unsteady flow version of HEC-RAS relative to the older existing UNET computer program. The river system hydraulics represented by the NMF project was selected for testing purposes because of its complexity and it contains most of the network connection options available for modeling purposes.

UNET

UNET is a one-dimensional unsteady open channel flow model that can be used to simulate flow in single reaches or complex networks of interconnected channels. Exchange of flow over levees with storage areas and many types of in-channel hydraulic control structures such as bridges, weirs and culverts can also be modeled. Because of its capability to include off-channel storage areas, simulate looped systems, compute levee overtopping and breach flows, it can be thought of as a quasi-two-dimensional model. It provides the user with the ability to apply both external and internal boundary conditions, including flow and stage hydrographs as well as stage-flow relationships at gated or uncontrolled hydraulic structures.

The UNET model consists of a geometry input file (.CS file), boundary condition file (.BC file), and Gage Data (Stages, Flows, Rating Curve) DSS files. The floodplain cross sections are encoded in a modified HEC-2 or HEC-RAS format. This format requires the geometric data sequence input from upstream to downstream. Boundary conditions are normally input from an existing HEC-DSS data file. Hydrographs and water surface profiles computed by UNET are output to HEC-DSS for graphical display and for comparisons with other simulation scenarios or observed data. HEC-DSS is advantageous to the point of necessity because it eliminates the manual tabular input of hydrograph data and is well adapted to a large number of input/output simulation scenarios.

The floodway UNET Model consists of three interconnected dynamic routing or conveyance reaches as follows: (1) Mississippi River from Cairo to New Madrid; (2) New Madrid Floodway; and (3) Mississippi River from New Madrid to Caruthersville. The modeling approach was based upon:

1. Frontline levee (FLL) overtopping flows from the right bank side of Reach 1 were connected directly to cross-sections within Reach 2 using a lateral weir option.
2. Planned FLL breaches or crevasses were first connected into a “hypothetical” storage area that was then directly connected to cross-sections in Reach 2 for routing through the NMF storage area.

3. Overtopping or cross over flows at major river bend spur levees were directly connected to downstream reach cross-sections using the lateral weir option..
4. An automated calibration rating curve technique was used to develop optimized conveyance properties for reaches between stream gage locations. The rating curve computer program reads observed stages and UNET computed flows from DSS files to develop a least squares best fit to the scatter of flow-stage data. Reach conveyance is optimized by developing an elevation vs. adjustment factor relationship at each cross-section within the reach. The procedure is repeated for all rating curve flows until it matches the known rating curve elevation values within a selected tolerance (0.1 ft).
5. Additional adjustments to conveyance ratios were made at individual cross-sections to better match observed high water elevations. High water elevation data was available for the 1997 calibration and 1995 verification flood hydrograph events used in development of the UNET model.
6. The proposed operation plan for the NMF was previously simulated at the Waterways Experiment Station using the MBM physical model. The data obtained from this model for the Project Design Flood event was used to determine lateral weir coefficients needed in the UNET model for simulation of levee breach and overtopping flows.

HEC-RAS

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for: (1) steady flow water profile analysis; (2) unsteady flow profile analysis; and (3) movable boundary sediment transport computations. A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. For unsteady flow simulation, HEC-RAS model is capable of simulating one-dimensional open channel flow through a full network of channels with various hydraulic structures, such as bridges, culverts, storage areas, dams, tunnels, pumping stations, and levee failures. The unsteady flow solver was adapted from the UNET model. The new Version 3.1 (released November 2002) model can now perform mixed flow regime (subcritical, supercritical, hydraulic jumps, and draw downs) calculations.

In this study, the new HEC-RAS model was applied to the same NMF system previously modeled using UNET. For comparison purposes, the same geometric data, boundary conditions, reach connections, and other modeling assumptions were made as close as possible to the simulation approach used for UNET. Both models were used to simulate stage and flow hydrographs for the following scenarios: (1) PDF – Levee overtopping flows only; (2) PDF – Levee breaching and overtopping flows; and (3) 2,5,10,25,50,100 Year frequency flow events.

RESULTS AND CONCLUSIONS

The HEC-RAS unsteady flow model was relatively easy to implement for this project because of the graphical user interface, where each individual analysis component is separated in the Windows environment. Generally speaking, data entry and editing of geometric and boundary data for a river reach were very user friendly. Any human input data errors or reach connection mistakes were easier to detect than with the UNET model. The whole river system schematic diagram (Figure 2) and geometric data window with pop up menu greatly assists the user in editing of the reach data and speeding up the time for calibration. However, the HEC-RAS model cannot always directly import geometric information from a UNET model. It depends upon how the original UNET model was set up (specific records used for modeling purposes). This was true for the NMF UNET model.

Example reach comparisons using both models are shown in the figures below for the first of the three simulation scenarios listed above. Figure 3 and Figure 4 depict the stage hydrograph for the Hickman, KY Gage (RM 922.0) in Reach 1 and Tiptonville Gage (RM 872.4). Generally speaking, the water surface elevations in the HEC-RAS model were less than the UNET model. The primary reason for this discrepancy is that the HEC-RAS model has yet to be totally calibrated using all of the known high water elevation data available for the original UNET model. The HEC-RAS model will be completed and all planned comparisons will be presented at the symposium in April.

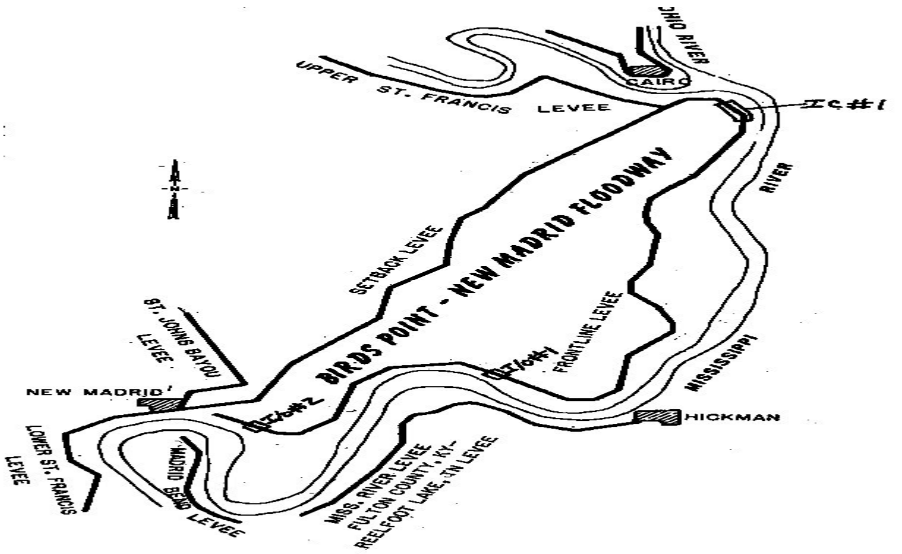

Figure 1. Schematic Diagram of Birds Point-New Madrid Floodway

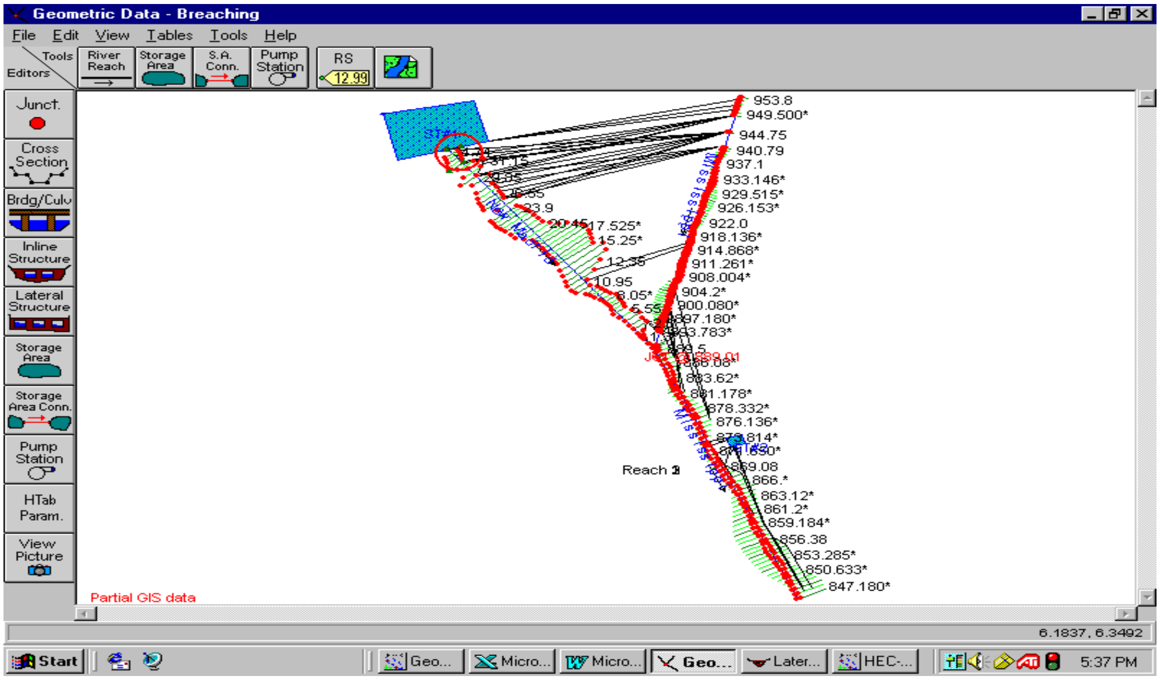

Figure 2. Schematic Diagram of the HEC-RAS Model

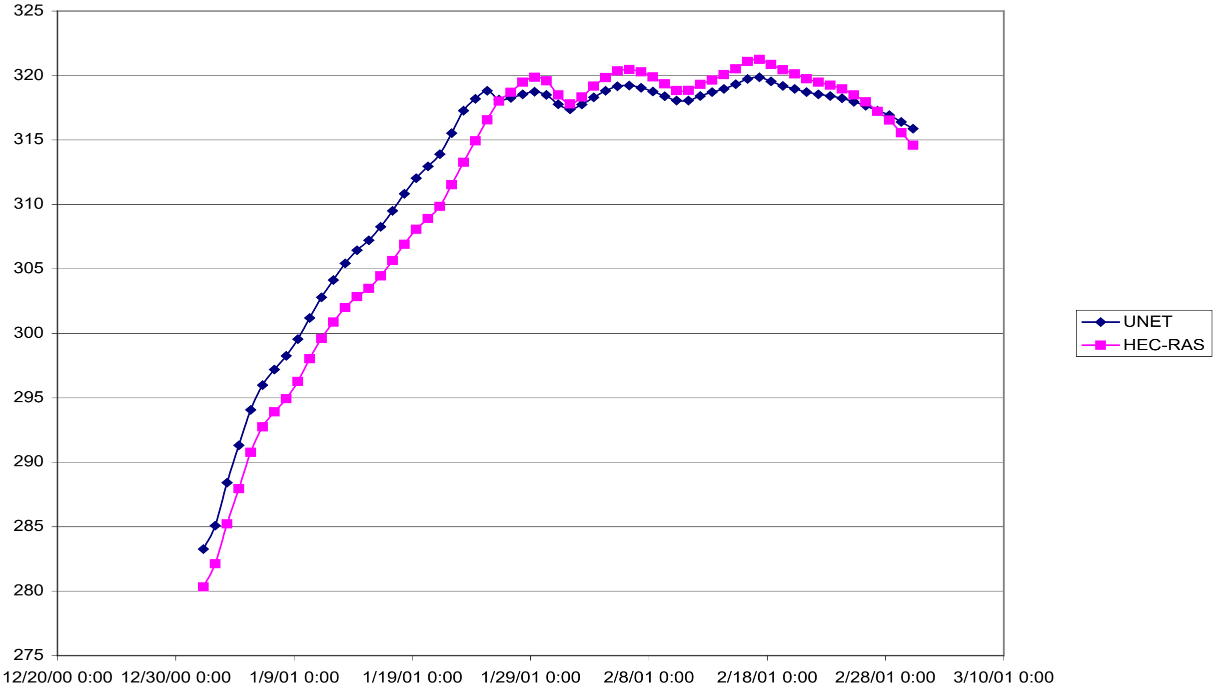

Figure 3. Comparison of Stage Hydrograph in Hickman between UNET and RAS

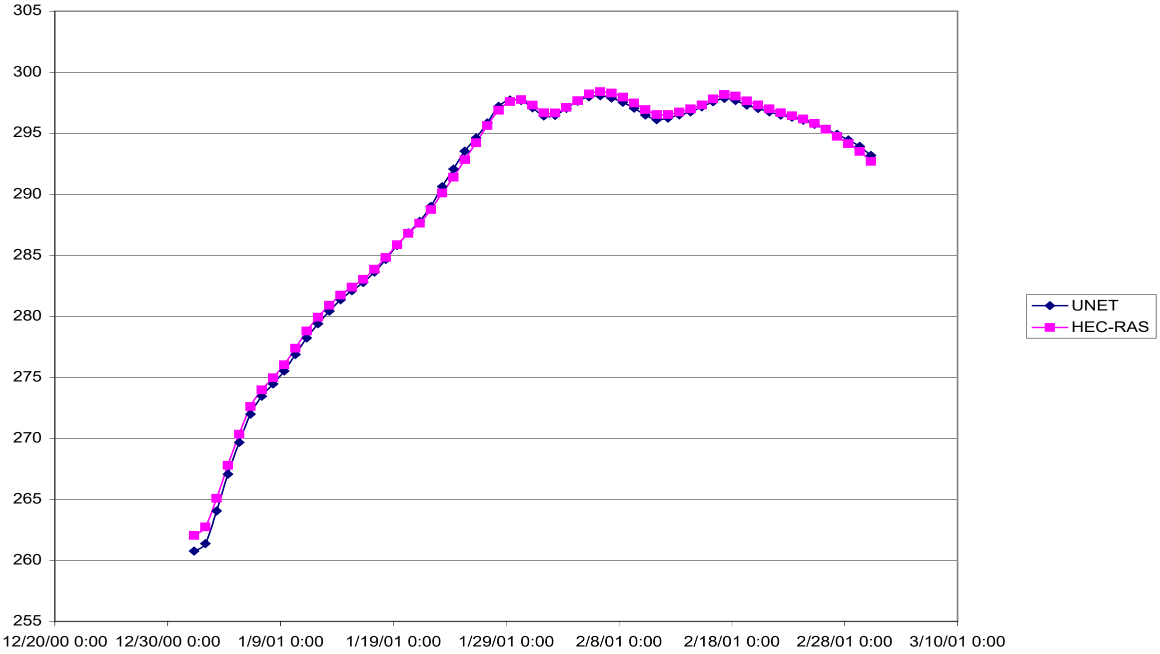

Figure 3. Comparison of Stage Hydrograph in Tiptonville between UNET and RAS

RECENT MEMPHIS DISTRICT PROGRESS IN PERFORMING CONTINUOUS HYDROLOGIC SIMULATION

Robert Hunt, U.S. Army Corps of Engineers, Memphis District[1]
Roger Smith, University of Memphis, Civil Engineering Dept.[2]

INTRODUCTION

In decades past, Memphis District water resources projects were built to protect property from the damaging effects of severe floods. Sizing the structural components of those projects was typically based on hydrologic and hydraulic analysis of extreme single floods.

Today, the Memphis District must manage water resources more comprehensively than in the past. Comprehensive water resources management requires attention to everyday hydrologic and hydraulic behavior, as well as attention to project performance under extreme conditions.

In response to increasing public expectations and the availability of greater computing power, the Memphis District has made increasing use of continuous simulation analyses during the past ten years. For example, the Memphis District has performed continuous simulation analyses on the Grand Prairie Irrigation Project for Arkansas, the Reelfoot Lake Project for Tennessee and Kentucky, and the St. Johns Bayou Project for Missouri.

CONCEPTUAL MODEL

Memphis District continuous simulation models are based on the water budget concept--that is, the quantification of water storage and movement within the hydrologic cycle. District water budget modeling can be complex, due to the variety of physical components involved, the time-variability of model boundary conditions, and the variability of project performance desired through seasonal and multi-year cycles.

Figure 1 depicts most of the physical components that may be included in a District continuous simulation model. Of course, a given model will probably not include all components shown. Components may include levees, gated culverts, weirs,

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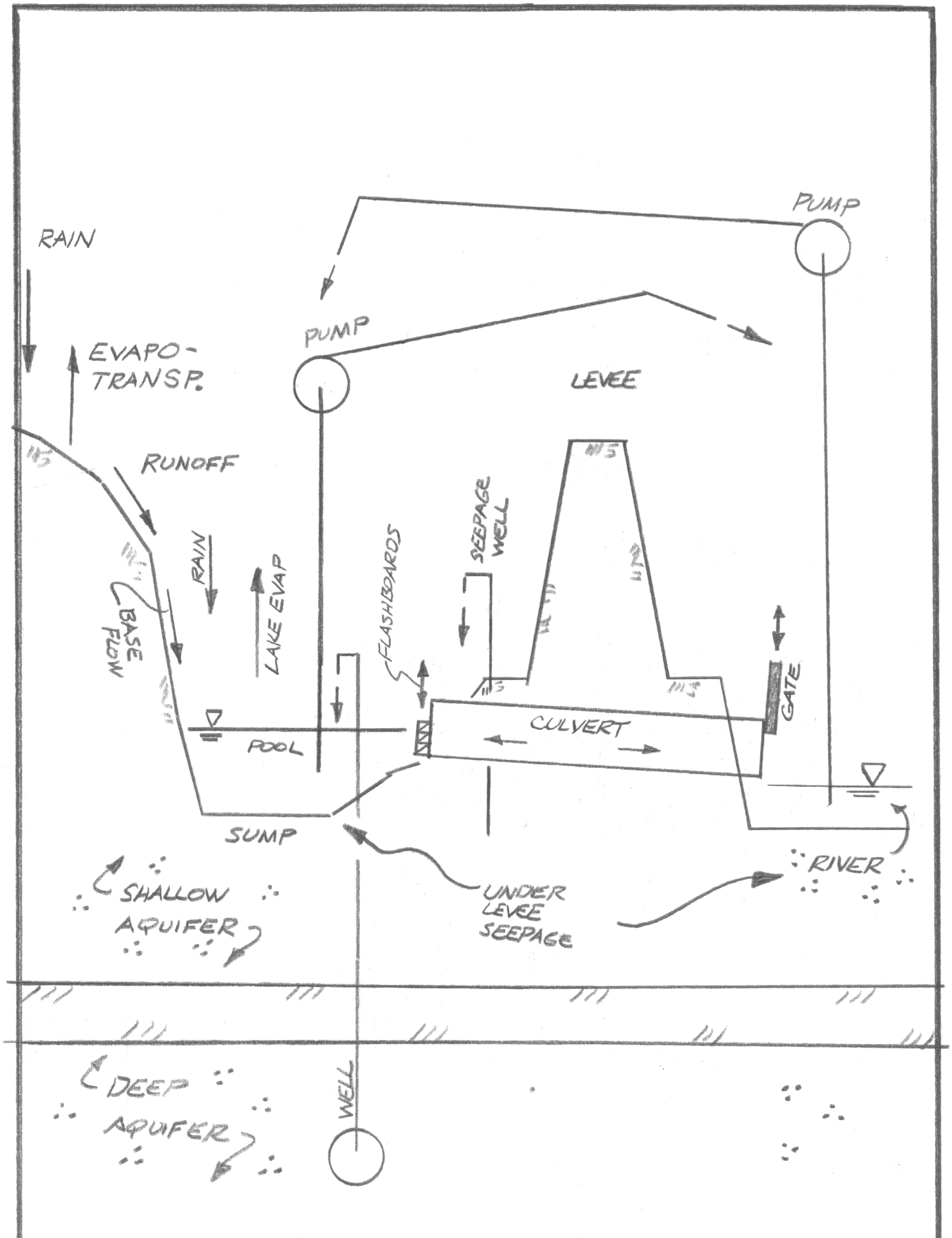

FIGURE-1 MODEL COMPONENTS

flashboards, pumps to remove water from a pool, pumps to add water to a pool, and levee seepage wells.

Hydrologic processes considered may include direct rainfall into pools, runoff from the landscape, evapotranspiration, lake evaporation, under-levee seepage, groundwater interactions, baseflow, and irrigation effects. Runoff is generally estimated using the Antecedent Precipitation Index (API) method.

Projects that include water level control equipment are analyzed using a plot of the limiting water levels desired throughout a typical year. As shown in Figure 2, pool levels are enveloped by an upper and lower rule curve.

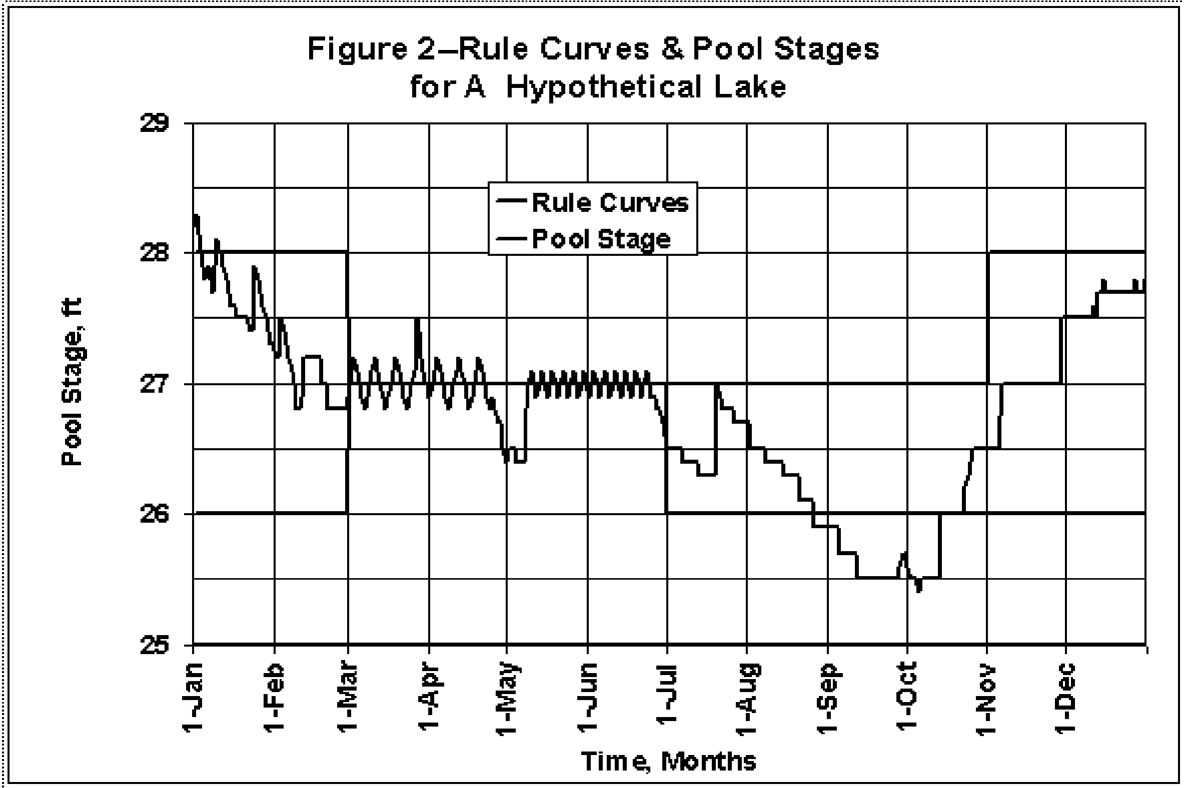

Figure 2 -- Rule Curves and Pool Stages

RECENT PROGRESS

Recent Memphis District progress in continuous simulation includes quantification of the following items:

- pump energy requirements
- levee relief well flows
- levee and canal freeboard available during flow transients
- hydroperiod effects on wetland habitat and lakeshore property
- coincidental frequency effects
- surface-water/groundwater relationships
- habitat quantification
- structural control effects
- fluctuation augmentation of lake levels on controlled project lakes
- multi-year lake drawdown cycle effects
- variable flashboard elevation setting effects
- sediment yield from upland tributaries into channels
- wetland elevations with respect to days of continuous inundation during the growing season.

The District has accomplished these results using a mix of published and in-house computer programs. Published programs used include:

-HEC-UNET, which simulates unsteady flow, levee breaching, and spillway gate control

-SOBEK, used for irrigation canal control simulation

-HEC-IFH, used for modeling flood control for the landside of levees

-HEC-6, used to predict long-term trends in channel sediment transport and channel dimensions.

In-house computer programs derive from a growing library of hydrologic, hydraulic, and statistical Fortran-77 and Fortran-95 subroutines.

FUTURE IMPROVEMENTS

Future Memphis District progress with continuous simulation will depend on funding for data, for more advanced computer programs, and for larger-scaled, comprehensive applications. These developments would probably occur over an evolutionary period of several years.

Additional hydrologic data and a more environmentally comprehensive data base should be obtained. Additional gages may be needed, particularly in small, upland watersheds. Dense gaging of one, or more, test watersheds in the District should be accomplished to improve water budget validation. Checking of raw data and building uniform databases for continuous simulation and forecasting should be automated. Detailed county soil surveys should be digitized and loaded into the District Geographic Information System (GIS).

Future District models will probably simulate both watershed processes and management alternatives in greater detail. Separate lumped hydrologic models and 1-dimensional hydraulic models may give way to 2-D hydrologic/hydraulic models that draw data from a GIS and can track runoff, sediment, nutrients, and pesticides. Also, the capacity of programs to simulate complex mechanical spillway controls and environmentally oriented rule curves should be further developed.

Future applications of continuous simulation may not only consist of separate analyses of particular projects, but may also evolve into regional, continually operating, real-time models able to furnish just-in-time information to support water resources management on the river-basin scale.

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IMPERVIOUS SURFACE MAP OF PART OF THE STONES RIVER WATERSHED, TENNESSEE

Mark Abolins[1], C. Stan Frazier[1], David Marquette[2], and Jason Powell[1]

Abstract

Impervious areas were mapped within 476 thousand acres of the Stones River Watershed in Davidson, Rutherford, and Wilson counties. The map depicts these areas circa 2000 with a 30 m cell size. Different kinds of land were mapped by combining information from satellite, population, employment, road, and political boundary maps. Kinds of land included medium and high intensity urban (e.g., apartment, retail, and manufacturing complexes), low intensity urban (e.g., residential developments of single-family homes), and rural residential (e.g., rural roads and five-acre residential lots). To estimate the impervious fraction within each kind of land, imperviousness was interpreted at hundreds of randomly-located points on aerial orthophotos. Medium and high intensity urban land was 49-89% impervious, low intensity urban land (and allied classes) were 15-49% impervious, and rural residential land was 2-14% impervious. For each kind of land, the imperviousness was multiplied by the area to estimate the area covered by impervious surfaces. Low intensity urban land and allied classes contained 8,010-17,200 acres of impervious surfaces (38-45% of the total for the study area), and rural residential land contained 4,530-14,500 acres (25-32%), underscoring the potential importance of homeowner behavior and residential planning in runoff management.

Introduction

The Stones River Watershed contains much impervious land, and the amount is growing. According to the U.S. EPA Urban Runoff Potential Map, one to four percent of the watershed may have been more than 25% impervious in 1990 (USEPA, 1995). Between 1990 and 2000, the population of the watershed increased by more than 80,000, suggesting that the amount of impervious land has increased since 1990. Where is the impervious land?

To find out, impervious areas were mapped in those parts of the Stones River Watershed within Davidson, Rutherford, and Wilson counties. These three counties contain most of the watershed (476 thousand acres or 85%). The map combines information from a 1999 Landsat image, 1997 digital orthophotos, Census 2000 population data, Census 2000 Tigerline roads, circa 2000 employment data (from the non-profit organization Cumberland Region Tomorrow), and political boundaries. Criteria for combining information were identified by a previous study (Abolins, 2002) of land cover/land use at over 1,000 randomly-located points within a ten-county region around Nashville, and are listed below under “Methodology.” Map units include low intensity urban land (e.g., residential developments of single-family homes), medium/high intensity urban land (e.g., apartment, retail, and manufacturing complexes), urban edge land (the boundary zone between more developed and less developed land), rural residential land (e.g.,

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rural roads and five-acre residential lots) and major highways. The imperviousness of each kind of land was interpreted from black and white digital orthophotos at more than one hundred randomly-located points.

Methodology

1. The October 1999 (leaf-on) Landsat image was registered by finding fifty-seven matching points on digital orthophotos. These points fit a first-order polynomial transformation with an overall root-mean-square (RMS) registration error of ~11 m. RMS errors for individual points were all less than 21 m.
2. A sub-image was created for the ten Nashville region counties (Cheatham, Davidson, Dickson, Maury, Montgomery, Robertson, Rutherford, Sumner, Williamson, and Wilson).
3. Unsupervised classification ("ISODATA" or "k-means") was applied to the sub-image to create a 30-class map. Landsat bands 3, 4, 5, and 7 were used in the unsupervised classification. The algorithm was initialized using principal component axes and the algorithm iterated until less than 0.3% of cells changed classes from one iteration to the next.
4. A 5X5 majority filter was applied to the 30-class map.
5. The following criteria were used to distinguish between different kinds of land:

Urban land (high, medium, and low intensity)

- Cells with a value of 24 on the 30-class map.
- Cells with values of 9, 15, 16, or 19 on the 30-class map
  AND within 120 m of a road
  AND (with a population density > 1.2 pers/acre OR employment density > 1.2 pers/acre).
- Cells with values other than those listed above
  AND within 120 m of a road
  AND (with a population density > 2.0 pers/acre OR employment density > 1.75 pers/acre).

"Urban edge" I land (border between more developed land and less developed land)

- Cells with values of 9, 16, 18, 19, 20, 22, 23, 25, or 27 on the 30-class map
  AND within 80 m of a road
  AND (with a population density > 0.8 pers/acre OR employment density > 0.5 pers/acre)
  AND not classed as developed based on any of the above criteria.

Rural residential land

- Category I (most densely developed rural residential).
  Cells with values of 12, 16, 18, 19, 20, 22, 25, or 26 on the 30-class map
  AND within 120 m of a road
  AND within a city or within 3 km of a city
  AND not classed as developed based on any of the above criteria.
- Category II
  Cells with values not listed above (for Category I)
  AND within 120 m of a road
  AND within a city or within 3 km of a city
  AND not classed as developed based on any of the above criteria.
- Category III
  Cells within 120 m of a road
  AND not classed as developed based on any of the above criteria.
- Category IV (least densely developed rural residential)

Cells within 200 m of a road
AND not classed as developed based on any of the above criteria.

6. Urban land was subdivided into high, medium, and low intensity urban classes through a combination of supervised classification and manual post-classification editing. An additional urban edge class ("urban edge II") was also mapped.
7. Within each kind of land, imperviousness was interpreted at over one hundred randomly-located points. Interpretations are based on black and white digital orthophotos acquired during 1997. At each point, the interpreter described imperviousness in one of four ways: 1) definitely impervious (e.g., a point falling on the roof of a building), 2) definitely pervious (e.g., a point falling in the middle of an agricultural field, 3) more likely impervious than pervious, and 4) more likely pervious than impervious.

Results

The imperviousness of each land class is listed in Table 1. The "low," "best," and "high" values represent self-assessed interpreter accuracy. The "low" value is the fraction of definitely impervious points, the "best" value reflects the sum of definitely impervious points and points that are more likely impervious than pervious, and the "high" value excludes only those points that are definitely pervious. Most of the impervious land in the watershed falls into one of four non-overlapping groups:

- high and medium intensity urban (49-89% impervious)
- low intensity urban, major highways, and some urban edge areas (15-49% impervious)
- rural residential (2-14% impervious)
- open space with a small amount of rural residential (0-2% impervious)

Of these groups, the high and medium intensity urban group is the most impervious (49-89%), but covers a relatively small amount of the watershed (<2%). Consequently, this group contains only 13-23% of the impervious surfaces in the study area. In contrast, the group consisting mostly of low intensity urban land is less impervious (15-49%), but covers more of the watershed (8%). As a result, this group contains the largest amount of impervious surfaces in the study area (38-45%). The rural residential group is even less impervious (2-14%) than the low intensity group, but covers more of the watershed (30%). This group contains about one quarter of the impervious land. Together, these three groups contain 95-97% of the impervious surfaces in the study area.

A portion of the impervious surface map is shown in Figure 1.

Discussion

The accuracy and precision of the imperviousness values would improve with additional ground and air photo observations. The accuracy of air photo interpretations could be checked at a random selection of locations on the ground, and a larger number of sample points would increase precision. Improvements in both accuracy and precision may be desirable before study results are used in any follow-on analysis.

Conclusion

The large area covered by impervious surfaces in low intensity urban and rural residential areas underscores the potential importance of homeowner behavior and residential planning in runoff management.

Acknowledgements

Land cover/land use research was supported by the Tennessee Space Grant Consortium, the Middle Tennessee State University Faculty Research and Creative Activity Committee, the Jennings and Rebecca Jones Chair of Excellence in Urban and Regional Planning at Middle Tennessee State University, and Cumberland Region Tomorrow.

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GROUPS	AREA Acres (% of study area)	CLASSES	AREA Acres	IMPERV-IOUSNESS (low-“**best**”-high)	IMPERVIOUS AREA Acres (% of impervious land in study area)
High and medium intensity urban	7,260 (<2%)	High intensity urban	3,782	66-**78**-89%	4,300-6,000 (13-23%)
		Med intensity urban I	1,881	52-**66**-78%	
		Med intensity urban II	1,597	49-**63**-76%	
Low intensity urban, major highways, some urban edge areas	40,112 (8%)	Low intensity urban	27,575	22-**32**-49%	8,010-17,200 (38-45%)
		Major highway	1,171	20-**23**-35%	
		Urban edge I	11,366	15-**22**-29%	
(overlaps other classes)	7,343 (<1%)	Urban edge II	7,343	7-**15**-28%	514-2,060 (3-5%)
Rural residential	145,220 (30%)	Rural residential I	18,239	6- **9**-14%	4,530-14,500 (25-32%)
		Rural residential II	44,890	4- **5**-12%	
		Rural residential III	82,091	2- **4**- 8%	
Open space	261,368 (55%)	Rural residential IV	88,754	1- **1**- 2%	888-5,230 (3-12%)
		Open space	172,614	0- **0**- 2%	
Water	15,194 (<4%)	Water	15,194	0- **0**- 0%	0 (0%)

Table 1. Imperviousness and impervious area in part of the Stones River watershed, TN.

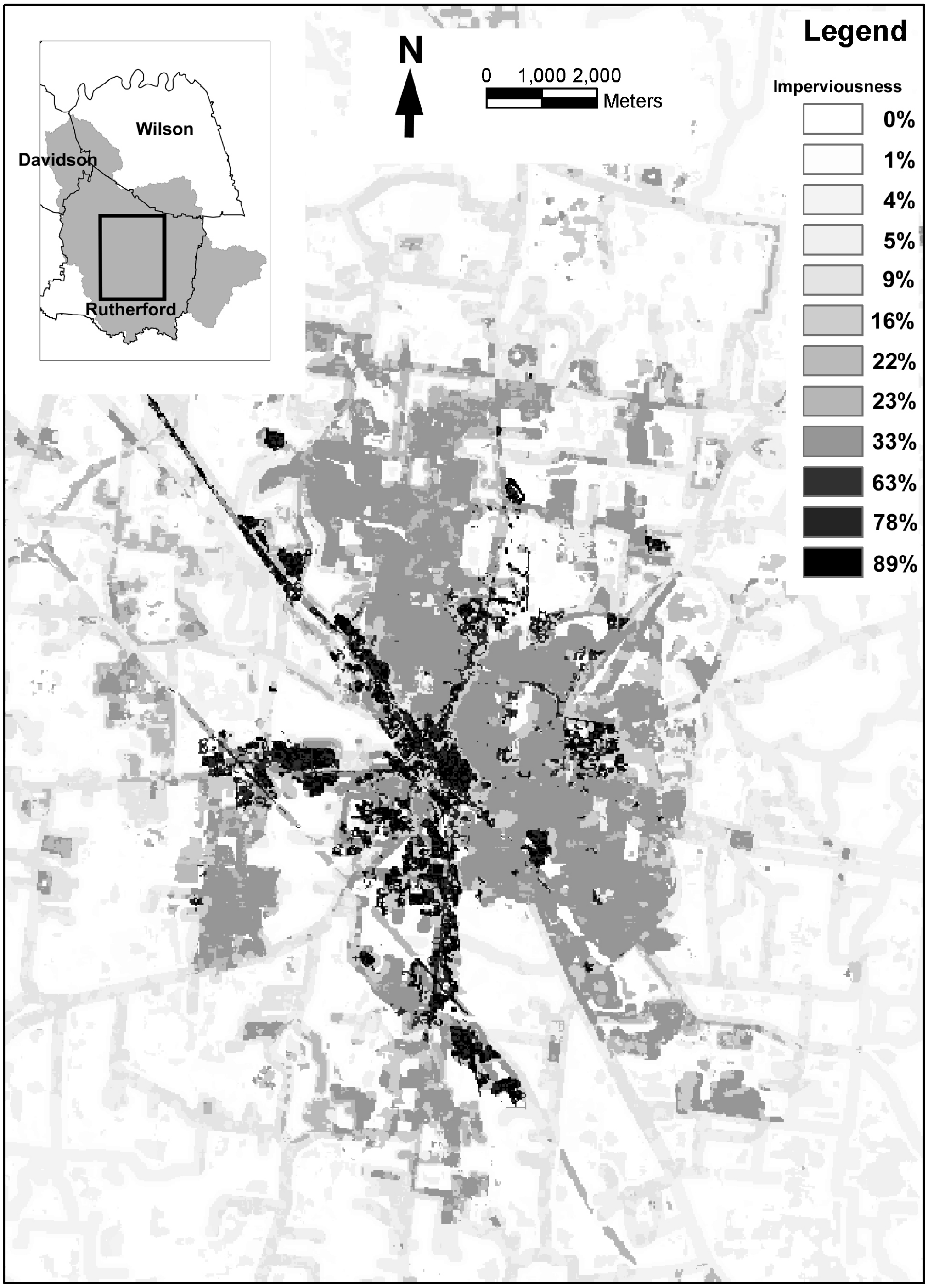

Figure 1. Impervious surface map of the Murfreesboro, TN area (circa 2000). Shading represents "best" imperviousness values from Table 1. The map for the rest of the Stones River Watershed in Davidson, Rutherford, and Wilson counties is available from the author upon request. The cell size is 30 m. The map is not site-specific.

THE EFFECTS OF DEM GRID SIZE AND TERRAIN TYPE ON ESTIMATES OF AVERAGE WATERSHED SLOPE

Jason Hill[1] and Vincent Neary[2]

The average watershed slope, or Y-slope, is an important watershed property that is required to determine the lag time used in the SCS unit hydrograph method, which is a popular technique for transforming excess rainfall into a runoff hydrograph for small to mid-sized watersheds. Several methods have been suggested for estimating the Y-slope, however, the most common method requires that a square grid be superimposed over a topographic map of the watershed. The maximum surface slope is then determined at each grid intersection and the values averaged. This method is easily implemented within a GIS because of the widespread availability of gridded topographic data in the form of DEM's (digital elevation models).

The accuracy of the estimate is dependent on DEM grid size and terrain type (mountainous, flat, etc.). Although numerous studies have shown that the estimate of Y-slope decreases as the DEM grid size increases, the limited availability of high-resolution topographic data has prevented a thorough analysis of both factors. Only recently has high-resolution topographic data, collected using LIDAR (Light Distance and Ranging) technology, become available. For this study, topographic data collected using LIDAR technology and conventional photogrammetric methods is being analyzed for watersheds exhibiting a wide range in size and terrain. The results should provide guidance to engineering practitioners on selecting the appropriate DEM grid size based on the terrain type of the watershed.

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WATER QUALITY OF SHALLOW GROUND WATER IN THE MEMPHIS AREA, TENNESSEE

James A. Kingsbury[1]

A network of 32 monitoring wells was installed and sampled in 1997 for a broad range of constituents to characterize the effect of recent development (post-1970) on shallow ground-water quality in Shelby County, Tennessee. Most of the wells (24) were completed in the fluvial deposits aquifer; however, in the southeastern part of the county, the fluvial deposits are dry and 8 wells were installed in the upper part of the underlying Memphis aquifer. Tritium data collected for the study indicate that about 80 percent of the wells contained "young" (post-1952) ground water (tritium concentrations greater than 1 tritium unit). Most of the samples with less than 1 tritium unit were collected from wells screened in the Memphis aquifer, however, two wells with tritium concentrations less than 1 tritium unit were screened in the fluvial deposits. Pesticides were detected in about 65 percent of the wells. All of the wells screened in the upper part of the Memphis aquifer had at least one pesticide detected. Simazine, atrazine, and tebuthiuron, the most frequently detected pesticides, were present in 24, 18, and 15 percent of samples, respectively. The maximum concentration of a single pesticide in a sample was 14.8 micrograms per liter of the herbicide 2,4-D. Detection frequencies of atrazine and simazine are comparable to the detection frequencies of these pesticides in similar urban-well networks across the country; however, tebuthiuron was detected about two times more frequently in this study than in other urban areas across the country. Volatile organic compounds were detected in about 78 percent of the samples, but concentrations typically were lower than the pesticide concentrations. Chloroform and carbon disulfide were among the most frequently detected compounds with maximum concentrations of 2.06 and 0.16 micrograms per liter, respectively. One or both of these compounds were detected in the eight wells screened in the upper part of the Memphis aquifer.

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GROUNDWATER CHEMISTRY- A COMPARATIVE EVALUATION OF POPULATION STATISTICS AND HYDROCHEMICAL RELATIONSHIPS BETWEEN QUATERNARY AND TERTIARY SAND AQUIFERS IN WEST TENNESSEE

Randy M. Curtis

Introduction

The groundwater chemistry of the West Tennessee area has been a subject for investigation for nearly 100 years. The heavy dependence of both the urban and rural populations on the groundwater resource has made the description of water quality and the physical evaluation of the various aquifers a matter of pressing interest. The early emphasis was on broad regional descriptions of the rock units, with compilations of water analyses by geographic base. Later, the emphasis shifted to measurement of man's impact on water quality through direct or inadvertent pollution, and establishment of background information was a main concern, in order to judge potential impacts. In more recent years, the thrust has been upon the establishment of hydrogeologic units on a regional basis to facilitate the integration of the physical and chemical characteristics of the groundwaters of West Tennessee via computer models. Much work still needs to be done, and it is the goal of this paper to re-emphasize the older, regional scale approach by using computer technology to investigate, in a rudimentary fashion, the groundwaters of the uppermost aquifers in West Tennessee.

Study Area and Hydrogeology

The study area consisted of that portion of West Tennessee bounded on the east by the outcrop belt of the Porter's Creek Clay, on the south and north by the Alabama and Kentucky state lines, respectively, and on the west by the bluffs of the Mississippi River and the boundary of Shelby County, Tennessee. Shelby County and the Memphis area were excluded from consideration because of the wealth of data that has been compiled from the many excellent studies of that immediate area and because of the long history of pumping from that vicinity. The outcrop belt of the Porter's Creek Clay ensures that all the wells considered were likely to be within more or less unconfined conditions. The potential aquifers within this area are all of Paleocene/Eocence or younger age, geologically, and fall predominantly within the Wilcox or Claiborne Groups. The stratigraphic units are the old Breastworks Formation and Fort Pillow Sand (also know as the '1400 foot" sand), the Memphis Sand (a.k.a. the "500 foot" sand), the Jackson/Cockfield Formation, Pleistocene/Pliocene Fluvial deposits (including terrace deposits), and Quaternary alluvial deposits (a.k.a. "Holocene Alluvium"). One of the first problems encountered by the geologist or hydrogeologist in working with the groundwater in the study area is the bewildering array of nomenclature and pseudonyms encountered in trying to anchor a specific water well to the regional contest.

Materials and Methods

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Because the goal of the study was to examine population statistics, i.e., mathematical descriptions of analytical data thought to represent distinct aquifer or hydrogeologic unit conditions, the first step was to determine a data source. There are numerous published compilations of basic aquifer chemistry for this area, including United States Geological Survey (USGS) publications dating back to 1933, as well as more recent, in part regulatory driven, investigations by the Tennessee Department of Environment and Conservation, Division of Superfund and Division of Solid Waste Management. The source ultimately used was located in cyberspace. The USGS site on the World Wide Web offers the capability of searching an extensive groundwater quality database by county, hydrogeologic unit, or place name. The well location map from Mr. Francis G. Wells' 1933 Water Supply Paper was used as a base map. The outcrop pattern of the Porter's Creek Clay was transferred and the latitude and longitude lines were augmented with additional grid lines every 12 minutes; thus, the area within a degree of longitude/latitude was subdivided into a series of blocks, two tenths of a degree on a side. This split up the search criteria into 44 discrete blocks covering all or portions of 15 Tennessee counties. A file request on an individual box with specified latitudes and longitudes at the corners yielded all known points for which chemical information was known in that search area. All surface waters were excluded from consideration. All wells of either unknown depth or unknown hydrogeologic unit affiliation were also discarded. Of the remaining wells, all those that had information from the analysis of a water sample for all eight of the following analytes were chosen: calcium, magnesium, sodium, potassium, chloride, sulfate, silica, and iron. These constituents were chosen because they are common rock forming constituents and might illustrate different source conditions of the aquifer materials, and because they are most likely to have a reportable concentration upon the completion of an analysis. The latter consideration is important because correlation and other potential statistical procedures are affected by the presence of large numbers on non-detections or zeros. Over three hundred wells had sample data that met the criteria. Of the three hundred and seventeen sets of data (more than one set of analyses from some wells), only 20 analyses for sulfate and 53 analyses for iron were reported as below a detection limit or present but not quantifiable. These were replaced with numbers randomly generated from an artificial dataset with a lower boundary of zero and an upper limit of the detection or quantification level. Each well's analyses were recorded with the date, well name, well depth, formation, search box description, and a random number assigned to that well's row of data in the event that statistical procedures called for a random selection of a particular well depth range or aquifer type. The data were loaded into a Microsoft Excel^{TM} workbook initially, where they were sorted and plotted. Data subsets were then transferred to spreadsheets in Minitab^{TM} Release 13 for Windows Statistical software for generation of descriptive statistics and evaluation of data distributions.

Results and Discussion

The first step of the data evaluation was to prepare descriptive statistics for the entire data set, from all depths and formations, and determine the frequency distributions. As expected, all of the analytes' plots appeared to represent samples from more than one population. The data were then sorted and grouped into four main categories, from youngest to oldest in geologic age of the aquifer materials. This resulted in a subset of data described in Table 1.

The same general pattern is seen in all the analytes except iron. Average values gradually decrease from high stratigraphic positions to older, lower stratigraphic positions. There are very slight increases in average concentration in the lowest formations examined. Iron rises in concentration from the upper units to the Tertiary deposits, then gradually decreases with depth. This is to be expected inasmuch as the fluvial deposits of the upper Tertiary would contain more relic paleosoils and the potential to collect iron in perched water zones as the precipitation water leaches the higher level deposits. The probability plots were re-examined for the smaller subsets of and the overall aquifer categories. While the data still were not normally distributed at a regional scale, a natural logarthmic distribution did produce a reasonable goodness-of-fit value. The relatively small data sets of 28 values produced some goodness of fit values in the distribution of natural logarithm values to justifiably allow statistical tests depending on an assumption of normality. The question of the suitability of the sample size for estimating probable mean and variance values becomes more important as the smaller datasets are evaluated. The problem becomes one of scale in that, because the region-wide values are not normally distributed, the statement of a regional average value becomes suspect. The core question is the scale at which the hydrologic unit and aquifer chemistry may be co-defined in relation to the regional aquifer unit. There are probably many sub-units within the Memphis Sand Aquifer, and their distinct populations were part of the sample set for this study, giving a wide variance for Wilcox Group statistics.

TABLE 1--Summary of Select Statistics for West Tennessee Aquifer Water Analyses

Analyte	Subset	Sample #	Mean	Truncated Mean	Standard Deviation	Quartile One	Quartile Three
Calcium	Holocene Alluvium	73	50.32	47.8	42	12.0	90.0
	Tertiary Deposits	28	18.99	18.33	17.17	3.6	34.0
	Claiborne Group	149	8.206	6.674	11.776	2.8	11
	Wilcox Group	67	8.769	8.162	7.580	2.9	13.0
Magnesium	Holocene Alluvium	73	16.2	14.53	14.96	4.5	26.0
	Tertiary	28	9.23	8.84	8.85	1.33	17.50

	Deposits						
	Claiborne Group	149	3.11	2.627	3.682	1.1	4.2
	Wilcox Group	67	3.253	2.897	3.413	0.870	5.0
Sodium	Holocene Alluvium	73	16.47	14.21	15.88	7.45	20.50
	Tertiary Deposits	28	9.49	9.03	5.9	6.53	10.75
	Claiborne Group	149	9.11	6.97	12.67	3.65	8.80
	Wilcox Group	67	9.239	8.385	7.320	3.9	12.0
Potassium	Holocene Alluvium	73	2.973	2.212	5.166	1.350	3.0
	Tertiary Deposits	28	1.368	1.265	1.530	0.4	2.125
	Claiborne Group	149	1.721	1.088	5.446	0.6	1.5

TABLE 1--Summary of Select Statistics for West Tennessee Aquifer Water Analyses (Cont.)

Potassium	Wilcox Group	67	1.670	1.469	1.694	0.6	2.0
Chloride	Holocene Alluvium	73	21.64	16.56	31.74	3.9	29.0
	Tertiary Deposits	28	6.71	6.25	6.52	2.40	9.32

	Claiborne Group	149	8.51	5.76	16	1.9	8.0
	Wilcox Group	67	7.193	6.095	8.086	1.8	11.0
Sulfate	Holocene Alluvium	73	19.84	18.37	18.24	3.7	29.50
	Tertiary Deposits	28	5.31	4.52	7.15	0.81	6.65
	Claiborne Group	149	5.406	4.054	8.238	1.2	5.0
	Wilcox Group	67	6.73	5.13	10.75	1.0	6.70
Silica	Holocene Alluvium	73	22.99	22.94	9.46	15.0	30.5
	Tertiary Deposits	28	22.21	20.87	12.29	14.5	24.25
	Claiborne Group	149	13.397	12.876	6.064	10.0	16.0
	Wilcox Group	67	15.679	15.172	6.064	13.0	17.0
Iron	Holocene Alluvium	73	4.361	3.297	8.109	0.015	8.550
	Tertiary Deposits	28	2.151	7.701	4.458	0.013	0.775
	Claiborne Group	148	1.541	0.727	5.623	0.010	0.7

	Wilcox Group	67	0.827	0.317	2.773	0.009	0.090

All base values in parts per million; Standard deviation is dimensionless; Q1 & Q3 are the upper and lower boundaries of the data spread about the mean; Truncated Mean discards outlier values. The large sample size of the wells screened in the Memphis Sand Unit might tend to bias the comparisons. To explore this effect, 28 samples, the same number as the smallest sample subset, the Claiborne Group, were randomly selected from the larger databases of the other subsets. Table 2 compares the Truncated Means for all eight analytes in these comparably sized subsets.

TABLE 2--Comparison of Truncated Means for Random Samples and the Claiborne Group Subset

Analyte	Holocene Alluvium	Tertiary Deposits	Wilcox Group	Claiborne Group
Calcium	51.41	18.33	9.05	8.75
Magnesium	15.68	8.84	3.63	3.712
Sodium	13.51	9.03	12.89	8.49
Potassium	2.212	1.265	1.27	1.350
Chloride	14.26	6.25	10.98	5.77
Sulfate	14.96	4.52	5.82	4.45
Silica	23.37	20.87	12.86	16.07
Iron	4.45	1.701	1.73	0.978

All values in Parts Per Million

The overall pattern becomes one of higher values in the upper group for calcium, magnesium, and silica, with less pronounced differences in the other analytes, though all analyses were higher in the uppermost deposits.

The averages of the values from the main formations were then graphically compared to examine the overall similarity of the results. The average values in parts per million were converted to equivalent parts per million and the resulting values are virtually indistinguishable, with a slight difference in the Holocene Alluvial's samples.

Conclusions and Recommendations

While there are obvious similarities in the regional averages of the selected anlaytes among the four aquifer groups, the frequency distributions are decidedly non-normal at the regional scale. The chemical data will approximate a normal distribution if transformed to natural logarthim scale; however, the goodness-of-fit values are not high when large amounts of sample data are considered. This variation may be attributed to the range of depth at which a particular named aquifer may be encountered. The Memphis Sand is represented by samples as shallow as twenty-four feet below ground surface and as deep as eight hundred feet below ground. The Holocene Alluvial deposits become thicker near the Mississippi River and receive the added contribution of material leaching from loess deposits, so a well near the Forked Deer River at Jackson Tennessee is grouped with a well near Reelfoot Lake, because they are both in the alluvial deposits. There will be places where the three dimensional aspect of aquifer interaction will delimit one portion of the Memphis Sand Aquifer from another because one part receives water leaking from a perched water table over an old weathered zone in the fluvial deposits while an area nearby receives infiltration as a straight fall through several tens of feet of clean sand. This will become an important consideration in future models of aquifer resource evaluation and potential contaminant impact.

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USE OF LUMPED PARAMETER MODELS FOR WELLHEAD PROTECTION DELINEATION

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Introduction

An important part of developing appropriate wellhead protection areas for a semi-confined aquifer is developing a good understanding of aquifer vulnerability to potential anthropogenic contamination. Typically used particle tracking or fixed radius methods of delineating wellhead protection areas may yield inadequate protection zones in areas where confining units are locally thin or absent. For semi-confined aquifers, wellhead protection areas may be evaluated based upon aquifer susceptibility using a combination of geochemical, hydrogeologic, and tracer data in conjunction with lumped parameter modeling. Wells that receive modern (younger than 50 years) water can be identified using age dating with environmental isotopic tracers such as tritium/helium-3 (3H/3He). In order to better assess aquifer vulnerability, lumped parameter models were developed for several wellheads within the Memphis Light, Gas, and Water Sheahan wellfield in Memphis, Tennessee, and will be calibrated with available tracer data in order to identify the most likely spatial location of a modern recharge source.

Wellhead Protection for Semi-Confined Aquifers

Wellhead protection areas (WHPAs) are defined in the Safe Drinking Water Act as, “the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield” (U.S. EPA, 1993). The goal of wellhead protection is to establish control mechanisms to prevent potential contamination of vulnerable recharge areas to wells. Wellhead protection zones should cover an area adequate to allow remediation of a contamination plume, should it enter the area in the vicinity of a wellhead, before it reaches the well screen (U.S. EPA, 1993).

Semi-confined aquifers are more vulnerable to contamination than completely confined aquifers because avenues exist for hydraulic communication with overlying shallow aquifers. Shallow aquifers are susceptible to potential contamination from anthropogenic sources and spills that may occur on the land surface or in surface water bodies. The Environmental Protection Agency (EPA) warns of the need to consider this potential threat if the potentiometric surface of the semi-confined aquifer has been reduced below that of overlying unconfined aquifers. The concern stems from the potential for downward propagation of water from the shallow aquifers (U.S. EPA, 1993). In such a case, the EPA recommends that extra measures be taken to identify subsurface features that may allow communication between shallow and semi-confined aquifers. The EPA also suggests that tracers such as tritium, which can

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indicate the presence of modern water in an aquifer, be used as a preliminary method of identifying areas where semi-confined aquifers may be most vulnerable to potential contamination (U.S. EPA, 1993).

Lumped Parameter Model Use in Groundwater Systems

Lumped parameter models can be applied to groundwater systems in order to determine hydrologic parameters, sources of recharge, or a type of flow regime, through calibration to available environmental tracer data. Lumped parameter models are characterized by an age distribution function that describes the movement of water from a source of recharge to a discharge location. Several different types of lumped parameter models are applicable to groundwater systems, including piston, exponential, exponential-piston, and dispersion models. For a semi-confined aquifer, the exponential-piston or dispersion models are the only applicable model types (Zuber, 1986; Maloszewski and Zuber, 1996).

The piston flow model requires flow to occur along parallel flow paths from a distant recharge source, while the exponential model includes very rapid travel times that would not occur in a semi-confined system (Maloszewski and Zuber, 1996). The exponential-piston model is modified such that the extremely short travel times are not included, yet the recharge source is in close enough proximity to the well that exponential flow paths are followed. In the exponential-piston flow model, a system is represented as having two components of flow in line, one having an exponential distribution of transit times, while the other follows a piston flow distribution (Maloszewski and Zuber, 1996). The dispersion model introduces into the age distribution function the one-dimensional solution to the dispersion equation for a semi-infinite medium in the flux mode. The theoretical basis for the use of the dispersion model is questionable because the use of such a model involves the supposition that recharge occurs immediately adjacent to the wellhead (Zuber, 1986). However, Zuber reports that very good solution fits can be achieved for some situations with its use (Zuber, 1986).

The use of lumped parameter models assumes a system at steady state with minimal spatial variations. Due to the fact that the models are applied at individual wellheads, the assumption of homogeneity does not introduce as much error as it would for a large system (Zuber, 1986). The advantages to using lumped parameter models are that an extensive data set is not required, and the relative ease of application. Valuable insight can be obtained from as few as two or three environmental tracer data points if used in combination with additional limited knowledge of the system (Zuber and Ciezkowski, 2002).

LPM Application, Memphis, Tennessee

In the current research, the use of lumped parameter models to identify the radial distance to and extent of a recharge source for an individual well is being evaluated for delineation of WHPAs for semi-confined aquifers. The study site selected for this research is the Memphis Light, Gas, and Water (MLG&W) Sheahan Wellfield located in Memphis, Tennessee. The location of the Sheahan wellfield within Shelby County and the Memphis municipal boundaries is shown in Figure 1. This study site was selected due to the wide variety of data available to suggest that certain wells within the wellfield are receiving a component of modern recharge (Brahana and Broshears, 2001; Graham and Parks, 1986; Ivey, 1997; Ivey, *et al.*, 2002; Larsen, *et al.*, 2001; Larsen, *et al.*, 2002; Larsen, *et al.*, in press; Parks, 1990). The MLG&W Sheahan wellfield has been the site of numerous recent geochemical sampling investigations, including sampling for the environmental tracers 3H and 3H/3He (Ivey, 1997; Ivey, *et al.,* 2002; Larsen, *et al*., 2001; Larsen, *et al.,* 2002; Larsen, *et al.,* in press.). This data provided insight into the recharge mechanisms near the wellfield.

Additionally, discontinuities or breaches in the confining unit overlying the Memphis aquifer (in which all Sheahan production wells are screened) have been identified in the vicinity of the wellfield (Graham and Parks, 1986; Ground Water Institute, 2001; Parks, 1990). The potentiometric surface of the Memphis aquifer has been reduced to levels below that of the overlying unconfined alluvial aquifer (Parks, 1990).

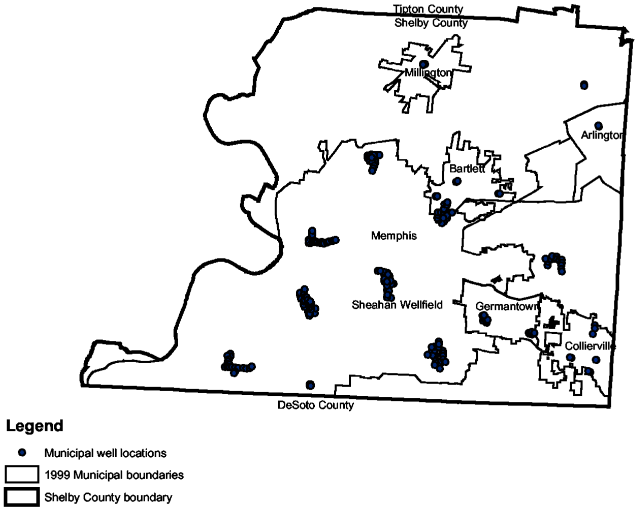

Figure 1. Location of the Sheahan wellfield within Shelby County. Municipal wellfields and boundaries are also shown.

This yields the potential for downward propagation of water from the shallow aquifer through the discontinuities, or "windows," in the confining unit to the Memphis aquifer. Further evidence for leakage from the shallow aquifer into the Memphis aquifer exists in that the water table in the shallow aquifer in the area of the Sheahan wellfield is depressed, as shown in Figure 2, with several shallow observation wells in the field being dry. Because there is no pumping from the shallow aquifer in this area, the depression in the water table surface is indicative of leakage (Graham and Parks, 1986).

Samples were collected from the MLG&W Sheahan wellfield for tritium analysis in fall, 1999 and spring-summer, 2000. From the results of the tritium analyses, five wells were targeted and sampled in the fall of 2000 for analysis of 3H/3He. The results indicated a general increase in age of the water in the sample with depth of the well screen (Ivey, *et al.*, 2002; Larsen, *et al.*, 2002). The five wells, along with an additional production well and the adjacent shallow well, were again sampled in 2002 for 3H /3He analysis. Additionally, geochemical data was collected during the sampling events, and two different types of water were determined to be present in the Memphis aquifer at the MLG&W Sheahan wellfield. The upper part of the aquifer was characterized by water with a higher total dissolved solids (TDS) content and a Na-SO_4-Cl rich composition with higher tritium concentrations, while the lower part of the Memphis aquifer was characterized as a Ca-Mg-HCO_3 type water with a low TDS concentration, and tritium levels near the detection limits (approximately 0.05 T.U.) (Larsen, *et al.*, 2001). This lead to the development of a conceptual model, which incorporated a component of modern recharge, for the affected wells screened in the upper part of the aquifer. However, wells screened at great depth showed levels of 3H indicating they were unaffected by modern recharge, and derived water primarily from a regional flow component. A diagram showing the conceptual model for an affected well is shown in Figure 3.

With the conceptual model for affected Sheahan wells developed from the analysis of geochemical and hydrogeologic data, the exponential-piston model was identified as the most appropriate for representation of wells receiving modern recharge. Four wells, highlighted in Figure 2, were selected for WHPA evaluation using the exponential-piston model due to available data. A tritium input function was developed for the Memphis area using monthly precipitation data obtained from the National Climatic

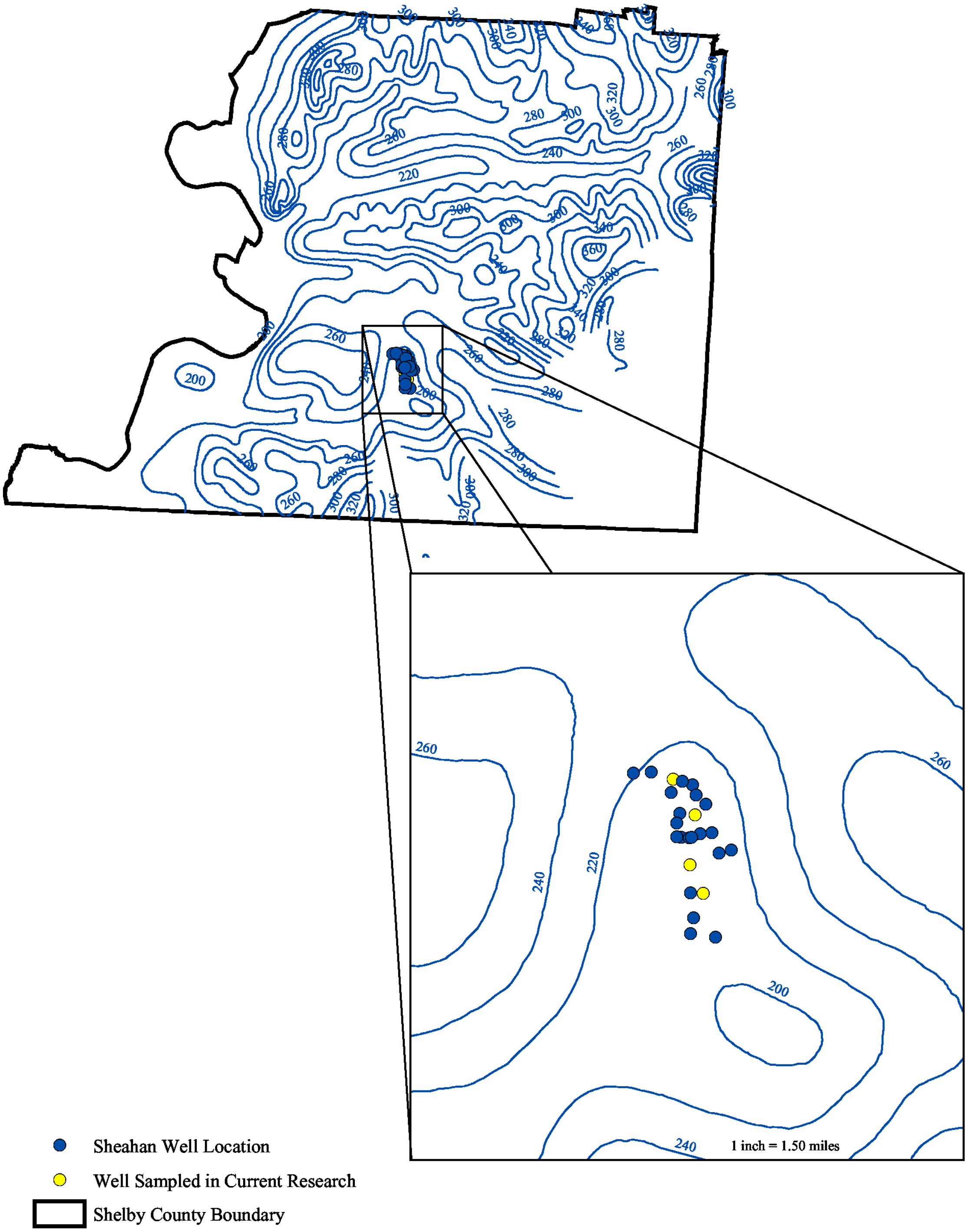

Figure 2. Elevation of the Shallow Water Table, 1988. Datum, MSL; Source: Parks, 1990.

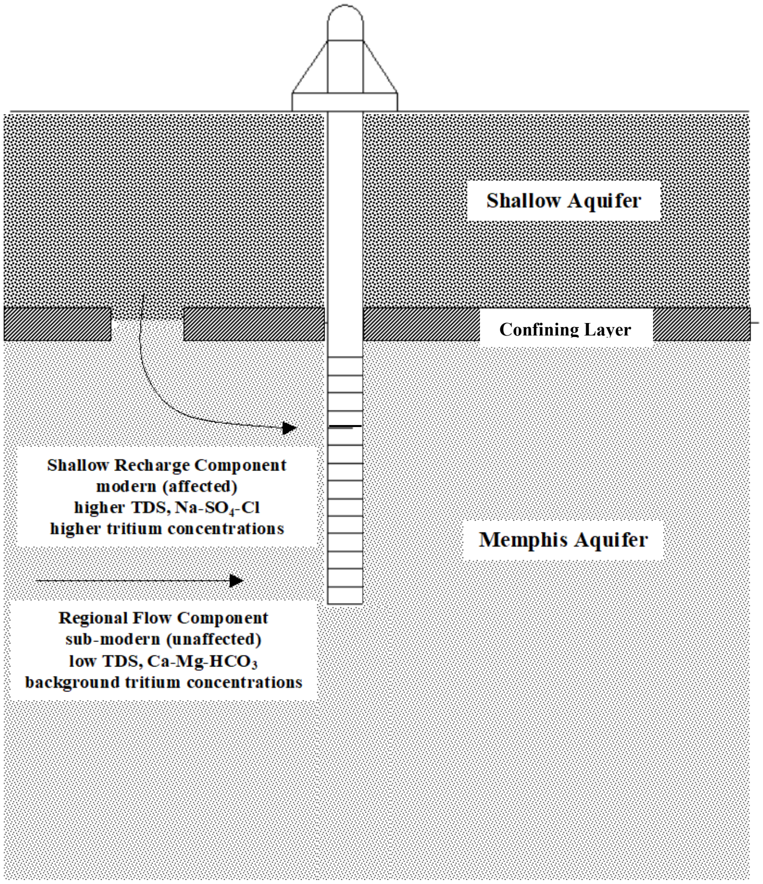

Figure 3. Conceptual Model of Wellhead Flow Regime Based Upon Geochemical Data.

Data Center for a station at the Memphis International Airport, and monthly tritium values for Memphis estimated by a program developed by the United States Geologic Survey (USGS) (Michel, 1989).

An inverse solution procedure was necessary to determine the radial distance to and extent of the recharge source for the wells. A computer program was written for this research to solve the forward problem. This resulted in an estimate of the tritium concentration, which could then be calibrated to available tracer data. Currently, the code is being modified so that it can be used in conjunction with UCODE, a universal inverse modeling code developed by the USGS, in order to automate the solution process (Poeter and Hill, 1998). UCODE was written so that it could be used with any type of application model with numerical input and output, but was specifically developed for use with groundwater problems. Nonlinear regression is used to solve the parameter estimation problem by minimizing a weighted least-squares objective function (Poeter and Hill, 1998).

Once the code for the exponential-piston model is adjusted to work in conjunction with UCODE, the radial distance to and extent of the recharge source for each well can be determined for WHPA delineation. Additionally, UCODE provides a sensitivity analysis so that the reliability of the resulting solution can be evaluated. This approach will allow a WHPA delineation to be made for each well based upon a model that is more representative of the flow system, and which incorporates the unique aspects of the semi-confined system, unlike currently used semi-analytical particle tracking techniques.

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RECHARGE TO THE AQUIFER SYSTEM IN WESTERN TENNESSEE

John K. Carmichael[1]

Ground water is the sole source of public water supply for nearly 1.5 million people in western Tennessee, including about 0.9 million people in Memphis and Shelby County. Although the region contains ample surface-water resources, use of ground water for public supply in the area began in the late 19th century following several surface-water-born disease epidemics earlier in the century. As a result of the importance of this resource, much has been learned about the hydrogeology of western Tennessee over the past 100 years; however, the mechanisms and rates of recharge to the aquifer system remain poorly understood. With demand for ground water in western Tennessee continuing to increase and as development continues in the subcrop and outcrop areas of the Memphis aquifer, the understanding of recharge processes becomes more important as the management and sustainability of this resource is predicated on a balance between rates of withdrawal and recharge.

Recharge in western Tennessee presumably is derived from two sources: direct infiltration of precipitation and, locally, surface-water (primarily streamflow) losses. These two modes represent possible end members of a continuum, with the relative contributions from each dependent on factors such as land slope, vegetation, surficial geology, degree of aquifer confinement, and location relative to major pumping centers (depth to water). The locations of losing or gaining stream reaches and the amount of streamflow lost to or gained from the ground-water system can be obtained by measuring stream discharge at sites of interest in a study area. Because of cost and complexity, however, few studies in western Tennessee have included direct evaluation of water-budget variables such as evapotranspiration and runoff, which exert control on the amount of recharge from infiltration of precipitation to the ground-water system. Furthermore, a poor understanding exists of the mechanisms and rates of water infiltration and percolation through the loess, the principal surficial geologic unit in much of western Tennessee. The effects of long-term and large-volume withdrawals from the Tertiary aquifers and associated water-level declines in these units on drainage of water from shallower zones also is poorly understood, as is whether these withdrawals have resulted in inducing additional recharge from streamflow.

A broad range of techniques for calculating or measuring recharge rates are available, ranging from relatively simple to complex, and generally may be categorized into methods based on water budgets, naturally occurring and applied tracers, streamflow hydrograph analysis, water-table fluctuations, and other techniques. Because of scarcity of water, much of the focus on developing methods for determining recharge rates has been in arid regions; however, many of these techniques also are applicable to regions like western Tennessee with more humid climates. Rates derived from all of these methods generally are regarded as estimates only because of error introduced from spatial and temporal non-uniformity of variables that control recharge.

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Generally, recent recharge estimates for western Tennessee have been made for, or as a result of, ground-water-flow modeling studies. However, because few of the studies have included detailed local assessments of variables that control recharge, the estimated recharge rates span a wide range, varying from less than 1 to as many as 10 inches per year. Methods used to obtain these estimates also vary from model to model, but generally are based on streamflow hydrograph analysis, or are estimated during model calibration based on assumed or known aquifer hydraulic properties and head matching, sometimes with limited or no information on ground-water fluxes into or out of the system, thus resulting in non-unique calibrated model results. Over the last 25 years, the vertical leakage of water downward from the surficial aquifer system to the deeper Memphis aquifer through “windows” in the confining unit separating the two zones has been identified at several locations in the Memphis area. This downward leakage of ground water rather than discharge to surface streams has further complicated flow-model application by removing one side of the flux term that could be used as a verification of recharge estimates in modeling studies conducted in areas containing these features. A better understanding of sources and processes that control rates of recharge in western Tennessee will enhance knowledge of the hydrology of the area and provide for more effective management of the resource by enabling improved simulation of ground-water flow in the aquifer system.

GROUND WATER TRACING AND WATER QUALITY RESULTS FOR SPRINGS IN RUTHERFORD COUNTY, TENNESSEE

Albert E. Ogden, Ph.D.[1], Rebecca James, Ph.D.[2], and John P. DiVincenzo, Ph.D.[3]

INTRODUCTION AND PURPOSE

Twelve successful ground water traces were conducted in 2002 from funding provided by MTSU's Faculty Research and Creative Activity Committee. Nearly all of Rutherford County and approximately half of Tennessee are underlain by limestone or dolomite. Due to the soluble nature of these rocks, karst topography has developed. Karst topography is characterized by numerous sinkholes, sinking and losing streams, karst windows (sinkholes with flowing streams in the bottom), springs, and caves. Ground water tracing using non-toxic dyes is the only way to establish a connection between sinkholes and sinking streams to springs. There are many reasons for conducting ground water tracing in karst terranes, but two of the most important are: 1) for understanding how sinkholes are interconnected to help prevent flooding from new development and 2) for knowing which spring to set up remediation activities should a spill or leak occur within a particular spring catchment area. In addition, by delineating the recharge area for a spring, potential sources of present spring water contamination can be located. This paper will present the tracing results for six springs and summarize water quality data for four of the springs.

STUDY AREAS

Figures 1 through 3 show the location of the springs involved in the research. All of the springs are located in Rutherford County. Murfree, James, Reed, Black Fox, and Oakland Mansion springs are quite large while Discovery Spring and Gaurdrail Spring have significantly less flow. Other springs were monitored during the ground water tracing activities but are not shown on the figures since no positive detection of the injected dyes were found. Water quality samples were collected and analyzed for Murfree, James, Oakland Mansion, and Black Fox springs.

HYDROGEOLOGIC SETTING

Rutherford County is located in the Central Basin physiographic province, which is underlain by limestones of Ordovician age that have been gently upwarped to form the Nashville Dome. The oldest rocks exposed in Rutherford County are those of the Murfreesboro Limestone, which is approximately 400 feet thick. Above the Murfreesboro Limestone is the Pierce Formation a shaly, thin-bedded limestone that confines water beneath it in the Murfreesboro Aquifer and perches water above it in the Ridley Limestone. The Ridley Limestone is the most karstic limestone in Rutherford County. Proprietary files of the Tennessee Cave Survey show that a majority of the 124 caves discovered and explored in Rutherford County occur in the Ridley Limestone aquifer. Snail Shell Cave near

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Rockvale is the largest with over nine miles of passage. All of the springs involved in the study are believed to emerge at the contact between the impermeable Pierce Formation and the overlying Ridley Limestone or the upper Ridley Limestone and the underlying Lower Ridley Confining Unit. Over 70 ground water traces have been conducted in Rutherford County. Approximately 20 have been performed by Crawford (1988) with the remaining conducted by Ogden and Scott (1997), Ogden et.al. (1998), and Ogden and Powell (1999).

GROUND WATER TRACING METHODS

The ground water traces were conducted using the following fluorescent dyes: eosine (pink), sulforhodamine B (red), and fluorescein (green). In addition, a colorless tracing agent, called an optical brightener (Tinopal CBS-X), was used. These tracing agents are non-toxic and routinely approved for use by various divisions of the Tennessee Department of Environment and Conservation. Prior to conducting the traces, the Tennessee Underground Injection Control Program was notified for their voluntary dye registration program. The injected tracing agents were detected by using activated charcoal packets that absorb and concentrate the levels in the water. The charcoal packets, called "traps", were suspended in the waters expected to receive the dyes on a stiff wire connected to a concrete base. Prior to tracer injection into a sinkhole or sinking stream, the traps were placed in the spring waters for approximately a week to test for background concentrations. The dyes are common coloring agents and frequently found as "contaminants" in the ground water. Optical brighteners are used in laundry detergents to “brighten” clothing and as a result, are also often found in karst ground waters. Once background levels were determined, new packets were set out immediately prior to injection. After injection of the tracing agents (usually during or soon after a storm event), the packets were changed at 5 to 10 day intervals and sent to the laboratory for analysis.

WATER SAMPLING AND ANALYSIS METHODS

Sampling began in September and will continue through the spring. Several field parameters were measured and utilized as pollution indicators. Conductivity was measured with a YSI Model 33 S-C-T Meter. Nitrate (NO_3^-), Ammonia (NH_3), and pH levels were determined using a HACH analysis kit. Dissolved Oxygen (DO) levels and temperature measurements were obtained using a Control Company DO Membrane Electrode with temperature probe. The grab sampling technique (Standard Methods 1995) was employed and the samples were preserved at 4 ± 1°C until taken to the laboratory for analysis. Standard Methods (1995) were used in measuring BOD_5, DO, and COD. The BOD_5 measured for the samples was determined as the sum of carbonaceous and nitrogenous demands because a nitrification inhibitory chemical was not used. DO levels were determined using a Winkler titration. The COD of the samples were determined by the Closed Reflux, Colorimetric Method.

TRACING RESULTS

Oakland Mansion Spring, Murfree Spring, and Discovery Spring

One dye trace was previously conducted to Oakland Mansion Spring by Ogden and Powell (1999). Oaklands Mansion Spring is located in the City Limits but receives some recharge water outside of town (Figure 1). Dye for the first trace was injected into a shallow sinkhole behind the Slick Pig Barbecue Restaurant and the Grogg Shoppe. The dye traveled nearly two miles in three or less days indicating open subterranean drainage pathways. Two new dye traces were conducted from storm water runoff from MTSU that sinks into the ground. Both traces were performed the night of January 11th during a storm event. One-half pound of fluorescein was injected into a small hole in the bottom of the drainageway next to Bell Street Parking Lot (Figure 1). Then, one pound of sulphorhodamine B was injected into a sinkhole in a wooded area behind Scarlett Commons. There was enough rainfall to form a sinking stream next to Bell Street so the dye moved rapidly to Oakland Mansion Spring. The dye was detected from "traps" removed just two days after injection. The sinkhole behind Scarlett Commons did not receive storm runoff that night. A moderate flooding event did occur to push the dye through the subsurface approximately three weeks later. The dye was detected at the spring from samples removed on February 1st.

The three traces that have now been conducted to Oakland Mansion Spring enable an accurate delineation of the catchment area for the spring. Previous tracing to Bushman Spring (Ogden, 1997) established the eastern divide. Therefore, nearly all of the runoff from MTSU that sinks into the ground emerges at the spring. In addition to runoff from parking lots and streets, there is a large cemetery, two gas stations, and possibly the hospital in the recharge zone that have the potential to contribute contaminants to the spring.

One dye trace was successfully completed to Murfree Spring by Ogden and Powell (1999). Murfree Spring is quite large and was once used as the City water supply. Although the spring is located in the City Limits (Figure 1), it undoubtedly receives recharge from more distance points in the County. The 1999 dye trace was from a sinkhole receiving the water that moves over the dam forming Todd Lake. The water that feeds Todd Lake comes from Blackfox Wetlands, which begins at Black Fox (Fox Camp) Spring located along Red Mile Road. One new trace was conducted to Murfree Spring from a large sinkhole behind Krogers and Freds off Tennessee Boulevard. Two separate sinking streams enter the sinkhole during large storm events. In addition, a large pipe that carries storm water occurs along the edge of the sinkhole. One half pound of fluorescein was injected into the sinkhole the night of January 11th during a storm event. The charcoal packets retrieved from the spring just two days later tested positive for the dye indicating rapid conduit flow conditions and little or no filtration of any contaminants that enter the subsurface.

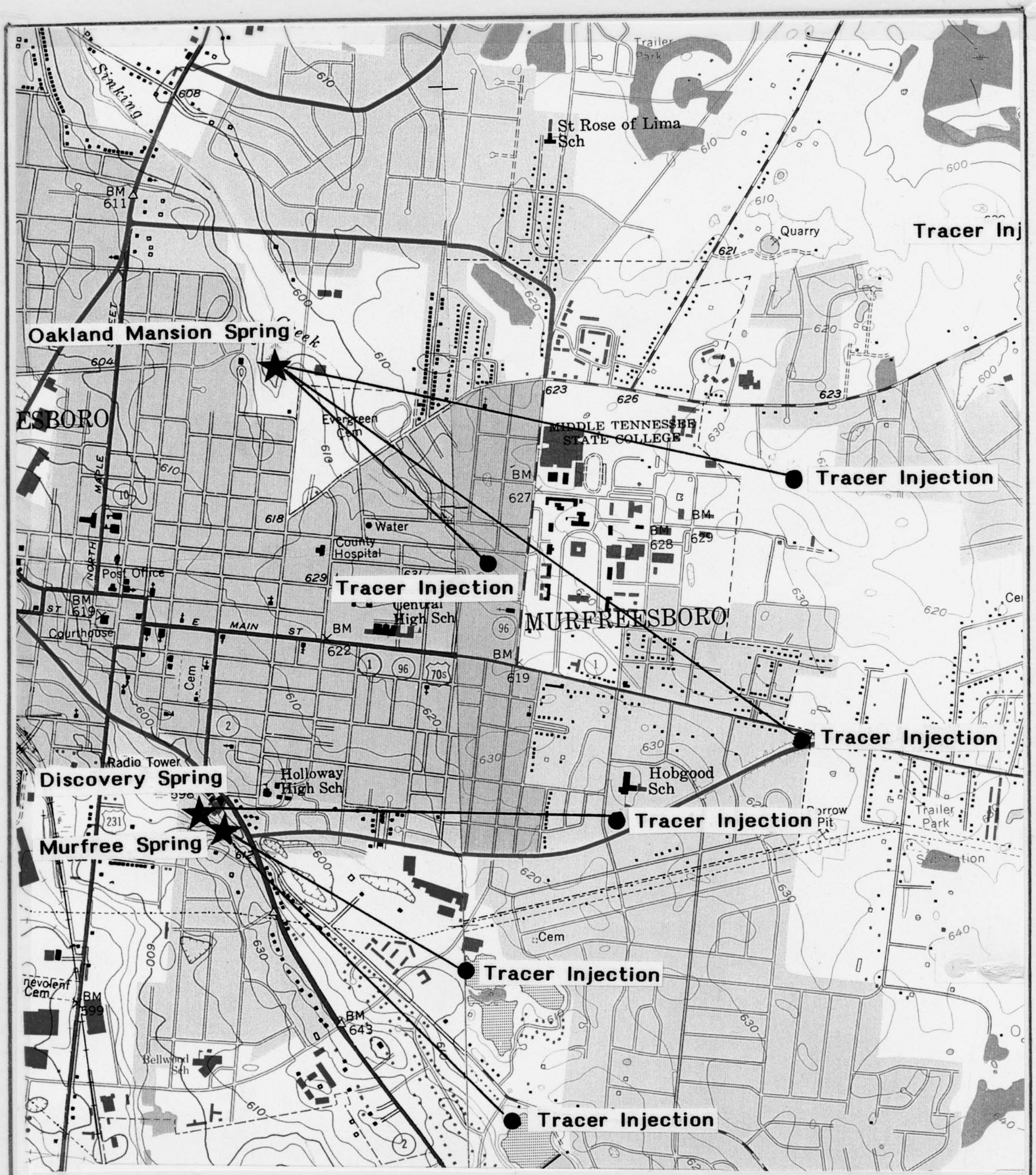

Figure 1. Tracing results for Murfree, Discovery, and Oakland Mansion springs.

Runoff from many store parking lots, as well as from the streets and yards of a large older subdivision, enters the sinkhole during storms. Numerous potential pollution sources other than street runoff occur in the recharge zone of Murfree Spring. Examples include gas stations, dry cleaners, and auto repair shops.

Two initial attempts to trace water that sinks during storms in a drainageway by Hobgood School failed (Figure 1). It was thought that the dye would emerge at either Murfree Spring or Oakland Mansion Spring. Discussion of these failures with one of the City engineers led to the discovery of a spring below the construction site of the new Children's Discovery House. The spring actually emerges within an abandoned settling basin of the old City Water Treatment Plant. The city engineer said that an overflow pipe from the basin pours water into Lytle Creek even during the driest of summers. Therefore, a spring must occur within the basin below the water surface. We named the spring, Discovery Spring. A third dye trace was conducted on March 4th using three-quarters pound of fluorescein. The fire department provided flush water to help move the dye through the subsurface. The dye detector retrieved at the pipe seven days later tested positive for fluorescein, as well as, the eosine used in one of the previous tracing attempts. The trace was important in defining the subterranean flow regime for the area between the Murfree and Oakland Mansion spring basins. Most of the recharge area for Discovery Spring is residential, but at least one auto repair shop occurs within the drainage basin. Potential contaminants include petrochemicals dripped onto streets and parking lots, as well as, lawn chemicals.

James Spring

Two ground water traces were conducted to James Spring. Prior to the present research, the source of the spring water was unknown. James Spring is a very large spring that discharges into the East Fork of the Stones River approximately 2000 feet downstream from the bridge on Guy James Road (Figure 2). Both traces were performed on January 16th during a storm event. For the first trace, three-quarters pound of fluorescein was injected into a stream entering a short cave where Factory Road intersects Halls Hill Pike. Three-quarters pound of sulphorhodamine B was then injected into a trash-filled sinkhole along Smith Hall Road. James Spring and Compton Spring (located in Compton) were monitored for the dyes. Both dyes were detected at James Spring from the charcoal packets retrieved six days after dye injection.

Although the recharge area for James Spring is suspected to be much larger than the two traces suggest, few significant potential contaminant sources are believed to exist in the suspected recharge zone. The area is quite rural with much of the land being forested or in pasture. Disposal of wastes into sinkholes could lead to pollution of the spring. Unfortunately, rural residents in karst terranes too often view sinkholes as places to dump garbage, metal trash, construction debris, and dead animals. Therefore, low volume pulses of a large range of contaminants may exist in the recharge area.

Reed Spring

Cripple Creek has a large drainage basin by the time it crosses under the new Woodbury Highway, but seldom does water flow under the bridge. Even after large storm events, the creek ceases to flow within a few days, and seldom reaches its confluence with the East Fork of the Stones River. The initial hypothesis was that the sinking waters of Cripple Creek emerge at James or Compton spring. Hiking of over a mile of creek below the bridge found numerous sinkholes in the bed of the stream. Many trips were taken to the creek to find optimum flow conditions for dye injection into a creekbed sinkhole. Time after time, the creek was either not flowing or flowed all the way to the river. As an alternative, five pounds of optical brightener were injected into a sinking stream near the intersection of Coleman Road and the new Woodbury Highway. Optical brighteners were used since there was the risk of turning the creek colored at its lower reach where a "blue-hole" was found in the dry creekbed that becomes a spring during higher flow conditions. Unfortunately, the optical brightener was never detected at either of the monitored springs. Thus, a search for another large spring was made. As a result, Reed Spring was found (Figure 2).

After re-establishing background levels of tracing agents at Reed Spring, flow conditions of Cripple Creek were observed. Once again, an optimum flow to reach a sinkpoint, but with no continued flow to the river, could not be found. Finally, it was decided to inject optical brightener into a pool formed by the State permitted discharge of Kittrell School treated sewage into the dry creekbed. Two pounds of optical brightener were injected into the pool on May 13th. The optical brightener was detected at Reed Spring, which is approximately 1½ miles north of the injection point. The tracing agent was also detected at the overflowing blue hole in the streambed.

The recharge area for Reed Spring is very rural and potential source of contaminants are limited primarily to what is dumped into sinkholes or that runoffs pasturelands during storm events. The results of this trace will prove quite useful for emergency response if a tanker truck were to overturn, for example, within the Cripple Creek drainage basin and sink into the ground. Response teams will now know to immediately set up remediation activities at Reed Spring.

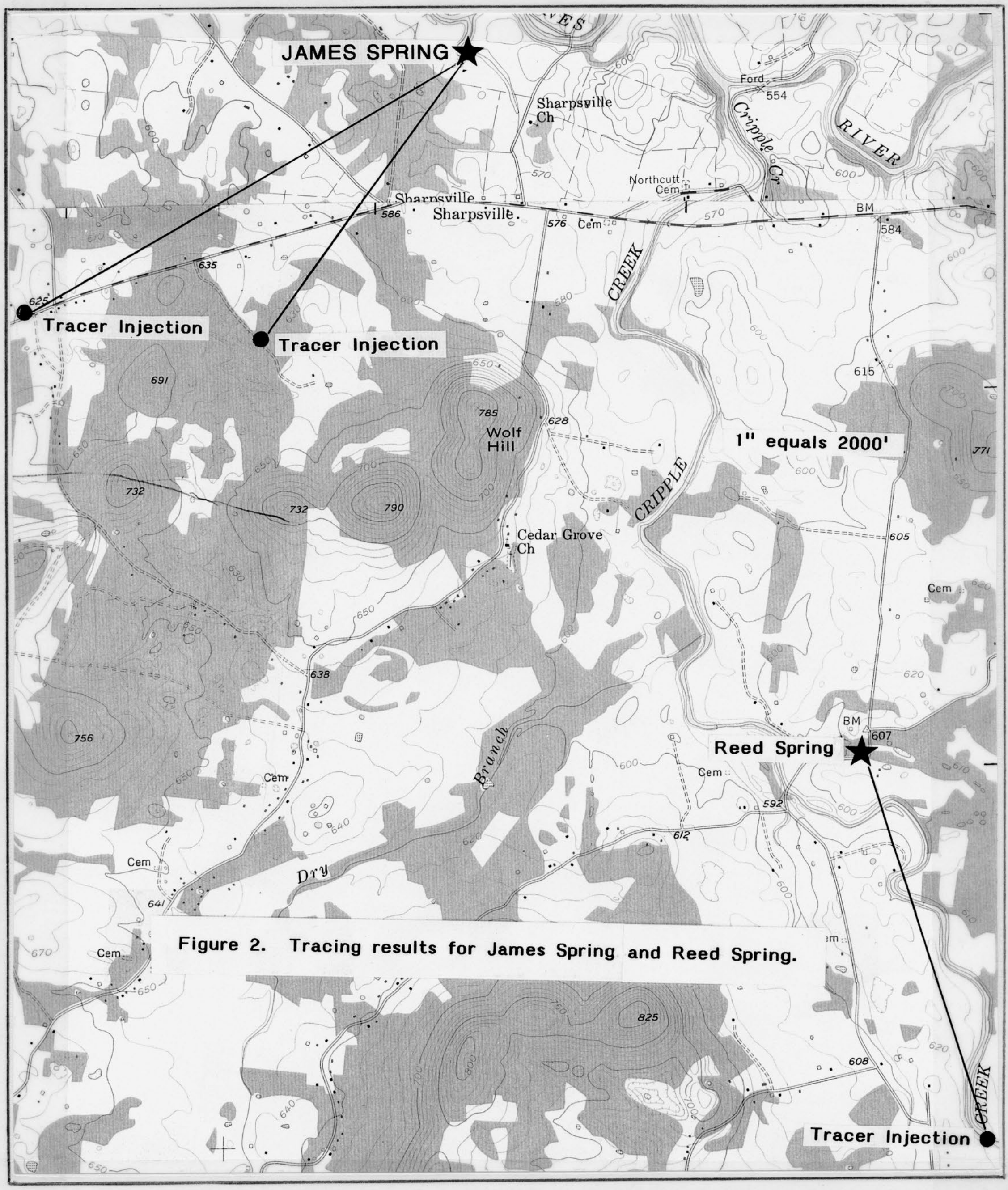

Figure 2. Tracing results for James Spring and Reed Spring.

Gaurdrail Spring and Black Fox Spring

One of the initial objectives of the research was to determine the source of Black Fox Spring. Previous ground water tracing in Rutherford County has shown that most ground water moves in a north/northwest direction. Therefore, sinkholes that could be used as dye injection points were located approximately three miles southeast of the Black Fox Spring. Dye detectors were placed at Black Fox Spring, Less Spring, Gaurdrail Spring, and in Lytle Creek (Figure 3). Black Fox Spring is not shown on the figure but is located about one mile north of Less Spring. On January 27th, one pound of fluorescein was injected into a sinkhole on a farm. A large storm the previous night caused a small stream to enter the injection point. An even larger storm event occurred soon after dye injection. As a result, the Middle Fork of the Stones River inundated Gaurdrail Spring. When the dye detectors where retrieved and analyzed, Gaurdrail Spring was the only monitoring location that showed elevated levels of fluorescein. Since fluorescein is the component that gives antifreeze its green color, it is commonly found in surface and karst ground waters due to poor disposal practices associated with changing radiator fluids in winter months. Therefore, the levels of detected fluorescein were insufficient to call the trace a positive. A second trace using one pound of sulphorhodamine B was then performed on February 2nd on same farm, but from a different sinkhole that had water entering it from an overflowing farm pond. The dye was detected at Gaurdrail Spring, confirming that the first trace was a positive, as well.

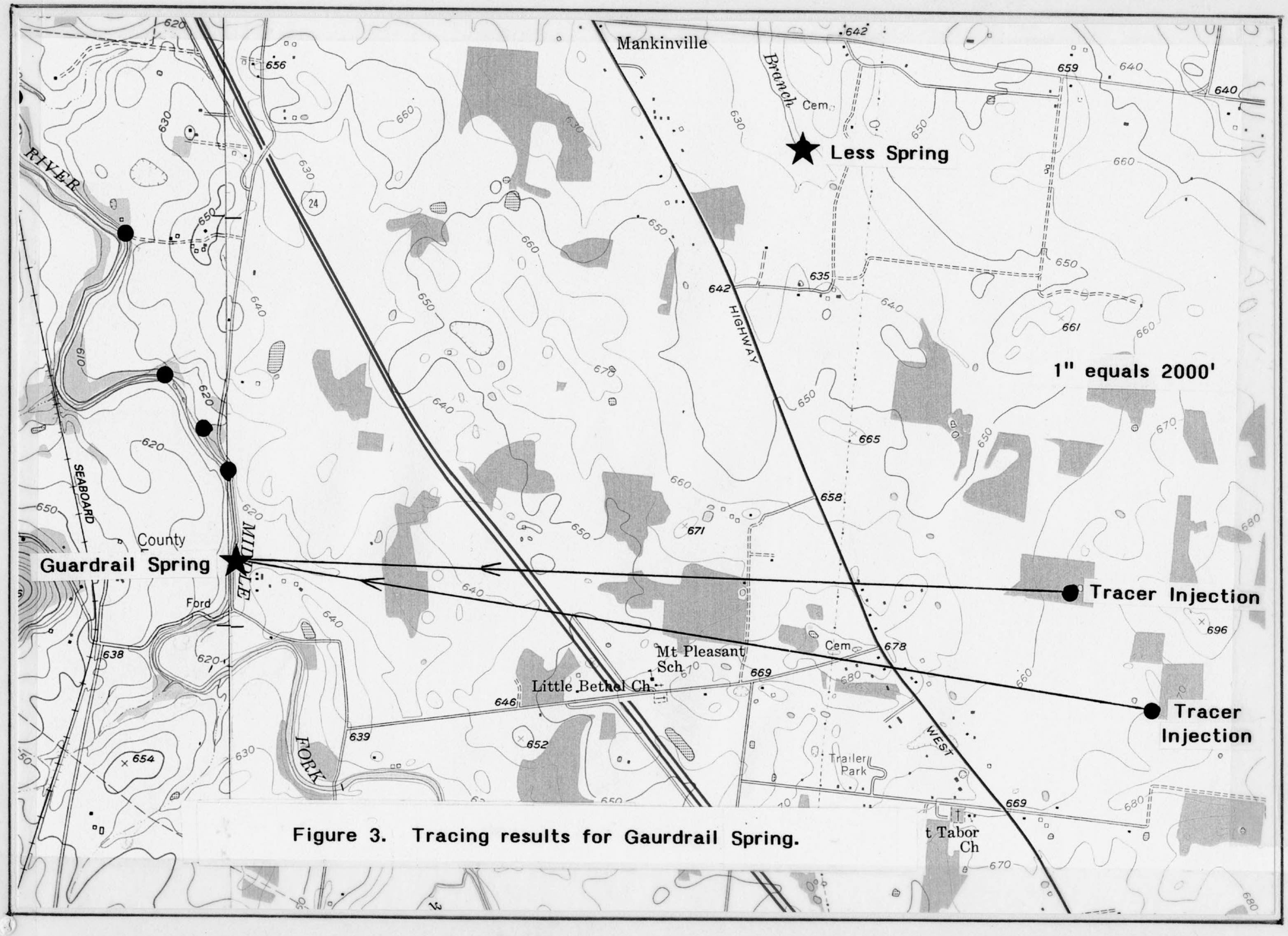

Figure 3. Tracing results for Gaurdrail Spring.

WATER QUALITY RESULTS

Black Fox and Oakland Mansion Springs were sampled on seven different dates, while Guy James and Murfree Springs were sampled on six of those same dates. The pH of all springs remained fairly constant throughout the sampling period. All springs showed low nitrate, ammonia, and BOD_5 levels. Although the COD levels were also low, they were greater than BOD_5 levels in all instances. This suggests either the presence of nonbiodegradeable organics or reduced metals. Preliminary results suggest that the COD levels in Murfree Spring, the most urban spring, may be higher than the other three springs. COD levels could also be correlated with rain events. The highest levels typically occurred during periods of no rain. Dissolved oxygen levels for all springs were lowest during September (≤ 5.0 mg/L) and highest during November. This is expected due to cooling temperatures. DO levels in all springs, except Guy James, the most rural spring, remained below 6 mg/L throughout the sampling period. Oakland Mansion Spring always showed the lowest level of DO (< 4.4 mg/L). This spring also consistently showed the highest conductivity measurements. Murfree Spring showed the greatest variability in conductivity with a range of 116 (µmhos/cm). Conductivity increased, as expected, during rainfall events. The temperature of all springs, except Murfree, was fairly constant throughout the sampling period. This may be due to Murfree Spring's small storage capacity and the influence of stormwater runoff entering sinkholes close to the spring orifice.

SUMMARY, CONCLUSIONS, AND DISTRIBUTION OF THE RESEARCH RESULTS

A total of twelve ground water traces were performed. The results show that stormwater and the contaminants it carries enters sinkholes and sinking streams and then moves rapidly through open caves to springs. As a result, little filtration of contaminants occurs in the subsurface. The tracing results will help identify potential responsible parties for any levels of contaminants found. The results have also led to a better understanding of how sinkholes in the area are interconnected within the spring basins. This will help in designing drainage from new development to help prevent flooding problems. A copy of the results has been given to the Rutherford County Planning Commission and the City of Murfreesboro. In addition, a report of the tracing results has been given to TEMA where it will be useful for emergency response should spills occur along any highway near the dye injection points involved in the study. The information gained from the research will enable TEMA to know which spring is connected to such a spill site so remediation activities can begin immediately.

Preliminary results suggest that the two most urban springs, Murfree and Oakland, show signs of water quality degradation. The springs show depressed DO levels, and elevated COD and conductivity levels. Sampling is on-going and will continue until May 2003. During that time, samples will be taken of stormwaters entering sinkholes, as well as, the springs, and total petroleum hydrocarbon (TPH) will be added to the list of parameters measured.

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SIMULATING 148 YEARS OF HYDROLOGICAL RECORD TO EVALUATE ECOLOGICAL CHANGE IN A FORESTED WETLAND

William J. Wolfe[1]

A simple water-balance model was developed and applied to Sinking Pond, an 80-acre forested wetland draining 830 acres on Arnold Air Force Base near Manchester, Tennessee. Sinking Pond is a seasonally flooded karst depression that supports a forest of water-tolerant oaks and other trees. The model was developed to reconstruct historical hydrological conditions in the pond to help evaluate apparent changes in tree regeneration. Previous investigations noted an absence of saplings in the deep interior of Sinking Pond, and repeated seedling-plot censuses, spatial analysis of tree and sapling size classes, and tree-ring analysis all indicated a temporal shift in tree regeneration and recruitment that suggested an abrupt and sustained change around 1970 to hydrological conditions considerably wetter than the historic norm.

For each daily time step, the model solves water-balance equations for the drainage-basin vadose zone:

$$BP = \Delta SB + BG + BR + BE,$$

and for the flooded area of Sinking Pond:

$$PP + BR = \Delta SP + PG + PR + PE,$$

where

BP is precipitation falling on the basin outside the pond;
ΔSB is the change in water storage in the basin vadose zone outside the pond perimeter;
BG is water flux from the basin vadose zone to ground water;
BR is surface-water runoff from the basin to the pond;
BE is evapotranspiration from the basin outside the pond;
PP is precipitation falling on the pond;
ΔSP is the change in water storage in the pond;
PG is water flux from the pond to ground water;
PR is surface runoff from the pond; and
PE is evapotranspiration from the pond.

Primary model input data are daily temperature and precipitation recorded at Tullahoma, Tennessee, from 1893 through 2002. The analysis was extended back to 1854 by disaggregating monthly temperature and precipitation records from Manchester, Tennessee (1872-1893), and Clarksville, Tennessee (1854-1872).

Model output is a time series of daily estimates of pond stage, surface-water outflow, ground-water recharge, and evapotranspiration. The model was calibrated using 2 years of published water-level and streamflow data from Sinking Pond recorded from February 1993 through February 1995. After calibration, simulated Sinking Pond water

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levels were compared to observed water levels recorded in Sinking Pond from October 1999 through September 2002. In all 3 years, the simulated water level lagged behind the initial seasonal rise in Sinking Pond by several days, but closely tracked winter storm peaks, the seasonal recession, and final draining event.

Applying the model to the input data set produces a simulated hydrological record showing increasing frequency, depth, and duration of inundation through time. Of 89 water years from 1855 through 1943, 46 (52 percent) show filling above the spillway elevation of 1,064.7 feet above the North American Vertical Datum of 1927 (NAVD27). For the period 1943 through 2002, filling exceeded the spillway elevation in 51 of 59 water years (86 percent). For the entire 148-year simulation, annual duration of inundation exceeded 200 days at some elevation in the pond in 38 years. Half of the years (19 of 38) having simulated inundation of 200 days or longer occurred in the 36-year period between 1968 and 2002, which represents 24 percent of the simulated record. Of water years in which duration of inundation exceeded 200-days, the median 200-day water-surface elevation prior to 1968 is 1,061.7 feet above NAVD27, and the maximum elevation is 1,063.8 feet above NAVD27. For the period 1968 through 2002, the median and maximum 200-day water-surface elevations, in feet above NAVD27, are 1,062.5 and 1,064.1, respectively.

Comparison of simulated 200-day water elevations with the ages and apparent germination dates of 48 oak trees sampled across the elevation gradient of the pond shows a strong relation between changes in tree regeneration patterns after about 1970 and the simulated hydrological record of Sinking Pond. Thirty-eight trees with germination dates between 1856 and 1969 were sampled elevations ranging from 1055.2 to1,062.9 feet above NAVD27. Ten trees dated between 1982 and 1987 were confined to a narrow elevation range of 1,063.0-to-1,063.3 feet above NAVD27; the upper limit of the elevation distribution for pre-1970 trees coincides with the lower limit of the distribution for post-1970 trees. Together, the botanical evidence and the results of hydrological modeling indicate that increasingly wet hydrological conditions driven by climate have altered the ecological balance of Sinking Pond.

COMPLEX CHANNEL EVOLUTION IN DRAINAGE CANALS OF WEST TENNESSEE AND NORTHERN MISSISSIPPI

Timothy H. Diehl[1] and Douglas P. Smith[2]

Watersheds of West Tennessee and northern Mississippi provide an opportunity to study a multi-decadal, large-scale watershed response to historic channelization. At least 150 reaches in the region are characterized by extreme aggradation and complex evolution. Examples in Tennessee illustrating evolution after channelization include Cypress Creek near Ramer, the South Fork Obion River at Jarrell Bottoms, and Stokes Creek.

Cypress Creek underwent channel blockage and avulsion followed by a channel evolution sequence including erosion of new channels, reoccupation of historic meanders, and continued occupation of non-occluded canal reaches. The head of the valley plug is currently migrating up-valley at approximately 30 meters per year.

The South Fork Obion River underwent channel blockage, valley-wide ponding, valley aggradation, and valley-wide conversion from forest to marsh. The evolution of the channel and floodplain involved incision of new channels and reoccupation of old meanders and non-occluded canal reaches.

Stokes Creek avulsed where a relatively steep reach of its canal entered the nearly flat floodplain of the North Fork Forked Deer River. The Stokes Creek valley plug includes a network of small braided and anastamosing channels developed upon a sandy alluvial fan.

The many aggradational reaches documented in the region share several characteristics: (1) the canal is filled or buried by sediment; (2) the system locally develops multiple channels; and, (3) in some cases, valley plugs foster the downstream development of stable channels by locally storing excess bedload on the floodplain. Valley plugs and alluvial fans can form at any time following channelization in response to a variety of causes.

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WOLF RIVER RESTORATION PROJECT

Richard Hite[1]

The Wolf River, which is 86 miles long, rises near the western edge of Tippah County, Mississippi and flows across Benton and Marshall Counties, Mississippi. It then enters Tennessee and flows through Hardeman, Fayette, and Shelby Counties to the Mississippi River near the center of Memphis. The major water resource problems of the Wolf River Basin are centered around headcutting in the channel of the lower Wolf River, urbanization, and sediment deposition in the upper basin. The upper and lower basins are quite different in character with their problems being very different. In the lower basin, the channel is headcutting and the adjacent wetlands are becoming too dry to support some wetland species. In the upper basin, the channel is filling with sand and the adjacent bottomland hardwoods are becoming too wet to support hardwoods. After a complete evaluation of the completeness, effectiveness, and efficiency of the alternative plans along with the evaluation of the environmental and economic impacts, both positive and negative, a final plan was selected. The features of this plan include: six channel stabilization weirs and seven tributary weirs, channel cut-off prevention, trails, boat ramps, and a wildlife corridor. This plan provides the highest level of environmental benefits which would help restore, enhance and preserve the Wolf River ecosystem. Negative environmental impacts of this plan, expected from construction activities, were minimal and greatly offset by the positive environmental effects of the project. Implementation of the recommended plan will improve both terrestrial and aquatic habitat in and around the Wolf River, provide habitat for waterfowl, and create economic benefits in the Shelby County area. The recommended plan will provide 2,056 Annualized Habitat Unit Values (AHUVs), 210,277 waterfowl use days annually, and $734,070.00 in recreation benefits at a total cost of $10,933,000. This project will help to return the Wolf River to a more natural and historic condition and protect the upper river from damage by the headcutting.

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DRAKES CREEK ECOSYSTEM RESTORATION PROJECTS
HENDERSONVILLE, TENNESSEE

Wayne S. Easterling[1]

INTRODUCTION

Drakes Creek in Sumner County, Tennessee, drains about 38 square miles, and forms a 4-mile long embayment on Old Hickory Lake. Non-point source sediment, from agricultural runoff, streambank erosion, and new construction, created a silt delta at the conjunction of the stream and the reservoir. More than a mile of the 4-mile long embayment had filled in. As a result, boating became hazardous, recreational opportunities were diminished, the fishery suffered, and exotic plant species such as purple loosestrife (*Lythrum salicaria*) were established within the area.

The City of Hendersonville asked the Corps of Engineers for assistance in cleaning out the embayment; however, the proposal was focused on restoring recreation and aesthetics. A reconnaissance study was completed and core samples were taken in the early 1990s. Because recreation is a low priority item no further actions were taken until the Corps was directed to study the matter under its relatively new ecosystem restoration program in 1997. Congressional direction authorized two projects in Drakes Creek, however, for practical and public relations reasons these have been treated as two phases of a single project. Phase 1 has been completed and is described in this paper. Phase 2 is currently under construction and should be completed by 2004.

PROJECT ASSESSMENT AND DESIGN

The Corps reviewed the project with a view toward ecosystem restoration as opposed to simple recreational dredging and identified as many problems as possible to determine what, if anything, could be done to improve the situation. Among the problems identified were:

- High sediment deposition rates resulting in shallow water and poor substrate
- Poor water quality conditions including low dissolved oxygen (DO), high biological oxygen demand (BOD), temperature extremes, and high organic loading
- Degraded habitat, particularly for fish and benthic organisms
- Invasive exotic species such as purple loosestrife
- Little or no beneficial vegetation
- Fish populations skewed toward undesirable species
- Excessively large waterfowl population
- Lost recreational access and opportunities
- Poor aesthetics
- Limited dredge disposal sites due to urban location

The initial design was fairly simplistic. The local fishery could be improved by creating several deepened holes and adding structures and protected nursery areas. However, from an engineering perspective such a plan was not practicable because any holes that were created would soon be refilled by the slumping of the surrounding unconsolidated substrate and by new, incoming sediment. Furthermore, the problem was compounded due to its urban setting and lack of a suitable disposal area nearby.

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The Corps' authority and direction was based on environmental concerns. The city's primary goals, however, were to improve the aesthetics and recreational opportunities.

It became clear that the deposition of sediment and the large flock of waterfowl caused most of the problems. The Corps does not have the authority to address the non-point sources of the sediment outside of the project area. That left two alternatives: either find a way to prevent the sediment from settling in the project area, or try to minimize its impacts and deal with it through routine maintenance.

Phase 1 was located immediately downstream of the Highway 31E bridge adjacent to Memorial Park and around a small island. The area is extremely visible and is heavily used by the pubic. To prevent new sediment from entering the area, the Corps elected to cordon the area off with a dike, leaving only a narrow channel at one end. This created a 13-acre sub-embayment. Dredging was required to deepen a portion of the sub-embayment to depths of up to 6 feet to remove the undesirable loose substrate. The remaining substrate was primarily gravel and bedrock. Wetlands were established in the remaining shallow areas of the sub-embayment to provide food and cover for juvenile fish.

The greatest problem to overcome was disposal of the dredged material. Approximately 150,000 cubic yards of material were to be removed. Normal hydraulic suction dredges only remove five to ten percent solids. That meant that as much as 2,000,000 cubic yards of low density material would have to be stored and dewatered. As the project area is in the middle of a developed urban setting, no suitable disposal site was readily available, and open water disposal was considered inappropriate for an environmental project. This problem was resolved by combining two technologies that have not previously been used by the Nashville District. The first technique involved a relatively new dredging method that produced disposal material containing about forty percent solids. This was accomplished by using a mechanical excavator to place the material in a hopper. A concrete pump in the hopper then pushed the material to the disposal site. The second technique involved using geotubes. Together these techniques significantly reduced the volume of sediment handled.

Geotubes were used to construct the dikes that formed the subimpoundment and disposal containment areas along the shoreline. When filled to capacity each geotube holds about 800 cubic yards of solid material. This also allowed the sediment to be used as construction material. Initially, the tubes appeared unnatural and obtrusive, but no more so than riprap. During the growing season, however, the sides became covered with vegetation from volunteer sources. In addition, approximately 1,000 bare root trees were sprigged through the geotextile into the consolidated dredged material. After only a few years the rooted vegetation is giving the geotubes the appearance of a natural riparian bank.

Geotubes are large tubes constructed of geotextile materials. Dredged sediment was pumped into the tubes and the geotextile fabric trapped the solid particulates, even the fine silts and clays, while allowing the excess water to drain. There was no visible sediment plume throughout the disposal process.

The large flock of resident waterfowl, more than 2,000 at times, was of concern for several reasons. They added 2 to 3 tons of organic waste to the area daily. Not only was this visually offensive, the waste directly affected the DO, BOD, and nutrient levels that lead to algae blooms. In addition to the hundreds of loaves of bread and other goodies provided by the public, the birds ate virtually all leafy riparian vegetation, preventing wetland vegetation from becoming established. The birds also serve as decoys to migratory birds. There was a fear that the severe overcrowding could lead to an outbreak of an avian disease that could be spread throughout the flyway. Although few diseases are transmitted across species lines, several notable diseases including salmonella and botulism are endemic within the population and created a concern for human health.

The Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, Texas, was asked for assistance in establishing viable wetland plants in the sub-impoundment. All plants were to be native to Tennessee and were selected for their suitability to this specific site. During July 2001, 18 species of aquatic plants were introduced into shallow water areas of the sub-embayment (0-3 feet in depth) to promote the development of desirable wildlife and fisheries habitat. Species selected for this project included submersed, floating-leaved, and emergent forms. Exclosure cages were used to protect plants from the feeding activities of aquatic grazers (carp, turtles, waterfowl, and muskrats), ensuring that plant colonies hade the opportunity to become established.

PROJECT RESULTS

Phase 1 has been completed and shows signs of being a great success. Phase 2 is still under construction and is benefiting from the lessons learned on Phase 1. The experimental use of geotubes has proven to be very satisfactory for some applications. The geotubes reduced the cost of constructing similar structures from riprap by approximately one third, and were rapidly colonized by creeping primrose (*Jussiaea repens*), smartweed (*Polygonum hydropiper*), black willow (*Salix nigra*), and cottonwood (*Populus deltoides*), as well as a number of species of grasses, rushes, and sedges.

Simply removing most of the waterfowl had a tremendous impact on the area. To date about 2,300 waterfowl have been removed from the area. Since the birds removal, a number of species of rush and sedge voluntarily appeared and colonized the area. In addition, the decrease in organic loading significantly improved water quality. Although the final report is not yet available, preliminary results indicate that water clarity within the lagoon, as measured with standard secchi readings, has at least doubled from 0.7 to 1.4 feet. Furthermore, pH decreased from recorded high of 10.5 to as low as 7.1.

Dr. Amundsen of the University of Tennessee and several of his students performed an independent study of the area, comparing post-project to pre-project conditions. In addition to measuring and recording some of the data above, his students also identified and recorded more than 200 species of vascular plants around the sub-embayment, about 30 of which had never before been recorded in Sumner County.

Several times over the following year LAERF personnel monitored the area. An assessment conducted during September 2002 found that the plants were doing well, in many cases better than expected, and all cages had plants within them. Evidence of waterfowl and muskrat grazing remained on some plants, but the plants seemed to be withstanding the herbivory. Softstem bulrush appeared to be the most heavily impacted by grazing (muskrats). Water willow was doing well, with no signs of grazing. Arrowhead, bluetongue, and creeping burhead had filled the small ring cages in which they were planted.

A number of species were noted to have spread beyond protected areas. Species exhibiting direct growth from cages included American pondweed, Illinois pondweed, eelgrass, water stargrass, white water lily, pickerelweed, lizard's tail, flatstem spikerush, slender spikerush, and water willow. Unprotected growth away from cages (from fragments or seeds) included American pondweed, water stargrass, arrowhead, bulltongue, arrow arum, and pickerelweed. In many cases, it appeared that water primrose was “masking” other species, effectively protecting them from herbivores.

Two problems were encountered with the geotubes. They were fabricated from two layers of geotextiles. The outer layer was intended to absorb ultraviolet light and protect the inner layer. Within 12 to 18 months, the outer layer had deteriorated and had large holes exposing the inner layer. The inner layer consists of an extremely tight weave. Although it is permeable enough to allow water to pass, roots of colonizing plants have been unable to penetrate the fabric. The colonizing plants are only able to establish themselves as high up the sides as the water wicks, i.e., about two feet. The exposed tops of the geotubes remained barren. To counter these problems two 50–foot experimental sections were established. The first section was heavily sprigged. The resulting vegetation effectively screened the geotube from the damaging effects of the sun.

A shroud of degradable planting textile covered the second 50-foot test area. The textile was attached to the geotube at the edges with staples and hog-rings. The space between the textile and the geotube was then filled with a growth medium such as potting soil. The textile was pre-planted with a mix of native grasses and flowers. Again, the growth medium and vegetation screened the geotube from ultraviolet rays.

Both test areas were judged to be successful. In future plans, the remaining geotubes will be punctured with an aerator so that roots can penetrate into the interior of the geotube. They will then be covered with a pre-vegetated degradable textile and growth medium and sprigged with additional plants through all the layers into the interior of the sediment.

SUMMARY

The project was particularly successful in that the sponsor’s objectives of improved aesthetics and recreation were shown to be compatible with environmental restoration. The Corps of Engineers was presented a combination of problems, which, although not unique, resulted in a difficult situation. The project was designed in such a way that should any single element fail it would not jeopardize the rest of the project. It involved using several techniques that, although known to work in their own right, have not, to our knowledge, ever been used in this combination.

Removal of the excess waterfowl was of paramount importance. The birds negatively impacted the water quality and would have destroyed any attempt to create wetlands. To date almost 2,300 waterfowl, most of them Canada Geese, have been captured and relocated. Only about 6% have so far found their way back. As a result, water quality criteria including clarity and pH have greatly improved.

Shallow waters were planted with a variety of native wetland species. The plants are growing better than anticipated and have spread beyond their protective exclusion cages. More than two hundred species of plants have found a niche in or around the sub-embayment.

Although several problems were encountered with the geotubes, overall they performed well. The geotubes provided a disposal area, allowed some of the dredged sediment to be used as a construction resource, improved water quality, and cost about 2/3 of traditional materials. The problems encountered were largely a result of inexperience with this new technique, but were easily fixed and can be avoided in the future.

Drakes Creek project area pre-construction. The photos were taken while the water was lowered about 1 ½ feet below the normal pool.

Left: Newly filled geotube. Initial public reaction was negative although the birds seemed to enjoy them. Right: 50’ test planting area consisting of native wildflowers and grasses. Muskrat heavily grazed the area on the right side of the photo. Although this decimated the wildflowers, it provided an opportunity for the native grasses to emerge.

Left: Waterfowl were a major contributor to the problems. They denuded the area of all low-lying beneficial aquatic and riparian and contributed up to three tons of organic waste per day. Right: volunteer vegetation after one growing season. Those visible are primarily smartweed and black willow. By the end of the second season the willows were up to 12 feet tall.

Left: TWRA, USDA, and Tennessee Tech volunteers assisting in planting aquatic vegetation in the upper end of the embayment. Two or three species were planted in each cage. Geotube is on the left. Right: Looking across the embayment at the geotube after one growing season.

Left: Water primrose covered the banks and provided cover and protection for a number of the species we were trying to introduce such as the arrow arum growing through the exclusion cage. Right: The upper embayment about a year after the aquatic planting. Although some of the plants were heavily grazed where they emerged from the cages, their root structures were left intact and many were spreading beyond the cages.

Left: Vegetation in the foreground and left of the photo is growing out of the side of a geotube. The bulrush growing in the exclusion cage was badly damaged by muskrats and probably won't survive. Right: An exclusion cage with both arrowhead and pondweed surviving after one year. The pondweed in particular has spread beyond the cages into the rest of the embayment.

THE ALCHEMY OF STREAM RESTORATION: IMPAIRED STREAM TO A THING OF BEAUTY II
THE NATURE CONSERVANCY'S BIG ROCK CREEK PROJECT
YEAR 1

Leslie Colley [1]

A major tributary to the Duck River, Big Rock Creek is listed by the State of Tennessee as an impaired stream due to siltation, excess nutrients, organic enrichment, and urban/stormwater run-off. During this first full grant year, TNC hired the Center for Watershed Protection(CWP) to assist in the development of a watershed plan that will include an assessment of the present or "baseline" conditions of various watershed features, identification of sensitive watershed features, and a prioritized list and detailed descriptions of watershed protection and restoration recommendations. The assessment, which is now completed, confirms that the sources of these stresses include poor agricultural practices, habitat alteration, riparian corridor loss, land development, and municipal sewer overflows. This suite of threats is common to many streams throughout the state and presents the opportunity to deal with a diverse array of issues and partners.

Our presentation this year will be to update progress on the Big Rock Creek Project and present CWP's findings and recommendations, as well as TNC's future plans in this sub-watershed. We believe that this project will help establish TNC's reputation as an organization that works with, not against, local governments and stakeholders to protect water resources in a fashion that may ultimately save taxpayer money and promote economic development. This type of results-oriented political capital is crucial to exporting strategies developed in this project to other communities in the watershed and beyond.

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VALIDATION OF A REAL-TIME PCR METHOD FOR THE QUANTIFICATION OF E. COLI IN SURFACE WATER

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Introduction

The detection of pathogens, such as *E. coli*, is fundamental for monitoring the quality of groundwater and surface water and for the development of Total Maximum Daily Loading (TMDL) plans to address contamination. Currently several different EPA methods are approved for the detection of bacterial pathogens including most probable number (MPN), plate, and filter membrane methods. All of these methods rely on culturing coliforms, fecal coliforms or *E. coli* and generally take around 24 hours. We are currently validating a cultivation independent assay, which should reduce the assay time to less than 3 hours and allow quantification of *E. coli* at field sites. This assay is based on quantitative real-time polymerase chain reaction (PCR) assays using a Taqman fluorescent probe.

Relationship of Coliforms and *E. coli*

Collection of "pathogen" data is not directly based on the detection of pathogenic organisms, rather pathogenic potential is inferred from the presence of fecal indicator bacteria identified as "coliforms", "fecal coliforms" or "*E. coli*". *E. coli* identified by Theodor Escherich in 1885, was first proposed as fecal indicator bacteria by Shardinger in 1892. However, culturing methods did not exist to distinguish *E. coli* from other fecal bacteria so in 1914 the U.S. Public Health service adopted the enumeration of "coliforms" defined as Gram-negative, facultative anaerobic rod-shaped bacteria that ferment lactose to produce acid and gas at 35ºC within 48 hours (Figure 1). Although the term coliform implies intestinal bacteria, the use of coliform bacteria as fecal indicators is complicated by other non-intestinal and soil bacteria capable of fermenting lactose at 35ºC such as *Citrobacter* and *Serratia*. The additional requirement for lactose fermentation at 44ºC (thermotolerant or fecal coliforms) reduces the number of non-intestinal bacteria quantified. However, up to 15% of *E. coli* strains are not thermotolerant so the use of fecal coliforms as an indicator may underestimate the potential pathogens (Feng, 2002). The use of *E. coli* as the preferred indicator of fecal bacteria regained favor with specific colorimetric dyes to identify the enzyme ß-glucuronidase (found in *E. coli* but not other lactose fermenting bacteria including *Klebsiella* and *Citrobacter*. Phylogenetically, coliforms all belong to the family *Enterobacteriacea* which includes *E. coli* and other pathogens such as*Salmonella* and *Shigella*. However, culture-based methods do not detect non-lactose utilizing *E. coli* and the closely related pathogens *Salmonella* and *Shigella*. In addition, currently

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accepted culture methods do not distinguish between pathogenic *E. coli* and non-pathogenic *E. coli,* or *E. coli* arising from human sources versus other natural sources such as wildlife.

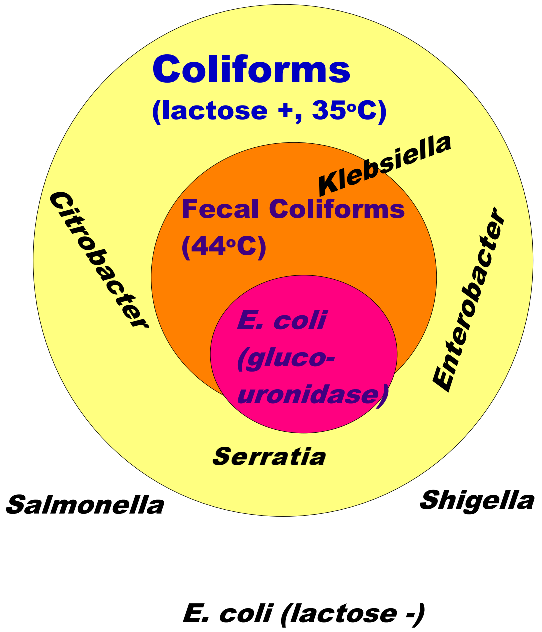

Figure 1. Relationship of Coliforms and *E. coli.*

Real-Time PCR

Real-time PCR is a molecular method in which a target DNA sequence is preferentially replicated and detected in a mixture of non-target DNA sequences. Real-time PCR is ideal for the detection of bacterial pathogens and fecal indicators because all bacteria contain unique sequences that can be used to identify them phylogenetically to the species or even strain level. In PCR, repeated cycles of heating to 95ºC and cooling to 50-60ºC are used to exponentially amplify the desired target sequence in a mixture of non-target DNA through the use of primers (small DNA sequences complementary to the target sequence). In real-time PCR an extra fluorescent DNA sequence complementary to the target sequence (Taqman probe) is added to monitor the exponential amplification of the target sequence. As the PCR progresses, the fluoroescent label is cleaved from the probe as the target DNA sequence is amplified. Therefore, as more target DNA is synthesized, the fluorescent output increases, resulting in sigmoid shaped fluorescence curves with respect to the number of cycles (Figure 2A.) In order to quantify target DNA copies per reaction from fluorescence, a cycle threshold (C_T) value is calculated. The threshold is the point at which the signal generated from the sample is significantly greater than the background fluorescence and the C_T is the cycle at which this occurs. The C_T is linearly correlated to the log of the copies per reaction for a set of standards, so the C_T of the unknown sample can be used to calculate the number of target copies in that sample (Figure 2B). For additional reviews on real-time PCR and an application of real-time environmental samples see Ginizer, 2002, Bustin 2000, and Harms et al. 2003).

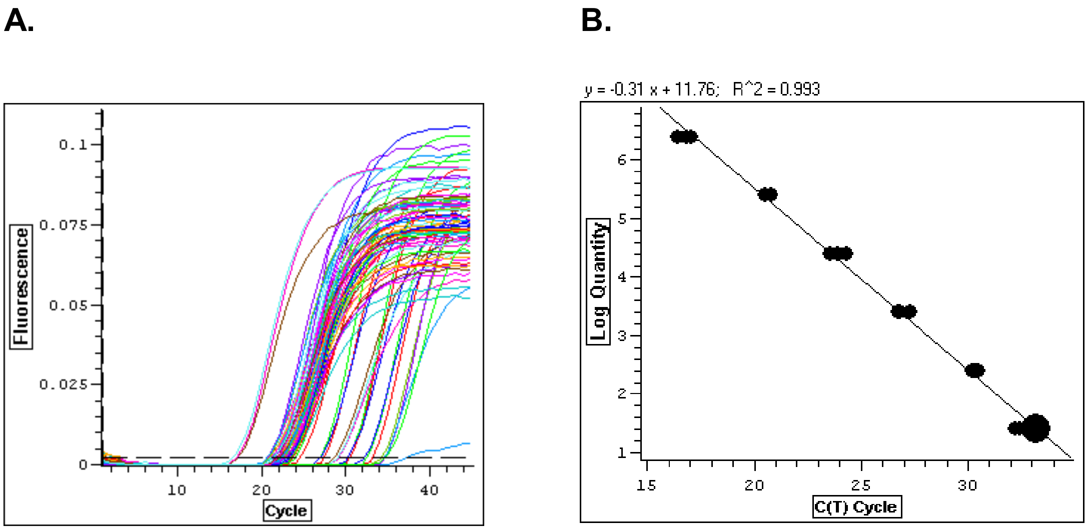

Figure 2. An example of a real-time PCR assay. A. The fluorescence output from cleavage of the fluorophore from a TaqMan probe as PCR cycles progress. B. The correlation of log copies of the target standard DNA and cycle threshold (Ct).

Methods

Total coliforms and *E. coli* were enumerated in creek water samples using the Hach filter membrane method (MEL/MF total coliform lab, HACH Company, Ames IA). Samples (100µl to 1000µl) diluted in 50 ml phosphate buffer saline (PBS) were collected on a membrane filter placed on top of filter funnel by suction. The sides of the funnel were washed with 25 ml PBS and excess liquid removed by suction. The filter membrane was placed on an absorbant pad in a petri dish soaked with 1 ampule of m-ColiBlue 24 broth. The petri dishes were incubated at 35°C for 24 hours. The following day, red colonies indicating coliforms and blue colonies indicating *E. coli* were enumerated.

For PCR analysis 10 to 50 mls of creek water were filtered across 0.2µm 25 mm HT tuffryn filters (PALL Corporation, Ann Arbor MI). The bacteria on these filters were eluted with 250 µl to 1000 µl sterile 10 mM Tris pH 8.0 using back pressure. A 70 bp portion of the *E. coli* 23S rDNA was the target for the assay and was amplified and detected using the primers and probes listed in Table 1. Direct PCR without DNA extraction (Fode-Vaughan et al. 1999) was performed on 2.5 µl concentrated creek water samples. The 25 µl PCR mixes contained 12.5 µl Quantitect master mix (Qiagen Inc, Valencia CA), 0.375µl of each the forward and reverse primers and 0.3125 µl of the Taqman probe. The PCR amplification protocol consisted of an initial denaturation at 95°C for 5 minutes, followed by 45 cycles of 95 °C for 30S and 55 °C for 30S. Cloned *E. coli* 23S rDNA was used as the standard for calculation of copies per PCR assay (25 copies to 2.5 x10^6 copies per PCR reaction). 10 mM Tris buffer without *E. coli* was used as negative control. In one experiment sterile water was filtered and concentrated (10x to 100x) and used as a control. In all calculations the copies/PCR in the negative controls were subtracted from the samples.

Table 1. PCR primers and probes used for the *E. coli* real-time PCR assay (modified from Smith et al. 1999).

Name	Sequence	Tm (nearest neighbor)
EC23Sf	GAG CCT GAA TCA GTG TGT GTG	53ºC
EC23Sr	ATT TTT GTG TAC GGG GCT GT	51ºC
EC23Srv1bhq	CGC CTT TCC AGA CG CTT CCA C	59ºC

Results and Discussion

Total coliforms CFU/100 ml and *E.coli* CFU/ 100 ml were measured in creek water samples for three weeks using the Hach m-ColiBlue 24 method (Table 2). All samples exceeded the water quality standard for recreation.

Table 2. Total coliforms and *E. coli* per 100 ml in Second Creek samples.

Date	Coliforms/100ml	*E. coli*/100ml
9/16/2002	4900	1200
9/17/2002	14200	2000
9/18/2002	196000	7200
9/19/2002	54700	9300
9/20/2002	17000	2500
9/23/2002	277300	28700
9/24/2002	51300	2000
9/25/2002	25900	4400
9/26/2002	226700	6700
9/27/2002	28300	2300
10/14/02	25300	1700
10/15/02	19300	1400
10/16/02	140000	3200
10/17/02	54300	4970
10/18/02	30700	1770

E. coli copies/ml were determined using the real-time PCR assay for 2 five-day periods. The detection limit in the *E.coli* real-time PCR assays was 1 x 10^3 copies per PCR assay. Complete assays including filtration of the creek water samples and PCR assays were completed in 2-3 hours. The data collected as total coliform CFU/ ml, *E. coli* CFU/ml, and *E. coli* copies/ ml were compared graphically (Figure 3). Graphical presentation of the *E . coli* CFU/ml versus *E. coli* copies/ml indicated that the two values were well correlated. The *E. coli* copies/ml in the 10X concentrate were approximately 1 x 10^4 fold higher than the *E .coli* CFU/ml. This results from a combination of factors including the fact that *E.coli* has 7-12 ribosomal copies and that less than 10% of bacteria are considered culturable.

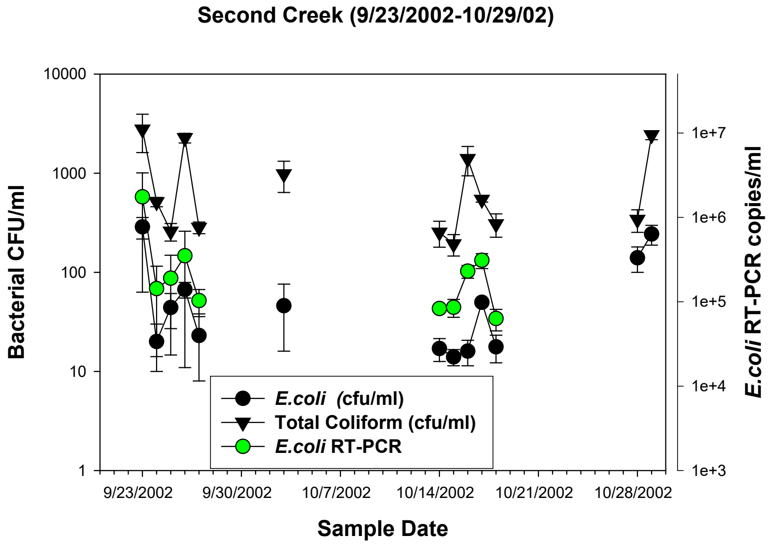

Figure 3. Comparison of total coliform CFU, *E. coli* CFU and *E. coli* copies/ml.

Based on the Hach Filter membrane *E coli* CFU the detection limit of the E. *coli* real time PCR assay was equivalent to 20 CFU/ml (2,000 CFU/100 ml). Therefore, additional concentration of the sample water may be needed to obtain the desired detection limit equivalent of 100 CFU/100 ml. One factor that limits the detection limit of the *E. coli* real-time PCR assay is the presence of *E. coli* sequences in the PCR reagents. This problem may be overcome by developing assay for other fecal indicator bacteria such as *Bacteriodes* or *E. coli* pathogenicity genes.

Our ultimate goal for using the *E. coli* real-time PCR assay and/or other real-time PCR assays is to develop field-portable versions of the assays for recently commercialized field portable real-time PCR equipment.

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SOURCE TRACKING WITH ANTIBIOTIC RESISTANCE ANALYSIS

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INTRODUCTION

Water quality monitoring has historically employed enumeration of indicator organisms (coliforms, "fecal" or thermotolerant coliforms, *E. coli*, fecal streptococci and/or enterococci) to provide a measure of the bacterial quality of the waterbody or discharge stream. Until recently, enforcement has focused on point source dischargers (primarily treatment plants) and significant reductions in point source discharges have occurred; however, these reductions have not eliminated water quality violations. Because of the persistence of violations, attention has shifted from point sources to non-point sources. This shift has added an additional layer of complexity to monitoring efforts. Unlike past monitoring, when sources were known, non-point sources are diffusely located and poorly defined. Thus simple indicator densities provide no information as to what source should be targeted to improve water quality. In order to target areas for reduction, more sophisticated tools are required to provide an indication of both the extent of the pollution and the source of the pollutant.

To that end, a number of assays have been developed that identify the source(s) of bacteria from unknown origin. These techniques, collectively referred to as Bacterial Source Tracking (BST) or Microbial Source Tracking (MST) methodologies, include genotypic approaches (classification based on genetic makeup) as well as phenotypic methods (classification based on secondary characteristics, such as antibiotic resistance or carbon utilization) (Scott et al., 2002; Simpson et al., 2002). While each has its benefits and pitfalls, none are capable of achieving the *Holy Grail* of source tracking (Harwood, 2002): namely species-specific, ubiquitous, plentiful and easily measured markers for each of the myriad potential sources in an urban environment.

Genetic techniques represent the future of MST; however questions remain as to whether currently available technology can achieve an accurate assessment of natural systems that are geographically diverse and require frequent sampling (Simpson et al., 2002). In addition to the problems of isolation and purification inherent in theses techniques (nonspecific amplification, interferences from nonviable genetic material and environmental contaminants such as humic and fulvic acids), the procedures can be experimentally cumbersome and typically requires a trained technician.

Multiple antibiotic resistance analysis (MARA), a simpler phenotypic MST method, exploits the differential sensitivity of bacteria from different sources (such as human, cow, horse, dog, etc.) to a suite of common antibiotics of varying concentration (Wiggins, 1996). Because of differences in diet, physiology, exposure, and environment, gastrointestinal bacteria from different sources have been shown to display characteristic resistance to antibiotics, resulting in antibiotic-resistant fingerprints for individual sources. Fingerprints from bacteria of unknown sources can be compared to a library of known source fingerprints and using multivariate statistical techniques unknown sources can be identified. A library of antibiotic resistance profiles for Davidson County has been developed and has been applied to field samples from known sources to validate the[1] method.

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MATERIALS AND METHODS

Samples of all sources were collected from across Davidson County, Tennessee. Livestock samples were collected from small (mostly < 200 ac) farms. Dog samples were collected from healthy animals in shelters and kennels. Deer scat was collected from parks and natural areas. Human samples were collected from sewers after the collection system atlas was consulted to identify areas in the system that served only residential areas and which collected from a large area. For each animal source (cow, horse, dog, deer) a mixture of at least 3-4 fresh specimens were placed in a Whirl-Pac bag using plastic spoons. All samples were placed on ice and returned to the laboratory for analysis

Source samples were diluted in phosphate buffer to achieve a final suspension concentration of about 10 to 100 CFU/100 mL. Diluted samples were filtered through 0.45 µm GN-6 mixed cellulose ester membranes on absorbent pads (Gelman, Ann Arbor, MI). After filtration, absorbent pads were saturated with 2 mL of ColiBlue24 media (m-CB24) and incubated for 24 hours at 35°C. After incubation, blue (*E. coli*) colonies were disturbed using sterile wooden toothpicks and transferred into a well in a 96-well microwell tray that had been filled with 200 µL of Colilert media (IDEXX Labs, Westbrook, ME). Micro well plates were labeled and incubated for 24 hours. After 24 hours, wells which turned yellow and exhibited fluorescence under UV light (β-glucuronidase positive) were considered presumptive *E. coli*. If no color change occurred or if the well did not fluoresce, the isolate was not included in the analysis.

Trypticase Soy Agar (TSA) was prepared by mixing the appropriate mass of TSA powder with deionized water and then dispensed in 100-mL aliquots into 250 mL bottles. The bottles and agar were autoclaved for 30 minutes at 129°C for sterilization, and then cooled to 50°C in a water bath. Antibiotics used in the preparation of this database were (values in parentheses are µg/mL): erythromycin (60, 70, 90, 100); neomycin (2.5, 5, 10); oxytetracycline, streptomycin, and tetracycline (2.5, 5, 7.5, 10, 15); cephalothin (15, 25, 35); rifampicin (5, 10, 15, 30); and amoxicillin (15). The appropriate volume of antibiotic (from 10 mg/ml, filter-sterilized, stock suspensions) was added to each of the sterile bottles and each bottle was swirled gently to ensure mixing. The mixture was then dispensed evenly into sterile plastic petri dishes and allowed to congeal. Once firm, plates were stored at 4°C until needed.

E. coli isolates were transferred from the microwell plates to the TSA agar surface using flame sterilized stainless steel 48-prong replica platers (Sigma Chemical, St. Louis, MO). Thirty-two (32) plates were inoculated for each assay (30 antibiotics and 2 controls). After the liquid innocula had penetrated into the agar, the plates were stacked, upside down, in plastic boxes with damp paper towels and incubated for 24 hours at 37°C.

The growth of each isolate on each TSA plate (each with a different antibiotic and/or concentration) was determined after incubation. "Growth " (resistance) was defined as colonies growing in a complete circle in the space where the replica-plater prong was applied and "mostly" filled in. (See Figure 1.) Incompletely filled circles, non-circular development, and non-growth were considered “non-growth.” Any isolate for which there was no color change and fluorescence in Colilert media or which did not grow on either of the control plates was discarded. Isolates that were obviously contaminated were discarded. Discriminant analysis (DA) (SPSS for Windows, 2000) was used to classify bacteria by source.

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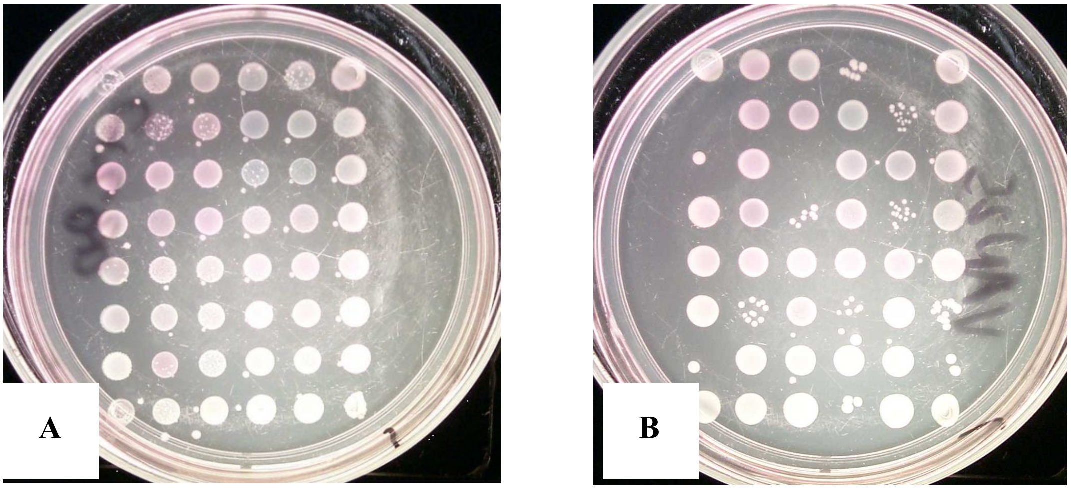

Figure 1: Growth of Isolates on Antibiotic-amended TSA. (A) Complete growth of all isolates (antibiotic resistance). (B) Susceptibility to antibiotics (non-growth).

DATA DISCUSSION

The current database has 2519 isolates from five sources: human, dog, deer, cow, and horse. Table 1 summarizes the results of the 4-way classification using DA, while Table 2 summarizes the results of the 2-way classification.

TABLE 1: FOUR WAY CLASSIFICATION OF *E. COLI* ISOLATES USING DISCRIMINANT ANALYSIS

Source	Predicted Membership (%)				
	Dog	Deer	Human	Livestock	Total
Dog	348 (**80.2**)	6 (1.4)	56 (12.9)	24 (5.5)	434 (100)
Deer	21 (6.3)	229 (**69.0**)	42 (12.7)	40 (12.0)	332 (100)
Human	75 (7.1)	112 (10.6)	717 (**68.2**)	148 (14.1)	1052 (100)
Livestock	96 (13.7)	35 (5.0)	98 (14.0)	472 (**67.3**)	701 (100)
MC	192 (9.2)	153 (7.0)	196 (13.4)	212 (11.7)	2519

2519 isolates from deer, dog, human, and livestock (cow and horse) sources
ARCC = 70.1%

TABLE 2: TWO-WAY CLASSIFICATION OF *E. COLI* ISOLATES USING DISCRIMINANT ANALYSIS

Source	Predicted Membership (%)		
	Human	Animal	Total
Human	818 (**77.8**)	234 (22.2)	1052
Animal	263 (17.9)	1204 (**82.1**)	1467
MC	263 (25)	234 (16)	2519

2519 isolates from human and animal (cow, deer, dog, and horse) sources.
ARCC = 80.3%

The Average Rate of Correct Classification (ARCC) is the frequency with which isolates of a given source are correctly classified using the discriminant function(s) developed from the data in the library. Discriminant analysis of this library using a 4-way classification yields an ARCC of 70.1%, while DA using a 2-way classification results in an ARCC of 80.3%. These rates are consistent with those observed by others for urban watersheds (Harwood et al., 2000; Whitlock et al., 2002). In addition, improved classification rates are generally seen as the number of potential sources decrease (Carson et al., 2001; Hagedorn et al., 1999; Hartel et al., 2002; Harwood et al., 2000; Wiggins et al., 1999). (See Table 2.) The classification of fingerprints in the database represents real differences in the antibiotic resistance of the bacteria from each source, and is not simply a statistical artifact. When data are arbitrarily assigned to a group and DA is run, ARCCs approach those predicted by chance (2-way: 51%; 4-way: 27%; data not shown).

The first attempts to validate the predictive ability of the *E. coli* database involved treating isolates collected from known sources as unknowns to determine if the procedure would correctly classify these isolates into the appropriate source. Both 2-way (human/animal, data not shown) and 4-way (human/dog/deer/livestock) classifications were assessed. Table 3 summarizes the results of one such validation. As the table indicates, the database is able to classify isolates from known sources into the correct source group at rates that are much higher than those predicted by chance.

TABLE 3: 4-WAY CLASSIFICATION OF KNOWN-SOURCE SAMPLES[a]

Source	Predicted Source			
	Dog	Deer	Human	Livestock
Cow (n = 48)	0	10	6	**64**
Human (n = 48)	19	2	**77**	2
Dog (n = 48)	**94**	0	0	6

[a] True identity of each source indicated in first column; predicted composition of each source indicated in subsequent columns

To date, several field tests have been performed in an attempt to validate the predictive capability of the *E. coli* database. These efforts involved sampling streams that had known source impacts (active sewer overflows and runoff from cattle pastures) and running the assay against isolates from these sampling events to determine if the correct source is identified. Tables 4 – 5 summarize the results of these trials.

Table 4 summarizes results from three overflow/bypass events that occurred during 2002.

- Sample B-1 was a bypass that occurred in the spring of 2002. The sample was collected downstream from the bypass, which was actively flowing at the time of sampling. Both the 2-way and 4-way classification of the isolates from that sample indicated the majority of them were of human origin (> 94%), consistent with expectations.
- Samples C-1 through C-3 represent three (successively downstream) samples that were collected during a sewer overflow during the early summer of 2002. The 2-way and 4-way classifications indicate that the majority of the isolates in these samples were of human origin, much like the data from the bypass (B-1).
- Samples R-1 through R-5 were collected from streams impacted by a sewer overflow in the late fall of 2002. Sample R-1 was collected upstream of the impacted sites from a large tributary (receiving stream), and suggests that the majority of the bacteria upstream of the impact were of animal origin. A 4-way classification suggests that dog and to a lesser extent, livestock, are responsible for the bacteria upstream of the sampling site. Samples R-2 through R-4 were collected in a low-flow tributary from the overflow site (R-2), to a point 25 m downstream from the overflow (R-3), to the confluence with the larger stream (R-4).

> Finally, sample R-5 was collected from the larger receiving stream about 2.5 km downstream of the confluence point with the smaller, impacted tributary. Samples R-2 and R-3 indicate that the majority of the bacteria in these samples are of human origin. Sample R-4, collected from the receiving stream at the confluence point, shows evidence of dilution by the larger receiving stream (sample R-1), however, this sample still has significant human character due to the overflow. Dilution calculations using the bacterial densities and the flow rates of each stream suggest that the proportion of animal and human isolates is consistent with predictions. Finally, sample R-5 shows the effects of further dilution, with animal sources becoming a larger fraction of the identified isolates.

Results from the overflow/bypass sampling suggest that ARA can correctly identify human source isolates from natural waters. In an attempt to collect isolates from known animal sources in the environment, pooled rainwater (A-1 through A-4) and stream water impacted by runoff (A-5) from a cattle farm was collected during wet weather in the fall of 2002. Results of this sampling are summarized in Table 5.

In contrast to the stream samples collected from the overflow/bypass sites, all of the data collected during this sampling suggest the bacteria in the puddles and stream water primarily is derived from animal sources (2-way classification, Table 5). If 25% is considered the threshold for identifying an actual source impact, then the 4-way classification indicate that livestock and dog sources are responsible for the animal isolates in this field trial. The fraction of isolates from dog sources was surprising and higher than expected; however there are several dogs that run free on the farm, and thus the impact of dogs is possible.

CONCLUSIONS

Over the past year, a library of antibiotic resistance patterns from dog, deer, human and livestock has been developed from samples collected at a number of sites across Davidson County in an effort to determine the source of bacteria in Davidson County Streams. Testing has confirmed that the antibiotics and concentrations used are able to discriminate between bacteria from the four major sources, and that the grouping represents real differences in phenotypic character. The fingerprints in the database are able to discern differences in bacteria from known sources, especially for a 2-way classification, and return intuitively consistent results when applied to field sites where contamination from known sources is occurring. In the future, additional samples will be added to the database to maintain the diversity of the database, and the technique will be applied to streams where water quality impairments have been historically observed.

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TABLE 4: FIELD TRIALS: SEWER OVERFLOWS

	Predicted Source				
Source	Human	Animal			
	(Human)		(Dog)	(Deer)	(Livestock)
B-1	**98**	2			
	(94)		(2)	(2)	(2)
C-1	**65**	35			
	(58)		(2)	(8)	(31)
C-2	**100**	0			
	(96)		(0)	(4)	(0)
C-3	**88**	12	0		0
	(75)		(2)	(13)	(10)
R-1	20	**80**			
	(20)		(60)	(0)	(20)
R-2	**75**	25			
	(65)		(21)	(2)	(13)
R-3	**78**	22			
	(78)		(8)	(0)	(14)
R-4	**60**	40			
	(46)		(29)	(2)	(23)
R-5	27	**73**			
	(21)		(35)	(0)	(44)

TABLE 5: FIELD TRIALS: RUNOFF FROM FARM

	Predicted Source				
Source	Human	Animal			
	(Human)		(Dog)	(Deer)	(Livestock)
A-1	44	**56**			
	(*44*)		(25)	(0)	(*31*)
A-2	26	**74**			
	(22)		(*46*)	(0)	(*33*)
A-3	19	**81**			
	(10)		(*42*)	(10)	(*33*)
A-4	13	**87**			
	(10)		(*58*)	(0)	(*31*)
A-5	28	**72**			
	(23)		(*37*)	(7)	(*33*)

COMPARISON OF MULTIPLE ANTIBIOTIC RESISTANCE AND CARBON UTILIZATION PATTERNS TO DETERMINE SOURCES OF FECAL ENTEROCOCCI IN THE DUCK RIVER, TENNESSEE

Ihrie, P.D.[1], Farmer, J.J.[2,3], and Bailey, F.C.[1]

Fecal pollution of environmental waters is a serious health problem that cannot be remedied unless sources are identified. A study was conducted to examine whether differential resistance to an array of antibiotics (AB) and biochemical tests from the Biolog®* identification system can be used in bacterial-host source tracking. Fecal samples were collected from human and agricultural sources as well as from surface waters in the Duck River Basin of Middle Tennessee. Human source and bovine source bacteria from the genus *Enterococcus* were isolated using *Enterococcus* agar and identified with the Biolog® system. Twelve ABs and triclosan were diluted in 100 milliliters of tryptic soy agar at 6 concentrations for each compound and poured into 150x15 millimeter petri dishes. An antibiotic resistance pattern (ARP) was established for each isolate by determining growth or no growth on these AB-treated agars. A carbon utilization pattern (CUP) "fingerprint" for each isolate was established from the 96 biochemical tests employed in the Biolog® system. Principal components analysis was used in the selection of the concentrations of the different antibiotics and of the particular Biolog® carbon sources that explained most of the variance observed among the different sources of bacteria. CUP and ARP fingerprints were used in discriminant analysis. Discriminant analysis was used to determine the percentage of correct classification to source group for known sources and to determine the source group classification for isolates from Duck River water samples. Known isolates had 79 percent and 98 percent average rates correct classification (ARCC) by host source based on their ARPs and CUP fingerprints, respectively. Isolates from the Duck River samples were classified into bacterial source groups. The distribution among the source groups (human septic, sewage, and bovine) was: 10 percent, 37 percent, and 53 percent, respectively, using ARP fingerprints, and 3 percent, 40 percent, and 57 percent, respectively, using CUP fingerprints. The source group distribution of ARP and CUP is similar despite differences in the ARCC. This study indicates that ARPs and CUP fingerprints can be used to group *Enterococci* isolates for human and bovine sources and may be useful in bacterial-host source tracking.

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STATISTICAL ANALYSIS OF BACTERIA DATA COLLECTED FROM THE NONCONNAH CREEK AND WOLF RIVER SYSTEMS

Don Hudgins, P.E.[1]

Introduction

A statistical study was performed on bacteria data collected from water samples taken from the Nonconnah and Wolf River systems in Memphis, Tennessee. Samples were collected from 12 stations established in Nonconnah Creek or its tributaries. Samples were collected from 7 stations established in the Wolf River or its tributaries. Thirty-five sampling events were performed during the period of June 2000 to August 2002 for a total of approximately 665 samples. Samples were analyzed for E. coli, Enterococcus, and Fecal Coliform by A&L Laboratories, Inc. in Memphis, Tennessee. When non-detected, the minimum detection limit was used for the concentration. When too numerous to detect, the maximum detection limit was used. Daily rainfall data from the Stiles Treatment Facility (and when not available, the National Weather Service at the Memphis International Airport) was utilized in the study. Rains events were defined as rain occurring on the day of and/or the day before sampling.

The analytical results were converted to $\log_{10}$ values prior to statistical analysis. Averages and other statistical operations were based on manipulation of the $\log_{10}$ results. The data was converted to Excel spreadsheet format and Minitab software was used to perform the statistical analysis. The data was analyzed for variation according to quarter (first quarter: January-March, etc.), rain versus non-rain events, and correlation among bacteria parameters.

Background

The Wolf River drains the approximate northern half of Shelby County. It has a mean daily flow rate of 1049 cubic feet per second (cfs), a mean minimum daily flow rate of 332 cfs and a mean maximum daily flow rate of 2,770 cfs. Nonconnah Creek drains the approximate southern half of Shelby County. It has a mean daily flow rate of 134 cfs, a mean minimum daily flow rate of 0.17 cfs, and a mean maximum daily flow rate of 1,230 cfs. The City of Memphis operates separate sanitary and storm sewer systems. The sanitary sewer system is not known to experience many wet weather overflows. Overflows are more likely to occur during dry weather due to grease accumulation. The typical overflow volume is 1000 gallons and approximately half of the overflows make it to a waterway.

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Characterization of Data

In the Nonconnah system, samples were analyzed for E. coli, Enterococcus, and Fecal Coliform. Sample concentrations ranged from below method detection limit (< 10 cfu/100 ml) to too numerous to count (> 80,000 for E. coli and Enterococcus and > 120,000 for Fecal Coliform.) In the Wolf River system, samples were analyzed for E. coli and Enterococcus with similar results.

Results

Rainfall was shown to cause increases in bacteria levels in both water systems, especially in the Nonconnah system. In the Nonconnah system, E. coli, Enterococcus, and Fecal Coliform levels associated with rain events were significantly higher ($p = 0.90$) than non-rain events. Average concentrations (approximate) for rain and non-rain periods for the Nonconnah system are shown as follows:

	Non-Rain	Rain
E. coli	60	400
Enterococcus	80	400
Fecal Coliform	400	1000

In the Wolf River system, no overall statistically significant increase was shown for E. coli concentrations in samples during rain events compared to non-rain events. However, an overall statistically significant increase in Enterococcus concentration was shown. Average concentrations (approximate) for rain and non-rain periods for the Wolf River system are shown as follows:

	Non-Rain	Rain
E. coli	100	125
Enterococcus	100	350

The bacteria levels in both river systems showed similar and statistically significant seasonal patterns. In the Nonconnah system, both E. coli and Fecal Coliform concentrations appeared to be lowest in the first quarter and highest in the second quarter. Enterococcus concentrations were highest in the first and second quarters and lowest in the third. The quarterly average concentrations (approximate) for the Nonconnah system are summarized as follows:

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
E. coli	50	250	100	90
Enterococcus	160	250	40	160
Fecal Coliform	280	1000	650	650

In the Wolf River system, E. coli concentrations were lowest in the first quarter and at similar elevated levels in the second, third, and fourth quarters. Enterococcus levels were highest in the second quarter and lowest in the third. The quarterly average concentrations (approximate) for the Wolf River data set are summarized as follows:

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
E. coli	50	140	100	120
Enterococcus	120	320	50	100

As part of the data analysis, the $\log_{10}$ of the bacteria concentrations were plotted against each other for the sampling events. The data was sorted according to rain or non-rain periods and correlation (R^2) values noted. A summary of the correlations is as follows:

Nonconnah System	Non-Rain	Rain
Fecal Coliform vs. E. coli	0.52	0.92
Fecal Coliform vs. Enterococcous	0.08	0.72
E. coli vs. Enterococcus	0.05	0.67
Wolf River System		
E. coli vs. Enterococcus	0.05	0.38

As shown above, strong linear relationships were shown between the variables during rain periods and weak or non-existent relationships were shown during the non-rain periods. Plots of Fecal Coliform vs. E. coli concentration of samples collected in the Nonconnah system during rain events and non-rain are shown in *Figures 1* and *2*, respectively. Plots of E. coli versus Enterococcous concentration collected during rain events and non-rain events are shown in *Figures 3* and *4*, respectively.

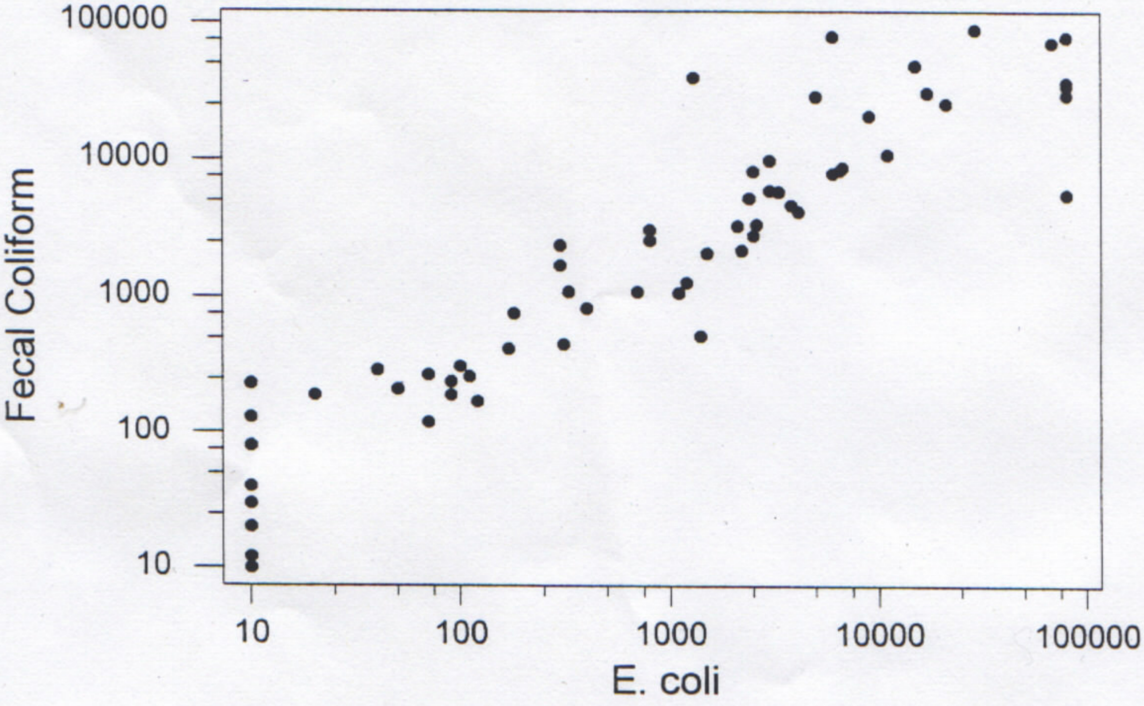
As shown in *Figure 1*, there was strong correlation between Fecal Coliform and E. coli concentration during rain events ($R^2 = 0.92$). During non-rain events, as shown in *Figure 2,* the relationship was less consistent ($R^2 = 0.52$) and there were instances of elevated Fecal Coliform levels with non-detected levels of E. coli. As shown in *Figure 3*, the relationship between E. coli and Enterococcus concentration was evident during rain events ($R^2 = 0.67$). The relationship was not evident during non-rain events ($R^2 = 0.05$) as shown in *Figure 4*.

Conclusions

These results suggest that during rain events, E. coli and Fecal Coliform are both reliable indicators of stream pollution. During non-rain events, E. coli may be a more reliable indicator of stream pollution than Fecal Coliform. Likewise, Enterococcus appears to be a less reliable indicator of stream pollution than E. coli and Fecal Coliform during rain events and an even more unreliable indicator during non-rain events.

Figure 1

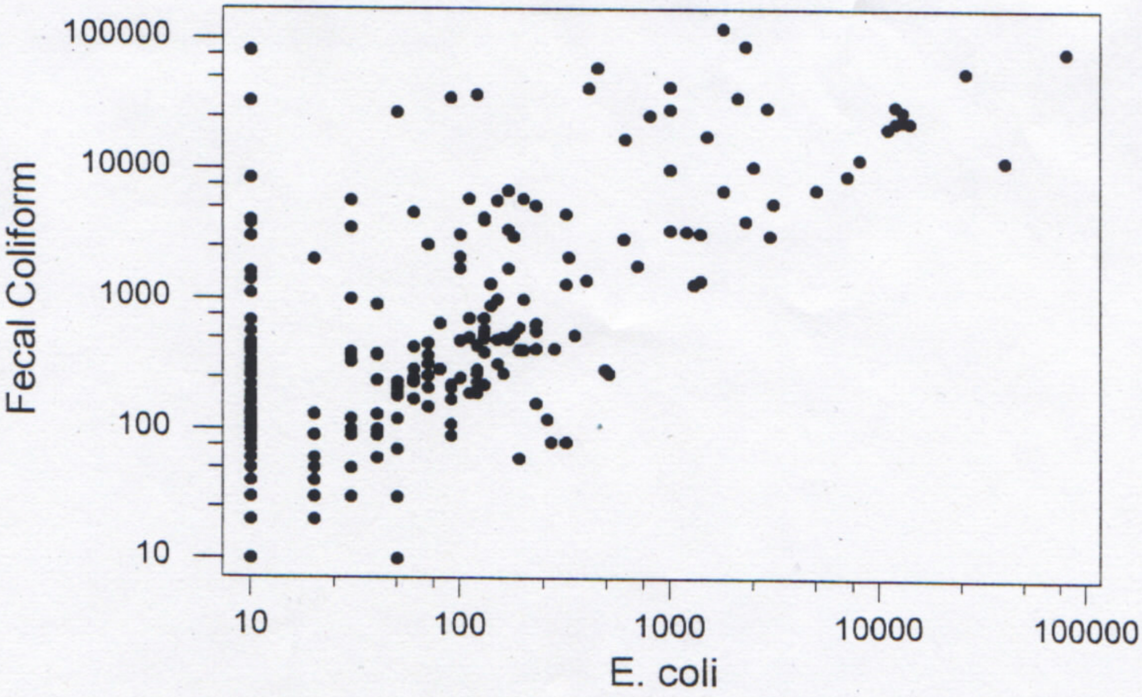
Nonconnah Creek System Fecal Coliform
vs. E. Coli Concentration during Rain Events



June 19, 2000 to August 7, 2002 Data Set

Figure 2

Nonconnah Creek System Fecal Coliform vs.
E. Coli Concentration during Non-Rain Events



June 19, 2000 to August 7, 2002 Data Set

Figure 3

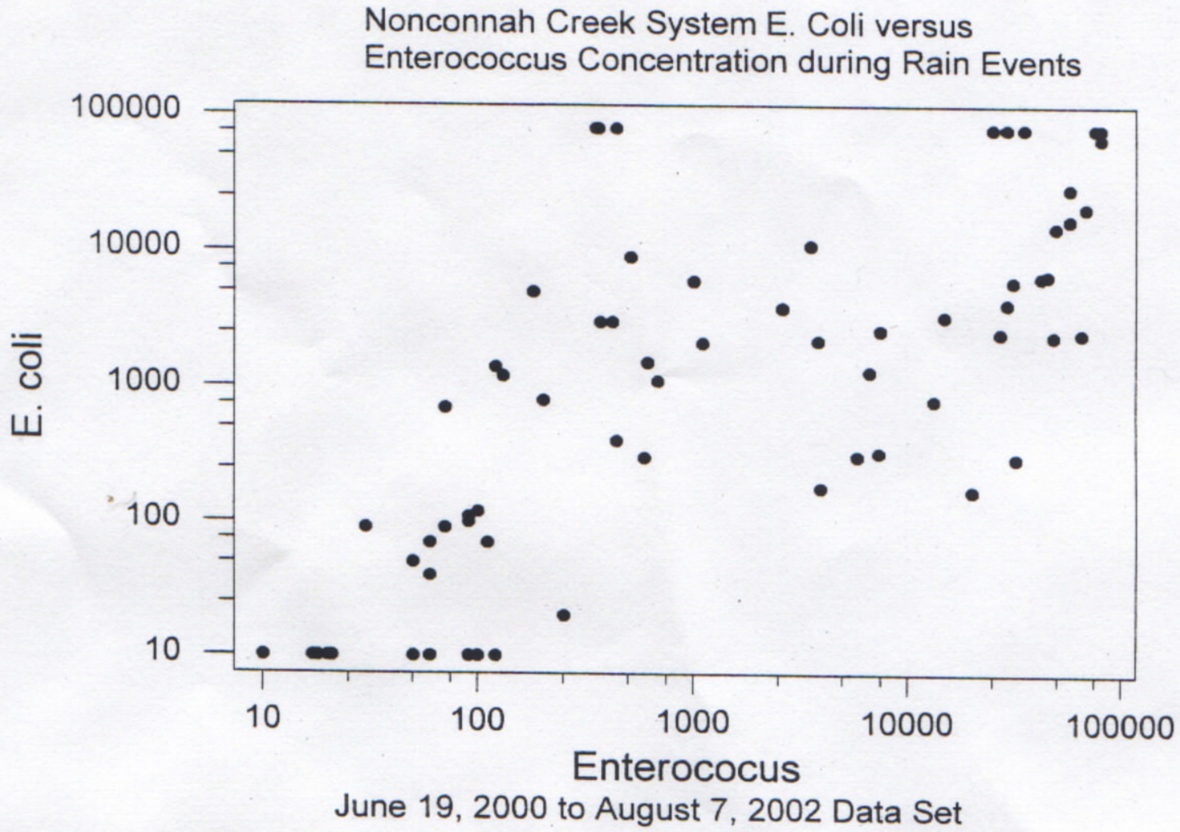
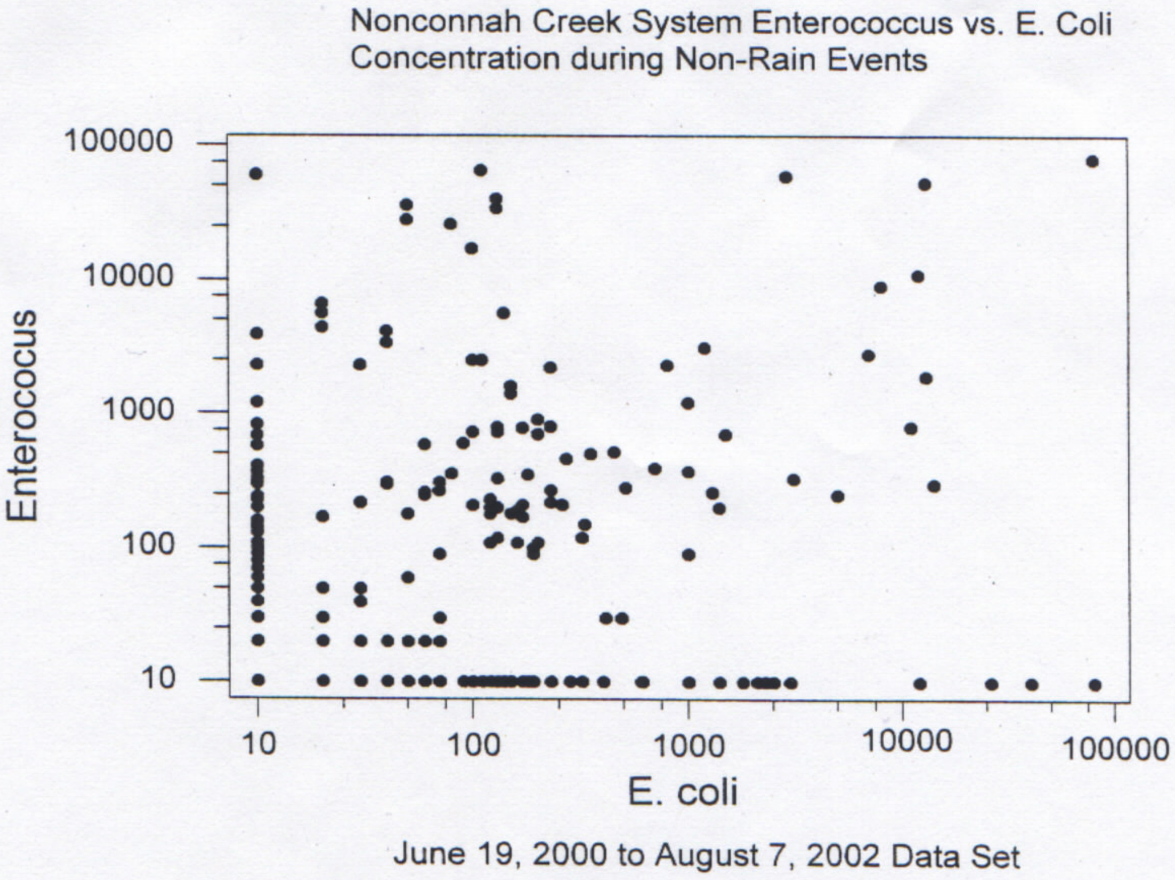


Figure 4



THE EVALUATION OF SELECTED CHEMICAL AND BIOLOGICAL PARAMETERS ASSOCIATED WITH THE SINKING CREEK TMDL

Douglas Dulaney, Maria Floresguerra, Kurt Maier, Phillip Scheuerman[1]

Abstract

Sinking Creek, a fecal coliform contaminated stream in northeast Tennessee, was added to the state 303(d) list and a TMDL for fecal coliforms was developed. Regulators and stakeholders formed a working group with two goals: 1) use Sinking Creek as a model for developing a cost-effective program for identifying sources of bacterial contamination in watersheds, and 2) use these data to reduce and mitigate sources of microbial pollution. The ultimate goals are to remove Sinking Creek from the 303(d) list, improve environmental quality, and reduce risks to public health.

Fourteen sites on Sinking Creek were monitored monthly and the concentrations of total coliforms, fecal coliforms, selected physical and selected chemical water quality parameters measured. All analyses were conducted using established methods with appropriate QA/QC. Fecal coliforms >1000 CFU/100 ml was present at sites 1 through 4. All other sites were <400 CFU/100 ml, indicating a significant input between sites 4 and 5. Chemical measurements at sites 1 to 4 (hardness 160mg/l as $CaCO_3$, alkalinity 184 mg/l as $CaCO_3$, phosphate loadings 65.7 mg/sec, nitrate loadings 514 mg/sec) were significantly elevated compared to all other sites (hardness 94 mg/l as $CaCO_3$, alkalinity 101 mg/l as $CaCO_3$, orthophosphate loadings 22.9 mg/sec, nitrate loadings 136 mg/sec). The focus of the study has now shifted to the implementation of best management practices around the first four sampling sites along the creek in an attempt to reduce current fecal coliform loading within the creek

Introduction

The Clean Water Act establishes the regulation of pollutant discharges in natural waters of the United States (40CFR§33). Section 303(d) of the Clean Water Act requires each state to identify and list waters that do not meet minimum water quality standards for their designated use classification. Listed waters are prioritized according to the severity of the pollution and designated use classifications. States are required to develop a Total Maximum Daily Load (TMDL) for each water body and pollutant causing the impairment. TMDL's are studies that quantify the pollutant loading that a water body can receive and still provide its designated uses. Also, TMDL's identify the source of pollution and recommend regulatory or other actions to improve the water quality of such waters (TDEC 2000).

Concern about Sinking Creek arose based on the results of two one-month sampling events in 1993 and 1994. Based on those results, the Tennessee Department of Environment and Conservation (TDEC) determined that Sinking Creek did not meet the minimum fecal coliform standards for recreational use due to urban runoff, storm-water,

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and agricultural runoff. On September 17, 1998, the USEPA Region IV approved Tennessee's section 303(d) list (TDEC 2000). The recreational standard states that the fecal coliform concentration in recreational surface water should not exceed 200 colony-forming units (CFU)/100ml as a 30-day geometric mean or 1000 CFU/100ml in any individual sample of water (TDEC 1999).

In late 2001, representatives from the Boone Watershed Partnership, Tennessee Department of Environment and Conservation (TDEC), East Tennessee State University (ETSU), First Tennessee Development District (FTDD) and the City of Johnson City formed a working group. This group focused on determining the cause of high fecal coliform concentrations in Sinking Creek. The expected outcome of the partnership will be to direct necessary resources on areas in the watershed that contribute to the bacterial contamination. The objective of this survey is to identify locations where concentrations of indicator bacteria are higher than the average concentrations within the watershed. This will help identify source(s) of the fecal coliforms found in Sinking Creek.

Materials and Methods

The Sinking Creek subwatershed (06010103130) is one of thirteen subwatersheds that belong to the Watauga River watershed (TDEC 2000a). Sinking Creek is partially located within Johnson City, Tennessee city limits. Sinking Creek is approximately 9.8 miles long, drains an area of 13.1 square miles, and enters the Watauga River at river mile 19.9. There are 19.8 impaired stream miles in the Sinking Creek watershed, including tributaries (TDEC 2000). Fourteen sampling sites within Sinking Creek were chosen to help identify sources of pollution based on land use, population demographics, and to assess the input from tributaries (Table 1). Triplicate samples were collected monthly for a year. The samples were transported on ice to the laboratory and were processed within the appropriate holding time for each procedure (APHA 1992).

Field parameters (water and air temperature, dissolved oxygen, conductivity, pH, depth, width, and velocity) were measured at each station. Bacteriological analysis was conducted using the membrane filtration method (APHA 1992). Nitrates as nitrogen and orthophosphates were measured using analytical kits manufactured by Hach Company (Loveland, CO). Hardness, alkalinity, and 5-day BOD were measured using procedures 2320 B, 2340, and 5210, respectively, described in Standard Methods for the Examination of Water and Wastewater (APHA 1992).

Results and Discussion

Fecal coliforms were found in 340 of 495 (68.7 %) water samples collected from Sinking Creek, ranging from <1 to 17,400 CFU/100ml. Of the 347 samples that contained fecal coliforms, 92 (18.6 %) contained concentrations that were above 1000 CFU/100ml.The highest average concentration of fecal coliforms (approx 1200CFU/100ml) in water samples occurred in the spring (Figure 2). The region with the highest average concentration of fecal coliforms in water samples was the agricultural region (Figure 1). Based on the information collected in this study, the source of fecal coliforms is in the agricultural region of Sinking Creek, in the spring.

Runoff from the pastureland that surrounds Sinking Creek in the agricultural areas is the most likely source of fecal coliforms. This observation is supported by the increase in fecal coliforms during the spring, which was the season with the most rainfall. In the agricultural area Sinking Creek is flanked by steep hills, which would facilitate runoff into the creek. In addition to the topographical characteristics of the agricultural area, there is at least one point above sample site 1 where cattle have access to the creek. Also near sample site 4 there is a resident population of ducks. Septic tanks located in the small group of houses that are located in the transition area between the agricultural area and the urban area at site 5 may also contribute to the fecal coliform loadings.

In the TMDL, point and nonpoint sources were defined as septic systems, leaking sewer lines, straight pipes, animals, and unknown sources. Point sources had their greatest influence in the summer dry season. Urban sources were supposed to be the dominating source of the fecal coliform contamination in the winter-wet season. Based on the results of this study, fecal coliform concentrations were highest in the agricultural region during the spring-wet season. The concentrations in this area were still elevated but declining during the summer dry months. This supports the idea that fecal coliform contamination was driven primarily by runoff, and secondarily, by septic tanks.

The orthophosphate and nitrate loadings were highest in the section of the stream where agricultural activity is more intensive and lowest in the section of the stream where urban and forest areas dominate the watershed. The highest average nitrate loading was 613.71 mg/sec. The mean for the yearly nitrate loading was 240.6 mg/sec. The highest average orthophosphate loading was 86.37 mg/sec. The annual mean orthophosphate loading was 34.6 mg/sec (Figure 2). The distribution of high nitrate and orthophosphate loading appeared to be related to agricultural land use. The annual means of alkalinity and hardness are 125 and 136 mg $CaCO_3$/L, respectively.

Summary and Conclusions

Fecal coliforms were found in 68.7 % water samples collected from Sinking Creek. Of the samples that contained fecal coliforms, 18.6 % contained concentrations that were above 1000 CFU/100ml. These high concentrations may indicate the presence of pathogenic organisms. Factors that could cause these elevated levels of fecal coliforms would be excessive nutrient loading, as a result of agricultural runoff and the presence of septic tanks in this area of the watershed. The highest fecal coliform and nutrient loadings occurred in the agricultural region during the spring. Monitoring is recommended during the implementation of all best management practices (BMP’s) for remediation of the sinking creek watershed.

Table 1. Sampling site locations on Sinking Creek.

Station Number	Location	Description	Concentration of livestock / wildlife	Population Density
1	New Sinking Creek Pump Station	Agricultural	High	Low
2	Bob Peoples Bridge	Agricultural	High	Low
3	Sinking Creek Church Rd.	Agricultural	High	Low
4	Joe Carr Rd.	Agricultural	High	Low
5	Dave Buck Rd.	Urban	Low	High
6	King Springs Baptist Church	Urban	Low	High
7	Old Sinking Creek Pump Station	Urban	Low	High
8	Bosch Braking Systems	Urban	Low	High
9	Lave Cox Dr.	Urban	Low	High
10	Hickory Springs Rd.	Urban	Low	High
11	Miller Ln.	Urban	Low	High
12	David Miller Rd.	Urban	Low	High
13	Jim McNeese Rd	Forest	High	Low
14	Dry Creek Rd.	Forest	High	Low

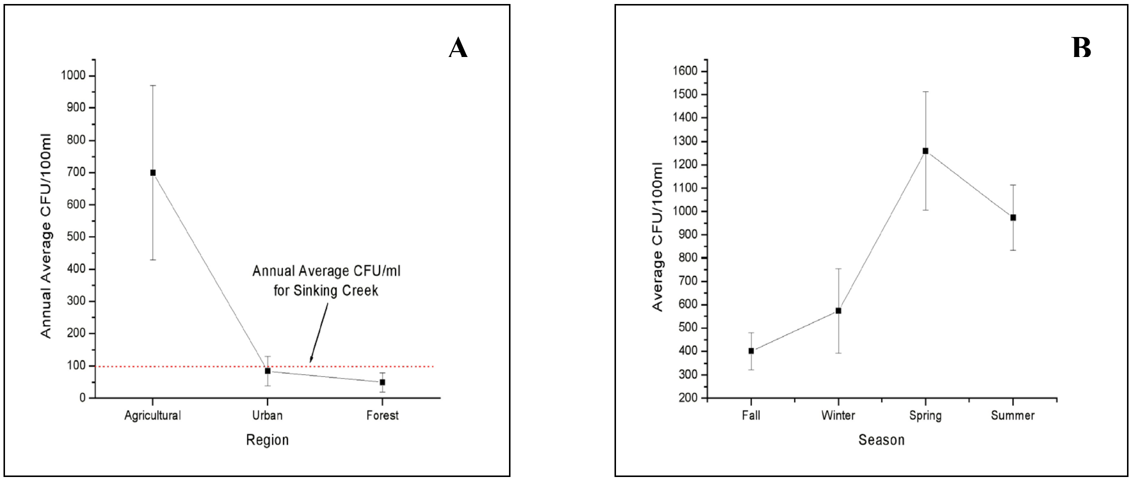

Figure 1. A: Regional fecal coliform variations in water; B: Seasonal fecal coliform variations in water. Error bars indicate standard deviation.

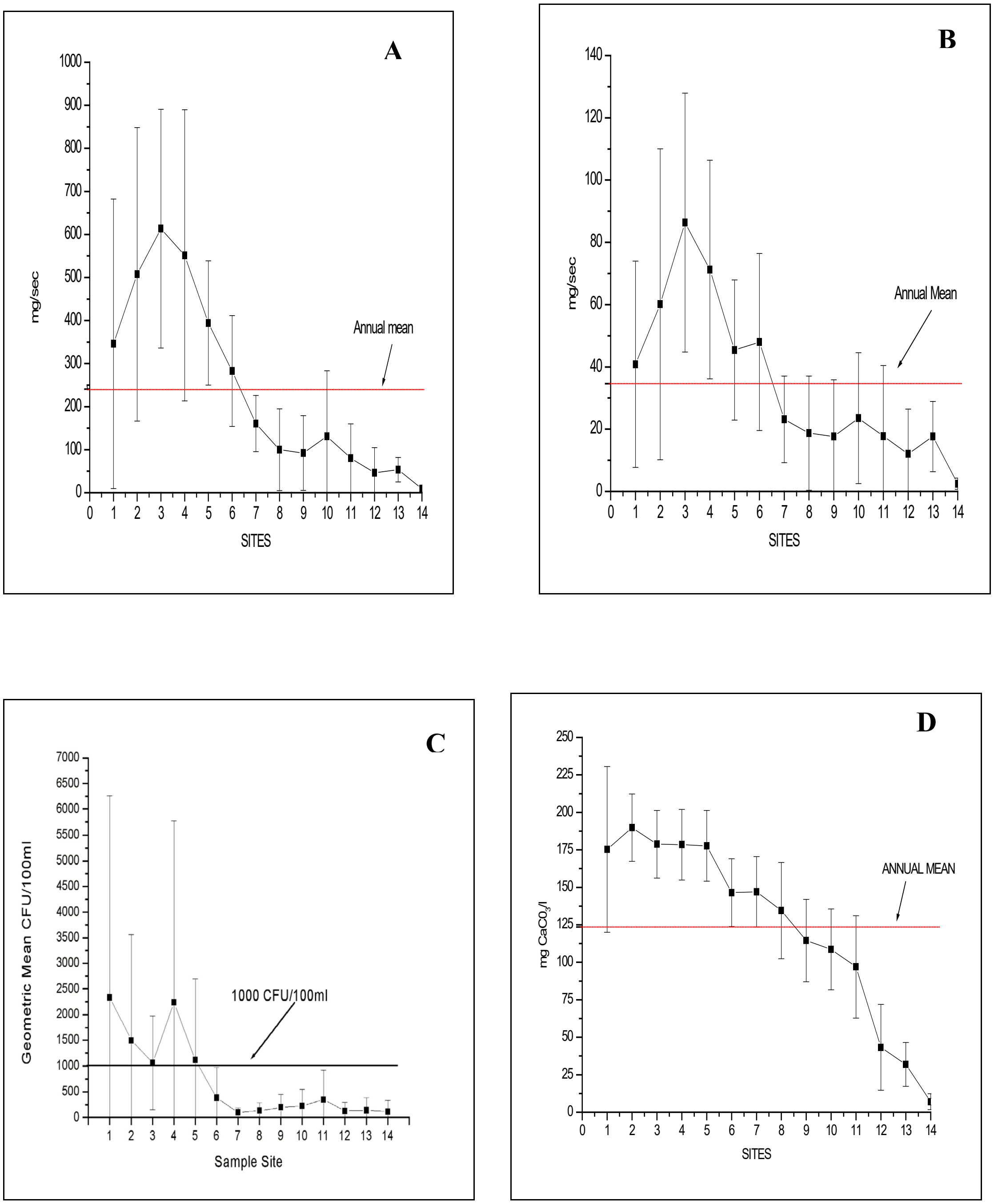

Figure 2. A: Annual average of Nitrate Loadings, B: Annual average of Orthophosphate Loadings, C: Annual Summay of Fecal Coliforms in water, D: Annual average of Alkalinity concentration. Error bars indicate standard deviation.

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DEVELOPMENT OF BACTERIAL SOURCE TRACKING METHODS FOR THE DUCK RIVER WATERSHED

James J. Farmer[1,2], Anthony O. Ejiofor,[2] and Terrance L Johnson[2]

A study was done to compare antibiotic resistance patterns (ARP) to carbon utilization patterns (CUP) used as “fingerprints” for bacterial source tracking. Bacterial sources evaluated were sewage influent, septic systems, and bovine feces. Two grams of feces from 22 cows, 21 samples of sewage influent from 8 sewage treatment plants, and samples from 15 septic systems were diluted and plated on m-TEC agar. Plates were incubated at 44.5 ºC for 24 hours. Ten lactose-fermenting colonies per sample were isolated by streaking on tryptic soy agar. Water samples from the Duck River were collected upstream and downstream of Shelbyville, Tennessee, and bacteria were isolated using the filter-membrane method. All isolates were identified to the species level using the Biolog®* system. *Escherichia coli* (*E coli)* isolates were analyzed to establish CUP and ARP fingerprints. ARP fingerprints were established by inoculating petri plates containing tryptic soy agar with various concentrations of 13 antibiotics. Plates were incubated 24 hours, and growth or no-growth patterns were recorded. CUPs were established by using the Biolog® identification system. In this procedure, a bacterial culture is used to inoculate 95 different carbon sources that contain a colorimetric indicator. A change of color indicates that the organism used the carbon source. The resulting pattern is the CUP of the organism. The fingerprints were compared using discriminant analysis. Discriminant analysis is a multivariate statistical method that attempts to maximize differences among groups and minimize differences within groups. Discriminant analysis with the 45 *E. coli* isolates from the Duck River using the CUP fingerprints classified the isolates as 60 percent from sewage influent sources, 29 percent from cattle sources, and 11 percent from septic sources. Using the ARP fingerprint, 81 percent were classified as being from sewage influent, 14 percent from cattle, and 5 percent from septic systems. The average rate of correct classification (ARCC) is the percentage that the isolates from the known source groups are re-classified correctly by the discriminant function. ARCC values for the CUP and ARP fingerprints are 96 percent and 81 percent, respectively. The higher ARCC for CUP implies that this type of fingerprint is superior to ARP fingerprints for bacterial source tracking for *E. coli* isolates. The CUP results indicate that of the three sources evaluated, sewage influent and cattle are both major contributors to fecal contamination in the Duck River near Shelbyville.

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TENNESSEE'S PEARL CULTURE INDUSTRY

Don Hubbs[1]

Tennessee Wildlife Resources Agency (TWRA) regulates freshwater pearl culture in Tennessee. Administrative rules, proclamations and contracts are employed to regulate the industry; and protect and manage its utilization of the natural resource. Although experiments in pearl culturing began in the 1960's, governing regulations were not developed until 1988. A panel composed of Agency fisheries personnel and industry representatives drafted the first regulations. Megalonaias nervosa (Rafinesque, 1820), the washboard, is the primary freshwater mussel species used by Tennessee's pearl culture industry. Because they command the highest price in the commercial shell market and legal sized individuals can be scarce, industry experts convinced the Agency to permit the use of sub legal sized washboards for economic reasons. Contracts, seasons and quotas were established to control the harvest of wild washboard mussels for the pearl culture industry. Use of sub legal sized washboards proved unpopular with many commercial shell harvester and wholesale shell dealers.

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WORKING WITH PRIVATE LANDOWNERS TO PROTECT HABITAT FOR THE RARE BARRENS TOPMINNOW (*FUNDULUS JULISIA*)

Brad Bingham[1]

The barrens topminnow (*Fundulus julisia*) once ranged across six Tennessee counties, all situated on the Highland Rim. Habitat loss and modification, however, have resulted in a drastic decline of *F. julisia's* numbers over the past 15 years. As of today, only three viable populations remain in the wild. The three remaining sites are all privately owned and located in Coffee and Cannon Counties, Tennessee. All sites provide suitable habitat for *F. julisia*, but the small sizes, locations, and private ownership pose potential problems for the fish in the near future.

An outreach effort to develop a level of trust between the U.S. Fish and Wildlife Service (Service) and local landowners was launched in 1997. This effort included contacting and developing a working relationship with the local Natural Resource Conservation Service District Conservationists for each county. Their valuable knowledge of the local agricultural community and problems related to it was an absolute necessity in developing successful landowner relationships. Problems encountered by the agricultural community and how they related to the problems contributing to the decline of the *F. julisia* populations were identified. For example, degraded water quality was identified as a major cause in the decline of suitable habitat for *F. julisia*. Water quality is also known to be a problem associated with livestock production in the area.

Utilizing the Partners for Fish and Wildlife Program as a funding source, practices including riparian livestock exclusion fencing, hardened stream crossings and accesses, hardened feeding areas, sediment removal from springs, and alternative watering sources (tanks) have been installed to reduce livestock impacts on springs and their associated runs. These practices, targeted to improve water quality, have been installed at 18 sites since 1997. In addition, *F. julisia* have been returned to eight of the 18 sites, all of which occur within the fish's historic home range.

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Ultimately, the Service's goal is not only to protect and enhance existing habitat, but to reestablish *F. julisia* throughout its historic range. By restoring habitat and establishing additional populations of *F. julisia,* the need to list the species under the Endangered Species Act should be precluded. Therefore, by working with private landowners, not only can we achieve the Service's goal, we can also assist landowners in their daily efforts to make a living producing livestock in a more environmentally friendly manner.

TOXICITY REDUCTION BY USE OF CONSTRUCTED WETLANDS TREATMENT

James R. Orr[1] and Don Deemer P.E.

Many NPDES permits contain a requirement that the treated effluent discharge shall not cause aquatic toxicity. The aquatic toxicity requirement usually consists of chronic toxicity testing using a vertebrate and/or invertebrate test organism. *Ceriodaphnia dubia* is commonly the more sensitive of the commonly used as the test organisms. Conventional wastewater treatment plants are typically designed for the removal of organic materials as measured by the BOD test, suspended solids, and in some cases nutrients, metals, and other constituents. While a conventional wastewater treatment system may do an exceptional job in removing these constituents and produce a clear effluent, trace amounts of both organic and inorganic compounds may still be present in concentrations great enough to cause aquatic toxicity. Natural systems such as constructed wetlands have shown an ability to eliminate the toxicity in wastewater effluents. There are many treatment mechanisms present in a natural system which, acting alone or together, serve to remove, change, or complex potential toxicants in a manner that renders them non-toxic. All this is accomplished in a simple, easy to operate, low cost process. A case history is presented that shows how toxicity at an industrial facility was reduced to compliance levels by the construction of a wetlands treatment system. In addition to reduction of toxicity to meet instream waste concentration, fish and invertebrate biodiversity studies indicate that the receiving stream has recovered significantly.

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RAINFALL PATTERNS AND THE INCIDENCE OF *ESCHERICHIA COLI* IN AN EAST TENNESSEE WATERSHED

Forbes Walker[1], Michael Mullen[2], Joanne Logan[3], Melody Sasser[4] and Tiffany Day[5]

Abstract

Pond Creek is a small watershed (TN06010202013) that forms part of the Watts Bar watershed in East Tennessee. Pond Creek includes areas of Monroe, McMinn and Loudon counties. Beef (pasture) and dairy farming are the dominant forms of land use in the watershed. Monthly water samples were collected at 8 locations in the Pond Creek watershed from June 2001 to June 2002. Samples were analyzed for a variety of water quality parameters including *Escherichia coli* (*E.coli*). According to Tennessee General Water Quality Criteria, the concentration and numbers of *E. coli* colony forming units (cfu) were much higher than the levels recommended for recreational uses (126 cfu per 100 mL) at most sampling locations on most sampling dates. Extremely high numbers (>10,000 cfu per 100 mL) were observed during wet months. Lower numbers (<1,000 cfu per 100 mL) were observed during drier months. The correlation between rainfall and the presence of high *E. coli* numbers in Pond Creek suggests heavy rainfall events “flush” *E.coli* in high numbers from the landscape. Reduction in the level of *E. coli* in the watershed cannot be achieved by merely excluding or restricting livestock access to Pond Creek, but should include a number of physical measures that will intercept the *E .coli* moving with runoff.

Introduction

In 1972, after many years with little or no regulation to curb water pollution, the United States Congress enacted the Clean Water Act (CWA). Twenty-five years after the CWA, the United States Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) jointly released the Clean Water Action Plan. This report highlighted the progress that had been made in the past twenty-five years following the Clean Water Act. More stringent controls had been placed on “point sources” (factories and city sewers) of water pollution. However water quality is still a problem in many parts of the country with runoff from agricultural and urban lands being identified as the predominant source of water pollution (EPA / USDA, 1998).

The Federal Clean Water Act of 1987 requires each state to assess water quality and report the results to the public. In Tennessee, the Tennessee Department of the

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Environment and Conservation (TDEC) produce two assessment documents (the 305(b) and 303 (d) Reports) to fulfill the requirements of the Federal Act. In these reports TDEC identifies impaired waterbodies in Tennessee, and identifies the sources of these impairments. In the 2000, 305(b) report agricultural activities were identified as a major source of impairment in Tennessee streams and rivers. Grazing related activities were estimated to be responsible for 42 percent of agricultural pollution sources with in-stream watering of livestock being cited as a significant source of fecal coliform bacteria (TDEC, 2000).

In 2001, it was estimated that there were approximately 2.1 million cattle and calves on about 50,000 livestock operations and about 95,000 dairy cows on 1,600 operations in Tennessee (TDA, 2002). The majority of these animals are reared on pastures, many of them in fields adjacent to or with direct access to surface waters.

Runoff from pastures, and the direct deposition of manures from in-stream watering of animals can produce significant loadings of a number of potential pollutants from manures. Potential pollutants include organic matter, nutrients (mainly nitrogen and phosphorus) and pathogens. Some manure pathogens (*Escherichia coli, Shigella, Campylobacter,* and *Cryptosporidium)* can potentially cause human health problems.

Pond Creek (TN06010202013) was one of two watersheds in East Tennessee chosen from the 1998 303(d) list for a water quality monitoring study. Pond Creek is a small watershed that forms part of the Watts Bar watershed in East Tennessee. Pond Creek includes areas of Monroe, McMinn and Loudon counties. Beef (pasture) and dairy farming are the dominant forms of land use in the watershed. In the 1998 303(d) list Pond Creek was listed as only partially supporting the water due to nutrients, sediments, and habitat alterations. The sources listed are removal of riparian zones and confined animal feeding operations.

This paper reports on occurrence of *E. coli* at sampling points along in a small watershed in East Tennessee from June 2001 to July 2002. The concentration of *E. coli* observed at each sampling point was compared with the magnitude of rainfall events in the days prior to sampling and the Ecoregion reference stream criteria for Ecoregion 67.

Materials and Methods

Eight sampling sites were selected along the length of Pond Creek, as well as two of it's tributaries (Mud Creek and Greasy Creek) in the upper reaches of the watershed. Monthly grab samples were collected at each of sampling sites from the mid-channel of the stream. Each sample was processed for microbiological analysis within 6 hours of sampling and measured as colony forming units (cfu) 100 mL^{-1}. *Escherichia coli* were determined using a commercially available kit, Colilert, from IDEXX Corporation (Westbrook, Maine). Other analyses conducted on the samples (but not reported in this paper) included microbial parameters (coliforms, fecal coliforms and fecal *Enterococcus*), several chemical parameters (total phosphorous, total nitrogen, nitrate, nitrite suspended and total dissolved solids) and measurements of the field conditions water pH, water and air temperature, dissolved oxygen, and relative humidity were taken.

Rainfall data was obtained from the National Weather Service station closet to Pond Creek at Lenoir City, Tennessee.

Results and Discussion

The maximum contaminant level (MCL) for reported for *E. coli* for Wolf Creek (the Ecoregion 67 reference stream for Pond Creek) is 126 cfu 100 mL^{-1}. This is also the standard for the Tennessee state regulation establishing water quality standards for surface waters of the State (http://www.epa.gov/ost/standards/wqslibrary/tn/tn.html). Higher levels than the MCL for *E. coli* (log 2.10 cfu 100 mL^{-1}) were observed at all sampling points on all sampling occasions in Pond Creek, except for PC1 on July, October and November 2001. The highest value of log 5.24 cfu 100 mL^{-1} (or 3 orders of magnitude higher than the MCL) was observed at PC4 on January 2002 (Table 1).

An analysis of variance (ANOVA) with (PROC GLM model, SAS, version 8.1, SAS Institute Cary, NC) was performed at α=0.05 to determine if there were differences in *E. coli* counts across sites or across sampling times (Table 2). The ANOVA was not significant for differences across the sampling sites. Over the sampling period, the mean *E. coli* counts were above the MCL at all sites.

The ANOVA did indicate significant differences for *E. coli* across sampling months (Table 3).

E. coli counts were significantly greater in December 2001, January 2002 and April 2002 than in any other month sampled. These correspond with the highest rainfall events (Figure 1).

Conclusions

The levels of *E.coli* in Pond Creek consistently exceeded water quality standards at most of the sites sampled on most of the sampling occasions . From observations on land use in the watershed it can be concluded that agriculture, specifically beef and dairy cattle are significant sources of the *E .coli* found in Pond Creek. Although, most of the cattle were observed to have free access to the river or river-banks near most of the sites sampled a more significant factor in Pond Creek appears to be the runoff from the landscape during rain events. The concentration (and thus total numbers) of *E .coli* were much higher during the “wet” months (January, April, September and December) compared to the “drier” months.

The results from this study suggest that reducing or excluding the access of cattle to the waters of Pond Creek will not necessarily result in a reduction in *E. coli* loading. It is suggested that other best management practices (BMPs) will also have to be employed.

The use of vegetative buffer strips along the river-banks may reduce the E. coli loading into the river during some runoff events.

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Acknowledgement

This project was funded, in part, under an agreement with the Tennessee Department of Agriculture, Nonpoint Source Program and the U.S. Environmental Protection Agency, Assistance Agreement #C9994674-95-0.

Table 1. Summary of E.coli (log CFU 100 ml^{-1}) data by month July 2001 to May 2002 and location

Site	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
PC1	1.99	2.93	2.91	1.52	1.53	4.03	4.31	2.59	3.19	4.96	2.91
PC2	3.19	3.44	3.34	2.61	3.30	4.51	4.16	2.64	3.54	4.28	3.02
PC3	3.02	3.40	3.38	2.91	3.30	4.61	3.41	2.99	3.38	4.94	3.38
PC4	3.33	3.42	3.30	2.72	3.05	4.54	5.24	2.71	3.24	5.05	3.15
PC5	4.09	3.49	3.15	3.49	3.23	4.31	4.59	2.99	3.50	4.86	3.16
PC6	4.07	3.15	2.86	3.20	3.30	3.90	3.83	2.20	3.19	4.61	2.76
GS	4.25	3.36	4.54	2.48	3.20	5.38	nd	3.22	3.15	4.76	2.87
MC	4.44	2.99	3.38	2.30	3.92	4.29	4.64	3.11	3.08	4.38	nd

nd = no data

Table 2. Mean *E. coli* counts (log CFU 100 ml^{-1}) for each site averaged over 11 months at Pond Creek Watershed, July 2001-May 2002

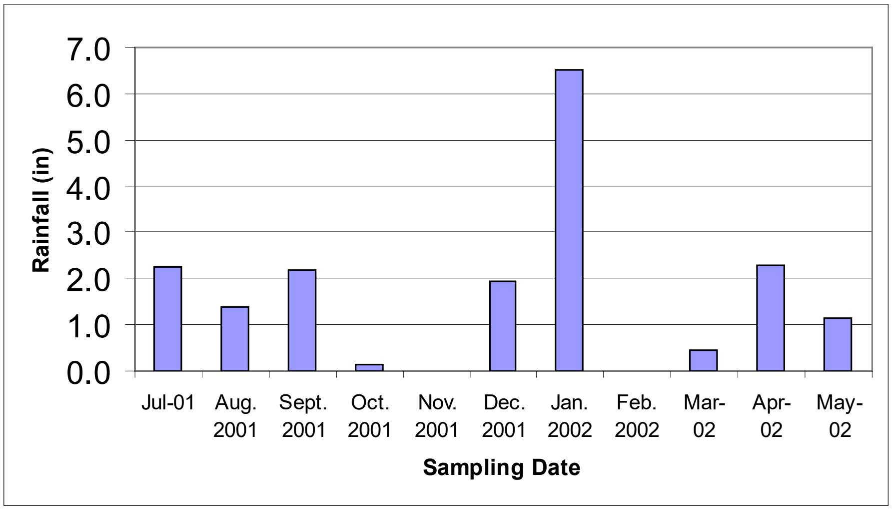
Site	E. coli
PC1 (Pond Creek)	2.99
PC2 (Pond Creek)	3.46
PC3 (Pond Creek)	3.52
PC4 (Pond Creek)	3.61
PC5 (Pond Creek)	3.71
PC6 (Pond Creek)	3.37
PC7 (Greasy Creek)	3.72
PC8 (Muddy Creek)	3.65

Table 3. Mean E. coli counts (log CFU 100 ml^{-1}) for each month at Pond Creek Watershed, July 2001-May 2002.

Month	E. coli
July 2001	3.55 c
August 2001	3.27 cd
September 2001	3.36 cd
October 2001	2.65 f
November 2001	3.10 de
December 2001	4.45 ab
January 2002	4.31 b
February 2002	2.81 ef
March 2002	3.28 cd
April 2002	4.73 a
May 2002	3.04 de
$LSD_{0.05}$	0.34

Means within a column followed by the same letter are not different by Least Significant Difference at α=0.05.

Figure 1. Total rainfall amounts during the seven days preceding sampling events for each month



EPA'S CAFO REGULATIONS AND THEIR POTENTIAL IMPACT ON TENNESSEE'S LIVESTOCK AND POULTRY INDUSTRY

H. Charles Goan[1]

Introduction

On December 16, 2002, the U.S. Environmental Protection Agency (EPA) released the final rule for concentrated animal feeding operations (CAFO). The new CAFO rule is a regulation that reinterprets the existing Clean Water Act and previous EPA policy. The rule establishes new effluent limitation guidelines and federal permit requirements for confined livestock and poultry operations. The new CAFO rule will bring added responsibilities, added costs, added public oversight and perhaps added legal risks for livestock and poultry farmers.

The final version of the CAFO rule is much different than the proposed CAFO rule which appeared for public comment two years ago. While there still will be financial hardship for some livestock and poultry farmers, fewer operations will be affected by the new CAFO rule than originally projected.

EPA expects the CAFO rule will affect approximately 15,500 livestock and poultry operations. EPA estimates an annual reduction of 56 million pounds of phosphorous, 110 million pounds of nitrogen, 2.1 billion pounds of sediment and 911,000 pounds of metals being released from CAFOs. A significant reduction in pathogen release is also expected.

The CAFO rule is estimated to cost $335 million annually which is substantially lower than the $940 million annual cost in the proposed rule. To help farmers with some of the added costs of meeting the regulations, Congress increased funding for land and water conservation programs in the 2002 Farm Bill by $20.9 billion. Additional funds to assist farmers were authorized in the Environmental Quality Initiative Program (EQIP) and 60 percent of these funds must go to livestock and poultry operations.

The final rule allows states some flexibility in tailoring regulations to meet individual state needs. While the large CAFOs will be required to be permitted, states will be able to use voluntary and incentive programs to help medium and small operations from becoming subject to the CAFO rule.

Criteria for AFOs and CAFOs

Two criteria are used to determine if a livestock or poultry farm is an Animal Feeding Operation (AFO). These criteria are (1) animals must be confined for at least 45 days in a 12-month period, and (2) there is not grass or other vegetation in the confinement area during the normal growing season.

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CAFOs are AFOs that must obtain a National Pollution Discharge Eliminations Systems (NPDES) permit. Presented in Table 1 are animal number thresholds for livestock and poultry operations. The operations are divided into large, medium and small categories. Operations with animal numbers in the large category are automatically designated a CAFO.

Operations in the medium size category will be a CAFO if (1) a man-made ditch, pipe, flushing system or other similar man-made device carries manure or process wastewater from the operation to surface water or (2) pollutants are discharged directly into surface waters which originate outside of and pass over, access, or through the facility and the animals come into contact with the water.

A small size operation can be designated a CAFO if it is inspected by a representative of the state or federal permitting authority and it is determined the operation is a significant contributor of pollutants to waters of the state.

Table 1. Animal Number Thresholds for Livestock and Poultry Farms

Sector	Large	Medium[1]	Small[2]
Cattle or cow/calf pair	1,000 or more	300 – 999	Less than 300
Mature dairy cattle	700 or more	200 – 699	Less than 200
Veal calves	1,000 or more	300 – 999	Less than 300
Swine (weighing over 55 lbs.)	2,500 or more	750 – 2,499	Less than 750
Swine (weighing less than 55 lbs.)	10,000 or more	3,000 – 9,999	Less than 3,000
Horses	500 or more	150 – 499	Less than 150
Sheep or lambs	10,000 or more	3,000 – 9,999	Less than 3,000
Turkeys	55,000 or more	16,500 – 54,999	Less than 16,500
Laying hens or broilers (liquid manure handling system)	30,000 or more	9,000 – 29,999	Less than 37,500
Chickens other than laying hens (other than a liquid manure handling system)	125,000 or more	37,500-124,999	Less than 25,000
Laying hens (other than a liquid manure handling system)	82,000 or more	25,000 – 81,999	Less than 25,000
Ducks (other than a liquid manure handling system)	30,000 or more	10,000 – 29,999	Less than 10,000
Ducks (liquid manure handling system)	5,000 or more	1,500 – 4,999	Less than 1,500

[1] Must also meet one of two "method of discharge" criteria to be defined as a CAFO or may be designated.

[2] Never a CAFO by regulatory definition, but may be designated as a CAFO on a case-by-case basis.

CAFO Permit Requirements

The NPDES permit issued to a CAFO must include requirements to (1) develop and implement a nutrient management plan, (2) keep all applicable CAFO records for five years, (3) provide the recipient of manure, litter or process wastewater going off-farm with the most current nutrient analysis and (4) submit an annual report to the state permitting agency.

The nutrient management plan must address the form, source, amount, timing and method of application of nutrients on each field to achieve realistic production goals while minimizing nitrogen and phosphorous movement to surface waters. Manure must be analyzed at lease once annually for nutrient value and soil analyzed at least once every five years. Records must be kept to document compliance.

Manure, litter and process wastewater may not be applied closer than 100 feet to any down gradient surface water, open tile intake structures, sink holes, agricultural well heads or other conduits to surface water. The CAFO may substitute the 100 feet setback with a 35 feet wide vegetated buffer where application of manure, litter or process wastewater are prohibited.

All existing and new beef and dairy operations will continue to use the 25-year, 24-hour storm design criteria for manure storage. However, new swine, poultry and veal calf operations will be required to design manure storage systems based on a 100-year, 24-hour storm event.

Summary

The final EPA CAFO rule appears to be compatible with Tennessee's existing CAFO regulations. While some differences do exist, for example, animal numbers for an operation to be designated a large CAFO, EPAs final rule will strengthen Tennessee's CAFO regulations. States will have some flexibility in developing programs to assist medium and small animal feeding operations. Tennessee has one year to make necessary changes in it's CAFO regulations.

The final rule states that true pasture and rangeland operations are not considered animal feeding operations. In a pasture based operation, animals may freely wander in and out of a particular area for food or shelter and this is not considered confinement.

CAFOs that most likely will have difficulty in meeting the new regulations are (1) operations with limited access to sufficient land for manure application, (2) operations with limited manure storage capacity and (3) operations in watersheds where phosphorous problems have been identified.

Several state and federal agencies including the Tennessee Department of Agriculture, Tennessee Department of Environment and Conservation, University of Tennessee Agricultural Extension Service, Natural Resources Conservation Service, Farm Services Agency and the U.S. Environmental Protection Agency are working to develop programs to assist Tennessee livestock and poultry farmers in meeting the new CAFO rule.

CENTER FOR DECENTRALIZED WASTEWATER MANAGEMENT

John R. Buchanan, Ph. D., P. E.[1]
Ronald E. Yoder, Ph. D., P. E.
C. Roland Mote, Ph. D., P. E.

The establishment of a center for decentralized wastewater management in Tennessee has long been a goal of onsite wastewater professionals in the state. This goal has now been realized. The University of Tennessee's Agricultural Experiment Station has formed a partnership with the Tennessee Department of Environment and Conservation (TDEC) (Division of Ground Water Protection), the Tennessee Valley Authority (TVA), and the Tennessee Onsite Wastewater Association (TOWA) and has secured a 319(h) grant from the Tennessee Department of Agriculture's Nonpoint Source Program to establish the Center for Decentralized Wastewater Management.[2]

Total funding pledged over a four-year period to establish the Center is $672,163. The 319(h) grant will provide 59% of the funds and the remaining 41% will be provided by the key cooperating agencies: TDEC, TOWA (donated services, equipment and supplies, and treatment systems for the Center), and TVA. Expectations are for the Center to become self-sustaining after the 4 year development period using income generated from its services and other sources.

The objectives of the Center are to:

1. Train Decentralized Wastewater Treatment Systems (DWTS) technicians (e.g., installers, septic tank pumpers, inspectors, systems operators, etc.) in the proper installation, operation, and maintenance of established and evolving DWTS technologies,
2. Educate DWTS professionals (e.g., system designers, regulation writers, etc.) in the science and practice of successful decentralized wastewater management,
3. Teach consumers/users of DWTS technologies (e.g., community opinion leaders, housing developers/builders, home owners, etc.) to recognize and appreciate the advantages and disadvantages of decentralized wastewater management,
4. Demonstrate/evaluate alternative decentralized wastewater management technologies, and
5. Develop and/or identify decentralized wastewater management technologies compatible with specific limiting soil/site conditions.

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[1] John R. Buchanan, Assistant Professor and Center Director, Biosystems Engineering & Environmental Science; Ronald E. Yoder, Professor and Head, Biosystems Engineering & Environmental Science, and C. Roland Mote, Assistant Dean, Tennessee Agricultural Experiment Station. Contact information for Buchanan: office phone (865) 974-7266 or email at jbuchan7@utk.edu.

[2] This project is funded, in part, under an agreement with the Tennessee Department of Agriculture, Nonpoint Source Program and the U. S. Environmental Protection Agency, Assistance Agreement #C9994674-02-0.

The overriding goal for the Center will be improvements in water quality in regions where water has been negatively impacted by improperly functioning treatment systems. A parallel goal is sustained growth and development in unsewered areas with no deterioration in quality of surface and groundwater reservoirs. Sustained operation of the Center should eventually result in detectable changes in the number of reported incidences of failing “septic tanks” and noticeable improvements in the quality of surface and groundwater reservoirs currently negatively impacted by domestic wastewater.

The Center will be an education, service, and research program of UT’s Institute of Agriculture. The Center’s principal training laboratory will be located at the Agricultural Experiment Station in Spring Hill. Training will also occur at a variety of other locations to provide regional service. An Advisory Board has been established that consists of two representatives from each the partners (TOWA, TDEC, TVA). Additionally, a representative from the Tennessee Association of Realtors, The National Rural Electric Cooperative Association, The Nature Conservancy, Home Builders Association of Tennessee, Tennessee Association of County Executives, and the Tennessee Environmental Health Association. This 12-member board will regularly review Center activities and provide advice for improving the Center’s educational and service programs.

GATHERING THE WATERS OF TENNESSEE SPRINGS MONITORING PROGRAM - PRELIMINARY MODEL FOR GROUNDWATER EDUCATION

Laurina Isabella Lyle[1], Tim Brown and Steven W. Hamilton

Tennessee is divided into seven physiographic zones. Each region has its own particular mosaic of groundwater from aquifers, seeps, springs, artesian springs and wells. A rich natural and cultural history exists concerning the locations and usage of these watering holes. Preliminary protocols are being developed to lay the groundwork for a statewide citizen springs monitoring project titled, Gathering the Waters of Tennessee. These protocols were developed from monitoring data and observations from four selected springs in Montgomery and Robertson Counties, Tennessee. (See T. Brown, *et. al. Preliminary Findings of a Comparison of Abiotic and Biotic Factors in Selected Springs in Montgomery and Robertson Counties, Tennessee*) The Gathering of the Waters of Tennessee is a water education project whose goal is to teach children, teachers, parents, non-formal environmental educators, landowners and other adults about biological monitoring, groundwater, springs, water conservation, and the culture and history associated with springs by standards based, hands-on, and inquiry-based activities.

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PROMOTING THE INVOLVEMENT OF WATER RESOURCE PROFESSIONALS IN ENVIRONMENTAL EDUCATION

Dana M. Ball[1]

The Clean Water Act has had notable success in reducing point source pollution. However, in some ways, control of non-point source pollution presents the greater challenge. Because non-point source pollution can be caused by a wide variety of human activities on the land, resulting from numerous daily decisions people often make without even thinking, it is important that citizens be made aware of the potential impacts of their daily decisions and of their lifestyles and be equipped to make informed decisions.

Although education efforts can target either student or adult audiences, there are several good reasons to target students. For one thing, today's K-12 students are the decision makers of tomorrow. Also, as cities grow, so will the need for water resource professionals and it will be today's K-12 students that will fill this need.

Here in Tennessee, it is especially important for high school graduates to be prepared to make future decisions regarding water resources in the Southeast. However, there is often a lack of information on regional water resources in K-12 textbooks and in school media centers. In addition, most K-12 teachers do not have specific training in environmental science. Therefore, there is a need for teachers to be provided with appropriate water education resource materials. Water professionals can help meet this need in a variety of ways.

Examples of Water Education Efforts in Tennessee

In the past, several successful environmental education programs have relied on partnerships. One of the earliest examples of collaborative water education in Tennessee was the promotion of the national Project WILD Aquatic supplementary curriculum. At one time, facilitator training for Project WILD included both resource professionals and environmental educators, who then worked in teams to provide teacher in-service programs that were scheduled through a central office in the state of Tennessee Department of Education. Budget cuts in the Department of Education, the Tennessee Wildlife Resources Agency, and the Tennessee Conservation League eventually led to the abandonment of this program.

There have also been successful water education programs sponsored by specific organizations and agencies. For example, the Kids in the Creek educational program, sponsored by the Tennessee Valley Authority (TVA), is designed to give students the opportunity to have hands-on learning about water quality. Several rotational stations are set-up at a stream, giving the students the chance to learn about macro-invertebrates, fish populations, and biological and chemical monitoring.

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Tennessee is one of the top states for holding Project WET *Make a Splash* festivals. This year, *Make a Splash* festivals took place on Friday, September 21 in towns across the country. This is the second annual Project WET effort of its kind, involving activities designed to teach children about the science and history of water, one of our most important natural resources. More than 50,000 children participated in the event.

A new water education program called Healthy Water, Healthy People sponsored by the Hach Scientific Foundation was launched to coincide with this years *Make a Splash* festival. The Healthy Water, Healthy People program is designed to make water quality concepts understandable and relevant for all students. Healthy Water, Healthy People Water Quality Education Stations, sponsored by the Hach Company and The Perrier Group of America, will involve students in hands-on activities that demonstrate the importance of healthy water for healthy people and environments.

The Catfish Out of Water Project is a collaboration of the Cumberland River Compact, Greenways for Nashville, and the Parthenon Patrons. The Catfish Out of Water Project uses public art to educate the community and encourage the protection our rivers. The public art is the state's legendary aquatic creature, the catfish, which will be placed in parks, on street corners and in local plazas. There are four main education components to the project: a stormdrain-labeling program, a booklet for grades 4 – 8 about catfish habitat and the effects of polluted runoff, an expansion to Warner Parks Junior Naturalist Program featuring a Catfish out of Water patch, the placement of placemats in local restaurants, and a interactive website for adults and children.

Since the mid 1980s, the Tennessee Aquarium Education Department has offered a graduate environmental education class for kindergarten through 8th grade teachers that emphasizes hands-on learning in aquatic habitats such as streams, marshes and ponds. The Tennessee Aquarium designs and teaches classes at the aquarium that focus on aquatic habitats, such as Stream Scene, where students become macroinvertebrates responding to pollution stresses. They also conduct stream ecology classes for teachers and students at regional environmental centers. In addition, they conduct Project WET, Aquatic Project WILD, and GLOBE (Global Learning & Observations to Benefit the Environment) workshops and in-services for teachers and scout leaders.

Over time several different organizations have attempted to involve students in stream monitoring projects. Examples of this attempt are the Harpeth River Project led by Judy Butler and Virtual Watershed led by Susan Kuner. These projects ended due to the difficulties of inconsistent funding and the fact that there was no statewide coordination.

Ideas for Involvement of Water Resource Professionals with Schools

There are a number of ways that water resource professionals, organizations, and agencies can work with schools and teachers to promote water education. Among these are the following:

- Develop teaching trunks for education centers
- Provide materials for loan to schools, such as kits, models, and EnviroScapes
- Be available as a guest speaker
- Provide opportunities for teacher in-service
- Adopt a science class
- Help a school plan a water festival
- Be available for job shadowing and Career Days
- Provide financial support for equipment grants to schools
- Mentor science fair projects
- List materials, data, and state specific information on the website.
- Develop useful power point presentations for teachers and list on website.
- Provide financial support for producing posters, handouts, and workbooks or field guides
- Sponsor outdoor recreational opportunities
- Set up Best Management Practice demonstrative sites or models
- Become a Project WET facilitator.

Tips for Creating Successful School Outreach Programs

For those groups that elect to develop their own educational materials and outreach programs, there are several guidelines derived from the experiences of successful programs.

- Wherever possible, draw on and adapt existing resources; don’t try to reinvent the wheel
- Correlate outreach activities and materials to state education standards
- Develop materials through partnerships that involve resource professionals and educators
- Remember that direct involvement in hands-on activities is more effective than lectures
- Field test education materials and programs and revise them accordingly
- Promote resources and opportunities through school system curriculum coordinators

Resources

Water Webliographer http://webliographer.com/Water/
A compilation of water resources and water-related issues.

Tennessee Science Standards
http://www.state.tn.us/education/ci/cistandards2001/sci/ciscibiology1.htm
Standards, Learning Expectations and Draft Performance Indicators

Project WET Tennessee http://www.apsu.edu/wet/intro.html
WET stands for **W**ater **E**ducation for **T**eachers. The project is an international, interdisciplinary, water science and educational program for formal and non-formal educators of K-12 students.

Aquatic WILD http://www.projectwild.org/resources/aquaticframe.htm
Project Aquatic WILD is a set of 40 activities that accompany Project WILD. Project WILD is a conservation and environmental education program for K-12 students.

WOW! The Wonder of Wetlands http://www.wetland.org/wow.htm
WOW! The Wonders of Wetlands is an instructional guide for educators that provides a resourceful and creative collection of activities, information, and ideas that focuses on the important topic of wetlands.

Enviroscape Models http://enviroscapes.com/
EnviroScape models are interactive tools that illustrate possible water pollution scenarios.

Izaak Walton League Save Our Stream Program http://www.iwla.org/sos/
Save Our Streams (SOS) is a national watershed education and outreach program.

SIGNS AND CARDS
Educating Construction Site Workers about Pollution Prevention

Kerry Moskal and Tom Lawrence[1]

One of the most time consuming aspects of the storm water program enforcement staff is dealing with pollution discharges from construction sites, primarily soil discharges. In order to address this problem at its source, the City of Memphis contracted with Hess Environmental Services to develop and implement an education program aimed at the people working at these construction sites, so that they could:

- Know why there are BMPs on the site.
- Know what to do if they see damaged BMPs or see pollutant discharges
- Learn the penalties for causing the discharge of pollutants

Using approaches, such as posting signs at the sites, having quick, simple handouts available and speaking to workers at their meetings, this program employs innovative approaches to educate a mobile, hard-to-reach audience.

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A WATER RESOURCES ALMANAC FOR THE MEMPHIS DISTRICT

Robert Hunt, U.S. Army Corps of Engineers, Memphis District[1]

INTRODUCTION

The Memphis District expects to produce and distribute a Water Resources Almanac for the benefit of the people living and working within the boundaries of the District. We hope that the Almanac will provide readers with water resources information useful in the pursuit of sustainable economic progress and environmental protection.

Although the Almanac may appear on the internet, a tangible book is considered indispensable for this effort. A tangible Almanac is required, partly because many people still do not have access to the internet. Additional reasons are the portability of a book, the ephemeral and disjointed nature of materials disseminated on the internet, readability, and the plain satisfaction that comes from having a book in hand.

The name "almanac" was chosen to convey the fact that the book contains miscellaneous information of interest to a broad range of readers. Descriptions such as "handbook" or "encyclopedia" might have been just as apt, but the more folksy name of "almanac" should correctly project the informal and inclusive nature of this work.

LITERATURE REVIEW

The idea for the Almanac resulted from an examination of the State of Tennessee's *Blue Book*. Published biennially, the *Blue Book* has essentially been the Tennessee citizen's state "owner's manual." In addition to state civics, the *Blue Book* presents geographical and cultural information of interest to young and old. The District believes that this kind of approach will be an effective and enjoyable way for citizens in the Memphis District to learn and share information about regional water resources. The Almanac will be their "owner's manual" for the incredibly rich natural resources of the Memphis District.

The familiar USDA county soil survey was also examined as a type of community "almanac." The county soil survey is a treasure of local geography, geology, climate, history, and culture, in addition to being a detailed inventory of soil resources.

Regional histories of water resources development, and the cultural effects of same, are available in books such as *The Tennessee, Rising Tide*, and *River at the Door*. It is hoped the Almanac can point the reader to the riches contained in these, and other, books.

[1] Robert Hunt, U.S. Army Corps of Engineers, Memphis District, Project Development Branch, 167 N. Main Street, B202, Memphis, TN, 38103-1894, (901) 544-0875.

DESIGN

The Almanac design includes physical characteristics, organization of material, and difficulty of material.

The Almanac's physical characteristics will be that of a paperback book made of 8.5" x 11" paper. The Almanac will have a few hundred pages.

The Almanac will be organized to permit the separation of its contents into subsets suitable for special audiences and presentations. An attempt will be made to keep time-sensitive material separate from other material, so updates can be made easily. The fundamental unit of the Almanac will be the "Article." An article will focus on a very narrowly defined subject and will be limited to a length of one page (whenever possible).

The Almanac's level of difficulty will be aimed at the eighth-grade reading level. Although vocabulary and sentence complexity will be limited, it is intended that the tone of the Almanac should not appear condescending. Rather, it is hoped that college students and professionals, for example, will enjoy quickly brushing up on a point or two

DISTRIBUTION

The Almanac will be distributed at no charge to all parties desiring a copy. As shown in Table 1, the Almanac will be offered to governments, businesses, and private individuals.

Table 1. Almanac Distribution

Public	Offices	Federal
		State
		Local
	Libraries	City
		High School
		University
Private	Individuals	as Community Leaders
		as Property Owners
		as Recreationalists
		as Environmentalists
		as Utility Customers
		as Consumers
		as Taxpayers
		as Mentors to Youth
		as High School Students
	Businesses	Agriculture
		Transportation
		Developers
		Manufacturers
	Organizations	Recreational
		Environmental
		Youth Development

OUTLINE

The Almanac will be divided into four volumes:

1. The Memphis District (as a government organization)
2. The Memphis District (as a geographical area)
3. Water Resources Technology
4. Special Topics for High School Students

Each volume may be subdivided into books, parts, chapters, and articles. Exhibit 1 presents a sample article on the subject of culvert cross sectional shapes. Italicized terms in the article will be included in a glossary.

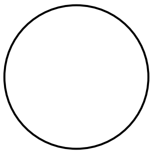
Exhibit 1. Sample Almanac Article

CULVERTS: Cross Sectional Shapes

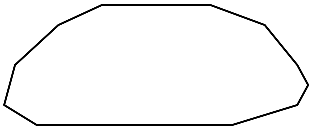
Culverts can be made in several *cross sectional* shapes. Here, we will only talk about the three most common shapes used in the mid-south--the *box,* the circle, and the *pipe arch*.

Figure 1 shows the three shapes. The (a) box is the only culvert shape with straight sides. The box can be built rectangular or square. The (c) pipe arch looks like a circle that has been partly flattened on the bottom, but not on the top.

(a) box



(b) circle



(c) pipe arch

Figure 1

Why do we use culverts of different shapes? There are several reasons that may come into play. In particular, engineers consider economy, strength, ease of construction, and flow behavior in selecting a culvert shape.

Selection of a culvert shape goes hand in hand with the culvert material. For example, sometimes the culvert shape we select is the least expensive shape to build using a material we have already selected.

Sometimes one shape may be quicker or less expensive to lay and *backfill* than another shape.

Sometimes one shape will support weight better than another. For example, a circular culvert will usually support more weight than a pipe arch culvert of about the same size and made of the same material.

Sometimes we choose a culvert shape to make water behave a certain way as it flows through the culvert. For example, the circular culvert is a very efficient culvert shape when flowing full. A box culvert, on the other hand, is good at moving water even when the box culvert is less than half full.

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PARTNERING FOR STUDENT STREAM MONITORING YIELDS MORE THAN DATA

Carol P. Harden[1] and Roger A. Milam[2]

Introduction

In the spring of 2002, one of us (Harden), a Geography Professor at the University of Tennessee (UT), was teaching a course on Water Resources. The other (Milam), a watershed specialist, was working in the Engineering Department of the City of Knoxville. The Water Resources Research Center at UT put us in contact with each other, and we developed a partnership that produced important benefits beyond the intended data. In this paper, we describe our collaboration and its results. While we don't have a "recipe" for success, we think our experience will encourage others to develop education–to–agency partnerships.

Overview of Spring 2002 Partnership

Our partnership in the spring of 2002 involved an undergraduate Water Resources class at the University of Tennessee, the City of Knoxville, and the Water Resources Research Center at UT. Harden divided 37 students into ten teams and assigned each a reach of Third Creek to monitor during the semester. Third Creek is an urban stream in Knoxville that is 303(d) listed for pathogens, nutrients, siltation, and habitat alterations. By planning together, we were able to focus student efforts on sites of special interest to the City. Students conducted weekly field sampling and were given access to a lab, where they met outside of class to do the water quality analyses (see Table 1). They made oral and written presentations at the end of the course to share results with each other and with the City.

Harden had purchased LaMotte test kits using funds obtained in a competitive UT award for improving undergraduate teaching. The City purchased and provided Coliscan test kits, and Ruth Anne Hanahan, from the Water Resources Research Center did an in-class Coliscan training session. The City also provided maps from its GIS: a watershed map for each team, one color land use map at a scale of 1 inch = 1500 feet, and more than 30 topographic maps at a scale of 1 inch = 200 feet so that students could study the contributing areas for their assigned reaches. Later, KGIS provided digital coverages of the watershed to a graduate student taking the class (who is now doing thesis research involving Third Creek). Harden reports that a key contribution from the City to this effort was its interest in the students' work, which provided context and motivation for the project. This was reinforced by Milam's visits to the classroom, once to give a guest lecture on water resource issues and later to hear student presentations.

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Table 1. Details of the class project

Course: Geography 436: Water Resources
Semester Spring 2002

Enrollment: 37 undergraduate and 2 graduate students
Number of undergraduate stream research teams: 10

Duration of team monitoring: February – April, 2002

Students determined:

Parameter	*Method*
Temperature	thermometer
pH	meter
conductivity	meter
turbidity	meter
Nitrate-N and Phosphate	LaMotte kit (color)
Ammonia	LaMotte kit (color)
Calcium hardness	LaMotte kit (titration)
Chromium, Copper	LaMotte kit (tablets, color)
E. Coli	Coliscan kits (24 hour incubation)
DO	LaMotte kit
Discharge	float method and channel geometry
Visual Assessment	NRCS protocol
Windshield survey	for sources of runoff and sediment and land-channel connections

Benefits from the Educator's Perspective

First, there were the usual educational benefits of doing group projects (of course, the usual headaches, too), and the important educational benefits of hands-on learning. These are summarized in Table 2.

Knowing that City and Water Resources Research Center personnel were waiting for their results heightened the students' sense of the importance of their work — no longer 'just an class assignment' the monitoring became professionalizing work with real meaning to the broader community. It must be noted that the Third Creek project and the training in water sampling and analysis was only one portion of this course, which also covered the water cycle, fluvial geomorphology, groundwater, wetlands, water law, and water management. Students were expected to learn about a wide spectrum of water resources topics through reading, lectures, and written assignments. Significantly, their involvement in the Third Creek project caused them to be much better engaged and motivated students in all aspects of the course. Attendance was excellent, and the students were eager to learn more.

Many of the educational benefits were subtle. Over the course of the semester, the students gained confidence in their field and lab abilities as well as a sense of mastery of techniques and understanding. With small sample sets, they struggled to interpret their data, directly confronting the complexity and variability of natural systems. Most gained important insights into the importance and the limitations of science to environmental management.

Table 2. Benefits of the Third Creek Project

Group 1 **Educational Benefits: General**	*Group 2* **Educational Benefits: Water Resources**
• Hands-on learning • Teamwork • Individual and team responsibility • Group dynamics • Leadership • Data-gathering and analysis • Oral and written presentations • Preparation for job environment	• Familiarity with a stream reach over an 11-week period (Feb. – Apr.) • Calibration and use of meters (e.g., pH) • Visualization of colonies of *E. Coli* • Appreciation of factors that can affect sampling • First-hand experience with watershed–stream connections • Basic introduction to water chemistry
Group 3 **Benefits to the City**	*Group 4* **Less Tangible Benefits for Students**
• Help accomplish education mission • Effective way to develop citizen consciousness of water resource issues • Increased frequency of observations • Data and observations about specific sites	• Appreciation for dynamic behavior of natural environment • Better sense of the certainties, vagaries, and processes of science • Sense of connection to a public agency

Benefits from the Students' Perspectives

Students were effusive with praise for the Third Creek project—they felt good about themselves based on what they had learned and accomplished during the semester. Harden asked them to complete a questionnaire at the end of the project. The first question solicited their impressions of the educational benefits of the Third Creek project. Everyone found benefits to write about. Here are a few excerpts:

> • Hands-on experience is the best way for a person to learn anything. Talking about water pollution in a classroom is good, but to get out in the field and see it first hand is something that will stick with a person.
>
> • It was good to get a hands-on look at current issues in the real world. It got the class very involved and much more interested in the course and what was going on in the world right around them.

- The educational benefits were learning the area and how our section of Third Creek functioned with the surrounding area. Another benefit is knowing what is right and what is wrong in the best interest of a stream and how certain things affect the way the stream functions. Most of all, I'm able to generally do testing and take measurements on a stream and come out with reasonable results.

- Monitoring and interpreting a real physical site helped me better understand the concepts in class, and I will definitely remember them. Great reinforcement! I also think it's very important to know how to apply the knowledge from class to the real world.

- It was nice getting out in the field, and having a feeling of responsibility for our section of the stream. The water testing part was also very cool.

- In fact, I'm just more aware of the stream conditions everywhere. While I drive or hike, I'm looking at the things we learned in class.

The second question asked students whether they thought their experience on this semester project might make them more interested in becoming involved in a volunteer citizen monitoring effort or a watershed alliance. The response was unanimous and resoundingly positive. Many wrote "yes," but others wrote more enthusiastically "definitely!" or "absolutely." One student added, "I think this class helped me realize the significance of pollution and that each individual can make a difference by sharing knowledge and monitoring." Students also made suggestions for improving such a project in the future.

Benefits from the City's Perspective

One might challenge some of the absolute values of the student-obtained data, but those that show the presence or absence of a particular constituent are especially revealing. Unusual readings for nitrates or phosphate, and high *E. Coli* counts, for example call attention to specific water quality problems. The data are valuable for what they document, but they are difficult to compare in a single database, since different groups of students sampled at different days, times, and flow conditions.

The weekly presence of the students at 10 sites along Third Creek and its tributaries was an important benefit—for about three months, the City had extra eyes, ears, and noses in the Third Creek watershed. Having so many observers in the field greatly increased the chances of encountering unusual conditions. One group reported chronically smelling gas but not seeing any obvious sign of it; another group reported an oily discharge and dead snapping turtle in a small tributary. The observations of these students, combined with biological monitoring by a high school class and existing knowledge, prompted City and TDEC staff to conduct additional tests for hydrocarbons in the area of concern. Those tests documented a significant problem, which is now being addressed. Milam had been particularly interested in establishing educational linkages with post-secondary education. Our collaboration not only met that objective, but appears to have had a profound and potentially long-lasting effect on the students.

A Brief Critique

It was clear from the start that the data resulting from the student project would be constrained by a number of factors. The issue of data quality and quality assurance is an ongoing concern in citizen monitoring. Even before the project began, it was evident that neither time nor supervisory personnel would be sufficient to insure rigorously controlled lab analyses. Highest priority was put on safety in the lab and field. Coliscan tests were closely supervised, while other analyses received less instructor attention.

It was not possible to standardize the timing of sampling due to the complex schedules of the students, who did this work outside of class between other courses, homework, sports, and jobs. The greatest challenge for each team was finding times when its members could work together. Each group sampled when it could, so that sampling occurred on various days of the week and in different flow conditions. Students did water quality tests in the lab (except temperature measured and DO samples fixed on site), and used kits (LaMotte) because the lab was not equipped with equipment, supplies, or personnel to train them or conduct analyses to a higher standard. Students found color-based determinations (e.g., for phosphate) difficult. They also were remarkably challenged by tests that required returning to the lab: several Coliscan plates spent multiple days in the oven, and several BOD samples remained in the dark cabinet after 5 days. Students did not have unsupervised access to turbidity and conductivity meters, so those readings were less frequent.

Some students were frustrated that they couldn't do more. One student wrote, "I would have liked to have done a little more with finding the sources and narrowing down what is polluting and where." We had to coach them to contact the city with their concerns rather than directly confront property owners, and to dissuade them from their desires to be vigilante patrols.

Conclusions

Based on student response, we consider this class project to have been a great success. Even though the actual data are of limited use, the project advanced the objectives of both partners and had a very positive effect on the students. Data acquisition is only one element of what can be accomplished by student stream monitors. These students, future citizens and leaders, had an educational experience that will remain with them throughout their lives. In retrospect, the non-material contributions of the City, especially in the form of professional interest and an expression of need for the information being gathered, were at least as important as the material support. Partnering with entities outside the university definitely made the course more meaningful to students, who have a new appreciation of the responsibilities of the City and are comfortable contacting the City about water. We encourage others to develop similar partnerships.

CONVERTING COMPLAINTS TO IMPLEMENTED SOLUTIONS

Jeff Albee[1] and Stephen Noe, P.E.[1]

Service providers have a constant inflow of complaints from users and/or customers. Public agencies are not excluded and often are overwhelmed by volume or difficulty of producing a response. This often results in a very slow response or worst case scenario of no response at all. Nashville-Davidson County's storm water program has experienced this for years. Year 2002 marks a drastic change in Nashville's ability to receive, evaluate, and respond to storm water complaints. The first step in solving this problem was the defeat of the programs nemesis "FUNDING." The second step was streamlining the process of complaint to implemented solution. The third step was the use of ARCIMS to facilitate data to display needs, schedules, and progress. This paper specifically discusses the use of ARCIMS to communicate to a project team, administrators, and the public.

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COMBINING THE SOIL STABILIZING EFFECT OF INDIGENOUS VEGETATION WITH THE ENGINEERED STRUCTURE OF A GABION BASKET IN ENVIRONMENTALLY SENSITIVE WETLANDS

Dominick Amari P.G.[1]

At the Banana River Estuary near Cocoa Beach Florida, Patrick Air Force Base was experiencing shoreline erosion as storm surge wave action and tidal inundation was encroaching upon an environmentally sensitive wetland. Over 2,000 feet of shoreline was experiencing severe erosion in an area the military wanted an environmentally sensitive response to maintain an aesthetically pleasing and natural shoreline. Of major concern to Federal and the State of Florida's environmental agencies was the survival of the adjacent wetland. Two existing techniques were uniquely combined on this project to produce a stable, erosion-resistant estuary shoreline. Initial shoreline stabilization was achieved by utilizing a row of stainless steel gabion baskets installed subterranean to the beach elevation and adjacent to the wetland. Mangrove trees and St. Augustine Grass were then planted on top of and seaward of the gabion structure. By burying the gabions, the natural appearance of the beach is maintained. The gabion structure will provide protection of the shoreline and wetland area until the mangrove plantings can establish extensive root networks in and around the baskets rock fill. The application of stainless steel wire for construction of the gabion baskets will guarantee their longevity through repetitive salty water incursions by the Banana River Estuary or exposure to other corrosive environments. Combining the soil stabilizing effect of indigenous vegetation with the engineered structure of a gabion basket in environmentally sensitive wetlands is an innovative approach to shoreline stabilization.

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City of Franklin, Tennessee
Stormwater Management Program

Robin Fothergill[1], Mark Hilty[2], and Don Green[3]

Introduction

Franklin, a town of approximately 42,000 people, is located in Williamson County, Tennessee, which is about 30 miles south of Nashville and is located within the Harpeth River Watershed. The Harpeth River Watershed is one of the fourteen watersheds that make the Cumberland River Watershed. The impact of growth and development in the Harpeth Watershed has been identified as a key issue for regulatory agencies and environmental interest groups, and many segments of the river are listed on the states 303(d) list of impaired waters. Sedimentation from urban runoff has been identified as an important water quality issue in the Harpeth. In addition to the historic setting in Franklin, the Harpeth River is an important element in the overall quality of life enjoyed by residents and visitors to the City. As a result, protection of the Harpeth River is a priority for the City.

The City of Franklin is currently in the third year of Stormwater Master Planning. Because of the City's population and its location within the urbanized area, the City is required to comply with EPA's Phase II stormwater regulations. However, because of unprecedented growth in recent years and the Harpeth River concerns, the City has taken a proactive approach in addressing stormwater quantity and quality effectively. The City leaders were following the development of the EPA regulations, and decided early on to take a diligent approach to not only meet the regulatory requirements, but to address the overall stormwater management needs of the City. In 1999 the City selected the firm of Camp Dresser & McKee (CDM) to facilitate the implementation of a master planning approach (similar to long-range planning done for water or wastewater services) to provide a comprehensive plan for stormwater management within the city and the Urban Growth Boundary. The master planning process has effectively involved city staff, watershed interest groups, local business owners, developers, citizens, and community leaders. The City of Franklin has also investigated various funding mechanisms to determine the best way to create a self-sustaining stormwater management program. Specific actions taken by the City are summarized below.

Stormwater Management Task Force

After an assessment of local regulations a local stormwater Task Force was formed to develop consensus on the City's watershed goals and stormwater management policies. The Task Force also evaluated compliance with the six minimum controls required by the MS4 Phase II permit. Franklin's mayor appointed individual stakeholders

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throughout the City to create a Stormwater Management Task Force. The Task Force is comprised of Aldermen from the City, as well as local business owners, developers, and environmental interests. The Task Force members were carefully selected to ensure that all the interests in the City of Franklin are adequately addressed. The purpose of the Task Force is to generate recommendations concerning stormwater policies and the regulations to control stormwater quantity and quality. The Task Force developed guidelines that will affect how stormwater is managed in the City.

The Task Force discussed the requirements to allow the Stormwater Management program to evolve into a self sustaining program. They made recommendations for funding stormwater management in the city by implementing a stormwater utility. Options for potential utility structures were also considered.

Much of the work of the Task Force has culminated in a draft comprehensive stormwater management ordinance (expected to be approved by early 2002), which includes the legal provisions required under the Phase II regulations. The ordinance also includes many watershed protection features, such as floodplain development limits, greenways, buffer zones, and long-term maintenance requirements. The ordinance will allow stormwater management requirements to be enforceable, and provides specific penalties when the requirements are not met.

The discussion of best management practices to protect stormwater quality was another topic of discussion for the Task Force. The development of a Best Management Practice (BMP) manual was recommended for the purpose of supporting the ordinance. The intent of a Best Management Practice Manual was to offer developers, business owners, and contractors alternatives to assist them in complying with the regulations set forth by the ordinance.

Comprehensive Stormwater Management Ordinance

The Stormwater Management Ordinance was developed by the Stormwater Management Task Force as a means to enforce and regulate stormwater management activities. Recent growth and development in the City has resulted in more attention on the quantity of stormwater entering the waterways, and the impacts of stormwater on water quality.

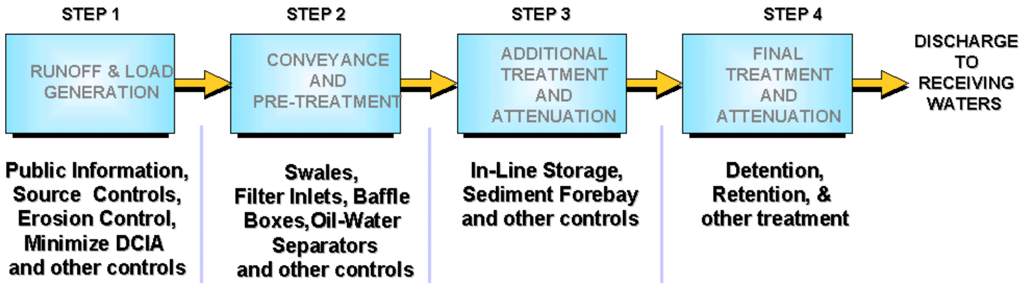
The ordinance addresses key issues affecting water quantity, such as design storm frequency, but also introduces an innovative method for detention analysis. This method, referred to as the “Volume-Time” method, requires that detention facilities be designed to not only address the peak flow rates, but address peak flow *volumes over critical time periods*. This results in better control over smaller storm flow (5-year and less) that can have a dramatic impact on water resources (quantity and quality) within the watershed.

Best Management Practice (BMP) Manual

The pace of development in the City requires special emphasis on Erosion Prevention and Sedimentation Control (EP&SC) during construction, as well as permanent structures to manage the increased stormwater runoff created by an increase in impervious areas. The manual of Best Management Practices (BMPs) includes techniques, approaches, and designs that promote sound use and protection of natural resources to meet City goals and levels of service (LOS). The BMPs provide for both short- and long-term water quantity and quality management.

The BMP manual is a tool for assisting developers, contractors, and various businesses and industries in complying with the MS4 Phase II regulations that the City will be required to abide by. Additionally, the BMP manual offers various practices that can be used to assist in complying with the City's Stormwater Management Ordinance. Specifically, this manual will assist in BMP selection, design, and implementation.

The City of Franklin emphasizes the concept of a "BMP Treatment Train" to be used as guidance for stormwater management and operation and maintenance of stormwater infrastructure. The figure below illustrates the "BMP Treatment Train", which focuses on prevention of runoff and runoff pollutants as the preference to treatment.



The BMP fact sheets in the manual are designed for easy reference. They are categorized, focused, and concise to allow easy access and expedient use. Each fact sheet can be used as a stand-alone document that may be distributed to facilitate focused discussion about design and/or implementation of each management practice. There are BMPs that require structural practices while many are non-structural practices where everyday activities may be performed in a manner that limits the impact of stormwater runoff to surface water quality.

Basin Masterplans

Stormwater management master plans are currently being developed for the major subbasins in the City. The watershed master plan includes: infrastructure inventory program design and supervision, model calibration, development of rating curves, establishment and delineation of flood profiles for a variety of storms under both present and future conditions, and comprehensive solutions for flooding problems identified. In completing this work, the City has been developing a stormwater GIS, as well as completing the inventory and mapping requirements under the Phase II regulations. The results of the master planning effort are being used to identify and plan for capital needs for stormwater quality and quantity control, as well as providing a tool for the City to use in evaluating potential new development plans.

Funding Stormwater Management

The Stormwater Management Task Force discussed several alternatives for funding of stormwater activities throughout the City of Franklin. The ultimate goal that the Task Force envisioned was to create a self sustaining program. Initially, there will be operation and capital costs that the City will have to cover from the general fund. However, before long the program will be able to sustain itself. This will be accomplished by creating a Stormwater Utility.

Community Involvement

The City of Franklin has developed and implemented a variety of programs in an effort to involve the community. The Stormwater Management Task Force was one of the first programs the City implemented for the purpose of Community Involvement. Through the Task Force different activities were recommended as possible ways to increase community involvement.

Other programs sponsored by the City include the City of Franklin Website where the public can view a draft of the proposed stormwater management ordinance. In addition, the City has held public workshops designed to educate the public on the latest regulations and programs the City is putting into practice. These workshops are broadcasted on the city television channel for increased public exposure to Stormwater Management Activities.

POULTRY LITTER PRODUCTION AND UTILIZATION IN TENNESSEE AND THE POTENTIAL IMPACT OF EPA'S PROPOSED CAFO REGULATIONS

H. C. Goan[1], W.M. Park[2], R.K. Roberts[2], and L. Warren[2]

Introduction

Poultry production is the largest concentrated animal farming enterprise in Tennessee. Over 16.8 percent of Tennessee's agricultural income comes from poultry, which ranks second to cattle and calves. With the Environmental Protection Agency (EPA) proposing new concentrated animal feeding operation (CAFO) regulations, it is important to know the potential impact these regulations may have on Tennessee's poultry industry.

Objectives

- Determine the location, number, bird capacity and type of poultry farms.
- Estimate the amount of poultry litter produced in each county.
- Estimate the amount of poultry litter used in the owners' farming operations.
- Estimate the amount of poultry litter moved off-farm by the farm owners.
- Estimate the amount of poultry litter moved off-farm by nearby farmers.
- Estimate the amount of poultry litter moved off-farm by poultry litter haulers.
- Project the potential impact of EPA's proposed CAFO regulations on Tennessee's poultry industry.

Methodology

- Assistance with the survey was provided by poultry company representatives.
- Company representatives contacted poultry farmers under their supervision.

Data Obtained

- Location of farms by county
- Total bird capacity per farm
- Type of birds housed on each farm
- Grow-outs or flocks per year
- Poultry farmers provided estimates on litter utilization

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Production and Utilization of Poultry Litter

The poultry litter survey revealed that as of June 30, 2001, there were 726 poultry farms (Table 1) related to the broiler industry. There was one table egg-type farm with white leghorn hens.

Table 1. Tennessee Poultry Farms

Type of Farms	Number of Farms
Broiler	555
Broiler Breeder	98
Broiler Breeder Replacement	73
Table Egg Hens	1
Total	727

Table 2 shows the estimated distribution of poultry litter by type of poultry farm and the utilization of litter. There was approximately 232,204 tons of poultry litter generated on farms related to the broiler industry. Over 81 percent of the poultry litter was generated on broiler farms.

Approximately 53.1 percent of the litter was utilized in the farm owners farming operation, 21.2 percent was removed by poultry litter haulers, 14.6 percent was removed from the farm by the owner and 11.1 percent was removed and utilized by nearby farmers.

Table 2. Production and Utilization of Poultry Litter in Tennessee

Type of Bird	Tons of Litter	Litter Used In Owner's Farming Operation	Litter Removed from farm by Owner	Litter Removed by Nearby Farmers	Litter Removed by Third Party
				(tons)	
Broiler	189,848	97,740	28,169	21,648	42,291
	Total %	51.5	14.8	11.4	22.3
Breeder	34,269	21,160	4,407	2,140	6,562
	Total %	61.7	12.9	6.2	19.2
Replacement	8,087	4,512	1,276	1,870	429
	Total %	55.8	15.8	23.1	5.3
Total	232,204	123,412	33,852	25,658	49,282
	Total %	53.1	14.6	11.1	21.2

It is evident that a substantial amount of poultry litter moves off the poultry farm. EPA has proposed that poultry farmers obtain a signed certification from off-site recipients who receive more than 12 tons annually. In personal discussions with some off-site recipients, they all have indicated they “would not” sign any type of certification form.

The off-site recipients would rather use more expensive commercial fertilizer rather than sign a form which would bring them under EPA regulations. Over 57 percent of Tennessee poultry farms move more than 12 tons of poultry litter off-site. This means over 400 Tennessee poultry farms have the potential of being a CAFO based on movement of poultry litter off-site.

Impact of EPA Proposed CAFO Regulations

On January 12, 2001, EPA’s proposed CAFO regulations appeared in the Federal Register. EPA proposed a two-tier or three-tier structure to determine which poultry farms would be classified as a CAFO. In the two-tier (Table 3) structure, livestock and poultry farms with more than 500 animal units (50,000 chickens) would be a CAFO. EPA estimated there were 148 Tennessee livestock and poultry farms in this category. In the poultry survey, 170 poultry farms were identified having more than 50,000 chickens.

Table 3. EPA Estimated Tennessee CAFOs in the Two-Tier Structure

Animal Units	Chickens	EPA Estimate Livestock & Poultry Farms	Survey Poultry Farms
<500	<50,000	-	502
500 - 1000	50,000 - 100,000	148	170
>1000	>100,000	114	55

In the three-tier structure (Table 4), livestock and poultry farms with more than 1000 animal units (100,000 chickens) would be a CAFO. EPA estimated 114 Tennessee livestock and poultry farms to be in this category. The poultry survey revealed there were 55 poultry farms with more than 100,000 chickens.

Farms with 300 to 1000 animal units (30,000 - 100,000 chicks) would need to meet certain conditions or risk being designated a CAFO. EPA estimated there were 265 livestock and poultry farms in this category while the poultry survey revealed there were 381 poultry farms.

Table 4. EPA Estimated Tennessee CAFO's for the Three-Tier Structure

Animal Units	Chickens	EPA Estimate Livestock & Poultry Farms	Survey Poultry Farms
< 300	<30,000	-	291
300-1000	30,000 - 100,000	265	381
>1000	>100,000	114	55

In addition to farm animal units, EPA listed other criteria for poultry farms potentially becoming a CAFO. Based on estimates of off-farm movement of poultry litter reported previously, the number of poultry farms in Tennessee classified as CAFOs may be even greater than projected by EPA.

Summary

- Nearly half (over 100,000 tons) of poultry litter generated on Tennessee poultry farms moves off-farm.

- EPA underestimated the number of Tennessee poultry farms that would be or potentially would be a CAFO.

- Requiring a certification form from off-site recipients of poultry litter has the potential to increase the number of Tennessee CAFOs, and seriously disrupt the off-farm litter market.

ADDRESSING SEWAGE, SILT, AND TRASH IN URBAN WATERSHEDS

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The Tennessee Izaak Walton League Clean Water Center has been addressing the impacts of urban runoff with a full time staff of natural resource based professionals for the past five years. We will exhibit our current projects and techniques for managing trash, silt, and sewage on seven urban streams in Knoxville, Tennessee.

Routine observations, demonstrations, and skimmers placed on creeks are some of the techniques we have developed to address the impacts on urban watersheds. We monitor for the use of Best Management Practices on construction sites, sanitary sewage overflows, and other impacts of non-point source pollution. We collaborate with developers by demonstrating proper erosion control techniques such as silt fence instillation and offering consultation on the use of BMPs. Skimmers, placed at the mouths of creeks and at road crossings, catch trash in stages allowing for the easy removal and collection of large volumes of trash.

POTENTIOMETRIC SURFACE FOR THE MANCHESTER AQUIFER, ARNOLD AIR FORCE BASE, TENNESSEE

John A. Robinson[1] and Gregg Hileman[1]

Arnold Air Force Base (AAFB) occupies about 40,000 acres in Coffee and Franklin Counties, Tennessee. The primary mission of AAFB is to support the development of aerospace systems. This mission is accomplished in part through test facilities at Arnold Engineering Development Center (AEDC), which occupies about 4,000 acres in the center of AAFB. The base is underlain by gravel and limestone aquifers, the most productive of which is the Manchester aquifer. The Manchester aquifer is the primary source of drinking water in the area. Ground-water contamination in this aquifer in and near AAFB has been well documented in numerous investigations. Several synthetic volatile organic compounds (VOCs), primarily chlorinated solvents, have been identified in ground-water samples collected at several Solid Waste Management Units (SWMUs). Private ground-water supplies are hydraulically downgradient from AEDC and could be affected by transport of VOCs in the ground water. Potentiometric maps of the Manchester aquifer may be useful tools in understanding ground-water and contamination flow paths in and near AAFB.

During May and October 2002, a comprehensive investigation of the ground-water resources in the AAFB area was conducted to better understand the ground-water flow system within the Manchester aquifer in and near the base. To meet this need, the U.S. Geological Survey (USGS), in cooperation with AAFB, conducted an investigation of the hydrogeology of the base and surrounding area. The ground-water flow system was investigated by measuring base flow in streams, measuring water levels in wells, and by constructing two potentiometric-surface maps of the Manchester aquifer in the study area. Data were collected from 199 private wells and 272 monitoring wells during the course of the study. Depths to ground water were determined for all private wells and monitoring wells. Land-surface altitudes for the private wells were determined by plotting well locations on 7.5-minute (1:24,000) USGS topographic maps determined using coordinates from a global positioning-system. Land-surface altitudes were interpolated from topographic contours. Land-surface altitudes and well depths for the monitoring wells were obtained from AEDC. Water-level altitudes ranged from 920 to 1,113 feet above the North American Vertical Datum of 1929 (NAVD 29) during May 2002 and from 920 to 1,104 feet above NAVD 29 during October 2002. Potentiometric surfaces were mapped by contouring altitudes of water levels measured in wells completed in the Manchester aquifer and altitudes of springs originating from the Manchester aquifer. The AEDC facility lies near the ground-water divide, which generally runs northeast to southeast and coincides with the Duck River-Elk River surface-water divide. Ground water generally flows toward the northwest, or toward the south or southeast, and discharges to the principal streams and reservoirs. Several troughs are present in the potentiometric surface.

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Analysis of Applied Conservation Systems

George F. Smith[1] and Tina M. Johnson[2]

The economic and environmental impacts of the Environmental Quality Incentives Program (EQIP) on three Tennessee farms were evaluated.

EQIP is a voluntary program offering information, cost-share financing and technical assistance for structural, vegetative and management practices.

The farms represented typical Tennessee operations:

- Row-crop farming, this case-study focused on erosion control.
- Beef cow/calf farming, this case-study focused on livestock-related concerns.
- Dairy farming, this case-study focused on waste management and utilization.

The analysis was conducted by the University of Tennessee Agricultural Extension Service in cooperation with the USDA Natural Resources Conservation Service.

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Handbook of Conservation Practices for Farming and Forestry

George F. Smith[1] and Tina M. Johnson[2]

The handbook describes 51 best management practices in words and pictures. Practices for row crops, animal operations, pest management, forestry operations and practices for all farming operations are included. Information on each practice includes:

- A description.
- Landowner benefits.
- Water quality benefits.
- Management and operational considerations, including complementary practices.
- Maintenance.
- Costs.

State and local agency contacts are included for more information. Copies are available in every County Extension and Soil Conservation District office in Tennessee.

The handbook was developed by the University of Tennessee Agricultural Extension Service for the Tennessee Department of Agriculture. The USDA Natural Resources Conservation Service assisted with technical evaluation, information and review.

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Home Hazards Hunt© Interactive CD

George F. Smith[1] and Tina M. Johnson[2]

Home Hazards Hunt© is an independent, self-paced interactive educational computer game that teaches users about practices and conditions in and around the home that can affect water quality, health and the environment. The intent is to help raise awareness that stewardship is everyone's responsibility. It is based on the national Home Assessment System (Home-A-Syst) program.

Users follow a family of cats as they evaluate their home. Users move independently through the house and yard, finding "hazards", learning about potential risks, and about recommended ways to deal with them. A separate introduction discusses our stewardship responsibilities.

The program is targeted for grades 4 through 6. However, younger and older children can enjoy and learn from it. A vocabulary list and quiz are included.

The program will run on both PC and Apple computers. All materials, including a complete script, can be printed from the CD.

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A STATISTICAL APPROACH TO DETERMINING HIGH- AND LOW-FLOW CONDITIONS IN A KARST AREA OF SOUTHERN INDIANA

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ABSTRACT

In karst terrain, the fluctuation of groundwater levels is not only correlated with rainfall events, but it is also affected by aquifer characteristics. Wet and dry periods are a function of rainfall and season, but flow conditions at springs and the water levels in monitoring wells are also a function of the character of the karst aquifer. This paper uses multivariate linear regression to determine the correlation between the available long-term precipitation data and water level data from two monitoring wells in a karst area of Southern Indiana. Criteria for high- and low-flow conditions were established based on these statistical analyses. The criteria are essential for guiding long-term groundwater sampling efforts at two springs in the study site.

INTRODUCTION

In karst hydrology, groundwater flow conditions can be generally categorized into base-flow, low-flow and high-flow conditions. Base-flow refers to the last part of a spring hydrograph in which the spring is sustained by groundwater flow from pores of the limestone matrix and its small cracks, fractures, or stratification joints (Padilla and others, 1994). Therefore, base-flow conditions occur in all hydrographs, either under high-flow or low-flow conditions. Precipitation is correlated with the fluctuation of spring discharge and water levels in monitoring wells. Although the terminology of "high-" and "low-flow" has been used frequently and for a long time in surface water hydrology, there seems to be wide variability in the meaning and use of this terminology. For example, the terms high-flow and low-flow have been used as synonymous with "wet" and "dry" seasons, respectively (Duke, 2001). For the collection of water samples, high-flow has been interpreted as the time when it rains, while low-flow has been interpreted as the time when it does not rain. In other case, the flow condition is determined by the interaction between groundwater and surface water. High-flow has been thought to occur when the surfaces water recharges groundwater, and low-flow has been thought to occur when the groundwater recharges surface water (Berndt and others, 1998).

In karst area, groundwater flow and water quality may vary depending on the flow condition, because conduits/caves tend to develop at multiple levels. The relatively quick response of karst aquifers to recharge events also necessitates the study of groundwater flow and quality under differing conditions. Much of the confusion over the water table, arises from two sources – the highly dynamic response of the conduit system to storm events and the low-permeability of the matrix block in the absence of solution openings. Karst aquifers are often conceived and modeled as storage reservoirs penetrated by trunk conduits (Smart, 1999). In response to storm events, conduits permit exceptionally rapid transfer of water and chemical constituents, while the storage reservoirs (fractures/matrix blocks), which contain the majority of the water in the karst aquifer, slowly adjust to autogenic recharge from sinkholes and backflooding from the primary conduits. During recession periods, the head loss in conduits is often much lower than that in surrounding fractures or matrix blocks and the water stored in the matrix gradually drains into the conduits to sustain the spring flow. If time permits equilibrium between the water flow in the conduits and that in the matrix blocks, a unified water level (or spring discharge) is obtainable. Considering the wide range of hydrogeologic conditions that can occur in karst areas, therefore, the use of water level (or spring discharge) data to define the flow condition should be tailored to represent site-specific circumstances.

BACKGROUND

The study site is located in a relatively small, independent karst drainage basin developed on St. Louis and Salem limestone bedrock, and containing small caves, sinkholes, and springs. Clayey overburden up to 40-feet-thick overlies the bedrock in many places. The site lies on the eastern slope of a small valley, which is approximately half wooded and half-cleared. A local creek occurs at an elevation of 590 to 600 feet above mean sea level (AMSL) and flows north into the East Fork of the White River, approximately 3 miles north of the site.

At the study site, springs and seeps are present at various elevations between 595 and 612 feet AMSL, as a result of a gentle bedding plane dip toward the local creek. When the groundwater level is below 602 feet AMSL, only one spring has water flow. When the groundwater level exceeds 612 feet, deeper conduits fill and the groundwater “spills” over to conduits at higher elevations and discharges through additional springs. That is, groundwater flows to different springs under high-flow conditions than it does during low-flow conditions. Two springs, labelled QRS and QNS, are the main groundwater sampling locations for the basin and have been monitored since July 2000.

However, the change in the flow configuration has the potential to lead to changes in the chemistry at the monitored springs (Quinlan and Ewers, 1989). Defining high- and low-flow conditions is essential when analyzing the changes in water quality at the springs over time, and it can also significantly aid in the selection of appropriate times to conduct high-frequency storm-induced sampling events. However, because the discharge at these springs is quite variable and affected by many factors (i.e., antecedent conditions, rainfall intensity and duration, hydraulic gradient, fracture/conduit size, flow-through area, etc.), it does not appear to be a reliable indictor of high- or low-flow conditions.

In 1999, five monitoring wells (M1 through M5) were installed in the up-gradient portion of the site basin. . Wells M2, M3, and M5 are not monitored routinely, but they are available for future use. Wells M1 and M4, 76.5 and 90.0 feet deep respectively, intersect small fractures, bedding planes and small voids (PELA, 2001). Dye tracing conducted in June of 1999 from these two monitoring wells indicated that they are not connected to the major conduits that lead to the springs. Water level monitoring data collected since December 1999 shows only minor and somewhat delayed changes in hydraulic head levels in response to recharge events. Therefore, the water levels within monitoring wells M1 and M4 can be generally considered to represent average aquifer conditions within the storage reservoir (matrix blocks).

Four weather stations surround the site and are located in Bedford, Mitchell, Williams and Oolitic, Indiana. The average annual precipitation from these four stations ranges from 44.93 to 46.09 inches (1971-2000) (National Climate Data Center). All of the monthly precipitation data for the last 55 years (1947-2001) from Bedford, Oolitic, and Williams, and for the last 22 years (1980-2001) from Mitchell were collected from the National Climate Data Center online (http://www.ncdc.noaa.gov). Although precipitation data is also obtained from a weather monitoring station located on-site, this data was not used due to the limited amount of data and concerns over the long term reliability of the regression analysis.

MULTIVARIATE LINEAR REGRESSION MODEL SET UP

Linear systems analysis was applied to karst aquifers by Knisel [1972] and Dreiss (1982, 1983 and 1989), and in their studies, excess precipitation and spring discharge were considered as an input time series and an output series, respectively. The identified kernel functions in these studies were analogous to instantaneous unit hydrographs for surface runoff. These theories and functions can be applied for the flow condition analysis in our project study.

Assuming there is a linear relationship between precipitation and water level for the multiple observed points, a multivariate linear regression equation can be established as follows:

$$Hi = a + b_1 * P_1 + b_2 * P_2 + b_3 * P_3 + \dots + b_i * P_i$$

where H is the predicted monthly water level elevation in feet; a and b are regression coefficients, P is the monthly precipitation in inches, and i is an index number for the current month when the water level is calculated.

APPLICATION FOR HIGH/LOW FLOW DETERMINATION

Water levels have been monitored at M1 and M4 since December 1999, but due to equipment problems not all data was collected for both wells. Although 19 monthly average water levels were calculated for both wells, some of these were based on limited data due to instrument malfunction. For M1 seventeen of the monthly averages are based on reliable data, whereas for M4 reliable data was only available for fifteen months. The average monthly water levels are correlated with the monthly precipitation averaged from three stations (Bedford, Oolitic and Williams). The following are the regression equations at M1 and M4, respectively.

At M1: $$H_i = 624.20-0.07P_1-0.19P_2+0.15P_3+0.28P_4-0.07P_5-0.12P_6+0.20P_7 \\ +0.13P_8-0.43P_9-0.08P_{10}+0.04P_{11}+0.08P_{12}-0.01P_{13}+0.12P_{14}+0.32P_{15}$$

At M4: $$H_i = 623.97-0.02P_1-0.09P_2+0.08P_3+0.10P_4+0.08P_5+0.11P_6+0.12P_7 \\ +0.08P_8-0.14P_9+0.12P_{10}-0.03P_{11}-0.01P_{12}+0.13P_{13}+0.14P_{14}+0.45P_{15}$$

These regression equations indicate that the impact of precipitation on the water levels at M1 and M4 is cumulative and has a memory length of approximately 15 months. Figure. 1 compares the measured water levels and the predicted water levels from January 2000 to November 2001. Most errors between the measured and predicted water levels are less than 0.3 feet, and the regression coefficients R-squared are 0.8781 and 0.8681, respectively (see Table 1).

These regression equations were used to retroactively calculate the water levels at monitoring wells M1 and M4 using the precipitation data from 1947 to 2001. Figures 2-1 and 2-2 present the averages of monthly water levels in M1 and M4. The calculated historical average water level elevations in M1 and M4 are 626.96 and 628.34 feet AMSL, respectively. Using only the most recent 10 years of predicted water level data gives similar results. Based on these calculated average water levels, the aquifer is considered to be in high-flow conditions when the water levels measured in M1 and M4 are higher than 626.96 and 628.34 feet AMSL, respectively. Similarly, the aquifer is considered to be in low-flow conditions when the water levels in M1 and M4 are lower than 626.96 and 628.34. feet AMSL, respectively.

The state-approved groundwater sampling plan calls for three precipitation-associated discharge pulses to be sampled during the high-flow regime and three during low-flow from each of the two springs at the study site. Four groundwater sampling events were collected between November 2000 and December 2001. Table 2 shows that one sampling event was collected in high-flow condition and three in low-flow conditions based on the above calculated historical average water levels at M1 and M4. Note that water levels in both wells agree for two of the readings, but conflict for two. Where there is disagreement the water level in M1 takes precedence, based on the more reliable data used in the correlation.

Table 2. Data from Groundwater Sampling Events

Sampling Event	Starting Time (mm/dd/yy hh:mm)	Ending Time (mm/dd/yy hh:mm)	Avg. Water level in M1 (feet)	Avg. Water Level in M4 (feet)	High/Low-flow 626.96 ft in M1 628.34 ft in M4
~~1~~	~~11/06/00 16:50~~	~~11/13/00 16:55~~	~~626.42~~	~~628.53~~	~~Low-flow~~
2	01/10/01 11:15	01/11/01 11:15	626.77	628.15	Low-flow*
3	01/29/01 18:03	02/05/01 13:03	626.71	628.67	Low –flow
4	12/12/01 12:30	12/16/01 12:55	628.44	628.89	High-flow

*This sampling event was not a precipitation-associated discharge pulse, but was simply the average of several samples collected under base flow conditions.

CONCLUSIONS AND DISCUSSION

Based on multivariate linear regression analysis, the flow conditions at the site are defined based on the water levels in monitoring wells of M1 and M4. The most recent water level data were used to establish a correlation with the local precipitation. The historical precipitation data from

1947 to 2001 were then used to predict the historical water levels at M1 and M4. The historical average water levels are 626.96 feet at M1 and 628.34 feet at M4. The aquifer is considered to be in high-flow conditions when the water levels are higher than their respective average values, otherwise, the aquifer is considered to be in low-flow conditions.

Although an excellent correlation has been observed in M1 and M4, this preliminary analysis can only be considered an estimate in terms of defining the flow conditions. It was conducted using the water level data available to date. This analysis should be tested and updated, as more data become available.

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Fig. 1 Calibration of Regression Equation at Monitoring Wells M1 & M4 from Jan. 2000 to Nov. 2001

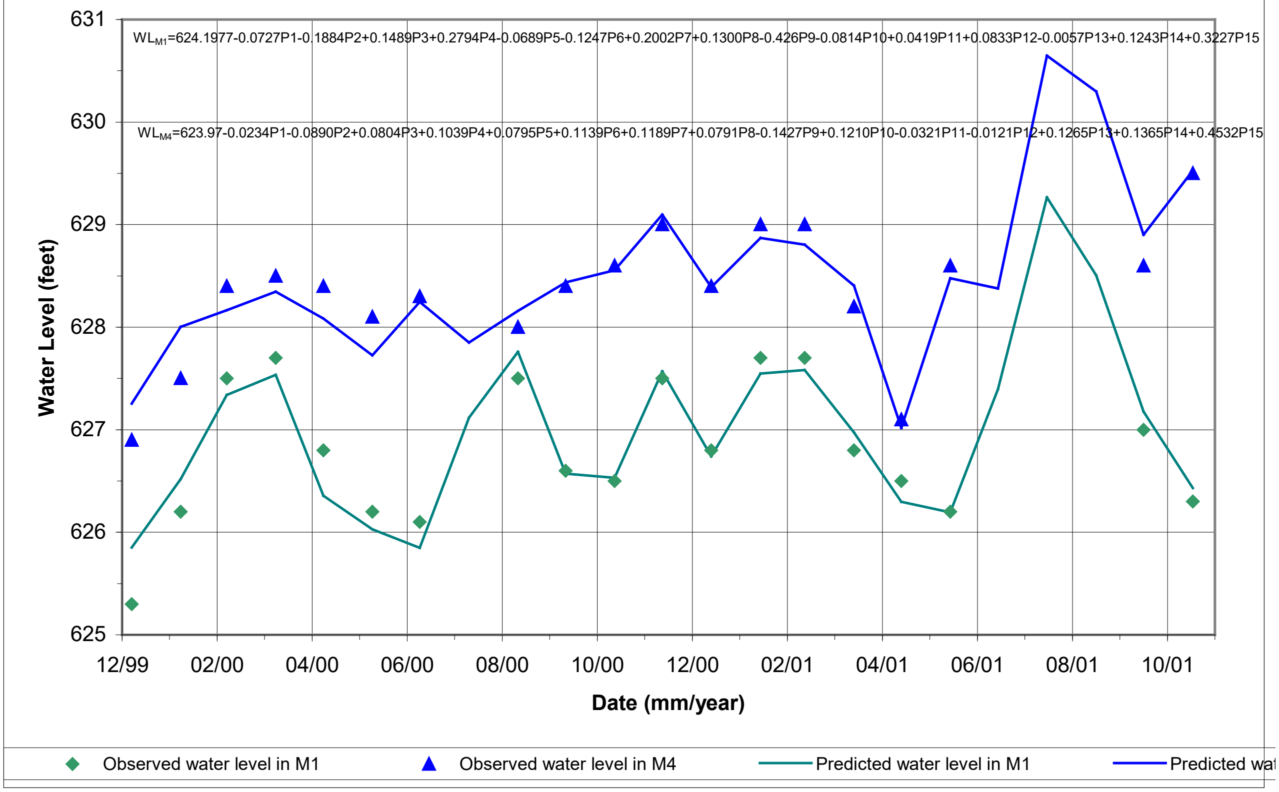
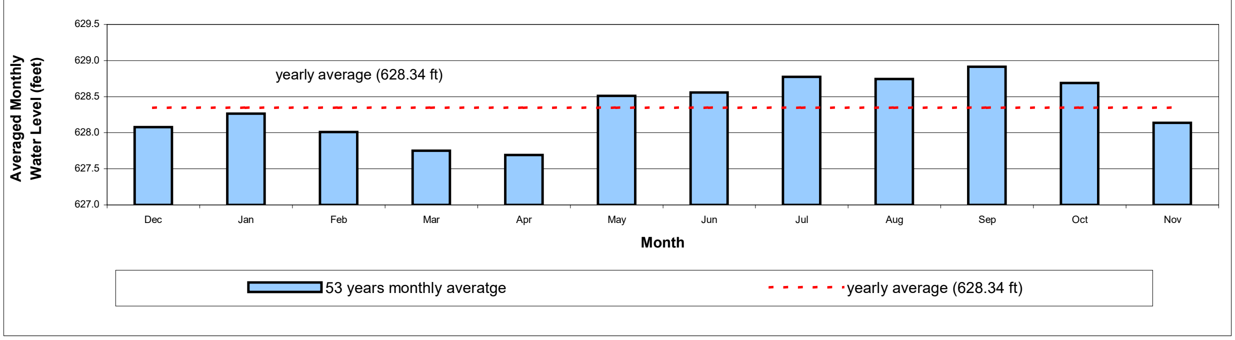


Fig. 2-2 Flow Condition Analysis Column Diagram Monthly Averaged Water Level (1949-2001) in Monitoring Well M4



COMPARISON OF DIFFERENT LACTIC ACID FORMULATIONS USED TO ENHANCE BIODEGRADATION OF PERCHLOROETHYLENE

Ahlam Ary[1], LyTreese Hampton[1], and Tom D. Byl[1,2]

A sanitary landfill situated on a karst terrain in northern Tennessee has leaked chlorinated solvents, such as perchloroethylene (PCE) and trichloroethylene (TCE), into a karst aquifer. Some biodegradation apparently has occurred based on the presence of breakdown products such as *cis*-dichloroethylene (cDCE) found in water from wells screened in the karstic bedrock. Sulfur-reducing bacteria, which are known to biodegrade chlorinated solvents, have been identified in water collected from these same bedrock wells. Previous studies have found that sulfur-reducing bacteria are stimulated by sodium lactate. A study was conducted to evaluate different formulations of lactic acid to determine which was the best for PCE biodegradation by indigenous karst bacteria. Water from the karst bedrock wells was collected and used to make 250-milliliter water microcosms. The microcosms were stocked with 2.5 milligrams per liter PCE and different formulations of lactic acid, including sodium lactate, lactic acid, magnesium lactate, iron lactate, crude lactate, methyl-lactate, potassium lactate, calcium lactate, ethyl-lactate, propyl-lactate, and ammonium lactate. The concentrations of the lactic acids were normalized so that each microcosm had the equivalent of 50 lactic-acid (reducing) electrons for each PCE molecule. Preliminary results indicate that all of the lactic acids stimulated the reductive dechlorination of PCE to TCE and cDCE. Trace amounts of trichloroethane (TCA) and 1,1-dichloroethylene also were detected in some of the microcosms. Within 4 weeks, a 40- to 60-percent decrease in PCE occurred in the treated microcosms compared to the sterile control microcosms. A concurrent rise in TCE also occurred during the same time period. The microcosms treated with ammonium lactate had PCE concentrations initially drop twice as fast compared to the other treatments during the first 10 days. But after 21 days, no significant difference between the ammonium lactate treatment and the other treatments was observed. After 45 days incubation, the microcosms treated with iron-lactate and magnesium lactate resulted in a 90-percent reduction of the initial PCE. The other lactic acid treatments contributed to a 50-to 70-percent reduction of the initial PCE after a 45-day incubation period. The sterile controls had a 30-percent reduction in PCE caused by abiotic processes such as volatilization and sorption in the same time period. In conclusion, ammonium lactate initially appears to stimulate PCE biodegradation, but the effect diminishes within 21 days. Iron and magnesium lactate appear to maintain enhanced PCE biodegradation over a longer period of time than the other lactic acid formulations tested.

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ASSESSING THE EXTENT OF VIRAL CONTAMINATION IN WELLS AND SPRINGS IN FRACTURED AND/OR KARST AQUIFERS OF EASTERN TENNESSEE

Trisha Baldwin[1], Larry McKay[1], Sid Jones[1], and Alice Layton[2]

Fractured subsoils, fractured limestone bedrock aquifers, and karst aquifers underlie east Tennessee. Previous work done by University of Tennessee researchers shows that microorganisms can travel very rapidly through these subsurface materials and these materials are therefore highly vulnerable to contamination by microbial pathogens. Wells and springs located in these materials are used for water supply by numerous small towns, rural schools, churches, farms, and private homes in east Tennessee. Many of these systems are susceptible to pathogen contamination from near-surface sources such as septic fields, leaking sewer lines, and livestock feeding areas.

New research at the University of Tennessee and the U.S. Geological Survey Tennessee District focuses on the frequency and occurrence of viral pathogens in wells and springs in fractured and/or karst aquifers of east Tennessee. The University of Tennessee's Center for Environmental Biotechnology is developing a fast, efficient method of quantitatively measuring occurrence and concentration of pathogenic enteroviruses and Hepatitis A viruses in water samples using real-time reverse-transcriptase PCR assays. Using this new technology, field researchers from the University of Tennessee and the USGS will sample potentially contaminated springs and wells for the distribution and occurrence of these viruses as well as the occurrence of total coliform and *E. coli*, which are commonly used indicators of microbial contamination in groundwater. Wells and springs will be sampled year-round and in both baseflow and stormflow conditions to assess the seasonal and short-term variability in virus occurrence. Results of these studies will be applied to assessing the effectiveness of currently used methods for determining aquifer vulnerability and state regulations for developing Wellhead Protection Plans.

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PRELIMINARY FINDINGS OF A COMPARISON OF SELECTED ABIOTIC AND BIOTIC FACTORS IN FOUR SPRINGS OF THE RED RIVER WATERSHED IN MONTGOMERY AND ROBERTSON COUNTIES, TENNESSEE

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In this study four springs in the Red River watershed were monitored for selected abiotic and biotic factors between the months of September and November 2002. Two of the four springs in this study were considered impacted, due to the high amount or frequency of human or livestock visitation. The other two springs were considered minimally impacted by humans and livestock. The purpose of this study was to monitor the springs and evaluate the results in an attempt to ascertain what abiotic or biotic factors may be useful in characterizing the biological health of springs. The abiotic factors measured in this study were, orthophosphate, total phosphate, nitrate/nitrite nitrogen, hardness, alkalinity, specific conductivity, pH, temperature, total dissolved solids, dissolved oxygen and turbidity. The biotic factor examined was the presence of fecal coliform and fecal streptococcus. The results indicated that all of the springs are impacted and further testing is required for better assessment.

ENHANCED BIODEGRADATION OF TCE IN A KARST AQUIFER USING LACTIC ACID, MOLASSES, AND SOY MILK

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and Byl, Tom D.[1,2]

A sanitary landfill situated on a karst terrain in northern Tennessee has leaked chlorinated solvents, primarily trichloroethylene (TCE), into a karst aquifer. TCE has been found in water samples collected from eight wells screened in the karst bedrock aquifer. Some anaerobic biodegradation apparently has occurred in four of the eight wells tested based on the appearance of trace amounts of breakdown products. Sulfur-reducing bacteria have been found in all eight wells. In July 2002, a mixture of dye, lactic acid, molasses, and soymilk was injected into six of the eight wells to determine if the mixture would enhance reductive dechlorination of TCE. Water samples were collected and electronic monitoring devices were placed in selected wells over a period of 4 months following injection to monitor changes for geochemistry and concentrations of TCE and breakdown products, and dye. Prior to injection, TCE concentrations ranged from 1 part per billion (ppb) to 74 ppb. After approximately 4 weeks, there was a noticeable decrease in TCE and *cis*-dichloroethylene (cDCE) concentrations in all but one of the wells. After 4 months, there was an 85- to 100-percent decrease in TCE concentrations in the eight wells, and a 65- to 100-percent decrease in cDCE concentrations in six of the eight wells. Two wells showed an increase in cDCE as TCE degraded to cDCE. Concurrent with decreases in TCE and cDCE concentrations were increases in sulfide concentrations. No dissolved oxygen was found in any of the wells 1 week after the mixture was injected. Dye concentrations decreased at varying rates during the 4-month sampling period, indicating that the injection mixture was being degraded or transported down-gradient. Trace amounts of 1,1-dichloroethylene (1,1-DCE) and trichloroethane (TCA) were found in some well-water samples, possibly due to secondary abiotic chemical reactions. These data indicate that a mixture of lactic acid, molasses, and soy milk enhanced biodegradation of TCE in a karst aquifer. However, further work is needed to determine how long the enhancement will last.

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IDENTIFYING MICROBIAL DEGRADATION OF PAHS THROUGH COMPOUND SPECIFIC ISOTOPE ANALYSIS OF PHOSPHOLIPID FATTY ACIDS

Alvin L. Coleman[1] and Maria E. Uhle, Ph.D.[2]

Polycyclic aromatic hydrocarbons (PAHs) are combustion-derived compounds typically introduced into the environment from natural (wildfires) and anthropogenic (coal tar, vehicle exhaust, fossil fuels) sources. Understanding the fate of the potentially carcinogenic and mutagenic compounds within the groundwater and subsurface soils is important in assessing the potential impact of these contaminants on an ecosystem. Due to the difficulty of isolating and removing PAHs from the environment, a better understanding of bioavailibility, source apportionment, and degradation of these compounds will facilitate remediation efforts in contaminated areas.

Samples were recovered from the Tennessee Products industrial site located in Chattanooga, TN. The site was occupied by a former coal coking plant where large amounts of coal tar and creosote were discharged onto the site. The soils, surface, and groundwaters are extensively contaminated with this material. This is particularly important since Chattanooga Creek flows adjacent to many residential areas, schools, and research facilities.

The main focus of this project is to assess the degradation of PAHs over time and identify microbial communities controlling this degradation. Key questions we will address are: Is degradation occurring? What is the degradation rate? Can phospholipid fatty acids (PLFAs) identify which microbial communities are causing degradation? A series of microcosm experiments will be conducted to provide insight into the transformation of parent PAHs to alkylated forms (a degradation product) over time. Carbon isotopic composition of the PLFAs will help identify microbial communities involved in the degradation process.

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COMPARISON OF WATER GEOCHEMISTRY AND REDOX ELECTRODES TO IDENTIFY TERMINAL ELECTRON ACCEPTOR PROCESSES IN AN AQUIFER

Ramona Darlington[1] and Tom D. Byl[1,2]

Several metabolic pathways of fuel biodegradation exist that have different efficiencies based on the terminal electron acceptor process (TEAP) present in the aquifer. The TEAP is determined by the oxidation-reduction (redox) potential of the aquifer, which is a measure of the system's capacity to give (oxidation) or receive (reduction) electrons. Because biodegradation can be an effective way to remove organic contaminants from ground water, depending on the TEAP, accurate redox measurements are essential. A study was initiated to determine whether a meter equipped with a platinum redox electrode could identify the TEAPs as effectively as geochemical analysis of the ground water. YSI[1] datasonde units equipped with a redox electrode, dissolved oxygen (DO), pH, specific conductance, temperature, and depth probes were deployed for 4 to 18 months in uncontaminated and fuel-contaminated wells screened in a karst bedrock formation. The datasonde units were serviced (probes re-calibrated, data downloaded, and batteries changed) every 2 to 3 weeks. Ground-water samples also were collected from the same wells during the datasonde servicing. The water samples were tested for temperature, pH, alkalinity, specific conductance, and DO within minutes of sample collection. Additional water samples were placed in clean glass amber bottles, packed on ice, and brought back to the laboratory for sufate, nitrate, soluble iron (Fe^{2+}), ammonia, and sulfide analyses. These data were used evaluate trends in aquifer geochemistry, redox potential, and depth over time. An equilibrium time of 2 to 4 hours was needed for the YSI datasonde redox electrodes to equilibrate with their surroundings. Comparison of the geochemical and datasonde data showed a good correlation between the concentration of geochemical constituents and the datasonde redox measurements, indicating the potential to use a platinum redox electrode to identify TEAPs in a contaminated aquifer.

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EVALUATION OF BIOLUMINESCENT BACTERIA AS INDICATORS OF WATER QUALITY IN WASTEWATER TREATMENT PLANTS

Martin Greene[1], Janique Suber[1], Tom D. Byl[1,2], Paul Frymier[3]

Toxic compounds in incoming wastewater can have a negative effect on the performance of activated sludge systems. Monitoring incoming wastewater by chemical analysis and periodic bioassays is often too slow to avoid problems. A more rapid response can be measured by respiration or by using bioluminescent bacteria with the luciferase enzyme. The objective of this study was to compare bioluminescence response with respiration response. The bioluminescence is correlated to metabolic activity and general health of the bacterium. Bacteria containing the luciferase enzyme will bioluminate under ideal conditions, and bioluminescence will decrease as conditions decline. Likewise, healthy sludge bacteria will respire (consume oxygen) at an even rate. During a toxic response, however, the bacteria will rapidly change their rate of respiration and reduce oxygen consumption. In this study, a bioluminescent bacterium, *Pseudomonas sp.* (developed at the University of Tennessee, Knoxville), was compared to the oxygen consumption of sludge bacteria after exposure to varying concentrations of suspected wastewater toxins. Bacteria containing the luciferase enzyme and a tetracycline resistance gene were grown in nutrient broth amended with 10 parts per million of tetracycline in batch cultures at 25 °C. After 48 hours the bacteria cultures were tested for bioluminescence using a modified fluorometer. The bioluminescent cultures were standardized to 900 fluorescence standard units, and were used for dose-response bioassays. Toxins, such as sodium hypochlorite or heavy metals, were added to the cultures in known concentrations. Changes in bioluminescence were measured as a response to the toxins. Preliminary results indicate that a 0.02-percent sodium hypochlorite solution elicited an immediate decrease in bioluminescence and oxygen consumption. Nickel (Ni^{2+}) and lead (Pb^{2+}) also elicited rapid decreases in bioluminescence and oxygen consumption. However, sodium thiosulfate enhanced bioluminescence at low concentrations (0.1 to 1.0 parts per million), and increased oxygen consumption at all concentrations. These preliminary results indicate that bioluminescence may be a sensitive and rapid indicator of water quality.

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MOVEMENT OF VIRUSES IN THE VADOSE ZONE: A REVIEW OF TRANSPORT MECHANISMS

Andrew B. Kenst[1] and Edmund Perfect[2]

Virus contamination is a potential threat to groundwater quality. In order to reach groundwater viruses must travel though the vadose zone. However, most research on virus movement in soils and aquifer materials has been conducted under steady-state, saturated flow conditions. Several factors are thought to influence virus adsorption and transport under such conditions. These include particle surface area and charge density, the presence of metal oxides and/or organic carbon, and soil water pH and ionic strength. Virus characteristics such as isoelectric point and protein coat properties also influence their mobility.

Only a few studies have investigated virus transport under partially-saturated conditions, and all of these were for steady-state flow. Under such conditions, air-water interfaces are present throughout the medium, and water films tend to be thinner and more tortuous. Air-water interfaces are thought to increase virus deactivation, while thinner water films increase the likelihood of viruses adsorbing to soil particles.

Steady-state flow rarely occurs in nature. Most flow in the vadose zone occurs under transient conditions, in which a zone of saturation forms as water advances into previously unsaturated soil. We are unaware of any research on virus transport during transient flow. Under such conditions, water films are expanded and air-water interfaces are mostly restricted to the wetting front. Thus, we hypothesize that the two additional mechanisms that retard virus transport in unsaturated soil under steady-state conditions will be eliminated, thereby increasing the distances that viruses can travel.

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EVALUATING OXYGEN-RELEASING COMPOUNDS TO ENHANCE FUEL BIODEGRADATION BY FREE-LIVING BACTERIA

King, Lashun[1], Hampton, LyTreese.[1] and Byl, Tom D.[1,2]

Anaerobic biodegradation of fuels is generally slower than aerobic biodegradation. During an anaerobic experiment, almost 100 days were required to biodegrade 2.5 milligrams per liter (mg/L) benzene and toluene in liquid-karst microcosms to less than 1 microgram per liter. However, it took less than 1 week to biodegrade the same amount of benzene and toluene under aerobic conditions. Considering that water in many karst aquifers moves at a relatively rapid pace, it follows that aerobic conditions are better whether efficient biodegradation processes are desired. The objective of this study was to evaluate if oxygen-release compounds (ORCs) enhance fuel biodegradation by free-living bacteria found in karst aquifers. One ORC that was evaluated is hydrogen peroxide (H_2O_2). Hydrogen peroxide can be toxic to many bacteria in high concentrations (3 percent volume:volume), but is relatively non-toxic in low concentrations (less than 0.1 percent). Two H_2O_2 will break down into oxygen (O_2) and water (2 H_2O). In a preliminary study, 250-milliliter liquid-karst microcosms were spiked with benzene and toluene. Half of the microcosms also were enriched with H_2O_2 to a final concentration of 30 milligrams per liter (mg/L), which would break down into 15 mg/L of dissolved O_2. The microcosms enriched with H_2O_2 continued to biodegrade benzene and toluene at a fast rate, whereas biodegradation in the non-enriched microcosms slowed down after 2 days. After 7 days, the H_2O_2-enriched microcosms had biodegraded three times as much benzene and toluene as the non-enriched microcosms. These preliminary results indicate that biodegradation by free-living bacteria found in karst aquifers can be enhanced by H_2O_2. Additional ORCs to be evaluated include magnesium peroxide and calcium peroxide. These ORCs differ from H_2O_2 by generating hydroxide ions, in addition to oxygen, which raise the pH significantly; they also tend to become solid and diffuse slowly into the water column.

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EFFECTIVENESS OF M-TEC AGAR FOR QUANTIFYING *ESCHERICHIA COLI* IN THE DUCK RIVER NEAR SHELBYVILLE, TENNESSEE

Allyson M. Morgan[1], James J. Farmer[1,2], Anthony O. Ejiofor[1], and Terrance L Johnson[1]

The filter membrane method using m-TEC agar for quantifying *Eshcerichia coli (E. coli)* concentration is based on the assumption that most of the lactose-fermenting, urease negative (LFUN) bacteria that grow on the agar are *E. coli*. Standard Methods (1995) published by the American Public Health Association recommends specific identification of LFUNs to determine the percentage of the bacteria that are *E. coli*; however, this procedure rarely is performed. A study was conducted to test the hypothesis that LFUN species can be highly variable in a specific watershed. Four water grab samples were collected from two sites on the Duck River near Shelbyville, Tennessee. Site 1 is upstream, and site 2 is downstream of Shelbyville. The samples were collected once during base-flow conditions and once during storm-flow conditions at each site. Water samples were filtered through 0.45-micrometer filters and placed onto m-TEC agar. Plates were incubated at 44.5 ºC for 24 hours. Filters were transferred to a pad saturated with urea containing phenol red. Isolates that remained yellow or brown after 15 minutes were considered to be urease negative. LFUN colonies were streaked onto tryptic soy agar for isolation. A total of 124 isolates were identified using the Biolog®* system. At site 1, *E. coli* composed 75 percent and 88 percent of the LFUN isolates from the base-flow and storm-flow samples, respectively. At site 2, 60 percent and 40 percent of the LFUN isolates were identified as *E. coli* for base-flow and storm-flow samples, respectively. The LFUN isolates that were not *E. coli* were identified as other enteric bacteria. These results indicate that for the samples from site 2, colony counts of LFUN bacteria would result in a poor quantification of *E. coli*.

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OPTIMUM PH FOR BIODEGRADATION OF BENZENE AND TOLUENE IN A KARST AQUIFER

Natascha Morris[1], Gregg Hileman[2], and Tom D. Byl[1, 2]

Jet fuel leaking from underground pipes contaminated the regolith and karst aquifer underlying a south-central Kentucky airfield. Benzene and toluene, components of jet fuel, were detected in seven fuel-contaminated wells at the airfield. Ground-water pH measured in these seven wells ranged from 5 to 11. Some microorganisms are capable of degrading aromatic hydrocarbons such as benzene and toluene, but the rate of metabolism varies with pH. A study was conducted to determine the optimum pH for biodegradation of benzene and toluene by bacteria indigenous to the karst aquifer. Batch microcosms (three replicates per treatment and sampling time) were set up using karst bacteria enriched with benzene and toluene. The pH of the water in the microcosms was adjusted to pH 2, 5, 7, 9, and 12. Little to no biodegradation occurred outside the pH range of 5 to 9; pH values higher than 9 or lower than 5 caused the rate of biodegradation to decrease rapidly. Tests of biochemical oxygen demand verified that dissolved-oxygen consumption stopped when pH values were outside the range of 5 to 9. Microcosms with a pH of 5 showed the greatest decrease in benzene and toluene concentrations (approximately an 80-percent reduction in 6 days), followed by pH values of 7 (70-percent reduction), 9 (65-percent reduction), 2 (25-percent reduction), and 12 (10-percent reduction).

During a 3-month pump-and-treat remediation process, ground-water pH was monitored in the seven fuel-contaminated wells. The pH of the water in six of the seven wells ranged from 5.2 to 6.8. One well, which initially had a pH of 11 attributed to grout water from a newly installed well 9 feet away, retained a pH above 10 during the 3-month remediation. Increased biological activity was observed in most of the wells because of the remediation. However, bacterial growth and oxygen consumption of fuel biodegradation were not indicated in the well where the pH was greater than 10. These results demonstrate that fuel biodegradation can be slowed by very high or low pH values.

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EVALUATION OF PASSIVE - DIFFUSION SAMPLERS TO MEASURE DISSOLVED OXYGEN, GEOCHEMISTRY, AND VOLATILE ORGANIC COMPOUNDS IN GROUND WATER

Namuduri, Sumedha[1], Hileman, Gregg[2], Chakraborti, Koushik[1], and Byl, Tom[1,2]

The efficiency of fuel or solvent biodegradation is dependent upon the amount of dissolved oxygen (DO) and other geochemical electron acceptors present in the water. Accurate measurements of ground-water geochemistry are essential when evaluating the potential for biodegradation at a contaminated site. Collecting ground-water samples with a bailer or pump can disrupt the concentration of constituents in the water and provide misleading information about the aquifer. The objective of this study was to determine if geochemical constituents and volatile organic compounds (VOCs) could be monitored more effectively using passive-diffusion (PD) samplers as compared to disposable bailers. Initially, laboratory experiments were conducted to determine whether polyethylene or cellulose-dialysis tubing should be used to make the PD samplers. PD samplers were constructed by filling polyethylene or cellulose-dialysis tubing with ultra-pure water, sealing the ends, and placing the samplers in 4-liter bottles of water with a known geochemistry and VOC concentration. The PD samplers were removed from the water at specific time intervals, and the contents of the samplers and bottled water were analyzed to determine the VOC concentration, DO, dissolved iron (Fe^{2+}), nitrate (NO_3^{2-}), sulfate (SO_4^{2-}), sulfide (S^{2-}), pH, alkalinity, and specific conductance. Results of laboratory studies indicate that the concentration of VOCs and DO in the polyethylene bags were at equilibrium with the bottled water by 48 hours. The polyethylene bags were not suitable for measuring pH, specific conductance, or any inorganic constituents. The dialysis tubing was better suited for measuring pH, specific conductance, and dissolved inorganic compounds such as Fe^{2+}, NO_3^{2-}, SO_4^{2-}, and S^{2-}. The geochemistry of the bottled water and the cellulose-dialysis sampler came into equilibrium within 4 to 10 hours in the laboratory experiments. In field trials where the results of PD samplers were compared with bailers, DO concentrations obtained using PD samplers were consistently lower by 0.1 to 0.5 milligrams per liter as compared to water collected with disposable bailers. Concentrations of Fe^{2+}, NO_3^{2-}, SO_4^{2-}, and S^{2-} were similar between water collected with dialysis tubing and water collected with bailers in field trials. Geochemical and VOC samples collected with PD samplers did not require filtering before analysis, which was beneficial where geochemical and VOC monitoring was done in wells enriched with molasses, lactic acid and soy milk. One drawback of the cellulose-dialysis PD sampler was that ground-water microbes often generated holes in the membrane when the samplers were placed in wells with aerobic conditions for 4 weeks or longer. However, the cellulose-dialysis samplers maintained integrity in anaerobic conditions over the same time period. There was no observable disintegration in the polyethylene samplers when they were placed in aerobic or anaerobic conditions over a similar time period. In summary, the cellulose-dialysis PD samplers were useful for obtaining accurate geochemical concentrations in ground water, and the polyethylene PD samplers were useful for obtaining accurate VOC and DO concentrations in ground water.

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FLUME EXPERIMENTS TO IMPROVE EQUATIONS THAT PREDICT THE FATE OF FECAL BACTERIA IN RIVER SEDIMENTS

Tarajee Rashid[1], Lonnie Sharpe[1], J.J. Farmer[1,2], and T.D. Byl[1,2]

Fecal pollution in surface waters is a serious problem. As a result, scientists have developed a number of models in an attempt to predict the fate and transport of fecal pollution in riverine systems. Various models, such as CE-QUAL-W2, predict the rate of bacteria removal from the water column based on density, settling rates and water velocity. Such models, however, do not consider re-suspension, or survival and reproduction of bacteria in sediments. Flume experiments are currently being conducted to improve numerical models by incorporating reproduction of bacteria in bed sediments and re-suspension into the water column, in addition to other parameters such as water velocity, initial bacteria concentration, and settling rate. The flume is 10 feet long and 6 inches wide with 2 inches of pre-sterilized sediment (gravel, sand and organic matter) spread on the bottom and 12 inches of water over the sediments. Water is circulated at a velocity of 0 to 0.5 meters per second using a small pond pump. Two strains of *Escherichia coli* (*E. coli)* and two strains of *Klebsiella* are then introduced into the circulating water at known concentrations and monitored as they settle or remain suspended. Bacteria concentrations are being measured in the water column and the sediment along the flume to determine bacterial fate and transport. The data on fecal bacteria survivability in sediments and re-suspension associated with different velocities are being used to improve a bacterial fate and transport model. Such a model could provide insight into sources of fecal bacteria in the water column.

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SOUTHEAST WATER POLICY INITIATIVE

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Water quantity and quality problems are increasingly challenging the efforts of decision-makers and citizens in the Southeast U.S. to maintain a sustainable economy and environment. These problems often escalate into intractable disputes between government agencies, businesses, conservationists, homeowners, and other interests in a region where water was historically abundant. Despite the increasing conflicts, there is limited understanding of how social, as well as environmental and other factors interact to drive disputes. The Southeast Water Policy Initiative (SEWPI) is an interdisciplinary research and education partnership working to develop policy and management tools for anticipating, averting, and resolving disputes over water supply through scientific research and policy development by researchers from the natural, social and engineering sciences. It employs a holistic approach to better understand the environmental and social factors driving disputes and the potential consequences of proposed solutions. SEWPI's purpose is to develop practical strategies for both decision-makers and citizens to protect water resources and meet water supply needs. Current projects include the development of a Web-based index of SE water dispute case studies and a prototype G.I.S. atlas for a regional water supply dispute.

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CONSTRUCTED WETLAND CLEANUP OF PIRTLE'S CONTAINER NURSERY RUNOFF:REMOVAL OF NITROGEN, PHOSPHORUS AND PRODIAMINE FROM A SUBSURFACE FLOW CONSTRUCTED WETLAND AT 1, 2 AND 3 DAY HYDRAULIC RETENTION TIMES

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ABSTRACT

A 192 m^2 gravel subsurface flow constructed wetland was designed and installed at Pirtle's Nursery in Smithville, TN. The wetland was 45 cm deep and contained approximately 20 m^3 of water. Softstem bulrush (*Scirpus validus*), cattails (*Typha latifolia* L.), and juncus (*Juncus* spp.) were planted in the wetland. A standpipe controlled water level in the wetland and a bypass pipe averted heavy flow. Total nitrogen (N), phosphorus (P), and the pesticide prodiamine were measured from the influent and effluent water during daily irrigation events. A water valve into the wetlands controlled hydraulic retention times (HRTs) of 1, 2, and 3 d. A Stevens Chart Recorder measured the influent water so that HRTs could be calculated. Mean N removal was 70 to 72% of total influent N. Mean P removal varied from -2 to 10% of total influent P. Mean prodiamine removal ranged from 49-65% of total influent prodiamine. The wetland required little maintenance other than occasional sediment removal after heavy rain, occasional sediment flushing of the inflow pipe to maintain flow and weed removal.

OBJECTIVE

The objective of this study was to determine the removal of nitrogen (N), phosphorus (P), and the herbicide prodiamine from irrigation runoff water at Pirtle's Nursery into a vegetated subsurface flow gravel constructed wetland at 1, 2, and 3 d hydraulic retention times (HRTs). Nurseries apply large amounts of agricultural chemicals to sloping terrains that are highly susceptible to soil erosion. Pesticides and fertilizers may run off into surface water causing detrimental effects to non-target organisms. Identification and implementation of best management practices, including constructed wetlands, which reduce agricultural chemicals in waterways are essential to reduce agricultural chemical pollution of water resources. N and P removal in constructed wetlands has been reported in a few studies, while pesticide removal has seldom been studied in constructed wetlands.

MATERIALS AND METHODS

Constructed Wetlands

The constructed wetlands are located at Pirtle's Nursery in Smithville, TN. Irrigation runoff water from a 1.0 ha container nursery pod flows into the wetland. The wetland is 45 cm deep and 25 x 7.68 m in surface area. The pore volume is estimated to be 20 m^3 based on 30% porosity. The media consisted of 23 cm (9 in) depth of limestone gravel (diameter size 2.5-5.0 cm) overlain by 23 cm (9 in) of finer gravel (diameter size 0.63-1.88 cm). The entrance to the wetlands held coarse gravel for the entire depth for a distance of 3 m to prevent the flow into the wetlands from being restricted by the fine gravel. The wetland was planted primarily with soft stem bulrush, cattails and juncus growing on the back edge of the wetland (Illustrations 1-4).

Illustration 1. Measuring effluent pH

Illustration 2. Checking the Stevens chart recorder

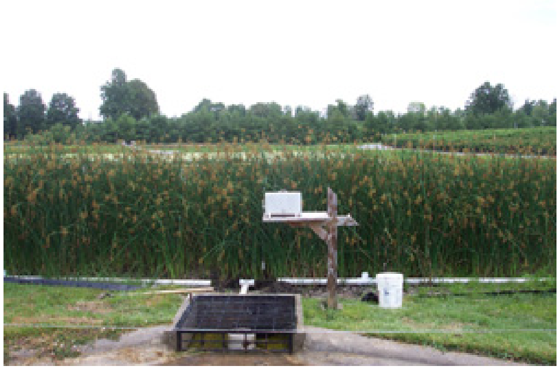

Illustration 3. Wetland inflow at the distribution box

Illustration 4. Wetland during the first year, 2000

Sampling

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

Flow Determination

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

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

Where,

Q = the discharge flow through the orifice (cfs),
C_d = coefficient of discharge (dimensionalless),
A_o = Orifice cross-sectional area (ft^2),
g = acceleration of gravity (fps),
h_i = water head (ft) at any specific time, and
h_0 = water depth to lower invert of orifice (ft).

The coefficient of discharge, C_d, was computed by measuring the discharge flow at various control valve settings (Table 1). The control valve limited the flow to the wetland.

Table 1. Wetland hydraulic flow computation

Valve (%)	Flow (cfs)	Flow (gal/d)	Orifice (sq ft)	h (ft)	Cd
100	0.0740	47800	0.049	0.375	0.307
75	0.0444	28700	0.037	0.375	0.245
60	0.0226	14600	0.029	0.375	0.156
50	0.0191	12300	0.025	0.375	0.158

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

N, P, and Prodiamine Analysis

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

RESULTS

N, P, and Prodiamine Removal in the Constructed Wetland

Table 2 shows percent removal of N, P, and prodiamine for 1, 2, and 3 day retention times. Included are the number of samples and the standard deviation. Nitrogen had 70 to 72% removal and there was no statistically significant difference in N removal from 1, 2, or 3 day HRTs. Mean phosphorus removal was less than or equal to 10% with a large standard deviation. The erratic nature of phosphorus removal via biological uptake and sorption was largely attributed to pH shifts in runoff water especially due to acid rain. Normally, the irrigation water runoff pH was around 7.5 and the outflow water was usually around pH 8. During rain events, water pH was lowered causing phosphorus to dissolve. Prodiamine removal varied between 48 and 65%, which was consistent with previous studies at Baxter, TN using constructed wetland cells. Results from the Baxter study showed that pesticides simazine and metolachlor were removed at 60-65% at 2- and 3-day retention time.

Table 2. Mean nitrogen, phosphorus and prodiamine removals in the constructed wetland

	1 d HRT*	**2 d HRT**	**3 d HRT**
	% Removal (∀standard deviation)		
Nitrogen	70.8a** ∀9.8 (n[+]=13)	71.8a ∀10.8 (n=16)	69.9a ∀11.4 (n=14)
Phosphorus	10.0a ∀3.97 (n=13)	7.7a ∀24.0 (n=15)	-1.7a ∀22.0 (n=14)
Prodiamine	57.9a ∀5.3 (n=3)	48.9a ∀27.7 (n=7)	64.8a ∀5.6 (n=5)

* HRT = hydraulic retention time

** Values followed by the same letter within a row are not different according to Tukey's mean separation test at the 5% level

[+] n=number of samples

DISCUSSION

Removal Processes

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

Significance

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

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NUMERICAL SIMULATION OF FLOW AND CONTAMINANT TRANSPORT IN A KARST AQUIFER CONDUIT

Valetta Watson[1], Roger Painter[1], and Tom D. Byl[1,2]

Computer models that simulate water flow or contaminant transport in unconsolidated aquifers have little transferability to karst aquifers because they are based on equations derived under the assumption of laminar flow. Flow through conduits developed in karst aquifers may be turbulent, and the locations of the conduits may not be well understood, limiting the usefulness of these models.

To address this issue, the Lattice-Boltzmann method (LBM), a powerful technique that can be used for computational modeling of complex fluid flow, was used to develop a numerical model to simulate water flow and contaminant movement in a theoretical karst conduit. The LBM is based on statistical physics and uses a numerical approach to solve the Navier-Stokes equations for fluid flow. In this study, two-dimensional images were generated using object grids that delineated the structure and surface of the karst conduit within which the fluid flow was being modeled. Fluid movement was visualized by assembling simulation outputs as a series of time-step animations. For the volume simulation outputs, transparency was used to indicate fluid density and color intensity was used to indicate fluid velocity.

The numerical results obtained from the simulations were compared against those obtained from a laboratory dye-tracer experiment to validate the model. An artificial karst conduit of varying dimensions was constructed in the laboratory by connecting a series of glass tubes (≤ 2 inch diameter). Once a constant discharge was observed at the outlet, rhodamine dye was injected at the inlet of the conduit and measured at the outlet as a function of time. An analysis of the quantitative experiment indicated that distinct re-circulation zones existed within the artificial karst conduit. These same features were captured in the LBM simulation. The agreement between the LBM simulation and the laboratory study demonstrates the potential for using the LBM technique to model the transport characteristics and residence time of contaminants within a karst system.

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