AWRA

Proceedings of
The Fifteenth
Tennessee Water Resources
Symposium

April 13 - 15, 2005

The Fifteenth Tennessee Water Resources Symposium

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Proceedings from the

Fifteenth Tennessee
Water Resources Symposium

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PREFACE

The State of Tennessee is fortunate to have an abundance of fresh water, both surface water and ground water. However overuse and contamination threaten these valuable natural resources. The Tennessee American Water Resources Association (TN AWRA) is proud to host a forum through which water-resource managers, federal, state and local governmental agencies and officials, and academia can exchange ideas and share innovations to ensure water resource sustainability and maintained water quality. This 2005, we celebrate the 15th Tennessee Water Resources Symposium.

We have a wide-ranging venue of topics that include surface water quality, ground water contamination, policy development, educational media, and watershed science to name a limited few. An exciting, new conference agenda is an outdoor session allowing attendees to participate in hands-on activities such as stream gaging, in-stream bioassessment, riparian assessment, and GIS/GPS technologies. We are also proud to provide an outdoor show-and-tell for our exhibitors to showcase their products. Still another new feature of this year's conference is a digital copy of these proceedings in Adobe PDF format. This format will allow for simple queries and includes color illustrations, otherwise black and white in print.

Each TN AWRA conference relies on the abilities of the planning committee to make the conference a success. These volunteers work behind the scenes, generously contributing their time and effort. I personally thank the committee members (listed on page v of these proceedings) for your commitment and dedication. I would like to extend a special thanks to Lori Crabtree for her guidance. I also extend a warm thank you to our sponsors and exhibitors for your generosity and participation.

We welcome you to the 15th Tennessee Water Resources Symposium.

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1:30 – 3:00 p.m.
Wednesday, April 13

Keynote Address by Dr. Mindy Lalor, National AWRA President
AWRA and TN AWRA: Partners in Community, Conversation and Connections

12:30 – 1:30 p.m.
Thursday, April 14

Luncheon presentation by Dr. Albert Ogden, Middle Tennessee State University
The World of Caves, Cavers, and Caving

SESSION 1A

EFFECTS OF SEDIMENTATION ON ECOSYSTEMS

SESSION 1B

POLICIES FOR BMPs

SESSION 1C

SURFACE WATER QUALITY I

SESSION 2A

SEDIMENT TRANSPORT

GEOMORPHOLOGIC INVESTIGATIONS

WATER QUALITY IN URBAN ENVIRONMENTS

SURFACE WATER QUALITY II

GROUND-WATER QUALITY & CONTAMINATION

BACTERIAL SOURCE TRACKING

STREAMFLOW ASSESSMENTS

DYE TRACING

SESSION 2C

SOURCE WATER

PUBLIC EDUCATION AND AWARENESS

TRENDS IN STORM WATER MANAGEMENT

STORM-WATER & WASTEWATER TREATMENT

SESSION 3A

SURFACE WATER QUALITY III

TENNESSEE WATER PROGRAMS

SESSION 3B

FIELD INVESTIGATIONS-RESTORATION

FIELD INVESTIGATIONS-REMEDIATION

SESSION 3C

GIS MAPPING & DATABASES

WATERSHED INVESTIGATIONS

PROFESSIONAL POSTERS

STUDENT POSTERS

THE WORLD OF CAVES, CAVERS, AND CAVING

Albert E. Ogden[1]

Caves are found in nearly half of Tennessee. As a result, many of us have explored the mysterious and dark world that lies beneath our feet. The more serious cavers of the state belong to the National Speleological Society (NSS) which is the nation's premier organization dedicated to the exploration, mapping, study, and conservation of caves. The NSS is divided into 12 regions which in turn, are composed of caving clubs called grottos. There are 10 grottos in Tennessee. Within the NSS, there are also 11 "Surveys" of which the Tennessee Cave Survey (TCS) is one. The TCS has documented over 8,500 caves in the state making it the most cavernous state in the country. Members of the TCS and various grottos hold a wealth of information that could be useful to your organization when working at a karst job site. Due to the ramped vandalism of our caves, the maps and other information are proprietary and heavily guarded. But if you present your case demonstrating the need for the information, you will likely get it, if you promise not to publish the data. After all, we cavers are dedicated to protecting and cleaning up our karst environments just like you. The TCS and various grottos can be contacted through the NSS web site, which is **caves.org.**

The luncheon talk will present pictorial views of splendid cave formations, types of caves, the rigors and safety in caving, and a few antics of the not so serious caver. For every caver that studies or maps caves, there are 10 who just like to explore the underworld for reasons perhaps only Freud could explain.

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SESSION 1A

EFFECTS OF SEDIMENTATION ON ECOSYSTEMS
3:30 p.m. – 5:00 p.m.

Turbidity, Transparency, and Habitat in Tennessee Streams
Timothy H. Diehl

Linking Ecological Response with the Dynamics of Fluvial Processes, Habitat Maintenance, and Sediment Characteristics: A Framework for Sediment TMDL Development
John S. Schwartz

Developing Links Between Aquatic-Community Structure and Sediment-Related Variables: Preliminary Results from the Ridge and Valley
Janna Owens, Robert Angus, Ken Marion, Scott Knight and Andrew Simon

TURBIDITY, TRANSPARENCY, AND HABITAT IN TENNESSEE STREAMS

Timothy H. Diehl[1]

INTRODUCTION

Transparency and turbidity, closely related optical properties of water, are commonly used as surrogate measurements for the amount of suspended sediment or for the detrimental effects of suspended sediment. Transparency is inexpensive and simple to measure; turbidity is easy to measure with moderately expensive equipment and can be monitored continuously. Transparency and turbidity are correlated, and transparency can be used to predict turbidity. Direct measurement of sediment is more expensive, and continuous sediment monitoring techniques are in their infancy.

Turbidity has been associated with harm to biota in several settings (Newcombe, 1997; Walters and others, 2001; Newcombe, 2003; Roy and others, 2003). In Tennessee streams, turbidity can reach levels causing stress to clear-water fish either during baseflow or stormflow. The relation of turbidity to sediment concentration is extremely variable (Wilson, in press), so the linkage between turbidity and harm to biota may be indirect and difficult to define.

In Tennessee, baseflow turbidity, habitat, and macroinvertebrates have been measured repeatedly at about 100 ecoregion reference sites (Sherry Wang, Tennessee Department of Environment and Conservation, written commun., 2004). Turbidity appears to vary independently from macroinvertebrate scores, but is linked to lower habitat scores.

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LITERATURE REVIEW

Newcombe (2003) explains the value of water-clarity parameters such as turbidity and transparency for monitoring and impact assessment. Newcombe (1997) provides a broader set of stress models for sediment and turbidity. These models suggest that non-salmonids are less sensitive to turbidity in flood waters than clear-water fishes, and therefore more likely to be stressed by chronically high baseflow turbidity. Newcombe (1997) also asserts that the most intolerant macroinvertebrates have sediment stress thresholds similar to those of clear-water fishes. Newcombe's models are based on a broad review of literature and unpublished research results. He cautions that much of the research doesn't describe the duration of exposure, and that turbidity effects on many species are unknown. To calibrate his model, the effects of optical characteristics on the species of interest would need to be studied in the ecological region in which monitoring and assessment will take place.

Studies in Georgia have identified links between turbidity and biota. Walters and others (2001) found a significant negative correlation of fish index of biotic integrity (IBI) with turbidity in Georgia Piedmont streams, with sites averaging more than 10 NTU rarely having fish IBI scores over 35. Roy and others (2003) found that urbanization in Georgia is detrimental to invertebrate biotic indices. Urban land cover is associated with decreased bed-sediment size, increased suspended solids, and increased turbidity. These reach-specific variables are more closely associated with declines in biotic indices than is percent of urban land cover by itself.

TURBIDITY DATA FROM THE U.S. GEOLOGICAL SURVEY AND HARPETH RIVER WATERSHED ASSOCIATION

Turbidity is highly variable wherever continuous data are available in Tennessee, even at sites with little disturbance. Peak turbidity occurs momentarily during floods, and may be contrasted with long periods of clear water during baseflow. Since organisms can tolerate high turbidity briefly, turbidity-related stress can be greatest during either floods or baseflow. The average turbidity from a few measurements during baseflow may be misleading in streams where the greatest biological stress from turbidity occurs during floods.

In Copperas Creek, turbidity has varied from less than 1 NTU during baseflow to more than 600 NTU for brief periods during floods (fig. 1). Based on the impact model of Newcombe (2003), turbidity in Copperas Creek would be stressful to clear-water fishes during periods with turbidity greater than about 200 NTU. These periods come during and after heavy rainfall and are hours in duration.

Transparency in the Harpeth River at Highway 100 was estimated for the 2000 water year, based on transparency measurements by Wilson (in press) and the continuous discharge record. Based on the impact model of Newcombe (2003), the stress on clear-water fishes would be greatest during periods of a month or more with transparency of about 20 to 50 cm. Based on a calibration of transparency to turbidity in the Harpeth basin (Wilson, in press), this range in transparency corresponds to about 15 to 55 NTU.

STATE OF TENNESSEE ECOREGION REFERENCE SITES

Average turbidity at ecoregion reference sites is bimodally distributed, with a strong mode around 2 NTU and a smaller mode around 13 NTU (fig. 2). This second mode is strongly associated with the ecoregions of West Tennessee. Sites in the Blue Ridge Mountains ecoregion (Griffith and others, 1997) tend to have lower turbidities and higher macroinvertebrate indices than the rest of the State, while the sand hills and loess plains of West Tennessee (ecoregions 65 and 74, the Southeastern Plains and Mississippi Valley Loess Plains) tend to have higher turbidities and lower macroinvertebrate biotic indices. Sites in the Mississippi Alluvial Plain ecoregion have high turbidities, combined with macroinvertebrate indices distinctly lower than those of any other Tennessee ecoregion. A statewide trend of lower macroinvertebrate indices at higher turbidities is apparent, but macroinvertebrate index is independent of turbidity within each ecoregion.

Macroinvertebrate indices are measured using one of two methods – SQKICK or SQBANK (Tennessee Department of Conservation, 2003). Within the group of sites using each method, macroinvertebrate indices are not correlated with average turbidity (fig. 3). The absence of riffles, which is the condition for the use of SQBANK, appears correlated with turbidity greater than 10 NTU, but both of these characteristics are related to the flat-lying topography and abundant loess in West Tennessee.

Other characteristics vary across the ecoregion sites, making interpretation difficult. For example, all sites with more than 40 percent Ephemeroptera, Plecoptera, and Trichoptera also have at least 90 percent forest land cover, but percent forest appears unrelated to turbidity.

Increased turbidity may be associated with biotic impairment, as studies elsewhere have found. Ecoregion reference sites represent one end of a spectrum of impairment, and would have to be studied parallel with impaired sites to test whether turbidity impairs stream biology.

TURBIDITY AND HABITAT AT ECOREGION REFERENCE SITES

Two habitat scoring methods are used for high- and low-gradient streams. Low values for most of the 10 parameters used in calculating habitat score can be a cause or a result of elevated sediment load. While low-gradient streams tend to have higher turbidity, the turbidity ranges overlap between the two types. A general pattern of decreasing habitat score, as shown by a smoothed average of ranked scores with increasing turbidity, is about the same in both high- and low-gradient streams (fig. 4). Over the range of average turbidity observed, habitat score decreases by about 50 points.

Because turbidity integrates conditions over the entire channel network, it may provide a more representative measure of impairment to the stream than a local habitat score. The hypothesis that turbidity is related to habitat impairment could be tested by combining habitat scoring with regular turbidity measurement at impaired sites as well as reference sites.

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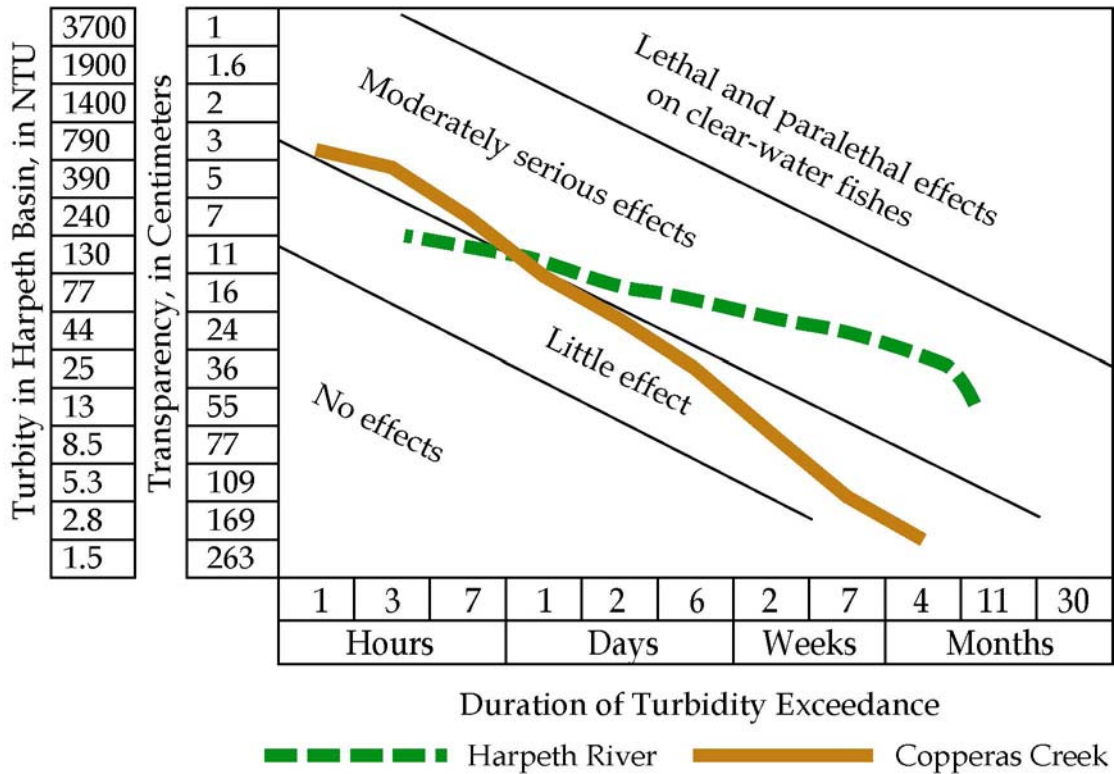
Figure 1.—Turbidity-duration relations for Copperas Creek and the Harpeth River based on Newcombe, 2003.
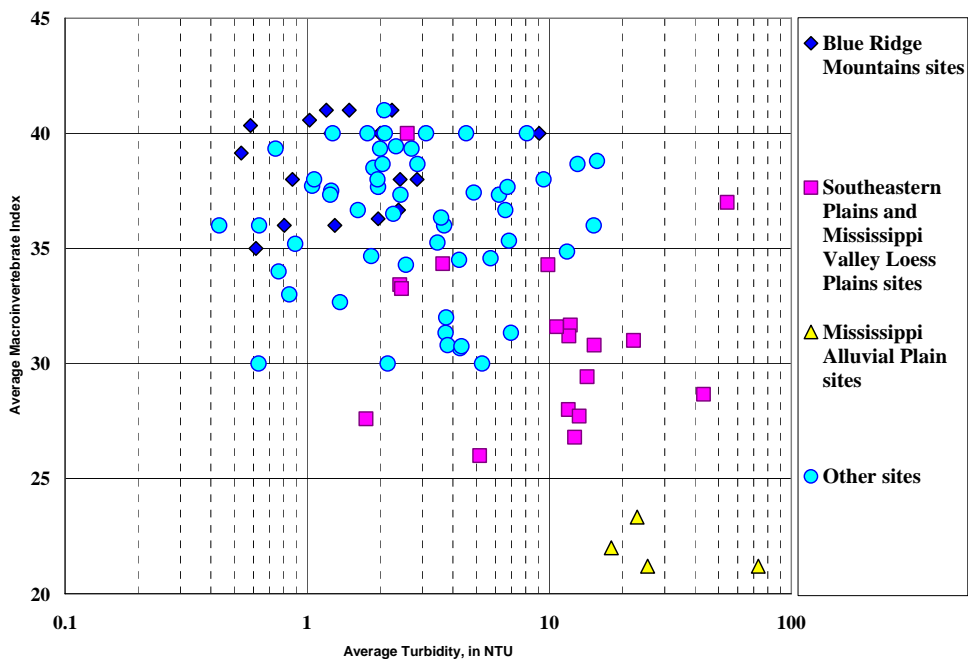
Figure 2.—Average turbidity and macroinvertebrate index for Tennessee ecoregion reference sites (from Griffith and others, 1997).
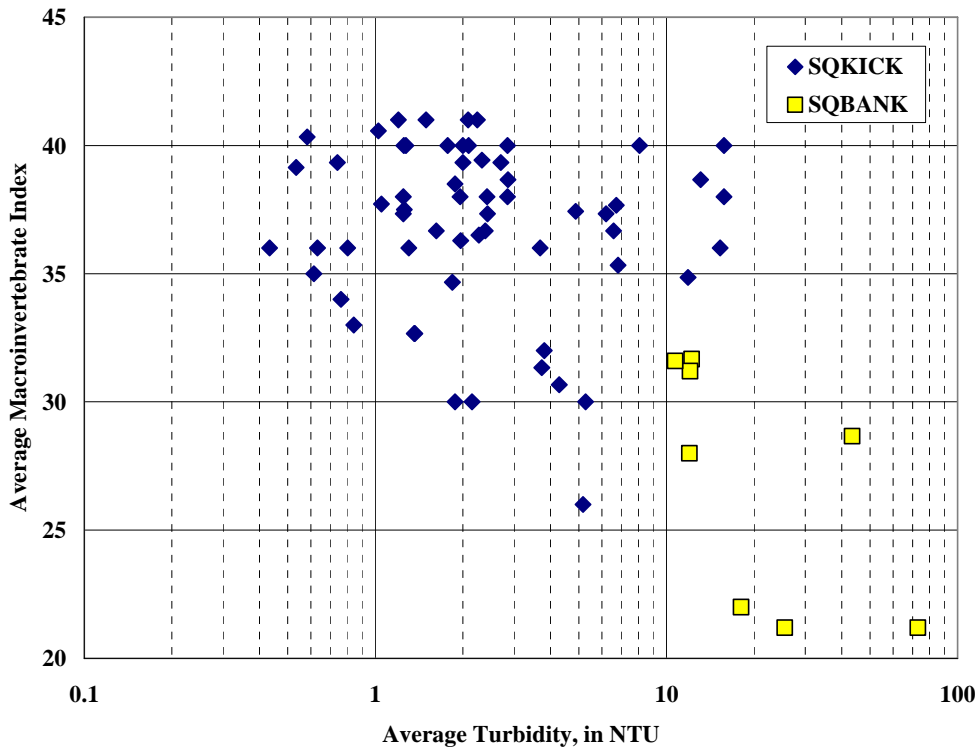
Figure 3.—Average turbidity and macroinvertebrate scores stratified by sampling method based on Tennessee Department of Environment and Conservation, 2003.
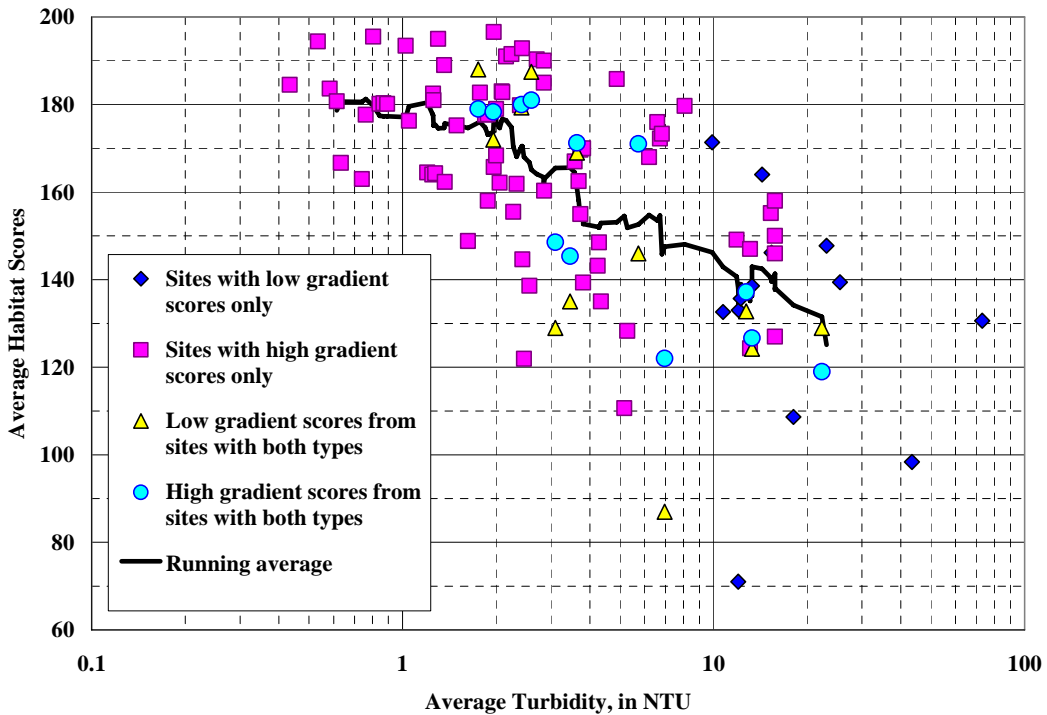
Figure 4.—Average turbidity and habitat scores at Tennessee ecoregion reference sites.

LINKING ECOLOGICAL RESPONSE WITH THE DYNAMICS OF FLUVIAL PROCESSES, HABITAT MAINTENANCE, AND SEDIMENT CHARACTERISTICS: A FRAMEWORK FOR SEDIMENT TMDL DEVELOPMENT

John S. Schwartz, Ph.D., P.E.[1]

A conceptual framework to link ecological response with the dynamics of fluvial processes, habitat maintenance, and sediment characteristics is presented that organizes relationships between biological and physical environmental domains and the relevant spatial and temporal scales in which they operate. Key elements to this framework include the ideas that 1) ecological response to a disturbance associated with a sediment regime n disequilibrium is organism dependent expressed individually by species traits and life histories; and 2) different sediment particle sizes cause different ecological responses, directly or indirectly. Critically needed is a research framework to improve our understanding of ecological response to stream sediment dynamics and habitat conditions, in order to link sediment TMDLs with biocriteria metrics, as promulgated in state water quality statutes.

Ecological response to episodic events of excessive sediment transport is a function of individual biological needs, in which an autecological database can be used to qualitatively evaluate how an aquatic organism may be impacted. Composite autecological data for a group of individuals can be summarized to complete a community-level assessment (Schwartz et al. 2001). An autecological database is a relational matrix of organism by ecological attribute (Table 1). Important ecological attributes include spawning behavior. For example, some fish need fine gravel at pool margins and others disperse eggs into the water column requiring no bed sediment, whereas others attach eggs to emergent vegetation (Smith 1979; Etnier and Starnes 2001). Not only are biological needs of individuals important, but also what changes in the particle size distribution that occurs and how those changes detrimental affect populations. Sediment size ranges have different ecological relationships in maintaining quality habitat, and sustaining various organism populations (Table 2). For example, some fish may be directly injured by excessive concentration of fine particle size, whereas others may be impacted because excessive sand-gravel transport degrades mesohabitat structure (Berkman and Rabeni 1987; Payne and LaPointe 1997; Wood and Armitage 1997; Milhous 1998; de Robertis et al. 2003; Newcombe 2003). In the framework proposed, fish are used as the biological indicator because of their broad- to local-scale responses to disturbances in channel sediment dynamics.

Research conducted within the proposed framework builds the informational database to create a future ecological model with the predictive capability to estimate species survivability from sediment regime disturbances. An ecological model combined with existing physical modeling tools would be useful in creating watersheds plans that resourcefully address sediment TMDLs. Physical modeling tools for watershed planning and sediment modeling have improved over the recent years. They include the USDA National Sedimentation Laboratory (NSL) merging of the watershed sediment delivery model AnnAGNPS with Concepts, a new channel adjustment and sediment transport model (Simon et al. 2002). Other modeling approaches include the use of USGS gauging stations with suspended sediment data that provide information on sediment concentrations at effective discharge and an estimate of sediment yield. Recently, the NSL completed a project estimating sediment yields for stable and unstable channels for select ecoregions, in which the stable channel estimates can be used as a reference sediment condition (Simon et al 2004). However, a reference sediment load and concentration lacks an ecological interpretation to be transferred to different watersheds with potentially different biological

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communities (Kuhnle et al. 2001). The proposed framework presented supports methodological development of an autecolgical assessment that supports an ecological interpretation of output from physical modeling and analysis tools.

Table 1. Example autecology matrix for selected Illinois fish species and ecological attributes (modified from Schwartz 2002).

ECOLOGICAL ATTRIBUTE * YOY = young-of-the-year	FISH SPECIES					
	Longear Sunfish	Sand Shiner	Central Stoneroller	Bluntnose Minnow	Creek Chub	White Sucker
Adult Feeding Position: shallow	X		X	X	X	X
Adult Feeding Position: deep pool	X			X		X
Adult Feeding Position: riffle		X				
Adult Feeding Position: glide/run		X	X	X	X	X
YOY Feeding Position: shallow	X			X		
YOY Feeding Position: deep pool						
YOY Feeding Position: shallow riffle		X	X	X	X	
YOY Feeding Position: glide/run	X	X	X	X	X	X
Spawning Behavior: nesting	X		X		X	
Spawning Behavior: dispersal, no		X				X
Spawning Behavior: attached eggs				X		
Spawning Substrate: debris						
Spawning Substrate: mud/silt						
Spawning Substrate: sand	X	X		X	X	
Spawning Substrate: gravel/rocks	X		X	X	X	X
Spawning Substrate: vegetation						
Spawning Current: none	X					
Spawning Current: slow	X			X	X	
Spawning Current: moderate		X	X			X
Spawning Current: fast		X	X			

Table 2. Geomorphic-habitat and ecological relationships with sediment size ranges transported during flood flows.

Diameter (mm) *(upper size bound)*	Sediment description	Transport function	Geomorphic-habitat role	Ecological role
0.010	**clay**	wash load	Transported	• Modification to **ecosystem energetics**; e.g., disrupt feeding efficiency
0.065	**silt**	suspended	Deposition in low-velocity areas during floods; **lateral habitat** maintenance in channel and floodplain platforms.	• Organism **injury**, e.g, fish gill abrasion; • Modification to **ecosystem energetics**; • **Habitat alteration**, e.g., spawning habitat degraded with fines; reduction in flow refugia for fish.
0.025	**fine sand**	suspended		
2.00	**sand**	suspended, bedload		
3.36	**very fine gravel**	suspended, bedload		
9.51	**fine gravel**	bedload	Saltating transport along streambed; Maintenance of **longitudinal habitat** structure.	• **Habitat alteration**, e.g., removal of spawning gravel in incised channels, reduction in deep pool habitat.
50.0	**gravel**	bedload		

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DEVELOPING LINKS BETWEEN AQUATIC-COMMUNITY STRUCTURE AND SEDIMENT-RELATED VARIABLES: PRELIMINARY RESULTS FROM THE RIDGE AND VALLEY

Janna Owens[1], Robert Angus, Ken Marion[2], Scott Knight and Andrew Simon[3]

Aquatic habitats are designated as a primary source of impairment for many listed surface waters, therefore, establishing links between aquatic populations and sediment-related variables is critical in developing watershed strategies. Although biological assessments are indispensable, impairment sources cannot be identified without associated variables quantifying the physical parameters that are related to biologic functions. Our objective was to explore potential relations between biologic community structures and local-scale sediment and geomorphic processes. Biologic collections and habitat evaluations were conducted using the rapid bioassessment protocol (RBP) for three years at sites in the Alabama section of the Ridge and Valley. Rapid geomorphic assessments (RGAs) and identification of the Stage of Channel Evolution were utilized to semi-quantify channel stability using a channel-stability index and to distinguish stable and unstable sites. This index can be used as an empirical surrogate for sediment load with higher index values representing greater instability and erosion, as well as higher sediment loads. Samples of bed-material particle size were collected to quantify the degree of fines deposition (embeddedness) within gravel-dominated substrates. Stable study sites, as indicated by low values of the Channel-Stability Index scores (<13) generally had low embeddedness values and supported good aquatic communities as determined from a modified EPT (Epheroptera, Plecoptera and Trichoptera) metric. Sites with the highest values of the Channel Stability Index and embeddedness (>13%) had poor biotic community structures. These data support the hypothesis that stream geomorphology and biological communities can be associated in water quality assessments. Monitoring strategies that link stream geomorphic variables and biological data will serve to better direct remediation efforts for watersheds.
KEY TERMS: Environmental Indicators, Geomorphology, Invertebrates, Monitoring, Water Quality, Sedimentation

INTRODUCTION

Currently within the United States, the principal causes of impairment to rivers and streams are siltation and habitat alterations; the known sources of these impairments are hydrologic and habitat modifications (US EPA 2002). It has been proposed that escalating urbanization and the ensuing increase in stormwater runoff has become the most influential factor of water quality. Previous research has associated urbanization with increasing impervious surfaces and alterations of stream channels. Historically, the focus of watershed management has been on the transport of stormwater off-site rather than the effects of this runoff to the receiving waterbody and its channel and geomorphic processes (Karr 1999). Reach-scale attributes that reflect these urban stressors range from sedimentation, erosion, bank incisions, altered channel morphology, substrate modification, increased flow and degradation of water quality (Roy et al. 2003). For the purposes of water quality screening and monitoring, the instream processes and surrounding topographical features of a reach-scale habitat can be a primary determinant of aquatic community structures.

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3 USDA Agricultural Research Service, National Sedimentation Laboratory, 598 McElroy Dr., Oxford, MS 38655

Incorporating specific geomorphic variables that quantify these potential impacts into water quality assessments requires an evaluation of the linkages between these physical parameters and the aquatic community.

A widely accepted protocol for biological sampling and habitat evaluation within rivers and streams has been the EPA's Rapid Bioassessment Protocol (RBP). Its habitat evaluation segment is composed of a cumulative score for ranked measures of local habitat parameters. Ultimately, the RBP habitat score will give a quantitative value for the overall habitat quality on a reach-scale, but stressor associations in biological monitoring can require more specificity. Integrating additional information with the EPA biosurvey technique is useful in developing comprehensive diagnostic assessments as aquatic communities integrate the effects of diverse stressors and can indicate a wide range of impairment sources (Barbour 1999).

Therefore, to integrate geomorphic characteristics and channel processes, rapid geomorphic assessments (RGA) and a determination for the stage of channel evolution can be applied to semi-quantify channel stability using a channel-stability index (CSI), which distinguishes between stable and unstable reaches. This index can be used as an empirical surrogate for sediment loads with higher index values representing greater instability and erosion, as well as higher rates of sedimentation (Simon 1989).

The objective of our study was to explore potential relations between biologic community structures and the local-scale channel and geomorphic processes through selected variables. The significant linkages between physical parameters and the biotic data would enhance interpretations of stressor responses as reflected in the biological community. The establishment of some of these variables as ecological indicators will aid in focusing the appropriate assessment questions in watershed management.

METHODS

Sites on the upper Cahaba River basin in Jefferson County, Alabama, were sampled seasonally for benthic macroinvertebrate collections and measurements of physical, chemical and habitat variables using the RBP for three years. Although a continuum of sites were not established in a single water body, similar physical, chemical and geographic factors are shared within the watershed of the Cahaba River which lies between the Coosa and Cahaba Ridges of the Ridge and Valley Province. A reference site on the Cahaba River mainstem was near the headwaters (G); further downstream were sites experienced increasing urbanization (H) and (C). A local tributary (L) had similar landuse as (H) before entering the Cahaba. Three sites on tributaries of the Cahaba, (M) and (S) on Shades Creek and (P) on Patton Creek, were located downstream of more urbanized areas, with increased impervious surfaces and decreasing forest. In the adjacent Warrior River watershed, Valley Creek (V) was added as a type of negative control as it has been severely impacted by both of urban development and industrial inputs.

To quantify the watershed characteristics for sample sites, a soil erosion-potential model constructed in a previous using Geographic Information Systems (GIS) and remote sensing technologies was utilized study (Owens et al. 2002). The cartographic model consisted of selected data layers for the study area, including NRCS soils, multispectral satellite imagery, parcel level land use, and a Digital Elevation Model. The derived layers were then combined to yield measurable areas expressed as percentages within the upstream watershed for such characteristics as impervious surface, urbanization and forests.

RGAs were performed at each sample site to determine its stage of the channel evolution (Simon 1989) and to quantify erosional and depositional processes with a stability ranking. Stream slopes

and cross-sectional surveys were conducted, along with Wolman "pebble counts". Sediment samples were taken on gravel-dominated substrates; the percentage of material finer than 2 mm was later quantified to establish on-site embeddedness.

Macroinvertebrate collections were conducted as prescribed in the RBP, which provides a standardized evaluation of habitat, water quality and biological measures. The physical characterization of the channel reach habitat included the parameters of stream descriptions, riparian vegetation, streambank conditions, water quality and sediment/substrate components. Benthic macroinvertebrates were collected in the riffle areas with a d-frame kicknet and identified to genus level whenever possible using standard keys (Barbour et al. 1999).

A total of 75 metrics were calculated from the macroinvertebrate collections for analysis. The metric categories were primarily: tolerance/intolerance values, trophic guilds, habitat preferences, assessment indices, taxonomic richness and composition. Patterns of biotic assemblages were explored for significant correlations with environmental/physical variables using descriptive, nonparametric and multivariate procedures. All data was appropriately transformed prior to analysis for assurances of statistical normality. Biotic and abiotic variables were ordinated through nonmetric multidimensional scaling (NMDS) constructed from Bray-Curtis similarity matrices in a spatial orientation of two dimensions. Using the principal components analysis (PCA) procedure, metrics that correctly discriminated the geomorphically stable and unstable sites were maintained in a subset to evaluate along with environmental variables (Clarke and Warwick 1993).

RESULTS / DISCUSSION

Determining the explanatory variables that represent channel and geomorphic processes was an important preliminary step within our study scope. On a watershed scale, land use characteristics had strong correlations with the reach-scale CSI and the median diameter of the channel substrate (D_{50}). The CSI scores increased proportionally with urbanization magnitude; sites with CSI values > 15 were considered unstable. The D_{50} was negatively correlated with rising urbanization as substrate diameters decreased with increasing urban percentages. Both of these geomorphic variables would be affected by additional stormwater quantities from increased impervious surfaces in urban areas. Conversely, the CSI and D_{50} had significant correlations to minimal impervious surfaces upstream ($p=.001$), which is indicative of the reduction in runoff volume (Table 1).

The CSI score incorporates rankings for reach-scale attributes that represent specific channel and geomorphic processes. It was strongly correlated with mean habitat scores determined with the EPA's RBP and designated the stability of samples sites comparable to the RBP (Figure 1). Sites designated in Stages I or VI of the channel evolution model (Simon 1989), generally had lower CSI values (<15), larger D_{50} for substrates and a lesser degree of embeddedness. An exception to this trend, considering the 78% urbanization upstream, was the channelized Valley Creek site with a composition of 5% of substrate fines <2mm. The CSI evaluation noted mass wasting of the channel banks, but post-rain event hydrologic flows at that site can be powerful and re-distribute the fine sediment depositions.

To reduce redundancy of the metrics describing the biological assemblage, those that correlated significantly with each other were narrowed down to a single metric. NMDS ordination and PCA was then utilized to assess which physical parameters and biotic metrics explained the taxonomic composition of site collections. Stable sites (Stages I and VI) had communities with lower average tolerance values, a low percentage of intolerant organisms and a greater proportion of the intolerant EPT (Epheroptera, Plecoptera and Trichoptera). Unstable sites had higher tolerance

values, a greater percentage of tolerant organisms, such as Chironomids and annelids, and contained a minimum of the intolerant EPT taxa. A modification to the standard percentage EPT metric (Barbour 1999) during our study discriminated site stability with greater clarity as it was calculated without the tolerant Hydropsychidae and *Baetis* taxa. The community structures at unstable sites generally had an EPT makeup that was almost solely tolerant organisms while stable sites had fewer of these organisms (Figure 2).

Ordination of the sample taxa differentiated the stable from unstable sites. NMDS of the species compositions demonstrates the degree of taxa similarity between sites, which are overlapped by their associated modified EPT for that sample (Figure 3). The PCA had 86% of the variation in the macoinvertebrate community explained by a few of the biological metrics and geomorphic variables. In particular, the CSI and D_{50} were strongly influential as reach-scale indicators of water quality and significant trends with biological samples. This supports the premise that monitoring strategies which link stream geomorphic variables and biological data will serve to better direct water quality management.

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Table 1. Watershed land use and reach-scale geomorphic characteristics for study sites. Stages of Channel Evolution in bold are designated as stable channel reaches in regards to channel and geomorphic process (Simon 1989).

Site	River / Stream	Drainage area (km2)	% Agriculture	% Urban	% Forest	Mean RBP Habitat Score	Stage Channel Evolution	Channel Stability Index	% Fines < 2 mm	D_{50} (mm)
G	Cahaba	8.7	1	5	88	186	VI	13.0	5.0	40
H	Cahaba	34.7	15	15	69	177	I	6.0	3.0	82
L	Little Cahaba	37.1	13	13	73	172	VI	8.5	13.9	68
C	Cahaba	50.5	2	58	39	136	V	15.5	23.0	23
M	Shades	40.7	0	80	18	131	V	15.5	17.5	27
S	Shades	69.6	0	69	31	124	V	16.0	18.0	39
P	Patton	9.0	0	75	25	104	V	16.5	29.0	12
V	Valley	131.0	2	78	20	89	V	17.0	4.0	36
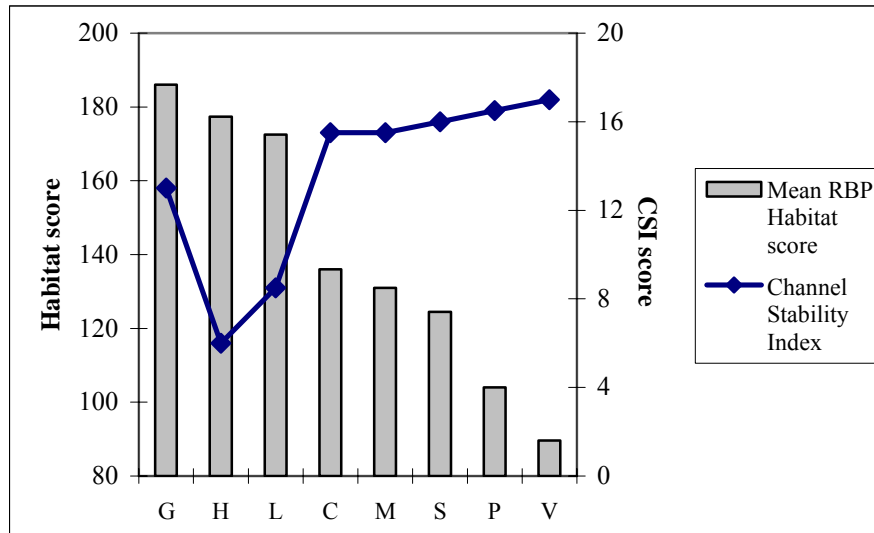
Figure 1. The mean habitat score derived by the EPA's rapid bioassessment protocol (RBP) compared to the channel stability index (CSI) score for all sites. The RBP range for an optimal habitat is > 166; the stable sites are G, H, and L, while (C), (M), (S), (P) and (V) are unstable geomorphically.
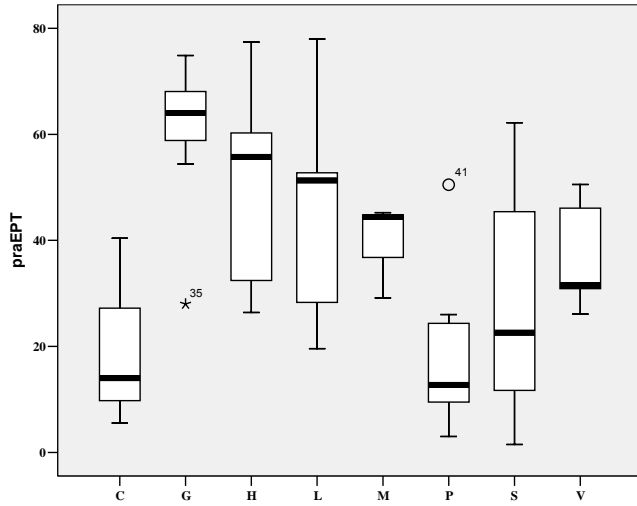
Figure 2. Boxlots: (Left) the percent relative abundance for Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa for all sites during 3 years of collection. (Right) The modified percentage of EPT (mod EPT) calculated without the tolerant Hydropsychidae and _Baetis_ taxa to illustrate proportion of the EPT that are particularly tolerant to sedimentation at all sites.
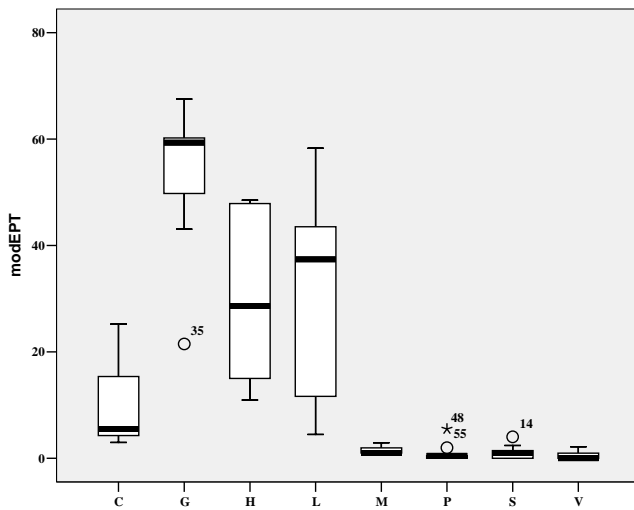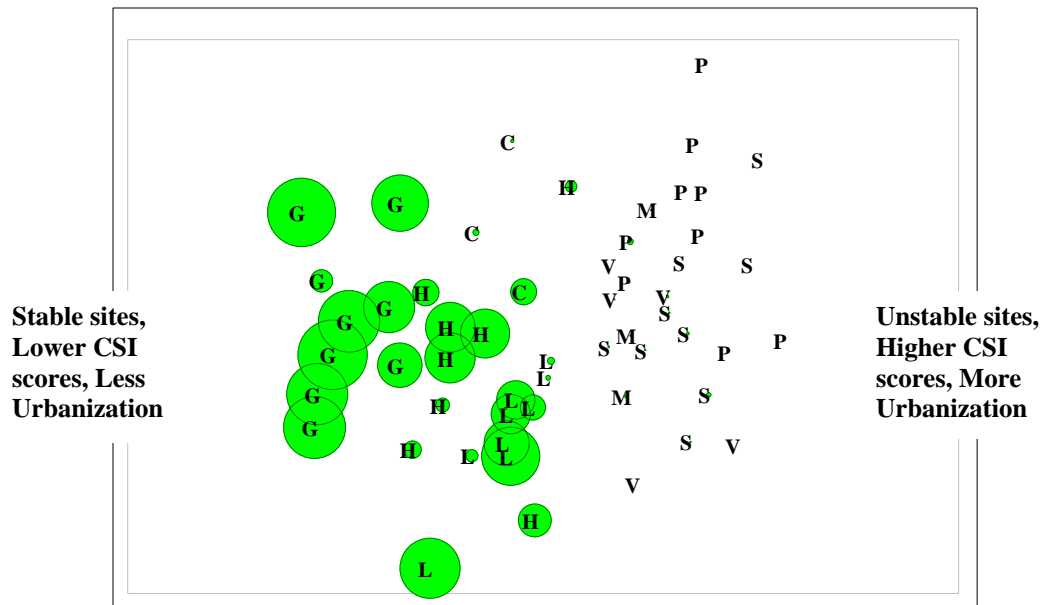
Figure 3. Ordination of all sites by taxonomic composition using nonmetric multidimensional scaling (NMDS). Site proximities represent similarity as determined by a Bray-Curtis similarity matrix; conversely, distance between sites indicates dissimilarity. Bubbles overlapping sites represent proportionally the modified EPT percentage for that sample. Sites G, H and L have either a Stage I or VI ranking (Simon 1989) and are considered stable. Site C, which is downstream of G and H on the mainstem of the Cahaba and below a marked urbanization increase, indicates a decline in water quality has occurred.

SESSION 1B

POLICIES FOR BMPs
3:30 p.m. – 5:00 p.m.

Improving Potassium Management to Reduce Non Point Phosphorus Losses and Improve Water Quality
Forbes Walker

Metro Nashville & Davidson County's MS4 Erosion Prevention and Sediment Control (EPSC) Grading Permit (GP) Program
Michael Hunt

The Use of Best Management Practices (BMPs) During Forest Harvesting in Tennessee: A Statewide Evaluation
Wayne K. Clatterbuck

IMPROVING POTASSIUM MANAGEMENT TO REDUCE NON POINT PHOSPHORUS LOSSES AND IMPROVE WATER QUALITY

Forbes Walker[1]

ABSTRACT

Many farmers apply animal manures, poultry litter and biosolids at rates that meet the recommended nitrogen needs of their crops or forages. In Tennessee, much of the poultry litter and dairy manure is being land applied on pastures, hay fields or forage crops. When poultry litter is land applied on pastures or hay fields to supply nitrogen needs, phosphorus and potassium applications greatly exceed requirements. The over application of phosphorus can potentially serious impacts on water quality, but there is little if any economic incentive to farmers to reduce application rates for phosphorus. The University of Tennessee Extension message is now to focus on potassium as a means to reduce phosphorus applications and reduce potential water quality impacts. While the over application of potassium is not considered to have an environmental impact, it has been long known that the over application of potassium stimulates "luxury" uptake by plants. Luxury uptake of potassium in Tennessee has been observed to not only produce widespread mineral imbalances in forages and copper deficiencies, but to seriously affect the health of cattle. These results suggest that there are strong economic reasons for farmers reduce animal manure, poultry litter and biosolid application rates on forage crops, pastures, and hay fields to levels that do not over apply potassium. The application of these materials at potassium rates will greatly reduce to amount of phosphorus being over applied and thus improve water quality.

INTRODUCTION

There is emerging evidence that Tennessee farmers do have an economic price to pay for the application of higher rates of animal manures and poultry litter on pastures and forage crops based on the over-application of potassium (K). Traditionally animal manures and poultry litters were considered to be excellent sources of plant nutrients. Manures and litters are complete but imbalanced fertilizers and relative to crop requirements, contain more phosphorus (P) and K than nitrogen (N) (Table 1).

Table 1. Typical Nutrient Values of Different Animal Manures and Poultry Litters (Tennessee Natural Resources Conservation Service, Conservation Practice Standard. Nutrient Management. Code 590)

Manure Type	Nutrient Content (lbs per ton)		
	Total Nitrogen*	Phosphorus (as P_2O_5)	Potassium (as K_2O)
Fresh Dairy Manure	7	3	6
Stockpiled Dairy Manure	7	9	10
Broiler Litter (with shavings)	50	54	36
Fresh swine manure (no dilution)	9	8	10

* With volatilization losses, plant available nitrogen will be approximately 50 percent of total nitrogen.

Farmers with a surplus or an inexpensive source of animal manures or poultry litter have had a tendency to apply manure or litter at the higher rates needed to supply all the crop N needs.

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Farmers who supply all crop nutrient needs from animal manures and poultry litter will over-apply P and K. On fields adjacent to surface water the over-application of P will result in an increased risk of P in runoff and will increase the risk of water quality impairments. Until recently there has been little, if any, economic incentive to apply the manure or litter at the lower rates needed to supply the crop P or K needs and to supply the balance of the N needs with a commercial fertilizer. The excess P that is applied to the field does not have any economic impact on crop production, and any environmental impacts from P lost in runoff are usually not evident to the farmer. When all the plant nutrient needs are supplied with poultry litter, the potential for over-application of P and K is high. For example, a farmer applying broiler litter to supply the N needs for a fescue pasture (with an analysis similar to Table 1) will over apply P (as P_2O_5) by 167, 197 and 227 lbs. per acre for low, medium and high testing soils (respectively) and over apply K (as K_2O) by 91, 121 and 151 lbs. per acre for low, medium and high testing soils (respectively).

New regulations in Tennessee will have some impact in reducing the rates of animal manures and poultry litter being applied on farms that will be required to apply for and implement the new concentrated animal feeding operation (CAFO) permit requirements. For farms that do not fall under the new CAFO permit requirements a voluntary approach to reducing manure and litter application rates is needed. Success in reducing manure and litter application rates will be greatest if farmers have an economic incentive to reduce application rates. Work conducted by the University of Tennessee Extension in recent years has emphasized the importance of good soil potassium (K) management. There are good animal health reasons and thus strong economic incentives for beef and diary farmers not to over-fertilize pastures, hay and forage crops with K.

As farmers gain a better appreciation of the animal health, and thus economic, importance of not over applying K from animal manures and poultry litters, then amount of excess P that is land applied on Tennessee pastures and forage crops will also be reduced.

TENNESSEE ANIMAL MANURE AND POULTRY LITTER REGULATIONS

Reductions in the over-application of manure and litter phosphorus have been achieved by regulations. In Tennessee current regulations require that livestock operations meeting certain size and location criteria are required to apply for general or individuals CAFO permits. An important part of complying with the CAFO permitting process is the development and implementation of nutrient management plans. Under the current Tennessee CAFO regulations, the determination of the rates at which animal manures or poultry litters can be applied depends on the crop and the soil test recommendations from the University of Tennessee Extension soil test laboratory in Nashville. On fields with soil P sufficient for crop needs, no further additional P is recommended and nutrient management planners are required to assess the potential for P loss using the Tennessee P Index[2]. Manure and litter applications at the higher nitrogen rates are permissible on those fields that are assessed to have low or medium risk for P loss. For those fields with a high or very high risk of P loss, P applications cannot exceed the crop removal rates of P. For fields where the soil test results recommend additional P, manure and litter application rates can be based on crop N needs.

In many situations, under the current regulations farmers can apply poultry litter at rates that meet pasture and forage crop N demands (over 4 tons per acre for many poultry litters). As a long-term strategy repeated high applications of poultry litter would not be advised. There are concerns about the implications for forage quality due to over-application of K.

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2 http://www.state.tn.us/environment/wpc/programs/cafo/CAFO_GP_04.pdf

SOIL POTASSIUM MANAGEMENT

Potassium (K) is not considered to have an environmental or water quality impact, so there is little or no mention of the importance of manure potassium management in CAFO regulations. It has been long known that the over application of K stimulates "luxury" uptake by plants. Farmers who over-fertilize with K will reduce their potential profits by incurring the extra expense of the unnecessary K fertilizer. Plants with access to more soil K than is needed for growth will take-up the excess. For most crops this does not pose any plant or animal health problems. Luxury uptake of K in forages and hay crops can have serious consequences on the mineral balance and can have serious and sometimes fatal impacts on animal health. Recent forage quality surveys conducted on farms by the University of Tennessee Extension have shown that the problem of the luxury uptake of K in Tennessee is widespread across the state. In addition to mineral imbalances, excess K uptake has an antagonistic impact on copper uptake resulting in widespread copper deficiencies. The surveys also reported high sulfur levels and low magnesium and zinc levels. The symptoms reported by cattle producers include rough, discolored hair costs, decreased breeding efficiency, bone and hoof problems and depressed immune system function[3].

RECOMMENDED BROILER LITTER RATES FOR FESCUE IN TENNESSEE

There is a need for Tennessee cattle producers to more closely monitor soil fertility levels on the approximately 5 million acres of forage being produced in the state. The most common type of forage grown in Tennessee is tall fescue with between 3 and 3.5 million acres (Neel, 2004[4]). Most fescue production is in areas where farmers have access to poultry litter. Based on the current University of Tennessee Extension fertilizer recommendations for fescue (Savoy and Joines, 1998[5]) and the average K content of broiler litter (Table 1) rates of poultry litter should not be exceed 2 tons for low K testing soils and 1 ton for medium K testing soils. It is not recommended that poultry litter be applied on fescue pastures that test high or very high in K. In most cases the application of these rates of poultry litter will meet the P demands of the pasture and forage crop. Gaps in the recommended rates of N should be met with commercial N fertilizer.

If farmers follow these recommendations forage quality will remain with the acceptable ranges. The use of lower K based rates of poultry litter application will have the added environmental and water quality benefits of reducing the over-application of P.

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3 http://animalscience.ag.utk.edu/beef/pdf/Mineral%20Survey%20Report.PDF

4 Neel, J. B. 2004. The Tennessee Cattle Industry and the Master Beef Producer Program. In Tennessee Master Beef Producer Manual. University of Tennessee Extension. PB 1722.

5 Savoy, H. J and D. Joines. 1998. Lime and Fertilizer Recommendations for the Various Crops of Tennessee. University of Tennessee Extension. P & SS Info. # 185.

METRO NASHVILLE & DAVIDSON COUNTY'S MS4 EROSION PREVENTION AND SEDIMENT CONTROL (EPSC) GRADING PERMIT (GP) PROGRAM

Michael Hunt*[1]

INTRODUCTION

On June 30, 1996, the Metropolitan Government of Nashville/Davidson County received a Municipal Separate Storm Sewer System (MS4) NPDES permit from the Tennessee Department of Environment and Conservation (TDEC), making Metro responsible for eliminating contaminates from entering "waters of the State" via the stormwater drainage system. Part of these permit requirements include implementing a program whereby EPSC measures on construction sites within Metro are appropriate, installed correctly, and are continually inspected and maintained so as to reduce sediment loss and/or water pollution. As part of the April 1, 2002 migration of Stormwater staff/activities from Metro Public Works to Metro Water Services (MWS), personnel from the MWS NPDES Office (Water Quality) began performing Metro EPSC oversight/enforcement activities. After conducting these inspections for several weeks, Water Quality staff generally found EPSC deficient (sometimes non-existent) and "no disturb" buffers being encroachmented upon at some sites. Given the regulatory issues involved and detrimental impact on waterways that such noncompliance creates, it was determined that measures had to be undertaken to improve EPSC measures and the maintaining of buffers on construction sites. These measures, which were implemented on June 1, 2002, included: that; each site will have a designated EPSC Professional; each site will attend a Pre Construction (Pre Con) meeting to discuss the various EPSC, etc. issues present at the site prior to being issued a Grading Permit; each site will install site EPSC measures prior to receiving a Grading Permit (with the Grading Permit to be issued after Metro inspects the site's EPSC and deems it acceptable); and sites that do not adequately install and maintain proper EPSC measures, as well as those that do not observe applicable "no disturb" stream buffers will be issued Notices of Violation (NOVs), Stop Work Orders (SWOs), Administrative Penalties, or taken to Metro Environmental Court.

APPROACH

The following letter from MWS Stormwater Division communicating EPSC-related policy changes was disseminated to the development community, public, etc. on June 1, 2002.

> As you may already be aware, the Stormwater Division of the Metro Department of Public Works has recently been realigned/relocated into the Metro Department of Water Services. With this realignment has come the opportunity to re-evaluate and restructure certain procedures that have been considered in need of added attention. This letter shall serve to inform and familiarize the developer/contractor/builder (DCB) of the new Metro Water Services procedures which are being implemented in an effort to strengthen and streamline the Metro development regulatory process, specifically as it pertains to the issuance and oversight of Metro Grading Permits. It shall also serve to reacquaint the DCB with certain provisions within the Metro Stormwater Management Manual (SWMM) that have been determined to be in need of additional attention and focus. These are provisions aimed largely at protecting the physical integrity of streams and rivers as well as overall water quality from the impacts of development. This letter pertains

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to disturbance/development work being done within "Metro" Davidson County and covers initial proposed plan submittal, the issuance of a grading permit, and compliance oversight through the completion of each respective development project.

It is important to note the reasons for this shift in focus. First, it is part of Metro's initiative (started April 1, 2002) to maximize the effectiveness and efficiency of its Stormwater Management Program, a large part of which deals with Metro's Grading Permit program. Second, it has never been more important from a Federal, State, and Local regulatory perspective to halt the excessive loss of sediment and other contaminates from construction/development sites. Currently, sediment contamination of our streams and rivers is considered to be the number one water quality issue in Tennessee. Relatedly, some local streams are considered by the Tennessee Department of Environment and Conservation (TDEC) to not be meeting their "designated uses" (use classifications) due to in-stream sediment levels. Third, sediment loss from development sites impacts downstream conveyances and neighbors by reducing stream flow capacities, which can in turn serve to increase the number of areas that are prone to flooding impacts.

Volume I, section 2.2 of the Metro SWMM gives Metro the authority to require an erosion prevention and sediment control (EPSC) professional to be on-site to act as an EPSC supervisor. *Starting June 1, 2002, every development project requiring a Metro grading permit shall be required to designate/attain the services of an individual which has been certified via the ongoing TDEC Water Pollution Control Erosion Prevention and Sediment Control training class* (applications and information for the next scheduled class are enclosed). This designation shall be noted on the Grading, Draining, and Erosion Control Plan. The EPSC professional (or their designee) shall be responsible for:
1) Physically investigating the potential development site prior to any clearing, grubbing, grading, etc. in order to identify potential issues/conflicts with waters of the State/community waters. If this individual detects any tributaries, springs, sinkholes, wetlands, etc. he or she must contact TDEC and be granted any necessary permissions (ARAP, etc.) for the alteration of these features before the initial placement of EPSC best management practices (BMPs). Note: Using a USGS topographical map as the sole source of reference when making these delineations will not satisfy this requirement.
2) Developing and implementing an effective Stormwater Pollution Prevention Plan (SWPPP). This plan should include strategies that will facilitate the ongoing improvement of any site BMPs that are not working effectively based on routine site evaluations.
3) Overseeing the installation of all EPSC BMPs in order to not only insure that they are installed to plan specifications, but to verify effectiveness through the duration of the project. Section 6.10.8 of the SWMM covers "Deficient Performance" and gives Metro the authority to issue a Stop Work Order (SWO) or rescind a grading permit if this provision is not met.
4) Overseeing the installation and placement of boundary markers (or any EPSC used as boundary markers) to insure that the applicable buffer zone has not been encroached upon or disturbed in any way.

5) Remaining available through the duration of the project to facilitate and oversee any changes that (per Metro) need to be implemented and incorporated into the site's SWPPP.

6) Signing the Grading, Draining, and Erosion Control Plan, stating that these provisions have been and will continue to be met through the duration of the project.

Upon completion of the installation of all EPSC BMPs, the DCB shall schedule an EPSC inspection with Metro Water Services. If, during the inspection, it is determined that minimum EPSC standards have not been met, the DCB shall be required to bring them up to standard and repeat the process.

Once the EPSC BMPs have been approved, the developer/builder/contractor shall be required to attend a pre-construction meeting at the Water Services Administration Building (1600 2nd Ave N) [(Note: This meeting location has since been changed to 1607 County Hospital Road at Water Quality Staff offices)]. There, the DCB must demonstrate that all applicable permits have been obtained through both Metro and the State of Tennessee/TDEC (as required of Metro via permit by the State). At this time, if the DCB has any outstanding issues/violations with Metro or TDEC, resolutions will be discussed.

[(Note: This process was subsequently modified so as to hold the Pre Con meeting prior to the installation of any site EPSC measures (as discussion of EPSC was found to be better conducted at a Pre Con meeting before EPSC installation was initiated).]

When all provisions of this letter have been met, the DCB shall be issued a grading permit. If subsequent EPSC issues are found to exist on a site, Metro reserves the authority to issue an enforcement action at any time, during any phase, of the project.

In summation, the developer/builder/contractor shall be responsible and held accountable for:
·Having on staff, an individual who has been "certified" via the ongoing TDEC Water Pollution Control EPSC Workshop.
·Identification of site features deemed "waters of the State" and the obtaining of any required Federal and/or State permits prior to the initiation of the project.
·Developing and maintaining an effective SWPPP.
·Overseeing the proper placement of BMPs and assuring effectiveness through the duration of the project (start to finish).
·Signing the Grading, Draining, and Erosion Control Plan.
If you have any questions pertaining to this letter please contact the Metro Water Services NPDES Office at (615) 880-2420.

The following steps (available at http://www.nashville.gov/stormwater/ images/gp_issuance.jpg) depict the current Metro Grading Permit process.
1. Grading permit application submitted to Metro by the applicant (stamped set of engineering plans of the development) outlining Stormwater-related calculations, EPSC, and floodway/floodplain considerations.

2. Application/Plans tentatively approved by MWS plans review engineers.
3. "Pre Con" meeting scheduled/held (which includes Water Quality staff, other Metro Departments, and site representatives to include their EPSC professional)
4. After "Pre Con," applicant receives letter authorizing installation of approved site EPSC measures.
5. Water Quality staff inspects site EPSC measures upon request of applicant. Grading Permit is issued on site if the site EPSC passes the inspection.

RESULTS AND DISCUSSION (JUNE 1, 2002 THROUGH JANUARY 1, 2005)

# of Grading Permit Pre-Construction Meetings held:	726
# of Grading Permits Issued:	654
Notices of Violations Issued:	272
Stop Work Orders Issued:	147
# of EPSC Inspections:	9,207
# of MS4 Infrastructure Inspections:	8,874

CONCLUSION

This initiative has served to increase both the awareness and implementation of EPSC practices on the various land development projects within Metro Nashville/Davidson County. It has also served to educate other Metro Departments regarding the importance of EPSC and stormwater management issues in general. Addtionally, there have been peripheral benefits to Metro with the establishment of a "Pre Con" meeting such as insuring that all other Metro permits and approvals have been secured prior to allowing land disturbance to commence at a site (such as traffic-related approvals, urban forestry, and Planning requirements).

As with any ongoing process, Metro Stormwater continually considers how to improve it's EPSC/Grading Permit program (for both Metro and its Development Community). Toward that end, Metro Stormwater is currently facilitating a series of Stakeholder meetings to modify existing Metro Stormwater Management regulations (to include EPSC and Grading Permit considerations) to make the associated processes more effective/efficient and to update overall Stormwater Management strategies to be consistent with other successful Municipal Stormwater programs across the country. These revisions will hopefully be implemented on or around July 1, 2005.

THE USE OF BEST MANAGEMENT PRACTICES (BMPS) DURING FOREST HARVESTING IN TENNESSEE: A STATEWIDE EVALUATION

Wayne K. Clatterbuck[1]

Abstract: An evaluation of forestry BMP implementation in Tennessee was conducted by the University of Tennessee, Dept. of Forestry, Wildlife & Fisheries and the Tennessee Dept. of Agriculture, Division of Forestry in 2003. A total of 215 harvest sites stratified among five regions statewide were evaluated in terms of haul roads, skid trails, log landings, streamside management zones (SMZs) and stream crossings. Ninety five percent of the BMP observations did not have any potential water quality threats, while 82 percent of the observations had BMPs correctly implemented. The difference between 95 and 82 percent (13 percent) came in areas where BMPs were not applied or incorrectly applied, but were not water quality threats. The West region had the greatest occurrence of potential water quality threats or cases where BMPs were applied incorrectly or not at all. Stream crossings and skid trails were the greatest sources of potential water quality threats. Conversely, stream crossings were avoided or not present on two-thirds of the sampled harvest sites indicating that loggers were making an effort to stay away from waterways. Precipitation from 2001-2003 in Tennessee was above normal, and excessively so (averaging 10+ inches above normal) for west Tennessee. This BMP evaluation and study was conducted during a period of wet weather.

INTRODUCTION

Forestry Best Management Practices (BMPs) have been established in Tennessee since 1989 (TN Dept. of Conservation, 1989; TN Dept. of Agriculture, 1993; 2003). More than 2,100 loggers and natural resource professionals have been trained in the use of BMPs through the Tennessee Master Logger Program (Clatterbuck and Hopper, 1996). Although informal field surveys have been conducted to observe whether BMPs are being utilized during harvesting operations, these surveys yield little information in evaluating the application of BMPs without the proper study design and statistics. The purpose of this study was to conduct an evaluation of BMP implementation rates and effectiveness in Tennessee through a statistically sound, experimental research approach.

STUDY DESIGN

Sample size, or the number of harvest sites evaluated, was determined for statistical validity (Cochran and Cox, 1957). For a test of significance at the 5% level and a probability of 90%, the smallest plausible sample size was 98. A sample size of 215 sites was used so there was adequate harvest representation of each Forest Inventory & Analysis (FIA) region (Schweitzer, 2000).

For each of the five FIA regions (East, Plateau, Central, West-Central and West) in Tennessee, we determined the amount of timber harvested (Schweitzer, 2000), and stratified the number of sample points (harvest sites) by the proportion of timber harvested. Thus, more plots were in regions where more timber was harvested, and vice versa, fewer plots in regions where less timber was harvested (Table 1).

The State was divided into 4 mile by 7 mile grids. One grid is roughly the size of half of a 7 ½ minute topographic map. Statewide, we had 1,445 grids. Grids that were not at least 50% forested through aerial (satellite or photographs) interpretation were discarded. Forested grids were numbered and catalogued by FIA region and put together in a computer database. Grids for sample harvest sites were selected by FIA region by a computer random generator. Thus, if a

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region had a proposed sample size of 35 plots, we used the first 35 forested grids selected by the generator.

Grids were visited to locate a harvest site. If a grid had two or more harvest sites, we evaluated the first harvest site found. If a harvest site was not found in a grid, that grid was omitted and another grid (next in order) was added from the computer generator selection. The only data taken at this time were Global Positioning System (GPS) coordinates of the site and location directions.

The harvest site was visited by an evaluator to judge BMP implementation on a 1 to 5 scale (Table 2). Five variables of the harvest site were evaluated: haul roads, skid trails, log landings, streamside management zones (SMZs) and water crossings. A sliding scale was used to determine the degree of BMP implementation. Not every site had all 5 variables. If a harvest site was on the side of a road, haul roads were probably not present. If the harvest site was not near water, SMZs and stream crossings were not valid variables.

Great care was taken to make sure that the selection of evaluated harvest sites statewide was not biased. The evaluators did not know about the harvest sites until those locations were sent to them.

Training of Evaluators

Two Tennessee Dept. of Agriculture, Forestry Division district employees (non-foresters) were selected from each district to be the BMP evaluators (12 evaluators total). In January 2003, evaluators attended a two-day training session to learn to assess the harvest sites according to the protocols established in the study. Several sites were evaluated as a group activity and then each evaluator visited two sites on his own to conduct his own independent evaluation. Protocols included:

a. Five variables and the 1 to 5 rating scale (Table 2),
b. Harvest had to be at least 5 acres,
c. Land must remain in forest designation, i.e., harvest for changing land
d. use ---- development, agriculture, etc. would not be included in the study,
e. If land was posted or landowners did not want their harvest evaluated,
f. evaluators were urged to omit that site and go to the next site,
g. Harvest must be completed, i.e., loggers had left the site, and
h. Harvest took place since January 2001.

If an evaluator had some prior knowledge about a logging site he was assigned to visit, he was urged to give that site to another evaluator to maintain objectivity during the evaluation process. Although we would have preferred only 2 or 3 evaluators statewide to ensure consistency in BMP evaluation, we did not have the resources (travel, time, labor) to have this luxury. We were well satisfied with the dedication and consistency of the 12 evaluators as judged by their evaluation sheets. They took their judgments seriously and gave good written notes about the logging sites.

RESULTS AND DISCUSSION

Statewide

A potential of 1,075 observations (5 BMP variables x 215 sites) was possible. However, 268 observations were not taken (SMZs, water crossings, etc. were not applicable to the site) leaving 807 total observations (Table 3). Thirty eight observations (4.8%) received a numerical rating of 1, which was considered a water quality threat, indicating that 95.2% of all observations did not pose a water quality threat.

One hundred forty six of the observations received a numerical rating of 1 or 2 (Table 3) indicating that 82% of the observations had BMPs applied. The difference between 95 and 82 percent (13 percent) were areas where BMPs were not applied or incorrectly applied, but were not water quality threats.

All means for the five BMP variables are in the 3 to 4 range on a scale of 1 to 5 (Table 3). Log landings had the highest mean score (3.88), while skid trails and stream crossings had the lowest scores (3.16 and 3.15 respectively) suggesting that more intensive logger training is needed for BMPs on skid trails and stream crossings.

Stream crossings had the lowest number of observations (69 of a potential of 215) indicating that loggers are avoiding stream crossings, designing timber sales where streams are not crossed, or the site harvested did not have a stream. However, this variable had the largest percentage of 1 and 2 ratings (30%) (Table 3). Of the five BMP variables, stream crossings had the greatest number of sites with a 1 rating (potential water quality threat), even though this variable had the least number of observations.

The skid trail variable was ranked as the second greatest variable with 26% of its observations with a rating of 1 or 2, followed by haul roads (19%), SMZs (15%) and log landings (7%) (Table 3).

Regions

Table 4 shows the mean BMP rating data by FIA region. The West region had the greatest number of observations with values of either 1 or 2. Mean values ranged from a low of 1.9 for stream crossings (the lowest mean value of any BMP variable in any region) to a high of 3.3 for log landings. Four of the five variables in the West region had mean values less than 3.0, the only values below 3.0 in the study. Presumably, the highly erosive Coastal Plain or Alluvial Plain soils make this region more susceptible to potential water quality problems associated with all the BMP variables than those soils in Middle and East Tennessee that have a higher component of rock in their soil profile.

The Plateau region followed the West region with the second most observations with a value of 1 or 2. Most of these values were in the skid trail and haul road observations. However, the means for each of the variables were above a value of 3.

Precipitation Data

Annual precipitation data by selected climatological sites for East, Middle and West Tennessee were summarized for 2001-2003 from published National Oceanic and Atmospheric Administration (NOAA) weather data.

For 2001, West TN had excessive, above normal amounts of precipitation, normal amounts of precipitation in East and Middle TN, and slight deficits on the Cumberland Plateau. For 2002, excessive precipitation (greater than 10 inches above normal) was recorded in West TN, with the remaining areas (East, Middle and Plateau) averaging about 5 inches above normal. For 2003, precipitation in all regions of Tennessee was well-above normal. In West and Middle TN, 2003 was within the top five years of greatest rainfall since the 1940s.

Thus, considering the 2001-2003 precipitation data, this study and the BMP evaluations were conducted during a period of higher than normal rainfall.

FUTURE EVALUATIONS

The greatest potential statewide improvement in the application of BMPs during forest harvesting operations is with stream crossings and skid trails. Future continuing education training in the Tennessee Master Logger Program will focus in these areas. These BMP data are currently being partitioned by landowner type (public, industry, private), trained or untrained logger, whether a forester was involved with the harvest, and by wood dealer to determine the demographics where BMPs are being implemented. We plan to conduct this evaluation every three years to track progress in future BMP implementation.

ACKNOWLEDGEMENTS

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Table 1. Stratification of Harvest Sites by Forest Inventory and Analysis (FIA)
Region in Tennessee Based on the Amount of Timber Harvested
(Schweitzer, 2000) for the Tennessee Best Management Practice (BMP) Study, 2004.

Region	Harvested Acres	Percent	# of Desired Sites	Actual Sample Sites
	---thousand acres---			
East	35.8	16.0	32	36
Plateau	47.3	21.1	42	47
Central	39.2	17.5	35	38
West Central	56.5	25.1	50	51
West	45.5	20.3	41	43
Total	224.3	100.0	200	215

Table 2. Explanation of Rating System for Harvest Areas, Tennessee Best Management Practices (BMP) Study, 2004 (modified from Davis and Clatterbuck, 2003).

Score	Haul Road	Skid Trail	Log Deck	SMZ	Water Crossing
1	A threat to water quality Induced	A threat to water quality induced	A threat to water quality Induced	A threat to water quality Induced	A threat to water quality induced
2	ASAs[1] Rock Used	ASAs Washout Visible Rutting Visible	Deck not level, Drainage from Deck Present *and* Garbage or Oil Present	SMZ too Thin for Slope Insufficient BA[2] Tops or Slash in Stream	Runoff diverted from the water body Crossing structure[3] used, but inadequate
3	ASAs Rock Used Waterbars *or* Turnouts *or* BBDs[4]	ASAs *NO* Washout *NO* Rutting	Deck not level *or* Garbage or Oil Present	2 of the above 3	Appropriate crossing structure used Crossing is perpendicular Rock Used Waterbars *or* Turnouts *or* BBDs
4	ASAs Rock Used Waterbars *and* Turnouts *and* BBDs	ASAs *NO* Washout *or* Rutting Waterbars *and* Turnarounds	Sufficient Distance from Water *and* Deck level *NO* Garbage or Oil *NO* Drainage	1 of the above 3 *example: tops in stream*	Appropriate crossing structure used Crossing is perpendicular Rock Used Waterbars *and* Turnouts *and* BBDs
5	ASAs Rock Used Waterbars *and* Turnouts *and* BBDs Revegetation of Road Surface	ASAs *NO* Washout *or* Rutting Waterbars *and* Turnouts Revegetation of Surface	Sufficient Distance from Water *and* Deck level *NO* Garbage or Oil *NO* Drainage Revegetation of Road Surface	SMZ Width Sufficient Sufficient BA *NO* Tops or Slash in Stream *NO* Streamflow Restriction	Appropriate crossing structure used Crossing is perpendicular Rock Used Waterbars *and* Turnouts *and* BBDs Revegetation of Approaches

[2] 60-70 Sq. Ft./Acre for Perennial Streams and 40-50 Sq. Ft./Acre for Intermittent Streams
[3] Bridges, Culverts, Fords,
[4] Broad Based Dips

Table 3. Best Management Practice (BMP) Statewide Data for the Tennessee BMP Study, 2004.

Stream Crossings	Hail Roads	Skid Roads	Log Landings	SMZs[1]	
# of Observations with a 1 Rating	7	11	6	6	9
# of Observations with a 2 Rating	28	44	9	15	11
# of Remaining Observations	144	154	197	117	49
Subtotal --- Actual Observations	179	209	212	138	69
# of non-Applicable Observations	36	6	3	77	146
Total Potential Observations	215	215	215	215	215
Mean	3.45	3.15	3.88	3.74	3.16
Standard Deviation	1.04	1.02	0.88	1.11	1.24

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[1] Streamside Management Zone

Table 4. Best Management Practice (BMP) Data by Region for the Tennessee BMP Study, 2004.

Stream Crossings	Hail Roads	Skid Roads	Log Landings	SMZs[1]	
East Region (n=36)					
# of Observations with a 1or 2 Rating	3	4	2	5	2
Total # of Observations	33	36	36	22	14
Mean	3.9	3.75	4.0	3.6	3.6
Standard Deviation	1.0	0.9	0.9	1.2	1.0
Plateau Region (n=47)					
# of Observations with a 1or 2 Rating	7	9	2	2	5
Total # of Observations	43	45	46	39	20
Mean	3.7	3.5	4.1	4.2	3.4
Standard Deviation	1.1	1.1	0.8	0.9	1.4
Central Region (n=38)					
# of Observations with a 1or 2 Rating	6	6	0	2	3
Total # of Observations	26	35	36	23	8
Mean	3.4	3.1	4.1	4.1	3.1
Standard Deviation	1.0	0.7	0.55	0.9	1.1
West Central Region (n=51)					
# of Observations with a 1or 2 Rating	5	9	1	0	1
Total # of Observations	42	50	51	26	15
Mean	3.4	3.2	3.9	3.9	3.3
Standard Deviation	0.7	0.7	0.85	0.6	0.6
West Region (n=43)					
# of Observations with a 1or 2 Rating	14	27	10	12	9
Total # of Observations	35	43	43	28	12

Mean	2.8	2.3	3.3	2.7	1.9
Standard Deviation	1.1	1.0	1.2	1.2	
1.2					

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[1] Streamside Management Zo

SESSION 1C

SURFACE WATER QUALITY I
3:30 p.m. – 5:00 p.m.

Storm Event Water Quality in the Great Smoky Mountains National Park
R. Bruce Robinson, J. Chadwick Roby, John Buchanan, Thomas Barnett and Stephen E. Moore

Facilitated Transport of Triclosan in the Receiving Environment of an Onsite Wastewater Treatment System: Cause for Aquatic Concern
Adrienne Roach, John Buchanan, Mark Radosevich and Jaehoon Lee

Development of a Transducer Network in an Urban Environment
Jerry Lee Anderson

STORM EVENT WATER QUALITY IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

R. Bruce Robinson[1*], J. Chadwick Roby, John Buchanan,
Thomas Barnett, and Stephen E. Moore

INTRODUCTION

The Great Smoky Mountains National Park (GRSM) receives some of highest rates of acid deposition in the U.S. (Johnson and Lindberg, 1992). Acid deposition in the GRSM is already suspected to have caused fish loss in multiple stream reaches. However, the current water quality monitoring does not monitor the worst water quality because the monitoring focuses on baseline conditions via grab samples. Baseline water quality data are critically important and do show worrisome trends. But baseline data are hydro-logically biased against storm events that should have much worse water quality.

The recent decision to rebuild a short road in the GRSM has offered an opportunity to collect additional storm water data. The GRSM management's concern is that the road construction have no long term impacts on the stream which is a headwater stream designated as an Outstanding National Resource Water (ONRW). As a result, GRSM management has required that the stream paralleling the road construction be monitored before, during and after construction with special attention to storm events.

METHODOLOGY

Monitoring stations were installed downstream (site 1 – 1370 ft elevation), in the middle (site 2 – 1514 ft), and upstream (site 3 – 1700 ft) of the planned road reconstruction and consisted of a YSI multi-parameter monitor (also called a sonde and takes 15-minute data on pH, turbidity, conductivity, temperature, and stage), an Isco auto-sampler triggered by sonde stage, and bi-monthly grab samples. A fourth sonde (site 4 – 2800 ft) without a turbidimeter was installed farther up the watershed in a stream reach with no fish. There were also two tipping bucket rain gauges in the watershed plus an open bucket wet precipitation and dry deposition collector and a sequential precipitation collector. All samples were analyzed for pH, acid neutralizing capacity (ANC), conductivity, Ca, Mg, Na, K, Cu, Zn, Fe, Mn, Si, Al, SO_4^{2-}, NO_3^-, and Cl^-.

RESULTS AND DISCUSSION

Figure 1 shows an example of the sonde data for site 2. The figure shows pH, stage, and turbidity vs date. Note the mirror images of stage and pH, i.e., as the stage rises during storm events, the pH drops. Turbidity also rises significantly during storm events and exceeds 1000 NTU in some cases. Interestingly, there is a very consistent initial short spike upwards in pH for nearly all storm events. Note also that the pH drops from a mean of about 6.5 to as low as 5.0. Sites 1 and 3 were similar to site 2 except that site 3 stream pH was about 0.2 units lower.

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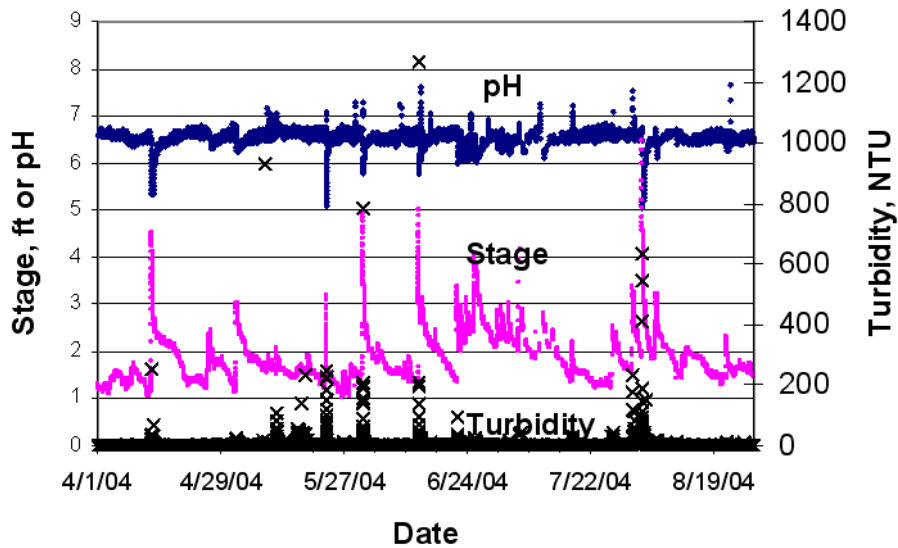
Figure 1. Stage, pH, and turbidity vs time at site 2.

Sites 1, 2, and 3 generally had good water quality and supported fish. However, compared to the other sites, site 4 is at a higher elevation, had a lower pH, and did not support fish. The lower pH at site 4 compared to the other sites is consistent with general elevation vs pH trends in the Park. Figure 2 shows a sample of sonde pH and stage readings from site 4. The median pH at this site was 5.8 but the pH dropped to as low as 4.0 during storm events. The pH at this site was less than 5.0 for 3.6% of the total time.
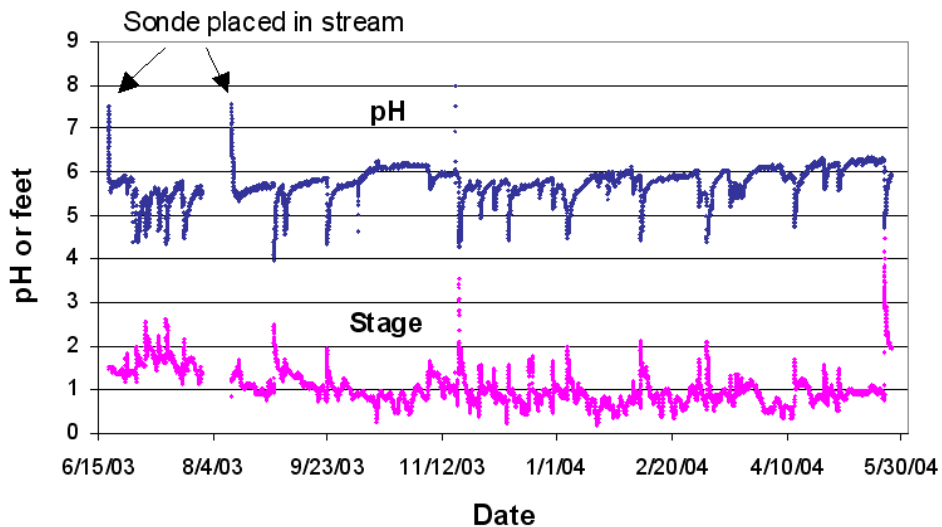
Figure 2. Stage and pH vs time at site 4.

The drops in stream pH to below 5.0 at site 4 may be responsible for no fish at this site. At Shenandoah National Park (SNP), which has areas of similar water quality and acid deposition characteristics to the GRSM, MacAvoy and Bulger (1995) found that base flow water quality conditions in streams with low ionic strength (i.e., streams similar to GRSM streams) were generally tolerated by young brook trout but that storm events resulted in deteriorated water quality due to acid deposition and led to substantial mortality. Although data have only been collected for one year, storm events in the GRSM is consistent with trends observed by MacAvoy

and Bulger (1995) in SNP with pH levels dipping to 5.0 and below. Later work by MacAvoy and Bulger (2004) monitored hematocrit in blacknose dace and did not find significant toxicity effects during moderate acidification events. The authors were careful to state that the storm events were not the most acute events seen. The largest pH drop observed was to 5.37 which is far above the pH seen in storm events in some streams of the GRSM.

Table 1 below shows the baseline ANC for the sites. The low ANC values for sites 3 and 4 classifies them as potentially sensitive and highly sensitive to acid deposition respectively according to a classification system proposed by Sullivan et al. (2004). However, all four sites have low ANC compared to most streams in the U.S. The low ANC is consistent with the large drops in pH during storm events because the watershed has little capacity to buffer acid sources. The low ANC results from the sandstone, siltstone, and Anakeesta geology of the watershed.

Table 1. Baseline ANC for sites 1-4

Statistic	Storm events ANC, µeq/L			
	Site 1	Site 2	Site 3	Site 4
Median	50.85	58.52	29.07	11.6
Mean	53.42	61.53	32.99	10.18
Std Dev	17.42	18.03	14.39	8.14
Maximum	96.2	103.6	68.6	17.5
Minimum	25.7	36.4	12.8	0
N	29	29	28	4

Storm events have the potential for significantly higher metal concentrations due to leaching, flushing, and direct deposition. Table 2 shows the concentration of metals during storm events. Table 3 shows the average increases in metals concentrations for all storm events compared to average base flow conditions at each site. The table shows considerable variability for some metals but aluminum, which is a concern for fish toxicity, shows consistent increases of 25-60% on average. Some storms events exceeded water quality criteria for aluminum. Interestingly, silicon showed consistent decreases which is probably due to dilution of groundwater base flow since the precipitation has very little silicon.

The metals concentrations were compared to the USEPA's water quality criteria (USEPA 2002). Table 4 shows the criterion maximum concentration (CMC) and the criterion continuous concentration (CCC) for aluminum, copper and zinc. The CMC and CCC for copper and zinc are functions of the hardness concentration with greater toxicity with

Table 2. Stream storm flow descriptive statistics for cations.

Statistic	Al (mg/l)	Ca (mg/l)	Cu (mg/l)	Fe (mg/l)	K (mg/l)	Mg (mg/l)	Mn (mg/l)	Na (mg/l)	Si (mg/l)	Zn (mg/l)
					Site 1					
Median	0.05	1.38	0	0.02	0.55	0.35	0	0.828	1.88	0
Mean	0.051	1.564	0.004	0.024	0.81	0.391	0.005	0.847	1.346	0.008
Std Dev	0.05	0.66	0.007	0.027	0.863	0.109	0.013	0.176	0.89	0.011
Maximum	0.29	5.17	0.03	0.19	4.43	0.73	0.05	1.433	2.35	0.05
Minimum	0	1.06	0	0	0.29	0.206	0	0.61	0.01	0
					Site 2					
Median	0.082	1.447	0.019	0.022	0.5	0.385	0.006	0.773	1.872	0.016
Mean	0.088	1.481	0.025	0.033	0.778	0.391	0.008	0.808	1.676	0.019
Std Dev	0.055	0.225	0.023	0.058	0.964	0.089	0.009	0.265	0.773	0.015
Maximum	0.318	2.019	0.101	0.443	5.913	0.627	0.04	2.124	3.116	0.058
Minimum	0	1.092	0	0	0.305	0.229	0	0.565	0.031	0
					Site 3					
Median	0.101	1.213	0.004	0.017	0.536	0.351	0.005	0.678	1.766	0.01
Mean	0.083	1.505	0.011	0.024	0.817	0.361	0.007	0.694	1.528	0.019
Std Dev	0.054	0.67	0.019	0.029	0.79	0.126	0.012	0.153	0.737	0.021
Maximum	0.178	4.076	0.093	0.165	4.917	0.778	0.063	1.527	2.869	0.087
Minimum	0	1.058	0	0	0.26	0.142	0	0.501	0.002	0

Table 3. Percent change in metal concentrations from base flow to storm flow.

Statistic	Percent change in metal concentrations from base to storm flow									
	Al	Ca	Cu	Fe	K	Mg	Mn	Na	Si	Zn
					Site 1					
Median	40%	2%	0%	50%	25%	4%	0%	-7%	-39%	0%
Mean	25%	11%	-4%	41%	50%	15%	57%	-11%	-72%	-39%
					Site 2					
Median	59%	7%	61%	9%	18%	14%	100%	-23%	-53%	36%
Mean	59%	5%	68%	32%	39%	15%	84%	-27%	-55%	0%
					Site 3					
Median	60%	-4%	-129%	-2%	20%	13%	56%	-28%	-34%	-68%
Mean	25%	15%	-10%	-71%	-1%	13%	53%	-28%	-42%	2%

Note: A positive number represents an increase during storm flow.

Table 4. Water quality criteria for hardness-dependent metals and for aluminum

1C-4

Hardness, mg/L as CaCO$_3$	dissolved Cu		dissolved Zn		dissolved Al	
	CMC, µg/L	CCC, µg/L	CMC, µg/L	CCC, µg/L	CMC, µg/L	CCC, µg/L
1	0.175	0.175	2.37	2.39	750	87
5	0.799	0.692	9.26	9.34	750	87
10	1.54	1.25	16.7	16.8	750	87
20	2.95	2.26	30.0	30.2	750	87

lower hardness. The data used by the EPA to formulate the hardness-dependent corrections were in the 20- 400 mg/l hardness range. In the past, EPA has allowed the criterion concentrations to be calculated as if the hardness was 25 mg/l for waters with hardness less than 25 mg/l as CaCO$_3$. Recently EPA has decided that capping hardness at this lower end should not be allowed because it might result in criteria that provide less protection than intended (USEPA 2002). The ability to extrapolate criterion concentration values for such low values of hardness still remains questionable. In the hardness-dependent equations, hardness is used as a surrogate parameter for the influence of factors such as calcium, magnesium, carbonate, and pH (Charles Delos, USEPA, personal communication, Sept. 3, 2004). If there are site-specific questions about the applicability of the 2002 Criteria, then the EPA suggests two alternative procedures both of which require data and information that are unavailable for this stream. Thus, the hardness corrections were applied as is. It is important to understand several aspects of the water quality criteria (Stephan et al. 1985). The criteria are somewhat overprotective of the majority of water bodies since site specific information is very limited. The criteria also represent a threshold of unacceptable effect rather than a threshold of no adverse effect. In other words, there may indeed be some adverse effect below the criteria. A four-day averaging period for the CCC is deemed appropriate because substantial fluctuations in concentration have more adverse effects than constant concentrations. A one-hour averaging period is appropriate for the CMC. Because of the abilities of water bodies to restore themselves, the USEPA believed an exceedance frequency of once every three years was appropriate.

Using the corrected CMC and CCC values discussed above, Table 5 shows the CMC and CCC exceedances for copper, zinc, and aluminum for base and storm flow samples for Sites 1 – 3. Copper and zinc exceedances were based on the hardness of that particular sample. Aluminum did not exceed the CMC for any samples. However, aluminum did exceed the CCC about 50 – 60% of the time during storm samples and about 25% during base flow. Increased aluminum exceedances during storm flow are another symptom of acidification. Copper and zinc had numerous exceedances during base and storm flow. The total exceedances for CMC for all metals were 33, 49, and 43% for Sites 1 – 3 respectively. This could represent serious water quality problems. In comparison with the EPA criteria, Hansen et al. (2002) found the zinc LC50 for rainbow trout to be approximately 0.125 mg/l at a pH of 6.5 and hardness of 30 mg/l as CaCO$_3$. The EPA CMC for the given hardness is 0.042 mg/l. Nevertheless, sites 1-3 do appear to support a healthy fish population and habitat.

The impact of acid deposition on pH depression in streams of the GRSM has been debated. Confounding factors are sulfidic geology, e.g., anakeesta geology, and natural organic acids. Clearly the precipitation in the GRSM is quite acidic with a median pH of 4.37 and minimum of 3.99 as shown in Table 6 for the bulk precipitation samples. The water quality for the sequential precipitation sampler was similar but the pH was 0.50 units higher and the ANC tended to be higher. Several arguments can be made for the importance of acid deposition on pH depression in the streams:

Table 5. Metal exceedances for stream sites 1 – 3.

Statistic	Metal exceedances of CMC's and CCC's for storm and base flow											
	Site 1											
	Storm Flow						Base Flow					
	Al		Cu		Zn		Al		Cu		Zn	
	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC
# exceedances	0	10	38	38	16	16	0	2	13	13	12	12
# events	57	57	57	57	57	57	24	24	20	20	24	24
% exceedance	0	18	67	67	28	28	0	8	65	65	50	50
	Site 2											
	Storm Flow						Base Flow					
	Al		Cu		Zn		Al		Cu		Zn	
	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC
# exceedances	0	28	55	55	39	39	0	2	15	15	16	16
# events	60	60	60	60	60	60	26	26	21	21	26	26
% exceedance	0	47	92	92	65	65	0	8	71	71	62	62
	Site 3											
	Storm Flow						Base Flow					
	Al		Cu		Zn		Al		Cu		Zn	
	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC	CMC	CCC
# exceedances	0	25	36	36	28	28	0	4	13	13	16	16
# events	49	49	49	49	49	49	25	25	20	20	25	25
% exceedance	0	51	73	73	57	57	0	16	65	65	64	64

Table 6. Bulk precipitation water quality.

Statistic	Water quality parameter								
	pH	ANC, μeq/L	Nitrate, μeq/L	Sulfate, μeq/L	Ca, μeq/L	Mg, μg/L	Al, mg/L	Cu, mg/L	Zn, mg/L
Median	4.37	0.0	19.6	37.0	20.6	2.14	0.013	0.002	0.020
Mean	4.49	0.43	30.4	51.2	26.1	3.21	0.028	0.004	0.024
Std Dev	0.40	2.02	35.3	58.7	17.0	3.37	0.029	0.006	0.025
Maximum	5.49	9.91	144.1	231.5	67.9	11.6	0.083	0.021	0.088
Minimum	3.99	0	0.0	8.3	9.55	0.0	0.0	0.0	0.0
N	24	24	24	24	19	19	19	15	19

- The mean concentration of sulfate in the bulk precipitation was 51.2 μeq/L compared to mean stream sulfate during storm events of 47.0-52.7 μeq/L, i.e., about equal which implies a strong influence of acid deposition on storm water quality.
- Base flow regression models from earlier work (Robinson et al. 2001) showed no statistically significant effect on base line pH of the fraction of sulfidic anakeesta geology in the watershed unless the anakeesta had been disturbed, i.e., exposed. In a well documented case where anakeesta had been disturbed by road construction, Huckabee et al. (1975) discuss data showing that there were no fish for at least 8 km downstream of the road bed fill even 10 years after construction but that tributaries did support fish. Brook trout toxicity tests clearly implicated lower pH and metals from leaching the sulfidic rocks. Also, "a dense whitish to yellowish precipitate coated the stream bed rocks for at least 2 km downstream from the road fill." At this point, no anecdotal

evidence has been reported of similar disturbance and stream conditions in the watershed upstream of site 4 which lacks fish, but neither has the watershed been surveyed to identify such conditions.

- A first cut mass balance shows roughly 6 to 50 times more sulfate and proton (hydrogen ion) entering the watershed from precipitation compared to what is exported in the stream during a storm event. The mass balance is limited by the lack of good stream flow measurements and small number of precipitation collectors.
- If acidity comes from iron sulfide then there ought to be either corresponding iron in the stream or deposits of iron oxyhydroxides in watershed. The iron concentration during storm events was about 50 times lower than the corresponding sulfate which means that the iron must accumulate in the watershed if sulfidic geology is a significant contributor. There is currently no information whether this is occurring.
- There is currently no information in the GRSM to assess the contribution of organic acids to pH depression, however, similar water quality work in the Shenandoah National Park has discounted organic acids as a significant contributor (personal communication with Rick Webb of the Univ. of Virginia, October 30, 2004).

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FACILITATED TRANSPORT OF TRICLOSAN IN THE RECEIVING ENVIRONMENT OF AN ONSITE WASTEWATER TREATMENT SYSTEM: CAUSE FOR AQUATIC CONCERN

Adrienne Roach[*1], John Buchanan[1], Mark Radosevich[1] and Jaehoon Lee[1]

ABSTRACT

Triclosan (TCS) is an antibacterial found in a host of consumer products ranging from toothpaste to textiles. TCS can enter the environment down-the-drain during normal product usage. While initially confined to health care settings, the increased popularity of antimicrobial products has resulted in a surge of products containing this compound and can currently be found in over 700 consumer products. Due to its hydrophobic nature ($S_w = 10$ mg L^{-1}), this compound has been found to persist in the environment at a greater extent than previously considered. The fate of TCS in wastewater treatment plants (WWTPs) and loss mechanisms once exposed to the environment is a topic which has gained much attention over the past five years. However, similar research in onsite systems, where its presence and subsequent persistence can potentially have a more profound environmental effect, is lacking. The fate of TCS in an onsite wastewater treatment system (OWTS), in particular, its facilitated transport in the presence of dissolved organic matter (DOM) is of concern. This study addresses factors that affect the stability of TCS in soil, and thus its increased potential for transport. Laboratory batch sorption and column transport studies are being used to generate data. Preliminary batch sorption studies indicate the potential for the increased solubility of TCS in the presence wastewater effluent from an OWTS. Data fit to the Freundlich isotherm model indicate a slight preference of TCS to components within the wastewater effluent used in the study. However, column transport studies are inconclusive. Additional data for both phases are currently being generated.

INTRODUCTION

Onsite wastewater disposal has been found to be a significant source of groundwater contamination throughout the United States (Rudel et al., 1998). In Tennessee alone, approximately 25% of homes are served by onsite systems and this number is steadily increasing. When properly installed and operated, OWTSs can generate effluent that meets that of some drinking water standards. However, site selection and wastewater characterization are key in effective treatment. OWTSs were originally designed with the primary goal of guarding human health with environmental protection as a subsequent objective. Nutrients and pathogens, such as, nitrate, phosphorous and enteric bacteria are most commonly recognized as major wastewater contaminates due to their direct effects on human health. Recent studies, primarily on WWTPs, have identified other classes of chemicals which are not completely removed in the wastewater treatment process and pose a long term threat to the receiving environment but are not considered as an immediate threat to public health. These compounds are identified as pharmaceuticals and personal care products (PCPPs), many of which function as endocrine disrupting chemicals (EDCs). They adversely affect the environment by their potential ability to cause abnormal physical processes, reproductive impairment in fish, increase in the incidence of cancer, development of antibiotic resistant bacteria, and increased toxicity when mixed with other chemicals present within an aquatic system (Kolpin et al., 2002).

One such compound gaining recent attention is TCS. While TCS is not classified as an EDC, it is among the vast list of PCPPs and has been proven to support the development of antibiotic resistant bacteria (Aiello and Larson, 2003; Daughton and Ternes, 1999; Koplin et al., 2002;

Levy, 2001; McBain et al., 2003; McBain and Gilbert, 2001; White and McDermott, 2001). TCS is an antimicrobial agent added as a preservative or as an antiseptic in medical products such as disinfecting hand soap, medical skin creams, and dental products. It can also be found in personal care products such as toothpaste, mouthwash, as well as household cleaners and textiles like sportswear, bed cloths, shoes and carpets (Singer et al., 2002). Because TCS is found in a wide variety of products as well as in certain pharmaceuticals as an antibiotic, understanding the behavior of this compound in the receiving environment of an OWTS can lead in the determination of the fate of similar unobserved compounds.

One of the most influential factors affecting the fate and behavior of contaminants is sorption to the soil and sediment. The nature of the compound, as well as, the composition of the soil and sediment, determines the extent to which chemicals are retained. Due to the nature of hydrophobic organic contaminants (HOCs), these compounds typically persist in the environment and accumulate within the soil matrix and are most commonly associated with soil organic matter (SOM). In the presence of water, mineral matter prefers to adsorb water due to similar polarities and therefore decreases its desire to sorb organic contaminants (Chiou and Kile 2000); these fundamental characteristics warrant the purpose of this study. Of concern is the enhanced transport of HOCs by dissolved organic matter (DOM) and in particular, that contained within wastewater effluent. The purpose of this study is to evaluate the role an OWTS plays to the potential presence of TCS in groundwater and other receiving water bodies. The primary objective is to investigate the facilitated transport of TCS by DOM contained within the effluent of an OWTS.

METHODS

Laboratory batch sorption and column transport studies are being used to generate data in this study. Studies are performed in two phases: 1) Batch sorption equilibrium with an isotherm approach. The sorption TCS to an absorbent material is analyzed in two bulk electrolyte solutions (5mM $CaCl_2$), one in an organic free solution and the other in wastewater. 2) Column transport in which the breakthrough of TCS is evaluated under saturated, continuous flow conditions. Sand is the medium of transport and a bromide tracer is used for breakthrough comparison.

Batch Sorption Experiment

An isotherm approach was taken as an initial step to observe the sorption behavior of TCS. The amount of compound sorbed (q) in mg kg^{-1} is plotted against the equilibrium solution concentration (c_{eq}) in mg L^{-1}. Equation 1 is used to calculate q.

$$q = V_l (c_{in}-c_{eq})/m_s \hspace{3cm} (1)$$

where

V_l = volume of liquid (L)
c_{in} = initial compound concentration (mg L^{-1})
c_{eq} = equilibrium solution concentration (mg L^{-1})
m_s = mass of adsorbent material (kg).

Pre-washed and oven dried sand was used throughout the batch studies at a 1:2 (mass: volume) soil/solution ratio. Two treatments were applied, 5mM $CaCl_2$ dissolved in deionized water (batch 1) and 5mM $CaCl_2$ dissolved in wastewater effluent (batch 2). TCS was added at five increasing concentrations (1, 5, 10, 20, and 40 mg L^{-1}) to each batch from a standard solution of TCS dissolved in 100% acetonitrile. Samples were allowed to equilibrate for 96 hours on a

reciprocating shaker set at 130 rpm. Aliquots from each bottle were centrifuged and analyzed by HPLC.

Column Transport Experiment

Pulse input breakthrough curves were generated under saturated conditions. The experimental configuration is shown in Figure 1. Stainless steel columns (12 in. × 2.5 in. i.d.) were packed with pre-washed, oven dried sand. Prior to TCS application, columns were saturated from the bottom with a background solution of 5mM $CaCl_2$. Two treatments were applied, each to a separate column, after establishing steady state conditions with the background solution. A constant head was established and maintained by use of a Marriott device for both background and input solutions. Input solution for treatment one was made up in deionized water and input solution for treatment two was made up in a matrix of wastewater effluent. Due to the low solubility of TCS, both treatments were prepared by supersaturating 20 mg L^{-1} TCS in 1.5 L of solution containing 5mM $CaCl_2$ and 15 mg L^{-1} potassium bromide as a tracer. Solutions were allowed to mix overnight and filtered to remove insoluble TCS prior to column application. Input TCS concentration was determined by analyzing filtrate by HPLC. Sample fractions based on pore volume were collected by an autosampler in 15 ml broscillate glass vials. Five to six pore volumes were collected from each column.   Flow rate was controlled by use of clamps on tubing at base of column. Teflon tubing was used to transport the input solution and outflowing solution from the column. TCS was found to be absorbed by vinyl tubing up to 90% in a previous column study. A range of samples were selected for HPLC analysis.
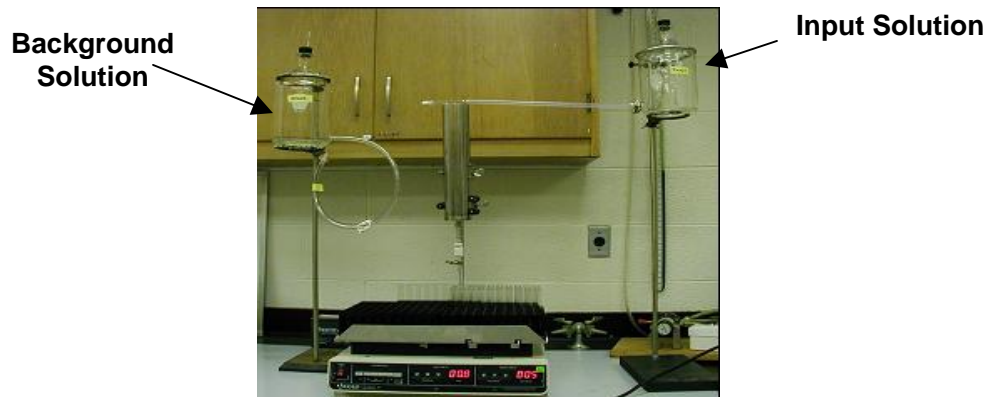
Figure 1. Breakthrough curve experimental configuration

PRELIMINARY RESULTS/DISCUSSION

Batch Sorption Experiment

Data was fit to the Freundlich isotherm model. The Freundlich model is used to account for the variation in q as a function of c_{eq} and can be described by equation 2. K_F, the Feundlich coefficient, is the amount of substance sorbed when c_{eq} = 1 mg L^{-1}.

$$q = K_F c_{eq}^{N} \tag{2}$$

where

N = the heterogeneity of the sorbing surface (0, very heterogeneous and 1, very homogenous)

To quantitatively describe the data, equation 2 is transformed into the following linear expression:

$$\log q = \log K_F + N \log c_{eq}. \tag{3}$$

A plot of $\log q$ against $\log c_{eq}$ yields a straight line with slope N and a y-intercept of $\log K_F$, if the Freundlich model describes the data (Essington 2003).

The Freundlich isotherm model provided a good fit for the data in both treatments ($r^2 = 0.999$ and 0.993). K_F indicated slightly less sorption of TCS to the sand in treatment two where wastewater was used as the bulk solution. Addition studies are needed to confirm this finding. The manner in which TCS was added to the soil/solution will be modified in future studies. It is suspected that the use of 100% acetonitrile interferes and alters sorption mechanisms. TCS will be added in a manner minimizing solvent volume.

Column Transport Experiment

TCS breakthrough was not observed in treatment one and TCS that broke through in treatment two was below the calibrated detection limit of the HPLC. Future column transport studies will be carried out under unsaturated conditions over an extended time period. Sectional column analysis and TCS desorption with various extractants will also be conducted.

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DEVELOPMENT OF A TRANSDUCER NETWORK
IN AN URBAN ENVIRONMENT

Jerry Lee Anderson[1]

INTRODUCTION

The City of Memphis and Shelby County, Tennessee pump water from two aquifers that provide a prolific amount of water and at times seems infinite. However, there are three water bearing aquifers within this region that is a part of a larger geologic system referred to as the Upper Mississippi Embayment. In Tennessee these three aquifers are named the alluvial (ground water) aquifer, the Memphis aquifer and the Fort Pillow aquifer. The United States Geological Survey (USGS) has been taking data in this region for many years and many published reports outline the potentiometric water levels of the these three aquifers. At one time many of the potentiometric measurements were taken with continuous recording devices, but due to different constraints placed on the USGS, many of these recorders were removed or discontinued. Now, most of the readings taken in this area are taken manually by a USGS technician.

In the spring of 2003, the Ground Water Institute (GWI) of The University of Memphis in cooperation with the USGS placed nine continuously recording pressure transducers in select observations wells across Shelby County, two in Eastern Arkansas, and one at Herb Parsons Lake just inside Fayette County. Specifically, of the nine placed in Shelby County, five transducers were located in the vicinity of the Sheahan Well Field, three in the Shaw Well Field, and one in the vicinity of Frazier in north Memphis. Later, three additional transducers were added to the original 12 in the vicinity of Arlington, TN, Collierville, TN and in Ensley Bottoms, near the Mississippi River. Also, a barometric transducer was placed in an observation well in the Sheahan Well Field and in one of the Eastern Arkansas observation wells.

Observation wells were instrumented with regard to the aquifer. Currently, there are five transducers in the alluvial/fluvial aquifer, eight transducers in the Memphis aquifer, and two in the Fort Pillow aquifer. These sites were selected with the intent of obtaining specific information as to the seasonal and pumping effects on the different aquifers.

PRESSURE TRANSDUCERS

The pressure transducer used was a Solinst Model 3001 Levelogger® F30. This transducer consists of a datalogger, battery, pressure transducer, and a temperature sensor housed in 0.875" x 4.9" case. The transducer automatically compensated for temperature. A ten-year battery life allows for an extended period of monitoring without removing or reprogramming the transducer. The accuracy of the transducer is 0.1% of full scale or ±0.03 feet. When downloading of the data occurs, the transducer is retrieved from the well casing and the absolute pressure readings are downloaded to a file on the computer using an optical reader.

At that time the transducer can be reprogrammed or simply re-suspended in the well casing for continuous monitoring. The transducer can be programmed for a fixed-time interval, event-based sample collection, or logarithmic sampling. The primary limitation is the transducer has a total memory capacity of 2 x 24000 readings. For the purpose of this research, a fixed-time interval of 1 hour was selected. A similar transducer was selected to measure the barometric pressures.

The pressure transducer is submerged by a stainless steel wireline in the borehole of each observation well and measures the absolute pressure. The absolute pressure is the local atmospheric pressure plus the depth of water above the transducer plane. Each transducer (pressure and barometric) measurement is adjusted for elevation and temperature. Figures 1 and 2 illustrate the raw data taken from AR:H-2 which is an observation well in Eastern Arkansas,
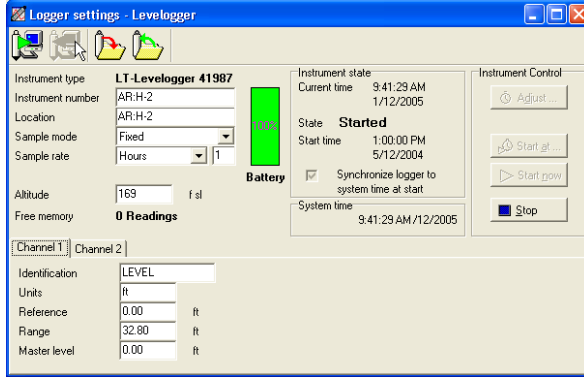
Figure 1. Logger settings
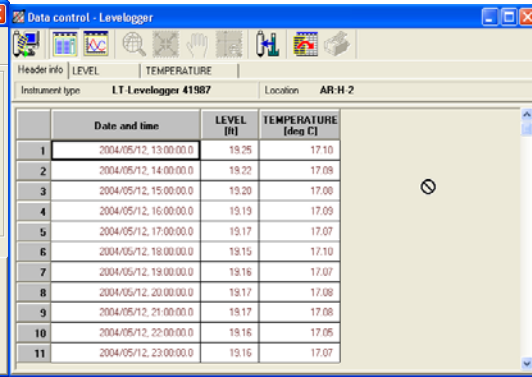
Figure 2. Raw data of pressure readings and temperature

Figure 1 has the logger settings and header information which details when the data was started, the elevation of the transducer measurement plane (169 ft, NGVD) and the sample rate of 1 hour. Figure 2 below contains the raw data of the depth of water plus the atmospheric pressure adjusted for elevation and temperature. Notice the data is recorded on the hour. At this point, the data is then compensated for the barometric pressure that has been measured with a barometer as illustrated in Figure 3. At the time the transducer is removed from the borehole to download the data, a water level measurement is taken and the time recorded. Consequently, the actual ground water level can be determined by the Barometric Compensation Wizard as shown in Figure 3. Figure 4 gives a graph of the ground water level over the time of the monitoring, but it is easier
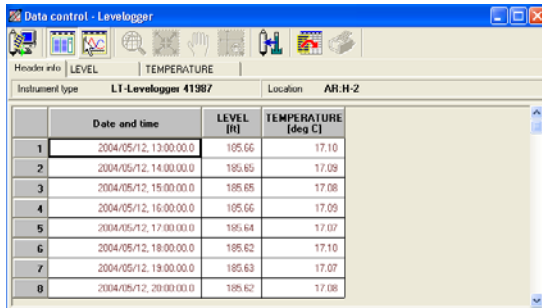
Figure 3. Compensated pressure reading adjusted to actual ground water levels
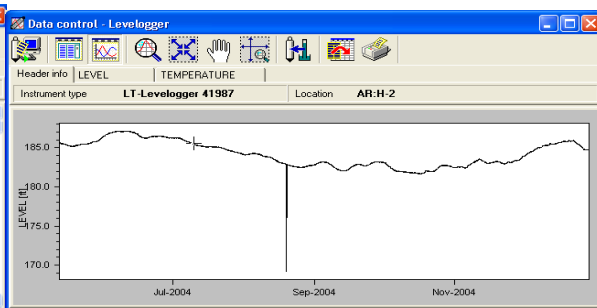
Figure 4. Ground water elevations in observation well AR:H-2

to use the data if it is exported to an Excel spreadsheet and subsequently analyzed.
For this particular observation, water quality and water chemistry samples were taken during the month of August and the transducer was removed from the well without stopping its measurements. So for most of the day, it was recording the barometric pressure since it was not submerged and out of the borehole. But Figure 4 displays the various changes in the observation AR:H-2 from 12 May 2004 until 29 Dec 2004.

MONITORING NETWORK

As previously discussed, fifteen pressure transducers and two barometric transducers have been deployed in the Mid-South area; thirteen in the Shelby/Fayette county area and two in Eastern

Arkansas. Table 1 outlines a general description of the transducer network. As Table 1 illustrates there are five transducers in the shallow water-table aquifer, namely four in the Shelby County region and one in Eastern Arkansas. There are seven in the Memphis aquifer; six in the Shelby/Fayette County region and one in Eastern Arkansas. There are only two in the Fort Pillow aquifer. Also five of the transducers (four in the Memphis aquifer and one in the Fort Pillow aquifer) are located in Memphis Light Gas and Water's (MLGW) Sheahan well field. Three transducers are located in the MLGW's Shaw well field, one in each aquifer. The Shaw well field's ground level surface is about 322 feet above sea level where Sheahan well field's ground level surface varies between 255 to 302 feet above sea level. The other two Memphis aquifer observation wells are located on the extremity of the pumping area, i.e. SH:O-1 and FA: L-1 at Herb Parsons Lake. Figure 5 gives a spatial representation of the transducer network.
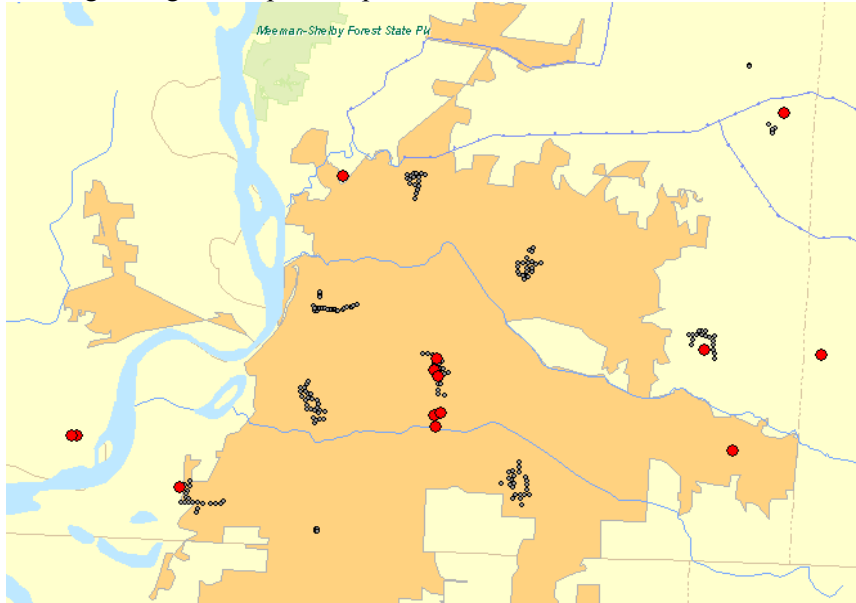
Figure 5. General Locations of Observations Wells in relation to MLGW well fields.

SHALLOW WATER-TABLE AQUIFER

Alluvium and fluvial deposits comprise the shallow water-table aquifer in the Memphis area. The alluvium occurs beneath the Mississippi Alluvial Plain and alluvial plains of streams draining the Gulf Coastal Plain and consists primarily of sand, gravel, silt, and clay. The unit generally consists of fine sand, silt, and clay in the upper part, and sand and gravel in the lower part. The alluvium ranges from 0 to 175 feet in thickness and is commonly about 100 to 150 thick beneath the Mississippi Alluvial Plain. The alluvium supplies water to many domestic, farm, industrial, and irrigation wells in the Mississippi Alluvial Plain. The fluvial deposits occur beneath the uplands and valley slopes of the Gulf Coastal Plain and consists primarily of sand, gravel, and minor clay lenses. The fluvial deposits range from 0 to 100 feet in thickness. The fluvial deposits provide water to many domestic and farm wells in the rural areas of the Gulf Coastal Plain.

Table 1. General Description of Transducer Network

WELL_ID	MLGW_ID	ADDRESS	WELL_FIELD	AQUIFER
99-S	99-S	715 Loeb	Sheahan	Alluvial
AR:H-2		Rimbert Miller Rd.		Memphis Sand
AR:H-2A		Rimbert Miller Rd.		Alluvial
FA:L-1		Herb Parsons Lake		Memphis Sand
MW2		Collierville		Memphis Sand
SH:H-19			Davis/Ensley Bottoms	Fluvial
SH:K-45	OF51	540 Zach Curlin	Sheahan	Fort Pillow
Sh:K-66	OM51	3926 Central	Sheahan	Memphis Sand
Sh:K-72		Getwell and Elliston	Sheahan	Memphis Sand
Sh:K-75	OT52	4063 Willow view	Sheahan	Alluvial
Sh:O-1		OK Roberson Rd.		Alluvial
SH:R-30	7F1	10320 Kentwood Est.	Shaw	Fort Pillow
SH:R-31	7M1	10320 Kentwood Est.	Shaw	Memphis Sand
SH:R-32	7T2	10320 Kentwood Est.	Shaw	Fluvial
SH:W-3		Arlington		Memphis Sand
Baro 99-s	99-S	715 Loeb	Sheahan	
Baro AR:H-2	AR:H-2A	Rimbert Miller Rd.		

As previously stated, five transducers were installed in observation wells in the shallow water-table aquifer. The five transducers are listed in Table 1. Two of the transducers, 99s and K-75 are located in the Sheahan well field. The GWI has been conducting research in the area of the Sheahan well field to better define the recharge area of the Memphis aquifer due to a large "window" in the confining unit and the effect that the flow in Nonconnah Creek has on recharge to the Sheahan well field. Reference is made to Figure 5 which shows the location of 99s and K-75 with regard to the Sheahan well field and Nonconnah Creek.

MEMPHIS AQUIFER

The Memphis Sand constitutes the Memphis aquifer. (Kingsbury, 1996). The Memphis Sand occurs in the subsurface of all of the Memphis area. In the eastern area of Shelby County, the eroded upper part of the Memphis Sand directly underlines the alluvium and fluvial deposits, and further to the west a confining unit, Jackson-upper Claiborne provides separation from those same deposits. The Memphis Sand is a regional aquifer in Tennessee, Missouri, Kentucky (Tallahatta Formation and Sparta Sand), and northeastern Arkansas. The Memphis Sand is equivalent to (in ascending order) the Tallahatta Formation, Winona Sand, Zilpha Clay, and Sparta Sand of northern Mississippi and the Carrizo Sand, Cane River Formation, and Sparta Sand of southern Arkansas. (Parks, 1990). The Memphis Sand consists mainly of sand, silt, clay, and minor lignite deposits and ranges from 650-900 feet in thickness. The sand is fine to medium or medium to coarse. The upper part contains lenses of fine sand and clay. This aquifer is the principal aquifer providing water for most domestic, commercial, industrial, and municipal supplies in the Memphis area. (Kingsbury, 1966)

Ground Water Levels in the Shallow Water-Table in Sheahan Wellfield
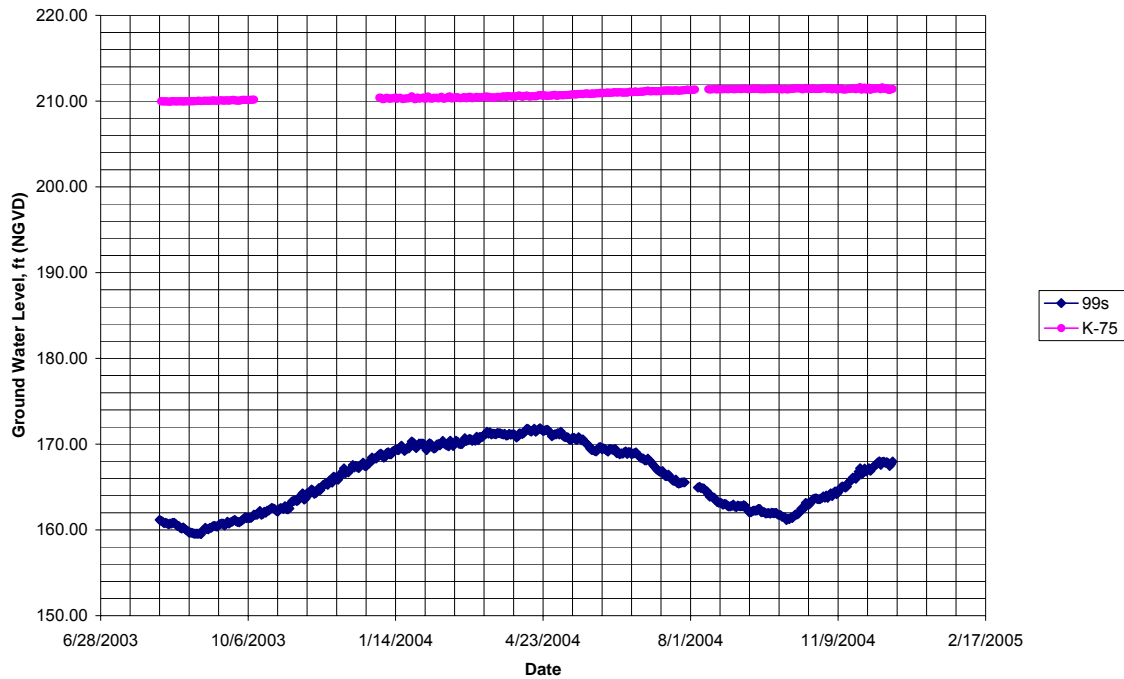
Figure 6. Ground Water Levels in the Shallow Water-table Aquifer

There are eight transducers in the Memphis aquifer; two in the Sheahan well field (SH:K-66, SH:K-72), one in the Shaw well field (SH:R-31), one in north Memphis(SH:O-1), one in Arlington (SH:W-3)(northeast Shelby County), one in Collierville(MW2), one in western Fayette County (FA:L-1), and one in Eastern Arkansas (AR:H2). Several observations can be made by referring to Figure 7 which is a graph of all of the water levels in all of the observations wells in the Memphis aquifer. As might be expected the closer to the axis of the upper Mississippi Embayment (approximately the current location of the Mississippi River) the lower the ground water levels. The lowest ground water level is K-66 which also happens to be close to a MLGW pumping well. The variation in the ground water levels can be attributed to the operation of the pump during the summer of 2004, but as the summer begins to end, the water level returns to a pre-pumping elevation of 168 feet. The next three graphs O-1, K-72, and H-2 all show changes that could be seasonal and subject to precipitation, however all three are supposedly in the region of the Memphis aquifer that should have a significant clay thickness. O-l shows approximately a 5 foot change over the sampling period and appears to be influenced by the wet and dry seasons of the year. During the rainy period of late fall and early spring the ground water level rises and during the summer months show a drop with a recovery going into the fall of 2004. The next four graphs are of ground water levels that are on the extremes of the pumping region and are in the "recharge area" of the Memphis aquifer. R-31 is in the Shaw well field and appears to be rather constant with a ground water level of about 227 feet with a drop off during to the summer of 2004. Also, R-31 is influenced by MLGW pumping wells in Shaw. The other three wells show hardly any change. The observation well that is furthest to the east is the one near Herb Parsons Lake, FA:L-1 and indicates effectively no change in the ground level over the 18 months of sampling. Also as might be expected the ground water levels are the highest in the east (furthest from the Mississippi River) and begin to drop off near the Mississippi River. The variations in the ground water levels in AR:H-2 will be discussed later.

FORT PILLOW AQUIFER

The Fort Pillow Sand of the tertiary-age Wilcox group composes the Fort Pillow aquifer. It consists primarily of sand with local minor lenses of clay or silt and is present in the subsurface throughout the Memphis area. In the Memphis area, the Fort Pillow aquifer ranges from about 100 to 300 feet in thickness. The Fort Pillow aquifer is considered as the secondary aquifer in the Memphis area. The Memphis Sand and the Fort Pillow Sand are separated by the Flour Island Formation confining unit. The Flour Island Formation consists primarily of clay and silt. (Kingsbury, 1996).

Memphis Aquifer Ground Water Levels
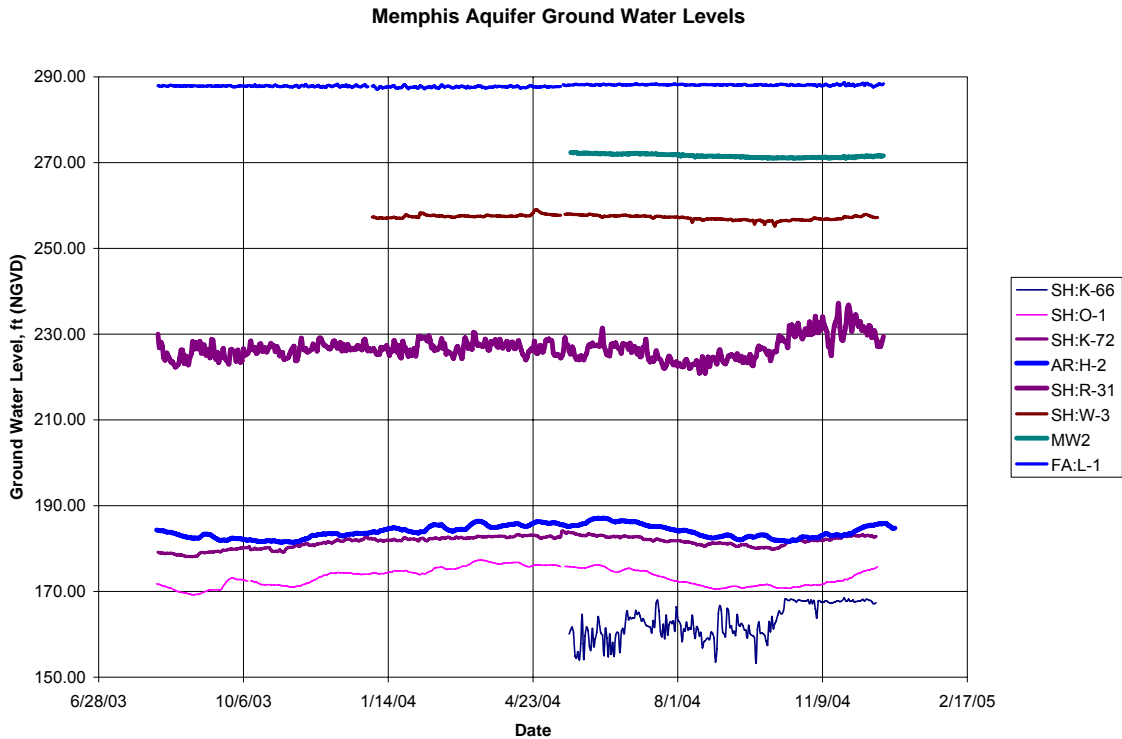
Figure 7. Ground Water Levels in the Memphis Aquifer

There are only two transducers in the Fort Pillow aquifer, one in the Sheahan well field, SH:K-45 and one in the Shaw well field, SH:R-30. As previously mentioned, the Fort Pillow aquifer is a secondary aquifer for drinking water in the Memphis area. The water has finely suspended clay and silt particles and requires more extensive treatment than the water from the Memphis aquifer. Figure 8 illustrates the ground water levels in the observation well in the Fort Pillow aquifer.

The ground water level measurements in SH:K-45 were unexpected. From the location of this observation well one might expect the ground water level to be constant at some value consistent with its location within the Memphis area, but it appears to respond to the seasonal changes of precipitation similar to the alluvial and Memphis Sand observation wells. Parks, 1990, has indicated an area in the Sheahan well field where the upper confining unit was very thin or absent. However, since this observation well is not in the recharge area nor in the Memphis Sand, the seasonal variation was not expected. It may indicate the leakage through a fault.

EASTERN ARKANSAS

As previously stated two of the pressure transducer were located in Eastern Arkansas. The aquifer differentiations in this region are similar to those in Western Tennessee. The two aquifers that hold primary interest in this research is the Mississippi River Valley alluvial aquifer (MRVAA) and the Sparta aquifer. The MRVAA is similar to the ground water table aquifer in Shelby county in that it was placed by alluvial process and has a wide variation in lithology over very short distances. Channel fill, point bar, and backswamp deposits associated with present and former channels have produced these

Ground Water Levels in the Fort Pillow Aquifer
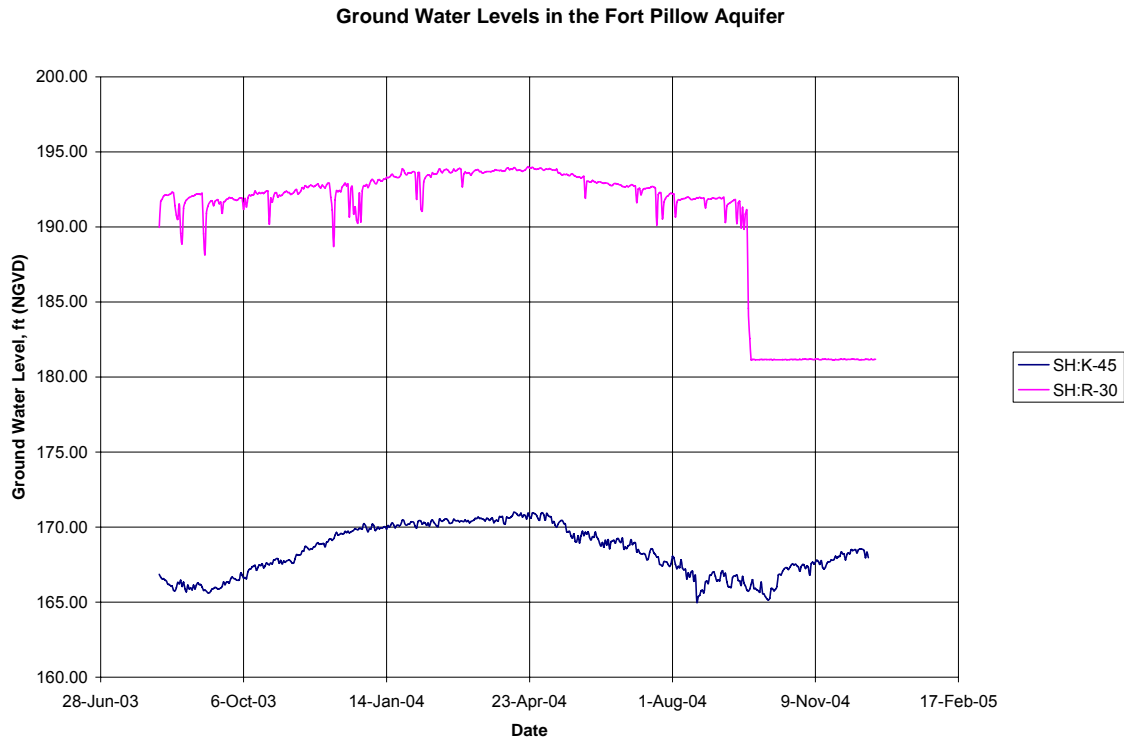
Figure 8. Ground Water Levels in the Fort Pillow Aquifer

abrupt differences. The MRVAA is underlain by the Sparta aquifer which is the same as
 the Memphis aquifer on the other side of the river and is named differently.

The Mississippi River Valley alluvial aquifer (MRVAA) underlies nearly all of Eastern Arkansas except for Crowleys Ridge which is a hydrologic barrier to the movement of ground water in the alluvial aquifer. The aquifer sediments are described as being divided into a lower aquifer which is composed of coarse sand and gravel grading upward to fine sand and an upper confining unit which is composed of clay, silt, and fine sand. The thickness of the alluvial sediments generally ranges from 125 to 200 feet and averages about 150 feet. Recharge to the alluvial aquifer comes primarily from precipitation which averages approximately 49 inches per year. However, it is noted that infiltration of water from streams and lakes is an important source of recharge, particularly those which are in good hydraulic connection with the aquifer. (Mahon and Ludwig, 1990)

As previously mentioned, two transducers were placed in Eastern Arkansas, one in the Sparta Sand (Memphis Sand) aquifer and one in the MRVAA. Reference to Figure 5 and Table 1 shows the location of these two transducer to be south of West Memphis, Arkansas on Reimbert Miller road. These locations are just south of the tip of President Island in Tennessee and almost

directly opposite the location of SH:H-19 on the Tennessee side of the Mississippi River. Figure 9 show the ground water elevations from August 2003 to late December 2004.

Ground Water Level in Eastern Arkansas
AR:H2 and AR:H-2A
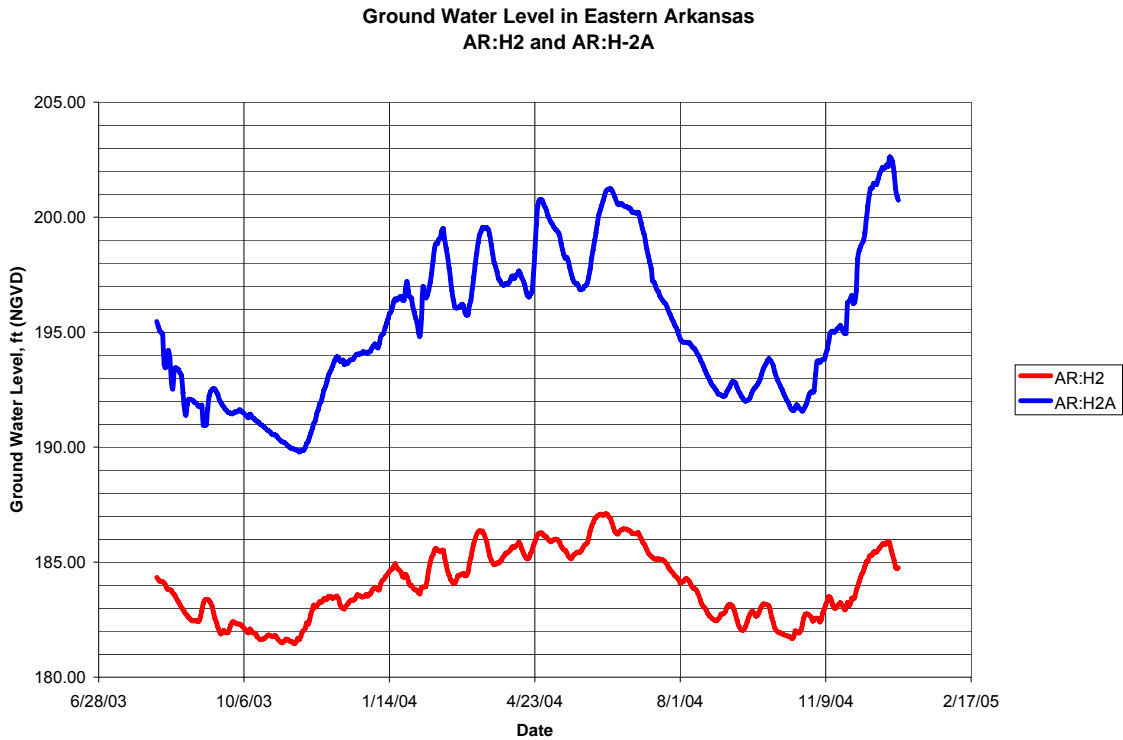
Figure 9. Ground Water Levels in Eastern Arkansas Wells AR:H2A and AR:H2

Observation well AR:H2 is a Sparta (Memphis) Sand well which is about 500 feet deep and is screened in the last 10 feet of the well. Observation well AR:H2 is a Mississippi River Alluvial well and is an out of service farm irrigation well about 100 feet deep. Since AR:H2 is in the Memphis Sand and is a considerable distance from any pumping center, the nearest being the MLGW Davis well field across the Mississippi River, is was unexpected to see the variations in the ground water levels as indicated in Figure 8. The variations in the alluvial ground waters were expected since the abandoned well was still in an active agricultural operations and additionally was subject to precipitation events. Mahon and Ludwig, 1990 state that the Mississippi River potentially provides an unlimited source of water to the aquifer and emulates a constant-head boundary condition. As such the variability of head in the MRVAA can also result from the changing water surface profile in the Mississippi River opposite the location of this irrigation well. But one would not expect the ground water levels in AR:H2 to similarly behave unless there was a unique connections to the Mississippi River. With this in mind, water surface elevations were determine on the Mississippi River at RM 723 which is immediately oppose the location of the observations. Figure 9 illustrates the variations in the ground water levels in the two observation and the Mississippi River. It is apparent from reviewing the data in the Figure 10 that there seems to be a direct and immediate response in the Memphis Sand aquifer with a change in the water surface elevation of the Mississippi River. At times the Memphis Sand is in a gaining position from the Mississippi River and at other times the Memphis Sand could be losing water to the Mississippi River.

Mississippi River Water Surface and Ground Water Level in MS and Alluvial Aquifer in Eastern Arkansas
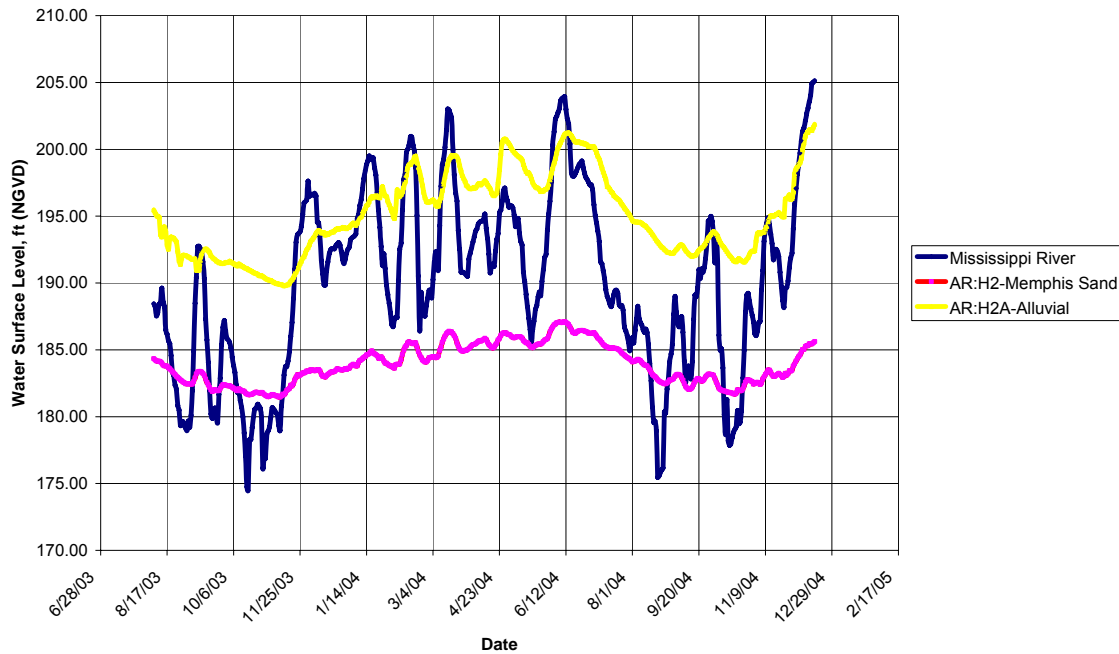
Figure 10. Mississippi River Water Surface and Ground Water Level in the Memphis Sand and Alluvial Aquifer in Eastern Arkansas

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SESSION 2A

SEDIMENT TRANSPORT
8:30 a.m. – 10:00 a.m.

Changing Sediment Dynamics in an Adjusting Watershed
M.A. Lisa Boulton and Carol P. Harden

Modeling of Sediment Delivery and Channel Transport Processes: Case Study Comparison Between an Urban and Non-Urban Subwatershed
Brantley A. Thames and John S. Schwartz

The Ten Commandments of Sediment Transport
Gary Moody

GEOMORPHOLOGIC INVESTIGATIONS
10:30 a.m. – 12:00 p.m.

Micromodeling: A Loose-Bed Study of the Loosahatchie-Memphis Reach of the Mississippi River
R.A. Gaines and Douglas W. Max

Environmental Restoration: A Micro Model Study
Douglas W. Max, John P. Rumancik Jr. and R.A. Gaines

Changes in Sediment and Nutrient Fluxes from Hillslopes in Response to Anthropogenically Disturbed Channels
Simon M. Mudd

WATER QUALITY IN URBAN ENVIRONMENTS
1:30 p.m. – 3:00 p.m.

Backtracking in Urban Waterways Using Coordinated Bacteria Tracking Assessments Methods Simultaneously
Tom Lawrence

Bacterial Water Quality During a Wet Weather Event
William Hamilton and Edward Thackston

Metro Nashville & Davidson County Aerial Infrared Sewer and Storm Water Line Inspection, 2004
Michael Hunt and Steve Winesett

SURFACE WATER QUALITY II
3:30 p.m. – 5:00 p.m.

Tier Evaluation for Implementation of Tennessee's Antidegradation Policy
Gregory M. Denton

Evaluation of the SPARROW Model for Estimating Transport of Nitrogen and Phosphorus in Streams of the Interior Plateau Ecoregion, Tennessee, Kentucky, and Alabama, 1992-2002
Anne B. Hoos

Treating Stormwater Runoff from a Travel Plaza: A Case Study
Rex Ausburn and John Ricketts

CHANGING SEDIMENT DYNAMICS IN AN ADJUSTING WATERSHED

M.A. Lisa Boulton*[1] and Carol P. Harden[2]

INTRODUCTION

Human modification of watersheds, including land clearance, agriculture, channelization, and urbanization, has reduced drinking water quality and impaired aquatic habitats in many watersheds. The desire to regain ecosystem functions and improve environmental aesthetics has increased interest in river restoration (Montgomery, 2001). Watershed impairment issues and river restoration practices necessitate better understanding of fluvial geomorphic adjustment processes in disturbed watersheds. Existing research emphasizes the importance of discharge and sediment load on geomorphic adjustment processes (Knighton, 1998). In equilibrated systems, discharge and sediment load balance the internal dynamics of the river system by determining the energy available for geomorphic work (James, 1999). In disturbed systems, it is often assumed that geomorphic processes will return to a balanced state given enough time or the right kind of intervention. However, in some cases of human modification, such as channelization, the magnitude of change may be substantial enough to have exceeded the natural range of variability in geomorphic processes. In such cases, it remains largely unclear whether it is possible to return to equilibrated and/or pre-disturbance conditions (Magilligan and Stamp, 1997; Montgomery and Piégay, 2003; Brooks and Brierley, 2004). Therefore, it is imperative that the full range of spatial and temporal variability of geomorphic adjustment processes that can occur in response to human-induced disturbance in river systems be understood.

One adjustment process that deserves further attention is system connectivity. There is a generally held assumption that the various components of a river function as an interconnected system (Schumm, 1977). Connectivity, within the context of this research, describes conditions where some component of the fluvial system, sediment in this case, is physically transferred between adjacent stream reaches. The spatial and temporal scales at which connectivity operates vary. For example, sediment connectivity may be measured as a function of bar to bar transmission or as a function of discharge of a particular magnitude (Hooke, 2003). Connections within a system are not static but instead evolve over time and space, varying with external (climate, for example) and internal dynamics (sediment exhaustion, for example) of the system (Harvey, 2000). Understanding spatial and temporal variations in system connectivity is significant to geomorphic adjustment because changes can be absorbed, translated, and/or mitigated depending on the degree of connectivity between the different components of the system (Fryirs and Brierley, 1999; 2001).

In this study, measurements of the continuity or similarity of channel morphology between adjacent reaches and the particle size of channel material were used as proxies for sediment behavior and used to examine sediment connectivity or exchange between adjacent reaches in three channelized, tributary streams of the Hatchie River of west Tennessee.

METHODS

In order to examine continuity of channel morphology as a surrogate for sediment connectivity, channel morphology surveys were conducted in a total of 35 reaches in the three study tributaries: Richland, Dry, and Jeffers Creeks. Channel bed material was sampled from the active part of the

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channel at each reach and dry sieved (particle size analysis) in the laboratory. Size divisions used in the particle size analysis adhere to the Wentworth scale. The cumulative frequency by weight was calculated and used in a mathematical linear interpolation to calculate the median (D50) particle size for each sample location (Bunte and Abt, 2001).

Four main morphometric variables were used for statistical analysis to test for reach channel morphology continuity: bankfull width, bankfull depth, bankfull area, and bankfull width/depth ratio.   Using the statistical program BLOSSOM (developed by the United States Geological Survey in Ft. Collins, CO) the four morphometric variables were analyzed using a non-parametric statistical technique – multi-response permutation procedure (MRPP) to test the degree of similarity between adjacent reaches. MRPP allows the similarity and/or dissimilarity between pre-defined groups (in this case, reaches) to be determined (Orlowski *et al.*, 1995). It provides a measure of the degree of clustering of variables comprising a group (in this case, channel morphology variables) within Euclidian geometric data space; this is known as the test statistic. It then calculates the probability of achieving the same arrangement (grouping) of observations by random chance by comparing the test statistic for the observed, predefined groups to test statistics generated for all other possible permutations or groupings of the data given the same data size structure. The statistical analysis results in two measures: 1) the test statistic, which can be used to infer the degree of clustering of observations in data space within groups, and 2) a probability value, which can be interpreted as the likelihood that the pre-defined groups being compared belong to the same population.

Channel morphometrics were grouped by reach and each reach was tested for similarity with the adjacent, downstream reach. If the p-value for a reach pair comparison was < 0.05, the reaches being compared were considered to differ significantly in their channel morphology, while reach pair comparisons resulting in p-values > 0.05 were interpreted as not having a significant difference in channel morphology. In addition, adjacent reaches indicated by MRPP as morphometrically dissimilar were interpreted as exhibiting discontinuity in channel morphology between them. A lack of significant change in channel morphology between reach pairs was equated to similarity in channel morphology characteristics and therefore, to channel morphologic continuity between the reaches. The spatial pattern of channel morphologic continuity and discontinuity was mapped for each watershed and interpreted in conjunction with the particle size data.

RESULTS

Results of the MRPP statistical analysis used to test reach channel morphologic continuity or similarity indicates the degree of continuity in channel shape varies considerably between the three study watersheds (Figure 1, Figure 3, and Figure 5). No study watershed exhibited reach continuity throughout its entire length, but Jeffers Creek exhibited the most channel morphologic continuity and Dry Creek the least. In Richland Creek, there is reach similarity or continuity in two segments of the watershed: between reaches R2 and R3 and from reach R6 through reach R8 (Figure 1). In Dry Creek reach morphologic continuity occurs in the upper portion of the watershed beginning with reach D1 and ending with reach D5 (Figure 3), but discontinuity occurs in the lower section of the watershed. In Jeffers Creek, there is considerable reach continuity throughout the watershed. This includes channel morphologic continuity between the two major subwatersheds that comprise Jeffers Creek (Rice Branch and Browns Creek) and the Jeffers main channel (Figure 5). However, results also suggest channel morphology is discontinuous between the main channel and two major tributaries in the lower section of the watershed: J2 and J3.

The particle size analysis conducted on channel material from each study reach indicates spatial variability in the *D50* particle size within each watershed (Figure 2, Figure 4, and Figure 6). The watershed with the most spatial variability in the *D50* particle size is Dry Creek, while there is

less spatial variability in Richland and Jeffers Creeks. In Richland Creek, the *D50* is near the range of coarse sand in the uppermost study reach near the stream's headwaters, but at the remainder of study reaches, the *D50* consists of medium sand, with a slight increase in particle size observed at study reaches R4, R5, and R8 (Figure 2). The *D50* in Dry Creek is in the range of medium sand from reach D1 in the headwaters to reach D7 in the middle of watershed (Figure 4). However, downstream of reach D7 there is a considerable change in the *D50* at two major tributaries, reaches D8 and D9, where the *D50* fines down to very fine sand, silt, and clay. Downstream of reaches D8 and D9, the *D50* increases to medium sand at reaches D10 and D11 and increases again to very coarse sand at D11 at the mouth. The *D50* in Jeffers Creek does not vary significantly along the main channel study reaches (RB4, J1, and J5) where it consists of medium sand (Figure 6). The exception is reach RB5, which has a *D50* that consists of very coarse sand. Headwater tributaries in the Rice Branch subwatershed have *D50* measurements larger than the main channel consisting of coarse sand to very coarse sand. Other major tributary streams, such as reaches RB3, RB6, B4, and J2 have similar *D50* measurements as the main channel reaches and consist of medium sand.

Figure 1: reach continuity in Richland Creek.   **Figure 2: downstream change of the D50 particle size in Richland Creek.**
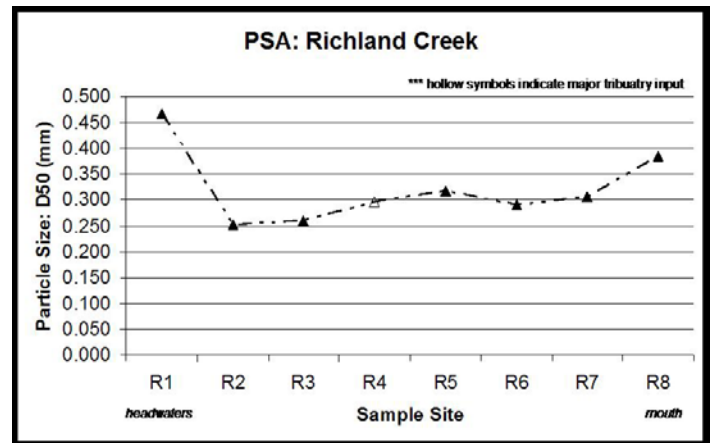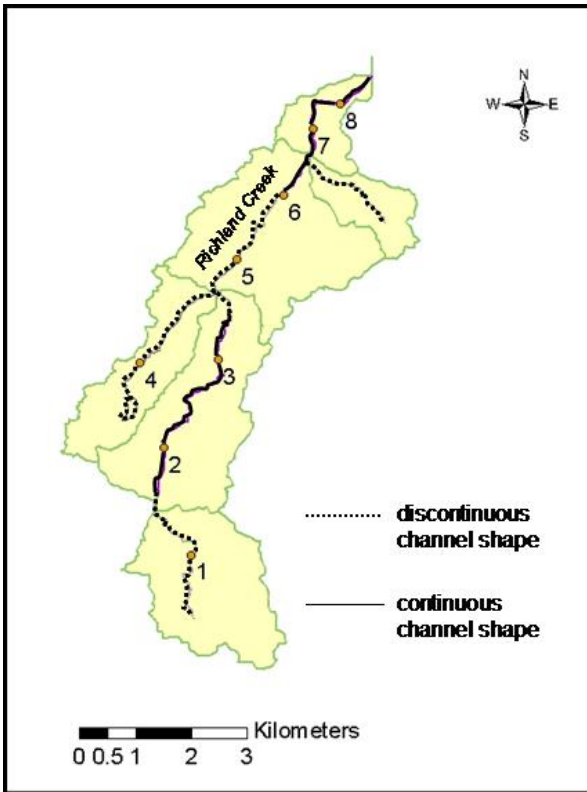
Figure 3: reach continuity in Dry Creek.   **Figure 4: downstream change of the D50 particle size in Dry Creek; note there is no**
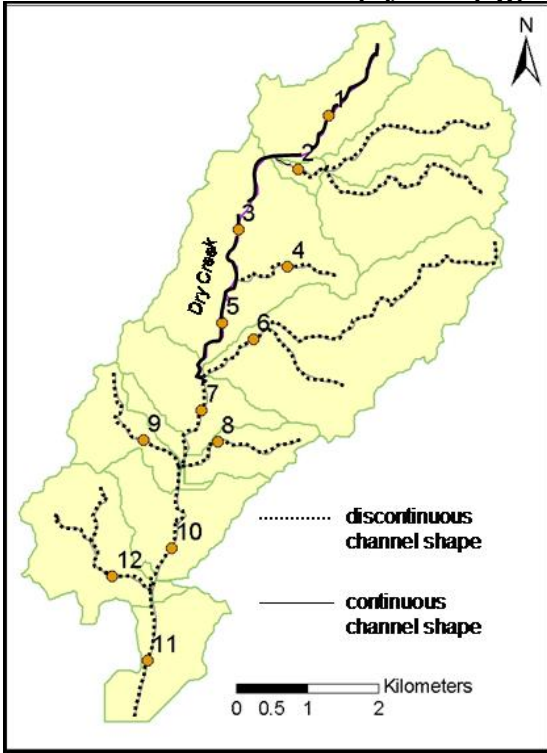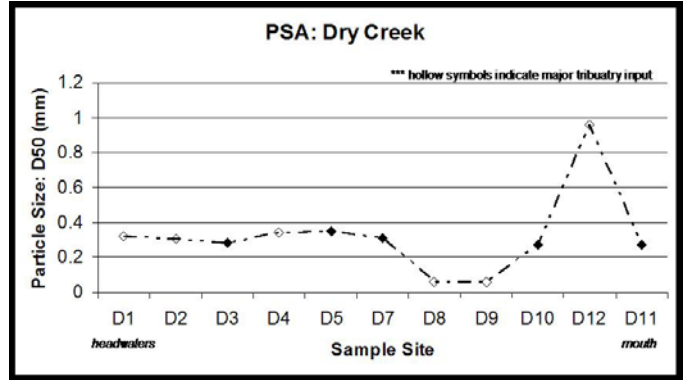
Figure 5: reach continuity in Jeffers Creek.   **Figure 6: downstream change of the D50 particle size in Jeffers Creek.**
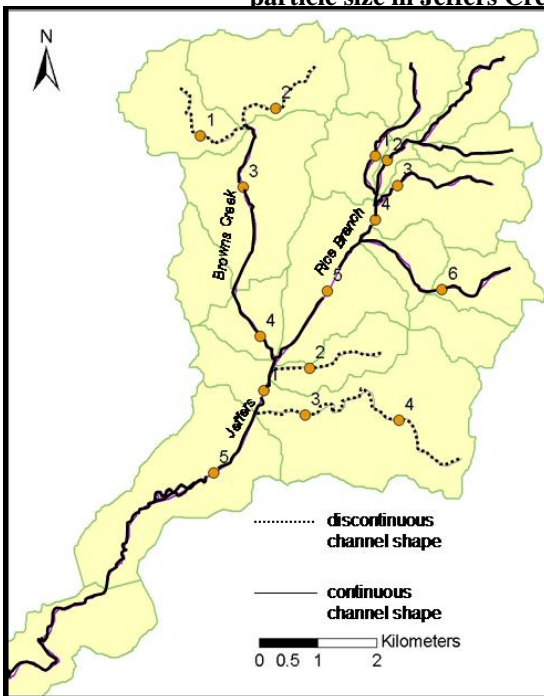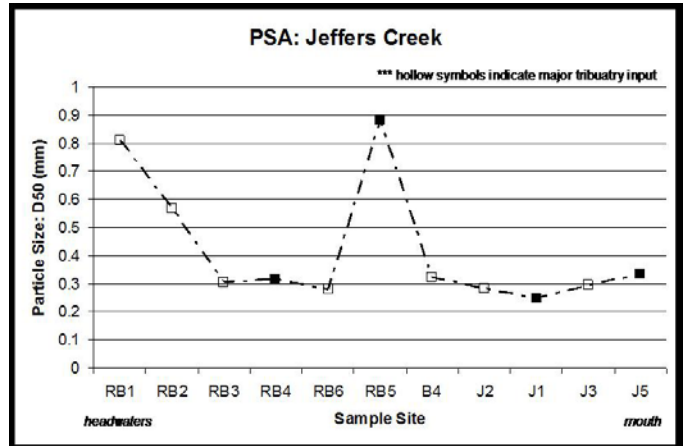
DISCUSSION AND CONCLUSIONS

Overall patterns of discontinuity and continuity in channel morphology indicate spatial variability in sediment connectivity. Because of the significant role of sediment in determining channel form, adjacent reaches exhibiting reach continuity can be assumed to have a high degree of sediment connectivity or exchange, while adjacent reaches lacking channel morphology continuity are assumed to have poor sediment connectivity. Poor sediment connectivity between some adjacent reaches suggests localized sediment sources for those reaches, in this case probably large-scale bank failures, which either satisfy local reach requirements for sediment load or overwhelm transport capacity and initiate sediment storage of some duration. This explains why Dry Creek, which has a high incidence of catastrophic bank failures, exhibited much less channel morphology continuity than Jeffers and Richland Creeks. Reaches with continuity in channel morphology suggest a high degree of sediment connectivity, with upstream reaches serving as sediment sources to their adjacent downstream partners. Observations made during field surveys suggest that the nature of this sediment transfer primarily consists of bar to bar transfers between reaches. In addition, Jeffers Creek, the watershed that exhibited the most reach continuity in channel shape, is the only one of the three study watersheds with an active and growing sediment blockage located at its mouth; it is positioned downstream of study reach J5 (Figure 5). This supports the idea that channel morphologic continuity between adjacent reaches is indicative of a high degree of sediment exchange or sediment connectivity between reaches.

Finally, results of the particle size analysis of channel material did not reveal a decrease in the median particle size in a downstream direction in any of the three study watersheds, which is generally expected due to hydraulic sorting along the course of a river (Knighton, 1998). The lack of a consistent decrease in median particle size along the profile of the study streams suggests variable source areas for sediment that are dependent upon reach-scale sediment dynamics in operation at any one location in the stream. The spatial variability of the size of the *D50* in each of the study streams does not exactly conform to the spatial pattern of the channel morphologic continuity observed. However, the general patterns are similar, with Dry Creek exhibiting the most spatial variability in the size of the *D50* along its course in conjunction with having the least amount of channel continuity amongst the three study streams. Additionally, the *D50* varied to a lesser degree in Richland and Jeffers and these streams also exhibited more channel morphologic continuity along their courses.

The results of this study suggest that connections between different components of the fluvial system do not always operate in a linear manner. It is important to understand the spatial and temporal variability of reach-scale geomorphic processes, particularly in relation to sediment dynamics, and to know the relative importance of reach-scale processes versus watershed-scale processes to understanding sediment behavior and geomorphic adjustment processes in an individual watershed.

ACKNOWLEDGEMENTS

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MODELING OF SEDIMENT DELIVERY AND CHANNEL TRANSPORT PROCESSES: CASE STUDY COMPARISON BETWEEN AN URBAN AND NON-URBAN SUBWATERSHED

Brantley A. Thames[1] and John S. Schwartz[2]

ABSTRACT

An AnnAGNPS-Concepts model was developed for two subwatersheds in the Beaver Creek watershed in Knox County, Tennessee. The two watersheds include Hines Branch, which is a highly disturbed urban subwatershed and Cox Creek, which is a subwatershed with minimal urban development. AnnAGNPS is a GIS-based sediment delivery model with land erosion rates determined by the revised universal soil loss equation. Concepts is a sediment transport and channel adjustment model that routes sediment input from AnnAGNPS and incorporates sediment inputs from channel bank erosion. Both models were developed at the USDA ARS National Sedimentation Laboratory. Research objectives for this study include: 1) applying the AnnAGNPS-Concepts model couple to learn its limitations in urban watersheds, 2) conduct a sensitivity analysis of the Concepts model to evaluate the significance of various model inputs that require field measurements (e.g., bank cohesion properties), and 3) evaluate model results between an urban and non-urban subwatershed to gain insight to dominant sediment transport dynamics resulting from urbanization of a watershed. Model results will be presented from Hines Branch and Cox Creek to meet the above research objectives as two case studies contrasting the key physical processes associated with excessive sediment transport in urban versus non-urban disturbed watersheds. Overall, the findings of this study support research to improve modeling capabilities related to development of sediment and habitat alteration TMDLs.

INTRODUCTION

The objectives of this project are two-pronged surrounding a common theme of understanding better the sediment dynamics in urbanizing watersheds. The variations in sediment discharge characteristics between urbanized and non-urbanized watersheds have received very little research attention. The Beaver Creek watershed in the northern portion of Knox County offers a graduated class of watersheds in terms of percent urbanization. The objective of this project is to make comparisons between highly urbanized and minimally urbanized subwatersheds within the Beaver Creek basin. The first analysis, by which to make these comparisons, is a modeling approach using the AnnAGNPS sediment delivery model in conjunction with the Concepts sediment transport model to describe the sediment characteristics moving through and out of these subwatersheds. Limited calibration data, such as gage data, exists within the Beaver Creek watershed; therefore, a major goal of this project will involve a sensitivity analysis of key parameters within these models. The Cox Creek subwatershed will be used as the non-urbanized case, and the Hines Branch subwatershed will be used as the urbanized case. The second analysis is a multivariate comparison of the entire Beaver Creek watershed using sediment size distributions for each subwatershed of the Beaver Creek watershed. Comparisons will be made with GIS-based variables such as percent urbanization and output from the AnnAGNPS sediment delivery model.

Stream impairment due to sediment has become an increasing concern nationally with the total maximum daily load (TMDL) limits set by the Environmental Protection Agency (EPA) over the past few years. In fact, a large percentage of streams on the 303d list in Tennessee are noted as

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being impaired due to siltation; therefore, further research is needed to determine sources and solutions to these environmental issues, especially on the impact of urbanization on sediment discharge and shifts in sediment size fractions. The modeling techniques listed above provide a vehicle by which to describe discharges and shifts in sediment size fractions.

With the advent of Geographic Information Systems (GIS), modeling on a watershed scale has become more facilitated for a wide-range of situations. These models are in a fairly infantile stage due to the recent emergence of sediment problems, and testing of such models is important in the progression of improving technology. In some cases, model output that reflects existing onsite conditions are very weak due to data constraints and calibration, but the governing equations for the most part have been field and lab tested to an acceptable level of confidence. The main governing equation forming the backbone of the AnnAGNPS model is the Revised Universal Soil Loss Equation (RUSLE). RUSLE is an empirical approach to determine an average soil loss rate. The Universal Soil Loss Equation (USLE) is the original equation for predicting soil loss rate; however, RUSLE can be used to ascertain better results in an easier way due to the introduction of new data, more involved calculation, and the facilitation with a computer program. The Concepts Stream Corridor Model employs classic sediment transport equations in order to predict sediment transport, sediment size routing, and bank failures.

In terms of the urbanized versus non-urbanized approach, several studies have been conducted to represent the effects of urbanization on sediment delivery and transport; however, limited work has been done to describe the sediment size distribution variation between classes of urbanized watersheds. Degradation of stream habitat exists in the streams affected by siltation; therefore, this study will attempt to better understand watershed processes related to siltation and model prediction limits. A few questions include: can the AnnAGNPS-Concepts modeling couple be used to accurately and feasibly represent sediment delivery and transportation through this system via a sensitivity analysis of key parameters used in this modeling couple? What are the affects of urbanization on the sediment size fractions in selected watershed?

METHODS

The goal of this research is to analyze the differences in sediment size distribution between an urbanized and non-urbanized watershed to determine if fining of bed material occurs due to urbanization. Determination of these paired watersheds is important for conducting the research, because the watersheds should be similar in size, soil composition, and rainfall distribution. In a best case, the watersheds would be identical in all aspects except land use.

A map of the entire Beaver Creek watershed is produced displaying the land use distribution in Arc View 3.3. The Beaver Creek watershed is separated into 23 subbasins based on tributaries entering the main stem of Beaver Creek. The paired watersheds will be selected from the 23 subbasins within Beaver Creek watershed. Several pairs within the watershed satisfy this description and are examined more closely to determine the most suitable pair. Percentages of urbanized areas are established to insure that the paired watersheds are drastically different in respect to urbanization. The makeup of the land use type is also observed to distinguish between highly impervious land use and moderately impervious land use. For instance, an industrial area may be more impervious than a high-density residential area; however, a low-density residential area may be much less impervious than a high-density residential area. By glancing at a land use
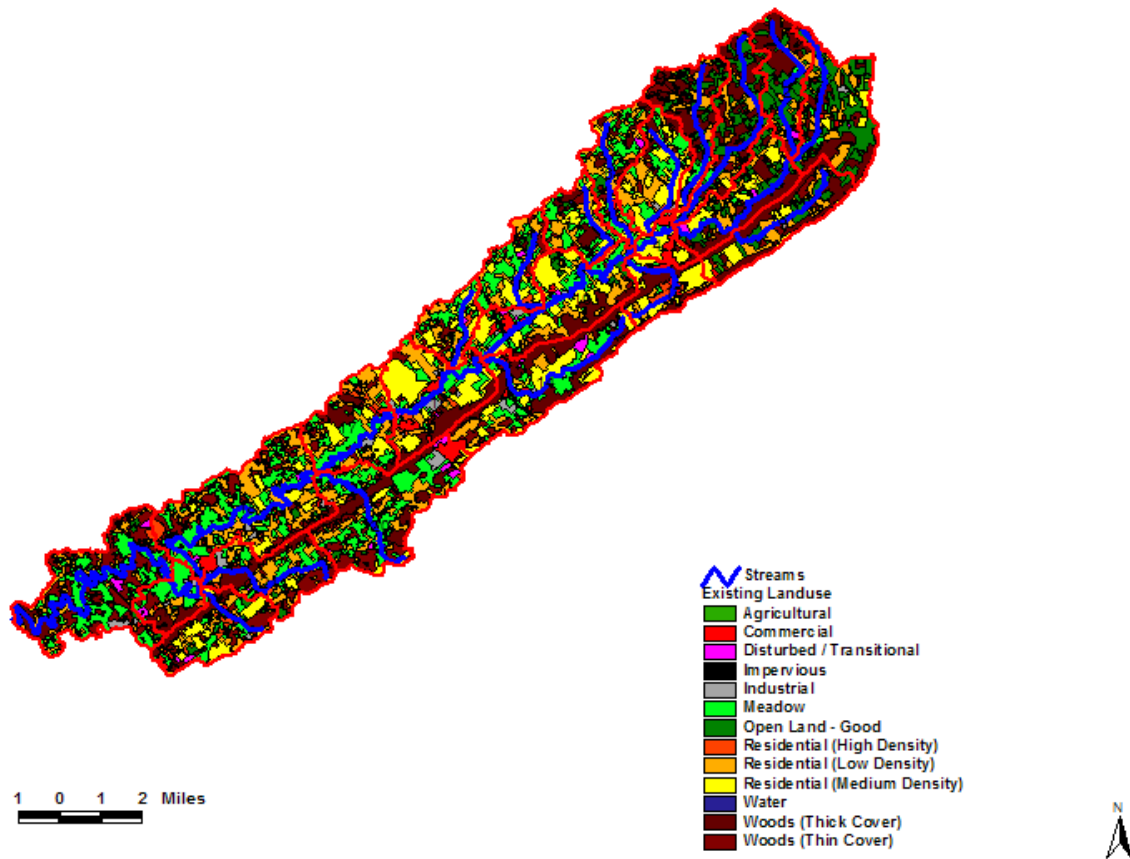
Figure 1: Existing Land use Map of Beaver Creek Watershed in Knox County, TN

overlay (Figure 1), the areas of urbanization can be misleading in the case that the subbasin contains a very large region of low density residential development, because this area may seem to be highly urbanized where only scattered impervious areas exist.

After a land use comparison of the paired watersheds, the topography of the pairs becomes more important. A stream power analysis is required to establish the ability of each reach to transport sediment. Stream power is a ratio of energy slope and effective discharge to stream width. Brookes (1987) defines stream power as a representation of energy disbursement at a particular point within a river system, and stream power is therefore linked to sediment transport, geomorphology, and channel stability. For the purposes of consistent data, the paired watersheds should exhibit similar stream power characteristics, such that, the streams in each sub basin have the same fluvial geomorphologic traits.

The Knox County government in conjunction with Knoxville Geographic Information System (KGIS) and AMEC formally OGDEN created a HEC-1 simulation to model the hydrology in the Beaver Creek watershed. Assuming the 2-yr frequency discharge was equivalent to the effective discharge, the modeled 2-yr discharge events are used to calculate the stream power values in the Beaver Creek network. KGIS also created a GIS layer of 4 ft. contour intervals. This data is used in two capacities. The first use is to determine a geologic breaking point by which to determine the locations to separate streams into reaches. Rather, than calculating an overall stream power for each stream or tributary, the streams are separate into reaches such that each reach maintains consistent gradient characteristics that are representative of the individual reach. The headwaters of most streams are much steeper than the rest of the stream; therefore using the entire length of

2A-9

each stream can greatly skew the results of the stream power analysis. The second use of the contour interval data is to actually calculate the slope of each reach. Displaying the stream and contour data in Arc View 3.3, a slope was calculated by comparing the length of each reach to the elevation change from each endpoint. A representative width is the last piece of data needed to calculate the stream power of each reach. The figure developed by Dunne and Leopold provides a correlation between basin drainage area and representative stream width in the Eastern United States. This relationship allows for the determination of a representative stream width for each reach. Field observations verify the data produced by this figure, but the verification may only succeed out of pure coincidence. The value of the stream width is not as important as other components in the equation for stream power, since it is a representative value and may vary dramatically longitudinally along the reach. However, the input data for calculating stream power is important due to the importance of stream power in the site determination process, so field verification is necessary. After all the reaches are assigned a value for stream power using Rhoads equation, a stream power network is displayed in Arc View 3.3. (See Figure 2.) Using this network, subbasins are compared to determine the suitability of the paired watersheds observed in the land use evaluation. The goal is that the reaches in each paired watershed possess similar stream power characteristics.

After all of the analysis, several paired watersheds are selected based on the similarities between drainage area, topography, soil composition, rainfall distribution, and stream power and the dissimilarities between land uses. Hines Branch and Cox Creek satisfy this relationship and are chosen for the AnnAGNPS-Concepts modeling procedure. Hines Branch is highly urbanized with similar soil composition, drainage area, and topography to Cox Creek, which possesses very little urbanization. The rainfall distributions in each watershed are analogous because the watersheds are adjacent to each other. The ranges of stream power in the paired watersheds are related; however, the stream power in Hines Branch (243 watts/m^2) is larger than Cox Creek (188 watts/m^2). This occurrence could possibly be due to the urbanization of Hines Branch increasing the 2-yr flood frequency event.
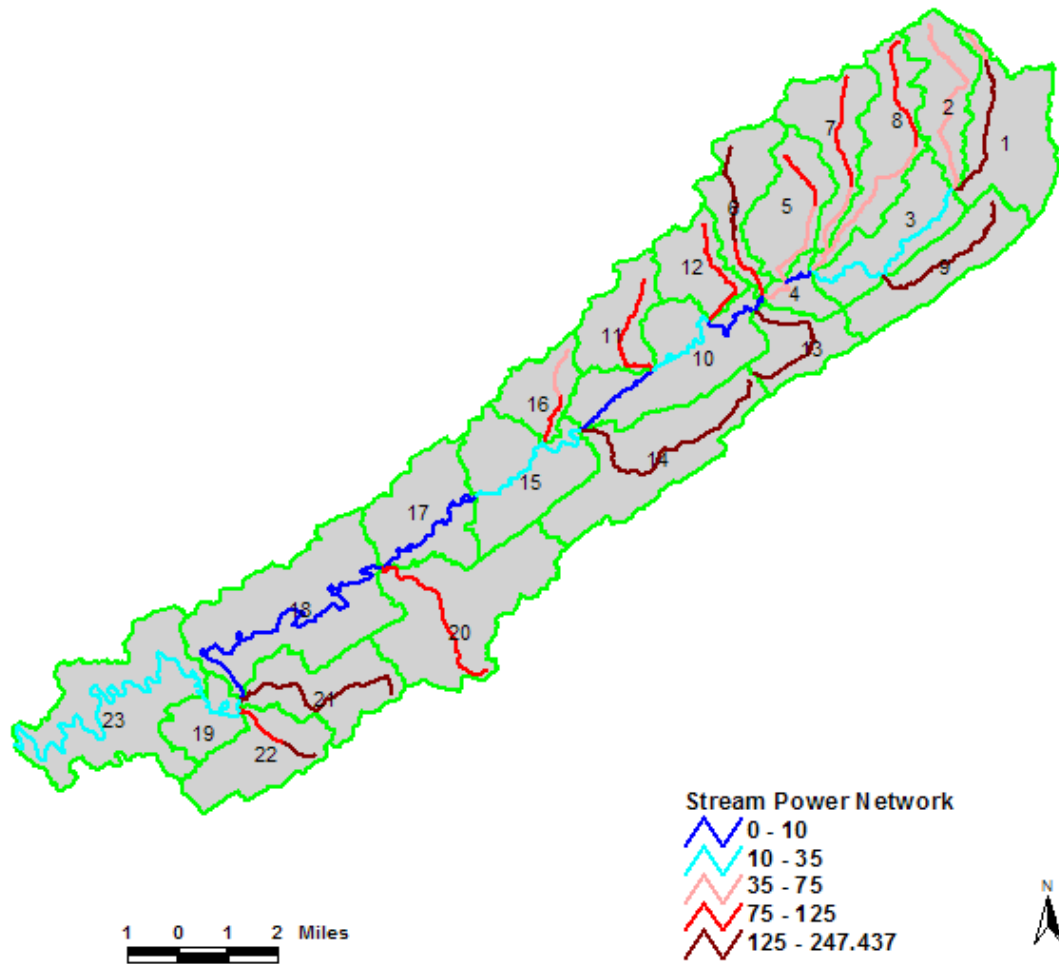
Figure 2: Stream Power Network of Beaver Watershed in Knox County, TN

After the sites for this study have been determined, field work must be done to create input data for the AnnAGNPS and Concepts models. AnnAGNPS requires several GIS input layers initially to create a model. A digital elevation model (DEM), land use, and soil (SSURGO preferred) layer must be obtained and can usually be located through government agencies. AnnAGNPS also requires that these data layers be in Universal Transverse Mercator (UTM) projections, and the model can not run without these layers being in this projection. Once these data layers are found and in the correct projection, soil and land use databases must be created to describe factors and descriptions of each soil and land use type. These databases are then read into the Input Editor portion of the model, which is where any RUSLE or hydrological factors will be placed to run a simulation. The storm and climate data is also entered into the Input Editor, and a synthetic weather generator is offered to create this data generically based on local climate gaging stations. After all input is correctly put into the Input Editor, the user has several output options to choose from in order to analyze results. In the case of this study, sediment and water are the output parameters of interest, and these outputs can be formatted into output files, which can be used as input files for the delivery of sediment and water into the Concepts model.

Concepts is a one-dimensional, unsteady sediment transport model with the capability to model bank failures, thus allowing for a quasi two-dimensional analysis laterally across the stream. The field work involved in this portion of the modeling process is much more intensive than that of

the AnnAGNPS portion. Inputs required for this model are cross-sections at an acceptable interval along the stream longitudinally. The placement of these cross-sections is dependent upon the scale of the reach length, changes in topography, and location of differing bank material. Sediment size distributions are required at each cross-section for bed and each bank material. The output files from AnnAGNPS that represent the routing of sediment and water into the reach must also be entered into the input files to route the deliveries through the study reach length. Concepts utilizes two other input file types in a hydrological file containing the flow hydrograph to be routed through the reach and a run control file that sets the simulation period, identifies the cross-sections to be considered in analysis, and other information crucial to initializing the model.

The second portion of this research involves the use of AnnAGNPS coupled with sediment size distribution samples from several different subwatersheds of Beaver Creek watershed, which is where Cox Creek and Hines Branch are located. Sediment size distributions will be determined at or near the outlet of each subwatershed of Beaver Creek watershed and compared with output from an AnnAGNPS simulation and percent urbanization of each subbasin using GIS. These comparisons will hopefully help to identify where sediment sizes exist and the implementation of a TMDL standard based on a certain sediment size fraction class in each subbasin.

The results and conclusions of this work will be presented at the Tennessee Chapter's AWRA Water Resources Symposium when the process of modeling these watersheds is completed.

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        England and Wales. Earth Surface Processes and Landforms 12, 337-351.

THE TEN COMMANDMENTS OF SEDIMENT TRANSPORT

Gary Moody[1]

INTRODUCTION

Jen-Hill is a comprehensive environmental corporation that covers all aspects of erosion and sediment control and stream and riparian protection and restoration. Jen-Hill partners with engineers, government agencies, environmental groups and contractors to assist in the design, planning, supply, QA/QC, and on-the-ground implementation of designs, selected BMP's, plants and other materials. The company uses 20 yrs of experience to design and provide technical site-specific solutions. We use Rosgen techniques to geomorphically characterize streams and apply that knowledge to the protection, construction, and restoration process. Jen-Hill is a licensed TN contractor capable of delivering a full service project. A detailed summary of the expertise of Gary Moody, Jen-Hill's lead Bioengineering /Restoration Specialist, who is a geofluvial morphologist, and a description of the range of stream restoration projects the company has performed covering design, planning, oversight, and construction, is available on request.

OBJECTIVES

To suggest the beginnings of the foundation for a bridge to merge the problem with potential solutions using the Ten Commandments as a template.

AREA OF CONCENTRATION

Construction and Industrial sites.

1st Commandment:
Regulatory-Legal: Thou shalt protect the surface water's beneficial
                                uses-for the survival or well being of man, plants and wildlife. (CWA
                                1.2.7)
Philosophical-Moral: The protection of tangible and intangible economic, social,
                                and environmental goals of all mankind.
Practical-Solution: The SWPPP includes 6 major phases. Because selection
                                of these controls depends on site conditions at the time of the phase
                                (moving targets), The practical solution for commandment 1, is
                                commandments 2 through 10. (4.6.3)

2nd Commandment:
Regulatory-Legal: Thou shalt choose &/or include "site specific" controls,
                                methods and installations. (1.4.6.2)
Philosophical-Moral: Sites are "DYNAMIC" One size "does not" fit all.
Practical-Solution: Work everlastingly (ceaselessly) for control learning how to
                                        Choose_____the proper BMP
                                        Position_____the BMP
                                        Change_____(modify) the BMP and
                                        Harness_____the attributes of the BMP

3rd Commandment:
Regulatory-Legal: Thou shalt reduce sediment by understanding the
                                comparative anatomy of erosion (source control) including

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soils, vegetation, topography, climate, and season. (2.3.0-
3.5)

Philosophical-Moral: Good intentions do not a best solution make.   "If a man . . .
takes an oath to bind himself . . . he shall not violate his word"
(Numbers 30:2).

Practical-Solution: Become a <u>PROFESSIONAL</u>. Educate yourself and
your workers. Help your operators and workers understand the
problem and how to solve it. Familiarity overcomes inertia and builds
confidence and competence. "Do not" cut corners on education,
products, personnel or equipment.   Explore the latest technology and
perform personal product assessments keeping records of successes and
failures. Listen and Change….

4th Commandment

Regulatory-Legal: Thou shalt divide and conquer. (2.6.3)

Philosophical-Moral: Less is best. Keep the drainage areas separate and
manageable. (SEPARATE and ISOLATE).

Practical-Solution: Use less invasive equipment in sensitive areas. Work on
sensitive areas either first or last but not at the same time.
berms or swales can help separate areas. Smaller or
low ground pressure equipment combined with proper
timing can increase production and reduce damage.
Consider subbing creek crossings and wetland work to
professionals.

5th Commandment

Regulatory-Legal: Thou shalt perform maintenance, maintenance, and more
maintenance. (4.6.3 & 4.6.5)

Philosophical-Moral: The term "TREATMENT" does not refer to a single event.
If it is working at greater than 60% capacity and 90+%
efficiency and there are no storms or additional
disturbances forthcoming, leave it alone. If not, be aware
that you can be fined for potential, and that potential equals
actuality in TN.

Practical-Solution: Maintain safety margins and freeboard in the system.
Develop a treatment-train approach. Do not rely on
individual or last line of defense (perimeter) products.

6th Commandment:

Regulatory-Legal: Thou shalt commit thy Owner, thy Company, and thy
esteem to the realization of the 1st Commandment as it is
interpreted in the SWPPP. (4.6.4)

Philosophical-Moral: "Visiting the iniquity of the fathers upon the children"
Translation: Spread the responsibility for
one person's sin (violation) among all legally responsible
parties. There shall be no confusion as to responsibility.
Liability is assumed upon signing.

Practical-Solution: Deliver on your promise.

7th Commandment:

Regulatory-Legal: Thou shalt not make unto thee any graven (engrave into
hard surfaces) images

Philosophical-Moral: Nature is jealous. She is simple in offering her secrets and

harsh in her lessons. She is rewarding of individuals that have the spirit and capacity to restore.

Practical-Solution: Remove as many trees as possible with a tree setter. Replant in sparse areas or after the crossing is repaired. Push down vs cut-off trees where possible to create rootwads for other restorations. Save the log portions for additional bank protection and to build a bankfull bench. Save the willow, sycamore, and species that grow from live stakes and Re-plant vs Rip-rap to stabilize banks (toes may require rip-rap.) Enhance the area of the crossing. Limb up the bank side (not the water side) of trees to allow sunlight into the newly planted grasses and understory.

8th Commandment:

Regulatory-Legal: Thou shalt seek professional help with your erosion and sediment control problems and one of those cannot be your Barber.   View proper sediment control as effective stress management.

Philosophical-Moral: Professional help is not synonymous with Specialist or Engineer

Practical-Solution: Don't confuse an Erosion and Sediment Control Professional with an inexperienced engineer, or a silt fence and erosion control matting installation contractor. TDOT Level II should be the absolute min. I recommend a CPESC or CPSWQ. Rosgen training is also preferred. A professional should be trained, knowledgeable and competent in any situation.
We should consider a tiered approach to the renewal of a Contractor's license. The firms CEO should receive training in the law and the spirit of the law. The firms Superintendents should receive training in the SWPPP and the spirit of the SWPPP. BMP has to become synonymous with Behavioral Management Procedures.   Ignorance is not bliss, and an Erosion Control Professional should be seen as a Time Management-Crisis Management-Stress Relief- and Economic Relief strategy or policy. Mediocre people and products yield mediocre results.

9th Commandment:

Regulatory-Legal: Thou shalt not adversely affect or do economic damage to individuals and society in general. (2.2.0)

Philosophical-Moral: Thou shalt love thy neighbor as thyself

Practical-Solution: "Move back and no one will get hurt"
Encroachment…Traditional construction practices…Down the watershed approach. DIVERT & DIRECT rather than use traditional construction practices which may negatively affect other water sources.
You should not only think about the legal consequences, but consider the moral and social consequences of your work to ensure that consideration and respect for fellow citizens has been rendered. Percolate it where it originates in design, construction, and in true LIDs.

Turns out you can predict the future.

10th Commandment:

Regulatory-Legal: Thou shalt address not only the pollutant load but also
velocity dissipation. (4.6.3)

Philosophical-Moral: Construction phases pose problems with sediment and
other pollutants. A treatment train that includes Filtration,

Dissipation, Dispersal, Isolation, and Control are necessary
during this phase. Post Construction WQU's provide clear
(hungry) water discharges. To avoid incision of, and allow
a mixing zone with, receiving waters, energy dissipation is
required. Waters of the state should be protected or
enhanced to receive the additional and longer duration f
flows to retain channel stability.

Practical-Solution   5X Outlet HW without head. 10X Outlet HW with head. 50
X Depth of water original velocity returns. Pre-determined headcuts,
Compound pool sequences. Other.

Final thoughts: A saying of mine that sparked a threat of legal action from a Contractor has
become one of my favorites. I asked them to consider, with all the technology and expertise, is it
Ignorance, Arrogance, or Indifference, that interferes with moving from the problem side to the
solution side?

We should all understand that only an unwavering commitment and ongoing investment, which
includes the aggressive and proactive approach
"Don't tell me what is says, show me what it means" will allow us to deliver on our promise of
equitable and sustainable natural resources to future generations.

General definitions:

1. CWA doesn't mean "Cover Williams As…"
2. CFS Doesn't mean "Channel Full of Silt" it does mean Cu Ft/Sec
    and Clear Flowing Streams
3. **DDISC** is a Jen-Hill term meaning DISSIPATE, DIFFUSE
    SEPARATE, ISOLATE, and CONTROL
4. The THREE C'S! When I was growing up my best friend and I
    created a sports acronym similar to the 3 R's. For us it was Coolness,
    Calmness, and Greatness. Today in our business we still have the 3
    C's but now it's   CONFIDENCE (familiarity), COMPETENCE
    (familiarity & education) & COMPATIBILITY
    (**Merriam-Webster Online**.**3 :** remarkable in magnitude, degree, or
    effectiveness)
5. Interfere: to act reciprocally so as to augment, diminish, or
    otherwise affect

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KF. Episode 166 Master Poe speaking to KCC:
Still glides the stream, and shall forever glide; the form remains; the function never dies. William Wordsworth (1770-1850) Sonnets from The River Duddon,
1820: After-Thought verses 5 & 6

Arthur Streeton, STILL GLIDES THE STREAM AND SHALL FOREVER GLIDE, 1890

MICROMODELING: A LOOSE-BED STUDY OF THE LOOSAHATCHIE-MEMPHIS REACH OF THE MISSISSIPPI RIVER

R.A. Gaines[1]* and Douglas W. Max[2]

ABSTRACT

A micro model study was initiated on the Mississippi River to provide insight into a complex navigation problem in the Loosahatchie-Memphis reach near Memphis, Tennessee. The micro model technique uses a small, highly distorted scale physical sediment model to evaluate the sediment transport and morphologic trends that could be expected to occur in the river when various channel improvement alternatives are placed in the reach. Large physical models have long been used to study complex riverine problems with great success. In recent years, the cost of these models prohibits their use leaving a void in available physical loose-bed modeling tools. To fill this void, Mr. Robert Davinroy of the St. Louis District Corps of Engineers developed a table-top, loose-bed modeling process which he termed Micro Modeling. The micro model consists of an insert that simulates the outline of the river in plan form, a flume base that holds the insert and contains the ancillary equipment necessary to provide water and sediment to the model. A computerized controller operates a ball valve to control the flow input to the model. Sediment consisting of polyester, specific gravity 1.28, was used in the Loosahatchie-Memphis micro model. The micro model technique was used in the Loosahatchie-Memphis reach of the Mississippi River to develop a series of alternatives that could reduce yearly dredging. Several of the most promising alternatives were chosen for possible implementation in the prototype and a team of engineers scrutinized the prime alternatives to determine the most practicable and cost effective alternative. This paper presents studies associated with improving navigation.

STUDY REACH

The Memphis-Loosahatchie reach is located on the Lower Mississippi River adjacent to the city of Memphis, Tennessee (Figures 1and 2). The study began near Mile 746.0 approximately 9½ Miles upstream from the Hernando Desoto Interstate 40 (I-40) Bridge and extended ½ mile downstream of the bridge to Mile 736.0, a distance of 10 miles. Beginning at Mile 746.0 the channel generally curves toward the southeast to Mile 740.5 where a fairly straight approach to the I-40 Bridge has been developed. The reach has numerous side channels and islands on both the left and right channel banks. Sandbars and wooded bars are present in the Above Loosahatchie, Redman Point, Sycamore Chute, Loosahatchie Bar, Robinson Crusoe and Hopefield Point dike fields. The Wolf and Loosahatchie Rivers converge with the Mississippi River within this reach as well.

REACH HISTORY

In the late 1800s serious bank caving occurred along the Memphis City Front that resulted in the loss of valuable property. "Between 1873 and 1876 over 350 feet of bluff had caved in at the foot of Jefferson Street, and the process was continuing at the rate of 100 feet per year."[1] The rate of erosion was even greater above the mouth of the Wolf River.[1] As a result of this caving, bank protection of the Mississippi River in the Memphis-Loosahatchie Reach began in 1878. Willows and other types of tree branches were woven into a fascine mattress and placed on the left descending bank at a cost of $508,000.[1] Construction of this mattress was interrupted on two different occasions when sieges of Yellow Fever closed down the operation.[2]

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In 1886, local interest expended over $43,000 dollars for the construction of spur dikes. These dikes were later maintained and eventually replaced by the Corps of Engineers. In 1915, eight crib and rock dikes were placed in this vicinity with the express purpose of protecting this same river bank from significant caving and to maintain a stable navigation alignment through the reach.[1]

The Redman Point dike field, Mile 743.0, was constructed in 1958 using wooden pile dikes to reduce excessive flow in the chute channel west of Redman Point Bar. It was thought that this action would decrease the flow through the back channel and lessen the deterioration of the main channel, which was becoming hazardous to navigation[1]. Since 1958, eight dike fields containing approximately 36 dikes were constructed in this reach. Many of these dikes were constructed to reduce the amount of flow going down the chute channels, with some built to improve navigation alignment and crossing depths. As a result of this work, most of the chute channels were closed off from the river at low river stages.

PREVIOUS STUDIES

The historical navigation problems in the Loosahatchie-Memphis reach and associated high dredging costs prompted the Memphis District to use a large-scale physical model to assess alternatives for improved navigation in the late 1980s. The US Army Corps of Engineers Waterways Experiment Station (WES) conducted a movable-bed model investigation for the reach between Miles 733.8 and 745.0 during the period from March 1987 to June 1995.[3] The WES study analyzed eight alternatives. Plan F-Modified consisted of structures placed in the river during the course of the model study and included new or modified structures within the reach. The study report stated that Plan F-Modified "produced a satisfactory navigation channel, but as with all plans evaluated during this study, this plan showed a tendency to shoal in the upstream approach to the I-40 Highway bridge." Plan F-Modified, with slight changes in dike elevations, was essentially constructed in the prototype as modeled with the exception that Robinson Crusoe Dike Number 1 was not completely raised as recommended from the model study.

In the period following construction of the adapted Plan F-Modified, dredging has been required on a consistent basis. Dredging records from 1976 to 2003 show only two years, 1979 and 1986, in which dredging was not required somewhere between Miles 736.0 and 746.0. Of interest, the WES model was verified to the 1986 prototype behavior. The total amount of material dredged from 1976 to 2003 amounted to approximately 77,000,000 cubic yards (2.8 million cubic yards per year average) at a cost of over $27,000,000 ($1 million/year average). Figure 3 shows dredging in this reach from 1976 to 2003.

CURRENT STUDY

Between Miles 747.0 downstream to Mile 736.0 the Loosahatchie-Memphis reach has very little curvature. Due to the absence of curvature, the normal meander pattern of sharp bends with deep pools and shallow crossings is not present. Also absent is a predictable thalweg location. The long, fairly straight, reach has a tendency to produce a shallow channel with an unstable thalweg that requires an excessive amount of dredging to maintain a reliable navigation channel. The major purpose of the study was to investigate the addition or alteration of various structures which, when changed or placed in the model, would reveal a tendency to reduce dredging requirements through the reach.

The micro model for this study used scales of 1 inch = 400 feet horizontal and 1 inch = 40 feet vertical producing a distortion ratio of 10:1. The model produced Froude number ratios of 3.0 and 2.2, model to prototype, for low and high flows, respectively. The model layout used recent high-resolution aerial photography of the Mississippi River to define bank lines, islands, and other pertinent landscape features. The resulting model template was placed in a large table-top flume 5-feet wide and 17.3-feet long (Figure 4). Model calibration utilized recent hydrographic surveys obtained in 1999, 2001, 2002, and 2003. During calibration, modeling clay and crushed limestone were used to simulate non-erodable material and to lessen scale effects where known revetment and hard point locations exist in the prototype.

During calibration, prototype hydrographic surveys served to determine the general trends that occur in the river bed through the model reach. However, each prototype survey for the Loosahatchie-Memphis reach displayed different trends, especially in thalweg location. Absent recent construction activities, the only viable explanation for the shifts in thalweg was due to the presence of secondary current patterns within the reach. Variability in prototype bathymetry and thalweg location evident from prototype surveys significantly complicated calibration of the Loosahatchie-Memphis micro model. Examination of the 2001 and 2002 surveys provides an example of the variability: a large bar present in the 2001 survey along the left bank at Above Loosahatchie Dike Number 6 was completely gone in the 2002 survey; also a large bar along the Island 40 revetment in the 2001 survey was absent in the 2002 survey.   Because it was not possible to establish actual prototype trends over time, the calibrated model was adjusted to attempt to capture trends that existed in at least one of the prototype surveys. By doing so, the study team members agreed that the model could be used to test alternative designs in an effort to remedy the severe dredging problems. The calibrated model served as the base test condition used in evaluating alternative response.

In all, twenty-six alternatives were tested in the model. Five of these alternatives focused on environmental restoration within the chute channels. Table 1 outlines relative bathymetric changes produced by each alternative. Each alternative was compared to the base test to determine the effects of a particular alternative on the bathymetry in the three locations where most dredging occurs. To be considered viable alternatives, model designs were required to alter bathymetry in the navigation channel by either moderate or significant amounts in at least two of the three problem areas.   The five most promising plans meeting these criteria were selected for additional consideration. A brief description of each alternative's objective follows. A complete description of alternative features and observed model response can be found in the draft study report.[4]

Alternative 4 used low-water weirs to realign the channel between Miles 741 to 745 to improve navigation depths in the lower Island 40 revetment crossing and dike extensions to constrict the channel width to approximately 1800 feet from Miles 738 to 739.5 to improve depths.

Alternative 7 included dike extensions to constrict the channel width to approximately 1800 feet from Miles 738 to 739.5. This alternative was tested to assess the effect of extending dikes to improve depths and to constrict thalweg migration.

Alternative 16 consisted of the most significant changes proposed among tested scenarios. This alternative narrowed the low-flow channel between Mile 744.3 and the I-40 bridge to a width of 1500 feet.

Alternative 20 was developed to produce a low-flow channel width of approximately 1800 feet. Various dikes in the reach were extended to accomplish this level of contraction.

Alternative 21 was similar to Alternative 20 except this alternative also attempted to shift the thalweg from the right descending bank towards the left bank several miles upstream of the present crossing adjacent to the Island 40 revetment. Several dikes were removed in the Above Loosahatchie Dike field. Dikes throughout the reach were extended to create a contracted low-flow channel width of approximately 1800 feet.

CONCLUSIONS

Providing a reliable navigation channel in the Memphis-Loosahatchie reach with minimal dredging maintenance proved difficult. Of the five alternatives considered to be viable, Alternative 4 is the preferred choice. However, no single alternative tested during this model study solved all dredging and alignment problems. Yet, there are promising improvements that result from select alternatives tested in the model. Those results warrant consideration by engineers and scientists for implementation in the prototype. As with other complex problem areas along the Mississippi River, phased construction over a period of years could be used to "tweak" the river in order to reduce required dredging while reducing the risks of full-scale implementation of any single alternative.

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TABLE 1

COMPARISON OF DESIGN ALTERNATIVES
LOOSAHATCHIE-MEMPHIS MICRO MODEL STUDY MISSISSIPPI RIVER, MILES 746.0 to 736.0

Alt	Effect on Bathymetry, Miles 744.5 to 742.8				Effect on Bathymetry, Miles 742.0 to 739.9				Effect on Bathymetry, Miles 738.0 to 736.1				Shift In Thalweg Location
	Neg./None	Slight Change	Moderate Change	Significant Change	Neg./None	Slight Change	Moderate Change	Significant Change	Neg./None	Slight Change	Moderate Change	Significant Change	
1	X				X				X				No
2	X					X				X			No
3		X			X					X			No
4				X		X					X		No
5	X				X						X		No
6	X					X						X	No
7			X		X							X	No
8	X				X					X			No
9	X				X				X				No
10	X				X				X				No
11	X				X				X				No
12	X					X					X		No
13	X				X				X				No
14	X				X					X			No
15	X				X				X				Yes
16		X					X					X	Significant
17	X					X					X		Yes d/s
18	X				X					X			No
19		X				X				X			Yes u/s
20	X							X			X		No
21				X			X					X	Significant
22*		X			X					X			Slight
23*	X					X				X			No
24*	X						X			X			No
25*	X					X					X		Yes u/s
26*			X				X					X	Yes

*Alternatives focused on environmental enhancement in Chute Channels
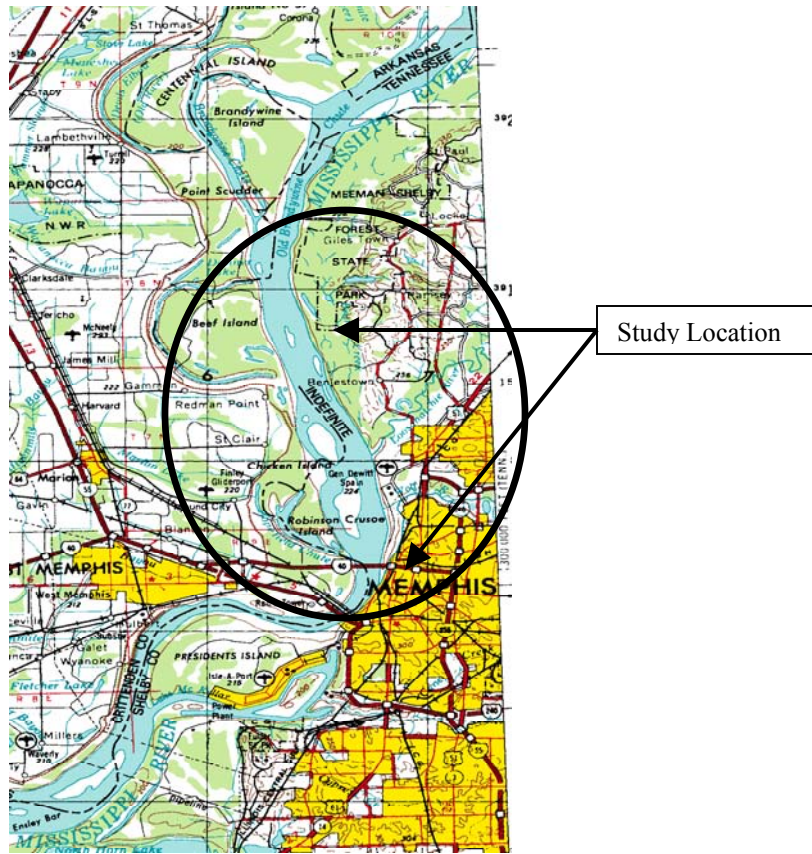
Figure 1 Vicinity Map

Figure 2 Study Reach
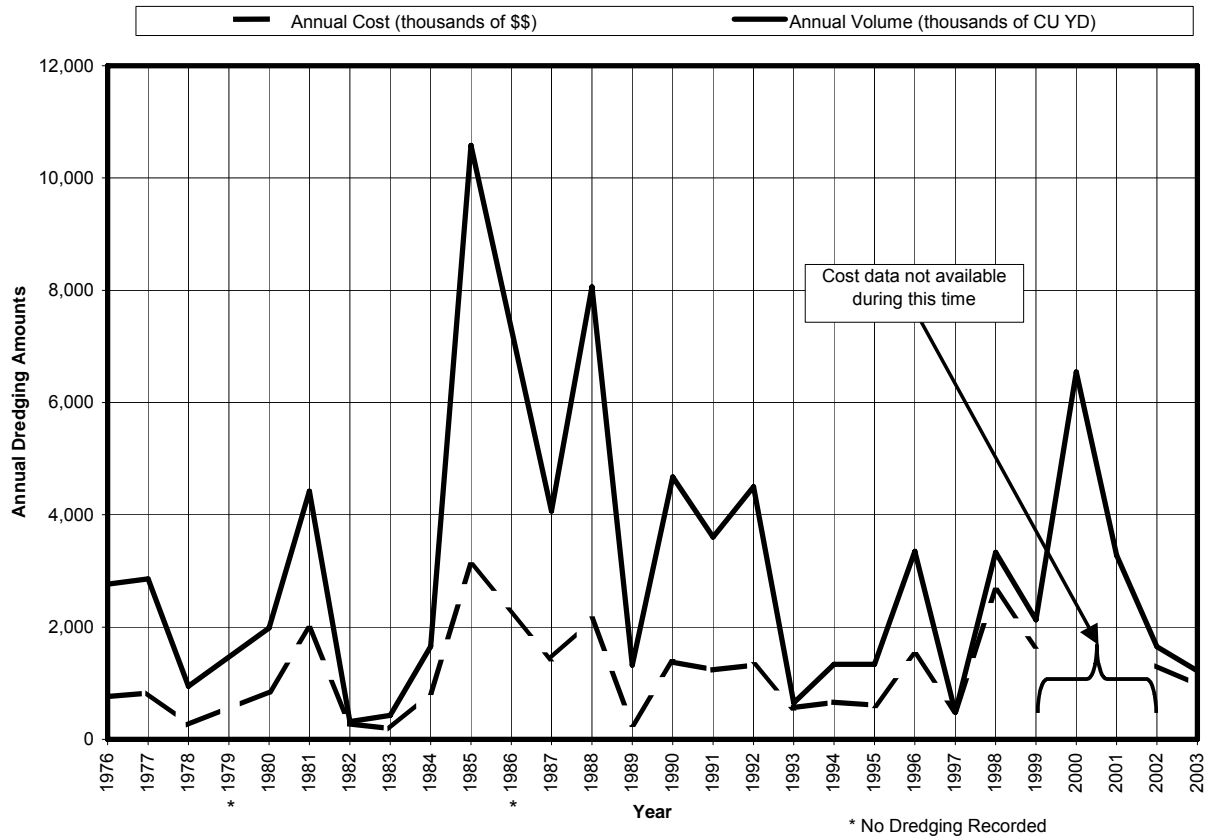
Figure 3 Dredging History, Loosahatchie-Memphis Reach
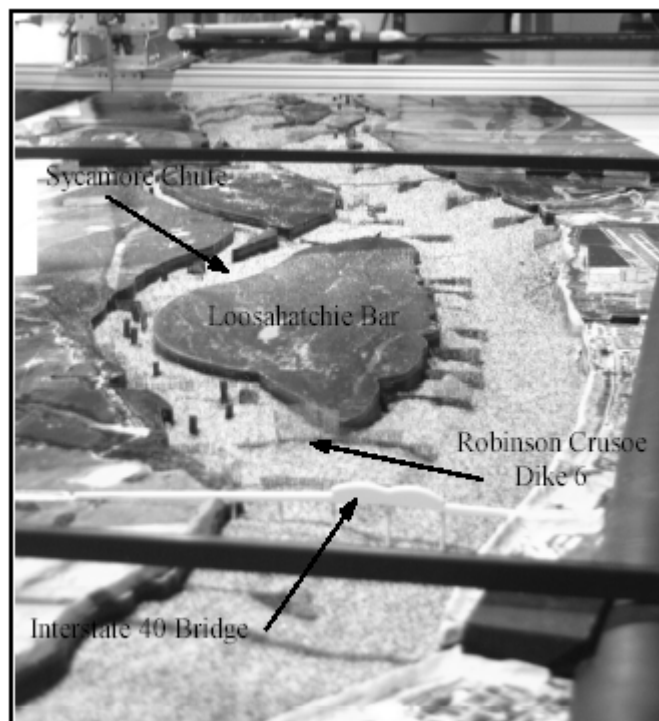
Figure 4 Micro Model Insert

ENVIRONMENTAL RESTORATION:
A MICRO MODEL STUDY

Douglas W. Max[1]*, John P. Rumancik Jr.[2] * and R.A. Gaines[3]

ABSTRACT

The Memphis District Corps of Engineers conducted a moveable bed model study on the Mississippi River near Memphis, Tennessee, to obtain insight into a complex navigation problem along this troublesome reach of the river. One component of this study investigated ways to restore environmental diversity in the side channels through structural additions and/or modifications. The goal of this segment was to look at ways to restore back channel fishery and aquatic habitats that have been lost throughout the river system. Various structures were placed in the model chute channels, including environmental notches, alternating dikes, chevrons and round points. Alternating low, medium, and high flows were then generated to simulate the wetting and drying effects of the sandbars and chute channels. These alternatives were designed to create environmental diversity in the chute channels and, at the same time, preserve the integrity of the navigation channel since navigation safety was paramount. The effectiveness of each plan was determined by comparison to a base test. Several of the most promising options will be chosen for implementation in the river utilizing a phased construction approach. A team of biologists and engineers scrutinized a range of conditions to rank those alternatives that provided the most effective environmental restoration features with consideration given for navigation, constructability and cost effectiveness.

INTRODUCTION

The Memphis-Loosahatchie reach is located on the Lower Mississippi River adjacent to the city of Memphis, Tennessee (Figures 1and 2). The study began near Mile 746.0 approximately 9½ Miles upstream from the Hernando Desoto Interstate 40 (I-40) Bridge and extended ½ mile downstream of the bridge to Mile 736.0, a distance of 10 miles. Beginning at Mile 746.0 the channel generally curves toward the southeast to Mile 740.5 where a fairly straight approach to the I-40 Bridge has been developed. Once through the bridge the channel makes a sharp right-hand bend to the west as it passes through two railroad bridges, Interstate 55 (I-55) and on to the end of the reach. This reach is characterized by numerous side channels and islands on both the left and right channel banks. Some of the older bars that formed when the river meandered are now wooded islands. Many of the chutes behind the sandbars have dikes which close off flow except during high water events. These closures have reduced water flow and fish passage required to sustain a healthy river fishery. Opening these back channels with dike notches and adding various rock structures would help restore lost aquatic river habitat.

RIVER HISTORY

In the late 1800s serious bank caving was occurring along the Memphis City Front resulting in the loss of valuable riverfront property.[a] "Between 1873 and 1876 over 350 feet of bluff had caved in at the foot of Jefferson Street, and the process was continuing at the rate of 100 feet per year." The rate of erosion was even greater above the mouth of the Wolf River.[b] As a result of this caving, bank protection of the Mississippi River in the Memphis-Loosahatchie Reach began in 1878. Willows and other types of tree branches were woven into a fascine mattress and placed

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on the left descending bank at a cost of $508,000[a]. Construction of this mattress was interrupted on two different occasions when sieges of Yellow Fever closed down the operation.[b]

In 1886, local interest expended over $43,000 dollars for the construction of spur dikes. These dikes were later maintained and eventually replaced by the Corps of Engineers. Twenty-nine years later, in 1915, eight crib and rock dikes were placed in this vicinity with the express purpose of protecting this same river bank from significant caving and to maintain a stable navigation alignment through the reach.[a]

The Redman Point dike field, Mile 743.0, was constructed in 1958 using wooden pile dikes to reduce excessive flow in the chute channel west of Redman Point Bar. It was thought that this action would decrease the flow through the back channel and lessen the deterioration of the main channel, which was becoming hazardous to navigation. Since 1958, eight dike fields containing approximately 36 dikes were constructed in this reach. Many of these dikes were constructed to reduce the amount of flow going down the chute channels, with some built to improve navigation alignment and crossing depths.[a] As a result of this work, most of the chute channels were closed off from the river at low river stages. This greatly reduced a habitat area that is important to the overall river fishery.

ENVIRONMENTAL CONSIDERATIONS

During the early days of river engineering very little thought was given to preserving aquatic habitat or maintaining ecological diversity in the river. Large river ecology was still unknown and, since the river was so large, back channel habitats were not given a great deal of consideration. As a result, there were no planned restorational components included with the construction projects, and the only environmental characteristics remaining after construction were those features that remained through happenstance. The passing of years has brought a new consciousness of the environment and the awareness of a necessity to preserve, protect and enhance ecosystems, not only during construction, but also to restore lost habitat when the opportunity arises. It is now known that back channel aquatic habitat is vital for a healthy river.

Habitat restoration features tested in the micro model were the results of previous interagency meetings among the U.S. Army Corps of Engineers, the Arkansas Game and Fish Commission, the Tennessee Wildlife Resources Agency, the U.S. Fish and Wildlife Service and the Lower Mississippi River Conservation Committee. Each state involved asked the Corps to help design and install projects on the Mississippi River specifically for habitat restoration in the back channel chutes. The Corps of Engineers agreed to participate in this effort provided there was a willing sponsor for the project. All agencies are now cooperating as one team to help prevent further habitat losses and begin restoring some of that which has been lost. This exciting new cooperation, a model in itself, is still in its infancy, but the first step of identifying overall preliminary locations for restoration projects has been completed. The second step of prioritizing restoration projects is now under way. This paper reports on a model study in which environmental restoration was included as a major consideration.

THE MICRO MODEL

Micro modeling is the use of a small-scale, physical, moveable-bed model to study prototype river conditions including the response to training structures placed in the model. The micro model consists of an insert that replicates the outline of the river in plan form and a flume base that holds the insert and contains the supplementary equipment necessary to supply water and sediment to the model. The insert was constructed according to recent high-resolution aerial photography of the Mississippi River and then placed in a large scale hydraulic flume 5 feet wide

and 17.33 feet long (Figure 3). Sediment was simulated using a fine granular 16/20 Type I polyester media with a specific gravity of 1.28. Rock structures and dikes were simulated with a small-mesh wire screen. Water stages and structure elevations were manually checked with a mechanical point gage attached to a sliding rail system as shown in Figure 4. Sediment transport was simulated through the model by introducing a variable shape hydrograph of approximately 18 minutes in length. This hydrograph was produced by stepping an electronically controlled valve through a user defined opening and closing sequence to control the water flow through the model. The resulting hydrograph consisted of five medium hydrographic peak flows of 7 to 8 gpm, with low flows of around 4.5 gpm. One hydrograph had a peak flow of approximately 12.0 gpm which occurred every sixth cycle. Flow was controlled by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to automatically simulate repeatable discharge hydrographs in the model and allowed wetting and drying of the sandbars with maximum and minimum flow in the chute channels.

HABITAT RESTORATION RESULTS

In the first model runs, several alternatives were placed in the Sycamore Chute side channel, an old river channel on the west bank just upstream of the I-40 Bridge. Alternatives included notches in Robinson Crusoe Dikes 1, 5, and 6, short alternating dikes, chevrons (small U-shaped dikes) and round points (high cones of rock) in an effort to develop a sinuous channel through the chute. Each of these alternatives provided additional or revised habitat. Figures 5, 6, 7 and 8 show a combination of these structures throughout the reach for a utopian habitat restoration design. In general, chevrons and round points were placed so that each successive downstream structure took advantage of the current patterns developed by the next upstream structure. These patterns were depicted using flow visualization techniques with polyester confetti.

Many combinations of structures were proposed and tried in the model including raising portions of existing dikes, installing new dikes, closing off unwanted chutes with rock revetment, notching existing dikes, widening and deepening existing notches, and installing round points and chevrons. The addition of these features in the chute channels provided additional habitat diversity. Structures were placed so that sinusoidal channels, deep holes, shallow flats and sandbars were formed. The variety of vertical relief created in this restoration effort would provide diverse spawning and rearing habitats for many different fish species.

It was observed that round points, Figures 5 and 6, greatly influenced river currents and habitat diversity. The model indicated that water currents usually deflected at approximately a 35-degree angle after passing a round point, depending upon the water velocity and river stage. Using this observation, round points were placed in tactical positions to divert flows to create a sinuous thalweg in the back channels. The most successful use of round points was just upstream of the I-40 Bridge in Sycamore Chute where a large sand bar now closes off the back chute at low river stages (Figures 3 and 5). A combination of notches, round points, two small dikes, and raising the middle portion of Robinson Crusoe Dike 6 resulted in a chute channel in the model that was open year round. This scenario would provide several miles of fish passage from the river up into the back chute as well as small boat access to take advantage of the fishing opportunities around the rock structures. Round points were also successfully placed in the side channels around and upstream of Hickman Bar in the upper reach of the project (Figure 6).

Chevrons were used to provide a wider and smoother current deflection (Figure 8). The angle and width of the wings determined how much the river currents were deflected and how quickly the surface currents merged after passing the chevron. Flow visualization indicated that chevrons separated surface current patterns with the confetti moving along each wing of the chevron. There were some eddy currents just downstream of the chevron; however, a majority of the

confetti remained separated for several hundred feet downstream of the structure after which there was a tendency for the confetti to become mixed in the flow schemes. Scour holes occurred in front of, alongside and also just downstream of each chevron. Most chevrons also developed a middle bar a few hundred feet downstream. In general, chevrons produced the most diverse bottom topography and therefore the best localized habitat diversity.

The endangered interior least tern has begun nesting in this reach with a colony on the bar between Sycamore Chute Dikes 2 and 3. The colony was of concern and to preserve the integrity of the site, a short un-attached dike, Sycamore Chute Dike 1U, was added and Dike 2 was notched, with two chevrons strategically placed downstream of the notch. This scheme enhanced the nesting site by keeping it isolated from the riverbank while still diverting flow through the Sycamore Chute channel and providing additional diversity around the structures. This bar could also be used for spawning by the endangered pallid sturgeon during higher river stages.

CONCLUSIONS

The use of micro modeling techniques proved to be a very useful tool in looking at various structural types to improve the navigation channel and still produce ecological diversity in the chute channels. The sizes and shapes of chevrons, round points and dikes affected the bathymetric relief observed in the model with the dikes and larger chevrons producing more topographical relief than the round points and smaller chevrons. However, strategic placement of a structure in relationship to other structures also affected scour, deposition and thalweg development to a great degree. It was found that placing a chevron directly downstream of a notch in a dike split the currents and provided more diversity. It was also learned that placing round points downstream of and offset in the path of the chevron wing took advantage of the current split created by the chevron and created additional habitat through development of a sinusoidal thalweg. The use of a small model to look at various structural features to restore habitat diversity proved to be a successful venture. Future efforts along this line are expected to provide the environmental community with another tool with which to evaluate habitat restoration in other venues. As some of these structures are placed in the river, they will demonstrate the tremendous value that the micro model contributed to restoration of important aquatic and fishery habitat in one of our Nation's most vital natural resources, the Mississippi River.

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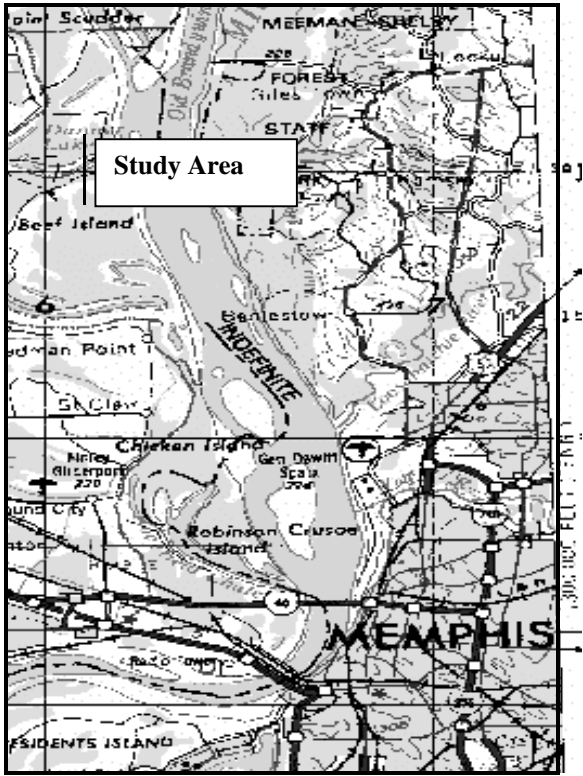
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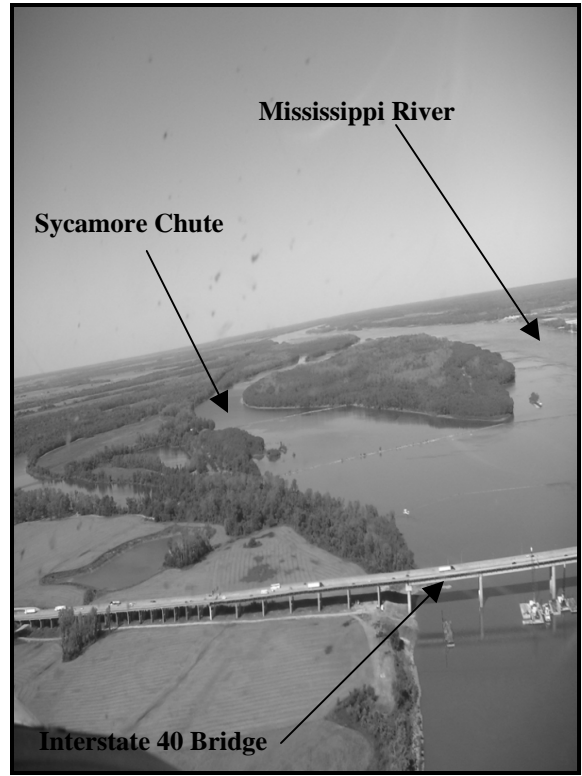
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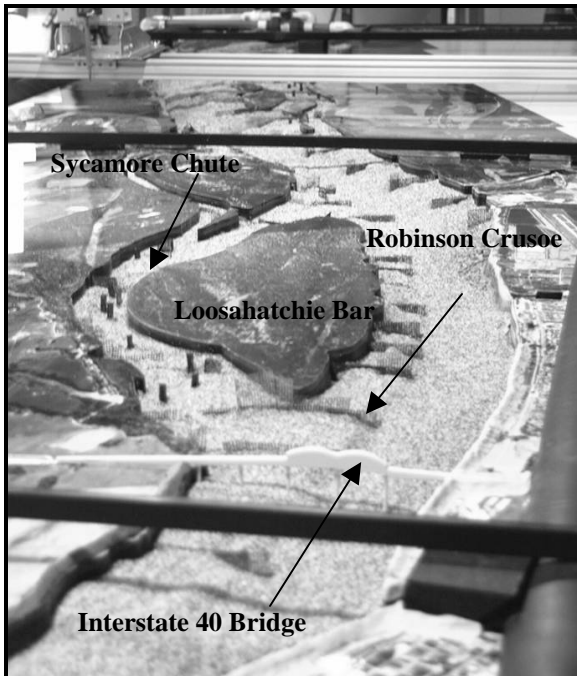
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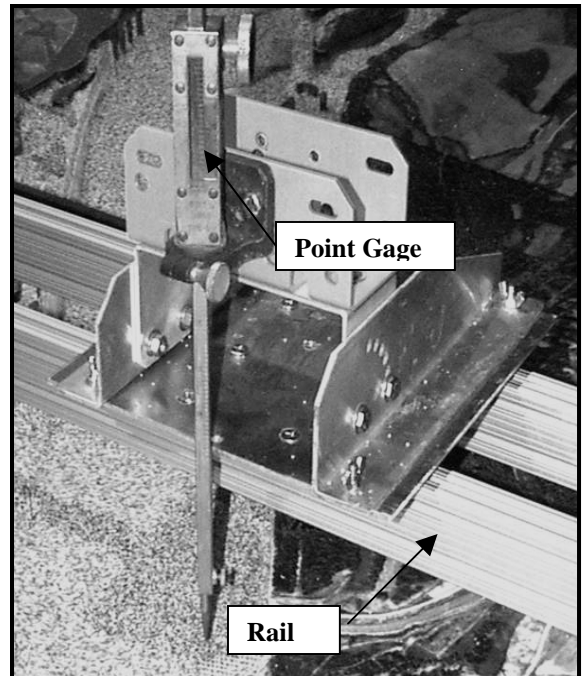
Figure 4. Point Gage
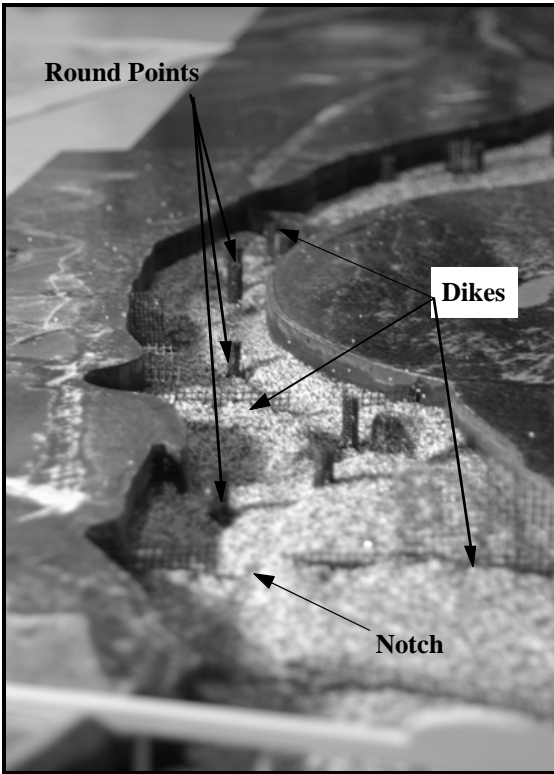
Figure 5. Sycamore Chute

Dikes/Round Points
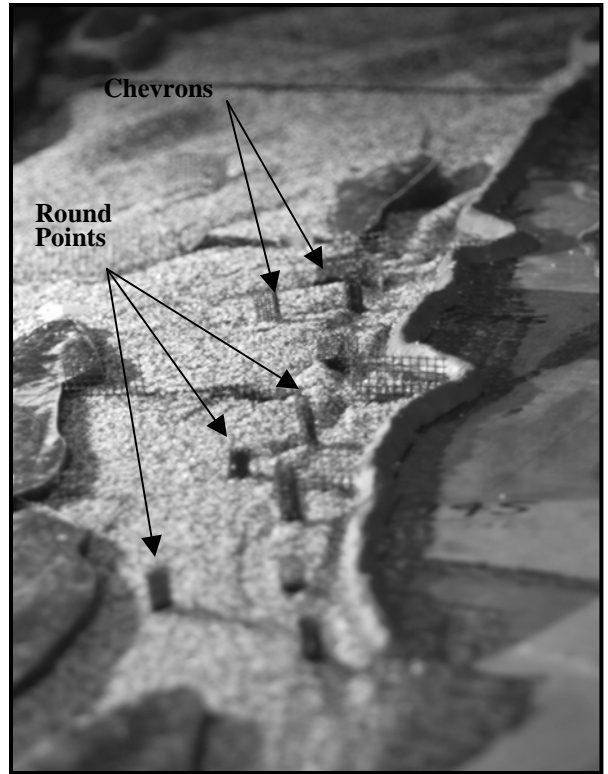
Figure 6. Hickman Bar Chute

Chevrons/Round Points
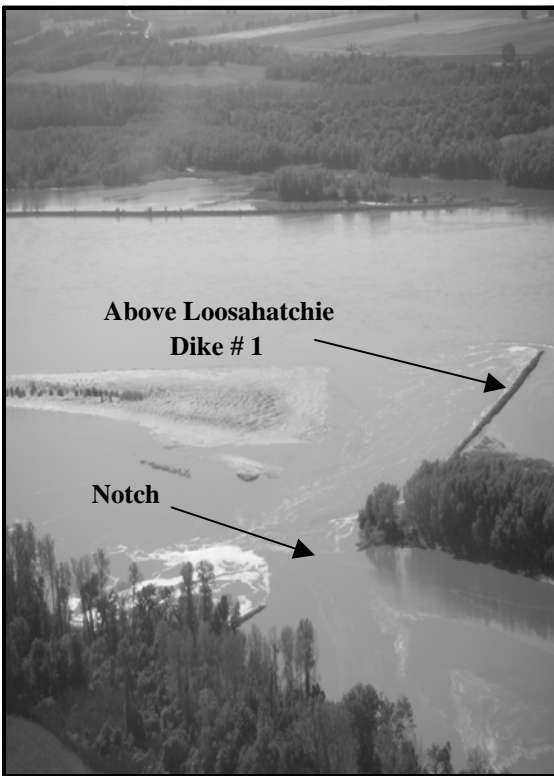
Figure 7. Notch in Dike
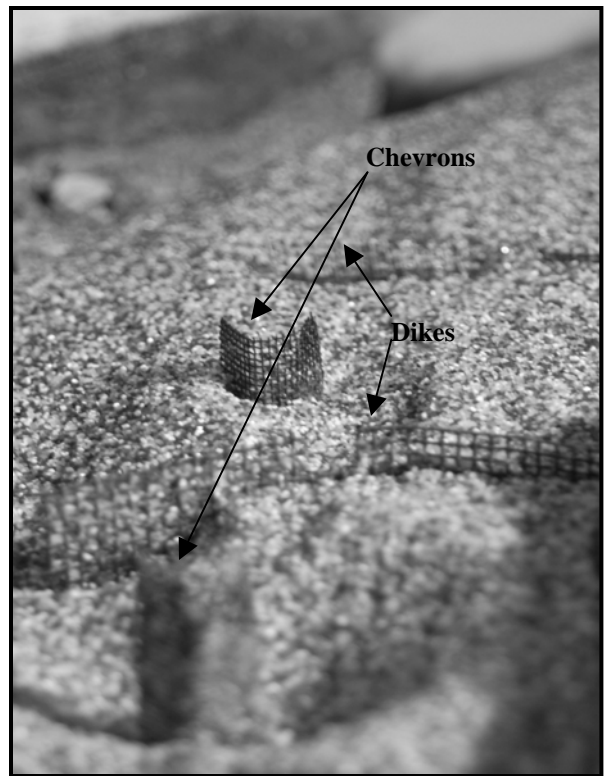
Figure 8. Chevrons

CHANGES IN SEDIMENT AND NUTRIENT FLUXES FROM HILLSLOPES IN RESPONSE TO ANTHROPOGENICALLY DISTURBED CHANNELS

Simon M. Mudd[1]

Hillslopes supply both sediment and nutrients to channels. When channels either incise or aggrade, the supply of sediment and nutrients to the channel from the hillslope is affected. Rapid changes in channel elevation can be created by anthropogenic disturbance and these transient adjustments in channel elevation will propagate onto adjacent hillslopes. The transient response of sediment and nutrient fluxes from hillslopes to channels is explored with a numerical model. Overall basin response will depend on drainage density, relief, background erosion rates, and the suite of sediment transport and weathering processes affecting the hillslopes.

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BACKTRACKING IN URBAN WATERWAYS
USING COORDINATED BACTERIA TRACKING ASSESSMENTS METHODS
SIMULTANEOUSLY

Tom Lawrence

INTRODUCTION

Pathogens are the 3rd leading cause of river and stream impairments in the State of Tennessee, after siltation and habitat alteration, thus pathogens are the most common impairments that have a direct effect on human health. Nationwide, pathogen impacts are one of the top three causes of impairments in most states. Although many stream segments are shown in the TN 303(d) list for pathogen impairment, few have had sufficient testing to show that they are actually impaired based on the water quality standard using a geometric mean for several samples collected over a 30-day period.

Within the last several years, the City of Memphis has worked with the State of Tennessee to revise the City's sampling strategy to use E. Coli, rather than the more general fecal coliform, which was common throughout the country in the past. The standards vary by state throughout the country with neighboring states that share watersheds sometimes having very different standards. Also, coliform is an indicator species, which indicates the possible presence of organisms that are harmful to humans. Thus, the source of coliform detected by a test is important, since many pathogens are species specific. For example, a result of 1000 cfu/100ml in a stream that has been impacted by human waste would tend to be more likely to harbor pathogens that can cause sickness in humans than a stream that had a result of 1000 cfu/100ml, but where the source was cows. The unit "cfu/100ml" is colony forming units per 100 milliliters of sample.

There are also one-time sample criteria, which many streams on the State of TN 303(d) list have exceeded, whether or not enough sampling has been done to determine if the 30-day geometric mean has been exceeded. In urban areas, however, virtually all streams will exceed the one-time sample standard at some point.

Using the State 303(d) lists as a guide, State and Federal agencies are proceeding with the development and implementation of Total Maximum Daily Loads (TMDLs) with little information about the actual extent of the impairment. For example, according to the information in the TMDL document for the watershed that includes South Cypress Creek (the subject of this project), the Creek was added to the list of impaired streams as shown by the 1996 305(b) Report after only 4 samples were collected over a 3.5 year period. It did not appear to have been listed in the 1994 305 (b) Report, although the 3 samples collected in 1993 and 1994 exceeded the 1000 limit, whereas the 1995 sample did not.

Often, there is virtually no information about the source of the fecal coliform detected other than anecdotal reports, possible sources based on studies in other parts of the county, suppositions, and guesses. Sources such as urban wildlife, native animals, migrating birds and the homeless are not given on the TN 303(d) list, although they are proven sources in many locations.

While it is not necessary to know the sources for listing a stream, since listing is caused by violation of the water quality standard (which can be determined whether or not the source is known), it is necessary to know the source in order to be able to fix a problem that has been identified. Since one of the main purposes of the 303(d) list is to identify impaired streams, so

that programs can be enacted to clean them up, it is critical that the sources be accurately identified and the relative contributions (or actual amounts) be quantified as well as possible.

There is no way for the goals of the Clean Water Act ("fishable, swimmable water") to be realized without source identification, since a program to reduce impacts from an incorrectly identified source will result in no water quality improvements and a waste of resources when the resources could have been better used addressing actual sources. Microbial Source Tracking (MST) studies show promise in being able to identify sources (or at least indicate probable sources), so that appropriate actions can be taken to achieve the water quality goals.

In January 2005, the City of Memphis implemented a large coordinated program to identify the sources of discharges to area waterways. The program involved several concurrent projects:

- **Infrared Flyover Survey:** Over several cold nights, a contractor flies along the lengths of the City waterways, filming the waterways with an infrared camera. The flow of liquid appears warm as compared to the surface water in a creek with the warmer water being represented on the photograph as a lighter colored point or streak. This is called an anomaly. Using their aerial infrared thermography experience, the contractor indicates the locations of the anomalies on the maps, which are provided to the City.

- **Field Verification:** Crews of City workers take the maps to the field to check for the presence of sources by visual and chemical testing. When discharges are confirmed, the appropriate actions are taken to eliminate the discharges.

- **Microbial Source Tracking Study:** A contractor collects samples at several places in a watershed at ten sampling events over a one month period. For the Memphis study, two samples are collected at each site five minutes apart. These samples are taken to a lab for analysis for e. Coli, then the plates are sent to a specialized lab for analysis to indicate the most likely animal sources for the types of the bacteria in the water.

- **Coliform Sampling Results:** The quantitative results of the bacteria sampling for the Microbial Source Tracking study, as well as other samples collected during the month, are analyzed to determine if there are correlations that can be used to identify pollutant sources.

As shown by the many types of studies underway, bacteria impacts to urban waterways are generally very complicated, from the beginning assessment of the extent of the impacts to determining the possible sources. Samples collected by the City and its contractors have shown widely varying results, even in samples taken 5 minutes apart or in samples split from the same bucket, but analyzed in different labs.

In addition to possible urban sources, past studies have shown impacts from many wild animal and agricultural sources, indicating that some apparent impacts to water quality may not be simple "identify and remove" situations. Rather they may require stakeholder involvement to reach decisions establishing the water quality goals for the urban waterways and may involve other agencies in addition to local government to determine the best follow-up approach.

Therefore, when addressing bacteria impacts in an urban environment, it may be necessary to utilize several tools to properly assess the source and extent of the coliform and to understand the context of the impacts to enable the best management practice to be implemented in a watershed.

STUDY WATERSHED DESCRIPTION

Although the infrared study was conducted over the entire Memphis urban watershed, the Microbial Source Tracking study was conducted in the South Cypress Creek watershed. The watershed is 14 square miles and is located completely within the City of Memphis. The USGS hydrologic unit code (HUC) is TN08010211007, which puts it within the Nonconnah Creek Hydrologic basin, although it does not join directly with Nonconnah Creek. Both Nonconnah Creek and South Cypress Creek terminate at Lake McKellar. Lake McKellar is actually an inlet of the Mississippi River (a cutoff stream meander), thus, water in Lake McKellar flows in a generally southwesterly direction toward the Mississippi River. The terminus of S. Cypress Creek is downstream of the terminus of Nonconnah Creek. During high river stages on the Mississippi River, water from the River/Lake can back up into the mouth of South Cypress Creek.

The water gradient for the mainstem of the Creek is very shallow (approximately 50' elevation drop over a steam length of approximately 18.1 miles), although much of the Creek's original sinuosity has been removed due to urbanization.

Development has generally been greatest in the upstream portions of the watershed as can be seen by the density of the streets, lessening toward the mouth of the Creek. Much of the lower portions of the Creek's watershed are relatively undisturbed forest and flood plains.

FECAL HISTORY

As shown by the data extracted from the TMDL, few samples had been analyzed from the watershed up to 1998. Beginning in 2001, in accordance with the State of TN's 5-year watershed cycle, State personnel began sampling monthly at 2 locations along with 6 other sites being sampled 1 to 3 times during the year. State sampling personnel reported a strong sewage-type smell at some locations and sporadic extremely high results, however, no sanitary sewer or other sources could be identified.

Further complicating the issue is the fact that the high results would appear on the same day at sites with no hydraulic connectivity indicating separate sources. Sometimes, sites downstream of sites with high levels would show much lower levels, indicating that the problem was much more complicated than a single source discharge at a single point. Also, there appeared no relation to the high levels and rainfall events or lack of rainfall.

In April of 2002, personnel from the local Environmental Assistance Center (EAC) contacted the City of Memphis regarding the high fecal coliform results. City personnel researched sanitary sewer records to see if there were any correlation to reported sanitary sewer overflows and the sample results, yet no correlation was found.

Therefore, in May of 2002 the City hired a contractor to collect ten samples over a 30-day period from nine locations, for a total of 90 samples, in the watershed to determine if sources of fecal coliforms to the watershed could be identified geographically. Again, high results would appear on the same day at some sites with no hydraulic connectivity. Sometimes, sites downstream of sites with high levels would show much lower levels. Also, there appeared no relation to the high levels and rainfall events or lack of rainfall. On several of the small tributaries, the results would be very low for most of the samples, with a few high results. The geometric mean of the sample result was near or below 200 for 5 of the sites with the other 4 ranging from 425 to 583. Thus, although there were some results over 30,000, which are violations of the State water quality standard, the geometric mean shows that these were extreme values that are probably not representative of the overall water quality. The fact though that they reoccur and that they occur

at a variety of sampling points does indicate that there may be a source that could be identified, at which point, it could be determined whether or not it were possible or prudent to implement measures to eliminate this source.

TDEC conducted additional sampling in June and July of 2002 to collect 10 samples at each of 4 sites within a 30-day period in order to determine if the water quality impact in South Cypress Creek is in excess of the water quality standards. Of the 4 sampling locations, three of which are on the mainstem of the Creek, all showed similar high levels of fecal coliform for most of the sampling events. The geometric mean of the samples ranged from 2998 to 21,258. Note that State personnel also tested for e. coli for which the geometric ranged from 652 to 3281.

TDEC EAC personnel met with representatives of the City of Memphis Sewer Department and the City of Memphis Storm Water Program to discuss their findings on January 7, 2003. At that meeting, the Sewer Department presented a map showing the location of the public sewer lines and the sewer overflow activity in the watershed. Both State and City personnel reviewed the sewer map, but could not find a correlation of sewer overflows to the high levels of fecal coliform and e. coli found in the samples.

Since December of 2002, the City of Memphis has added a site on South Cypress Creek at Riverport Road to its monthly ambient sampling program. The monthly sample from this site is analyzed for e. coli.

STUDY RESULTS

Data for the January 2005 program is being collected and will be presented at Symposium.

BACTERIAL WATER QUALITY DURING A WET WEATHER EVENT

William Hamilton[1]* and Edward Thackston[1]

INTRODUCTION

Bacteria are the primary source of impairment to the nation's waters [1], and the third most frequent cause of 303(d) listing in Tennessee [2]. Nationally, 13% of assessed stream miles are impaired due to bacteria, a value that is consistent with observations of assessed streams in Tennessee (20% of assessed stream miles).

Controlling bacteria pollution is difficult because of the myriad potential sources. In addition to anthropogenic sources (sewer and septic systems), other wild and domestic animals serve as potential sources of bacteria in streams. Differentiating between these sources is an ongoing challenge.

Wet weather events (rainfall) can enhance transport of bacteria from all potential sources to creeks and streams, leading to indicator densities well in excess of state water quality standards. Rainfall can generate overland flow, washing natural fecal material or leachate from on site treatment systems (OSTS) into streams; it can increase stream turbulence and resuspend bacteria associated with sediments; and it can cause an increase in infiltration and inflow (I/I) in sewage collection systems, leading to surcharge conditions (combined and sanitary sewer overflows, or CSOs and SSOs, respectively). In order to understand the relative importance of these different sources in wet weather stream flows and to concentrate efforts on reducing these inputs, the sources must be differentiated.

Recently, both genetic and phenotypic protocols have been developed to identify sources of bacteria [3, 4]. These techniques can be coupled with wet weather surveys to identify sources of bacteria and suggest rational remedies to improve wet weather water quality. The purpose of this study was to determine the impact of wet weather on the bacterial water quality of an urban stream in Nashville, Tenn. and to apply tools to attempt to identify the sources of in-stream bacteria during wet weather events.

METHODS

Study area: Richland Creek (TN05130202 314) is a large urban stream (approx 18 mi.) in southwest Davidson County, Tennessee (Figure 1). From its source until it discharges into the Cumberland River, Richland Creek intersects a number of land uses, ranging from agricultural and residential in the upper reaches to commercial, residential and some industrial in the downstream reaches. Richland Creek has a history of CSO and SSO activity. Currently there are 5 active SSO sites in the Richland Creek Basin [5].

Sampling strategy: The goal of the study was to collect samples over the course of a rainfall event that would produce overland flow. Samples were collected at the beginning of the storm, at the peak of the storm, and as the storm dissipated. In addition, samples were collected prior to the storm and 48 hours after the rainfall event to provide baseline conditions and post storm stream response conditions. Throughout the study, stream flow (cfs) was monitored using the USGS

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real-time stream flow gage located at Charlotte Pike (03431700) while rainfall data (in.) were collected from the Metro Water Services (MWS) rain gage at West Park.

Ten sampling sites were identified along the length of the stream (Figure 1). Sites were picked so as to isolate certain features in the watershed (the confluence of a large tributary or a change in land use character, for example). For safety, sites had to be accessible during wet-weather conditions. In addition to visiting sampling sites, known overflow sites were continually monitored during this study to determine if any SSOs were occurring. (None were observed.)

Sampling and analysis: Grab samples were collected using sterile, 500-mL Whirl Pak bags (Nasco, Ft. Atkinson, Wisc.). Telescoping poles or sampling reels were used to collect samples from the middle of the stream when possible. Samples were placed on ice and returned to the lab for analysis (within 6 hours for bacteria isolation).

Samples were analyzed for physicochemical parameters (turbidity, pH, temperature) as well as for *Escherichia coli* (EC), fecal coliform (FC), Enterococcus (Ent), and fecal streptococci (FS). *E. coli*, fecal coliform and fecal streptococci were enumerated by membrane filtration using commercially available isolation media and standard membrane filtration protocols [6], while Enterococcus was enumerated using the Idexx (Westbrook, Maine) most probable number (MPN) procedure [6]. Based on studies by others, bacteria densities based on colony forming units (CFU) and MPN were considered equivalent [7].

Antibiotic resistance analysis (ARA) was conducted on *E. coli* isolates using a suite of antibiotics and a library of over 2500 known source (human, cow, dog, deer) isolates developed for the Middle Tennessee region [8]. Individual colonies that turned blue on m-ColiBlue24® media (Hach Co., Loveland, Colo.) were considered presumptive *E. coli* and incubated in Colilert® media (Idexx, Westbrook, Maine) in individual wells of a 96-well microwell plate for 24 hours. Wells that showed evidence of growth (fluorescing after incubation at 35°C for 24 hours) were replica-plated onto nutrient agar plates containing Colilert media and one of 30 different antibiotic concentrations. After incubation for 24 hours, inoculates were assessed for growth by visual inspection. Isolate viability was analyzed using discriminant analysis (SPSS ver 12, Chicago, Ill.) to characterize the isolate source as either human or animal (nonhuman).

RESULTS AND DISCUSSION

A 0.58-inch rainstorm hit the Richland Creek basin on November 5, 2003. The storm lasted for about 3 hours, and samples were collected almost continuously from 10 sites along Richland Creek for the duration of the event. Figure 2 summarizes relevant monitoring data over the course of the storm from 3 sites along Richland Creek which were in the proximity of precipitation and flow monitoring gages: Knob Road, Urbandale, and West Park.

As the data in the Figure indicate, the background samples at Urbandale and West Park had relatively low *E. coli* densities, while the density at Knob Road was elevated for dry weather conditions. (Dry weather is operationally defined as five or more consecutive prior days without precipitation. In the late fall, dry weather bacteria densities typically fall in the 100 to 1000 CFU/100 mL range.) As streamflow increased, bacterial densities began to rise at all three sites, peaking during peak stream flow conditions. The Knob Road site displayed the largest density of the three sites, while bacteria densities decayed with downstream distance. (Urbandale and West Park had similar densities which were approximately half of the density observed at Knob Road.) Forty-eight hours after the storm, densities at all three sites had dropped significantly from peak rainfall and streamflow conditions. Interestingly, the density observed at Knob Road after the storm was significantly lower than that observed prior to the event. This suggests that a washout process occurred during the storm.

Indicator ratios (FC/FS and EC/Ent) were calculated for all samples collected during the sampling event. While indicator ratios are generally not considered a definitive source tracking tool, we have had good success using ratios as a conservative, first estimate of fresh human bacteria sources. The problem with ratios is that the decay rates of the different bacteria species and strains vary widely, especially in the presence of oxidants such as chlorine and sunlight [9]. However, for bacteria with relatively short travel and environmental exposure times, ratios may provide an inexpensive indication of sewage contamination.

Prior to the storm, FC/FS and EC/Ent ratios (Figure 2) were low at Urbandale and West Park, but slightly elevated at the Knob Road site. (Generally, we consider values above 1.5 to 2.0 to be elevated values.) As the storm intensity and stream flow rate increased, ratios at Urbandale and West Park increased initially, and then dropped precipitously and remained low for the duration of the storm; at Knob Road, ratios first dropped, but then increased slightly before decreasing again. By the end of the storm, all ratios suggest animal sources, although the EC/Ent ratio at Urbandale was borderline.

Antibiotic resistance analysis was conducted on *E. coli* isolates from these sites and the results are presented in Figure 2. Consistent with the ratios observed for the three background samples, Knob Road show evidence of a human source, while samples from Urbandale and West Park had little human character. As the rain began, the human character increased at all three sites. (Similar to the EC/Ent ratios at Knob Road, human character initially fell at the Knob Road site, but increased in subsequent samples.) Peak human character was associated with peak storm intensity, and the highest human fraction was observed at the most upstream site (Knob Road). Peak human fractions decreased with downstream distance. As the streamflow decreased, the human fraction in each sample also decreased. Two days after the storm, samples from Knob Road and West Park showed little human character, while the sample at Urbandale, while having a relatively low *E. coli* density (300 CFU/100 mL), showed elevated human character. This is consistent with the EC/Ent ratios observed at this site.

Wet weather flows produced bacteria densities along the length of the stream that violated water quality standards (data not shown). Indeed, densities observed at the sites reported here had considerable nonhuman character, suggesting that other sources (wild or domestic animals) have a considerable impact on wet weather water quality.

Source tracking tools such as indicator ratios and ARA are useful for determining the source of bacteria in streams. Bacteria ratios (EC/Ent and FC/FS) may be less reliable than more contemporary techniques during wet weather events due to the introduction of aged non-point source fecal material; however, source information determined from ratios collected during dry weather (background), and to an extent in the post storm samples, was similar to the sources estimated with ARA.

Field investigations conducted in 2004 during dry weather (thermograph, routine sampling and analysis) revealed evidence of a leaking manhole upstream of the Knob Road site, corroborating the results of the dry weather ratios and ARA. The site was repaired and subsequent field sampling has shown considerable improvements (i.e. decreases) in indicator densities at this site.

ACKNOWLEDGEMENTS

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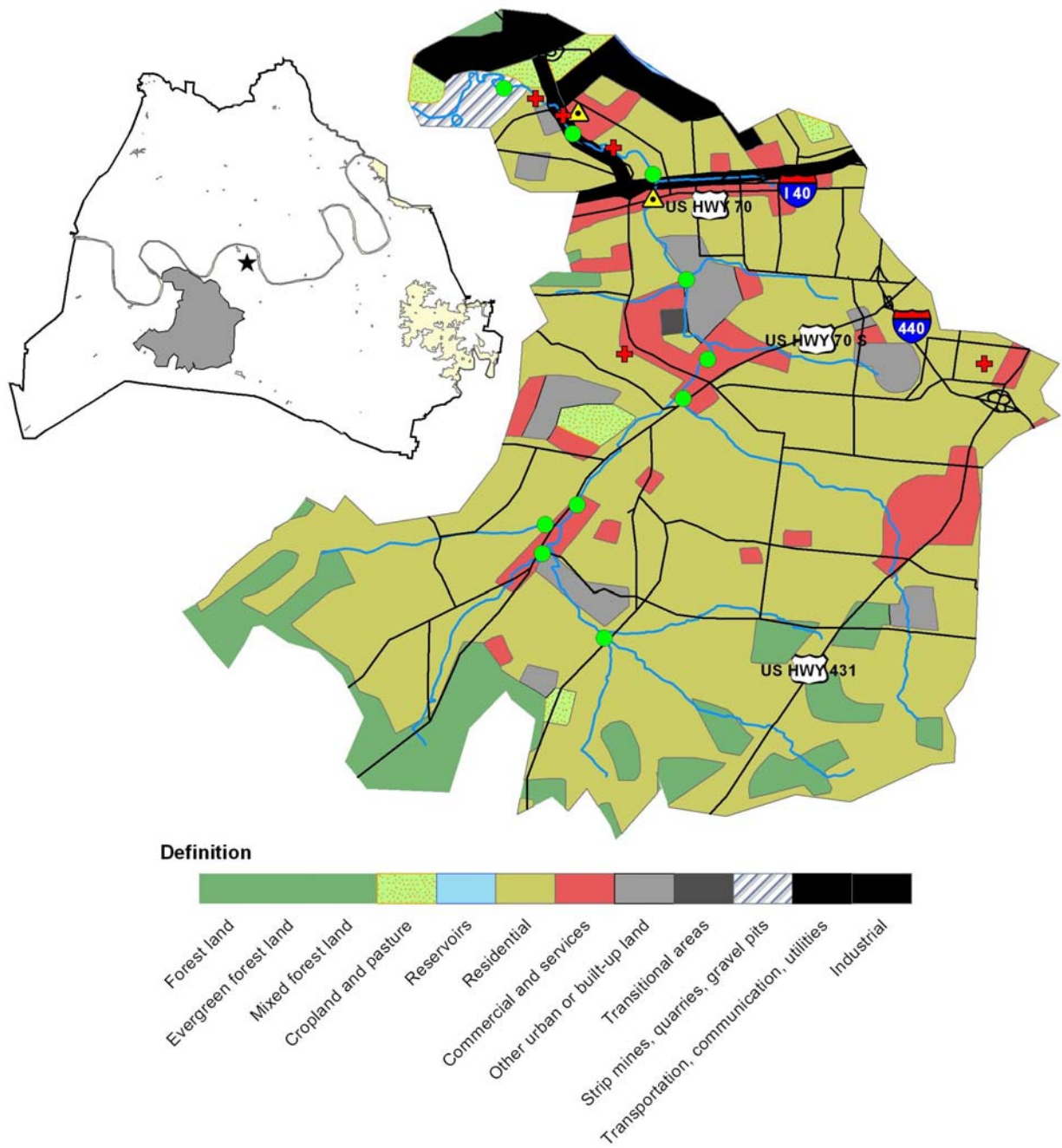
Figure 1: Richland Creek Watershed with sampling points (circles), active SSOs (crosses), precipitation and stream flow monitoring stations (triangles), and land use indicated.
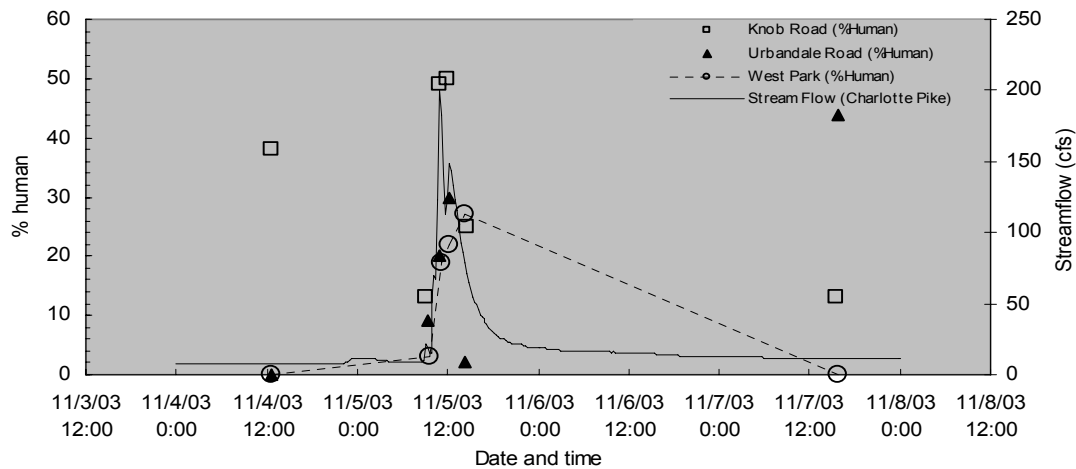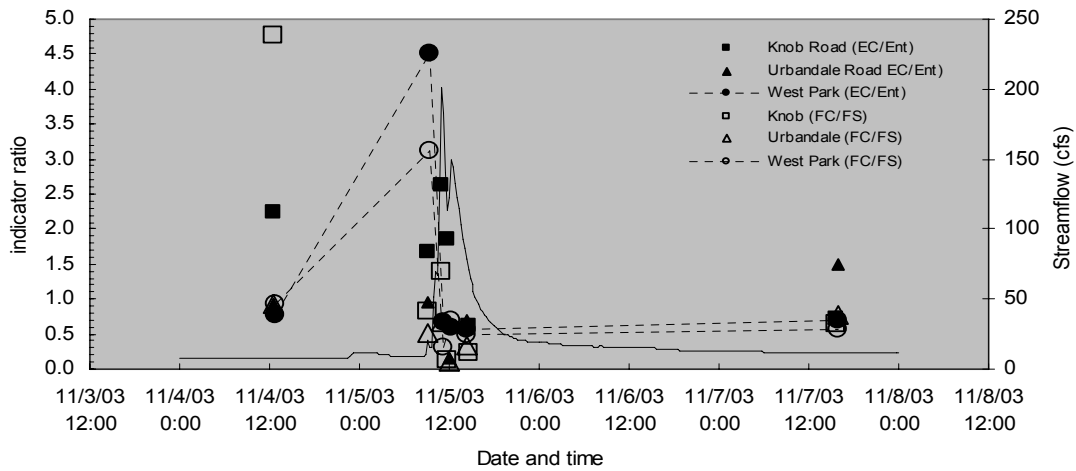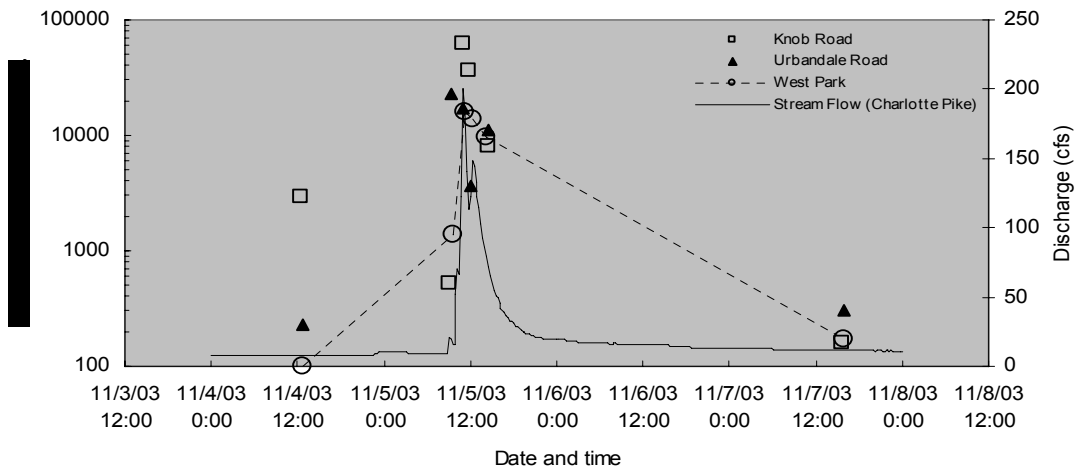
Figure 2: Biological Parameters as a Function of Stream Flow. (a) *E. coli* **density (CFU/100 mL), (b) EC/Ent and FC/FS ratio, and (c) % human (ARA, 2-way classification).**

METRO NASHVILLE & DAVIDSON COUNTY AERIAL INFRARED SEWER AND STORM WATER LINE INSPECTION, 2004

Michael Hunt[1] and Steve Winesett[2]*

INTRODUCTION

Metro has and continues to utilize various methods that aim to identify and eliminate sources of water pollution that adversely affect the quality of Davidson County streams and rivers. As part of this ongoing effort, Metro applied for and received a grant from the Tennessee Division of Water Pollution Control to utilize infrared "thermography" as part of several simultaneous pilot projects conducted across the State of Tennessee. Thermography (as used in this project) is a photographic procedure that involves taking aerial photos of stream segments using infrared film that can effectively and efficiently assist in the identification of leaking sanitary sewers and various other illicit discharges. For 2003 these photographs were taken at night during winter (so as to minimize light and foliage sight interferences) by a contracted aircraft flying at 1,200 to 1,500 feet altitude. However, for 2004 we utilized a Metro Police helicopter fitted with an infrared camera flying near dusk at an altitude of about 500 feet. Illicit wastewater plumes discharging to land, conveyances, or directly into the stream segments are expected to have a somewhat elevated temperature compared to ambient flows that have been directly exposed to the environment for extended periods. These fugitive flows (although invisible to the naked eye) appear white on the infrared film and are identified and classified as "anomalies." Metro staff and their representatives investigated these anomalies, conducting the necessary sampling and source tracking in order to identify and eliminate any discovered illicit discharges.

APPROACH

During February and March 2004, ten Nashville streams were the subject of an aerial infrared (IR) survey. Liquid from a leaking underground sewage or storm water line typically appears warm compared to the surface water in a creek, stream or river--particularly during cooler times of the year, due to the relative warmth of the ground a short distance below the surface. Leaks from nearby lines often come to the surface through lateral transfer to the creek bed or to a slope leading down to the surface of the water. These leak areas and the warm plume of liquid joining and flowing downstream with the body of water are visible in the thermal infrared spectrum due to the temperatures difference of the two flows. Late fall, winter and early spring are well suited to this type of inspection because of the different water temperatures (ground and surface waters) and because sight interferences by foliage is minimized. Ground water seeps and outfalls of many types are also easily distinguishable for similar reasons.

A helicopter with a thermal imager was flown along subject creeks in a manner that allowed the creek bed to be imaged and recorded on VCR tape. Flights were conducted late in the day when overcast to avoid glare from the sun. Air speed varied between 30-60 mph at an altitude of 500-1000 feet. The advantages to using a helicopter instead of a contracted airplane were cost, since Metro Police only charged for fuel and pilot time, and the ability to hover and/or backtrack for better image capture. Likewise, since the helicopter was more agile and slower flying, more tributaries were able to be photographed.

Once the flyovers were complete, the infrared imagery was reviewed and the various images and locations of the thermal anomalies were plotted on GPS software. A map was then prepared

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which showed locations (see example, Figure 1) of the anomalies.   The imagery exhibited 240 anomalies for the approximately 89.19 stream miles of Davidson County creeks flown.

Richland Creek	(80 anomalies)	Brown's Creek	(12 anomalies)
Mill Creek	(44 anomalies)	Mansker's Creek	(8 anomalies)
Sevenmile	(32 anomalies)	Dry	(11 anomalies)
Gibson	(24 anomalies)	Pages	(14 anomalies)
Stones	(9 anomalies)	McCrory	(6 anomalies)

Figure 1

Using GIS maps generated from the flyover (see example, Figure 2), Metro staff initiated the "ground truthing" phase of the process.   This involved identifying a team of investigators, making the necessary sampling/analytical testing arrangements, and formulating an investigation process. Investigation teams were chosen based on their knowledge of the respective areas of Davidson County. These teams then did field investigations and sampling, where determined necessary. Observations and data gathered at the site were then considered per the problem resolution flow chart that had been formulated. This flow chart documented the standard process by which sites would be investigated, documentation of investigations, problem sites determined, who would be responsible for problem resolution based on inspection data, and the ultimate resolution status of each anomaly (or other issues evidenced during field investigations). The main anomaly categories were natural ground water seeps/spring flow, leaks/discharges, and those found to be no longer flowing at the time of the field investigation.

Browns Therm. Sites 5

Legend
- ☆ anoms_stpl_sewermain_dist
- ■ Sewer Mains selection
- ► conduits
- ► channels
- mpc_roads
- culverts
- ● Manholes selection
- mpc_nhd_streams
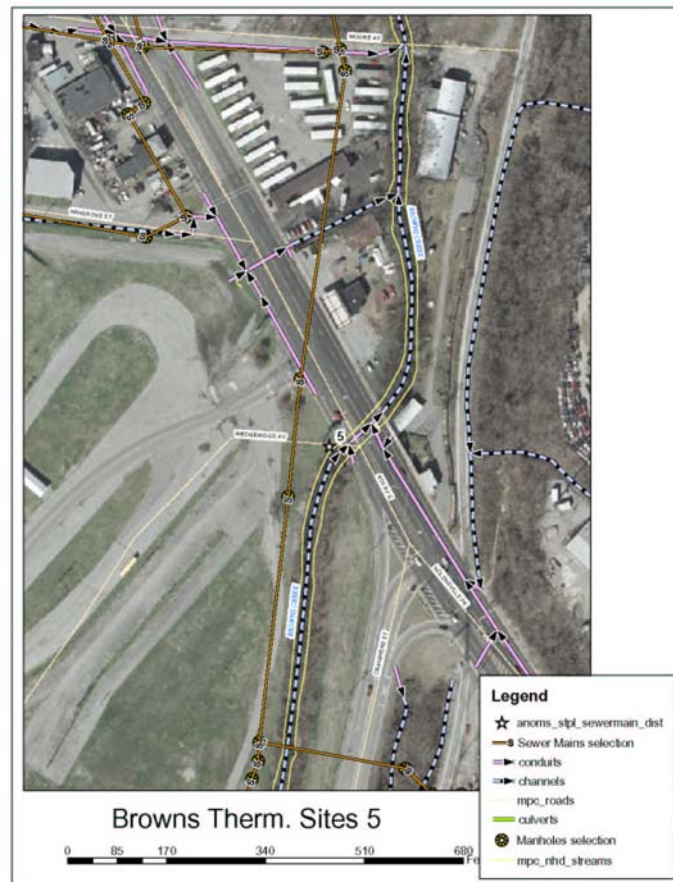
Figure 2

RESULTS AND DISCUSSION

In considering the various, possible outcomes of this project, the basic goals were to…

- · gain overall experience using Infrared technology
- · gain some degree of proficiency in collecting and interpreting thermographic data
- · develop proficiency in generating GIS maps needed during the flyover and subsequent field investigations
- · identify and eliminate any illicit discharges discovered during the project
- · document the Project, to include "anomaly investigations"
- · determine if this technology/method can provide long-term environmental and cost-effective benefits for Metro and, if so, formulate a strategy by which future thermographic studies can be increasingly effective and efficient.

In considering the results of our field investigations of identified anomalies, it was somewhat disappointing from a staff resource expenditure perspective to find relatively few anomalies that were eventually identified as illicit discharges.   Conversely from an environmental and remedial perspective, it was extremely encouraging to have identified so few illicit discharges.   Data (Table 1) and chart (Figure 3) relating our categorical findings are shown below.

Table 1

Anomaly Category	Number Found	% of Total
No issue	149	62%
No flow - revisit	38	16%
Elevated E. coli	34	14%
Elevated Fl	13	5%
Open – source identified	6	3%
Total=	240	100%
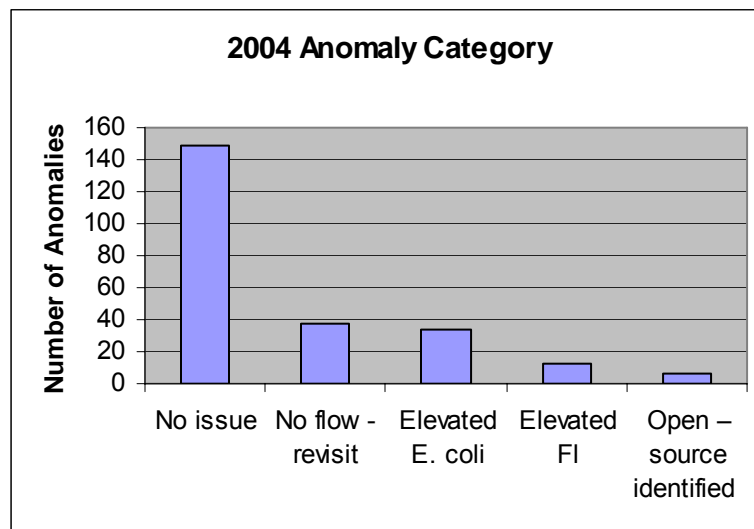
Figure 3

CONCLUSION

In considering the various project data and findings, Metro is optimistic that the thermography technology holds promise in making periodic, wide scale leak/discharge detection investigations in urban settings possible, while at the same time cost-effective. As Metro moves forward with additional thermography projects in the future, the lessons learned by this initial flyover will be invaluable as we will be better able to consider such flight variables as time of flight (day, dusk, night, etc.), day of the week (weekday verses weekend), air temperature at the time of the flight, ambient water temperatures at the time of the flight, recent weather conditions, visibility issues, etc. All of these initial project experiences will serve to make Metro's ongoing oversight of its utility systems (sanitary sewer, storm sewer, and potable water lines) and NPDES-related water pollution control obligations within the community more effective.

TIER EVALUATION FOR IMPLEMENTATION
OF TENNESSEE'S ANTIDEGRADATION POLICY

Gregory M. Denton[1]

An Antidegradation Policy is required by federal regulations and is an important part of any state's water quality standards. The purpose of the policy is to establish a systematic approach for the regulation of degradation. Degradation is a decline in water quality caused by either the addition of pollutants or the removal of habitat. Pollution occurs when degradation causes the public's uses of the waterbody to not be supported.

Tennessee's regulation establishes three "tiers" of protection for streams. Tier III, or Outstanding National Resource Waters, can only be established by action of the Water Quality Control Board. Tier II waters are "high quality" waterbodies that contain good water quality, outstanding scenery, significant ecological considerations, and important public recreational opportunities. All waterbodies not in Tier II or Tier III are considered Tier I.

In Tennessee, degradation can be allowed in Tier I streams only if (1) the stream is not already considered impacted by the substance or condition and (2) the applicant has justified that an alternative to the degradation is not feasible. In Tier II streams, degradation can only be authorized if the applicant has additionally demonstrated that an important social or economic need will be served by allowing the alteration. The state cannot allow degradation in Outstanding National Resource Waters under any circumstance. (It is important to note that the regulatory implications of the provisions of the Antidegradation Policy are limited to activities permitted by the agency and do not extend to activities exempted by statute.)

When an applicant requests permission to alter a waterbody by either adding pollutants or altering habitat, the proper tier of the waters must be established. Tennessee's water quality standards assign the responsibility for differentiating Tier I and II waters to the Division of Water Pollution Control. We needed an objective method to evaluate streams based on the description of the attributes of high quality waters provided in the regulation.

In response, a tier evaluation process was developed to, as objectively as possible, rate a waterbody for scenic, recreational, water quality, and ecological values. Attributes of a waterbody that are scored during the evaluation include, but are not limited to, the presence of listed species, the existence of wetlands, the measured diversity of the biological community, fishing and boating potential, the presence of public lands, such as parks or natural areas. As difficulties have been encountered while evaluating streams, or as the regulation has been modified, this tier evaluation process has evolved in response.

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EVALUATION OF THE SPARROW MODEL FOR ESTIMATING TRANSPORT OF NITROGEN AND PHOSPHORUS IN STREAMS OF THE INTERIOR PLATEAU ECOREGION, TENNESSEE, KENTUCKY, AND ALABAMA, 1992-2002

Anne B. Hoos[1]

The U.S. Geological Survey, in cooperation with the Tennessee Department of Environment and Conservation, is developing a SPARROW (SPAtially Referenced Regression On Watershed attributes) model of mean annual nitrogen and phosphorus loads in streams of the Interior Plateau ecoregion. SPARROW is a hybrid statistical and deterministic model that uses nonlinear regression equations to relate observed instream nutrient loads to watershed attributes (nutrient sources and landscape and stream characteristics). These equations then can be used to estimate nutrient loads for unmonitored streams, to estimate relative contribution of different sources to instream transport, and to understand watershed export and instream processing of nutrients. The SPARROW technique has been applied on a national scale to estimate nutrient loads and concentrations in streams throughout the continental United States.

Predictions from the national SPARROW model of mean annual nitrogen and phosphorus loads for streams in the Interior Plateau ecoregion (termed Ecoregion 71) have an average error of 60 and 105 percent, respectively. Prediction error was characterized by comparing calculated annual loads at 39 water-quality and streamflow monitoring stations in Ecoregion 71 (only 8 of which were available for calibration of the national model) with the national-model predictions for the stream reach associated with the monitoring station. The magnitude of the prediction error limits usefulness of national-model estimates for regional- and watershed-scale assessments of water quality in this area. The current regional modeling effort for Ecoregion 71 seeks to increase prediction accuracy by improving characterization of watershed attributes and calibrating a SPARROW model specific to this ecoregion.

Environmental variables that are statistically significant in the preliminary SPARROW nitrogen model for Ecoregion 71 include permitted wastewater discharge, atmospheric deposition, fertilizer application, animal waste, urban land area, drainage density, air temperature, and reservoir hydraulic load. Environmental variables that are statistically significant in the preliminary SPARROW phosphorus model include permitted wastewater discharge, area underlain by phosphate-rich limestone and soil, animal waste, land-surface slope, instream travel time, and reservoir hydraulic load. Estimation errors associated with the preliminary regional-model predictions of nitrogen and phosphorus loads are 20 and 65 percent, respectively, which represent a decrease in average error compared with national-model predictions of about 40 percent for both nitrogen and phosphorus. The largest residuals (positive and negative) for total phosphorus are associated with sites on six streams that drain the Bluegrass region of Kentucky and may be caused by inadequate delineation of outcrops of phosphate-rich limestone within the watersheds for these sites.

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TREATING STORMWATER RUNOFF FROM A TRAVEL PLAZA: A CASE STUDY

Rex Ausburn[1] and John Ricketts*[2]

Treating the stormwater runoff from a major travel plaza prior to meet the USEPA mandated discharge requirements was the daunting task faced by Flying J at their Oak Grove, Kentucky, Travel Plaza. The design for treating the stormwater runoff had to incorporate the following challenges:

- Stormwater runoff from several acres of truck parking lot had to be treated
- Karst topography had to be factored into the design
- The travel plaza had to remain fully functional during the construction process
- The existing stormwater management system needed to remain functional while the new facilities were being constructed

The selected design included a large stormwater retention basin that allowed for settlement of solids and with an appropriately designed outlet works provided a uniform flow rate to the constructed treatment wetlands. The effluent from the wetlands is then discharged into the sinkhole.

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SESSION 2B

GROUND-WATER QUALITY & CONTAMINATION
8:30 a.m. – 10:00 a.m.

Controversy Over Disposal of Contaminated Soil in a Sinkhole in South Knoxville, Tennessee: Environmental Interpretations, Appropriate Application of Dye Tracing, and Political Ramifications
Wanfang Zhou, Barry F. Beck and Ramona C. Josefczyk

Temporal Variability of Agricultural Chemicals in Ground Water and Implications for Water-Quality Sampling
A.F. Choquette, R.D. Turner, J.D. Haber, P.A. Lucas, D.H. Daiker and E.C. DeHaven

Hydrologic Assessment of Leakage from Nonconnah Creek to the Shallow Aquifer in the Vicinity of the Sheahan Well Field, Memphis, Tennessee
Daniel Larsen, Jason Morat, Brian Waldron, Stephanie Ivey, Jerry Anderson, Angela Owen and Christopher Garner

BACTERIAL SOURCE TRACKING
10:30 a.m. – 12:00 p.m.

Use of Flow Duration Curves and Load Duration Curves to Enhance Fecal Bacterial Source Tracking in Stoners Creek, Davidson County, Tennessee
F.C. Bailey, J.J. Farmer, A.O. Ejiofor and T.L. Johnson

Comparison of Antibiotic Resistance Patterns, Carbon Utilization Profiles, and Pulsed-Field Gel Electrophoresis of Escherichia Coli for Fecal Bacterial Source Tracking in the Duck River, Middle Tennessee
J.J. Farmer, F.C. Bailey, A.O. Ejiofor and T.L. Johnson

Monitoring of Enterovirus and Hepatitis A Virus in Wells and Springs in East Tennessee
Trisha Baldwin, Alice Layton, Larry McKay, Sid Jones, Greg Johnson, Shay Fout and Victoria Garrett

STREAMFLOW ASSESSMENTS
1:30 p.m. – 3:00 p.m.

Flood Frequency Prediction Applications for Tennessee Using Traditional and Newer Methods
Ali R. Hangul

Methods for Estimating Flow Duration and Low Flow Frequency Characteristics of Unregulated Streams of Tennessee
George S. Law and Gary D. Tasker

Linking Stream Habitat Assessment Scores with Stream Morphology for Creating Sediment TMDLs
Nick Jokay and Brian Watson

DYE TRACING
3:30 p.m. – 5:00 p.m.

Elizabethton's Big Spring: A Case for Karst Aquifer Protection
Robert Benfield, Sid Jones and Gareth Davies

The Dissolution of a Conceptual Model: The Karst Hydrogeology of U.S. DOE Oak Ridge Reservation
Don Gilmore, Jack Wheat, Robert Benfield and Sid Jones

Ground Water Tracing Results and Sinkhole Analysis in LaVerne, Tennessee, for Interpreting and Remediating Sinkhole Flooding Problems
Albert E. Ogden, Austin C. Cowell, J. Clay Kennedy, Steve Mishu and Jerry Gann

CONTROVERSY OVER DISPOSAL OF CONTAMINATED SOIL IN A SINKHOLE IN SOUTH KNOXVILLE, TENNESSEE: ENVIRONMENTAL INTERPRETATIONS, APPROPRIATE APPLICATION OF DYE TRACING, AND POLITICAL RAMIFICATIONS

Wanfang Zhou[1], Barry F. Beck[2], and Ramona C. Josefczyk[3]

In the winter of 2001, approximately 800 to 3,000 truckloads of concrete debris and soil from a former Superfund site were disposed of in a privately owned sinkhole in south Knoxville, Tennessee. The sinkhole occurs in the Ordovician Lenoir Limestone, in which groundwater flows through complicated interconnecting and solution-enlarged fracture networks. The discovery of contaminated residential wells in the vicinity of the sinkhole in April 2002 received considerable attention from local news media with the backfilled sinkhole as the suspected source of contamination. Chemical analyses conducted by the Tennessee Department of Environmental and Conservation (TDEC) and various consultants confirmed the presence of a variety of contaminants in the wells, and those contaminants were also present in the soils that were disposed of in the sinkhole. A dye trace performed in August 2002 was inconclusive in linking the contaminated sinkhole with the contaminated wells, which added a high degree of uncertainty to the interpretation of the local groundwater flow system and to legal and financial implications for the parties involved. As a result of this controversy, several lawsuits have been filed against the City of Knoxville and its contractors. P.E. LaMoreaux and Associates, Inc. (PELA) has been involved as karst experts to provide technical advice for a group of local residents. This paper explores the events leading to the discovery of the contaminated wells, the associated hydrogeological investigations, and the political and environmental ramifications.

INTRODUCTION

A sinkhole is a geologic feature that is characteristic of karst areas. It is a natural drain to the subsurface, an entrance to a cave, or a collapse that can destroy houses and roadways. Water funnels into a sinkhole either seeps downward through the soil at its bottom or quickly drains into the subsurface if the sinkhole has an open swallet.

A sinkhole also provides a "convenient" place to deposit trash. People who have sinkholes in their yards may want them to be filled in the hope to increase their property values or to make their yards more usable. However, disposal of materials into a sinkhole requires very careful geological and hydrological considerations. Any contaminants disposed of in sinkholes may end up in the caves, springs and water wells in the area of the sinkhole.

The controversy over more than 800 truckloads of contaminated debris from a Superfund site dumped into a sinkhole in south Knoxville, Tennessee provides exemplary materials to demonstrate that the philosophy "out of sight, out of mind" is not applicable to karst terranes. A sinkhole is not just a hole in the ground. It bears geological and hydrological significance. Within the karst hydrologic system, a sinkhole often develops as a drainage input point into the larger subsurface conduits. The conduits not only carry the recharge water from the sinkhole depression into the aquifer, but they also transmit any suspended sediment carried by the turbulent flow and any materials resulting from human activities (including contaminants). A sinkhole may also be a part of an integrated ecological system that may support atypical species of plants or animals.

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SIGNIFICANT EVENTS IN THE CONTROVERSY

The following describe the major events that took place during the controversy in a chronological order. These events are selected from those reported in The Knoxville News-Sentinel.

Late 2001 and early 2002: Approximately 800 to 3,000 truckloads of concrete debris and soil from a former Superfund site were disposed of in a privately owned sinkhole in south Knoxville, Tennessee by the contractors of the City of Knoxville.

Late January 2002: Soil samples were collected by TDEC from the sinkhole and various contaminants including arsenic, lead, and diesel fuels were detected to be above the residential soil limits.

April 2002: A lawsuit was filed by two local residents to seek unspecified damages arising from the materials dumped into the sinkhole.

May 2002: Selected wells and a spring were tested by the City of Knoxville for industrial contaminants and the results were negative.

May and June 2002: Contaminants, such as arsenic, lead, and petroleum hydrocarbons were detected by TDEC to be above the drinking water limits in some of the area wells.

July 2002: A lawsuit was filed by the sinkhole owners to seek $1.25 million in compensatory damages and $2.5 million in punitive damages arising from disposal of contaminated debris into the sinkhole. The plaintiff also wanted the defendants to clean up the contaminated sinkhole.

July 2002: The East Tennessee Environmental Crimes Task Force was involved to investigate possible violation of environmental laws in the sinkhole dumping.

August 2002: A clean water task force was formed by local residents and other concerned citizens to request the removal of the contaminated debris in the sinkhole and construction of a public water line for the affected residents.

August through December 2002: A groundwater tracing study was conducted by TDEC and its contractor. The injected dyes were detected at a spring approximately one mile northeast of the sinkhole (Figure 1). However, the results are inconclusive in terms of the connection between the contaminated sinkhole and the tainted wells.

September 2002: State politicians were involved to help the affected residents with a public water line.

November 2002: PELA advised a second groundwater tracing test during high-flow conditions, which was later echoed by the contractor of TDEC who performed the first groundwater tracing test.

April 2003: A federal grand jury issued subpoenas for the records on the sinkhole dumping case to investigate any possible violations of the environmental laws.

April 2003: A class-action lawsuit was filed by 72 local residents. Each plaintiff in the class was seeking $1 million in compensatory damages and $2 million in punitive damages. The lawsuit also seeks $20 million in compensatory damages and $20 million in punitive damages for others who may later join in the lawsuit.

<u>July 2003</u>: The debris in the sinkhole was removed by the City of Knoxville and its contractors.

<u>October 2003</u>: A water line was constructed for the affected residents.

<u>October 2004</u>: A mediation session was arranged with an attempt to reach an agreement between the local residents and the defendants for the lawsuit filed in April 2003.

Although the materials were removed approximately one and half years after they were dumped in the sinkhole, this controversy is not over and will likely continue into the foreseeable future. A trial is set for 2006 in the Knox County Circuit Court for the lawsuit filed in April 2003.

GROUNDWATER TRACING STUDY

It is clear that the sinkhole is contaminated by various contaminants; however, whether the contents in the sinkhole are responsible for the contamination in the well water of the area is still a source of debate. This results from the complexity and unpredictability of groundwater flow and contaminant transport in karst aquifers. The sinkhole area is underlain by the Ordovician Lenoir Limestone. Like any other karst aquifer in the Valley and Ridge Province, the Lenoir Limestone is a multiple-porosity and multiple-permeability medium, which includes minute pores between the grains of rock, planar partings in the rocks, and solution-enlarged channels or conduits. The multi-porosity drainage network has concentrated inlets at sinkholes and concentrated outlets at springs. Because the conduits offer the least resistant pathway, groundwater and the associated contaminants move preferentially through them.

When a residential water supply well is drilled into a karst aquifer, the chance to intercept a major conduit is very small. Most domestic wells tap into the network of fine fractures and bedding planes. Those that miss both the conduits and the fractures tap only the pores in the limestone and they do not normally yield enough water to be useful, in this area.

Groundwater tracing from sinkholes is a common technique in karst investigations. When designing the tracing test and interpreting the results, however, one must consider the hydrologic system in the karst aquifer, and that this underground drainage system is dynamic, responding to rain and storm events and transmitting recharge through the integrated solution openings in the aquifer. The dye trace, designed and conducted by TDEC and its contractor, was under low-flow conditions when little precipitation occurred in the greater Knoxville area. Under such conditions the groundwater level in the matrix and fractures might be higher than that in the conduits because these small openings tend to drain more slowly. The conduit system might collect water from its tributary fractures and the matrix. Therefore, the groundwater in the residential wells tapping the fractured limestone would drain toward the conduits during this period. Under this flow condition, the injected dye might not flow toward the wells, but would simply flow through the large, open conduit system to the nearby springs.

However, the flow condition may change during periods of higher precipitation and large storms. When it rains, many sinkholes rapidly transmit surface runoff into the underground conduit system. As a result, conduit passages flood rapidly, often in minutes or hours, and there may be a backflooding of the water above the level of the conduit because of the hydrostatic head provided by the upstream channels and sinkholes. The sinkholes may then fill completely with water. Under such high-flow conditions, the water level in the conduits tends to be higher than that in the fractures and matrix pores. This can create a condition where the groundwater and any associated contaminants move toward the network of small fractures criss-crossing the rock from which the residential wells likely tap the water. The contaminants that were flushed into the matrix and small fractures may stay there for years or even decades.

Interpretation of the nature of karstic groundwater flow often requires tracing tests under different flow conditions. The dye tracing test, as performed by TDEC and its contractor, would determine the preferential groundwater flow directions within the aquifer under low-flow conditions. Figure 1 shows that one of the two injected dyes was positively detected at three monitoring locations including one natural spring that is the nearest to the sinkhole. The other two monitoring locations are in a local creek, a tributary to the French Board River, where the spring water discharges. The positive detection of the dye at the spring is undoubtedly indicative of the flow connection between the sinkhole where the dye was injected and the spring. Because of the reasons discussed above and others related to the test design, such as the type of tracer used, the amount of tracer used, the monitoring methods, and the pumping activities at the monitoring wells, the absence of the tracer in the residential wells could not be used to prove that the sinkhole is not hydraulically connected to the wells. The article in The Knoxville News-Sentinel on December 22, 2002 has reflected some of our discussions, as schematically shown in Figure 1.

COST ASSOCIATED WITH THE CONTROVERSY

The exact dollar amount associated with the controversy is not available to the authors. According to an article in the Knoxville News-Sentinel on February 17, 2003, the total cost of the redevelopment of the Superfund site where the contaminated materials originated, including site development, the regulatory probe, and the estimated cleanup, could run approximately $10.1 million. In addition, the cost for the water line was estimated to be 1 million dollars. The legal fees and the pending lawsuits will further drive the total cost up.

REGULATIONS OVER SINKHOLE DUMPING

The controversy discussed in this paper is caused by sinkhole dumping activity. In Tennessee, people can dump concrete, brick, asphalt, rock, clean dirt and tree stumps into a sinkhole. Dumping contaminated materials into sinkholes is illegal and is regulated by TDEC. However, compliance with the environmental laws is up to those discarding wastes and TDEC does not initiate environmental investigations until they receive complaints from citizens. Penalties for illegal dumping depend on the type of the materials and the threat posed to the public. Fines could reach $5,000 for each day when the site is in violation. Under current regulations, the private-property owners or their contractors are left to police themselves. It is conceivable that similar situations may occur again as long as legislation does not impose mandatory penalties on those who knowingly use a sinkhole as a garbage dump. Backfilling or alteration of sinkholes is not a simple earthwork. Professional input from geologists or engineers who have experience with sinkholes and karst is essential to avoid unexpected consequences.

CONCLUSIONS

Sinkhole dumping is not a recommended practice for disposing of unwanted materials. Filling sinkholes requires oversight of regulatory agencies and the assistance of knowledgeable professionals. If a sinkhole is not filled properly, it may lead to unexpected consequences, and the price tag associated with the consequences could be very high. When groundwater is contaminated in karst aquifers, hydrogeological Investigations of the causes for the contamination can be challenging and the associated remediation could also be costly.
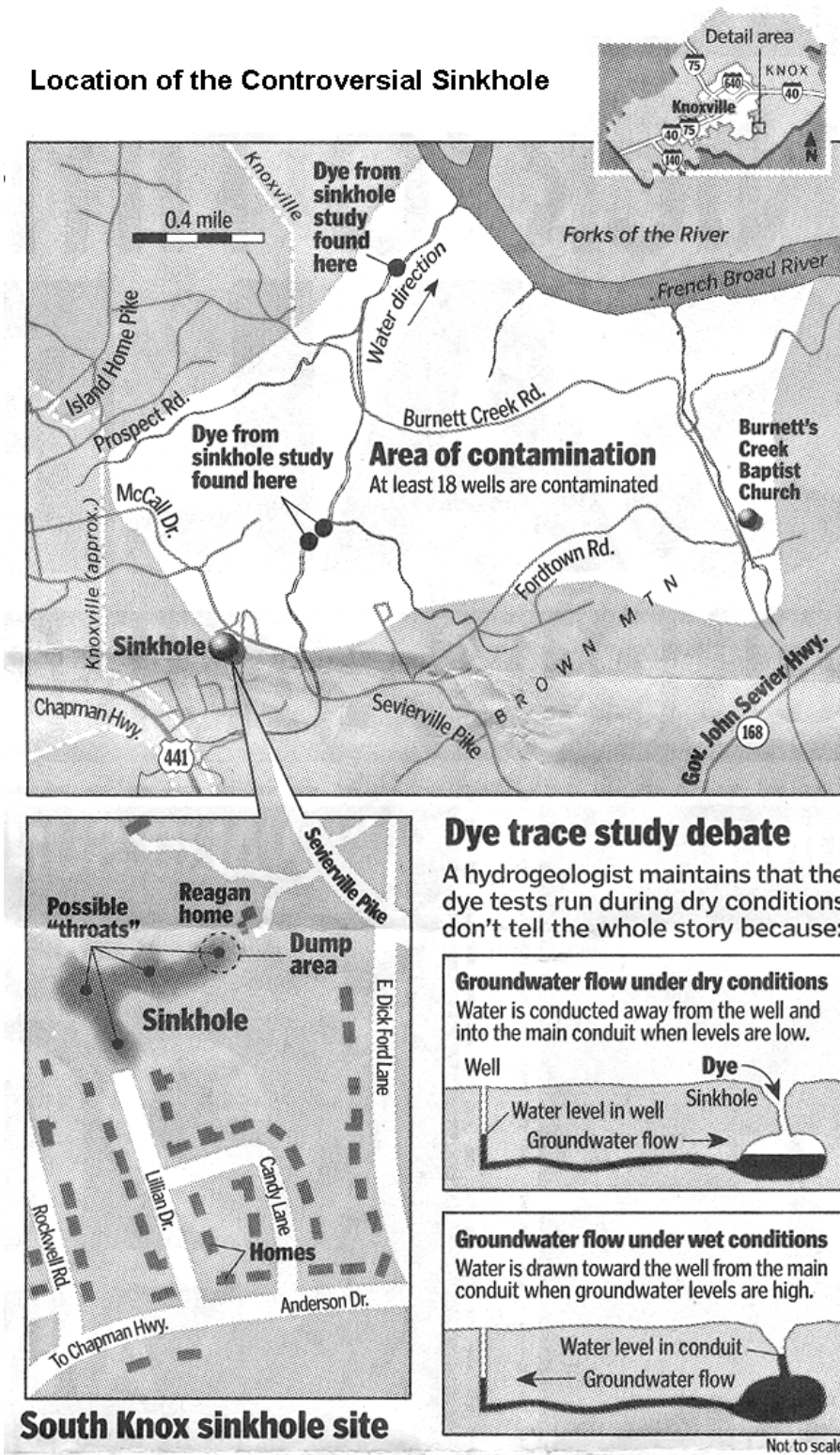
Figure 1. Site Location and Illustrations for Groundwater Flow in Karst Aquifers (This diagram is presented in an article of The Knoxville News-Sentinel on December 22, 2002. It combines materials from City of Knoxville, MACTEC Engineering, and PELA).

TEMPORAL VARIABILITY OF AGRICULTURAL CHEMICALS IN GROUND WATER AND IMPLICATIONS FOR WATER-QUALITY SAMPLING

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ABSTRACT

Ground-water monitoring in an extensive citrus region of central Florida has yielded detections of 12 pesticide compounds and elevated nitrate. The 684-mi^2 study area is underlain by relatively homogeneous sandy soils and marine sands that are vulnerable to leaching of agricultural chemicals. Significant temporal variability has been observed in the occurrence of these agricultural chemicals in ground water. Long-term and short-term (quarterly) records of selected analytes between 1993 and 2004 are presented as examples of temporal variations occurring in this ground-water system. Long-term records (12 years) of bromacil and norflurazon in ground water indicated relatively rapid changes corresponding to changes in usage of these pesticides. Quarterly samples from the monitoring wells showed significant temporal fluctuations in concentrations of nitrate (as N), simazine and its degradate (chloroethylamino s-triazine), norflurazon, and aldicarb and its degradates (aldicarb sulfoxide and sulfone), often varying by 100 to more than 200 percent between successive quarters, and at times fluctuating above and below human-health criteria. Dynamic changes in solute concentrations in this region are likely influenced by seasonal rainfall, episodic recharge, minimal organic content of soils (limited sorption of pesticides), and high hydraulic conductivity of soils and subsurface lithologic units, in combination with spatially and temporally episodic chemical-usage patterns. Results of this study indicate that low-frequency sampling (e.g. semi-annual or greater) could underestimate the range and variance of solute concentrations and provide limited definition of agricultural chemical concentrations in ground-water systems.

INTRODUCTION

Monitoring programs designed to assess regional-scale ground-water quality often rely on sampling intervals ranging from annual to multi-year frequency (Gilliom and others, 1995; Barbash and Resek, 1996; Ouellette and others, 1998). Short-term variations of dissolved contaminants in ground-water systems are often assumed to be minimal, on the basis of typically low variability in naturally occurring inorganic constituents, and the generally slow rates of ground-water movement through the subsurface. Additionally, the costly analysis of organic chemicals (e.g. pesticides) often further restricts sampling frequency. However, inferences regarding the magnitude of chemical concentrations with respect to health standards may be misleading in the absence of information on potential variability in concentrations. Furthermore, few ground-water quality networks have been collecting data using consistent design and analytical methods for a sufficiently long period to examine long-term trends in water quality (Barbash and Resek, 1996). Repeat sampling can provide valuable information regarding the effects of changing hydrogeologic influences (such as climate) and land-management practices on ground-water quality.

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Water-quality data collected quarterly in a region of concentrated citrus groves in central Florida indicate variations of agricultural chemicals in ground water can be significant, and that long-term changes in chemical concentrations can be related to chemical-usage practices. The Lake Wales Ridge (subsequently referred to in this paper as "the Ridge"), in central Florida (fig. 1), has been the focus of a number of monitoring efforts because of the occurrence of intensive citrus agriculture on sandy soils considered vulnerable to leaching of applied chemicals. Seasonally high precipitation rates further enhance the probability of leaching in this area. Based on previous studies on the Ridge indicating transport of agricultural chemicals into the surficial aquifer (Miller and others, 1989; Katz, 1993; Ouellette and others, 1998), a regional monitoring network was established on the Ridge through a cooperative effort between the Florida Department of Agriculture and Consumer Services (FDACS), the U.S. Geological Survey (USGS), and the Southwest Florida Water Management District (SWFWMD) (Choquette and Sepulveda, 2000). The Ridge network consists of 31 wells that are surrounded by citrus groves and which tap the unconfined surficial aquifer. Of the 29 target pesticides and degradates analyzed in samples collected from this network between 1999 and 2004, 12 have exceeded FDACS laboratory detection limits, and include (in decreasing frequency of occurrence): norflurazon, desmethyl norflurazon, simazine, bromacil, diuron, chloroethylamino s-triazine (CEAT), aldicarb sulfoxide, aldicarb sulfone, metalaxyl, aldicarb, imidacloprid, and thiazopyr monoacid (Choquette and others, 2003; web site: http://fisc.er.usgs.gov/Lake_Wales_Ridge/index.html). Detections of target pesticides and degradates in a single well during this period ranged up to as many as eight different compounds; in 55 percent of the wells, five or more different compounds have been detected. Concentrations in a relatively small percentage of samples (<5%) have exceeded drinking-water criteria[1] for five target analytes and two parent-degradate sums. However, concentrations of the pesticides in the Ridge ground water are elevated in comparison to ground-water concentrations in other regions of the United States (Choquette and others, 2003; USGS, 2004). Nitrate concentrations also are elevated in this area, where 90% of the network wells have yielded one or more samples with concentrations exceeding the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 10 mg/L. Long- and short-term records for selected agricultural chemicals are presented as examples to illustrate temporal variations that have occurred in this relatively homogeneous sand aquifer system influenced dominantly by citrus land use. Analytes selected to illustrate long-term changes include bromacil and norflurazon. Analytes selected to illustrate short-term variability include nitrate (as N), norflurazon, simazine and its degradate, and aldicarb and its degradates.

[1]Drinking-water criteria used for reference in this paper include the USEPA MCL's [simazine (4 μg/L); and the sum of aldicarb and its degradates (7 μg/L)]; for compounds with no specified USEPA MCL's, the FDEP health-guidance concentrations (non-enforceable guidelines) were used [norflurazon (280 μg/L), bromacil (90 μg/L), the sum of simazine and its degradates (4 μg/L)].

DESCRIPTION OF THE STUDY AREA

The study area (fig. 1) is defined by the Lake Wales Ridge physiographic feature (Brooks, 1981) within Polk and Highlands Counties and covers an area of 684 mi^2. Polk and Highlands Counties were the top two counties statewide for 2002-2003 total annual citrus production (National Agricultural Statistics Service web page data, http://www.nass.usda.gov/fl/rtoc0ci.htm), and represent one of the most productive citrus regions in the world. Citrus groves cover 169 mi^2 (24 percent) of the study area (Southwest Florida Water Management District, 1998).

The subsurface of the Ridge consists of a mantled karst terrain where unconsolidated Pliocene-Pleistocene relict beach and dune deposits overlie an irregular limestone surface (Brooks, 1981). The surficial aquifer predominantly consists of fine to coarse sand that thickens from about 50 ft in the northern part of the study area to more than 300 ft in the south (Barcelo and others, 1990; Yobbi, 1996). The soils in this region typically consist of fine to medium sand, contain less than 1

percent organic carbon, and less than ½ to 2 percent organic matter in the surface layer (U.S. Department of Agriculture, 1989 and 1990). Sand-sized particles comprise about 97 to 99 percent of these soils and hydraulic conductivity is high, typically 24 to 51 in/hr throughout the soil profile. Mean annual rainfall in the vicinity of the Ridge ranges from about 45 to 51 inches, with about two-thirds occurring during summer months (National Oceanic and Atmospheric Administration (NOAA), 2003). Precipitation rates, particularly from convective and tropical storms, can be quite high.
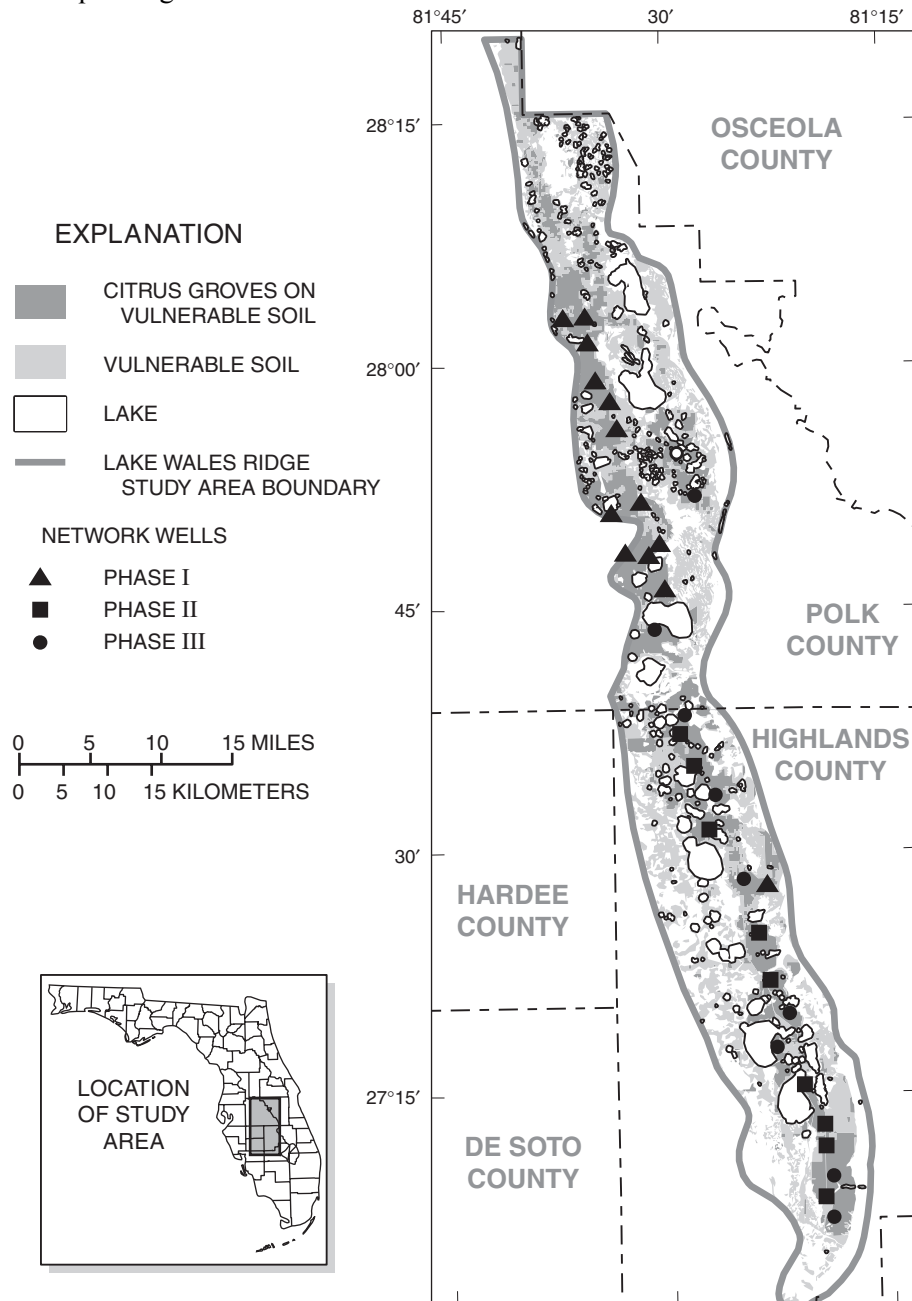
Figure 1. Extent of citrus land use and vulnerable soils in the study area, and locations of network wells. Vulnerable soils are defined as sandy, well-drained soils prone to leaching (State of Florida, 1994).

Traveltimes for ground water to move through the unsaturated zone to the water table vary locally due to a number of factors including climate conditions, soil moisture and morphology, and

lithology and thickness of the unsaturated zone. Local-scale studies on the Ridge using conservative tracers indicate that transport rates can vary significantly over time and space; where the depth to water table ranged from about 9 to 15 ft, traveltimes ranged from about 2 to 10 months (Graham and Alva, 1997; Danny Moore, Florida Dept. of Agriculture and Consumer Services, written commun., June 5, 2003). Preferred pathways of flow, commonly referred to as "flow fingering," can contribute to variations in traveltimes through the unsaturated zone (Glass and others, 1988). Small-scale heterogeneities in the Ridge sands contribute to the development of flow fingers in the study area (Pendexter and Furbish, 1991), which may decrease ground-water traveltimes by a factor of 2-3 times faster than expected from a uniform wetting front. Previous studies of the surficial aquifer in the vicinity of Polk and Highlands Counties indicate an average specific yield ranging from about 25 to 30 percent, and a range in hydraulic conductivity from about 0.9 to 24 ft/day (Barr, 1992; Yobbi, 1996; Graham and Alva, 1997).

SAMPLING NETWORK AND LABORATORY ANALYSES

The Ridge monitoring network was established in three phases and currently includes quarterly sampling of 31 wells (fig. 1). Well sites were randomly selected using grid sampling within the areas of citrus groves on soils classified as vulnerable to leaching, which include about 93 percent of the citrus area on the Ridge (Choquette and Sepulveda, 2000). The network is envisioned to be a long-term monitoring effort (10 to 20 years) that will provide early warning of agricultural chemical transport into the surficial aquifer, assess spatial and temporal variability of agricultural chemicals in ground water, and identify potential factors affecting the occurrence of agricultural chemicals in the aquifer. Phase I sampling (12 wells), Phase II sampling (9 wells), and Phase III (10 wells) began in April 1999, April 2000, and October 2001, respectively. Phase I consisted of existing monitoring wells, and Phases II and III consisted of new wells. Eleven of the Phase I wells had been sampled intermittently between 1989 and 1999 by the Florida Department of Environmental Protection (FDEP), the SWFWMD, and the USGS. Well depths range from about 21 to 150 ft below land surface, and depth to the water table ranges from about 4 to 103 ft below land surface.

Water samples were collected and processed using Teflon or stainless steel equipment according to FDEP ground-water sampling protocols (Florida Dept. of Environmental Protection, 2002; Morse, 1999), which included a minimum purge of three well volumes and stabilization of pH, dissolved oxygen, specific conductance, and temperature. Samples were analyzed for major dissolved inorganic constituents, nutrients, pesticides, and selected trace constituents. Nitrate (as N, throughout this paper) and pesticide analyses were performed at the FDACS Pesticide Laboratory and included USEPA and FDACS custom methods (Rygiel, 2001 and 2003; Brock and Rygiel, 2003; Page and Stepp, 2003).

RESULTS AND CONCLUSIONS

Data collected for this monitoring program indicate temporal changes in long-term detection of pesticides as well as significant short-term fluctuations in concentrations of nitrate and pesticides. Long-term sampling records available for a subset of the Phase I network wells (fig. 2) show changes in ground-water quality that correspond with changes in pesticide-usage practices. Bromacil detections occurred in 82 percent of the wells in 1993, 90 percent in 1996, and subsequently declined from 68 percent to 25 percent between 1999 and 2004 (fig. 2). During this period, norflurazon detections steadily increased from 10 to 75 percent. Bromacil was prohibited from use in most Ridge citrus areas in December 1994 (State of Florida, 1994), and was subsequently replaced by other herbicides including norflurazon and glyphosate. The continued pervasive occurrence of bromacil in ground water about 1.5 years after the ban on its usage is

likely due to the chemical persistence of bromacil as well as the time required for the chemical to travel into and through the ground-water system. Measurements of the half
life of bromacil range from 2 to 8 months in soils and up to 2 months in water (Hornsby and others, 1996; Spectrum Laboratories Chemical Fact Sheet, http://www.speclab.com/compound/c314409.htm).
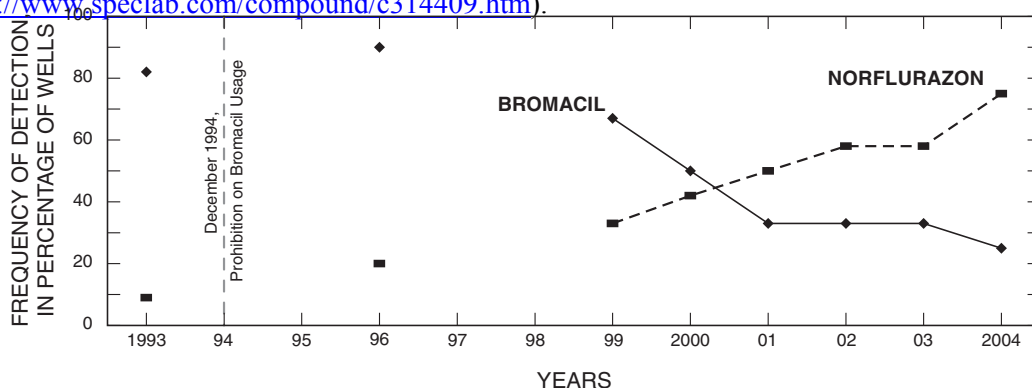
Figure 2.   Detections of bromacil and norflurazon at a subset of network wells (n=11) with long-term records. In December 1994, bromacil use was prohibited from use in citrus groves on well-drained sandy soils vulnerable to leaching. Laboratory detection limits were 2 μg/L for bromacil and 1 μg/L for norflurazon.

Chemical persistence in source areas is indicated by the continued bromacil detections at 25 percent of these wells in 2004, nearly 10 years after its ban. Although it is difficult to verify that bromacil has not been applied in the regions surrounding these wells during the 1995 to 2004 period, its estimated use was likely negligible based on the sparsity of non-citrus areas in the vicinity of wells and the fact that it has not been used in this area for roadside weed control (Danny Moore, FDACS, pers. comm., July 2003).

Increasing detections of norflurazon in ground water in these Phase I wells coincides with increasing trends in measured concentrations at a number of network wells (fig. 3). In these wells, the highest concentrations and fluctuations occurred where the water-table depths were relatively shallow (averaging 23 ft below land surface), and where sampled zones (well screens) were both short (10-11 ft) and in close proximity to the water table (wells 1 through 3, fig. 3). Lower and less variable concentrations occurred in wells 4 through 8 (fig. 3) where water-table depths were generally deeper (averaging 41 ft below land surface), and sampled zones were longer (20 ft) and(or) deeper within the saturated zone (as much as 47 ft). The FDEP health-guidance level (280 μg/L) for norflurazon has not been exceeded in samples collected from network wells through 2004.

In ground water from network wells, temporal variations in concentrations of most detected pesticide compounds and nitrate were significant, often varying by 100 to 200 percent between quarters. In figure 4, results are shown for wells that yielded some of the highest concentrations of simazine and its degradate chloroethylamino s-triazine (CEAT[2]); aldicarb and its degradates aldicarb sulfone and sulfoxide; and nitrate. Concentrations of these compounds in ground water from some wells fluctuated above and below human-health criteria between consecutive quarters. The water-table depths and sampling (well-screen) depths at these wells (fig. 4) also indicate that there may be some association between the magnitude and variability of agricultural chemical concentrations and the depth zone of ground water sampled. The simazine-degradate and aldicarb-degradate concentrations were generally highest and most variable at sites with shallow water tables (averaging 30 and 39 ft in figs. 4 a and b, respectively) and from shorter sampled zones (10-ft-long screened intervals) near the water-table interface (fig. 4 a and b). Elevated nitrate concentrations, however, extended to deeper water-table depths (averaging 57 ft in fig. 4c)

and deeper within the saturated zone of the aquifer: occurring at water-table depths of 97 to 103 ft below land surface, and from 20-ft-long screened (sample) intervals at depths as much as 22 to 53 ft below the water table (fig. 4c). These data indicate a need for additional evaluation of vertical and areal patterns in agricultural chemical concentrations including all network wells to determine if patterns are consistent and if causative factors can be related to observed patterns. Such spatial variability in chemical concentrations could be related to usage history and properties of the chemicals (e.g. persistence, solubility, sorption potential), as well as a number of other biogeochemical factors, such as redox conditions, pH, microbial populations, and ground-water ages. Analysis of the influence of these factors on water quality of ground water and lakes on the Ridge is ongoing (web site: http://fisc.er.usgs.gov/Lake_Wales_Ridge/index.html).
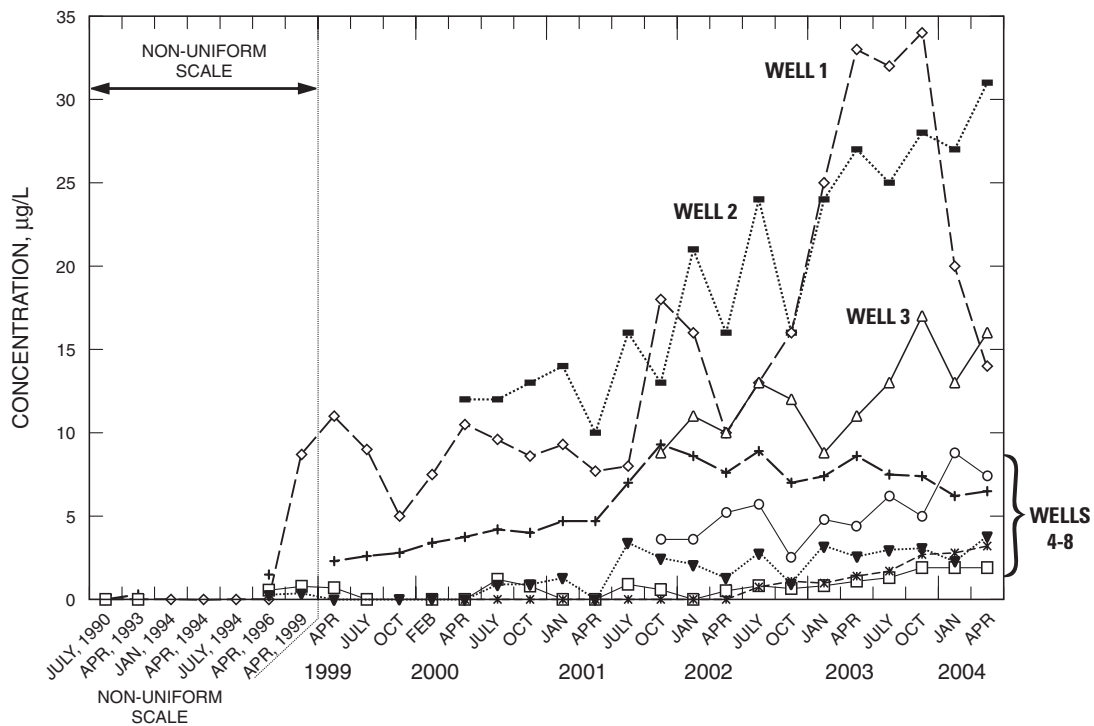
Figure 3. Trends in concentrations of norflurazon in ground water from selected Ridge network wells. Concentrations have not exceeded the Florida health-guidance value for norflurazon (280 µg/L).

Results from the Ridge network indicate the presence of complex spatial and temporal distributions of agricultural chemicals in the unconfined, surficial aquifer system, in spite of the generally uniform crop type in the vicinity of wells, and the relatively homogenous soils and lithology on the Ridge. The dynamic variability of agricultural chemicals in ground water in this region is likely due to a number of factors including the episodic nature of chemical applications and of ground-water recharge, combined with variations of agricultural chemical properties and relatively rapid recharge rates and transport via preferential pathways (flow fingering) within the unsaturated zone (Pendexter and Furbish, 1991). The water-quality data indicate that the variance of solute concentrations would likely be underestimated with longer sampling intervals. These results underscore the need for evaluations of agricultural chemicals in ground water to include assessment of short-term temporal variability in order to accurately depict water-quality conditions and human-health risks associated with drinking-water sources.

[2] CEAT is equivalent to desmethyl simazine and deisopropylatrazine.
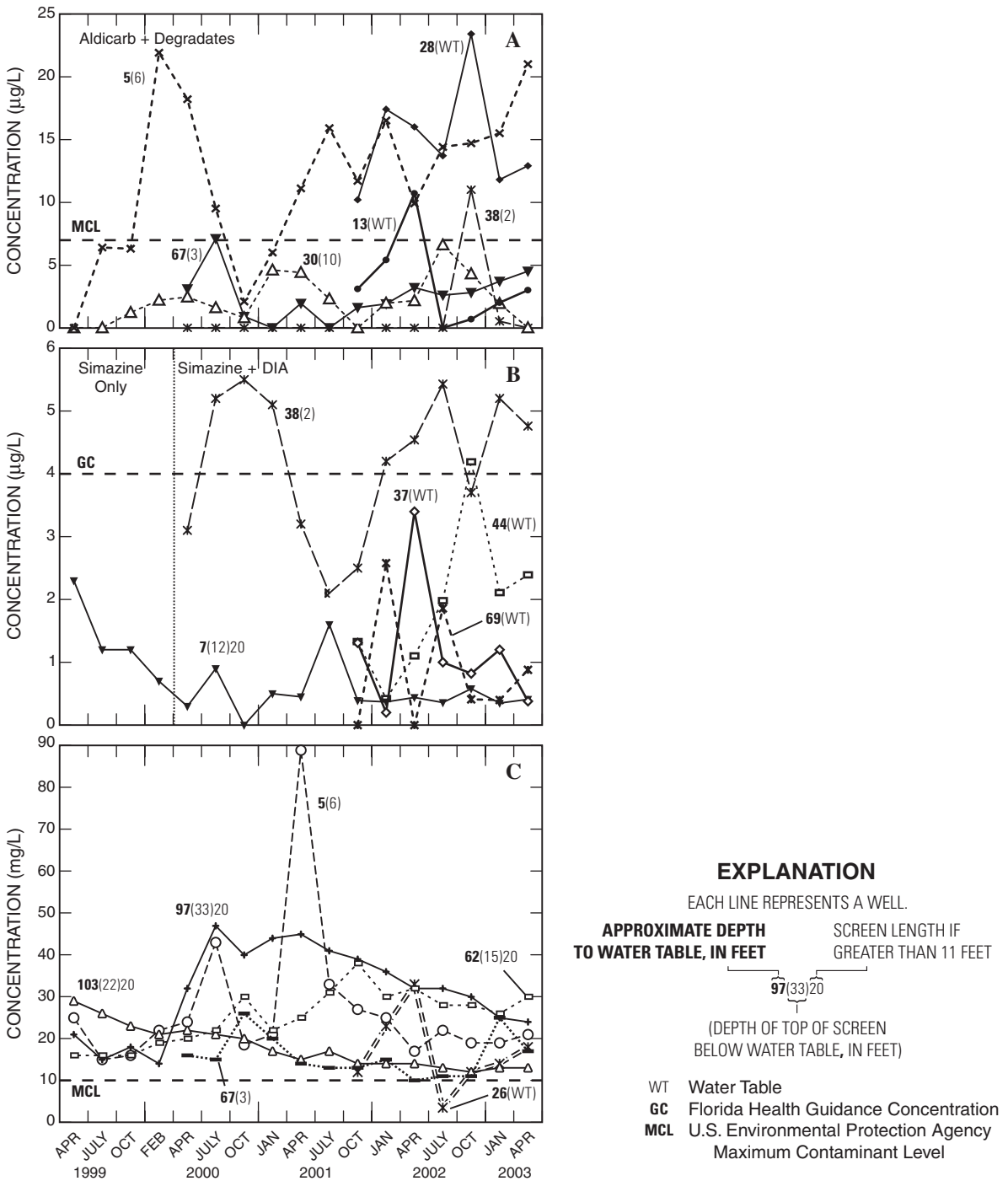
Figure 4. Concentrations of (A) aldicarb and its degradates: aldicarb sulfone and sulfoxide; (B) simazine and its degradate, chloroethylamino s-triazine (CEAT); and (C) nitrate, as N, in ground water from selected wells.

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HYDROLOGIC ASSESSMENT OF LEAKAGE FROM NONCONNAH CREEK TO THE SHALLOW AQUIFER IN THE VICINITY OF THE SHEAHAN WELL FIELD, MEMPHIS, TENNESSEE

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The potential of surface water from an impaired watershed (Nonconnah Creek) to infiltrate into a shallow aquifer system that recharges the Memphis aquifer is being investigated near the Sheahan Well Field in Memphis, Tennessee. Previous research results indicate that water pumped from shallow production wells in the Memphis aquifer contains as much as 30% of a chemically distinct modern water (15 to 20 year residence time) that is entering the upper part of the Memphis aquifer near the Sheahan well field. The shallow aquifer overlying the upper Claiborne confining unit and Memphis aquifer is unsaturated near the Sheahan pumping station, but becomes progressively saturated toward Nonconnah Creek, 2.7 miles south of the pumping station.

The project is designed to determine the flux and quality of water leaking from Nonconnah Creek to the shallow aquifer during a one-year period using multiple approaches: (1) assessing stream discharge loss (or gain), (2) assessing potential for leakage to shallow groundwater using hydraulic head data, (3) geochemical and environmental tracer (^{3}H/^{3}He and CFC's) studies, and (4) finite-difference computer modeling of stream-aquifer-pumping response. Three monitoring wells (NC-1, -2, and -3) were installed and screened at successively greater depths in the shallow aquifer at Nonconnah Creek and Getwell Road during April 2004; a stilling well was installed nearby during August 2004. Initial water-level data indicate that a downward vertical gradient exists from the stream to the shallow groundwater during the summer months. Stream discharge measurements made in Nonconnah Creek and tributaries during June and August indicate stream losses of approximately 1/3 of the upstream discharge at the Getwell Rd. site. Water quality and environmental tracer data from 6 wells and Nonconnah Creek sampled during May and August 2004 are forthcoming. In regard to model development, boundary conditions, hydraulic head data and ground water withdrawals have been estimated from existing hydraulic data. A three-dimensional geologic block structure was constructed from dense well-log data and discretized to produce a 55-layer model. Model calibration and sensitivity testing are currently being performed.

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USE OF FLOW DURATION CURVES AND LOAD DURATION CURVES TO ENHANCE FECAL BACTERIAL SOURCE TRACKING IN STONERS CREEK, DAVIDSON COUNTY, TENNESSEE

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Fecal bacterial pollution of streams and rivers continues to be a significant problem in Tennessee and elsewhere in the United States, with many streams still listed on the U.S. Environmental Protection Agency 303(d) list as impaired due to pathogens. In order to remedy this situation, the sources of the fecal pollution must be determined. While many different methods have been used for fecal bacterial source tracking (BST), the work presented here only will address the use of carbon utilization profiles (CUP) for BST and the use of flow/load duration curves to enhance the process. Specifically, BST information will be presented for Stoners Creek in the Stones River Watershed, Davidson County, Tennessee, using CUP data from *Enterococcus sp.* and *Escherichia coli* isolates presented in a load duration curve format.

A flow duration curve for a particular stream is used to relate flow values for that stream to percentage of time those values have been met or exceeded. The curve is generated by calculating the cumulative frequency of the historic average daily flow data for this stream. This gives a graphical description of general hydrologic conditions for the stream and provides a useful way to communicate technical information in an understandable format. The flow duration curves can be transformed to load duration curves by multiplying the flow values along the curve by a numeric water-quality criterion (such as *E. coli* CFU/100 mL). Water-quality monitoring data and BST data can be displayed in a duration curve format to help the understanding of watershed processes and possible solutions.

The basic assertion of all BST methods is that a certain species of bacteria from a particular host source or a certain *characteristic* of a particular bacterial species is unique to that host source. In particular, the CUP method for BST is known as a library-dependent method and requires the acquisition of a "library" of fecal bacteria from different known fecal sources. For this study, *Enterococcus sp.* and *E. coli* were isolated from bovine, human, deer, duck, dog, and goose feces found in the Stones River Watershed. The CUP "fingerprint" for each isolated bacterium from the known sources was then determined using the Biolog® identification system.

The Biolog® system uses a 96-well microtiter plate to hold 96 different carbon sources. The wells are inoculated with a standardized inoculum of bacteria culture. The plate is then incubated for 24 hours at the appropriate temperature. If the bacteria use a particular carbon source, a purple precipitate is formed. A plate reader is used to measure the color change. This pattern of carbon source utilization is compared to the Biolog® database to identify the organism to genus and species. The pattern generated by this method is also the CUP "fingerprint" for bacterial source tracking. The premise of this method is that the selection pressures acting on fecal bacteria living in a particular host will drive the evolution of enzymes necessary to use carbon sources available in that environment. Thus, a species of bacteria living in one of the fecal sources may have a different CUP as compared to the same species of bacteria living in a different source.

The library of CUP fingerprints from the bacteria of known fecal sources was then subjected to discriminant analysis. From this analysis, discriminant functions were developed based on the 96

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variables used to generate the fingerprint. These functions group the fingerprints from particular host sources together by maximizing the differences between different host source's fingerprints and minimizing differences within particular host source's fingerprints. Bacteria isolated from Stoners Creek water samples were fingerprinted by the same technique that is used for the bacteria from known fecal sources. These fingerprints were classified against the fecal bacterial library (the groups of bacteria from the known fecal sources) by the discriminant function. The percentage of the bacteria that was classified to each source is considered to be the percentage that each source is contributing to the pollution. Based on the CUP data averaged from 9 different sampling dates, *Enterococcus sp.* and *E. coli* from Stoners Creek were classified as 21 percent bovine, 14 percent goose, 8 percent duck, 15 percent deer, 6 percent dog, 13 percent human, and 23 percent unknown. When the CUP BST data from the 9 different sampling events are displayed in load duration curve format, the relation of hydrologic conditions and sample date to the BST information can be seen in a graphical format. The graphical format can reveal patterns in the data, such as a particular season or hydrologic condition when certain sources are contributing more fecal pollution to the stream.

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COMPARISON OF ANTIBIOTIC RESISTANCE PATTERNS, CARBON UTILIZATION PROFILES, AND PULSED-FIELD GEL ELECTROPHORESIS OF *ESCHERICHIA COLI* FOR FECAL BACTERIAL SOURCE TRACKING IN THE DUCK RIVER, MIDDLE TENNESSEE

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The Duck River in Middle Tennessee frequently is used for recreational purposes and is classified as fully performing in the Tennessee Department of Environment and Conservation's water-quality assessment. Total maximum daily loads of *Escherichia coli* in the Duck River can exceed recommended limits, and when recommend limits of this fecal indicator bacterium are exceeded, the risk of exposure to pathogens is increased. Remediation procedures for reducing high bacterial loads cannot be adequately addressed until the source of fecal bacteria is identified. This study compares antibiotic resistance patterns (ARP), carbon utilization profiles (CUP), and DNA fingerprinting by pulsed-field gel electrophoresis (PFGE) for bacterial source tracking in the Duck River using the same *Escherichia coli* isolates in each method.

E. coli were isolated from cows, septic systems, and sewage influent in the Duck River watershed and were "fingerprinted" by the above three methods. The data were then entered into a library for discriminant analysis. The ARP for each isolate was determined by growth on tryptic soy agar plates containing various concentrations of nine antibiotics. Bacteria were identified and CUP were determined using the Biolog® bacterial identification system. PFGE was performed on restriction digests (XbaI restriction enzyme) of bacterial DNA extracts. Environmental bacteria from two sites on the Duck River, upstream and downstream of Shelbyville, Tennessee, were collected during the fall and spring by the filter-membrane method and fingerprinted using the above three methods. Discriminant analysis was used to classify environmental bacteria against the library of the three potential sources.

Results from this analysis indicated that classification probabilities were higher for CUP (95 percent) than ARP or PFGE (72 and 59 percent, respectively). Environmental *E. coli* from the upstream site were classified using CUP as 43 percent sewage, 20 percent cow, 13 percent septic, and 24 percent unknown. For the same bacterial isolates, ARP indicated 43 percent sewage, 27 percent cow, and 30 percent unknown, while PFGE data identified the bacteria as 13 percent sewage, 13 percent cow, and 74 percent unknown. *E. coli* from the downstream site were classified by CUP as 50 percent sewage, 31 percent cow, and 19 percent unknown. ARP indicated 47 percent sewage, 22 percent cow, and 31 percent unknown, and PFGE data grouped the bacteria as 6 percent sewage, 31 percent cow, and 63 percent unknown. Counts of *E. coli* from the filters were converted to daily load and plotted on a load duration curve. Results from the load duration curve plots indicate that the samples were taken during mid-range, moist, and high-flow conditions.

Loads exceeded target loads at both sites for three of the four sampling dates. Seasonal variation was present at both sites. The source tracking data indicated that at the upstream site, sewage was the major contributor during all seasons. At the downstream site, sewage was the major contributor in the fall, and cows were the major contributor in the spring. All three methods appear to have promise for fecal bacteria source tracking, but the higher classification probability for CUP indicates that it is the most reliable of the three methods. The use of the load duration

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curves allows for good visual comparison of the results from the different sampling dates and shows the importance of sampling under different flow conditions.

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MONITORING OF ENTEROVIRUS AND HEPATITIS A VIRUS IN WELLS AND SPRINGS IN EAST TENNESSEE

Trisha Baldwin[1], Alice Layton[2]*, Larry McKay[2], Sid Jones[1], Greg Johnson[3]
Shay Fout[4], and Victoria Garrett[2]

ABSTRACT

A monitoring program is underway to measure occurrence and concentration of the common human viral pathogens, enterovirus and hepatitis A virus, in ground water samples from community water supply wells and springs in east Tennessee. Viral assays are carried out using three different approaches: 1) tissue culture assays using green monkey kidney (GMK) cells, which are carried out at the EPA National Exposure Research Laboratory in Cincinnati, OH; 2) quantitative real-time reverse transcription-polymerase chain reaction or QRT-PCR using probes and primers developed at the University of Tennessee; and 3) conventional RT-PCR, which provides a measure of presence/absence of the viruses. A total of 3 wells and 5 springs are being monitored in the study. Half of these are in high-risk settings for contamination with human fecal material (i.e., karst settings, high concentrations of fecal bacteria, high or variable turbidity, occurrence of sewage lines or septic fields in the catchment area, etc.). The other wells or springs are also in fractured or karstic rock, but have low concentrations of fecal indicators and low turbidity. These wells are expected to have lower risk of pathogen contamination because of the presence of overlying unconsolidated sediments or the absence of human development in the watershed. Typically, sampling involves filtering 200-500 gallons of water from the well or spring, usually under baseflow conditions, and then removal and concentration of the viruses prior to analysis. Preliminary results indicate that detectable levels of enterovirus are present in most of the water samples. Additional work is underway to determine viral concentrations, to confirm detection limits and to test the potential for "false positives".

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FLOOD FREQUENCY PREDICTION APPLICATIONS FOR TENNESSEE USING TRADITIONAL AND NEWER METHODS

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Up-to-date streamflow statistics, derived from traditional regional regression and the newer, robust region-of-influence regression, are needed for flow prediction of floods along rivers and streams of Tennessee. These calculations are important in the design of roads, bridges, culverts, and buildings located near rivers and streams.

Traditional regional regression is used to compute single-variable and multivariable prediction equations from fixed, regional groups of streamgages located in the study area. Contributing drainage area is the explanatory variable in the single-variable equations. Multivariable equations use contributing drainage area, main-channel slope, and a climate factor as explanatory variables.

The newer region-of-influence regression method is used to compute multivariable prediction equations from a variable group of 60 similar streamgages located anywhere in the study area. Explanatory variables in region-of-influence equations may include contributing drainage area, main-channel slope, a climate factor, and a physiographic-region factor. A computer application is needed to estimate flood-peak discharges for unregulated, ungaged streams in Tennessee using the region-of-influence method.

This presentation compares flood-frequency predictions for more than 100 bridge/culvert sites crossing unregulated, ungaged streams in Tennessee. The 100-year flood discharges computed using the single-variable regression and region-of-influence regression methods are the streamflow statistics used for this comparison. The regression methods are discussed in detail in USGS publications "Flood Frequency of Streams in Rural Basins of Tennessee" (1993) and "Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee, 2000" (2003).

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METHODS FOR ESTIMATING FLOW DURATION AND LOW FLOW FREQUENCY CHARACTERISTICS OF UNREGULATED STREAMS OF TENNESSEE

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

Planners and engineers require reliable estimates of the low-flow frequency and flow duration of rivers and streams to design and maintain water and wastewater treatment facilities. Assimilative capacity studies and total maximum daily load plans need up-to-date information and techniques for predicting streamflow statistics to protect the public and the environment and minimize pollution-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 low-flow frequency and flow duration of unregulated streams of Tennessee.

Rivers and streams of Tennessee are the primary sources and receptors of drinking water and treated wastewater, respectively, for the citizens, businesses, and industries of the State. Improvement, protection and sustainability of the quantity and quality of these waters is essential for the good health of the people and environment of Tennessee. Environmental and water resources managers rely on accurate and up-to-date methods for characterizing the natural flow of water in rivers and streams. Streamflow statistic estimation methods developed by the U.S. Geological Survey are based on gaging station records and streamflow discharge measurements. These methods can be used to estimate the 7Q10 and 30Q5 low-flow frequencies, and the 99.5-, 99-, 98-, 95-, 90-, 80-, 70-, 60-, 50-, 40-, 30-, 20-, and 10-percent flow durations for unregulated rivers and streams in Tennessee.

The U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Environment and Conservation (TDEC), developed and tested a computer application that automates the complex calculations necessary to predict low-flow frequency and flow duration at gaged and ungaged sites. The computer application allows planners and engineers to compute selected streamflow statistics for unregulated rivers and streams of Tennessee using the region-of-influence regression method.

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LINKING STREAM HABITAT ASSESSMENT SCORES WITH STREAM MORPHOLOGY FOR CREATING SEDIMENT TMDLS

Nick Jokay and Brian Watson[1]

In West Tennessee aquatic habitat impairment by siltation is a frequent concern on 303(d) listed streams. Previous sediment TMDL estimation efforts by Tetra Tech have focused on predicting sediment loads from upland sources using "Sediment Tool," a GIS/USLE based computer model. However, stream channels, depending on their stability, may also contribute to the sediment load, thus their contributions cannot be accounted for using only a USLE based model. In order to incorporate stream generated sediment into the TMDL estimate some type of dataset is necessary. The optimum dataset would include channel slope, bed and bank material geotechnical properties, bankfull depth, and other properties of the reach. However, few streams in Tennessee have been documented with this degree of quantitative data, therefore an alternative approach using existing qualitative data indicating channel condition was proposed. The goal being to sort streams, based on qualitative channel stability factors, and then apply an appropriate TMDL estimation method.

The Tennesee Department of Environment and Conservation has an extensive database of "habitat assessments" for 303(d) listed streams. The habitat assessments, collected as part of TDEC's SOP for macroinvertebrate stream survey program contain qualitatively scaled observations of channel morphology. By linking the habitat assessment scores to the erosion potential of stream channels, the channel sediment could be incorporated into a computer model to further refine the sediment TMDL estimates. In order to correlate habitat assessment scores with channel stability, a TDEC biologist was teamed with a Tetra Tech geomorphologist to conduct simultaneous stream assessments: the biologist using the habitat assessment method and the geomorphologist conducting Rapid Geomorphic Assessments (RGA) based on the Channel Evolution Model (CEM) of stream morphology. This RGA method originally developed, through a USGS study of west Tennessee streams, as a technique of evaluating channel erosion potential based on channel morphology.

The methodology was tested on the Cypress Creek watershed in McNairy County, Tennessee during the summer of 2004. Assessments were conducted at 27 sites throughout west Tennessee with 4 sites located within the Cypress Creek watershed.

Two (of 10) factors surveyed during the habitat assessment had strong correlations with the two (of 9) factors surveyed during the RGAs; "bank stability" and "sediment deposition."   The bank stability and sediment deposition scores from the habitat assessments were plotted against the RGA scores and thresholds were then drawn to classify the channels as having low, moderate, or high erosion potentials.

The low, moderate, and high erosion potential channels were assumed to be contributing background, moderate, or high amounts of sediment respectively to the total sediment load in the watershed. However, to be useful, the values of low, moderate, and high need to be correlated quantitatively to sediment load before they can be used in a TMDL estimation model. We assumed that "low" indicated the channel contributions were negligible and therefore the USLE based model linked with a watershed area based sediment delivery ratio would result in a reasonable estimate. However, due to the lack of channel specific data, quantifying sediment loads from channels classed as "moderate" and "high" are more difficult, therefore work is still being conducted to evaluate the best methods.

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ELIZABETHTON'S BIG SPRING:
A CASE FOR KARST AQUIFER PROTECTION

Robert Benfield[1]*, Sid Jones[2], Gareth Davies[3]

Big Spring represents a significant and valuable source of ground water and it deserves the highest protection under Tennessee's classification rules. Both Elizabethton's public utility and private well owners use this East Tennessee carbonate rock aquifer associated with Big Spring. Big Spring is a major tributary to Gap Creek providing natural aesthetic qualities as well as wildlife habitat. Springhead or wellhead protection in carbonate aquifers is closely dependent upon having knowledge and understanding of hydrogeological conditions in those settings. By using basic techniques to determine flow velocities and ordinary practices for karst investigations, competent delineations of management zones are achieved that aid the owners and users of the aquifer and ground water. Only thoughtful and cautious land use practices in the springhead management zones of vulnerable ground water sources such as Big Spring will keep water treatment costs low and prevent loss of beneficial uses.

OVERVIEW OF STUDY

The town of Elizabethton in Carter County Tennessee currently uses three springs as municipal water sources. Two of these discharge from the Rome formation, and have some characteristics comparable to confined karst aquifers. Big Spring discharges from the Knox aquifer (Knox group plus upper Conasauga group carbonates), a more typical unconfined carbonate aquifer. The primary focus of this work was to better delineate the recharge area for Big Spring and to determine a travel time in the Knox aquifer to the spring. The tracer test is part of ongoing ground water research by hydrogeologists interested in better understanding the carbonate aquifers of Carter, Johnson, and Unicoi counties (Benfield and Hughes, 1999).

A quantitative groundwater trace to Big Spring using an appropriate quantity of a Food & Drug Administration approved fluorescent dye was conducted in September 2004. Results show that a recharge event (or possible discharge/spill) in a distant portion of the aquifer (1.4 miles or 2.2 km) could be detected at the water treatment plant on Big Spring approximately a week later. Traveling at about 1000ft/d (0.004 m/s or 0.3 km/d) provides scant reaction time by the water supplier to avert contaminated water from entering the distribution system. Upon conclusion of this study, this area should receive a groundwater classification of *Special Source Ground Waters* due to its vulnerability, proportion of the population using it, and cost of maintaining versus replacing should the source of groundwater become compromised (Rules of TDEC Division of Water Pollution Control Chapter 1200-4-3-.07).

Due to massive bedding and complex structural histories of the carbonates in this area, these aquifers present challenges for the karst hydrogeologist. Delineation of groundwater basins in this area may not be possible using an approach based on topography, geology, and hydrologic budgets, as may be inferred from the caveats to the latest EPA guidance on source-water protection in the valley and ridge physiographic province (EPA, 2002). Rather, extensive ground water tracing may be required.

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WELLHEAD-SPRINGHEAD PROTECTION

The approved Wellhead Protection Plan for Big Spring shows a management zone based primarily on topographic analysis and a recharge formula given in Tennessee Department of Environment and Conservation (TDEC) Division of Water Supply (DWS) guidance (TDEC, 1994). A previous study published by the Center for the Management, Utilization, and Protection of Water Resources at Tennessee Technology University included a ground water trace from a swallet in Gap Creek to Big Spring, as well as water chemistry measurements and an analysis of the karst geomorphology of the area (Ogden, Hamilton, and Brown, 1990). This study indicated that water quality problems in the Gap Creek watershed could impact water quality at Big Spring. In another study published by the Tennessee Valley Authority Office of Natural Resources – Water Systems Branch, the recharge area for the spring was estimated based on a hydrologic budget approach for estimating minimum recharge area for a karst spring (Foxx, 1981). Rules TDEC DWS Chapter 1200-5-1-.34 requires that a consultant with expertise in ground water tracing establish the wellhead protection zone using TDEC approved methods for a source used by a Category 4 Public Water System (>3000 connections or 1 million gallons per day). However, the authors of this study felt that insufficient ground water tracing had been performed to accurately deduce the recharge area for Big Spring or to demonstrate the extent of aquifer vulnerability to contamination.

CLASSIFICATION

The Watauga River Regional Water Authority has evaluated the feasibility of constructing a water source to replace both Elizabethton's Big Spring and Valley Forge Spring. An estimated cost of 27 million dollars will be required to establish a surface water treatment plant capable of 24 million gallons per day. In general terms, it would take at least 3 million dollars to replace Big Spring based on current pumping demands. The cost of a private well is about 5,000 dollars to the homeowner. Loss of this resource would be a considerable burden to current and future users. Cost of maintaining this source based on population served is extremely low. This area needs only to have smart decisions based on facts and not self-indulgence to guide its land use. Laws and regulations are in place that will consider the effects of development. The predominant recharge is steep slopes and sinkholes that do not lend themselves to large construction at low cost. Due to its natural and rural charm, many of the local landowners want to maintain this area in its current state. It is only the ones with large sums of money and wanting more money without regard to others that have the ability compromise this special source of groundwater. These entities present the greatest potential for adverse costs to maintain the current use for this special source. Having a classification helps to offset cost of unreasonable land use by communication of standards.

METHODS

To establish groundwater flow velocity and direction, a quantitative test was designed based on a field inventory of springs, caves, wells, sinkholes and other features such as sinking streams found in the vicinity of Big Spring. In addition geologic maps, topographic maps and studies previously conducted were utilized to facilitate the design of this test. For this study water samples were collected from an ISCO automated sampler and hand grabbed samples from springs and streams in the area. Analyses for the tracing compound were preformed on a Shimadzu 5000U scanning spectrofluorophometer.

ANALYTICAL RESULTS

Considering the variability in background fluorescence and the reproducibility of results, analytical errors appeared to be in the range of 10 to 20 parts per trillion. Consequently, dye concentration errors were relatively small compared with peak concentrations of over two hundred parts per trillion dye found in Big Spring samples. Based on a reported pumping rate of 1.5 million gallons per day and an estimated one million gallons per day spring discharge, dye recovery at Big Spring over the study period was about five percent of the introduced tracer mass.

GEOLOGIC SETTING

The dominant geologic structure is the Stony Creek Syncline, in which lower Paleozoic age rock strata plunge to the southeast. This area is the east most representation of the Valley and Ridge province and consists of the Conasagua group and Knox group rocks. The Nolichucky shale of the Conasagua group is described as limestone with silty layers and of the 248 feet of section exposed near Big Spring, only the lower 26 feet is described as clay shale (King, Ferguson 1960). The Nolichucky shale is mentioned because its relation to the topographic high of Bryant Ridge and its stratigraphic location between the Honaker dolomite and Knox group. Ogden's work indicates no significant lithologic barrier for groundwater between the Honaker dolomite and the Knox group. Foxx and Ogden both place emphasis on protecting sinkholes north of Big Spring on both flanks of Bryant Ridge. Considering the open-hole bedrock wells, cross cutting fractures and cave pits, it is unlikely groundwater barriers are extensive over the synclinal structure. Our results agree with previous studies where the recharge is identified between Doe River and Gap Creek up the plunge along strike.

CONCLUSIONS

Rapid flow (about 1000 feet/day) to Big Spring inferred from the travel times reported by Ogden et al and this study is comparable to that documented in other Tennessee karst aquifers. These ground water velocities are consistent with data in karst regions from over forty countries and are considered normal for such hydrogeological settings. Unconfined carbonate aquifers typically exhibit convergent, rapid flow in conduits of sufficient size to sustain turbulent flow and to permit rapid transport of suspended particulate matter, including bacteria. US EPA guidance (1996) state that such aquifers cannot be assumed to behave as porous media. Neither the time to peak concentration nor the shape of the tracer recovery curve shown in Figure 1 indicates significant opportunity for mass transfer processes to attenuate a slug of contaminant transported through the conduits of the aquifer to Big Spring. This investigation confirms the predicted vulnerability of this aquifer based on characteristics of rapid flow and direct recharge via sinkholes.

Springhead protection as mandated in Rules TDEC DWS Chapter 1200-5-1-.34 is an important first step toward protection of the ground water resource, but these rules do not give the utility authority to prohibit residential or industrial development in the management zone. Even a utility with a proactive wellhead program and support from local government may be unable to defend the management zone from a developer willing to expend vast resources. Current Tennessee rules might prevent a residential septic drain field based on steep slopes, depth to bedrock, or karst features, but might not preclude land application of treated wastewater. Classification of important ground water resources allows the state to establish stringent water quality criteria that may preclude certain land use practices or require additional treatment of discharged wastewaters, thus encouraging state environmental programs to share the burden of aquifer protection with local authorities, utilities, and landowners. Analysis shows potentially 17,000 people could be served by Big Spring. Replacing the source would cost more than 3 million dollars. Cost of

maintaining the source is subjective when considering potential tax collections when offsets by infrastructure expenditures or need for additional revenue is considered.

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Figure 5 Tracer Breakthrough Curve (Fluorescein)
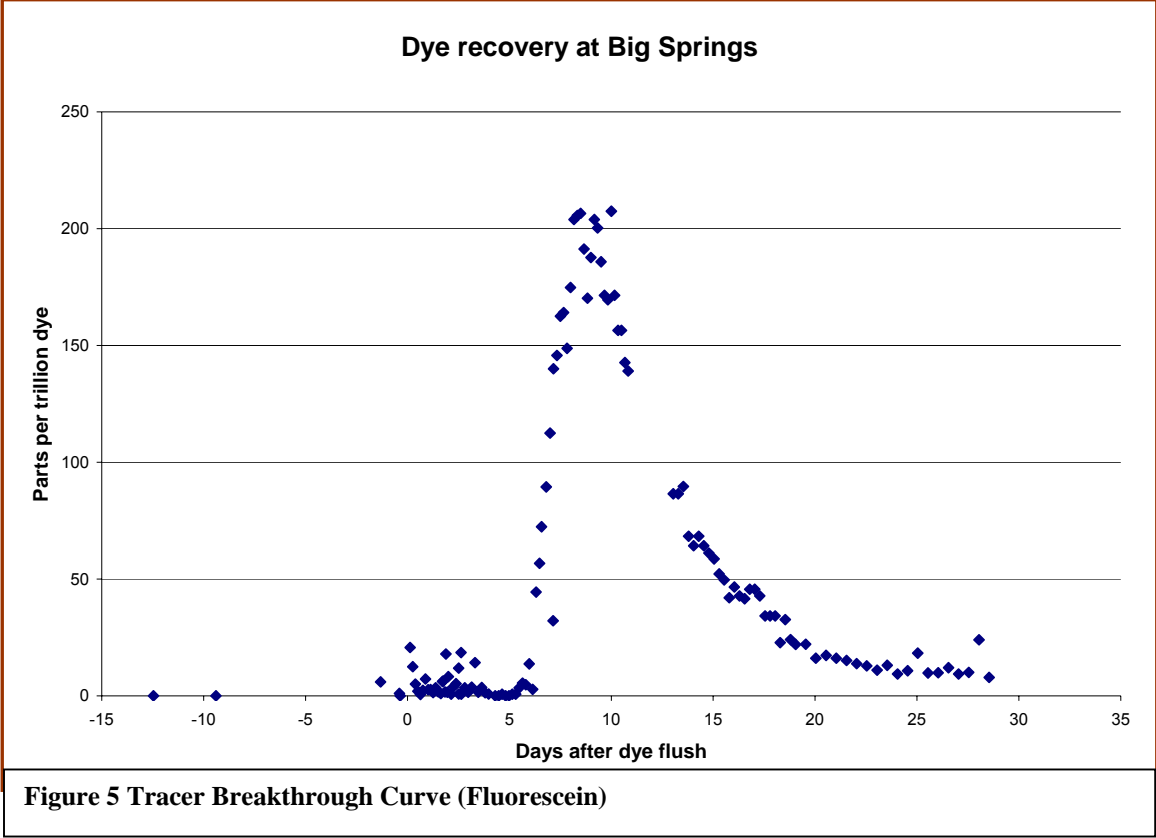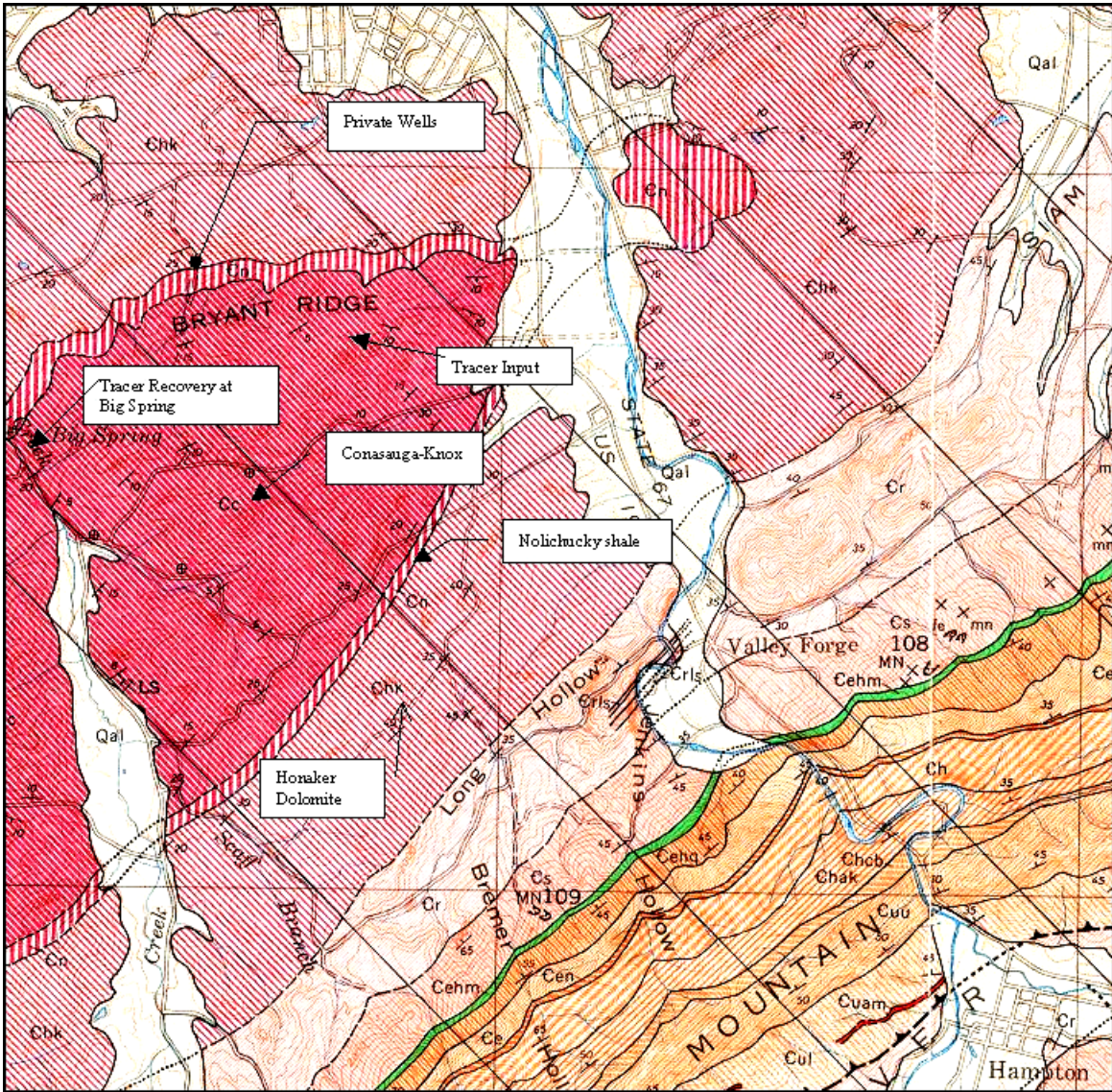
Figure 6 Geologic Map (King & Ferguson 1960) Elizabethton Tennessee Tracer Study 2004

THE DISSOLUTION OF A CONCEPTUAL MODEL:
THE KARST HYDROGEOLOGY OF U.S. DOE OAK RIDGE RESERVATION

Don Gilmore[1], Jack Wheat[2], Robert Benfield[3] and Sid Jones[4]*

The hydrogeology at the Department of Energy Oak Ridge Reservation in Anderson and Roane counties of east Tennessee has been, in many respects, studied as extensively as at any Tennessee site. The thirty five thousand acre reservation is divided administratively into three facilities. They are the Oak Ridge National Laboratory (ORNL), the Y-12 nuclear weapons plant, and the former K-25 gaseous diffusion plant, now the East Tennessee Technology Park. Hydrogeologic studies were carried out for various purposes at these three facilities, but typically were done as basic research or in support of waste disposal or environmental restoration activities. A total of over three thousand borings, piezometers, and monitoring wells have been drilled on the ORR, and hundreds of slug tests were completed (Y-12, 1993; Geraghty and Miller, 1989; Moore, 1988a).

A site conceptual model was developed for the ORR after the reservation was placed on the U.S. EPA National Priorities List in 1989 (Solomon et al, 1992). The model classified ORR rocks as aquifer, aquitard, or aquiclude. The Knox group and the underlying Maynardville limestone were grouped into a single aquifer. The aquiclude was delineated based on the presence of saline groundwater and included rocks at depths greater than a few hundred meters. All other rock units were considered to be aquitards, including some carbonate units. Rapid groundwater velocities were generally considered to be limited to a shallow interflow zone during storms, which was estimated to carry ninety percent of subsurface flow. Significant flow in the bedrock was confined primarily to fractures, and solute velocities were thought to be greatly reduced by mass transfer between the fractures and the rock matrix.

Experiments to deduce the details of streamflow generation were carried out in the Walker Branch watershed, located on the dip slope of Chestnut Ridge in the Knox group near ORNL (Mulholland, 1993). The Walker Branch experiments indicated that the percentage of flow through the stormflow zone was significantly less than 90 percent of all subsurface flow at this site, as did other studies in Melton Valley carried out in aquitards. This led to a modification of the conceptual model with regard to the importance of interflow (Huff, 1998). However, other aspects of the model were unchanged.

Much of the supporting evidence for the conceptual model was drawn from investigations made near the large waste disposal sites in Melton Valley, an area underlain primarily by shale. Given that Paleozoic carbonate rocks underlie about 60 percent of the ORR and that these rocks also host significant contamination, few studies were carried out to determine the influence of karst processes on groundwater flow and contaminant migration. Prior to 1995, studies of the ORR carbonates included inventories of cavities encountered during the drilling of wells (Moore, 1988b; Shevenell and Beauchamp, 1994), of sinkholes and caves on the reservation (Huff, 1998), and of seeps and springs (Johnson, 1996). Later, geophysical studies (Kaufmann, 1996; Doll et al, 1998) were used to discern the size and shape of large subsurface voids encountered during drilling. Recession analyses of spring and well hydrographs were also performed (Desmarais, 1995; Shevenell, 1996). Tracing with fluorescent dyes, a standard tool for determining ground-

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water flow paths and travel times in any carbonate setting, was rarely attempted (Ketelle and Huff, 1984).

Beginning in 1995, Department of Environment and Conservation (TDEC) staff, in conjunction with Cambrian Ground Water Co. of Oak Ridge, performed a number of ground-water tracing tests at locations on the ORR indicated in Figure 1. The results of these tests are summarized in Tables 1 and 2. They showed that ORR ground-water flow paths could be kilometers long and that velocities were rapid and similar to ground-water velocities in carbonates in other parts of the state. The shape of tracer recovery curves, such as that shown in Figure 2, indicated little mass transfer from primary flow paths along dissolutionally enlarged fractures to the bedrock matrix. In some cases, so-called scaling effects (differences between hydrogeologic data from well tests and tracer data) were dramatic, with traced velocities being many orders of magnitude faster than those inferred from Darcy calculations or numerical models (Bailey and Lee, 1991). With the discontinuation of a centralized Groundwater Program Office at ORNL, DOE has not attempted to modify the original site conceptual model, which clearly does a poor job of describing groundwater flow and contaminant transport in the carbonates of the ORR.

Table 1. TDEC/Cambrian Subsurface Tracing Results

Site	Distance (meters)	Travel Time (hours)	Velocity (meters/day)
Northeast Tributary	560	22	610
Northwest Tributary	1220	68.5	430
K-901 Pond	130	<24	>130
Mount Vernon	230	44	125
Chestnut Ridge Security Pits	2250	54	1000
East End Union Valley	300	288	25
Chestnut Ridge East Borrow Area	1010	<500 (10 in storms)	>50 (2500)
K-1070A Burial Ground	640	23	670
Bear Creek	970	35.5	650
Spallation Neutron Source	360	126	70
Union Valley	1080	110	240
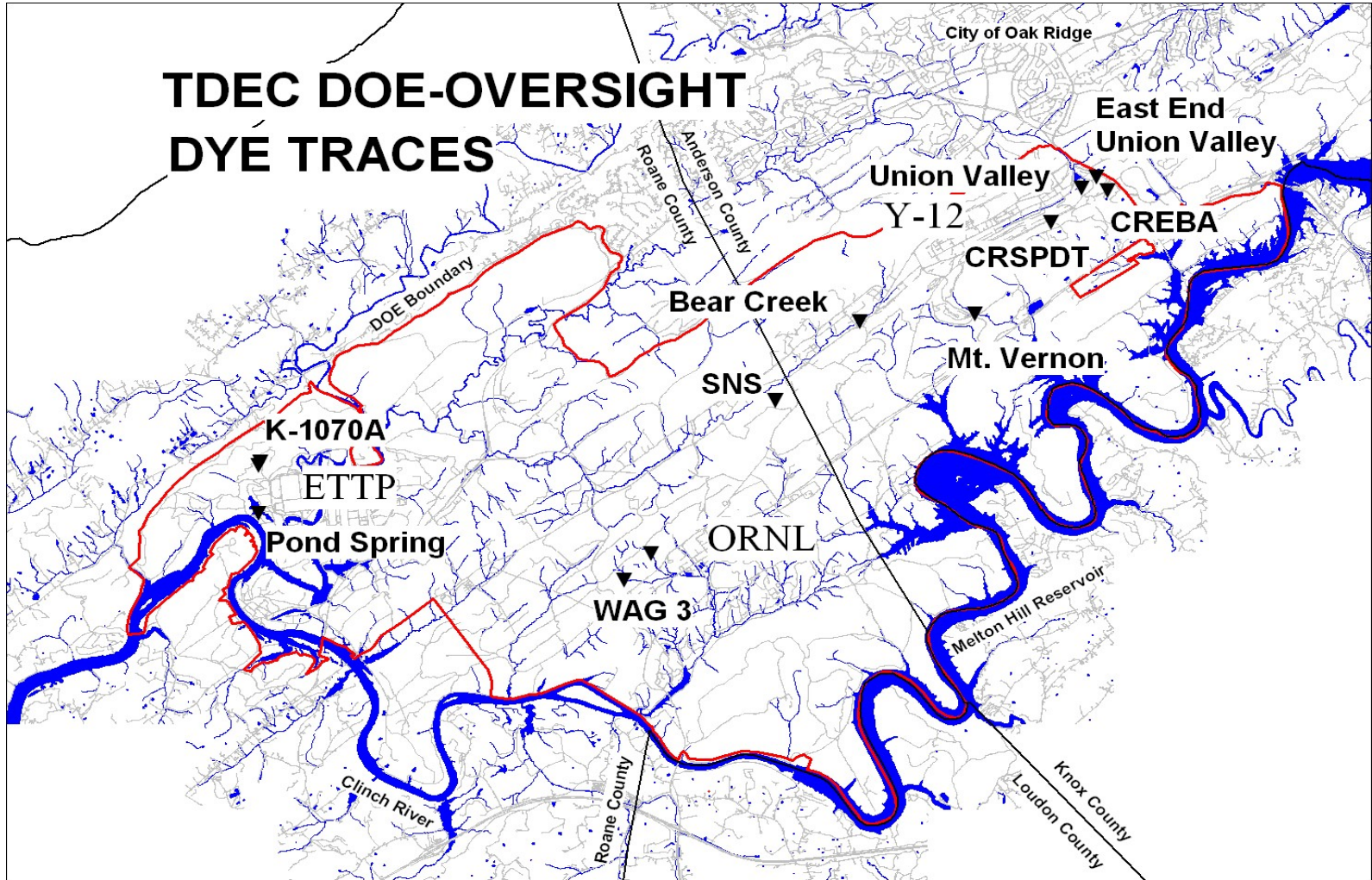
Figure 1. Dye Tracing Locations

Table 2. TDEC/Cambrian Subsurface Tracing Locations

DYE TRACE	LONGITUDE	LATITUDE	DYE USED	DATE
Chestnut Ridge East Borrow Area (CREBA)	-84.23226	35.99122	Rhodamine WT	6/1/1995
K-1070A	-84.41076	35.94323	Fluorescein	1/16/1996
K-1070A	-84.41031	35.94267	Sulphorhodamine B	1/16/1996
Union Valley	-84.23446	35.99387	Sulphorhodamine B	3/10/1997
K-901 Pond (Pond Spring)	-84.41091	35.93440	Rhodamine WT	10/31/1997
East End Union Valley	-84.23773	35.99185	Eosine	7/11/1998
Chestnut Ridge Security Pits (CRSPDT)	-84.24424	35.98558	Floxine	4/12/1999
Northwest Tributary (WAG3)	-84.33473	35.92106	Fluorescein	6/14/1999
Northeast Tributary (WAG3)	-84.32916	35.92580	Floxine	6/14/1999
Mt. Vernon	-84.26054	35.96894	Fluorescein	9/14/1999
Bear Creek	-84.28467	35.96798	Fluorescein	5/16/2001
Spallation Neutron Source (SNS)	-84.30261	35.95369	Fluorescein	8/15/2001
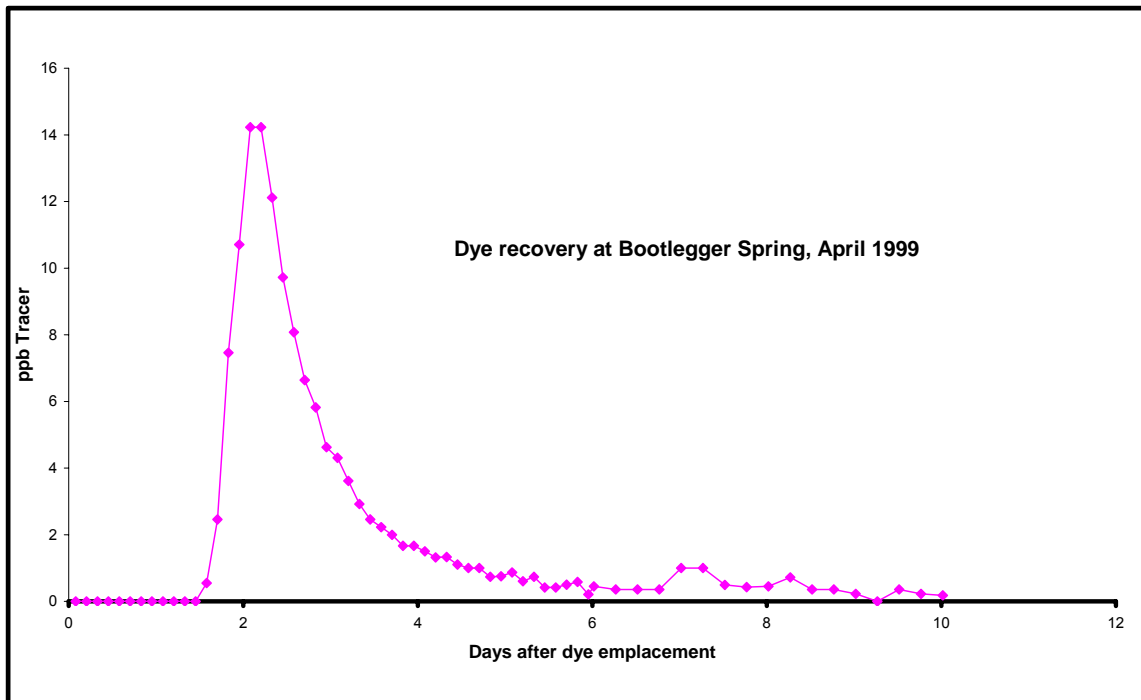
Figure 2. Typical Dye Recovery Curve

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GROUND WATER TRACING RESULTS AND SINKHOLE ANALYSIS IN LA VERGNE, TENNESSEE, FOR INTERPRETING AND REMEDIATING SINKHOLE FLOODING PROBLEMS

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INTRODUCTION AND PURPOSE

Rutherford County is the fastest growing county in Tennessee, and La Vergne has grown with it. Nearly all of La Vergne is underlain by soluble limestones that have developed a karst topography with numerous sinkholes, sinking streams, springs, and caves. As a result, new growth has occurred in and around many sinkholes. The increased development has caused a larger amount of water to run off due to areas being paved and covered by rooftops. Stormwaters that once slowly infiltrated into the ground, now rapidly enter the sinkholes. Sinkholes that once could handle the former runoff from moderate storms, now often flood due to greater peak in the storm hydrographs. Caves, unlike storm sewers, naturally change in size. Increased runoff into sinkholes can thus back up behind natural constrictions. In addition, sediment resulting from development, as well as, trash can clog sinkholes and portions of the subterranean drainage. In some cases, sinkholes have been filled, and this has increased storm runoff volume. Sinkholes are not solitary entities. Therefore, development around one sinkhole will likely have a pronounced impact on all others down-gradient within the subterranean basin that leads to the spring discharge point. The first step in understanding sinkhole flooding in a karst terrane is to determine how the caves, springs, and sinkholes are interconnected so that future growth can be planned. This is done through ground water tracing using fluorescent dyes. This report presents the results of 11 dye traces that were conducted. In addition, the ground water tracing results have allowed determination of the elevation difference between sinkhole bottoms and the springs to which they drain. This enables better prediction of the success of potential engineering solutions in areas exhibiting sinkhole flooding problems. The final section of the paper will discuss these potential solutions at specific areas.
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STUDY AREA

La Vergne is located in northern Rutherford County and lies within the La Vergne and Smyrna 7½ minute USGS topographic maps (Figure 1). Dye tracing was conducted to 4 spring basins. These springs are located along Hurricane Creek to the northwest, Sinking Creek to the north, and Rock Springs Creek to the south. These creeks drain into Percy Priest Lake which is located along the north and eastern edges of the city limits.

HYDROGEOLOGIC SETTING

La Vergne 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. There appears to be two anticlinal (domal) structures in the study area separated by a syncline that trends in a north/northwest direction. The first detailed geologic study of the La Vergne area was conducted by Galloway in 1919. Now, detailed geologic maps on a topographic base exist for the study area. Those used for the investigation were Wilson, Jr., 1966a (La Vergne) and Wilson, Jr., 1966b (Smyrna). The oldest rocks exposed in the study area are those of the Ridley Limestone

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Above the Ridley is the Lebanon Limestone which crops out throughout most of the study area. The Carters Limestone is above the Lebanon. The Ridley Limestone ranges from 100 to 150 feet thick whereas the Lebanon and Carters limestones range from approximately 50 to 100 feet in thickness. Each of these three limestones are very cavernous and form sinkholes. Eight of the dye traces were conducted from sinkholes in the Lebanon Limestone while three traces were conducted from sinkholes developed in the Carters Limestone. The Hermitage Formation is above the Carters Limestone and is composed primarily of sandstone, shales, and thin sandy limestones. The Hermitage Formation crops out on Sand Hill where layers of sandstone are abundant. The occurrence of the Hermitage in this area is a result of a gentle downwarping of the rocks (basin/syncline).

The primary joint and photo-lineament trends mapped by Ogden (1999) are N20º-40ºW. No ground water tracing has been conducted in La Vergne prior to this investigation. Two ground water traces were previously conducted to Gwyn Spring along Rock Springs Branch in Smyrna by Ogden (2001).

GROUND WATER TRACING METHODS

The ground water traces were conducted using the following fluorescent dyes: eosine (pink), sulphorhodamine B (red), and fluorescein (green). These dyes are non-toxic and routinely approved for use by various divisions of the Tennessee Department of Environment and Conservation. Prior to conducting the dye traces, the Tennessee Underground Injection Control Program was notified through their voluntary dye registration program. The injected dyes were detected by using activated charcoal packets that absorb and concentrate the level of dyes in the water. The charcoal packets, called "traps", are suspended in the waters expected to receive the dyes on a stiff wire connected to a concrete base. These are referred to as "gumdrops". Prior to dye injection, the traps were placed in the waters for approximately a week to test for background concentrations. The dyes are common coloring agents and frequently are found as "contaminants" in the ground water. Once background levels were determined, new packets were set out immediately prior to injection. After injection of the dyes, the packets were usually changed at one week intervals and sent to the laboratory for analysis. Analyses were performed using a scanning spectrofluorophotometer which can detect dye concentration as low as a few parts per trillion.

GROUND WATER TRACING RESULTS

A total of 11 ground water traces were conducted in four spring drainage basins. Table 1 shows the locations and dates of dye injection and springs testing positive for the dyes. The interconnection of injection points and springs are shown on Figure 1. Straight lines have been drawn between the points of dye injection and sites testing positive for dye, but subterranean flowpaths are obviously much more complex than a straight line between points.

TABLE 1. Summary of Dye Tracing Activities.

Dye Injection Dates	Injection Locations	Sites	Testing Positive
3/3/04	Stones River Road/Stones River Court (¾ lb. Sulphorhodamine B)	Town	Spring
3/3/04	End of Highland Street (1 lb. Eosine)	Town	Spring
3/3/04	Near intersection of Hazelwood St. and JFK Drive (¾ lb. Fluorescein)	Town	Spring
3/15/04	South side of Ingles Street (1 lb. Fluorescein)		Town Spring
3/15/04	Near intersection of Deer and Parrish streets-Injection Well (1 lb. Fluorescein)		Town Spring
3/15/04	Post Office-Injection Well (1 lb. Eosine)		Schreibman Spr.
3/31/04	Intersection of Nelson & Merritt(1 lb. Fluor)	Gwyn	Spring
3/31/04	Blue Valley Injection Well (1 lb. Eosine)	Town	Spring
3/31/04	Sand Hill Road Sink-Injection Well (½ lb. Eos.)		Unknown
3/31/04	Clayton Estates-Injection Well (½ lb. Eosine)		Cave Spring
3/31/04	Bill Steward Blvd near new fire station site (½ lb. Sulphorhodamine B)		Cave Spring

IMPLICATIONS OF THE RESULTS TO SINKHOLE FLOODING PROBLEMS WITH RECOMMENDATIONS FOR SELECT SINKHOLES

OVERVIEW

Rapid movement of the tracing agents suggest that there are not significant artificial clogs in the subsurface, but natural changes in cave size occur that cause water to back up behind small passages during flooding. Nearly all sinkholes will flood during major storm events such as those that occur at 20 or more year intervals, but the situation has worsened in many areas in La Vergne due to increased runoff associated with development. There are a few sinkholes where trash and debris have washed in, likely reducing the drainage rate. The dye tracing results show which sinkholes are hydraulically connected in each spring basin (Figure 1). Development that has occurred in the past or in the future that increases runoff to a particular sinkhole has the potential to adversely affect all others down-gradient in the same spring basin. This is particularly true for sinkholes in which the bottom elevations are not significantly higher than the spring to which it is connected. More precise elevations of selected areas involved with the tracing activities were obtained from two foot contour interval maps provided by the City of LaVergne. The elevations of the springs compared to the bottom of the sinkholes show that the subterranean karst water

table is quite flat and very close to the surface in many areas. This information will be subsequently used when discussing whether digging out and/or constructing drainage wells is a viable solution to the flooding problem.

TOWN SPRING DRAINAGE BASIN

Town Spring is located at an elevation of approximately 535 feet where the Old Nashville Highway and Murfreesboro Road meet. Six successful dye traces were conducted to this spring as shown on Figure 1. This spring basin contains the sinkholes with some of the worst flooding
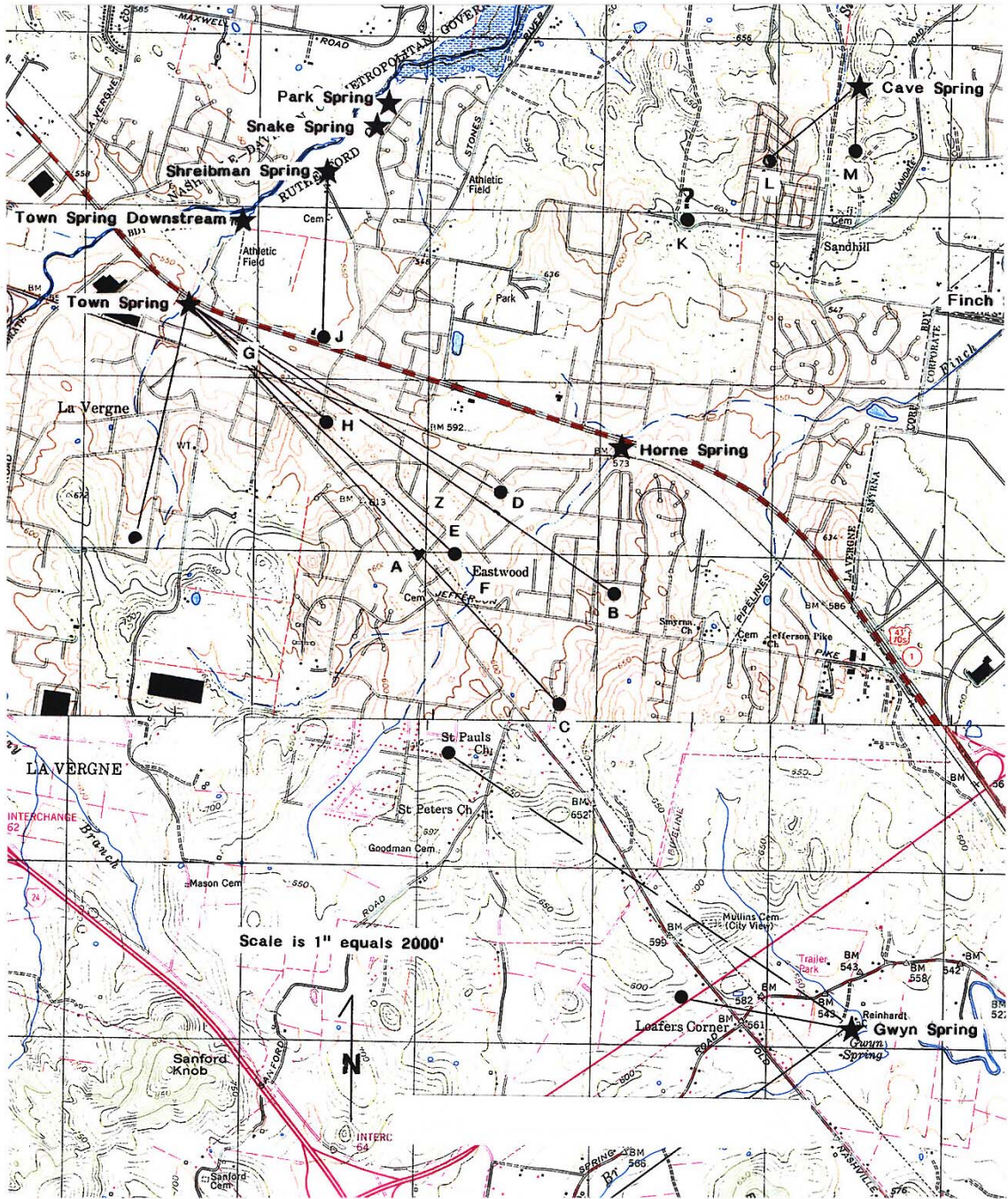
Figure 1. Dye tracing results.

problems. Significant flooding occurs in Eastwood Subdivision, the intersection of Ingles Street and Sullivan Trail, and where the Old Nashville Highway goes under the railroad track. The sinkhole bottom at Ingles and Sullivan (Point B) is at an elevation of approximately 582 feet which is significantly above the 535' level of Town Spring. Therefore, it is believed that cleaning the sinkhole out and installing one or more drainage wells could significantly reduce the occurrence of flooding in the area.

Sinkhole D is located near the intersection of Deer Drive and Parrish and has a bottom elevation of approximately 578 feet. Sinkhole A is located near the intersection of Greenfield Drive and the Old Nashville Highway and has a bottom elevation of approximately 567 feet. Both of these sinkholes contain drainage wells but they have nearly filled with sediment and debris due to being constructed with a grate at ground level. These two drainage wells should be cleaned out and modified with a new cover that is built above the surface elevation.

Some of the worst sinkhole flooding problems in La Vergne occur in the Eastwood Subdivision. This is particularly true for a group of sinkholes located near the intersection of Sunrise Avenue and Deer Drive (Point Z). Sinkhole bottoms in this area range from approximately 566 to 570 feet. Since this elevation range is significantly higher than the elevation of Town Spring, they should drain more rapidly than they do. It therefore appears that cavities leading from Eastwood to Town Spring have natural constrictions (change from large cave passage to very small). As a result, drilling drainage wells will likely not solve the flooding problems. In addition, note that Sinkhole E has a bottom elevation of approximately 568 feet which is essentially the same as those just mentioned. Sinkhole E receives a sinking stream during wet weather that drains a significant area to the southwest. As Sinkhole E fills with large volumes of stormwater, it is believed that water may actually rise out of the bottom of the sinkholes along Sunrise and Deer. Once the cavities down-gradient of Eastwood fill, ground water basically backs up through the sinkhole bottoms.

There may be a unique and cost effective method of solving many of the flooding problems in Eastwood. Note on Figure 1 that the drainage to Sinkhole E previously flowed entirely on the surface to the drainageway leading by Horne Spring. In the relatively recent geologic past, the surface drainage was pirated to the subsurface via the sinkhole. During large storms, Sinkhole E backs up and some of the flow returns to its previous surface pathway. Both channelways were walked. Point F is the approximate location where the channels split. The drainageway leading to the sinkhole has cut a channel 4 to 6 feet deeper than the former surface pathway.   It is therefore proposed that a small dam approximately eight feet high and 30 to 40 feet wide be constructed where the channels split. By eliminating flow into the sinkhole and returning it to the surface pathway, significantly less water will enter the subsurface cavities that lead to Town Spring. This should allow sinkholes in Eastwood area to drain much more quickly. This proposed solution may even help the flooding problem where the Old Nashville Highway goes under the railroad (elevation estimated at 543'). The area is very close to the elevation of Town Spring (535'), but with less water entering the spring's subterranean drainage system, the cavities between the railroad and spring will less often completely fill and back water up. In addition, less water will enter the low area in the road if Sinkhole G is cleaned out and a drainage well constructed in it. At present, water backs up on the southwest side of the railroad due to the culvert being clogged with trash and flows down to the low point in the highway beneath the tracks. The water that makes it under the railroad through the culvert soon enters a trash-filled sinkhole (Sinkhole G) which rapidly fills during storms, overflows onto the road, and then flows down under the railroad track to the highway's low point. Construction of the proposed dam may also help flooding of Sinkhole H located at the intersection of Buchanan Street and Stones River Road for similar reasons. The sinkhole bottom elevation (558') is significantly higher than Town Spring. The sinkhole is filled with mud, which is probably the main cause of the slow drainage.

Therefore, it is recommend that the sinkhole be dug out and a drainage well constructed with a top above ground level.

Flooding occurs within the loop at the end of Blue Valley Road. A drainage well has been recently installed, but it has been constructed in a solitary sink with no drainage from the adjacent hill runoff capable of entering it. A ditch should be constructed so that the drainage from the hill can enter the sinkhole. This should help the flooding problem.

SCHREIBMAN SPRING DRAINAGE BASIN

Schreibman Spring is located along the east side of Moore Way near its intersection with Nir Schreibman Boulevard within the Madison Square subdivision. The spring occurs at an elevation of approximately 518 feet. A trace was conducted to this spring from the sinkhole/drainage well (Sinkhole J) just south of the Post Office. This sinkhole experiences common flooding problems largely due to the significant amount of paved surface east of the sinkhole. Another problem is that the drainage well has largely filled with sediment and debris reducing the rate at which stormwaters can enter the subsurface. The sinkhole bottom is at approximately 548 feet which is 30 feet above the spring. Therefore, removing the sediment fill and constructing a standpipe several feet above the sinkhole bottom should reduce the frequency of flooding events. There is a drainage well in the parking area for the Post Office, but because it is at a high elevation within the lot, appears to serve no purpose in mitigating the flooding problem. It is recommended that a water injection test using a nearby fire hydrant be conducted to see if this well can accept large volumes of water. If it does, it is further recommended that a drainage pipe be constructed beneath the parking lot connecting the two drainage wells. This would be a relatively economical method to significant reduce the flooding problem.

Another area with flooding concerns in this spring drainage basin exists south of Schreibman Spring along the east side of Moore Way. At this location, water has been observed to boil up at several locations during larger storm events. The elevation of the "boils" range from 526 to 529 feet which is only about 10 feet above the spring. It is hypothesized that the cavities that lead to Schreibman Spring fill to an elevation at least 10 feet above spring level during large storms leading to the creation of the boils which act as an overflow pathway. If this is correct, there is little that can be done to solve this problem.

CAVE SPRING DRAINAGE BASIN

Cave Spring is located on the eastern side of Sinking Creek and at an elevation of approximately 565 feet. The area has relatively steep topography so sinkhole flooding has not been a serious problem to date. Two successful dye traces were conducted to the spring from deep sinkholes (points L and M). The dyes were visibly observed by a neighbor along the creek, as well as, City personnel. The dyes moved rapidly to the spring within less than 48 hours indicating the openness of the subterranean cavities leading to the spring. Sinkhole M is located near to the site of a newly planned fire station with the sinkhole bottom being at an elevation of approximately 579 feet. Sinkhole L is located in Clayton Estates with the sinkhole bottom being at approximately 587 feet. Two injection wells exist in the bottom of Sinkhole L. These were not found until the trace had begun due to being covered with trash and debris. As the sinkhole bottom began to fill from the fire hydrant water being used for the injection, the drainage wells were discovered. Upon removing the trash, the injection water quickly ran into the wells and drained the water that had started to pool in the sinkhole. This dramatically demonstrated that the problem with this and other drainage wells in the City is that they were constructed at ground level and fill with debris and/or get covered with trash. Maintenance of the drainage well should prevent future flooding of residents adjacent to the sinkhole.

A trace was also conducted from Sinkhole K, but the dye was never found. Lineations of sinkholes in a northwest direction suggest that sinkhole K is hydrologically connected to a spring along Hurricane Creek that was not found during the karst inventory. A drainage well exists in the bottom of the sinkhole at an elevation of approximately 571 feet with a top slightly above ground level. Collapse around the edges of the drainage well allows mud and plant debris to easily enter before reaching the top of the standpipe. Therefore, it is likely that this newly constructed well will begin to fill with sediment defeating the purpose of its construction. Due to the significant depth of the sinkhole, flooding of newly constructed homes to the north and the road to the south, should not be a problem.

GWYN SPRING DRAINAGE BASIN

One dye injection from the intersection of Nelson and Merritt streets is believed to have traveled to Gwyn Spring which is along the north side of Rock Springs Branch in Smyrna (dashed line, Figure 1). None of the monitoring locations tested positive for the injected fluorescein, but the owner of Gwyn Spring reported seeing a bright green coloration of his spring one to two days after the dye had been injected. No other tracing in the area had been reported to the State, so it is extremely likely that this was a positive trace. Subterranean drainage to Gwyn Spring from areas to the north has been confirmed from a previous tracer test from a sinkhole near the intersection of Sam Ridley Boulevard and the Old Nashville Highway (Ogden, 2001). It therefore appears that some areas on the southwest side of La Vergne drain under the surface drainage divide which is not uncommon in karst terranes. The tracing results suggest that southwest areas of La Vergne along the interstate also drain to Gwyn Spring.

Potential Adverse Effects on Sinkhole Flooding Frequency from the Construction of Percy Priest Lake

Percy Priest Lake began filling in 1967, and the result was a significant rise in the water table. Prior to lake construction, there was considerably greater elevation difference between the bottom of sinkholes in La Vergne and the elevation of springs located along the edge of the Stones River. The rise of the water table is evidenced by Brents Cave which is located close to the lake and approximately 1½ miles north of the La Vergne city limits. A visit to the cave found it to be totally flooded with a pool of water at the entrance reflecting the summer pool elevation of the lake. Barr (1961) describes the cave as having a stream with over 1,175 feet of passage leading in a northeast direction toward the nearby Stones River. Undoubtedly, stormwaters that once easily flowed through the cave now back up in the drainage basin causing sinkholes to drain more slowly. In some cases, water may actually rise up from the bottoms of sinkholes due to the water table now being so close to the surface. This may not affect sinkhole flooding in many areas of La Vergne during smaller storms at lower winter pool elevation. Large storm events, though, that flood Hurricane Creek along which Town and Schreibman springs are located, have the potential to back up water-filled cavities that lead to these two springs.

SUMMARY AND CONCLUSIONS

Ten dye traces were successful in delineating much of the watersheds (recharge areas) of four springs in the study area. Sinkhole flooding in La Vergne is a result of: 1) the karst water table (spring elevation) being very close to that of some sinkhole bottom elevations, 2) natural constrictions in the subsurface cavities that cause stormwaters to backup and fill the up-gradient sinkholes, and 3) present drainage wells having filled with sediment and debris due to being constructed at ground level and not properly maintained. Most of the existing drainage wells have been cleaned out since the tracing study was completed. As city funds become available select sinkholes will be dug out to improve drainage and a few more drainage wells may be

constructed. A small stream diversion dam near the Highland Street sinkhole is under consideration, but this could result in other areas being flooded during large storm events. New city regulations regarding filling of sinkholes have been passed since the tracing study was completed which should reduce the occurrence of new flooding from development. The results of this investigation will be important for a purpose other than to help solve flooding issues. If a spill or leak of a hazardous substance or waste product occurs that enters a sinkhole, it is now known to which spring an emergency response team should go to begin remediation activities

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SESSION 2C

SOURCE WATER
8:30 a.m. – 10:00 a.m.

Source-Water and Regional Ground-Water Flow
Michael W. Bradley

Consider the Source: Protecting Tennessee's Public Water Supplies
Tom Moss

Reclamation Projects in Scott County, Tennessee
Jack Lay

PUBLIC EDUCATION AND AWARENESS
10:30 a.m. – 12:00 p.m.

Protecting the Source: Tennessee's Drinking Water
Tom Moss

An Assessment of the Need for Non-Point Source Pollution Education Near Streams Flowing Through Developed Areas within the Stones River Watershed, Tennessee
Mark Abolins and Andrea Wonnell

Low-Head Dam Hazards: (How) Can We Make Them Safer?
Bruce A. Tschantz

TRENDS IN STORM WATER MANAGEMENT
1:30 p.m. – 3:00 p.m.

Franklin Tennessee Stormwater Program: Protecting Quality of Life
Don Green

Slatermill Creek – Solving Local Problems; Developing a County-Wide Plan
Dave Briglio

The Alchemy of Stream Restoration: Impaired Stream to A Thing of Beauty Year Three: The Nature Conservancy's Big Rock Creek Project
Leslie Colley

STORM-WATER AND WASTEWATER TREATMENT
3:30 p.m. – 5:00 p.m.

Evaluation of Peat Moss as a Filter Media for the Removal of the Herbicide Simazine
Kim Stearman, Thenmozhi Ramar, Dennis George and Lenly Weathers

Case Studies in Effluent Toxicity Treatability
Scott Hall and Rick Lockwood

Storm Water Detention Basin Retrofit
Thomas C. Neel, Vincent S. Neary, G. Kim Stearman and Dennis B. George

SOURCE-WATER AND REGIONAL GROUND-WATER FLOW

Michael W. Bradley[1]

The source-water protection program administered by the Tennessee Department of Environment and Conservation, Division of Water Supply, provide for the identification and protection of recharge zones to public-supply wells and springs. The requirements have grown out of a proactive emphasis on the prevention of pollution to the sources of public water supplies. Source-water protection for ground-water based systems relies on the Wellhead Protection Program requirements for the definition of protection zones and identification of potential sources of contamination.

The source-water protection includes Zone 1, an area adjacent to the well or spring where contamination could be drawn into the supply point, and Zone 2, the surrounding recharge area to the well or the spring.   The wellhead protection zones provide for the immediate protection around the supply well or spring and also provide for a broader area delineated on the basis of ground-water flow and the recharge area to the supply well or spring. In West Tennessee, the zone 2 protection area is based on a modeled 10-year time of travel area. In Middle and East Tennessee, the zone 2 protection area is based on the delineated ground-water recharge basin.

The public-water systems benefit from the information and planning provided through the source-water protection program. The larger ground-water based public systems will also benefit from the definition and understanding of the regional ground-water flow system. Thirty-eight water systems use more than 1 million gallons per day and eleven systems use more than about 4 million gallons per day. Seven of those eleven systems are in West Tennessee (4 are in Shelby County), one is located in Middle Tennessee, and 3 are in East Tennessee.

Defining and monitoring the regional ground-water flow systems can help identify trends in ground-water changes, identify other stresses that could impact the water systems, and help identify other issues before problems develop. Measurements of the regional potentiometric surface and long-term water-level monitoring for the Shelby County area have identified changes due to local changes in production and provided information on potential declines in water availability due to water-level declines in other counties. The continued monitoring and ground-water modeling near Hixson, Hamilton County, Tennessee identified recharge areas that were not readily apparent and provided information on ground-water conditions and water availability in the event of long-term drought conditions.

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CONSIDER THE SOURCE: PROTECTING TENNESSEE'S PUBLIC WATER SUPPLIES

Tom Moss[1]

Protecting our drinking water supplies is critical for the public health and economic welfare of Tennessee. Once thought to be safe from contamination, the aquifers and streams used for drinking water are at risk to contamination from a variety of sources. The prevention of contamination of our public water supplies is much more cost effective than the increased treatment costs at the water plant or the remediation of the stream or aquifer. Educating the general public to the importance of source water protection is an ongoing mission of the Division of Water Supply.

The Tennessee Department of Environment and Conservation's Division of Water Supply contracted with University of Memphis's Ground Water Institute for an educational video on protecting public drinking water sources. The Ground Water Management Section in the Division of Water Supply contracted for the video with EPA ground water grant funding. The resultant video is titled "Consider the Source: Protecting Tennessee's Public Water Supplies." The video is being distributed to schools and other non-profit organizations on a limited basis across the state as funding allows. This video is the third in the series of drinking water/ground water videos that have been contracted. The first was with Middle Tennessee State University and is titled "Hollow Ground: Land of Caverns, Sinkholes and Springs" and the second was with the Ground Water Institute and titled "Drops of Water in Oceans of Sand: Ground Water Resources of West Tennessee."

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1 Tennessee Department of Environment and Conservation, Division of Water Supply

RECLAMATION PROJECTS IN SCOTT COUNTY, TENNESSEE

Jack Lay[1]

The coal-mining industry is important to many areas of East and Middle Tennessee. When an area is used as a strip mine, the community is often faced with the dilemma of deciding how to reclaim that property. Scott County is located northwest of Knoxville and this community has begun to look at options to reclaim property after the mine has been closed. Recently there have been several projects that have brought renewed life to a once unusable land. These projects have helped protect waters that flow through the area and have even helped to create a new water source for one utility. This presentation will discuss some of these projects and how the area has benefited from those projects.

The Town of Oneida has been instrumental in securing funding for a major reclamation project. Oneida worked with various agencies to develop a plan for reclaiming an abandoned strip mine as well as determining the best method for implementing this plan. This project not only reclaimed an abandoned strip mine but also contributed to improving water quality in the area.

The Huntsville Utility District provides water to a growing area of Scott County as well as providing water to a neighboring utility for their customers. The Utility District needed an additional water source. An abandoned strip mine developed into a reservoir that provides the system with a source of water that has a consistent quality.

The Big South Fork National Park is working with several citizens groups to develop a plan to improve stream quality within the park as well as develop educational materials that can be used in local elementary schools. Grants applications were submitted and those grants, once received, will help fund these projects.

The Town of Oneida has begun an aggressive program to eliminate subsurface sewer disposal systems within the city limits. The high concentration of these disposal systems coupled with the topography of the area has resulted in an unacceptable failure rate. This project will bring public sewer to citizens who have long seen this as a much needed service.

In 2004 the State of Tennessee recognized the efforts to improve source water in Scott County by including representatives of the Town of Oneida in their source water video. This video will be made available to communities across the State of Tennessee to be used to help educate their youth, their citizens as well as their community leaders.

Jack Lay is the Mayor of the Town of Oneida. He has been a leader in developing a plan to reclaim property in Scott County as well as helping to secure the funds necessary for these projects.

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1 Mayor of the Town of Oneida

PROTECTING THE SOURCE: TENNESSEE'S DRINKING WATER

Tom Moss[1]

Protecting our drinking water supplies is critical for the public health and economic welfare of Tennessee. Once thought to be safe from contamination, the aquifers and streams used for drinking water are at risk to contamination from a variety of sources. The prevention of contamination of our public water supplies is much more cost effective than the increased treatment costs at the water plant or the remediation of the stream or aquifer. Educating the general public to the importance of source water protection is an ongoing mission of the Division of Water Supply.

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1 Tennessee Department of Environment and Conservation, Division of Water Supply

AN ASSESSMENT OF THE NEED FOR NON-POINT SOURCE POLLUTION EDUCATION NEAR STREAMS FLOWING THROUGH DEVELOPED AREAS WITHIN THE STONES RIVER WATERSHED, TENNESSEE

Mark Abolins[1] and Andrea Wonnell[2]

ABSTRACT

Four streams flowing through developed areas within the Stones River Watershed support more than 7 macroinvertebrate families/orders but riparian forest buffers are generally narrow (<30 m wide) or absent. The four streams are Scott's Creek and part of Dry Fork Creek in Davidson County, TN and parts of the West Fork of the Stones River and Lytle Creek in Rutherford County, TN. A total of fourteen locations were investigated. Habitat scores range from 105 to 149, and 7-16 macroinvertebrate families/orders are present. Near-stream (within 150 m) impervious surfaces and forest were mapped by combining the interpretation of recent (1997-present) air photos with field observations. Mapping reveals near-stream imperviousness[3]of 23-47%, and 43-83% of each near-stream area is buffered by less than 30 m of forest. Together, observations show that these streams preserve habitat and contain aquatic life, but potential sources of non-point pollution abound and riparian buffers are narrow or absent. Consequently, residents need to be informed about ways to reduce non-point source pollution and maintain riparian buffers. A brochure, fact sheet, and PowerPoint presentation address these needs.

INTRODUCTION

The investigators examined the need for environmental education near four streams flowing through developed areas within the Stones River Watershed, central Tennessee by:
- inventorying aquatic life and observing habitat;
- mapping impervious surfaces;
- measuring the width of riparian forest buffers.

First, the report describes the presence of aquatic life in developed areas. Then, second, the report shows that widespread potential non-point pollution sources could threaten this life. Finally and third, the report demonstrates the general absence of riparian forest buffers that would otherwise ameliorate pollution. Taken together, these three points suggest the need to educate residents about ways to minimize the impact of non-point pollution and maintain riparian forest buffers. The investigators created a brochure, fact sheet, and PowerPoint presentation to address these needs.

RATIONALE AND SCOPE

Within the Stones River Watershed, habitat alteration impacts more stream miles than any other cause of use impairment according to the Year 2000 Water Quality Assessment (Goodhue et al., 2002). This result suggests that impervious surfaces might encroach on many streams, and that riparian forest buffers might be narrow or absent. Nonetheless, two streams – Scott's Creek and Dry Fork Creek in Davidson County (see Figure 1 for locations) - are described as being in full water quality attainment even though they flow through highly developed areas. The investigators quantified aquatic life and near-stream (within 150 m) imperviousness and buffer

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3 Imperviousness is used here to mean "the percentage of impervious cover by area within a development site or watershed, often calculated by identifying impervious surfaces from aerial photographs or maps." This definition is found in the Environmental Protection Agency's "Eight Tools for Watershed Protection" glossary (Kwon etal., 2002).

width for these streams. For comparison, the investigators also examined a partial attainment stream – the West Fork of the Stones River – and a non-attainment stream – Lytle Creek in Rutherford County (see Figure 1 for locations).

AQUATIC LIFE IN DEVELOPED AREAS

Andrea Wonnell inventoried macroinvertebrates and recorded habitat scores at fourteen locations along the four streams (Table 1) and Table 2 lists the results. (The authors will provide detailed information about methods and results upon request.) As described in Table 2, the number of families/orders varies between 7 and 16 and habitat scores range from 105 to 149. These observations show that streams flowing through developed areas contain aquatic life and preserve habitat. However, results may not represent water quality throughout the year because data was acquired during a short time interval. Also, please note that the comparison of results from one stream with those from another is difficult both because channel width varies and because data was collected at different times.

NEAR-STREAM IMPERVIOUSNESS AND RIPARIAN BUFFER WIDTH

Wonnell used black and white air photos acquired during 1997 (Dry Fork Creek) and color air photos acquired after 2000 (all other streams) to map impervious surfaces and forest. Maps were field checked. As shown in Table 3, all four near-stream areas are more than 23% impervious, and at least 43% of each near-stream area is buffered by less than 30 m of forest. These observations demonstrate the widespread presence of potential non-point pollution sources as well as the general absence of riparian forest buffers that might otherwise ameliorate pollution.

EDUCATIONAL MATERIALS

The co-location of aquatic life and potential pollution sources in areas lacking riparian forest buffers suggests the need to educate residents about water quality. To address this need, the investigators created a fact sheet, brochure, and PowerPoint presentation. These materials address three points:
  1) a watershed includes all of the land from which water drains to a particular stream;
  2) streams flowing through developed areas contain aquatic life and wildlife habitat;
  3) residents can take a few simple steps to help keep aquatic critters healthy.
The first point is important because many residents are not aware of watersheds and do not realize that they live in one, and this lack of awareness is likely a barrier to participation in non-government watershed stewardship organizations like the Stones River Watershed Association. The second point addresses the need to overcome skepticism about the presence of aquatic life in developed areas. Finally, to address the third point, materials explain the need to use mulch, maintain a clean septic tank, avoid mowing stream banks, and avoid overusing pesticides and fertilizers. In addition, the materials list places where residents can recycle oil, oil filters, and antifreeze. These materials are available at the following URL's:
  * Fact sheet (including a map of the Stones River Watershed):
    http://www.mtsu.edu/~mabolins/stones_river_watershed.pdf
  * Brochure (including recommendations for residents):
    http://www.mtsu.edu/~mabolins/stream_brochure.pdf
  * PowerPoint presentation
    http://www.mtsu.edu/~mabolins/healthy_streams.pps

ACKNOWLEDGEMENTS

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Goodhue, A., Holland, J.E., Smith, J.R., Cochran, R.E., Duhl, D., Fathi, S., Vann, A., and Wang, S., 2002, Stones River Watershed (05130203) of the Tennessee River Basin Water Quality Management Plan, Nashville, TN, Division of Water Pollution Control, Tennessee Department of Environment and Conservation, http://www.state.tn.us/environment/wpc/watershed/wsmplans/stones/ (21 January, 2005)

Kwon, H. Y., Winer, R., and Schueler, T., 2002, Eight Tools of Watershed Protection in Developing Areas, Washington, D.C., Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency, http://www.epa.gov/watertrain/protection/ (21 January, 2005)

Location	Longitude	Latitude
Scott's Creek (full attainment)		
SC-1	86deg34'43.04"W	36deg13'9.48"N
SC-2	86deg35'13.31"W	36deg12'54.44"N
SC-3	86deg35'7.73"W	36deg12'55.51"N
SC-4	86deg34'58.40"W	36deg12'59.48"N
SC-5	86deg35'30.79"W	36deg12'10.70"N
Dry Fork Creek (full attainment)		
DC-1	86deg36'27.51"W	36deg10'59.88"N
DC-2	86deg36'9.54"W	36deg10'56.61"N
DC-3	86deg35'41.01"W	36deg10'57.67"N
W. Fork, Stones River (partial attainment)		
WF-1	86deg25'22.37"W	35deg53'15.47"N
WF-2	86deg25'16.04"W	35deg53'12.37"N
WF-3	86deg24'38.56"W	35deg51'36.67"N
Lytle Creek (non-attainment)		
LC-1	86deg23'29.84"W	35deg49'42.78"N
LC-2	86deg23'48.49"W	35deg50'45.14"N
LC-3	86deg24'1.05"W	35deg50'52.96"N

Table 1. Locations where habitat and macroinvertebrates were investigated.

Scott's Creek (full attainment) 16 April, 2004 (SC-2, SC-4, and SC-5) and 19 April, 2004 (SC-1 and SC-3)		
Location	Macro-invert.	Habitat Score
SC-1	7	96
SC-2	10	129
SC-3	10	134
SC-4	?	70
SC-5	13	149

Dry Fork Creek (full attainment) 27 June, 2004		
Location	Macro-invert.	Habitat Score
DC-1	14	137
DC-2	11	134
DC-3	13	141

West Fork, Stones River (partial attainment) 5 June, 2004 (WF-1 and WF-2) and 23 June, 2004 (WF-3)		
Location	Macro-invert.	Habitat Score
WF-1	16	143
WF-2	13	110
WF-3	13	130

Lytle Creek (non-attainment) 22 June, 2004		
Location	Macro-invert.	Habitat Score
LC-1	9	105
LC-2	7	110
LC-3	9	109

Table 2. Number of macroinvertebrates and habitat scores.

Stream	% Impervious	% of near-stream area buffered by < 15 m of forest	% of near-stream area buffered by < 30 m of forest
Scott's Creek	23%	75%	83%
Dry Fork Creek	23%	34%	43%
Stones River	27%	43%	61%
Lytle Creek	47%	63%	77%

Table 3. Imperviousness and buffer width within 150 m of each stream.
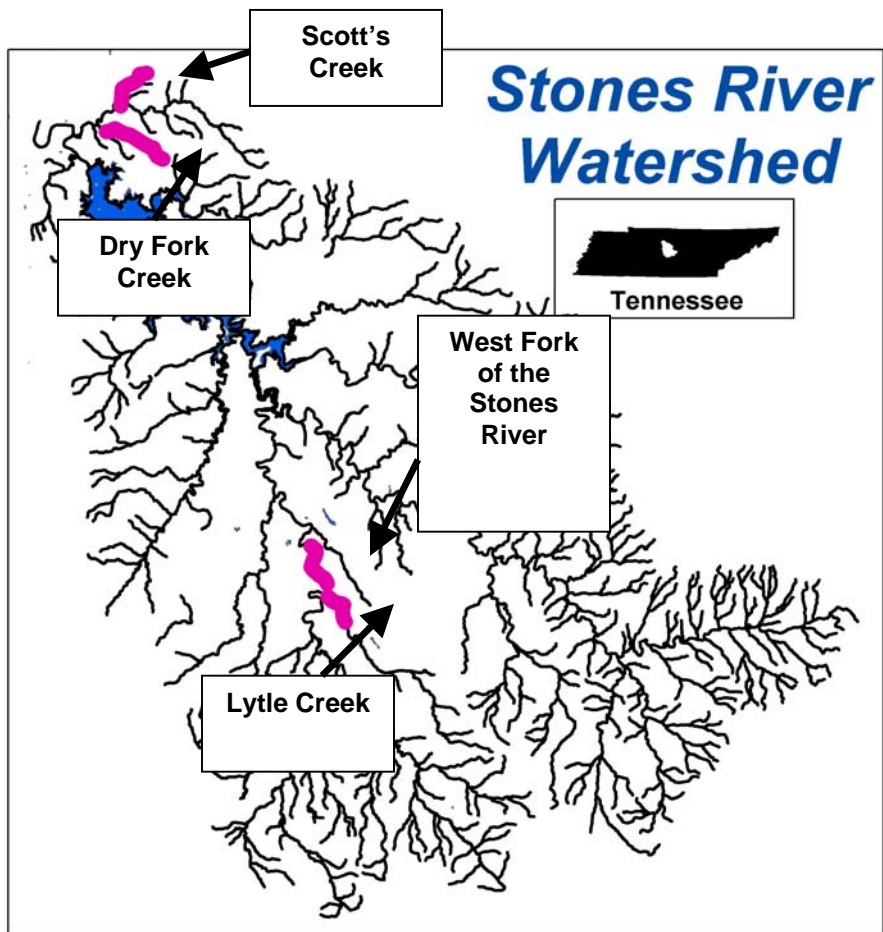
Figure 1. Location map.

LOW-HEAD DAM HAZARDS: (HOW) CAN WE MAKE THEM SAFER?

Bruce A. Tschantz, P.E.[1]

BACKGROUND OF THE PROBLEM

Low-head dams, a.k.a. "killer dams" and "drowning machines," often present a safety hazard to the boating public because of their ability to trap people in the submerged hydraulic jump, or "hydraulic," just downstream from the dam. Low-head dams are run-of-the-river overflow weir or hydraulic structures, normally producing water surface drops in the range of 1 to 15 feet and constructed across rivers and canals for the purpose of raising the water level to improve industrial and municipal water supplies, protect utility crossings, and enhance recreational opportunities. Hundreds of these low-head dams were built across the U. S. during the 1800s to power gristmills and small industries. Hundreds more have been constructed for irrigation diversion on rivers throughout the West. Although most states generally do not know how many low-head dams they have, Pennsylvania maintains an inventory of 280 low-head dams and Virginia estimates having between 50 and 100. In Ohio, over 200 low-head dams are reported and New Jersey has 120. Across

Example of a dangerous low-head dam built for water supply.

the country, many older dams that no longer serve their original purposes have been abandoned and fallen into disrepair, creating dangerous conditions for the public. Unwary swimmers, boaters and anglers generally don't notice this danger or understand the power of moving water that these dams introduce.

All hydropower dams licensed by the FERC, including low-head types, are required to have a public safety plan which includes appropriate warning signs and other safety devices to protect swimmers, boaters and fishermen. According to an Association of State Dam Safety Officials (ASDSO) survey of state dam safety programs in 2000, only a handful (KY, LA, MA, PA, & WI) of 42 responding states indicated a requirement that some type of warnings or buoys be placed near certain low-head dams. Some states (IN, IA, MN, & OH) said they recommend or encourage owners to post signs near dams. Pennsylvania, following several drownings at low-head dams, enacted its 1998 Act 91 (P.L. 702) requiring notified owners of low-head, run-of-the-river dams to warn the swimming, fishing and boating public of the hazards posed by such dams with upstream/downstream exclusion or warning zone signs and other specified markers. Pennsylvania's dam safety program is responsible for inventory and notification activities, and the Fish and Boat Commission is responsible for establishing and enforcing sign and warning regulations at such dams. In Ohio, after a recent rash of drownings, legislation was introduced to require owners of low-head dams to install warning signs and buoys. The proposed bill failed after an ill-advised amendment, opposed by ODNR, was added requiring that gates be locked at public boat ramps during dangerous water conditions.

Where dams and waterways are not marked with warnings, boaters are often unaware of, or do not appreciate, the potentially extreme hazards at low-head dams and, for different reasons, unwittingly or purposefully glide over a seemingly innocuous dam, capsize in the falling water, get trapped in the downstream turbulence, and drown in the circulating and reversed currents.

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Unfortunately, these counter-currents within the downstream "hydraulic" are stronger than even the most competent swimmers can overcome. The downstream turbulence, accompanied by high aeration as evidenced by foaming or "whitewater" conditions, decreases the water density and therefore the buoyancy of objects by as much as twenty to thirty percent, causing personal flotation devices or lifesavers to be less effective and making it hard for even a neutrally buoyant victim to stay afloat. Heavy logs, tires, drums and other debris trapped in the hydraulic maintain a strong rotating pattern and create an additional hazard to already helpless, panicking, quickly tiring and disoriented victims. A kayaker who drowned in 2000 was reported to have been stripped of his life vest in the swirling waters below a low-head dam on the Musconetcong River in New Jersey. Temperature of the water is often cool enough to add hypothermia to the mix of life-threatening hazards. Adding to all of these is the dynamic force of the water dropping over the dam that can exert hundreds of pounds on a person's body. In sum, these factors combine to create what some describe as a nearly perfect "drowning machine."

While accidents and drownings at low-head dams are reported regularly in the local and national media, little statistical data is available to assess the full extent of the problem. Minnesota's Boat and Water Safety Section of the Department of Natural Resources reports 52 deaths and 50 injured or rescued people at low-head dams in that state between 1974 and 2002. In Illinois, the Fox River has a notoriously dangerous segment of 15 dams in the 115-mile reach just west of Chicago between Wisconsin and its mouth at the Illinois River. At one 7-foot high dam, in Yorkville, at least 12 people are reported to have drowned since it was rebuilt in 1960. Drayton Dam on the Red River in Minnesota claimed 12 lives between 1965 and 1995. Recent research of about 100 documented injury or death accidents at low-head dams in 20 states, reported in news articles and various databases, shows that there have been at least 34 injuries and 97 drowning deaths distributed over 17 states during the period 1970-2004, with 33 drowning deaths since 2000 in 15 states as shown in the

YorkVille Dam on the Fox River
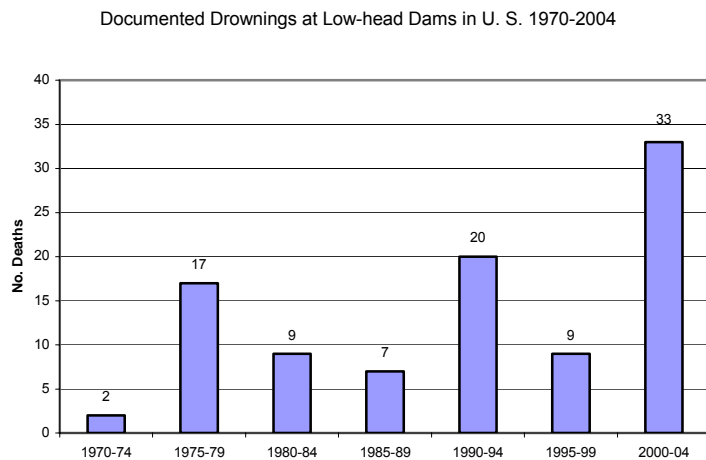
chart. In 2003, thirteen drownings were reported in Alabama, Illinois, Missouri, North Carolina, Ohio, Virginia, and Canada (one each in Manitoba and Ontario). Tennessee has had at least five low-head dam deaths since 1997, four occurring on the Little River in Blount Co. and one on the Stones River in Rutherford Co.

Documented Drownings at Low-head Dams in U. S. 1970-2004

Most states, including Tennessee, do not regulate the design, operation or safety of these structures because of their small heights and/or impounding capacities and low hazard potential to downstream property or life *in event of failure*. For example, most states regulate only larger concrete or earthen dams that are typically higher than 25 feet and create large impoundments and lakes. Typically, low-head dams are not classified as high potential hazards, since, by definition, their heights and capacities are limited. Nevertheless, low-head dams can be very hazardous to recreational users because of the variable hydraulic conditions from overflow forces and reversed downstream currents. In the field of dam safety engineering, the tendency has been to focus primarily on

design, construction and operation of safe *structures.* A well-recognized public safety hazard of dams is structural failure.   Over the last 30 years or so since the Buffalo Creek disaster and the failures of Teton and Toccoa Falls dams, warranted emphasis has been given by the dam safety community on preventing dam failures and protecting the public should failure occur. Considerable resources have been expended to inventory and classify dams, remediate or remove unsafe dams, promote owner responsibility and public awareness, develop and improve dam safety technology, and generally regulate their safety. However, there are inherent environmental hazards with safe structures that many design engineers tend to overlook. One paper presented at the 1988 ASCE National Conference on Hydraulic Engineering emphasizes this oversight in its title: "Dam Safety, Yes, But What About Safety at Dams?" (Leutheusser, 1988). In his paper, Leutheusser captures the irony of emphasis on structural safety at the expense of other public safety needs:

> Hydraulic engineers by their very calling are aware of the forces associated with the motion of water. Indeed, it is the containment and control of these forces which render their profession so very challenging and satisfying. However, a safely designed and executed hydraulic structure does not, by itself, render a water flow harmless. For instance, large amounts of energy are released and dissipated, under fully exposed conditions, in structurally safe weir-and-stilling-basin assemblies. While the environmental dangers associated with these flow processes are well respected by hydraulic engineers, they are less so by the general public, and serious accidents may be the consequence ….

Paddle sports and other water-based recreational activities have dramatically increased in popularity over the past twenty years. The American Canoe Association reports that 48 million Americans experienced canoeing, kayaking and other paddle sports in 2002, and participation in watercraft recreation is expected to increase (Donahue, Earles, 2003). However, as accidents continue to occur, it has become apparent that the special hazards created by low-head dams to boaters and other water users have fallen between the cracks of attention in both the dam safety and the boating safety communities. A 2003-04 survey of state boating law administrators, conducted by the author through the National Association of State Boating Law Administrators (NASBLA), an organization representing state officials responsible for administering and/or enforcing state boating laws, asked three questions to obtain each state boating law administrator's perception of the issue:

> 1. How many documented injuries and deaths have occurred in your state due to watercraft accidents at low-head dams over the last 10 years?
> 2. If an inventory is available, approximately how many low-head dams (i.e., run-of-river dams that typically raise the water level less than 10 to 15 feet) are there in your state?
> 3. Does your state have laws or regulations that require owners of low-head dams to post warning signs or provide other means for marking hazardous conditions to the various water users in your state?

The following table summarizes the NASBLA survey results for 37 responding states.

Reported #Deaths in Last 10 Years	Known L-H dam inventory	State regulations for posting warnings
15 states-indicated 0, none, or not aware of any	5 states– indicated 0 or none	3 states – Yes, regulations (FL, SC, & PA)
5 states – unknown or no information available	13 states – unknown or no information available	29 states – None
1 state – "several"	1 states – a "few"	2 states – Unknown
1 state – a "few"	16 states – indicated a range of 2 to 298 dams for an estimated total of 1684-1686 L-H dams	3 states – no response
1 state – indicated 20 at a single dam since 1964		
14 states – indicated a range of 1 to 10, for approx 59-64 deaths	2 states – no response	

The reader is referred to the attached survey summary table for state-by-state results, which are somewhat limited because few states maintain inventories of or publish information for these smaller structures. Only three states (FL, PA, SC) apparently have warning sign posting requirements at low-head dams. PA and SC are the only states to cite specific sign posting laws to mark hazardous conditions and prohibited access areas at dams. However, various federal agencies, such as TVA, USBR, USCOE, and FERC, that own, operate or regulate dams have general water hazard marking guidelines that may be applicable to low-head dams, not regulated by the states. For example, FERC has comprehensive public safety signage standards, developed with the assistance of several other organizations and agencies, that are applied to each of its licensed hydropower projects (FERC, 2001). Because the majority of low-head dams are not federally owned or regulated, public safety remains a serious problem.

A CHALLENGE TO STATES AND DAM SAFETY & BOATING SAFETY COMMUNITIES

As the number of people attracted to water recreational opportunities increases, water-related accidents and deaths are inevitable; but engineers, state and federal officials, boating safety organizations, and recreational watercraft organizations need to work together to reduce or eliminate the environmental hazards at low-head dams. A four-pronged approach is proposed to reduce the risk to the public from dangerous conditions at low-head dams:

1. *Public awareness programs* that promote safety education and cognizance of the potential dangers at low-head dams. These programs would require the cooperation of several communities: the boating public, including national canoeing, rafting, kayaking and boating organizations; local clubs; design engineers; dam owners; public officials, including legislators and local, state and federal regulators; and boating safety and boating law administrator organizations to better educate swimmers and watercraft users. The Internet, print media, television, videotapes, CD/DVDs, workshops, and schools offer unlimited opportunities for reaching and educating the public about the dangers around dams. This effort presupposes the need to thoroughly understand the extent of the problem on a state-by-state basis in order to put the issue into perspective and to prioritize the needs. Specific target audiences and potential organizations for promoting education and awareness need to be identified. Materials such as boating safety information and training videos, CDs, brochures, maps showing low-head dams, public

service announcements, on-line courses, and Internet websites need to be inventoried to determine what is already available, what works, and what remains to be developed in order to promote effective educational programs.

2. ***Effective legislation and regulation*** at the state level requiring dam owners to install appropriate warning, escape, portage, safety and other devices or systems at low-head dams. All low-head dams should be inventoried and periodically monitored and inspected for safety compliance. Hazardous dams with a history of accidents should be identified and receive priority for warning and protecting the public. Existing state legislation and regulations related to public safety at low-head dams should be researched, and model legislation and regulations should be developed. NASBLA is currently studying the technical and legal issues for marking low-head dams and is researching standards for developing statutory and regulatory models for state-administered, public safety enforcement programs at these dams.

3. ***Structural modification*** of hazardous low-head dams. The physical hazard to boaters, fishermen and swimmers around and below low-head dams needs to be reduced or eliminated wherever practical, given the reality of technical, legal, environmental and financial constraints. A technical manual should be developed for design engineers to stimulate a range of practical alternatives such as full or partial dam removal; use of engineered structures like stepped spillways, gabion baskets, flat slopes, cascading pools, or dumped rock to dissipate energy and eliminate the hydraulic; chutes to accommodate boaters; and portage ways for boaters to safely bypass a dam.

    Killer dam tamed with stepped spillway.

4. **Rescue training** programs to help state and local water rescue professionals understand and respond to the special hazards created at low-head dams. Many rescue personnel have died attempting to save others trapped inside a reversed current below low-head dams. The Boat and Water Section of the Minnesota Department of Natural Resources has a study guide and 3 training videos for Minnesota-based organizations that review conditions and rescue techniques at fast-water and lowhead dams, including one called "The Drowning Machine" (Minnesota DNR, 1997). ASDSO, NASBLA, federal agencies, and the various national watercraft safety organizations should form a "core" team to coordinate the development of a standard state training program, perhaps modeled after Minnesota's program.

In summary, hundreds and possibly thousands of low-head dams create dangerous hydraulic conditions to boaters and other water users. As water recreation increases and more people become exposed to the hazards created by low-head dams, the need for structurally reducing the hazard should be complemented with programs for warning and educating the public. States should take the lead in protecting the safety and health of their citizens from this hidden menace.

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Summary Table of 2003-04 Low-Head Dam Survey Results from State NASBLA Representatives

State	No. Deaths - last 10 years	Estim. L-H Dam Inventory	State regulations?
AL	0	None[2]	No
AK	6	2	No
AZ	0	0	No
AR	0	Few	No
CA	4	Unk	No
CO	Unk	18[3]	
CT	At least 1		
DE			
FL	Few	Unk	Yes[6]
GA	5	At least 6 indicated	No[7]
HI	0	0	No
ID			
IL	Unk	250	No[8]
IN	6 to 10	34-36	No
IO	3 or 4	204	No
KS	1	133[4]	No
KY	Several		
LA			
ME	0	Unk	No
MD	NA	NA	No
MA			
MI	None	NA	NA
MN	8	100	No[9]
MS			
MO	NA		No
MT	2	32[5]	No
NE	None	None	No
NV	None	100	No
NH			
NJ			
NM			
NY	None	Unk	No
NC			
ND	20 (at 1 dam since 1964)	64	No
OH	8	204	No[10]
OK			
OR	None	None	No

Notes: NA – information not available; Unk – information unknown

2 None on major river systems

3 Does not include rivers in the eastern plains

4 Based on database search – may contain more or fewer L-H dams

5 Based on local game warden poll, but probably at least 10 more

6 FL requirements would be covered by DEP. All L-H dams are posted, most likely for liability. Most L-H dams owned by   WM Districts

7 No state controls, but Georgia Power controls the majority of low-head dams, posting signs above and below dams

8 Most of regulations fall under federal guidelines

9 Minnesota DNR publishes and distributes public awareness materials on L-H dams. Signs, buoys, markings, etc. are offered.

10 Ohio has laws allowing & enforcing "no boats" signs above & below dams. Buoy & sign program for marking boat hazards

11 SC has law that prohibits watercraft within 500' of dam intake or spillway. R'strct'd area must be marked by signs by Dept.

12 Not aware of any regulations

PA	8	298	Yes
RI	1	NA	No
SC	None on record	NA	Yes[11]
SD	None	<10	No[12]
TN	5	23	No
TX	None on record	NA	No
UT	None on record	NA	No
VT			
VA	1	206	No
WA	None	Unk	No
WV	NA	NA	NA
WI			
WY			

FRANKLIN TENNESSEE STORMWATER PROGRAM: PROTECTING QUALITY OF LIFE

Don Green[1]

Franklin is beginning its second year of Municipal Separate Storm Sewer System (MS4) Stormwater permit from the EPA through Tennessee Department of Environment and Conservation. The city of Franklin has been given the opportunity to have more control, on the environmental side, of important growth issues. The MS4 permit sets out minimum requirements as to how the city is to protect this valuable resource: Water -- and in the process, protecting the quality of life of its citizens.

Urban Problems:
* Landscape designed for cars not people
* Imperviousness
* Water quality
* Water quantity

Old and new methods to solve the problems:
* Traditional Neighbor Development (New Urbanism)
* Cluster Development
* Buffers Buffers Buffers
* Infiltration/bioretention BMPs
* Erosion Prevention and Sediment Control

The MS4 permit sets up six minimum control measures:
1) Public Education and outreach,
2) Public involvement/ participation,
3) Illicit discharge detection and elimination,
4) Construction site stormwater runoff control,
5) Post-construction stormwater management in new development and re-development and,
6) Pollution prevention/good housekeeping for municipal operations.

As you can see two of these control measures involve education---this reflects the importance of letting everyone in on the secret of the link of water to the health and viability of the community. In association with the minimum control measures, the city developed milestones and action items delineating how the city is to accomplish these millstones for each of the 5 years of the permit.

Some major emphasizes currently under way:
1)   Education and Outreach:
        a.   Developing an education curriculum with Williamson County Schools, Franklin Special School District and Tennessee Project WET.
        b.   Newspaper, brochures, etc.
        c.   Public Service Announcements, PSAs, working with Tennessee WaterWorks!
        d.   Other education opportunities: MS4 Working group, developers training and workshops; working with Harpeth River Watershed Association and Cumberland River Compact and other organizations.
2)   On-going battle to keep dirt on the landscape, off the roads, out of the storm drains and our streams!
3)   Stormwater User fee billing: How do you get the public's attention? Send them a bill!

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SLATER MILL CREEK – SOLVING LOCAL PROBLEMS; DEVELOPING A COUNTY-WIDE PLAN

Dave Briglio[1]

INTRODUCTION

Since being established in 1985, the Douglasville-Douglas County Water & Sewer Authority (WSA) has been performing watershed assessments in Douglas County, Georgia as part of its water withdrawal and NPDES discharge permit requirements. In 2003 WSA signed an agreement to become responsible for stormwater management for the City of Douglasville, and in 2004 WSA signed a second agreement with Douglas County to manage the stormwater in the unincorporated areas of the County as well. Both the City of Douglasville and Douglas County are NPDES Phase II communities, and like all other Phase II communities WSA has much to do in meeting the requirements of this new program. With the added responsibility to address federal and local mandates, WSA established a stormwater utility within the City of Douglasville in 2004 and will begin collecting user fees for the unincorporated portions of Douglas County in early 2005. With a funding mechanism in place, WSA began the process of implementing solutions to stormwater problems with the *Slater Mill Creek Capital Improvement Program and Watershed Action Plan* (Slater Mill) project in September 2004.

The Slater Mill project exemplifies WSA's efforts in providing stormwater management services in a *balanced* manner, addressing both customer needs and regulatory requirements through the identification and implementation of immediate and long-term objectives. This project focuses on an urbanized, headwater basin approximately 1 square-mile in size, and will address both flooding and water quality issues, satisfying community needs and regulatory requirements. It will also allow WSA to move toward construction of recommended improvements and Best Management Practices (BMPs) after its completion in March 2005. The Slater Mill project will also be used to develop standardized methods to study other Douglas County basins and to develop long-term stormwater management programs.

Newly collected county-wide data, including survey / imagery / topography, regional water quality and BMP data, will be combined with advancements in floodplain modeling and mapping will be used to develop the blueprint for similar studies This blueprint will not only be a list of tasks to be performed in each basin, it will also evaluate available data management (GIS) modeling tools and assess implementation of various tasks on a County-wide scale, Furthermore, it will ensure that WSA complies with the stormwater mandates of the newly established Metropolitan North Georgia Water Planning District (District).

DISTRICT MANDATES

The District was established on May 1, 2001 to develop regional and watershed-specific plans for stormwater management, water supply and conservation and wastewater management in the 16-county area that comprises metropolitan-Atlanta. The Atlanta Regional Commission (ARC) provides planning staff for the District; the Georgia Environmental Protection Division (GEPD) has provided ARC with minimum standards for the watershed plans. These include both technical guidance and model ordinances. In August 2001, the ARC and GEPD released the first version of the Georgia Stormwater Management Manual. On October 3, 2002 the District adopted five model ordinances, including Floodplain Management / Flood Damage Prevention

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and Post-Development Stormwater Management for New Development and Redevelopment. These three critical stormwater management elements are explained below.

- <u>Floodplain Management:</u> One of the more significant features of the floodplain ordinance is its applicability to all streams, regardless of their FEMA designation (Zone A, AE, etc.), with 100-acres or more of drainage area. All such stream segments will have the limits of the *Regulatory Flood* defined, which is based on the one-percent chance (100-year) storm assuming that the drainage basin is *fully developed*. These stipulations require significant efforts to be placed on new floodplain modeling and mapping.
- <u>Post-Development Stormwater Management for New Development and Redevelopment:</u> The post-development stormwater management ordinance addresses both water quality and quantity. It provides performance criteria and specifies local requirements for the use of structural stormwater controls and nonstructural practices (i.e. BMPs). The ordinance also requires the local permitting authority to utilize the policy, criteria, technical specifications and standards in the latest edition of the Georgia Stormwater Management Manual.
- <u>The Georgia Stormwater Management Manual:</u> This guidance document provides the details related to performing the water quantity and quality analyses needed to provide sound floodplain management and select effective BMPs to prevent future and mitigate existing water quality impacts.

IMPROVED BASE DATA

The quality of all studies and action plans is dependant on the available data. The most important data sets for stormwater projects are stream alignment, land use, and topography. Such information supports hydrologic, hydraulic and water quality analyses, as well as BMP performance and site selection. These data sets have historically been difficult, if not cost-prohibitive, to collect and maintain. However, the increasing use of technologically advanced and cost-effective techniques such as Light Detection and Ranging (LiDAR) and high-resolution photography have made collecting such data more practicable for communities. Collecting the data by such means has enabled WSA to develop more accurate modeling data with less effort. Furthermore, such data is provided in digital format, allowing data exchanges among different governmental departments (or other entities) and direct importing with automated modeling and mapping tools. One data set can be used for multiple objectives, including those outside of stormwater management, thereby offsetting the cost and making floodplain and water quality modeling less of a burden and more of an opportunity.

Beyond the digital (GIS) base layer data is water quality pollutant loading, which in the Atlanta region is focused on Total Suspended Solids (TSS). Recent watershed studies in the region have resulted in positive correlations between TSS loads and land use, based on stream sampling and water quality simulations using the EPA BASINS model. These studies have reduced the need for initial sampling and calibration on projects the size of the Slater Mill study, allowing communities such as WSA to perform water quality analyses that focus on identifying *hot spots*. These hot spots can then be used to direct more detailed efforts such as BMP site selection and performance.

BETTER TOOLS AND TECHNIQUES

There is a clear need for updating floodplain maps and identifying BMPs, and expanding such efforts to smaller streams. In Douglas County, WSA customers want solutions to specific stormwater problems, and the District and GEPD require comprehensive, long-term stormwater management planning. Becoming familiar with the latest and most advanced tools and techniques will dictate how quickly, effectively and economically WSA and other metro Atlanta

communities can meet these needs. With better data sets and data management tools available, advanced modeling can be utilized on a wider range of projects. GIS tools are no longer limited to creating maps or providing limited support to generate modeling input data. Public domain, proprietary, or custom applications are now available for a wide range of floodplain and stormwater management problems. The individual's needs and skill sets will determine which are best suited for the project at hand. Below is a brief description of a few of those tools:

- The long-standing hydrologic (HEC-1) and hydraulic (HEC-2) models developed by the U.S. Army Corps of Engineers have not only been upgraded to a new platform (HEC-HMS & HEC-RAS, respectively), but the models can now be developed directly from GIS databases. The GeoHMS and GeoRAS GIS interfaces increase the efficiency in which the basic modeling structure is developed and how floodplain and floodway limits are mapped. These tools have been used in Slater Mill, providing the first step in developing a county-wide modeling network for hydrology and hydraulics.
- There has been an increased use of spreadsheet models in place of more complex water quality models (SWMM, BASINS, etc.) that require large amounts of data. As an example, JJG's *Pollutant Load Reduction Goal* (*PLRG*) *Modeling Tool* was used in the Slater Mill study. PLRG is a spreadsheet model that utilizes a GIS interface to predict TSS loads throughout the basin and identify BMPs with the most potential to protect or improve stream health. Such tools are quick and effective, address site and watershed conditions, can identify BMP type and size requirements, and enable more rapid BMP implementation.

A PLAN THAT PAYS OFF

Gathering a good base data and using the latest analytical tools will not only benefit WSA, it will allow hydrologic and hydraulic model data exchange with developers and other private parties, thereby reducing the cost of developing such data. It will also expedite the implementation of solutions to projects, providing visible benefits to WSA residents for their user fees.

The value of developing basin-wide network models can now be seen. Instead of comparing separate models from developers with overlaps and omissions, a true baseline model can be the starting point for assessing site development impacts. WSA can provide the entire hydrology and hydraulic model, allowing the developer to modify it with additional details and provide an assessment of downstream impacts. WSA can also review the submitted models in less time and with greater confidence, knowing that submissions are based on an approved model. And because third parties develop their own simulations, WSA will have a reduced maintenance effort associated with the hydrologic and floodplain mapping.

The spreadsheet-level water quality analyses will provide identification of hot spots, pinpointing locations that are most beneficial for water quality sampling or for future BMPs. Furthermore, the sampling and site identification efforts can be coupled to review BMP performance results after construction, improving BMP site and type selection.

CONCLUSION

With the guidance of local mandates, higher quality base data, and the most technologically advanced modeling tools, WSA has implemented a stormwater action plan, starting with the Slater Mill project, which will address both long- and short-term issues. JJG and WSA have made a commitment to collect and use the most accurate data possible with the greatest value to WSA and the community, applying the appropriate level of analytical details at the right time. The Slater Mill project is the first step in an incremental, but progressive implementation plan. This plan balances customer service demands and regulatory compliance, recognizes that time

and funds are always in limited supply, and will result in a better quality of life for the community and better protected environmental resources.

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

Leslie Colley[1]

The Nature Conservancy (TNC) was approached by the TN Department of Agriculture Nonpoint Source Pollution Program and asked to develop a project that would address nonpoint source pollution issues in some portion of the upper Duck River watershed. 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. 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, which added to this project's appeal..

Now well into the third year of the project a great deal of activity is underway. Using the Management Plan created by the Center for Watershed Protection to guide our efforts, The Nature Conservancy is addressing a variety of issues in the Big Rock Creek watershed including agriculture, urban stormwater and education. From working with city officials on the new greenway along the creek in downtown Lewisburg to planning a demonstration day at the University of Tennessee Experiment Dairy, raising awareness in the community and working with a wide array of partners have been crucial elements in the ongoing success of this project.

Big Rock Creek flows through downtown Lewisburg and has been impacted by a number of urban activities. Floodplain filling, loss of riparian habitat, channelization and increasing impervious surfaces all contribute to the poor condition of this reach of the stream. Conservancy staff have worked with city officials and the local Community Development Board to create a walkway along the stream as it flows through town. Two hundred balled-in-burlap trees have been planted along the creek bank and a bioengineering firm has been hired to further improve stream condition by repairing severely eroded streambanks and creating better instream habitat. As each section of the greenway is completed, more and more residents of Lewisburg are using the trail, developing a new appreciation for Big Rock Creek and becoming aware of the relationship between good streamside management and water quality.

Because the creek flows right through town, urban stormwater runoff is an issue which required attention. Lewisburg is a Phase II stormwater city and The Nature Conservancy has worked with elected officials and Public Works staff to educate decision makers and insure that a sound stormwater ordinance is in place. This is a delicate and politically charged issue in any community, but with the help of the Tennessee Growth Readiness program and committed local people, the new ordinance was passed. While many challenges still exist in dealing with old problems, a greater understanding of this issue will ultimately lead to improved water quality.

Even as Middle Tennessee experiences rapid growth and land use changes, agriculture continues to impact many of our streams. The Big Rock Creek Project affords us the opportunity to work with a variety of landowners - from the UT Dairy and several private dairymen to farmers who raise beef cattle and row crops. A person has been recently hired to focus exclusively on these landowners and is making great strides implementing best management practices such as livestock exclusion fencing and alternate water sources throughout this sub-watershed. We have worked closely with the UT Dairy over three years and have planted nearly 5,000 trees in an

effort to create a buffer and better riparian habitat. Our work with the UT Dairy is ongoing and a number of engineering practices will be put in place there over the next few months. This site is highly visible and serves as a role model for dairymen throughout the area. Plans are underway to have a demonstration/field day at the site next spring.

Possibly the greatest challenge in the long-term conservation of a place is education. It is the future generations who must not only understand the impacts we have on water quality, but care enough to change behaviors and make a difference. The Nature Conservancy contracted with Austin Peay University to design and implement an education program for elementary teachers in Marshall County. The curriculum is focused on the Duck River, Big Rock Creek and water quality in general. Even though this program has just gotten started, response has been very positive and it holds a lot of promise for the future of Big Rock Creek and the citizens of Marshall County.

EVALUATION OF PEAT MOSS AS A FILTER MEDIA FOR THE REMOVAL OF THE HERBICIDE SIMAZINE

Kim Stearman[1], Thenmozhi Ramar[1], Dennis George[1] and Lenly Weathers[2]

ABSTRACT

Simazine is one of the most heavily used herbicides and has been reported in drinking water in the United States. It is considered a priority chemical for testing in drinking water. Therefore, there is much interest in removing simazine from water runoff prior to its entering lakes, rivers and ponds. This study was conducted to delineate removal of simazine from water by adsorption using peat moss. The adsorption capacity of autoclaved sphagnum peat screenings, which are used primarily for heavy metals removal at industrial sites (HMP), was studied for the removal of simazine. Approximately 35% of the simazine was adsorbed by the peat moss. The solid-water simazine distribution ratio (K_d = 0.026 L/g) and rate constant (k = 0.046 L/g-hr) for the HMP peat were determined from batch isotherm and kinetic studies, respectively. From column studies, the breakthrough curve of simazine was obtained. The solid-water simazine distribution ratio, K_d (0.017 L/g), was determined from the column study by proposing a linear equilibrium transport model. Studies showed that simazine was adsorbed within 3 hr to the available peat moss surfaces and reached equilibrium in a short time (< 4 hr). In addition to adsorption of simazine by peat moss, microbial degradation of simazine in peat moss is being studied. By combining both simazine adsorption and degradation in peat moss filters, the filters can properly be designed for field use.

OBJECTIVE

The objectives of this project were to determine the treatment performance of peat moss for removal of simazine by conducting batch adsorption and kinetic studies and column studies and to develop a kinetic and transport model of simazine removal.

Container nurseries apply large amounts of pesticides and herbicides to the plants and surrounding gravel beds. These agricultural chemicals are retained, transformed or transported in the media substrate or taken up by plants (8, 9, 18).

Constructed wetlands have been used successfully to treat container nursery runoff. There are two types of constructed wetlands: free water surface wetlands and subsurface flow wetlands. When subsurface flow constructed wetlands are used, herbicide removal may range from 60 to 90% (9, 13, 18). When compared to natural wetlands, constructed wetlands offer several advantages such as site and size selection, vegetation selection, media selection, and control over the hydraulic pathways and retention time. A significant disadvantage of constructed wetlands is that hydraulic retention times of several days are necessary for the microbial degradation of pesticides and herbicides, which results in large land area requirements (8, 13, 18). To increase the herbicide removal rate, several organic carbon substances, including peat moss, have recently been studied (1, 2, 6, 7, 12). Peat moss's high organic content increases microbial degradation of the herbicides while its physical and chemical properties increase the rate of pesticide adsorption (6, 14, 15). Also, peat moss is more economical ($88 per metric tonne) compared to other adsorbents like silica, carbon and alumina ($1,100 to $22,000 per tonne) (5). Peat has been used in treating wastewater (5, 14), removing heavy metals (4, 11, 16) and removing organics (14, 19).

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MATERIALS AND METHODS

The sphagnum peat moss screenings used for heavy metals removal at industrial sites (HMP) (Fafard® Company, Floodwood, MN) were used for the experiments. The manufacturer's analysis indicated that it had an organic content of 95%, ash content of 5%, and pH in the range of 3.4 to 4.4. The fibrous peat moss screenings were ground in a Wyley mill and sieved. From the size distribution curve, the effective particle size (D_{10}) was determined to be 0.25 mm and was used in further studies.

BATCH ISOTHERM AND KINETIC TESTS

Batch isotherm tests were conducted in triplicate. Simazine (98% purity) was purchased from ChemService (West Chester, PA). Three experimental controls consisted of an autoclaved simazine solution but no peat moss. Autoclaved HMP peat moss masses of 0.25, 0.5, 0.75, 1, 1.25, 1.5, 2, 3, 5 and 7 g were added to Erlenmeyer flasks containing 150 mL of buffered (0.02 mM phosphate) simazine solution (0.4 mg/L). All the flasks were covered with aluminum foil, agitated for 24 hr using a rotating shaker table at 150 rpm and analyzed for simazine.

The kinetic tests were performed with 2g of HMP peat that were added to each of the flasks that contained 150 mL of 0.55 mg/L simazine solution. Two flasks were sacrificed for simazine analysis every hour for 8 hr and then at time intervals of 12, 15, 21 and 24 hr.

SIMAZINE ANALYSIS

C_{18} SPE cartridges (1g) were conditioned with 3 mL methanol, 3 mL ethyl acetate, 3 mL methanol, and 2 mL ethyl acetate in that sequence. A 20-mL sample was drawn through the cartridges, and the cartridges were allowed to dry under a vacuum for 5 min. Simazine was then eluted with 5 mL of ethyl acetate into a 5-mL volumetric flask and analyzed by gas chromatography (GC). A model 6890 Series GC (Agilent Technologies, Wilmington, DE) with an electron capture detector (ECD) was utilized for simazine analysis.

COLUMN STUDIES

The rapid small-scale column experimental setup consisted of an adsorption column (4.4 cm [OD] x 16.5 cm), a positive displacement peristaltic pump, and an inflow (1L) and an outflow (1L) reservoir. Thirty grams of dry autoclaved HMP peat moss were supported in the column by glass wool placed at the top and bottom of the peat moss of 11.5 cm depth. The peat moss was wetted before being added to the column to decrease the likelihood for entrapped air. A simazine solution of 0.4 mg/L, prepared in a phosphate buffer (0.02 mM) solution, was pumped through the column at a flow rate of 4 mL/min, which resulted in a theoretical retention time of 18.7 min based on the porosity of the peat moss (52%) in the column. The first seven samples were collected every 30 min, and thereafter samples were obtained at 1-hr intervals. At each sampling period, samples were collected and analyzed for simazine according to procedures previously outlined. A tracer study was conducted using a 10 mg/L sodium bromide solution to determine the flow through the column. The tracer solution was pumped through the column, and every 5 min, samples were collected. The samples were filtered through a 0.45 μm nylon filter and bromide analysis was conducted by ion chromatography (IC) (EPA 300.0).

DATA ANALYSIS

Statistical Analysis Software (SAS®, Version 8, 1999) was used to determine if sample means were statistically different. Analysis of variance procedures using a general linear model (GLM) were used to determine significant differences among data sets.

RESULTS AND DISCUSSION

Batch Adsorption Isotherm Studies

The maximum simazine removal (53%) was obtained with 7 g of peat moss. Statistical analysis of batch adsorption isotherm data indicated that equilibrium simazine concentration (C_e) values in solution containing 1 g peat moss and less were not significantly ($\alpha = 0.05$) different from the initial simazine concentration. There was no significant ($\alpha = 0.05$) difference in equilibrium simazine concentration among solutions containing 1.25, 1.5 and 2 g. When the mass of peat was increased approximately by a factor of two, i.e., from 1.5 to 3 g or from 2 to 5 g and 3 to 7 g, a significant ($\alpha = 0.05$) difference in simazine concentration was observed.

Simazine removal can occur through hydrolysis, photolysis, microbial degradation or by adsorption (10). Chemical hydrolysis, photolysis and microbial degradation were not likely factors in the removal of simazine in these studies since all the experimental samples had a pH that will not favor hydrolysis (< 4 or > 10) (3). Experiments were carried out in a dark, controlled environmental chamber to avoid photolysis, and the peat and the test solutions were autoclaved for 30 min before the start of the experiment to eliminate microbial degradation. Therefore, under the experimental conditions tested, adsorption was the primary factor for simazine removal.

Isotherm Curve

A linear isotherm model was used to describe the liquid phase equilibrium concentration of simazine (1)

$$Q_e = K_d C_e \tag{1}$$

where Q_e = mass of adsorbate per unit mass of adsorbent (mg/g),
C_e = liquid phase equilibrium concentration (mg/L), and
K_d = solid water distribution ratio (L/g).
The linear isotherm model indicated that as the equilibrium simazine concentration increased, the mass adsorbed per gram increased. There was no maximum adsorption capacity for the peat under the conditions tested. Regression analysis performed on the isotherm model significantly ($\alpha = 0.1$) defined the data with a coefficient of determination (r^2) of 0.54 (Figure 1). This mathematical model defined the data variability more than the traditional Freundlich and Langmuir equations. The linear isotherm provided a solid water distribution ratio, K_d, of 0.026 L/g for that data set range.
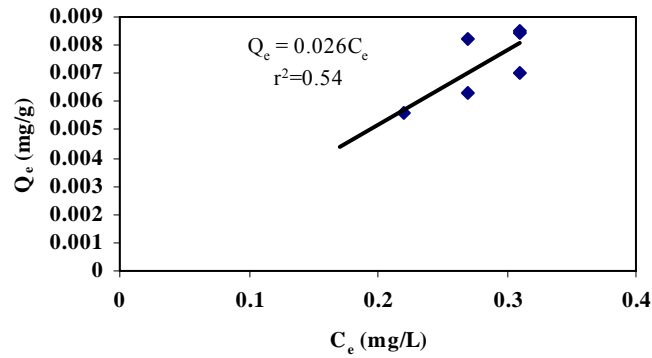
Figure 1. Linear Isotherm Curve for HMP Peat

Q_e = mass of adsorbate per unit mass of adsorbent (mg/g),
C_e = liquid phase equilibrium concentration (mg/L

Kinetic Studies

A significant (α = 0.05) removal of simazine (18%) was observed at a 2-hr contact time. Equilibrium was achieved in approximately 3 hr (Figure 2). The aqueous concentration of simazine was about 0.36 mg/L at equilibrium. After 3 hr, the removal percentage remained constant at 33%.

Based on the above findings, the following first-order equation was proposed:

$$\frac{dC}{dt} = -k(C - C_e) \tag{2}$$

where C = the simazine concentration (mg/L),
$\quad\quad$ t = time (hr),
$\quad\quad$ k = the pseudo first order rate constant (hr^{-1}), and
$\quad\quad$ C_e = the equilibrium simazine concentration (mg/L).

Integrating Equation 2 with the boundary conditions $t = 0$ to $t = t$ and $C = C_0$ to $C = C$ and $C_e = 0.36$ mg/L yields the following equation:

$$C = C_o e^{-kt} + C_e(1 - e^{-kt}) \quad . \tag{3}$$

The equilibrium concentration was taken as the average of the aqueous simazine concentrations from time 4 hr to 24 hr since the concentration value was relatively constant (0.36 ± 0.01). Using Microsoft Excel® Solver package and by method of curve fitting, the final k value was found to be 0.61 hr^{-1}. The concentration of peat moss suspended in the solution was 13.33 g/L. Dividing the k value by peat moss concentration, the normalized k value was 0.046 L/g-hr. Using Equation 3, the transient response of the experimental simazine concentration and model simazine concentration can be graphically compared as in Figure 2.
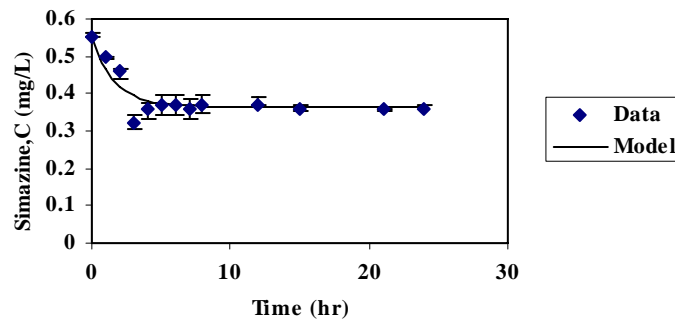
Figure 2. Plot of Experimental Simazine Concentration Versus the Model Simazine Concentration for HMP Peat Moss from Kinetic Model

Column Studies

The breakthrough curves for the peat moss filter column experiments conducted with the sodium bromide (NaBr) tracer and simazine at a flow rate of 4 mL/min are shown in Figure 3. Bromide was detected in the effluent after about 20 min while simazine was not detected until 3.5 hr. Comparing the bromide breakthrough time (i.e., the time when the output simazine concentration was 50% of the initial input concentration) to the longer simazine breakthrough time confirmed that simazine was retarded by adsorption as it moved through the column.
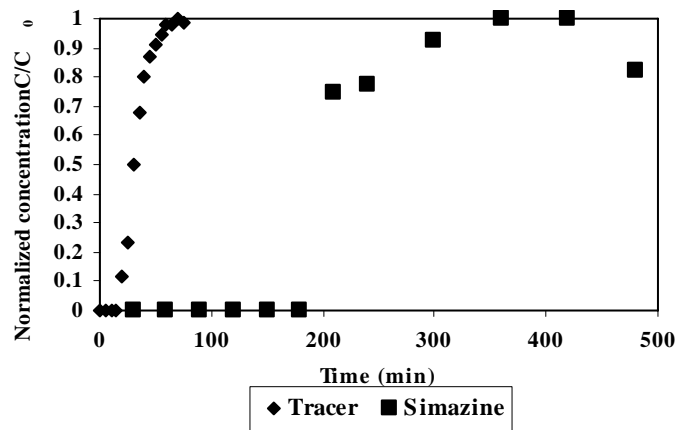
Figure 3. Breakthrough Curves for Tracer (NaBr) and Simazine

The simazine was removed by instantaneous adsorption to the readily available peat surfaces. When the peat moss surfaces' easily accessible sites were filled, simazine breakthrough occurred. A K_d of 0.017 L/g was obtained from the column studies using a linear partitioning expression.

CONCLUSIONS

Laboratory studies were conducted to determine the effectiveness of a peat moss filter as a treatment process to remediate container nursery runoff containing the herbicide simazine. More specifically, the adsorption properties of peat moss and the breakthrough characteristic of simazine using peat moss were assessed.

The overall results indicate that HMP peat moss may be an effective filter media in the constructed wetlands. Studies showed that simazine was adsorbed within 3 hr to the available peat moss surfaces and reached equilibrium in a short time (< 4 hr). A dynamic mass transport model using a linear partitioning expression with a K_d of 0.017 L/g adequately predicted effluent simazine breakthrough concentrations from small peat filter columns.

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CASE STUDIES IN EFFLUENT TOXICITY TREATABILITY

Scott Hall*[1] and Rick Lockwood[1]

Toxicity Reduction Evaluation (TRE) studies often utilize bench- or pilot-scale assessments of full-scale Whole Effluent Toxicity (WET) control methods. However, traditional Toxicity Identification Evaluation (TIE) studies, typically preceding TREs, do not incorporate bench-scale evaluations of full-scale treatments. Such bench-scale data can be useful in the design of pilot-scale studies or can provide data to identify key sources of WET.

The approach combined conventional TIE/TRE laboratory procedures with bench-scale treatments providing preliminary treatability and/or source control data. A variety of physical/chemical and biological treatments were utilized, as was effluent re-synthesis, and unique approaches, such as species sensitivity patterning to make use of known toxicological differences between species for specific toxicants, such as salts. Anytime conventional TIE procedures were implemented, standard USEPA methodologies were followed.

STEEL PRODUCTS

NPDES testing for a steel products company had indicated the intermittent presence of WET. The effluent generally demonstrated no toxicity to the water flea, *Ceriodaphnia dubia*, but acute and chronic toxicity to the fathead minnow was often observed. Furthermore, dose/response and mortality effects for intra-test exposure replicates were erratic, and "fungal-like" or filamentous growths were often observed on fish prior to death. Review of bench parameters and analytical results from monitoring chemical-specific compliance data found no obvious cause for the mortality or apparent pathogen outbreaks. Initially, we considered the pathogen outbreaks in the WET tests as a secondary "symptom" caused by chemical stressors. Conventional EPA fractionation methodologies (EDTA, sodium thiosulfate, etc.) were not successful in characterizing a chemical toxicant, although initial source studies were useful to narrow the likely plant areas contributing WET. The standard, chemical-based TIE strategy was complicated by the presence of fish pathogens, and through revision of this TIE strategy we determined that the pathogen interference was the primary cause of WET.

At the time this study was conducted, pathogen interference in the fathead minnow chronic WET test was not recognized by EPA as a source of test interference. As such, no formal compliance relief measures had been proposed. Subsequently, the TRE strategy developed to assess pathogen interference as a WET test artifact, and pathogenicity as a WET problem requiring full-scale treatment.

Measures to understand and correct pathogen interference as a test artifact included characterizing the statistical anomalies of the WET tests, histopathology and culturing studies to identify the infectious agents, reinfection tests, and development of bench sterilization techniques that would have minimum impact on potential chemical toxicants in the effluent. Techniques for reducing full-scale WET included a wide range of disinfection and filtration/flocculation methods: filtration at various pore sizes (11 micron to 0.22 micron), heating, chlorination, peroxide, caustic, acid, chlorine and other biocides, ultraviolet irradiation, ozone, ferric iron and alum flocculation, Granular Activated Carbon (GAC), and biological treatment.

"Reinfection tests," the addition of effluent-exposed fish to unexposed fish in control water, proved to be a very successful technique to document the presence of a pathogen when fish not exposed to the effluent developed the same symptoms and lethal effects. This alleviated the

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concern that physical and/or chemical effects due to effluent exposure were necessary in order to induce pathogen effects. Through microscopic evaluations by a veterinary fish pathologist, iron bacteria were determined to be the causative infectious agent. Filtration at 0.45 μm or 0.22 μm essentially provided sterile conditions and controlled fish pathogens. Biological treatments (activated sludge and attached growth medium) were the most successful at reducing pathogen interference in studies of potential full-scale treatments. In effluents with greater than 90 percent mortality, attached growth medium and activated sludge reduced fathead minnow mortality to less than 20 percent.

Biocides, particularly chlorine, did not produce consistent results and, in many cases, exacerbated pathogenic growth. Micro-filtration was not practical as a full-scale solution, and a stand-alone biological plant was considered too costly to implement despite its obvious potential. A source-survey for high-pathogen waters resulted in a "housecleaning" program for clarifier basins. A second clarifier was added to allow rotation during cleaning.

Differences in chemical parameters before and after cleaning events were not evident, indicating the utility of a source-oriented as opposed to chemical-specific TIE approach. One microbiological parameter, growth on Selective Cytophaga Agar (SCA) medium, did seem to indicate decreases with decreases in WET. SCA growth is indicative of filamentous bacteria, and similar decreases in growth on Ordals medium, indicative of flexobacter, seemed to indicate the causative pathogens were filamentous and/or iron bacteria.

An additional clarifier was put on line, which made alternating maintenance and cleaning of an existing clarifier practical. Presently, this has made a significant improvement with pathogen problems in this effluent, and full WET compliance has been achieved. Since the study was completed, EPA has provided remedies for altering WET test methods for control of pathogen interference.

LATEX PRODUCTION

Effluent samples from a latex product manufacturer were evaluated for chronic WET per NPDES monitoring requirements. Because effluent ammonia concentrations were known to be high, the effluent was tested in a CO_2-enriched chamber to control pH drift during WET testing. The effluent demonstrated acute toxicity (as indicated by mortality prior to the end of the chronic tests) and failed to meet the chronic compliance In-stream Waste Concentration (IWC) limit of 4.4 percent effluent with both the fathead minnow (*Pimephales promelas*) and water flea (*Ceriodaphnia dubia*). Scheduling of subsequent re-testing was problematic due to the treatment plant's frequent upset conditions and resultant high ammonia concentrations. Subsequent re-testing continued to demonstrate WET and a TIE/TRE was initiated.

The history of the treatment plant and effluent variability was considered in developing the TIE/TRE strategy. The treatment plant had a historic (though intermittent) capability of producing low-toxicity effluent. Thus, some potential for toxicity removal was evident. The toxicity evaluation studies focused on improved toxicity reduction rather than identification of a specific toxic constituent (i.e., in contrast to chemical-specific protocols). Based on product manufacturing information and the strongly aromatic nature of the effluent, biocides and volatile organics were suspected as a primary cause of toxicity. Regardless, a more comprehensive array of TRE fractionation testing was designed to cover other possibilities. Combinations of fractionations and "treatment trains" were also utilized to cover the potential of multiple toxicants. Flexibility was required to adjust these treatment trains in successive tests as the nature of the effluent toxicants became better understood. For example, some treatments were adjusted based on preliminary analytical data for newly-received samples. Subsequently, batch testing of

activated sludge was conducted with various plant products and additives to determine potential causes of plant upsets. Following treatment, all samples were readjusted to their original pH, if necessary.

Since the effluent typically demonstrated high acute toxicity, acute testing formats were used initially to reduce costs and response time for results. Chronic testing of selected fractionation methods was implemented as proofing, following interpretation of the acute results. The discovery of nitrite in the effluent was key to understanding the cause of effluent toxicity. Nitrite is not typically observed in nitrifying biological treatment plants. Nitrite in this effluent was often present at concentrations of over 100 mg/L. Therefore, nitrite was a key suspect toxicant in subsequent evaluations. The concentrations of ammonia, COD, and nitrite varied considerably in each tested sample.

Interpretation of the acute TRE data led us to conclude that the combination of ammonia and nitrite in the effluent was the primary source of toxicity to the test organisms. For example, pH 6 treatments of effluents sometimes resulted in decreased WET (increased LC50) to the fathead minnow, which is more sensitive to ammonia than *Ceriodaphnia*. Likewise, due to *Ceriodaphnia*'s higher sensitivity to nitrite as compared to the fathead minnow, decreased nitrite and WET levels implicated nitrite as a key toxicant.

A series of chronic TRE tests utilizing peroxidation, or combination peroxidation/zeolite fractionations was conducted to confirm the hypothesis of dual toxicants (ammonia and nitrite). In all three trials conducted, the combination fractionation produced the best results and reduced toxicity to within compliance levels. For example, the chronic 25 percent Inhibition Concentration (IC25 value) was 50 percent effluent or greater for both organisms following zeolite/peroxide treatment. Associated decreases in nitrite (NO_2) and ammonia were observed. Subsequent treatability efforts focused on plant nitrification problems to ultimately solve effluent toxicity problems.

ORGANIC CHEMICALS

A comprehensive TIE/TRE program was utilized to confirm the apparent TDS or ionic imbalance-related acute WET in an industrial effluent. Because neither conventional fractionation nor treatability-based approaches removed TDS (salt)-related constituents (data not shown and reverse osmosis and dual ion exchange resin were deemed ultimately not cost-effective and thus not attempted in early treatability efforts), a unique approach was developed. The program was divided into three main areas of investigation: 1) historical effluent data review, 2) major ion and heavy metal toxicity literature review, and 3) laboratory assessments of effluent and major ion toxicity. Review of the historical effluent data indicated a high-TDS effluent, dominated by six key ions: Ca, Mg, F, K, Na, and SO_4 (TDS approximately 2,500 mg/L). The literature review of the major ion and heavy metal toxicity data was conducted, not only to compare the historical effluent concentrations of the various constituents to published toxic values for each test organism, but also for developing Toxicity Ratios (TRs) for effluent toxicant characterization. The laboratory assessments were divided into four tasks:

- Parallel toxicity and chemical testing to ensure that there was a comparable baseline to the historical data;

- Toxicity testing of a re-synthesized "mock" effluent to rule out the possibility of hidden toxicants (i.e., non-salt related toxicants. Such an approach is very useful with salts in that no effluent parameters, such as TSS or TOC should affect salt toxicity, as would be

the case with many other toxicants. Additionally, the toxicity of salts is generally additive, and the toxicity of many combinations of cations and anions is known;

- Comparison of toxicity test results to the Salinity Toxicity Relationship (STR) model; and

- Comparison of effluent Acute to Chronic Ratios (ACRs) to in-house sodium chloride ACRs.

Review of the historical data demonstrated no correlations between metal and other toxicants (including product-related organics) and WET but a strong correlation between TDS and WET. This correlation was reinforced with the subsequent major ion and heavy metal toxicity literature review. The literature review corroborated the observed patterns in species sensitivity with: *Ceriodaphnia* more sensitive than *Daphnia magna*, more sensitive than fathead minnow to salts/TDS. Correlation assessments of individual ion concentrations and WET identified calcium and chloride as the highest probability toxicants and eliminated from consideration the heavy metal and conventional constituents assessed (e.g., ammonia, sulfide, cyanide). Literature reviews of calcium and chloride toxic concentrations relative to effluent concentrations confirmed the likely role of calcium and chloride in causing WET. Comparison of test species sensitivity (Figure 1) for these ions confirmed the general species sensitivity trends previously discussed. Assessing the Toxicity Ratios (TRs, the ratio of the effluent concentrations of the various ions at the effluent LC50 level to the average reported LC50 for a given ion) once again implicated the major ions, especially calcium and chloride, as the source of WET.

With the weight of evidence narrowed down to major ions as the causative toxicants, other laboratory assessments were conducted. Parallel toxicity and chemical testing established a baseline that was consistent with the historical data with respect to toxicity and major ion concentrations of 720 mg/l or greater for calcium and chloride concentrations in excess of 1,200 mg/l. The 48-hour acute and 7-day chronic toxicity tests were performed and the LC50 to NOEC ACRs were determined to be in the range of ACRs for the in-house NaCl reference toxicant database and ACRs for other salts reported in the literature. Effluent ACRs for C. *dubia* were approximately 3.0 compared to an in-house value of 2.1 and fathead minnow ACRs of just over 1.0 for both effluent and in-house NaCl tests. Data obtained from the STR model accurately predicted the LC50 values for fathead minnow, *Ceriodaphnia*, and *Daphnia magna*, again indicating that salts were likely the sole effluent toxicant. Re-synthesized "mock" effluent testing consisted of testing of laboratory waters to which reagent grade salts were added to mimic specific effluent samples that had been previously WET tested. The re-synthesized effluent toxicity tests produced good results compared to their actual effluent counterparts for all species tested (Figure 2).

The comprehensive problem solving program not only demonstrated the toxic effects of major ions in an industrial effluent, but also demonstrated how both laboratory and literature-based investigations can be integrated to resolve such difficult questions.

Figure 1. Species Sensitivity Comparisons for CaCl2 and NaCl
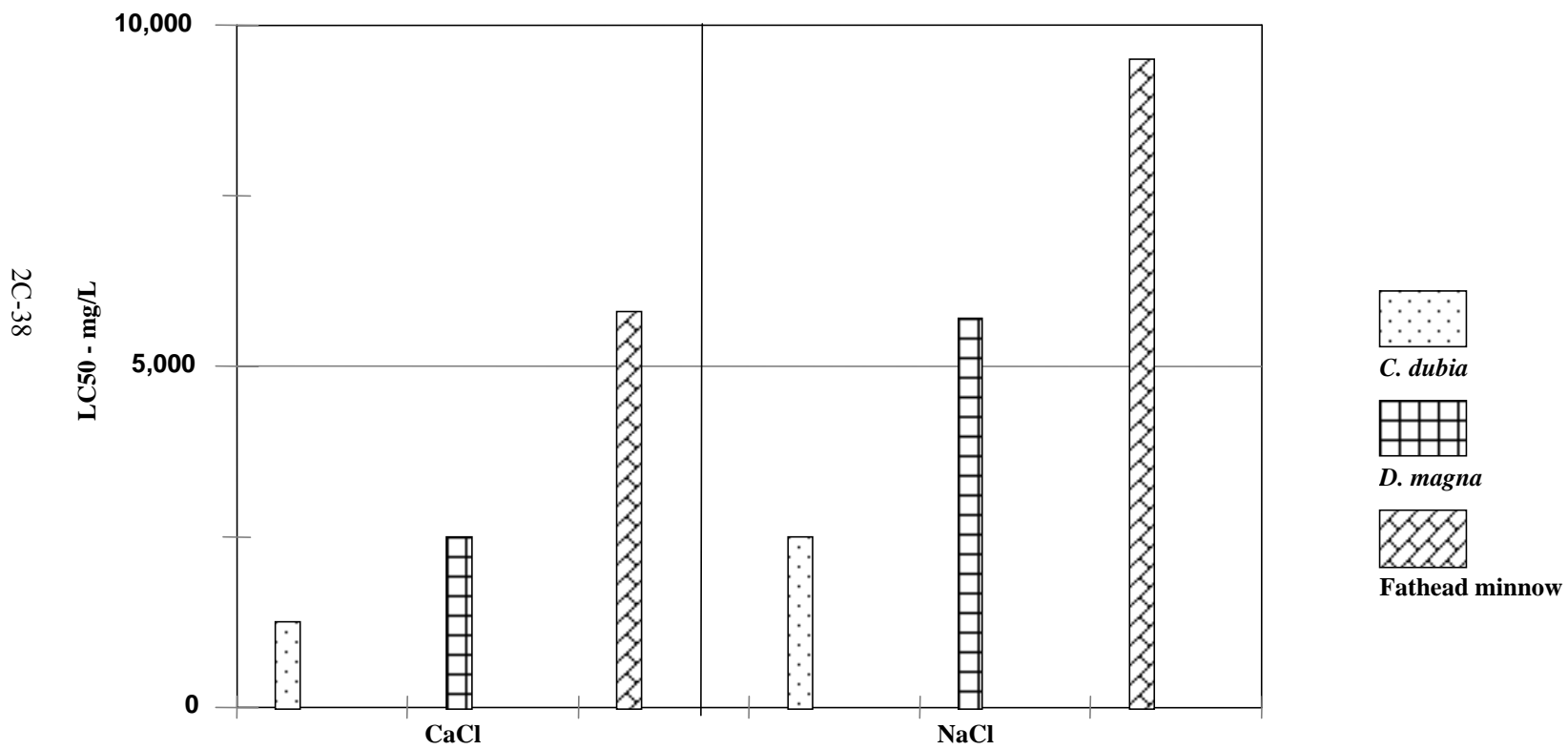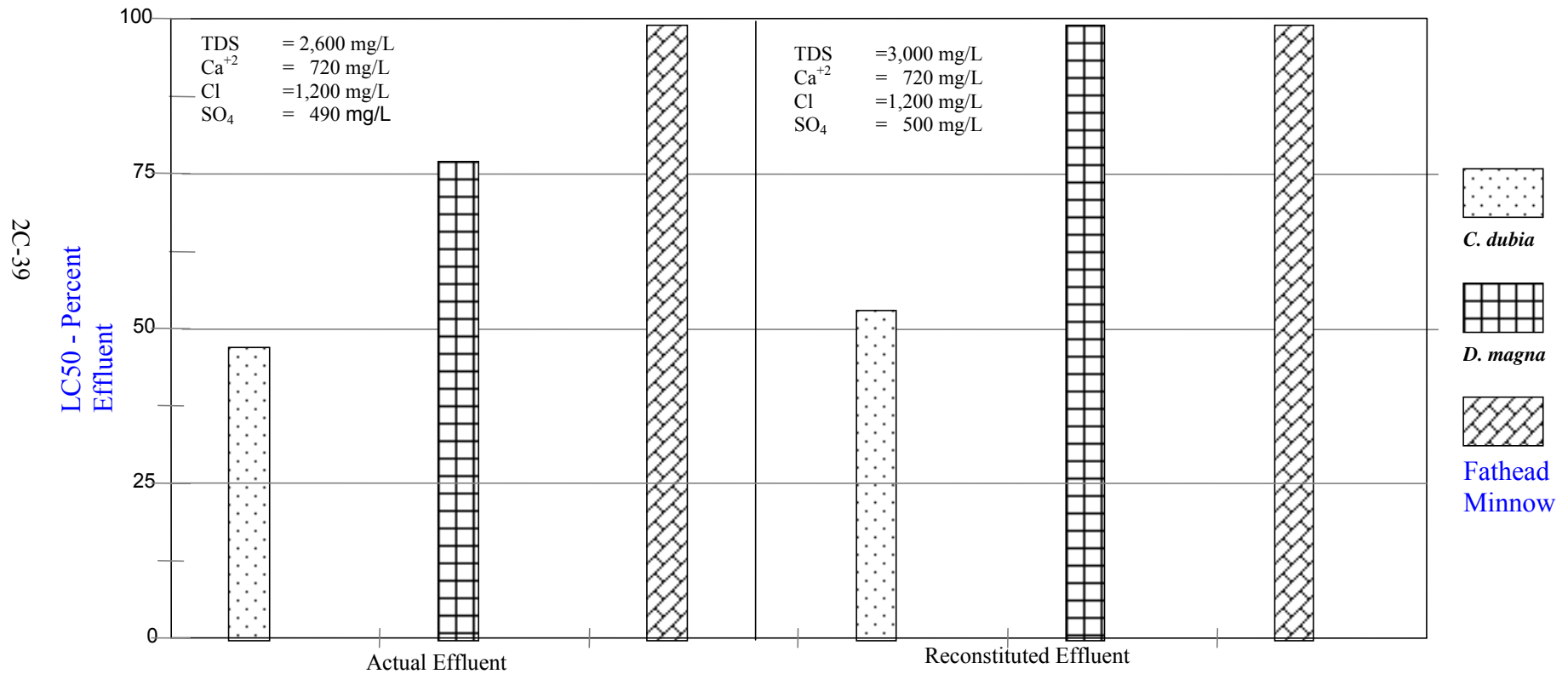
Data Expressed as the Whole Salt

Figure 2. Comparison of Actual and Reconstituted Effluent Toxicity to C. *dubia*, D. *magna*, and the fathead minnow

(over 90% of TDS due to "Six Major Ions")

STORM WATER DETENTION BASIN RETROFIT

Thomas C. Neel[1*], Vincent S. Neary[2], G. Kim Stearman[3] and Dennis B. George[4]

ABSTRACT

A detention basin receiving storm water runoff from a shopping center parking lot in Cookeville, Tennessee was retrofit to determine if a modified outflow riser could encourage removal of settlable pollutants while maintaining existing peak-flow reduction. The original detention basin consisting of a concrete outflow riser box with a bottom orifice was designed solely for peak-flow reduction for the 10-year return event. To determine the baseline removal efficiency of the flow control basin the concentration of total suspended solids (TSS) was monitored for six runoff events between December 2001 and August 2002. The results indicated relatively little overall impact to TSS with an average removal of $-5.4\% \pm 46.4\%$ which was within the range of peak-flow detention studies in the literature. To add water-quality improvement parameters to the system a water-quality pool was created at the bottom of the basin with the remaining storage for peak-flow control. The height of the riser box was increased to add additional volume to compensate for lost peak-flow control storage, and the bottom orifice was filled and replaced with a floating riser to drain the water-quality volume. Four post-retrofit events were monitored during the summer of 2003 with a marked increase in average TSS removal ($38.1\% \pm 51.4\%$) despite having a water-quality volume almost five times smaller than that required by design guidelines. The basin outflow average TSS concentration was also significantly reduced by the retrofit from 45.4 mg/L to 11.9 mg/L.

STUDY SITE

The detention basin drains into Breedings Mill Branch Canal, which travels through Ensor Sinkhole to Pigeon Roost Creek. Pigeon Roost Creek is considered impaired by the Tennessee Department of Environment & Conservation (TDEC 2004) due to organic enrichment, low dissolved oxygen, nutrients, and habitat alterations resulting from urban runoff, hydromodifications, and a major municipal point source. The detention basin receives runoff from concrete pipes 76 cm (30-in) and 61 cm (24-in) in diameter draining 2.41 ha (5.95 ac) and 0.31 ha (0.77 ac) watersheds, respectively. During lower flow the detention basin drains through a 30 cm (12-in) diameter low-flow orifice in the bottom of the 1.6 m (5.25 ft) tall concrete riser situated at the south end of the basin which is connected to a 46 cm (18-in) diameter corrugated-metal outflow pipe. The basin contains a brim-full volume of 460 m^3 (0.37 ac-ft).

METHODS

To determine pollutant loading both constituent concentration and flow rate were required. ISCO® model 4150 area-velocity flow loggers were used to measure flow rate in one-minute increments at the two inflow pipes. When a specified volume of runoff was measured the flow loggers were programmed to trigger the ISCO® model 2700 and 3700 automatic samplers to collect 1-L storm water samples. An ISCO® model 4230 bubbler flow meter measured stage in the concrete riser and flow was calculated using a stage-discharge relation determined using a

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4150 flow logger in the outflow culvert. The 4230 bubbler meter triggered an ISCO® 3700 automatic sampler to take volume based samples during pre-retrofit monitoring and two ISCO® 6700 automatic samplers were used to withdraw discrete time-based samples from the basin outfall and from the original low-flow orifice location during post-retrofit monitoring. Rainfall data was collected using a Rainwise® data logger tipping bucket rain gage. To calculate pollutant loading the midsample method outlined by Charbeneau and Barrett (1998) was used to divide runoff volume for assignment to specific sample concentrations. The load was then the cumulative sum of each sample concentration multiplied by its respective runoff volume. The removal efficiency for each event was then the difference in total load entering and leaving the basin divided by the load coming in the basin.

To determine the watershed drainage area a topographic survey of the basin's catchment area was conducted and drainage features including inlet grates, flow paths, and flow obstructions were located. Geographic Information Systems (GIS) mapping software was used to convert the survey coordinates to a Triangulated Irregular Network (TIN) from which contours were interpolated to delineate the watershed areas draining to the two basin inflow pipes. To determine the basin storage volume a 10 ft grid topographic survey was conducted and the survey points were converted to contour lines as above. The area within each contour line was determined and the average end area method was used to calculate basin storage volume.

Modeling the basin outflow hydraulics required analysis of each of the concrete riser components shown in Figure 1 including the low-flow orifice, the overtopping riser, and the outflow culvert. First the stage-discharge analysis of the outflow culvert was computed. Submerged and unsubmerged inlet control culvert equations were used to develop a culvert stage-discharge relation as outlined by FHWA (2001). The large and small orifice equations

$$dQ = C_d (Bdh) \sqrt{2gh}_e \qquad (1)$$

$$Q = C_d A \sqrt{2gh}_p \qquad (2)$$

were also used to develop inlet control culvert relations where dQ is the flow through an elemental horizontal strip, C_d is the orifice coefficient, B is the width of an elemental strip, dh is the height of the elemental strip and h_e is the depth of the elemental strip from the free surface. The orifice equations with an orifice coefficient, C_d, of 0.5 most closely corresponded with measured data and were used in further analysis. Outlet control for the culvert could not be computed because the culvert tailwater elevation was not known. Because the orifice at the bottom of the concrete riser was not in free-discharge, the orifice was analyzed in conjunction with the culvert hydraulics to develop the riser hydraulics. For basin stages below the top of the riser when flow was only through the orifice, the basin stage was computed by using a given culvert flow and stage in the riser as orifice discharge and tailwater stage, respectively, with the orifice equation is the form

$$H_1 - H_2 = \left(\frac{Q}{C_d A} \right)^2 \Big/ 2g \qquad (3)$$

where H_1 is orifice headwater in the basin, H_2 is orifice tailwater in the riser, Q is discharge, A is orifice area, and g is acceleration due to gravity. When overtopping weir flow occurred for stages above the riser, the combined weir and orifice equations were used to calculate basin stage given the total flow and riser stage from the culvert hydraulic relation. The resulting stage-discharge relation for the basin is given in Figure 2.

To determine the basin's performance during hypothetical frequency events a calibrated hydrologic model of the watershed was developed. HEC-HMS software used measured rainfall to generate hydrographs at the two inflow pipes where flow was monitored. A SCS curve number loss method and Clark transform method using time of concentration calculations from McCuen and Okunola (2002) for microwatersheds were used to model the hydrology. The slope, length, diameter, and roughness of the concrete pipes conveying basin runoff were also incorporated into the hydrologic model. Four storm events for both catchments during March 2002 were used to validate the hydrologic analysis. The hydrologic model was then used to determine if the existing detention basin met local design regulations (City of Cookeville 2002), which require post-development 10-year peak flows to not exceed pre-development conditions. When the detention basins peak outflow of 0.55 m^3/s (18.1 ft^3/s) for the 24-hour duration, 10-year frequency event was compared to both pasture and woodland pre-development conditions, 0.19 m^3/s (6.3 ft^3/s) and 0.09 m^3/s (3.1 ft^3/s), respectively, it was shown to exceed both, which did not meet the local regulations. Because a majority of the detention basin storage was filled during this event and the objective of the study was to implement water-quality improvement, the decision was made to maintain but not enhance peak-flow reduction in the retrofit design.

The hydrology model was then used to ensure the new outflow riser provided equivalent peak-flow reduction for the design event while allocating water-quality storage. The retrofit outflow riser would be taller to prevent increases in peak-flow rate due to higher water levels in the basin resulting from peak-flow storage being transferred to water-quality storage. A large orifice would be installed in the concrete riser at a raised position to allow passage of flood flows in a controlled manner. The invert of the orifice would be the boundary between the water-quality volume below and the flow control volume above. The retrofit riser design process consisted of selecting an orifice raise height, setting the orifice area to provide adequate peak-flow reduction, and determining if the maximum basin water surface elevation was exceeded. The chosen retrofit riser design pictured in Figure 3 included raising the riser height by 0.99 m (3.25 ft) to prevent riser overtopping during the 10-year event and cutting a 0.85 m (2.80 ft) wide by 0.53 m (1.75 ft) high rectangular orifice in the riser with an invert 1.07 m (3.5 ft) above the bottom of the basin. The retrofit outlet resulted in an increase in the maximum water surface elevation of 12 cm (0.4 ft) for the 10-year event and 3 cm (0.1 ft) for the 100-year event, which approached basin full for the later event but was still over 0.62 m (2 ft) lower than the overtopping bank elevation. Despite maximizing the orifice raise height and thereby the water quality storage the resulting water-quality pool was only 148 m^3 (0.12 ac-ft) while local design guidance (City of Nashville 2000) required 715 m^3 (0.58 ac-ft) or nearly five times more water-quality storage based on the watershed area, the runoff coefficient, and the mean storm depth.

To partially offset the effects of a small water-quality volume several water-quality outlets were investigated to determine which could provide the highest pollutant removal. Regulatory guidance suggested the use of V-notch weirs, perforated risers, and single orifices to drain water-quality volumes. A floating riser such as illustrated by Jarrett (1998) that moves with the dynamic pool to draw water from near the surface was also considered. In order to evaluate several outlet types in terms of enhanced removal of settlable pollutants the outlet types listed above were assessed based on their average detention time and the flow-weighted withdrawal depth for an arbitrary detention basin holding 1420 m^3 (50,000 ft^3) of runoff at a depth of 1.52 m (5 ft). Each outlet type was sized to drain 99% of the storage volume within 40 hours. The results of the flow-weighted withdrawal depths are displayed in Figure 4 with the orifice outlet withdrawal at the bottom, the uniform notch weir and perforated riser withdrawal 0.30 m (1.0 ft) above the bottom of the 1.52 m (5 ft) water column and the floating riser withdrawal at 0.76 m (2.5 ft), which was the best from a pollutant settling removal standpoint. The most striking characteristic of the different outlets was their average detention time. As shown in the draw down curves in Figure 5 the weir and perforated riser average detention times were only 3.4 and

4.7 hours, respectively, for a drain time of 40 hours while the floating riser average detention time was one-half of the drain time or 20 hours due to a constant withdrawal rate and the orifice average detention time was 11.0 hours. Based on this assessment the floating riser would likely provide the best pollutant removal efficiency followed by the single orifice. Given this data the floating riser was chosen for the retrofit water-quality inlet. Note, however, that an 'ideal' outlet for settling removal would not drain at a constant rate but hold runoff until the maximum drain time before draining the entire volume assuming basin inflows occur mostly at the beginning of runoff detention. For additional sediment removal benefits turf grass sod was placed on the bottom and sides of the detention basin for sediment stabilization to cover poorly vegetated areas.

RESULTS

Between December 2001 and August 2002 six runoff events were monitored to determine the event based TSS removal efficiency of the pre-retrofit basin. As shown in Table 1 the TSS removal of the six individual events ranged between -75.4% and 42.9% but the average removal of -5.4% $\pm$ 18.9% indicated the overall TSS removal was marginal. This average value was within the range of five peak-flow detention basins cited in the literature with TSS removal ranging from -310% to 6% (Bartone and Uchrin 1999, National BMP Database 2003). Because the detention basin was designed to control peak flow from the 10-year return event, storage was negligible during more frequent events. The low-flow orifice positioned at the bottom of the outlet structure also drains the basin from the lower levels of the water column, which is not ideal for settlable pollutant removal.

Table 1. Pre-retrofit TSS Removal Efficiencies

	12/17/2001	1/10/2002	3/12/2002	3/20/2002	7/10/2002	7/23/2002	Average	Standard Error
Removal Efficiency	32.4%	-0.3%	42.9%	-75.4%	-46.4%	14.5%	-5.4%	18.9%

Between June and July of 2003 four post-retrofit runoff events were monitored for TSS removal. The retrofit outlet with a floating riser water-quality inlet and improved vegetative cover provided an average TSS removal of 38.1% $\pm$ 25.7% as shown in Table 2. This average TSS removal value was less than other water-quality improvement basins cited in the literature that ranged between 68% and 91% (Strecker et al. 1992, National BMP Database 2003, Guo et al. 2000) but was still significant considering the relatively small extended detention pool was only 0.52 watershed centimeters (0.21 in) where the mean storm depth is 1.6 cm (0.63 in). As outlined in USEPA (2002) the pre- and post-retrofit outflow TSS concentrations were compared and the mean outflow TSS concentration of 11.9 mg/L during post-retrofit conditions was shown to be less than the 45.4 mg/L mean outflow concentration during pre-retrofit conditions at the 95% level of significance using the student's t test. Runoff samples taken near the bottom of the basin at the location of the original orifice during post-retrofit monitoring were also used to calculate the bottom drain efficiencies given in Table 2. These samples indicated that if the water-quality pool had been drained with a bottom orifice then a negative removal efficiency of -105.3% $\pm$ 13.4% would have resulted. The correlation between runoff capture which is the percentage of runoff that is 'captured' and does not spill over the water-quality pool, and removal efficiency was computed for the post-retrofit events and shown to have a 95.1% level of significance. This correlation plotted in Figure 6 illustrates that a negative removal efficiency of -24.5% resulted from the largest runoff event with very low runoff capture efficiency of 7% and a high TSS removal efficiency of 87.9% resulted from the highest runoff capture of 45.1%. These results indicate that increased turbulence during large runoff events may produce negative removal efficiencies while during lower flows bypassed runoff can still experience some removal.

Table 2. Post-retrofit TSS Removal Efficiencies

Removal Efficiency	6/11/2003	6/15/2003	6/27/2003	7/10/2003	Average	Standard Error
Floating Riser	87.9%	-24.5%	71.4%	17.5%	38.1%	25.7%
Bottom Drain	47.7%	-501.2%	65.4%	-33.2%	-105.3%	13.4%

CONCLUSIONS

Although this study is based on only a limited amount of storm events, it provides evidence of improvement in TSS removal efficiency resulting from a relatively simple and inexpensive detention basin outlet retrofit, which maintained the basin's original storage capacity. The study also demonstrated the high variability of TSS removal efficiency performance due to varied hydrologic conditions and basin outlet configurations. Future efforts will use the data collected in this study to develop and calibrate models that can simulate removal efficiencies for individual events, as well as the annual average removal efficiency.

ACKNOWLEDGEMENTS

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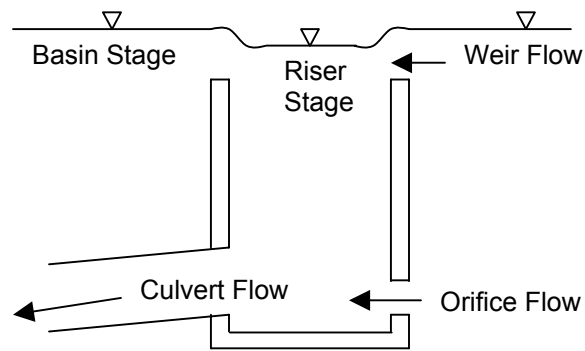
Figure 1. Concrete riser components.
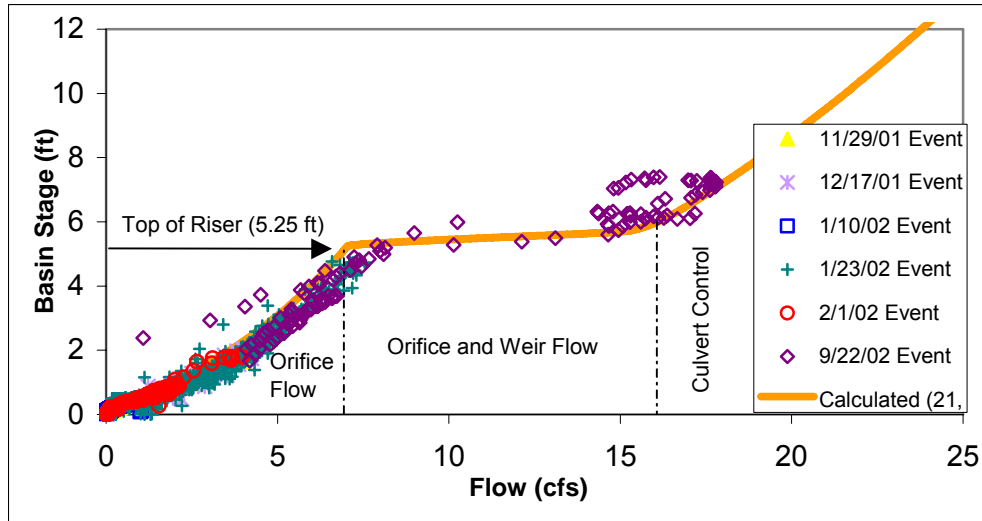
Figure 2. Basin stage-discharge relation for pre-retrofit outlet.

Figure 3. Modified concrete riser outlet.
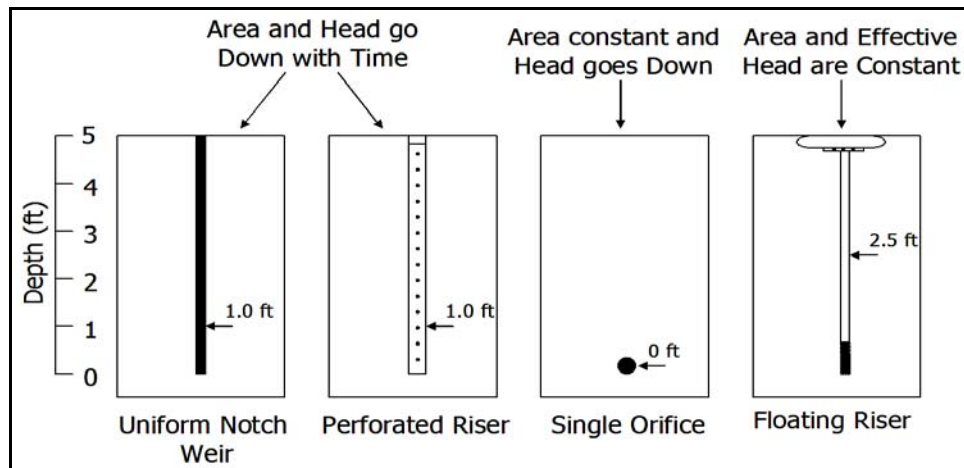
Figure 4. Effective withdrawal depths for different outlet types.
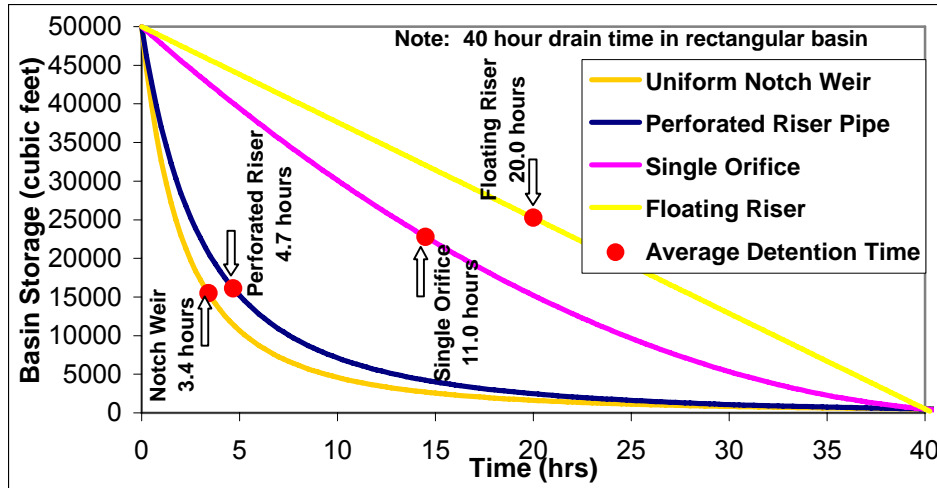
Figure 5. Average detention times for different outlet types.
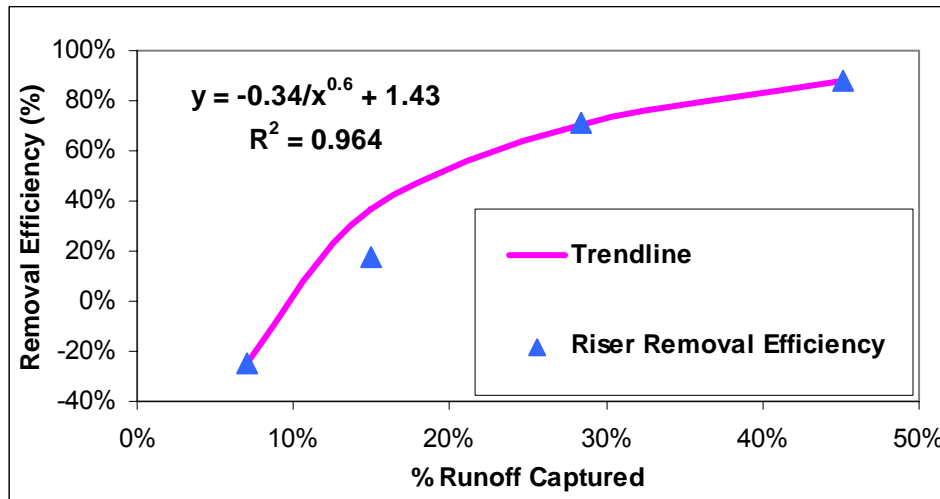
Figure 6. Post-retrofit riser TSS removal efficiency versus runoff capture.

SESSION 3A

SURFACE WATER QUALITY III
8:30 a.m. – 10:00 a.m.

Trend Analysis of Various Water-Quality Parameters for the Mississippi, Cumberland, and Tennessee River Basins in the State of Tennessee
Rebecca James

Point Source Impacts on the Loosahatchie River
Larry Moore, Calvin Abernathy, Paul Palazolo, Jerry Garrett and Paul Hampson

Design Considerations for Open Channel Sections
Paily P. Paily

TENNESSEE WATER PROGRAMS
10:30 a.m. – 12:00 p.m.

Water Pollution Control Update
Saya Qualls

Water-Science Planning: Issues and Initiatives for the U.S. Geological Survey in Tennessee
W. Scott Gain

The Quest for Measurable Water Quality Improvements: An Overview of Tennessee's Nonpoint Source Program
John McClurkan

TREND ANALYSIS OF VARIOUS WATER-QUALITY PARAMETERS FOR THE MISSISSIPPI, CUMBERLAND, AND TENNESSEE RIVER BASINS IN THE STATE OF TENNESSEE

Rebecca James[1]*

INTRODUCTION

The Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control is responsible for planning, monitoring, assessing, and reporting the quality of surface water throughout the state. The Division has developed a strategy based on watershed management to undertake these responsibilities. There are 54 watersheds that drain to one of five main river basins. Three of these river basins, the Mississippi, Cumberland, and Tennessee, drain most of the state's water. A study focused on long-term surface water-quality data is being developed for these large basins.

OBJECTIVES

This study is intended to describe water-quality trends (or lack of trends) for multiple monitoring sites in the state of Tennessee. The 15 parameters selected for the trend analysis include pH, dissolved oxygen (DO), total hardness, total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), nitrite plus nitrate, nitrogen ammonia, total phosphorus, total aluminum, total copper, total iron, total lead, total manganese, and total zinc. The Mann-Kendall non-parametric test was applied to the data to determine the existence of trends in water-quality. The Mann-Kendall method for trend detection has been used by the United States Army Corp of Engineers (2001), United States Geological Survey (2004) and in other states such as Kansas (Yuys et al., 1993). The modified version of the Mann-Kendall test, the seasonal Kendall tau, has been used to detect trends in states such as Delaware (Marino et al., 1991), Virginia (Zipper et al., 2002), and Arizona (Baldys et al., 1995). Due to the lack of data for every month of each year the sites were sampled, the seasonal Kendall tau test was not used for all parameters. The analyses performed on each parameter will be used to identify the existence of station-wide trends and basin-wide trends in Tennessee.

STUDY AREA

Figure 1 shows the location of the 130 sites selected for the analysis. The study sites were chosen based on the availability of historical records. All of the sites selected have at least ten years of data. There are 18 sites located in the Lower Mississippi-Hatchie River Basin, which drains West Tennessee. There are 65 sites in Middle Tennessee and 47 sites in East Tennessee that drain to the Cumberland and Tennessee River basins.

West Tennessee is divided into four level III ecoregions. These are the Southeastern Plains, the Mississippi Valley Loess Plains, the Mississippi Alluvial Plains, as well as a small portion of the Western Highland Rim subregion of the Interior Plateau. The natural vegetation of the plains of West Tennessee is mainly oak-hickory and oak-hickory-pine forests. The low gradient streams located within these ecoregions tend to have sand or silt for bottom substrate. Many West Tennessee streams have been highly altered through channelization.

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Middle Tennessee consists of a single Level III ecoregion, the Interior Plateau. Open hills, irregular plains, tablelands, and karst landforms characterize the topography of Middle Tennessee. The natural vegetation is primarily oak-hickory forest. The low to moderate gradient streams located in this ecoregion contain chert gravel and sand substrates with areas of bedrock. The streams in this area have the most diverse fish fauna in Tennessee. Many of the streams are impacted by agricultural activities and rapid urban development.
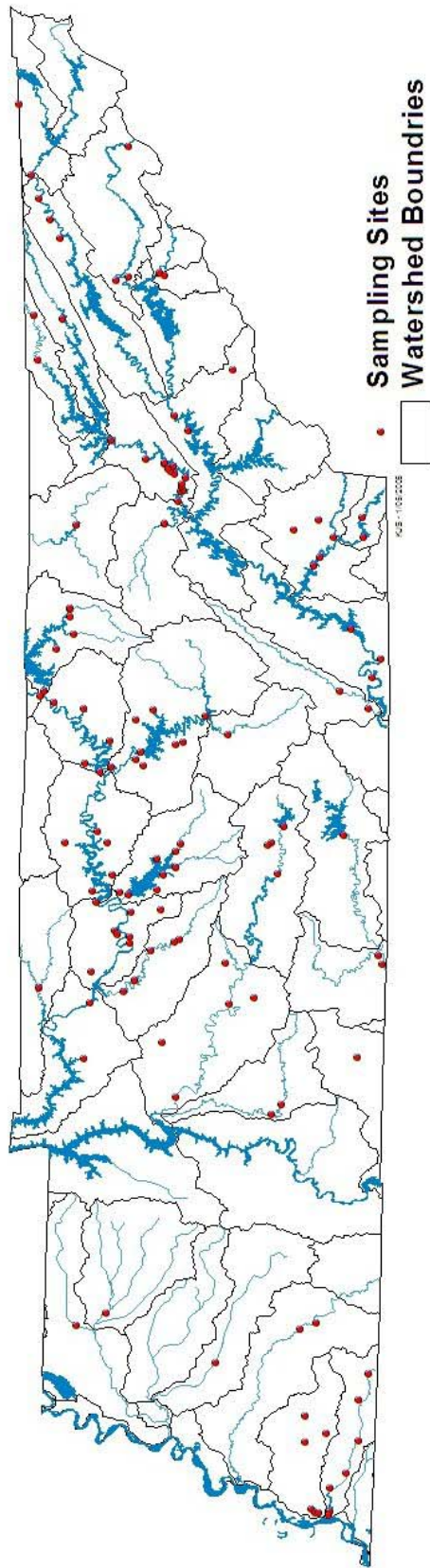
Figure 1. Sampling Site Locations

There are four Level III ecoregions in East Tennessee. These are the Blue Ridge Mountains, the Ridge and Valley, Central Appalachians, and the Southwestern Appalachians. The streams in

these ecoregions tend to be moderate to high gradient due to the rugged ridges, valleys, and mountains of East Tennessee. The natural vegetation is very diverse, including mesophytic forests, areas of mixed oak and northern hardwoods, as well as, pines and Southeastern spruce-fir forests. Historical mining and logging activities as well as new development impact streams in some areas. However, some of the most protected streams in the state are in this region.

DATA COLLECTION AND METHODOLOGY

Data was acquired from the Tennessee Department of Environment and Conservation Division of Water Pollution Control water quality database, the Army Corp of Engineers Nashville Office, the Department of Energy Oversight, the Tennessee Valley Authority, and the United States Geological Survey. Other agencies were contacted, but did not have data that met the criteria for this report. All monitoring stations included in this report were chosen based on the continuity and length of record. Monitoring sites with records less than ten years or records with large time gaps were discarded. The period of records used in this analysis varies among monitoring sites.

Once the data was compiled, it was sorted to eliminate ambiguous data. Data with time gaps greater than five years, alphanumeric values, estimated values, positive results in the blank, and data with results known to have been preceded by a storm event were discarded from the analysis. Data from filtered water samples and data with values less than the minimum detection limit (MDL) more than 50% of the time were also eliminated. When data reported below the MDL was used, a value of half the MDL was assigned to that data. Due to the lack of continuous, robust records for the parameters of interest, the Mann-Kendall test was the most powerful method for the trend analysis.

SUMMARY STATISTICS AND TREND ANALYSES

Summary statistics were calculated for the median values of each year the parameter was sampled. Statistical analyses for monotonic trend were performed on each of the 15 parameters of interest using the non-parametric Mann-Kendall trend test. An Excel template application called MAKESENS was acquired from the Finnish Meteorological Institute (2002) to perform the analyses.

The null hypothesis for the Mann-Kendall test is that no monotonic trend exists in the data values. The basic Mann-Kendall test ranks the data, and then the differences between each datum and its previous datum are computed across a triangular table. The test statistic is the difference between the number of positive differences found and the number of negative differences found between each of the datum. The presence of an ascending or descending trend is determined by the test statistic.

A large enough positive value for the test statistic suggests the existence of an upward trend. A large enough negative value for the test statistic suggests the existence of a downward trend. This test works well for small sample sizes (less than ten values). When the sample size is greater than ten, a normal approximation to the Mann-Kendall test can be used.   The normal approximation to the Mann-Kendall test was used for almost every site and parameter.

The results of these tests will be used to identify the presence of increasing and decreasing trends in water-quality for each station examined. Once the analyses have been performed on the available data, comparisons will be made between the stations. Comparisons among stations that lie within the same watershed can be used to determine if the same types of water-quality degradation exist throughout the watershed. The comparisons will help determine whether there are similar water-quality problems within the watersheds or unique problematic areas.

Furthermore, the analyses will help identify where these problematic areas exist and the type or types of degradation causing impairment.

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POINT SOURCE IMPACTS ON THE LOOSAHATCHIE RIVER

Larry Moore, Calvin Abernathy, Paul Palazolo, Jerry Garrett and Paul Hampson

BACKGROUND

Much of the Loosahatchie River is impacted by municipal wastewater treatment plant discharges. The river is listed on the State's 303 (d) list as potentially impaired for aquatic life support due to organic enrichment, low dissolved oxygen, and other problems such as nutrients and siltation. These water quality problems must be addressed if the river is to be restored to a level that fully supports aquatic life uses.

The cities of Oakland, Arlington, Lakeland, Mason, Gallaway, and Bartlett are currently planning new wastewater treatment plants (WWTPs) that will be significantly larger than existing facilities. Design engineers for these cities are anxious to know what effluent limits they must design these WWTPs to meet. A modified Streeter-Phelps model with conservative assumptions using very limited field data was developed by the Tennessee Department of Environment and Conservation (TDEC) Division of Water Pollution Control (DWPC) to determine initial discharge limits for the cities. Based on this conservative approach, DWPC initially determined that the effluent limits should be as follows:

$CBOD_5$	10 mg/l
TSS	30 mg/l
Ammonia-N	2 mg/l
Minimum DO	6 mg/l

Based on the Streeter-Phelps model, these limits were necessary to maintain the minimum DO in the river at 5.5 mg/l under low flow conditions ($7Q_{10}$).

TDEC's DWPC would like to use a more sophisticated model (QUAL2K) to conduct the waste load allocation process. The QUAL2K model will be used to establish effluent limits for "organic enrichment/dissolved oxygen" in a steady-state, one-dimensional analysis. The model will be developed to account for nutrient and carbon loadings from point sources during dry weather conditions. Examples of data needed for the model include:

- Time of travel data
- Stream slope
- Channel cross sections
- Biological rate constants (e.g., BOD decay rate)
- Reaeration rate
- Water quality data
- Point source discharge data
- Exact location of dischargers

During the months of June – October, 2004, the research team collected extensive field data for the Loosahatchie River. The research team consisted of faculty and graduate students of the University of Memphis Civil Engineering Department along with technical staff from U.S. Geological Survey and TDEC. The upper end of the study area was River Mile (RM) 30.3, where Highway 70 crosses the river. The lower end of the study area was RM 9.1, where Highway 51 crosses the river.

PROJECT OBJECTIVES

- Determination of profile of water quality during initial reconnaissance investigation

- Determination of field data for calibration and verification of the water quality model QUAL2K

- Determination of waste loadings from the major point sources

- Use of QUAL2K to determine waste load allocations for municipal dischargers along the Loosahatchie River

These objectives have been achieved. Determination of waste load allocations will be performed by TDEC using QUAL2K calibration and verification data provided by the research team.

MATERIALS AND METHODS

The materials and methods were designed to facilitate attainment of the project objectives noted above. The primary research activities involved field measurement of physical, chemical, and biochemical characteristics of the Loosahatchie River in Shelby County, Tennessee. One of the primary research activities was to determine the physical characteristics of the river. This involved determining appropriate streams sampling stations along the river. The research team identified 10 sampling stations along the 21-mile stretch of river. The 10 sampling stations are identified below:

Station No.	Station I.D.	River Mile
1	Highway 70 Bridge	30.3
2	Highway 205 Bridge	28.6
3	Highway 385 Bridge	27.1
4	Below Clear Creek	25.6
5	Brunswick Road Bridge	22.8
6	Power Transmission Line	21.4
7	Highway 14 Bridge	17.8
8	Singleton Parkway Bridge	16.1
9	Raleigh Millington Bridge	13.3
10	Highway 51 Bridge	9.1

Another important research activity involved the accurate determination of stream flow rates at specific locations using USGS protocol. USGS staff established gaging stations at Station No. 1, 5, and 10. In addition, flow measurements were made at each sampling station during sampling events and tracer studies.

The University of Memphis Civil Engineering Department measured the slope of the water surface throughout the 21-mile study segment using a Total Station, survey rod, and GPS equipment. The slope of the water surface was determined from these field measurements and was used as a surrogate for the bed slope of the river. The slope and velocity data can be used in empirical formulas to estimate the reaeration rate.

Three continuously recording water quality probes were placed at Station No. 1, 5, and 10. These probes recorded dissolved oxygen, pH, temperature, and conductivity at 30-minute intervals throughout the June-October, 2004, data collection period.

Another important research activity was to determine the chemical and biological characteristics of the river. The primary event for collecting these data was the calibration event of September 22, 2004. Water quality sampling for the calibration event was conducted from two separate boats on September 22, 2004. One boat (with Dr. Palazolo and a graduate assistant) began at Station No. 1, and another boat (with Dr. Moore and a graduate assistant) began at Station No. 5. Dr. Palazolo's sampling team began about 0730 hours (Station No. 1) and concluded about 1600 hours (Station No. 5). Dr. Moore's sampling team began about 0730 hours (Station No. 5) and concluded about 1900 hours (Station No. 10). Samples were taken at each sampling station according to standard USGS protocol. The samples were split into two samples, preserved, and iced in the field and transported to the University of Memphis Civil Engineering Laboratory and to the TDEC Laboratory in Jackson, Tennessee. Samples were analyzed for $CBOD_5$, ultimate (120-day) BOD, TOC, suspended solids (TSS), TKN, ammonia-N, nitrite/nitrate-N, and total phosphorus. In addition, the two sampling teams measured dissolved oxygen and temperature at numerous points along the river.

Another important research activity was to determine time of travel for the river. This was done on September 22 and 30 and on October 6 and 7, 2004, by USGS staff. This effort involved selecting appropriate stream segments and conducting time of travel studies using Rhodamine WT dye tracer and fluorometric measurements.

A major research activity was to determine field reaeration rates in conjunction with the time of travel studies. This was accomplished using propane gas injection into the river and subsequent collection of gas samples at downstream locations.

PROJECT RESULTS

During the low-flow period of August and September, 2004, the flow rate at Highway 70 was about 100 cfs. The flow rates increased at some downstream stations and decreased at others, indicating that minor losses of stream flow may have occurred in some reaches. However, the observed decreases in stream flow rate were usually within the error of the flow measurement. Nevertheless, the flow rate at the most downstream station (Highway 51) was about 130 cfs. The flow rates were relatively stable at the 3 gaging stations during September, except for one storm event on September 11. By September 16, the flow rates were back to their pre-storm levels. The low flow rates measured in September were about 41% higher than 7Q10 flow rates.

In the initial TDEC modeling done, the estimated stream slopes varied from 0.25 to 4.4 ft/mile. Based on the field surveys, the actual stream slopes were much more consistent, varying from 1.72 to 3.44 ft/mile.

The continuous water quality data at Highway 70 (Station 1) and at Brunswick Road (Station 5) recorded by the Stevens field probes were erratic during June and July. Consequently, these two probes were replaced by YSI probes during August. Diurnal variations in DO, which were evident in the continuously recorded data during much of the summer, indicate that algal photosynthesis and respiration were occurring; this phenomenon seemed to be more pronounced at the Brunswick Road site. Conductivity levels recorded by the field probe at Highway 70 usually were about 50 to 60 µmho/cm. Conductivity at Brunswick Road normally was about 70 to 80 µmho/cm according to the probe. Minimum and maximum temperatures at Stations 1 and 5 during August were about 18°C and 26°C, respectively. Continuous data for Highway 51 for

September are not available because backwater from the Mississippi River has made it impossible to retrieve the monitoring probe and to download its data.

On August 18 during sampling from a boat, the temperatures in the river were about 20°C at 0700 hours and about 26°C in the middle of the afternoon. Dissolved oxygen levels were lowest at 0700 hours (approximately 7.5 mg/l) and highest in the middle of the afternoon (about 8.5 mg/l). The turbidity in the river was 12 to 19 ntu, and conductivity varied from 53 to 89 μmho/cm. Conductivity was lowest at the upstream stations and highest at the downstream stations. The pH values were typically in the range of 6.7 to 7.3.

DO levels measured by the continuous probe at Highway 70 varied between 8.7 and 9.5 mg/l on September 22, which was about 1 mg/l higher than the level measured by the field sampling team on that day. The continuous probe data at Brunswick Road on September 22 indicated DO levels in the range of 7.6 to 11.9 mg/l; the high values are 2 to 3 mg/l higher than that measured by the field teams. Temperature levels measured by the continuous probe on September 22 at Brunswick Road were lowest at about 0800 hours (17.5°C) and highest at about 1800 hours (24.5°C).

BOD_5 values at all ten sampling stations on September 22 were less than 2 mg/l. The ultimate BOD (120 day) values were in the range of 3.0 to 4.0 mg/l. The BOD_{ult} to BOD_5 ratio for all ten sampling stations were in the range of 4 to 6. This indicates that the rate of oxygen depletion due to biological metabolism is relatively low. The BOD decay rates (base e) were in the range of 0.04 to 0.06 day^{-1}. The $CBOD_5$ values for the lagoon effluents were typically about 20 mg/l. The $CBOD_5$ values for the Bartlett Oxidation Ditch and the Dupont discharge were less than 5 mg/l.

TOC levels in the Loosahatchie River were also relatively low, ranging from less than 1 mg/l to about 3.5 mg/l. These data were consistent with the low BOD values and indicate that organic content is slightly increasing in the downstream direction.

On September 22, TSS were generally 15 to 30 mg/l at the first five sampling stations, increasing to the range of 25 to 50 mg/l at the last five sampling stations. It should be noted that these TSS values are relatively low for the Loosahatchie River and can be attributed to the lack of rainfall during the August through September period. Under most conditions, the river is too turbid to support significant photosynthesis.

Ammonia-N was non-detectible during the September 22 sampling event. The ammonia-N data for the wastewater treatment plant (WWTP) discharges were less than 1 mg/l, with the lone exception of the Lakeland Lagoon (ammonia-N = 18 mg/l). Consequently, the ammonia-N data in the river are excellent. TKN levels were below 0.5 mg/l for all river samples according to analyses by the University of Memphis Civil Engineering Department.

Nitrite/nitrate-N data for most of the sampling stations on September 22 was in the 0.2 to 0.4 mg/l range. The highest nitrite/nitrate-N concentration of 0.691 mg/l was measured at Highway 51. The nitrite/nitrate-N levels in most of the WWTP discharges were in the range of 0.5 to 3 mg/l. The exceptions were less than 0.1 mg/l for the Dupont discharge and 17 mg/l for the Bartlett lagoon effluent.

Total phosphorus levels in the river samples on September 22 were in the range of 0.05 to 0.14 mg/l. These phosphorus levels along with the nitrite/nitrate-N levels appear to be adequate to support eutrophication. Total phosphorus in the WWTP discharges was in the 2 to 4 mg/l range. Because the cumulative WWTP flow rates comprised about 3% of the river flow rate, these data were consistent.

Time of travel data indicated that the velocity in the river between Highway 70 (Station 1) and Singleton Parkway (Station 8) was about 1 ft/sec. Stream velocity from Singleton Parkway (Station 8) and Highway 51 (Station 10) was about 0.5 ft/sec. The total time of travel from Station 1 to Station 10 was approximately 39 hours.

Analysis of the propane gas concentrations along the river indicated that the reaeration rates varied from 4.44 to 10.5 day^{-1}. The average reaeration rate was approximately 7.0 day^{-1}.

DESIGN CONSIDERATIONS FOR OPEN CHANNEL SECTIONS

Paily P. Paily[1]

Open channels are used for conveying flows in many applications including wastewater treatment facilities and storm water management systems. In situations where anticipated bed and bank erosion is unacceptable or the ground slope along channel alignment is steep they require lining. When the channel lining material is susceptible to erosion design of channel sections requires special consideration to ensure that the velocity of flow is well below the scour velocity for the lining material. This situation does not apply when the lining material is nonerodible, such as concrete.

Analysis of open channel flows is achieved using the Manning's equation for uniform flow, given by

$$Q = A V = A \left[\frac{k}{n} R^{2/3} \sqrt{S} \right] \tag{1}$$

where Q is the flow rate (cfs or m3/s), V is the mean velocity of flow (ft/s or m/s), n is the Manning's coefficient which depends on the channel wall material, R is the hydraulic radius (ft or m) which is the ratio between the flow area (A) and the wetted perimeter (P) of the flow area, S is the channel bed slope, and k is a constant based on the unit system used, with a value of 1.0 for meter units and 1.486 for foot units. For a given channel slope and section shape, the channel section that provides maximum flow rate is the best hydraulic section (BHS). From the Manning's equation, it is evident that a BHS will have the largest value for the section parameter, A R2/3, or, minimum value for the section perimeter for a given area, since A R2/3 = A5/3/ P2/3. Commonly used channel section shapes include rectangular, triangular, trapezoidal, semicircular and parabolic shapes.

The values of Manning's coefficient, n, and the maximum permissible velocities for different channel wall materials are given in Table 1[1].

Table 1[62]

Material	Maximum permissible Velocity (ft/s)	Manning's n
Fine sand	1.50	0.020
Sandy loam	1.75	0.020
Silt loam	2.00	0.020
Firm loam	2.50	0.020
Stiff clay	3.75	0.025
Fine gravel	2.50	0.020
coarse gravel	4.00	0.025

For a specified flow rate, the design of section proportions for a channel is limited by three factors: cost of lining, maximum permissible velocity based on the lining material and the channel slope. Since the area to be lined is given by the product of the section perimeter and the channel length, minimum lining costs will occur when the section proportions meet the best hydraulic section conditions.

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When designing channel sections, the geometric proportions of the section are determined based on two of the three constraining factors, namely the BHS section proportions, maximum permissible velocity and the channel slope, and then checked for compliance with the third constraint. Based on this, three different options are possible for channel section design:

(1) Option one: Channel with BHS proportions and specified slope. For a valid design the section geometry should provide a flow velocity that is less than the maximum permissible value.

(2) Option two: Channel with specified slope meeting the maximum velocity constraint. In this case, the BHS requirements are not met. The section proportions should be practically acceptable values.

(3) Option three: Channel with BHS proportions meeting maximum velocity constraint. The channel slope established based on the section proportions should be an acceptable value for this option.

To illustrate the applications of the design options, a trapezoidal channel section will be considered since it is the most popular shape used in practice. Usually channel section proportions are identified by at least two parameters, the flow depth (y) and the water surface (or top) width (T). For a trapezoidal section, the side slope is also specified in the form z:1 (horizontal: vertical). The geometric relations for a trapezoidal section are the following:

(1) bottom width, $b = T - 2zy$ (2)

(2) flow area, $A = (T - zy)y$ (3)

(3) wetted perimeter, $P = (T - 2zy) + 2y\sqrt{(1+z^2)}$ (4)

(4) BHS conditions: $T = 2y\sqrt{(1+z^2)}$ and $R = \dfrac{y}{2}$ (5)

The above equations apply to a rectangular section with $z = 0$ and to a triangular section with $b = 0$. The best value of z for a trapezoidal BHS is $1/\sqrt{3}$, and for a triangular BHS it is 1. BHS value of T for a triangular section is represented by equation (1), not equation (5).

BHS conditions for various section shapes can be found in text books dealing with open channel flow, for example, Open Channel Hydraulics by French[2].

The following numerical values will be used to apply the design options:

    Trapezoidal section, side slope , z = 2
    Channel bed slope, S = 0.0025
    Manning's coefficient, n = 0.015
    Maximum permissible velocity, V = 5 m/s

1. Procedure for design for BHS and slope:

Using equations (3) and (5), area (A) is expressed in terms of depth (y) and substituted into Manning's equation (1) along with BHS relation for R. This leads to the solution for y and then top width, bottom width and area are calculated from equations (2), (3) and (5). The flow velocity is then obtained from V = Q/A.

 Example 1: Q = 100 m3/s: $A = [2y\sqrt{1+4} - 2y]y = 2.472y^2$

$$100 = (2.472\,y^2)\,[\frac{1}{0.015}(\frac{y}{2})^{2/3}\sqrt{0.0025}\,]$$

y = 3.03 m;   T = 13.56 m;   b = 1.43 m
A = 22.73 m2
V = 100/22.73 = 4.4 m/s (acceptable design)

Example 2: Q = 200 m3/s: Same steps as above will provide
            y = 3.93 m;   T = 17.57 m;   b = 1.85 m
            A = 38.23 m2
            V = 200/38.23 = 5.23 m/s (not acceptable)

The above analysis indicates that the design option with BHS and slope is valid only for discharges below a certain base value of discharge. From manipulation of the geometric and hydraulic relations, the following expression can be derived for this base value of discharge (QB):

$$Q_B = 8V\,(\frac{V\,n}{k\,\sqrt{S}})^3\,(\sqrt{1+z^2}-1)\quad\text{for trapezoidal sections}\tag{6}$$

$$Q_B = 8V\,(\frac{V\,n}{k\,\sqrt{S}})^3\qquad\text{for rectangular section}\tag{7}$$

The value of QB for the present example can be calculated as 167 m3/s. Design providing a velocity below the maximum permissible velocity is possible only for discharges equal to or less than this value for the BHS and slope option.

2. Procedure for design for maximum velocity and slope:

The most common practice in open channel design is based on this approach which calculates same value of R for all section shapes. Using the area calculated from the flow rate and velocity data (A = Q/V) and R calculated from the Manning's equation (1), the wetted perimeter is calculated (P = A/R). The expressions for area (equation 3) and perimeter (equation 4) are then combined to develop a quadratic equation for depth y. Solution of the quadratic equation provides the value of depth and the remaining section parameters can then be calculated.

Example 1: Q = 200 m3/s: $$5 = \frac{1}{0.015}R^{2/3}\sqrt{0.0025}\qquad\text{and } R = 1.837 \text{ m}$$

            A = 200/5 = 40 m2
            P = 40/1.837 = 21.78 m
    using equation (4)   T = 21.78 – 0.472 y
    using equation (3)   40 = (21.78 – 2.472 y) y
            y = 2.62 m;   T = 20.54 m;   b = 10.10 m

Example 2: Q = 100 m3/s: R = 1.837 m (same step as in example 1)
            A = 100/5 = 20 m2
            P = 20/1.837 = 10.89 m
    using equation (4)   T = 10.89 – 0.472 y
    using equation (3)   20 = (10.89 – 2.472 y) y

The discriminant of the quadratic equation has a negative value in this case, making the solution impossible.

The above result indicates that for the design with maximum velocity and slope option, there is a base discharge value below which design cannot be done. By proper analysis, the expressions for

the base discharge QB can be derived and they are the same as given in equations (6) and (7). Table 2 below summarizes design results for several discharge values.

Table 2

Discharge Q (m3/s)	Perimeter P (m)	Area A (m2)	Depth y (m)	Top Width T (m)	Bottom Width b (m)
200	21.78	40	2.61	20.54	10.10
500	54.44	100	2.02	53.48	28.58
750	81.65	150	1.95	81.65	72.93
1000	108.87	200	1.92	108.87	100.28
1200	130.65	240	1.91	130.65	122.11

The above data indicate that as the discharge increases, the change in calculated depth is not very large; however other section parameters (top width and bottom width) increase significantly. A channel of large section proportions to carry a flow with a very small depth may not be a practically acceptable solution.

3. Procedure for design for BHS and maximum velocity:

This option is the simplest in terms of calculations. Using area obtained from discharge and velocity data (A = Q/V), the flow depth is calculated using equation (3) after which the other section parameters are calculated. The required channel slope is the calculated from Manning's equation (1) with R = y/2.

Example 1: Q = 100 m3/s: A = 100/5 = 20 m

$$20 = [2\,y\,\sqrt{1+4} - 2\,y]\,y$$

$$y = 2.84 \text{ m}; \quad T = 12.72 \text{ m}; \quad b = 1.36 \text{ m}$$

$$5 = \frac{1}{0.015}\,(\frac{2.84}{2})^{2/3}\,\sqrt{S} \qquad \text{which gives S} = 0.0035$$

Results for several values of flow rates are summarized in Table 3.

Table 3

Discharge Q (m3/s)	Area A (m2)	Depth y (m)	Top Width T (m)	Bottom Width b (m)	Slope
100	20	2.84	12.72	1.36	0.0035
200	40	4.02	17.79	1.91	0.0022
500	100	6.36	28.44	3.00	0.0012
1000	200	8.99	40.22	4.26	0.0008

The above results indicate that at large flow rates the section proportions are more realistic in this case. The slope values, even though smaller than the originally specified value of 0.0025, are also realistic values which can be practically applied.

3A-14

The present analysis leads to the following conclusions:

(1) There is a base value of discharge given by equations (6) and (7).

(2) When the design flow rate is below the base discharge value BHS and slope option method will apply.

(3) The maximum velocity and slope option is valid only for flow rates above the base discharge value. However, at large values of discharges, this option provides section proportions that are too large compared to flow depth.

(4) The BHS and maximum velocity option is simple to use and may be preferred for large design discharges to generate realistic section proportions.

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WATER POLLUTION CONTROL UPDATE

Saya Qualls[1]

In the future, you can expect watershed based permitting as well as full integration of TMDLS in permits. Tennnessee will also be placing an emphasis on wet weather discharges. To do this, we plan to bring in ourMS4 permittees as partners in water quality protection.

Our enforcement priorities will also look to address wet weather water quality concerns particularly in the areas of sanitary sewer overflows, urban runoff and construction site runoff.

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1 Tennessee Department of Environment and Conservation, Division of Water Pollution Control

WATER-SCIENCE PLANNING: ISSUES AND INITIATIVES FOR THE U.S. GEOLOGICAL SURVEY IN TENNESSEE

W. Scott Gain[1]

Several years ago the U.S. Geological Survey in Tennessee began a science planning process intended to identify the most important science goals and priorities to address water-information needs in the state of Tennessee. As a result of this process, high-priority issues and long-range science initiatives were organized into five principal areas of concern.

Water Use and Availability – Concern for future water-supply in Tennessee has grown in recent years as we become more aware of growing conflicts among our own water-use needs, water needed for environmental integrity, and the water-use needs of neighboring states. A continuing assessment of water availability (when, where, and how much) for Tennessee and how that water is used is critical to the economic health of the state.

Landforms and Ecology – The quantity and quality of aquatic resources in Tennessee are strongly related to landscapes and landforms through many complex hydrologic interactions. Improved understanding of how wetlands, aquatic habitats, and other sensitive ecosystems respond to landscape disturbance is crucial for effective management of these resources.

Watersheds and Land use – Urban sprawl and sustained population growth present new and challenging issues for water resource managers and the citizens of Tennessee. An understanding of the intricate balance among land use, water quality, and the health of aquatic communities will be necessary to address development issues across the state.

Occurrence, Fate and Transport of Contaminants – Contamination of surface water and ground water affects the adequacy and safety of water resources. Enhanced understanding of geochemical, biological, and hydrogeologic processes will be necessary to improve strategies for pollution prevention, mitigation, and remediation.

Floods and Droughts – Financial losses from natural disasters average about $52 billion per year in the United States. Some of the greatest natural disasters in Tennessee are associated with extreme storms or droughts. Timely, high-quality information about floods and droughts is critical to protecting and improving the quality of life in Tennessee.

In recent months the USGS in Tennessee began a process of review and revision of these science plans with input from numerous partners, collaborators, and stakeholders who share a vested interest in water-science research in Tennessee. This presentation will include a general description of the results of that science planning process to date and a discussion of the science needs and initiatives identified as having the highest priority.

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THE QUEST FOR MEASURABLE WATER QUALITY IMPROVEMENTS: AN OVERVIEW OF TENNESSEE'S NONPOINT SOURCE PROGRAM

John McClurkan[1]

The Nonpoint Source Program within the Tennessee Department of Agriculture (TDA) is committed to achieving measurable water quality improvements in impaired watersheds and to the maintenance of high water quality in fully supporting or threatened watersheds. To accomplish these aims in a non-regulatory environment requires the development of strong partnerships at the watershed level, realistic incentives and effective education of the owners of riparian lands. EPA has made specific requirements of all nonpoint programs relative to the development of watershed-based plans prior to funding on-the-ground Best Management Practices. Recent budget cuts at the federal level have brought goal attainment very acutely into focus. Additionally, TDA has performance-based budgeting goals set at the direction of the General Assembly that make our work in impaired and threatened watersheds a priority. This presentation will highlight some successful case studies and offer insights for the future.

1 Administrator for Water Resources, Tennessee Department of Agriculture

SESSION 3B

FIELD INVESTIGATIONS-RESTORATION
8:30 a.m. – 10:00 a.m.

Quantifying Streambank Stabilization Using Common Riparian Species and a Deterministic Bank-Stability Model
Andrew Simon, Natasha Pollen and Eddy Langendoen

Thoughts on Stream Restoration and Mitigation in the Interior Low Plateaus Province of Kentucky and Tennessee
Michael S. Lighthiser

Success and Failures in Best Management Practice Implementation, River Restoration Project of the Tennessee Scenic Rivers Association and the Harpeth River Watershed Association
John F. McFadden

FIELD INVESTIGATIONS-REMEDIATION
10:30 a.m. – 12:00 p.m.

Precipitation Infiltration and Its Affect on Groundwater Recharge in a Soil / Carbonate Bedrock Aquifer
Jerry Boyd, Stephanie Weir and Randall Pugh

A Streamlined Approach: Impacts of Early Actions on the Ecological Risks at the Copper Basin Mining District Site
Griff Wyatt, Franklin Miller and Kati Bell

Natural Channel Design for a Stream Realignment Incorporating Flood Insurance Program Requirments
Ken Barry, Elizabeth Porter, Michael Pannell, Brent Wood, Angela Hemrick and Jamie James

QUANTIFYING STREAMBANK STABILIZATION USING COMMON RIPARIAN SPECIES AND A DETERMINISTIC BANK-STABILITY MODEL*

Andrew Simon[1], Natasha Pollen[1] and Eddy Langendoen[1]

INTRODUCTION

The use of riparian buffers has become an increasingly popular means of improving habitat and streambank stability in stream restoration schemes. Research at the National Sedimentation Laboratory on quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability, combined with the development of a deterministic bank-stability model (Simon *et al.*, 1999; 2000) has been used to evaluate the controlling processes and conditions for improving bank stability. Measurements of root distributions and the tensile strength of roots for a range of common riparian species have permitted quantification of the magnitude of increases in shearing resistance due to root reinforcement. Root numbers and area for woody species decrease non-linearly with depth and are virtually absent below 1 m.

BACKGROUND

The theory for quantifying root reinforcement stems from literature developed to calculate the increased strength added to other composite materials used in the construction industry, such as reinforced concrete. Greenway (1987) notes that the magnitude of root reinforcement depends on root growth and density, root tensile strengths, root tensile modulus values, root tortuosity, soil-root bond strengths, and the orientation of roots to the principal direction of strain. The most common method used to estimate root-reinforcement of soils are physically-based force-equilibrium models, such as the simple perpendicular root model developed by Waldron (1977) and modified by Wu *et al.* (1979). These root-reinforcement models are based on the Coulomb equation in which soil-shearing resistance is calculated from cohesive and frictional forces. Roots are assumed to extend vertically across a horizontal shearing zone, with roots acting like laterally-loaded piles. The increased shear strength due to roots (ΔS) is treated as a simple add-on factor to the soil strength. ΔS is calculated using the root-tensile strengths and the cross-sectional area of the roots relative to the area of the shear surface Wu *et al.* (1979):

$$\Delta S = T_r (A_R /A) \times 1.2 \qquad (1)$$

where T_r is root tensile strength, A_R / A is root area ratio (dimensionless), A is the area of the soil (m^2), and A_R is the area of roots (m^2). The value 1.2 was used by Wu *et al.* (1979) to replace the term in Waldron (1977) that accounts for the angle of shear distortion and soil friction angle. Sensitivity analysis carried out by Wu *et al.* (1979) showed that this term was fairly insensitive to changes in soil properties and approximated 1.2 under most conditions.

Several assumptions are made by the Wu *et al.* (1979) model. Investigations by Pollen (2004) and Pollen *et al.* (2004) have shown that the most critical of these assumptions for accurately predicting root-reinforcement is the assumption that all of the roots attain ultimate tensile strength simultaneously during soil shearing. In reality, roots break progressively, producing large overestimations in ΔS in the models of Waldron (1977) and Wu *et al.* (1979). A new root-reinforcement model (RipRoot) was developed based on fiber-bundle theory to account for progressive root breaking during shearing (Pollen *et al.* 2004). As with Wu *et al.* (1979), the RipRoot model produces an add-on factor to soil strength representing root-reinforcement. Comparison of results using RipRoot compare well with laboratory direct-shear tests of root-permeated soils (Pollen *et al.*, 2004).

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For young woody species (2-9 years-old), average increases in cohesion due to root reinforcement averaged over 1 m ranges from 0.6 to 8 kPa with species such as Eastern sycamore (*Plantanus occidentalis*) and River birch (*Betula nigra*) providing the greatest benefits (Simon and Collison, 2002). These are significant values given the moderate cohesive strengths of common alluvial materials. Herbaceous species such as Alamo switch grass (*Panicum vircatum 'Alamo'*) can have rooting depths up to 3 m and contain enough fine roots to provide up to 20 kPa of additional cohesion.

SELECTED RESULTS: CRITICAL CONDITIONS WITH AND WITHOUT VEGETATION

The role of riparian vegetation on increasing bank stability was investigated using a Bank-Stability Model developed by Simon *et al.*, (1999; 2000). An example is provided from model runs carried out for a site on the Upper Truckee River, California for a range of bank angles and a 2.7 m bank. Critical conditions, defined by $F_s = 1.0$ were calculated and plotted for varying levels of flow and the phreatic surface. Model runs were then repeated using the additional 5.5 kPa of root reinforcement provided by Lemmon's willow and plotted on the same graph (Figure 1). Data for Lemmon's willow were used because of the significant amount of the significant amount of additional cohesion provided by this species and its potential for use as a bank-stabilization measure. Differences in the plotted position of the line of critical conditions for each bank angle, with and without vegetation, represent the effect Lemmon's willow on critical conditions.

Modeling results show that the addition of 5.5 kPa of root reinforcement has a significant effect on the flow depths and water table heights that delimit stable and unstable conditions for each bank angle. The results can be viewed in two different ways: (1) the reduction in the angle of an unvegetated bank that would be required to achieve the stability of a vegetated bank of the same angle, and (2) the level of the phreatic surface that can be withstood by a vegetated and unvegetated bank of the same angle.

The addition of vegetation has the same effect as reducing the angle of the bank face, with this effect becoming more significant as the bank angle becomes flatter. Therefore, a vegetated bank with an angle of 90° has similar critical conditions to an unvegetated bank with an angle of 80°. A 45° vegetated bank has similar critical conditions to an unvegetated bank of less than 30°. Adding 5.5 kPa of root reinforcement to the bank, therefore, has the equivalent effect of reducing the bank angle by 10° to more than 15°. For of bank-stabilization, the addition of vegetation is equivalent to reducing the bank angle.

The dotted, horizontal line on Figure 1 represents a typical low-flow depth (20% of the bank height) which, during saturated conditions is critical because of the lack of a confining force to support the bank. As an example, it can be seen that with vegetation a 70° bank can withstand an increase in the elevation of the phreatic surface from 15% to 33% of the bank height. At shallower bank angles, the difference in critical phreatic-surface heights between vegetated and unvegetated banks were lower, but even at 45° there was a difference in critical water-table depth of 10% of the bank height. The effect of the additional strength provided by root reinforcement is, therefore, equivalent to providing bank drainage (phreatic-surface lowering) of as much as 0.5 m.

Using the Bank-Stability Model, analyses were conducted for streambanks of varying heights, angles and composition under a range of surface water heights and pore-water pressures. Results, expressed in terms of the Factor of Safety (F_s) were used to then develop nomographs of critical bank conditions (height and angle) without vegetation. Additional cohesion due to root

reinforcement for various species was then provided as model input to (1) evaluate the additional stability provided by root reinforcement of different species, (2) to calculate the additional height and steepness that could be withstood while maintaining stability, and (3) to develop critical bank conditions with vegetation.

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Wu, T.H., McKinnell, W.P. III, and Swanston, D.N., 1979. Strength of tree roots and landslides on Prince of Wales Island, Alaska. Canadian Geotechnical Journal, 16, 19-33.

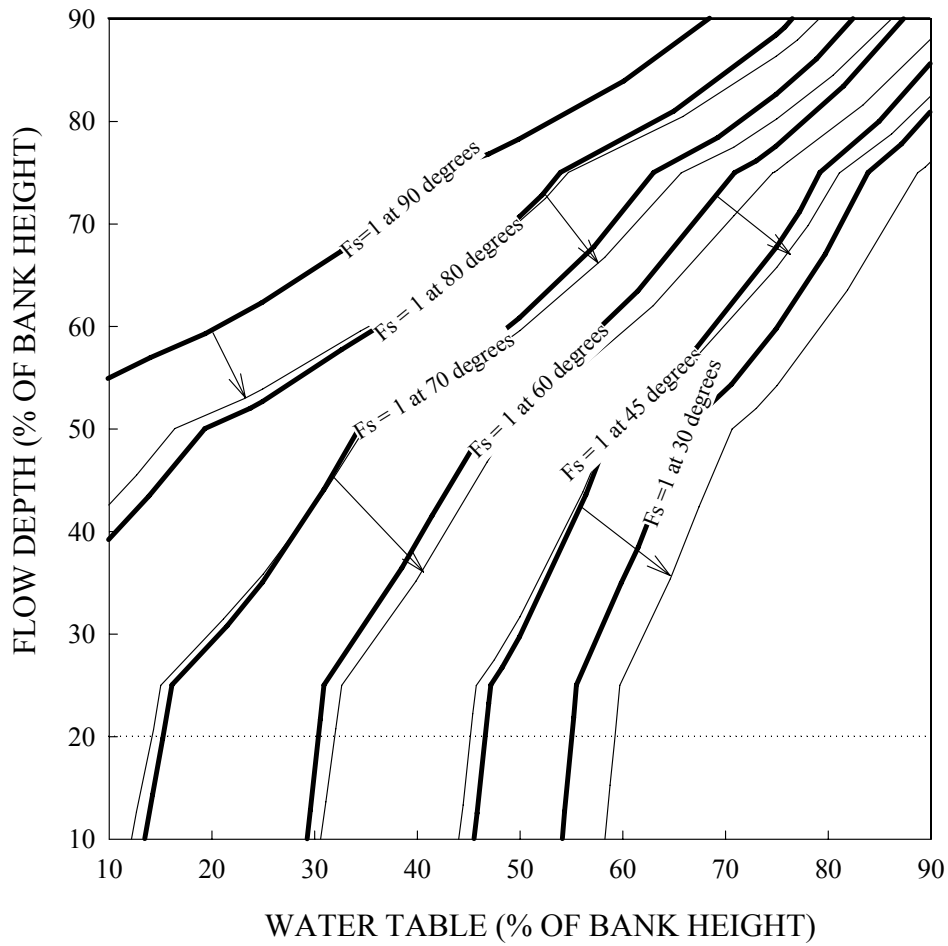**Figure 1. Critical bank-stability conditions for a site on the Upper Truckee River, California with and without vegetation for a range of bank angles, flow depths and phreatic-surface elevations. Dotted, horizontal line represents a typical low-flow depth. Arrows indicate the stabilizing effect of 5.5 kPa additional bank cohesion from vegetation (Lemmons willow) to a bank of a particular angle.**

THOUGHTS ON STREAM RESTORATION AND MITIGATION IN THE INTERIOR LOW PLATEAUS PROVINCE OF KENTUCKY AND TENNESSEE

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

INTRODUCTION

Visits to Lexington, Kentucky and Nashville, Tennessee reveal interesting similarities. Both regions have landscapes characterized by lush, rolling hills. Lexington is known as the "horse capital of the world," and the counties south of Nashville also have many horse farms. In addition, the two areas have a long and colorful history of converting limestone-spring water and locally-grown corn and rye into Kentucky Bourbon or Tennessee Whiskey.

While these examples of alikeness may seem more appropriate to tourism than water resources, they are based on one relevant commonality – the geology of the two regions. Both cities are situated on relatively higher parts of an old rock formation called the Cincinnati Arch, formally designated the Lexington Plain and Nashville Basin within the Interior Low Plateaus Province (Figure 1). The Cincinnati Arch is made of Ordovician-aged (438- to 505-million-year-old) limestone and shale. These sedimentary rocks formed from the remains of invertebrate marine organisms and mud that settled out in the shallow seas that existed long ago. Fossils of crinoids and brachiopods, both from the Ordovician Period, are in the exposed rocks around Lexington and Nashville, demonstrating their common geologic history (Figure 2). These same rocks helped form the rolling hills, fertile soils, and iron-free springs characteristic of the two regions.

Another similarity between Lexington and Nashville is urbanization and the unfortunate accompanying degradation of local streams. In response, demand has increased for governments to help protect and improve streams and to mitigate for impacts permitted under existing regulations. Attempts at ecological restoration require developing an understanding of the system to be restored, and a closer look at the streams in the Lexington Plain and Nashville Basin reveals unique characteristics that are strongly influenced by the region's geology and history. Restoration and mitigation activities need to take this uniqueness into account in order to be successful.

STREAM MORPHOLOGY

Many streams around Lexington and Nashville have wide, flat beds of limestone bedrock (Figures 3 and 4). Pools are few and only slightly deeper than average channel depth. Flow is usually shallow except during runoff events and can be almost nonexistent during dry periods. Bank heights typically vary; in some locations they are low and stable, while in others they are too high and actively eroding.

In addition, these streams usually have limited alluvial features such as riffles or point bars. Only bedrock or boulder- and cobble-sized plates of limestone line the bed and are too large to be transported except in bigger rivers. As a result, bed material does not appear to be a significant component of the sediment load.

Both natural and human factors play a role in the morphological characteristics of streams in the Lexington Plain and Nashville Basin. The effect of geology is evident in the channel beds; at a certain depth, they hit bedrock, which reduces the stream's ability to cut down further and limits the formation of pools. A wide and homogenous bed thus results. However, history shows that

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this morphology may not have existed prior to European-American settlement. In Kentucky, practically all of the forest that existed on the Lexington Plain 200 years ago was cleared for agriculture. The resulting change in hydrology would have increased the water flowing in the streams, causing the channel to enlarge and erode. In addition, the loss of tree cover combined with agricultural activities would have contributed large loads of silt that would have raised floodplain levels. Also, streams were typically straightened and relocated to the edge of the valley to maximize crop production. Straightening would have increased instability, causing incision, bank erosion, and channel widening. Relocating to the valley edge would have put the stream closer to bedrock, since it is typically higher at the edge than in the middle of the valley. Consequently, the pre-settlement channel morphology may have been smaller and narrower with beds of alluvium rather than bedrock.

ITEMS TO CONSIDER FOR RESTORATION AND MITIGATION

Geology and history play an important role in the current condition of streams in the Lexington Plain and Nashville Basin. Attempts at restoration or mitigation require looking at the following items:

1. Historical channel location: Is there evidence that the stream was located elsewhere in the valley? Is this land available for relocating a restored stream?

2. Bedrock elevation: Are there areas in the valley where the bedrock is lower, thus providing enough depth for pools? If proposed construction is considering relocation of the stream to another part of the valley, is the bedrock low enough in that new location to avoid rock excavation?

3. Past siltation: Did past activities likely cause large loads of silt that would have filled the floodplain? Does the soil horizon show evidence of past settlement activities? Could the floodplain be lowered and riparian wetlands created along the stream?

4. Sediment transport: Are there alluvial features such as point bars? Is there a supply of gravel- or cobble-sized material that the channel needs to accommodate?

5. Condition of the watershed: Will land use be changing in the future, or has it stabilized? How does current land use compare to the past?
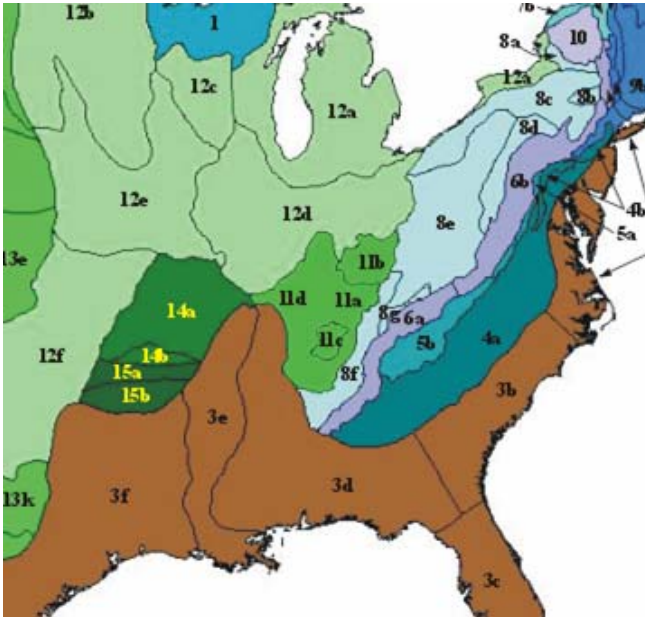
Figure 1. Map of Eastern U.S. physiographic provinces. The medium-green area numbered "11" delineates the Interior Low Plateaus Province. "11b" and "11c" are the Lexington Plain and Nashville Basin, respectively.

Figure 2. Limestone rock with brachiopod fossils.

Figure 4. Sevenmile Creek in Nashville, Tennessee. Note the wide, flat bedrock bed.

Figure 3. Dry Run near Shelbyville, Kentucky. Note the wide, flat bedrock bed.

SUCCESS AND FAILURES IN BEST MANAGEMENT PRACTICE IMPLEMENTATION,
RIVER RESTORATION PROJECT OF THE TENNESSEE SCENIC RIVERS ASSOCIATION AND THE HARPETH RIVER WATERSHED ASSOCIATION

John F. McFadden[1]

The Duck River Opportunities Project (DROP) and the Harpeth River Watershed Association were formed in 1999 with the intent of protecting and enhancing water quality within the two watersheds. Both organizations utilized a collaborative approach to the implementation of Best Management Practices (BMP). In addition, the river restoration projects were interested in the collection of basic data to evaluate BMP effectiveness. Data collected include water quality data such as benthic macroinvertebrates and vegetation survival rates.

The restoration project has implemented BMPs at 16 sites in the Duck River watershed and 9 sites in the Harpeth River Watershed. BMPs included short-term control measures such as the placement of hay bales, silt fence and rock check dams and long-term activities designed to promote the natural functioning of the land such as riparian reforestation and stream bank stabilization. Generally the project has included the following phases, 1) initial assessment, 2) BMP implementation and 3) follow-up assessment.

METHODS

Initial assessment included identifying available data and water quality sampling. The most often source of available data was from Tennessee Department of Environment and Conservation's 303 (d) list, however, data was provided by other agencies. Water quality sampling was conducted in accordance with U.S. Environmental Protection Agency's *Rapid Bioassessment Protocols in Wadeable Rivers and Stream* (EPA, 1999) and the U.S. Tennessee Valley Authority's Clean Water initiative, *Volunteer Stream Monitoring Methods Manual* (1995). Water quality data collected was limited to benthic macroinvertebrates, habitat assessment and some physical/chemical information. Water quality data was collected at seven of the twenty-five sites. Five of these seven sites have had follow-up data collected to date. Three of these sites were chosen for discussion based on applicability to the topic. In addition, survival rates of vegetation are discussed with particular reference to problem sites.

RESULTS

BMP implementation has included livestock exclusion from waterways, providing alternative water supplies, waste lagoons, riparian restoration, stream bank stabilization, cross fencing and erosion control such as hay bales, silt fences and rock check dams. Collectively the project has been involved in excluding livestock from over 14,000 (+/-) feet of stream, planted 20,000 (+/-) seedlings in riparian reforestation projects and stabilized 1500 (+/-) feet of eroding stream bank in the Harpeth and Duck River watersheds.

Site 1 – unnamed Tributary to Gin Branch, Maury County, Tennessee
Generally data collected following BMP implementation indicate water quality improvement. Livestock were excluded from three headwater springs, 2000 (+/-) feet of 1st order stream, while students from Whithorne Middle School and volunteers worked with project staff, Maury County Natural Resources Conservation Service and the landowner to plant 750 (+/-) seedlings along the stream.

Post BMP implementation data indicate that water quality has improved. Vegetation increased as a result of livestock exclusion, increasing habitat and soil stability. The post BMP implementation habitat score was 141 as compared to pre BMP implementation score of 53. Benthic macroinvertebrate (BMI) data indicate slight improvements in water quality. For example, ephemeroptera, plecoptera and tricoptera (EPT) increased from 0 species to 3, total number of organisms increased from 98 to 332, number of intolerants increased from 1 to 2, and percent Chironomidae decreased from 8 to 0.03 following BMP implementation. However, total number of taxa decreased from 22 to 17 and NCBI increased from 7.26 to 7.56 following BMP implementation.

In addition, volunteers collected chemical data that identified one of the springs as having high phosphates (>5ppm). Project staff collected samples phosphates and sulfates for laboratory analysis. Laboratory results, 6.7 ppm phosphorus and 720 ppm sulfates confirmed volunteer data and proved a key factor in the landowner's motivation to exclude cattle from the aquatic system as the sulfate number was greater than twice the amount allowable for cattle (United States Department of Agriculture, 2000).

Site 2- Unnamed tributary to Pott's Branch, Maury County, Tennessee
Unnamed Tributary to Pott's Branch was listed on the 2000 303 (d) list for organic enrichment, low dissolved oxygen and pathogens associated with combined animal feeding operations. Two dairy operations are located on a ridge above the unnamed tributary to Pott's Branch. Both dairies were discharging parlor waste directly to the stream.
Water quality data collected in June 2000 and June of 2002 indicate improvements in water quality associated with installation of waste lagoons for the dairy waste. Total number of BMI species increased from 32 to 45, percent dominance decreased from 41 % to 19 %, percent Chironomidae decreased from 85 % to 35 % and the North Carolina Biotic index decreased from 6.85 to 5.87 following BMP implementation. EPT index was 9 before and after BMP implementation while total number of individuals decreased from 5664 to 2832. Lastly, habitat assessment score decreased from 155 to 138.

Livestock continue to have access to Pott's Branch and one landowner is apparently not maintaining the waste lagoon. As a result, TDEC continues to 303 (d) list Pott's Branch due to high fecal coliforms.

Site 3- Unnamed tributary to Hurricane Creek, Maury County, Tennessee
Livestock were excluded from 600 (+/-) linear feet of a 1st order spring fed unnamed tributary to Hurricane Creek. Pre BMP visual data indicated a highly eutrophic aquatic system. Water quality data indicate that BMP implementation had a negative impact on the aquatic system. For example, the EPT index decreased from 3 to 0, NCBI increased from 5.13 to 7.20, percent Chironomidae increased from 24 % to 63 % and percent dominant species increased from 28 % to 75 % post BMP implementation.

Conversely, the habitat assessment score increased from 89 to 119 indicating better habitat following BMP implementation. After field evaluation of BMPs it was discovered that the overflow for the livestock water supply discharged to the downstream section of the site. This dried up a section of the unnamed tributary. Project staff is currently working to resolve this issue.

Park and Development Sites
Volunteers initially planted 1000 seedlings in the riparian zone associated with the Tower Park Greenway in the winter of 2002. Park managers utilize contractors to mow areas including parks and greenways, and as a result of poor communication between project and park staff and

contractors 500 (+/-) trees were bush hogged in the summer of 2003. Volunteers returned to the site in the winter of 2004 to replace the lost trees. When project staff returned to check survival rates in the fall and winter of 2004/2005 it was discovered ball field construction had once again taken a heavy toll on tree survival. A total of 304 living trees were counted out of a total of the 1000 (+/-) planted. The survival rate at Tower Park when one takes into account the mowing and contractor impacts was 61 % (304/500).

Volunteers planted 300 (+/-) seedlings at Jerry Erwin Park in Spring Hill Tennessee. Again a mowing contractor working for the County Parks Department took a heavy toll on the seedlings. The initial estimate was that 50 % (150) seedlings had been destroyed. In the winter of 2005 when staff returned to JEP 39 trees were found living, a 26 % survival rate (39/150).

Volunteers and staff planted 500 seedlings along a 500' section of Aenon Creek in a development located in Spring Hill. Project staff assessed this site in winter of 2005 and found 64 trees surviving a 13 % survival rate.

CONCLUSIONS

The implementation of site-specific BMPs can reduce pollutant loading, and enhance water quality, yet in some cases improper installation may actually have the opposite effect. In highly manicured environments, seedlings should be marked with something better than flagging tape, and/or perhaps larger trees should be planted. Site-specific BMP implementation in the absence of watershed planning is not likely to be effective in restoring the ecological health of aquatic systems and meeting the goals of the Tennessee Water Pollution Control Act.

HRWA and the DROP continue to receive support from a number of agencies and are now focused in two major areas. One area for the DROP is the formation of a local stakeholder advisory council to advise project staff on the direction of the project and to help implement BMPs via Volunteer River Restoration Corps. The second area is to help communities develop watershed restoration plans, in an effort to de list streams and help educate landowners, citizens, municipal officials, and developers about the importance of watershed conservation for the future.

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PRECIPITATION INFILTRATION AND ITS AFFECT ON GROUNDWATER RECHARGE IN A SOIL / CARBONATE BEDROCK AQUIFER

Jerry Boyd, Stephanie Weir and Randall Pugh

Utilizing time-domain reflectometry and continuous groundwater elevation data to study the effects of precipitation infiltration on the recharge of groundwater has not been fully explored. TDR science and data-logging capability coupled with accurate on-site weather data and continuous groundwater elevations can provide answers to numerous questions concerning the effects of precipitation on groundwater recharge. At a site along the northern flank of the Highland Rim of Middle Tennessee, the collection of this data commenced during the assessment of volatile organic compounds (VOCs) and dissolved metals impacts to groundwater beneath a municipal solid waste landfill. The data has lead to a better understanding of the migration of precipitation and occurrence of groundwater in an aquifer that transects the soil / bedrock interface. Understanding the subsurface processes governing the occurrence of both soil moisture and free water will help determine the best remediation strategy for the site.

A STREAMLINED APPROACH: IMPACTS OF EARLY ACTIONS ON THE ECOLOGICAL RISKS AT THE COPPER BASIN MINING DISTRICT SITE

Griff Wyatt[1], P.E., Franklin Miller[2], P.E., and Kati Bell[1], Ph.D.

BACKGROUND

The Copper Basin Mining Site ("Copper Basin"), located in southeast TN, is the site of extensive metals and copper mining and sulfuric acid production dating back to the mid 1800s. Historic mining and related activities have resulted in environmental degradation in the Basin. Various government agencies and private parties have taken steps to revegetate the area; improvements in erosion control and habitat restoration are evident. However, the Copper Basin remains environmentally degraded from the presence of mining materials and mineral processing by-products, and continued releases of acidic, metal-laden water. Accordingly, OXY USA, Inc. and its subsidiary Glen Springs Holdings, Inc. (OXY/GSH), the US Environmental Protection Agency (USEPA), and the Tennessee Department of Environment and Conservation (TDEC) agreed to address these remaining environmental concerns, including reducing ecological risk to the Ocoee River. Part of this agreement was to develop and implement interim actions in the lower reaches of Davis Mill Creek (DMC) that would reduce contaminant loading to the Ocoee River so that immediate progress in improving ecological health could be realized while a phased approach of long-term remedial actions are identified and implemented in upper parts of the watershed.

SITE DESCRIPTION

The Ocoee River passes through the Copper Basin which includes the Ducktown mining district drained principally by North Potato Creek (NPC) and Davis Mill Creek (DMC). Downstream of DMC and NPC, aquatic life in the Ocoee River rapidly diminishes; this is believed to be largely due to poor water and sediment quality. Both DMC and NPC are contaminated by historical mining and processing wastes remaining in the watersheds. Based on sampling by the EPA in 2000, it was shown that although DMC contributes only 1% of the total river flow of the Ocoee, it accounts for 51% of copper, 81% of iron, 63% of manganese, and 86% of zinc loadings in the surface water in the Ocoee River.

The headwaters reach of DMC is marked by seeps and springs adjacent to a pile of high-sulfur iron calcine that was placed in the late 1960s and 1970s. The bed and banks of this portion of the stream have been altered by the disposal of iron calcine and granulated slag, which has displaced the streambed to the southeast. Base flow in this portion of the drainage is provided by iron-rich seepage from waste piles and saprolite. The location of the uppermost Retention Pond 1 marks the confluence of DMC with Belltown Creek, which is a major west-flowing tributary that conveys flow from more than half of the watershed. Base flow of Belltown Creek is routed via a 20-inch pipeline to a point downstream of Retention Pond 3. The DMC headwaters reach and Gypsum Pond tributary join at the upstream end of a slag pile and flow southwest along the edge of the slag pile, past the Calloway B Mine and a vegetated pile of concentrated ore, and into Retention Pond 1. The substrate within this upper portion of the DMC includes a hard chemical precipitate of iron oxyhydroxide or iron hydroxysulfate material, intermixed and overlying granulated slag, sand and gravel, and other materials. The West Drainage Channel which is composed of numerous small seeps and tributaries confluences with DMC just upstream of the Ocoee River. The DMC watershed is shown in Figure 1.

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Figure 1 – Davis Mill Creek Watershed
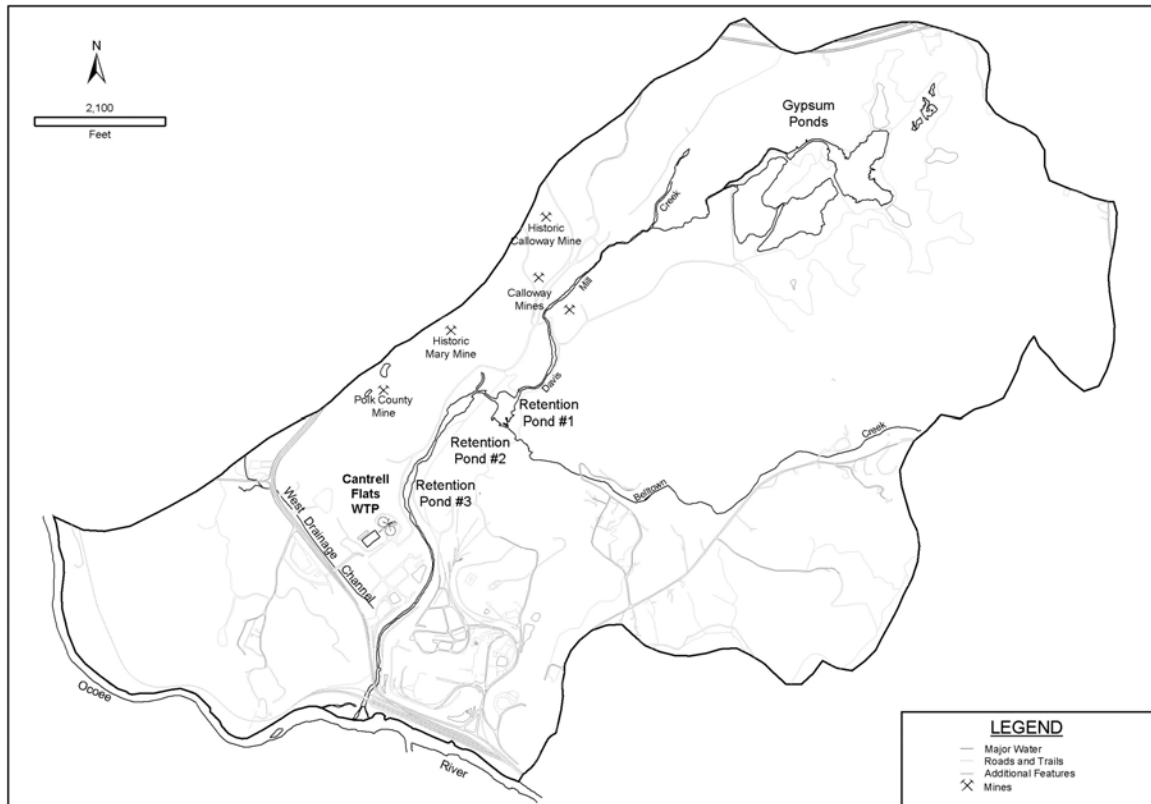
CONTAMINANTS OF CONCERN

Contaminants of potential concern (COPC) in DMC were identified by comparing median concentrations of target analyte list (TAL) metals as well as pH and acidity to ecological benchmark values (USEPA AND USCOE, 2003a). The chemicals of greatest concern in DMC were identified as copper, iron, manganese, and zinc; pH and acidity were also included as parameters of priority concern (USEPA AND USCOE 2003b).

APPROACH

The USEPA, and OXY/GSH reached an agreement in an Agreement of Consent (AOC) to implement two actions within the DMC watershed: 1) treatment of the entire base flow of DMC upstream of its confluence with the Ocoee River, and 2) diversion of clean water, around the acid generating, metal producing materials in the DMC watershed. The strategy of eliminating commingling of clean water with contaminated water allows for maximum treatment of the most contaminated waters in the DMC watershed. The existing lime neutralization facility, Cantrell Flats Wastewater Treatment Plant (CFWWTP), was proposed to treat DMC base flows and some stormwater flow. Conventional lime neutralization is considered the best available treatment for acid mine drainage (AMD) and other acidic effluent when AMD cannot be controlled at the source (Kuyucak, 1998; Zinck and Aube, 2000).

The CFWWTP was originally designed to treat a combination of water from several industrial processes, stormwater and mine water waste streams. The treatment process provides for pH adjustment, aeration and metals removal from wastewater generated onsite. By 2001, industrial

activities had largely ceased, except for production of organic chemicals and fungicide (BWSC, 2001). To maximize the treatment potential of the CFWWTP, unnecessary treatment of non-degraded water in the DMC watershed was avoided by diverting the base flow of Belltown Creek downstream of the DMC pumping system, which is the influent to the CFWWTP.

Based on a review of the original engineering designs for CFWWTP, it was determined that the capacity of the plant was 2200 gallons per minute, however an evaluation of the actual operating flows indicated a hydraulic capacity of all plant components of approximately 4200 gallons per minute. A 2001 review of the plant revealed that, although the plant was operable, most of the equipment reflected the 25 year age of the plant. In addition, poor environmental conditions at the facility (e.g. low influent pH, surrounding soils) added to the general wear and deterioration of the equipment. A recommended scope of refurbishment was developed (BWSC, 2001). Major refurbishment activities included modification of the existing DMC pumping system to facilitate withdrawal of water from the creek and delivery to the CFWWTP, refurbishment and/or replacement of pumps and piping within various reactors within the plant, and modification of the underflow system to accommodate an alternate disposal location. These refurbishment activities were completed by OXY/GSH in the fall of 2002.

OXY/GSH developed a plan to operate the CFWWTP and to address water quality monitoring requirements. Prior to refurbishment, the CFWWTP was operated under an NPDES permit issued in 1994. The original permit noted that the combined effluent was a monitoring point for treated process wastewater, treated contaminated cooling water, treated natural background water from DMC, storm water runoff, and treated domestic wastewater. Effluent limits for COPCs designated by the 1994 NPDES permit are reported in Table 1. Prior to operation of the refurbished CFWWTP, TDEC provided interim effluent limits for discharge from the plant; the interim limits for COPCs are also shown in Table 1.

Although the effluent limitations provide for a wide range of operating conditions relative to pH, determination of the operating pH can be complicated due to the fact that the different metals of concern have different minimum solubility at various pH values. In general, the COPCs identified in DMC have minimum solubility at pH values greater than 8.5. Because the interim NPDES requirements for pH were set at 6 – 9 to provide for protection of the ecological health of the Ocoee, the CFWWTP was operated at the higher end of this range to provide for maximum metals removals and remain in compliance with interim NPDES requirements.

Table 1 - NPDES Permit Effluent Limits for Selected Parameters

Effluent Characteristic	Effluent Limitations				Interim Monitoring Requirements	
	Monthly Average		Daily Maximum			
	1994 Permit Concentration (mg/L)	Interim Permit Concentration (mg/L)	1994 Permit Concentration (mg/L)	Interim Permit Concentration (mg/L)	Frequency	Sample Type
Flow	Report[1]	Report[1]	Report[1]	Report[1]	Continuous	Recorder
Copper-T	0.141	0.141	0.457	0.457	2/Week	Composite
Iron-T	3.6	3.6	10.0	10.0	2/Week	Composite
Manganese-T	---	Monitor	---	Monitor Only	2/Week	Composite
Zinc-T	---	---	2.0	2.0	2/Week	Composite
Acidity	---	Monitor	---	Monitor Only	1/Week	Composite
pH[2]	6.0 – 11.0	6.0 – 9.0	6.0 – 11.0	6.0 – 9.0	Continuous	Recorder

1 Flow shall be reported in Million Gallons per Day (MGD)

2 Where the pH is to be monitored continuously, the pH must remain within the specified limits range except under the following conditions: 1) The total time during which the pH values are outside the specified limits range shall not exceed 7 hours and 26 minutes in any calendar month; and, 2) No individual excursion from the specified range shall exceed 60 minutes.

RESULTS AND DISCUSSION

Results from this interim, early action are impressive. The CFWWTP has been refurbished and began operation in November 2002. Water quality monitoring results from biweekly sampling indicate that acidity and COPC metal concentrations in DMC have been significantly reduced. It is estimated that over 13 million pounds of acidity have been neutralized in the first two years of plant operation based on total flow treated and the average acidity neutralized from March 2003 through November 2004 (data were not collected for acidity prior to March 2003). Evaluation of the COPC metals for the first two years of CFWWTP operation shows that nearly 6 million pounds of iron, copper, manganese, and zinc have been removed from DMC. Average removal efficiencies for the COPC metals and acidity through the plant are greater than 97% and interim NPDES interim limits are consistently met. Monitoring data for zinc are shown in Figure 2; loading reductions for acidity and all COPC metals are shown in Table 2.

Table 2 – Loading reductions from DMC for the first two years of operation

COPC	Average DMC Concentration[1] (mg/L)	CFWWTP Effluent Concentration[1] (mg/L)	Removal Efficiency (%)	Load Removed[2] (lbs)
Acidity	914	16	98.3	13,900,000
Copper	0.65	0.02	97.3	9,830
Iron	323	0.93	99.7	4,610,000
Manganese	39.5	2.81	92.2	514,000
Zinc	54.4	0.18	99.7	838,000

1 Average concentration is based on biweekly sampling for the period of November 2002 through November 2004

2 Total removals are reported for the period of November 2002 through November 2004.
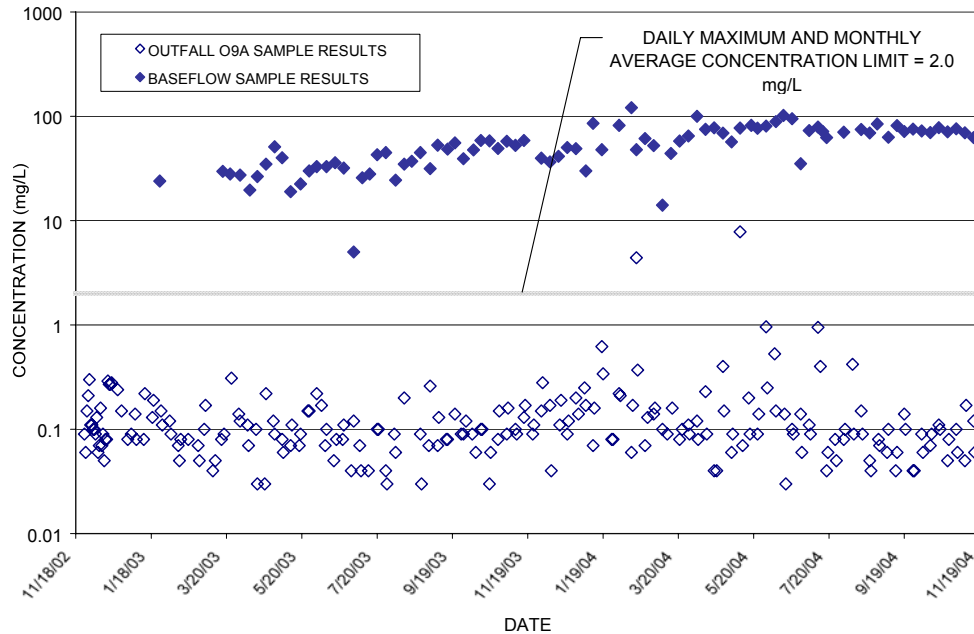
Figure 2 – Monitoring data for zinc for the first two years of operation

Evaluation of the flow of DMC treated demonstrates that the CFWWTP during its first year of operation (November 2002 through November 2003) captured approximately 73% of the cumulative flow. This may be attributed to the additional storm water flows in DMC that could not be immediately treated or stored. Although approximately 27% of the cumulative flow of DMC was not treated during the first year of CFWWTP operation, it is important to consider that the untreated flow was storm water that was typically much more dilute than base flows. In the second year of the CFWWTP operation, the vast majority of water in DMC is treated. The additional actions that have been completed to address the commingling of relatively clean water from the Gypsum Pond and Belltown Creek with degraded water in DMC provide nearly complete treatment of DMC. First, diversion of the Gypsum Pond Tributary flow was completed in April 2004. Retention Ponds 1 and 2 have been modified to operate as detention basins to retain greater amounts of DMC storm flows for treatment. Finally, construction of a diversion pipe to accommodate the clean water from large storm flows in Belltown Creek has been completed. Since completion of these diversion projects, the CFWWTP has been treating the entire base flow and the vast majority of storm flow from DMC; in the second year of operation, over 97% of the entire DMC flow was treated.

CONCLUSIONS

Use of a streamlined approach has allowed for early identification of the most significant problems that impact the ecological risks to the Ocoee River. This has made possible implementation of early remedial actions while on-going investigations continue for a phased approach to developing long-term remedial actions to protect the Ocoee River. Refurbishment and operation of the CFWWTP has produced immediate positive effects to the water quality in DMC resulting in reduction of risks and significant improvement to the ecological health of the Ocoee River. Current and future work in both the DMC and NPC watersheds will be designed and developed based on results of early actions, such as the refurbishment and operation of CFWWTP. This overall strategy should provide stepwise improvements in the ecological health of the Ocoee River. The major benefit of this process is identification and remediation of the worst problems in a complex set.

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NATURAL CHANNEL DESIGN FOR A STREAM REALIGNMENT INCORPORATING FLOOD INSURANCE PROGRAM REQUIREMENTS

Ken Barry*, Elizabeth Porter, Michael Pannell, Brent Wood,
Angela Hemrick[1] and Jamie James[2]

Love Creek in eastern Knoxville, Tennessee has seen over a century of impacts beginning with agriculture and, in the last thirty years, urbanization. Impacts have included straightening, removal of riparian vegetation, trash dumping, and urban run-off.

As part of the expansion of an existing commercial facility, an approximately 1300-ft. section of Love Creek will be realigned and 1.1 acres of wetlands created. The realigned reach has been designed using natural channel design techniques (reference reach, bank full discharge, in-stream structures, bio-engineering of banks, etc.).

A complication in the application of natural channel design techniques was the need to comply with the "no-rise" provisions of the Federal Emergency Management Agency and City of Knoxville Flood Insurance Program. These programs require that the 100 and 500 year recurrence interval flood elevations are not increased by the channel and floodplain modifications. Intensive modeling was undertaken using the U.S. Army Corps of Engineers HEC-2 and HEC-RAS surface water models to satisfy the FEMA requirements.

The initial modeling results indicated some modifications to the initial design would be necessary to meet the FEMA and City of Knoxville requirements. These mainly were concerned with revising bank stabilization treatments in order to obtain a lower Manning's friction factor. Iterations of the modeling were also made to examine modifications to the proposed channel's plan and to improve the model's performance.

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SESSION 3C

GIS MAPPING & DATABASES
8:30 a.m. – 10:00 a.m.

Internet Tool Assisting Comprehensive Nutrient Management Planning in Tennessee
Brooks A Jolly

Application of Information Technology to Study Karst Features at Local and Regional Scales
Yongli Gao

A Role for Geospatial Information Systems in Identifying Potential Tennessee Water Quality Trading Markets
David C. Roberts and Christopher D. Clark

WATERSHED INVESTIGATIONS
10:30 a.m. – 12:00 p.m.

Estimating Agricultural Water Use in a Watershed
J. Bert Britton

Watershed Characteristics in Karst Area
Peter Li.

Fact or Fiction: The Truth about Water Contamination in Manchester and Tullahoma, TN
Kelsey Bitting, John Ayers and Kaye Savage

INTERNET TOOL ASSISTING COMPREHENSIVE NUTRIENT MANAGEMENT PLANNING IN TENNESSEE

Brooks A Jolly[1]

ABSTRACT

Runoff from agricultural fields has been identified as a major source of non-point source pollution. The adoption of best management practices, including the development and use of nutrient management plans, can significantly reduce the potential for non-point source pollution from agricultural fields. New federal regulations will require many agricultural producers to develop comprehensive nutrient management plans (CNMP). Accurate farm and field maps are one of the basic components of a CNMP. Maps not only accurately indicate the relative location of fields in an operation, but are used to identify sensitive sites on a farm that have to be more carefully managed to protect environmental quality. This project uses ArcIMS software to develop an Internet-based farm-mapping tool that will enable producers and agricultural professionals to produce accurate farm and field-scale maps of agricultural operations in Tennessee. This tool is intended assist nutrient management planners in the development of CNMPs, and enable producers to improve their animal manure and poultry litter management and reduce the impact of animal manure and poultry litter on water quality. The maps will delineate sensitive areas such as streams, rivers, sinkholes and field boundaries that should not be used for the land-application of animal manures and poultry litter. The development of accurate farm maps, with good estimates of the land area that is available for the land application of animal manures and poultry litters, will fulfill a basic requirement for the development of comprehensive nutrient management plans.

INTRODUCTION

In recent years the agricultural community has become increasingly aware that some agricultural activities have a negative impact on water quality. For example, the nutrients and pathogens in the runoff from agricultural fields have been identified as a major source of non-point source pollution. The amount of nutrients contained in runoff can be significantly reduced through the adoption of best management practices (BMPs), including the development and use of nutrient management plans. Such plans are useful management tools for animal operations where quantities of animal manures and poultry litter are typically land-applied. In such applications, animal manures and poultry litter are unbalanced fertilizer sources that contain more phosphorus relative to crop needs than nitrogen. Application of manures or litter on a nitrogen basis typically over applies phosphorus and thus increases the risk of phosphorus release in runoff which negatively impacts water quality.

Nutrient management planning is a process used to identify plant nutrients in an agricultural operation to optimize production and prevent pollution of the environment. Such planning is a way to assess and monitor the potential environmental risks posed by agricultural operations. Large confined feeding operations (CAFO's) using liquid manure in Tennessee must have a comprehensive nutrient management plan (CNMP) prepared by a certified planner. The nutrient management plan for large, dry (non-liquid nutrient applications) and medium sized CAFOs can be prepared by any person.

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In Tennessee producers and nutrient management planners need an accurate and reliable method to create and reproduce farm and field maps. Accurate farm and field maps are one of the basic components of a CNMP since they not only indicate the relative location of fields in an operation, but are used to identify sensitive sites on a farm that must be more carefully managed to protect environmental quality. An accurate assessment of the area of each field, and of the area of the field to which manure or litter can be land-applied, is crucial for the development of a CNMP; yet in many cases no accurate measurements of fields are available. Further problems may be created by the proximity of sensitive sites to some fields, which may reduce the field acreage available for the land-application of manures and litters.

The Center for Agricultural Resource and Environmental Systems (CARES) at the University of Missouri has developed a spatial nutrient management planner (SNMP) decision support tool (Lory and Stark, 2005). The SNMP tool enables producers and planners in Missouri to develop and create farm specific maps using online Digital Orthophoto Quads (DOQs) as an aerial photograph background for drawing more accurate farm and field boundaries. The tool can be used to delineate farm and field boundaries and local features such as location of streams, wells, ponds and neighbors. The SNMP will automatically show setbacks and buffers required for manure application and calculate the area of a field available for manure spreading. Soil test information can be entered for each farm field and used to create soil test maps of the farm as well as to generate fertilizer recommendations for selected crops (Figure 1). The SNMP will automatically create a farm map showing setbacks that can be printed and used as the basis for a CNMP or other nutrient management plans. The CARES group at Missouri offered to share the SNMP with Tennessee and assist them with the development of a similar tool for use in the state.

The CARES SNMP tool was developed for ArcView 3.x and requires that end-users have the ArcView program installed on their computer and have access to the necessary spatial datasets. Many agricultural produces that could benefit from the SNMP tool do not have access to the necessary GIS programs and datasets required to implement the tool. The purpose of this project is to develop an open Internet-based farm-mapping tool that will enable producers and agricultural professionals to produce accurate farm and field-scale maps of agricultural operations in Tennessee. The maps will delineate sensitive areas such as streams, rivers, sinkholes and field boundaries that should not be used for the land-application of animal manures and poultry litter. The development of accurate farm maps, with good estimates of the land area available for the land application of animal manures and poultry litters, is a basic requirement for the development of comprehensive nutrient management plans (CNMPs). This project is intended to assist nutrient management planners in the development of CNMPs, and enable producers to improve their animal manure and poultry litter management and reduce the impact of animal manure and poultry litter on water quality.

BRIEF OVERVIEW OF TECHNICAL ASPECTS OF THE TENNESSEE SPATIAL NUTRIENT MAPPER WEBSITE

The Tennessee Spatial Nutrient Mapper uses ESRI's ArcIMS 9.0 HTML interface with standard frame design to deliver client services. The HTML interface is a 'thin-client' interface that performs much of the application processing on the server. While this can result in slower replies to individual client request it does not require the user to download any applets and both the 'business' functionality and data reside on the server. The ArcIMS services are delivered via Microsoft's Internet Information Services Web server. ArcIMS is essentially a map server and offers very little out of the box topologic functionality. To provide topologic functionality for the Tennessee Spatial Nutrient Mapper website I intend to use Geometry Engine – Open Source objects written in C++ (GEOS, 2005).

CURRENT WEBSITE FUNCTIONALITY

Initial website construction was performed with ArcIMS 9 tools. Custom tools allowing dynamic image display, polygon delineation, and image extracts where adapted from available code downloaded from the ESRI support website. Several of the custom functions use Active Server Pages (ASP) that require clients use the Microsoft Explorer browser. Currently clients may display, query, buffer, and select data layers. Custom tools also allow clients to dynamically display Digital Ortho Photo Quads (DOQQs), delineate a single field boundary, and extract image layers (Figure 2). Using a Dynamic Image display function for the DOQQ's allows updated DOQQ's, when they become available, to be easily made available to clients. Extracted image and feature layers are downloadable in the Tennessee State Plane format, and world coordinate files are automatically generated for clipped images. This is an advantage to the client in that they are not required to re-project original data or images into the same projection. Because ArcIMS does not allow feature data sources, in the shapefile format, to be created or edited through the web interface, all new polygons are created on the acetate layer as graphic objects. Current datasets available through the website are: Roads (Census Data), SSURGO soils data where available (NRCS), National Hydrography Dataset Streams, Stream Area, and Water bodies (USGS), Digital Ortho Quarter Quads (USGS), and National Geographic Topographic Quads (Southern Appalachian Information Node). With the exception of the National Geographic Topographic Quads these dataset where obtained from public websites and are housed on a server maintained by the Department of Biosystems Engineering and Environmental Sciences at the University of Tennessee. The National Geographic Topographic Quads are accessed through a Spatial Data Engine interface from the Southern Appalachian Nodes server housed on the campus of the University of Tennessee - Knoxville.

FUTURE CUSTOM WEBSITE FUNCTIONALITY

A major output from this project will be the modification and adaptation of a spatial nutrient management-planning (SNMP) tool developed by the University of Missouri. To this end clients must be provided the ability to add polygon, line, and point features and apply topologic functions (i.e. clip, buffer, intersect, etc.). I intend to provide this functionality through server side C++ objects. The primary output from this website will be automatically generated maps necessary for the development of comprehensive nutrient management plans. This maps will be image files that include a farmstead sketch map, local proximity map (using Topo background), aerial maps of land application area, individual field maps with marked set backs, buffers, and waterways; environmentally sensitive areas, such as sinkholes, wells, gullies, tile inlets, etc.; and a soil map, with appropriate interpretations. During the development process I will modify website functionality as much as possible to provide for the specific needs of the target clients (agricultural professionals and agricultural producers). Future plans also include a migration of datasets from a shapefile format into a feature dataset format that can be accessed by ArcIMS via ESRI's ArcSDE.

CONCLUSIONS

While the specific purpose of the Tennessee Spatial Nutrient Mapper website is to facilitate the development of comprehensive nutrient management plans, the long term goal of the project is to improve the quality of Tennessee's surface waters by reducing nutrient runoff from agricultural non-point sources. The use of more accurate maps and mapping tools in the development of comprehensive nutrient management plans will increase producers' ability to better use their animal manures and poultry litters, and improve stakeholders and citizens knowledge on non-point source pollution. Geographic datasets are currently served over the Internet from many sources; this website hopes to make geographic analysis functions as well as geographic datasets readily available to clients. I believe this website is an example of the possible future of GIS and

water resources - the ability of public agencies to provide not only the internet delivery of geographic datasets but analysis functions as well will enable technical data and decision support tools to be made available at low cost to local stakeholders and management agencies. This is potentially useful in meeting public education requirements and increasing the effectiveness of management decisions related to improving water quality.

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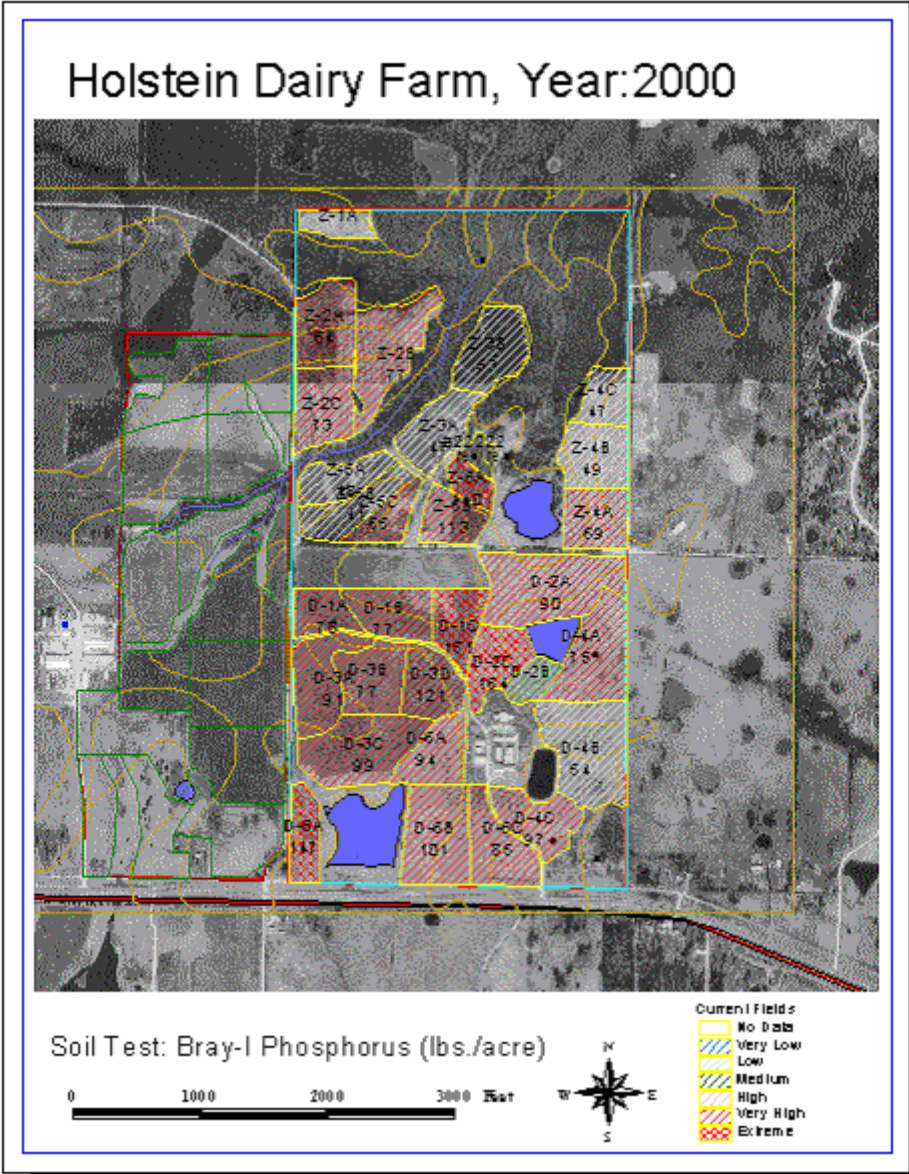
Figure 1. An Example Map Generated from the Spatial Nutrient Management Planner (SNMP) Tool developed by the University of Missouri

Source (Lory and Stark, 2005)

Figure 2. An Example of a Delineated Field is Shown Overlaying a DOQQ -Generated From the Tennessee Spatial Nutrient Mapper website.

Source (http://gis.ag.utk.edu/website/TNSNMP_Beta)

APPLICATION OF INFORMATION TECHNOLOGY TO STUDY KARST FEATURES AT LOCAL AND REGIONAL SCALES

Yongli Gao

INTRODUCTION

In the past decade, GIS-based Database Management Systems (DBMS) have been widely used in the karst communities in the U.S. and other countries to manage and analyze karst hydrological and geomorphologic datasets (Denizman, 1997; Whitman and Gubbels, 1999; Cooper and others 2001; Lei and others 2001). However, many existing GIS and DBMS packages lack the ability of manipulating complex karst feature data models and retrieving information through comprehensive spatial queries. A conceptual karst feature database (KFD) model was established to include new structural elements and modules (Gao, 2002). This database model aims at improving spatial queries and transformations and conducting spatial statistics and hydrological modeling on local and regional karst hydrological and geomorphologic datasets (Gao and others, 2002).

The conceptual model of the KFD includes three interactive modules: spatial operation, spatial analysis, and hydrological modules (Gao, 2002). All three modules manipulate data from the central database, verify and update attribute values of selected karst features, and visualize results from module implementation. A working database is developed to include many mapped karst features in Minnesota. Standardized metadata and management tools were developed for this database that will be beneficial for management and future study of karst features in Minnesota. Nearest neighbor analysis (NNA) and decision tree models were implemented on the KFD. NNA was extended to include different orders of NNA, different scales of concentrated zones of sinkholes, and directions to nearest sinkholes. Decision tree and cartographic models were developed to create sinkhole probability maps in southeastern Minnesota. The models and methodology developed in this database are expandable to construct comprehensive databases for other karst areas in the U.S.

KFD CONCEPTUAL MODEL

Figure 1 illustrates the conceptual model of the KFD. The conceptual model of the KFD includes three interactive modules: spatial operation, spatial analysis, and hydrological modules (Gao, 2002). The three modules and the central DBMS are interconnected to each other rather than standing alone. The integration of these modules has been widely used in some recent hydrological research. For instance, Storck and others (2000) used distributed hydrological modeling to investigate hydrological effects of land use change.

In the conceptual model of the KFD, all three modules in Figure 1 are highly interactive. They all manipulate data from the central database and load some of the results back into the database. Spatial operations provide essential tools and data for spatial analysis and hydrological modeling. Results from spatial analysis and hydrological modeling could be reprocessed by spatial operations to refine the analysis and modeling. The spatial analysis module processes and estimates hydrological parameters for hydrological modeling. Results from hydrological modeling could be tested and operated again by spatial operation and spatial analysis modules. In other words, the three modules and the central DBMS as shown in Figure 1 can operate recursively to converge on internally consistent results (Gao, 2002).
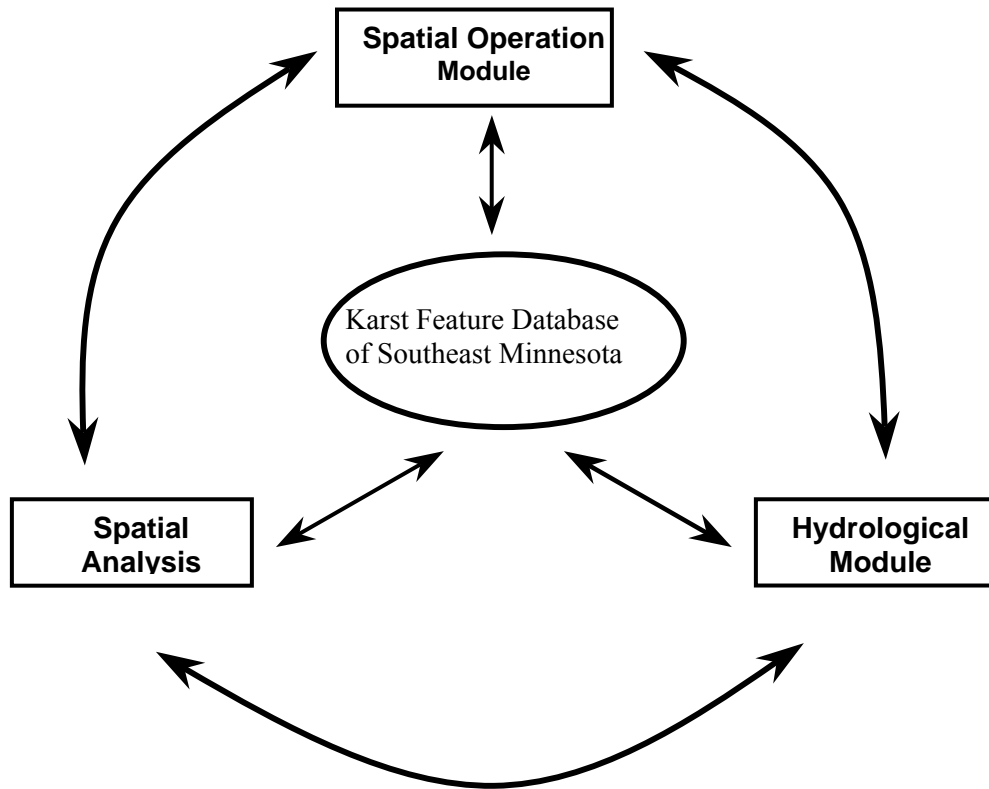
Figure 1. Logical data modeling of Minnesota Karst Feature Database (Gao, 2002)

KFD DEVELOPMENT IN MINNESOTA

A working database is developed to include many mapped karst features in Minnesota. Standardized metadata and management tools were developed for this database that will be beneficial for management and future study of karst features in Minnesota.
Microsoft Access 2000 and ArcView 3.2 were used to develop the working database. Existing county and sub-county karst feature datasets have been assembled into a large GIS-based database capable of analyzing the entire data set. Data tables were stored in a Microsoft Access 2000 DBMS and linked to corresponding ArcView shape files. The current KFD of Minnesota was initially loaded onto a Windows NT server (Gao, 2002) and then moved to a Windows 2000 Citrix at Minnesota Geological Survey (MGS). The server is accessible to researchers and planners through networked interfaces.

11,682 karst features had been loaded into the KFD of Minnesota by November 17, 2002. Figure 2 shows the number of karst features sorted by feature types. Sinkholes and springs account for

approximately 78% and 20% of all the karst features stored in the KFD respectively. The main data sources of the database are from County Atlas projects (Alexander and others, 2003; Alexander and Maki, 1988; Dalgleish and Alexander, 1984; Tipping and others, 2001; Witthuhn and Alexander, 1995).

The development, implementation, and data analyses of the Minnesota KFD are described in detail in the author's Ph.D. dissertation (Gao, 2002). The methodology used to design this DBMS is applicable to the development of other GIS-based databases to analyze and manage geomorphic and hydrological datasets at regional and local scales.
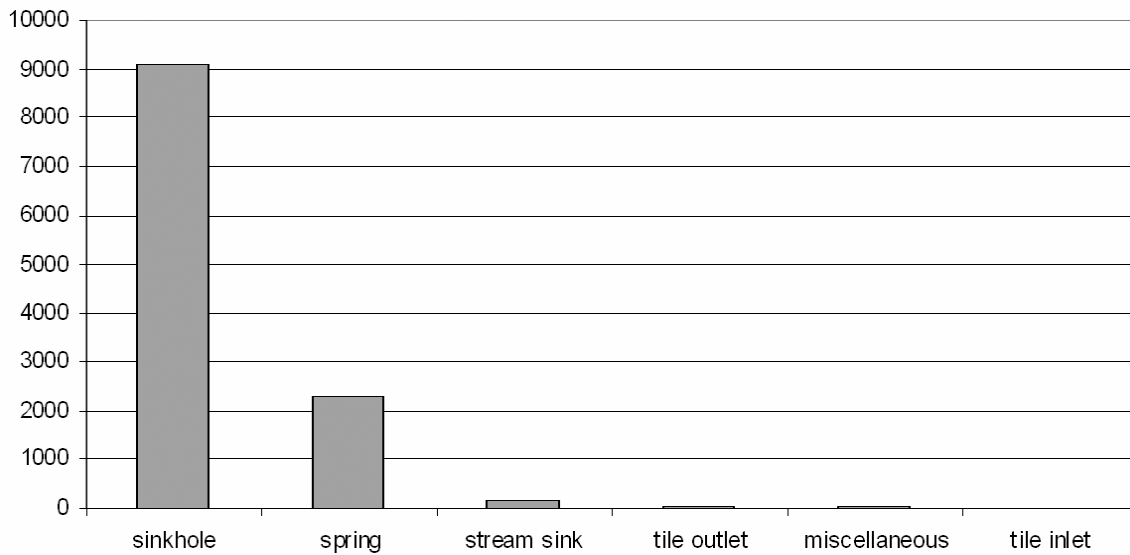
Figure 2. Number of karst features sorted by feature types in Minnesota (Gao and others, 2005)

KFD IMPLEMENTATION

Parts of the spatial operation and spatial analysis modules in the conceptual database model (Figure 1) were implemented in Minnesota. The hydrological module has not been implemented. Figure 3 illustrates two sets of applications built for the KFD. The five applications (data entry, data edit, data lookup, data report, and code maintenance) shown on the left side in Figure 3 were built in Microsoft Access. The five applications (digitizing, visualization, location verification, spatial transformation, and map generation) shown on the right side were built in ArcView 3.2 GIS. These application interfaces were used to process karst feature records surveyed and stored on topographic maps. Both kinds of applications allow users to enter, edit, and query karst feature data stored in the KFD (Gao, 2002) under both GIS and database environments.

Data Entry			Digitizing

GIS

| Data Lookup | | | Visualization |

| Data Edit | | | Location Verification |

| Code Maintenance | | | Spatial Transformation |

DBMS

| Data Report | | | Map Generation |
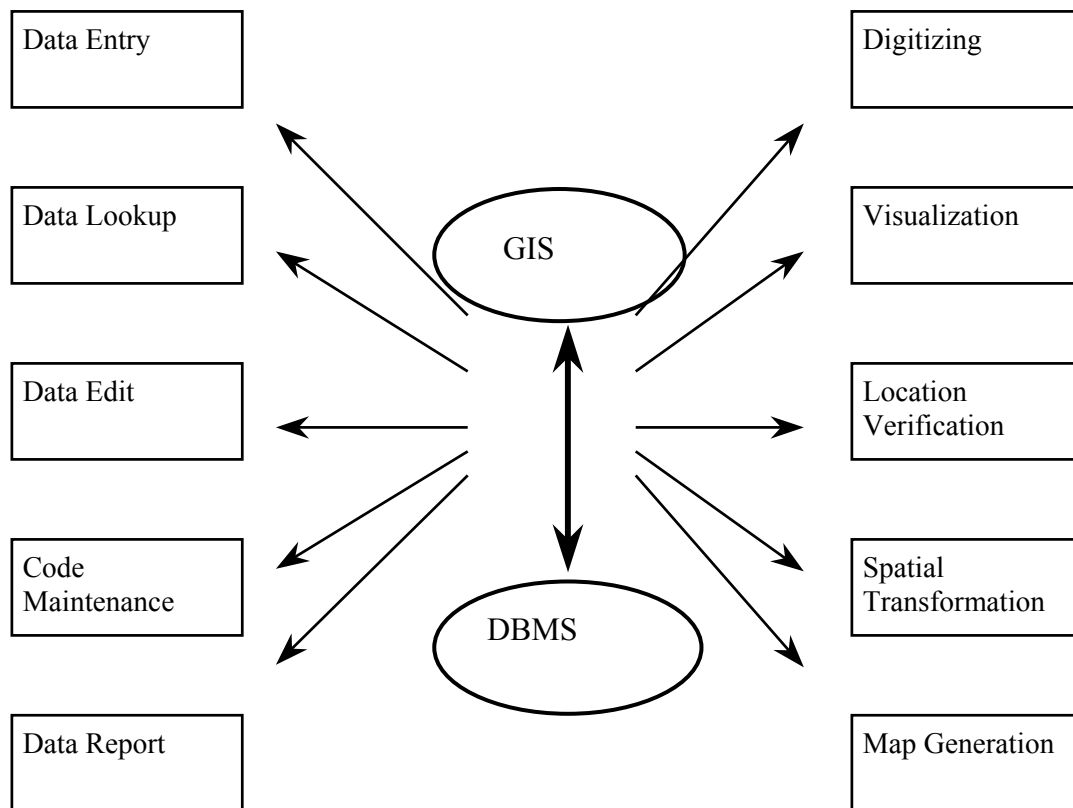
Figure 3. Applications built for the GIS-based KFD of Minnesota (Gao, 2002)

NNA was implemented in the KFD to investigate sinkhole distribution in Minnesota. The distributions of distances to the first through third nearest sinkholes match lognormal distributions for the majority of the sinkhole population (Gao, 2002). NNA was extended to include different orders of NNA, different scales of concentrated zones, and directions to nearest sinkholes. The statistical results, along with the sinkhole density distribution, indicate that sinkholes tend to form in highly concentrated zones instead of scattered individuals. The pattern changes from clustered to random to regular as the scale of the analysis decreases from 10 - 100 km2 to 5 - 30 km2 to 2 - 10 km2 (Gao, 2002).

Decision tree and cartographic models were constructed to create sinkhole probability maps in southeastern Minnesota. A partial sinkhole probability map was created in Goodhue, Wabasha, Olmsted, Mower, and Fillmore Counties (Gao, 2002). The decision tree model was implemented to construct a revised map of relative sinkhole risk in Fillmore County using ArcView and

ArcInfo GIS (Gao and Alexander, 2003). The decision tree model reproduced most of the important features seen on the original maps in the high density areas and led to new insights about the internal structure of high density areas. The model is less successful in capturing the details of the lower density areas where the subjective criteria are more significant (Gao and Alexander, 2003).

The models and methodology developed in this database are expandable to construct comprehensive databases for other karst areas in the U.S. Progress has been made to include sinkhole and bedrock geology data into the KFD in Minnesota. The short-term goal of this research is to develop a KFD for the Upper Mississippi Valley Karst and the long-term goal is to expand this database to manage and study karst features at national and global scales.

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A ROLE FOR GEOSPATIAL INFORMATION SYSTEMS IN IDENTIFYING POTENTIAL TENNESSEE WATER QUALITY TRADING MARKETS

David C. Roberts and Christopher D. Clark[1]

INTRODUCTION

The Clean Water Act (CWA) principally enables EPA to restrict point source (PS) discharges, or pollution from entities that release contaminants directly to waterways through a pipeline or other similar, "discrete conveyance" (33 U.S.C. § 1362(14)). Controlling PS emissions is a logical first step in effecting water quality improvements, since the pollutants that seem to pose the most serious and immediate threats to human and animal health are those produced by industry – the kind that cause burning rivers and fish toxicity. Industrial PSs are also very visible polluters, so they can be more easily monitored and regulated than non-point sources (NPS), such as agriculture and other sources of diffuse runoff. However, while PS regulations and corresponding government investments have improved water quality, they have failed to meet the ambient water quality goals of the CWA. Their implementation has also depleted the range of cost-effective options remaining for the control of PS discharges. Thus, to further pursue pollution abatement by stricter command-and-control regulations on municipal and industrial PSs will mean increasing marginal abatement costs. Estimates from EPA and AMSA put the funding needs of municipal treatment works over the next 20 years at approximately $139.5 billion and $330 billion, respectively, to fill currently unmet needs for water infrastructure nationwide (Association of Metropolitan Sewerage Agencies and the Water Environment Federation). Though these cost estimates vary widely, they indicate the great expense of improving water quality through regulation of PS polluters alone.

By definition, the current system of pollution abatement is not cost-effective, since the marginal costs are not equal for all pollutant sources (Goodstein). A market-based approach to pollution regulation that could theoretically equalize the marginal cost of pollution abatement among PS and NPS polluters who emit the same contaminants is known as Water Quality Trading (WQT). EPA has expressed interest in and support for WQT, formally endorsing WQT in January of 1996 by issuing a brief policy statement endorsing the idea (USEPA b), which was followed by a more detailed "Draft Framework" document just four months later (USEPA a). The newly published WQT handbook is a guide from EPA to assist policy-makers in establishing WQT markets in suitable watersheds (USEPA c). Under such a program, a polluter under regulatory pressure to further reduce emissions (such as a PS whose emissions cap has been lowered) has the option of purchasing a credit; i.e., paying another polluter (a PS or NPS) to meet abatement requirements. Limited pilot programs trading in nutrients, metals and dissolved oxygen improvements are in place in the United States, some of which have successfully achieved their goals (McGinnis). Tennessee may be well-suited to the use of WQT between PSs and NPSs as a cost-cutting method for further pollution reductions, since agriculture is a contributing factor in about 37% of stream and river miles (TN Department of Environment and Conservation).

The intention of this study is to assess the suitability of Tennessee's watersheds for a WQT program involving PSs and NPSs, specifically trading in sediment or total suspended solids, using a Geospatial Information System within ArcMap[TM] software. Sediment is the pollutant of choice for this study because reducing sediment loadings from agriculture through installation of riparian buffer strips will likely also have positive externalities by reducing runoff of nitrogen and

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phosphorous from agricultural operations, thus reducing over-nutrification and dissolved oxygen depletion in waterways (Lee, Isenhart, and Schultz).

DATA AND METHODOLOGY

ArcMap[TM] software was used in conjunction with geospatial data to create a map of the 56 watersheds that are either partially or completely contained by Tennessee's borders. Information on water quality impairments is based on the Year 1998 303(d) List and was downloaded from EPA's WATERS web page at http://www.epa.gov/waters/data/ downloads.html. EPA's Permit Compliance System (http://www.epa.gov/enviro/html/ pcs/index.html) provided information on current PS permits. The National Hydrography Dataset (http://nhdgeo.usgs.gov/viewer.htm) provides information about the total riparian meters within each watershed. Land use data was obtained from National Land Cover Dataset (1992), which is available for download at http://seamless.usgs.gov/website/ seamless/viewer.php.

Two hurdles were used to eliminate watersheds unlikely to support a WQT market in sediment credits by 1) selecting only watersheds that contain more than 13 Km of river and stream segments that are impaired by sediment and 2) selecting only watersheds that contain PSs with NPDES permits for total suspended solids. Step one brings the number of relevant watersheds to 24, while step two reduces the number to 23. Sediment impairments in the eliminated watersheds could probably be more efficiently remedied through existing government programs that subsidize agricultural best-management practices, such as the Conservation Reserve Program, in conjunction with further PS regulation as needed.

For each of the aforementioned 23 watersheds, the acreage in agricultural land uses was calculated based on the National Land Cover Dataset (1992). In the dataset, agricultural land use includes the categories "row crops", "hay/pasture", "small grains" and "fallow." When combined with some sediment emissions factor according to the land use category, this information will provide an aggregate sediment load for agricultural NPSs within each watershed. For the purpose of this brief study, the assumption was that greater aggregate agricultural acreage (as a percentage of total watershed area) leads to greater agricultural sediment emissions relative to the watershed size. Greater emissions, in turn, signify a greater potential for agricultural emissions reductions, which can be purchased by PSs seeking to compensate for further regulatory pressures without actually lowering their own loadings. Agricultural NPS loadings could be reduced through the use of practices such as reduced tillage and/or riparian buffer strips.

In order for a riparian buffer strip to be most effective at remedying water quality problems, it should be located adjacent to (or slightly up stream of) an impaired stream segment. Thus, all land use features bordering riparian features impaired by sediment and related causes (organic enrichment, low dissolved oxygen, and nutrients) were selected in each watershed, and were then clipped to within 100 ft (the CRP maximum average width of grass filter strips) of the impaired segments. The aforementioned sediment-related impairments were included in this step for two reasons:

    1) Because the BASINS geospatial data list only one cause of impairment per segment, some segments impaired by sediment are not accounted for. Since 58% of these related impairments are concurrent with a sediment impairment (based on calculations made from the 2002 303(d) list), including them allows the inclusion of more sediment-impaired features.
    2) Due to the potential positive externalities of trading sediment in a segment that is concurrently impaired by the related impairments.

To create a ranking scheme, a continuous relative score from 10 (best for WQT) to zero (worst for WQT) was assigned to each watershed for each of several equally-weighted objectives: 1) the percentage of the watershed land in agricultural use; 2) the total meters impaired by sediment; 3) the total meters impaired by nutrients, organic enrichment and/or low dissolved oxygen (related impairments); 4) the number of NPDES permits for total suspended solids (i.e., TSS or sediment); 5) the total acreage of potential agricultural riparian buffer strips adjacent to segments impaired by sediment and related impairments; 6) the single or multi-state location of the tradable impairments; and 7) the percentage of the total riparian miles impaired by toxics, including PCBs, mercury, metals, chlorine, and dioxin. On the basis of the equally-weighted average of the rankings for each watershed, each watershed was given a ranking relative to the others for overall suitability for a WQT program in sediment. Objectives one, four and five aid in identifying the potential quantity of tradable emissions reduction based on presence of producers (NPSs) and consumers (PSs); two and three identify the extent of the need for a solution to sediment problems; six identifies the potential for inter-state conflicts; and seven provides a measure of the extent to which toxic impairments might interfere with the potential environmental benefits.

RESULTS

Table 1 at the end of this paper lists the 23 watersheds (by 8-digit hydrologic unit code) that contain a relatively large number of sediment-impaired riparian meters. Listed with them are the percentages of total watershed area in agricultural use, the total sediment-impaired meters, the total meters impaired by related causes, and other information relevant to this study. The watersheds that are grayed out may not be of much interest to Tennessee policy makers because all the tradable impairments lie in other states.

Table 2 presents the 23 watershed with their relative ranking for each objective. The relative score is the equally weighted average of the seven objectives for each watershed. A priority level has been assigned to each watershed according to its relative score. Note that hydrologic unit code 08010204 (North Fork Forked Deer) received top priority, despite the rather sparse presence of NPDES permits for TSS. Economic theory indicates that the number of buyers and sellers may be the best predictor of the success of a potential market, so ranking watersheds by the equally weighted average of the objectives may not make sense from an economic standpoint. The seven objectives used will be differently weighted in future studies according to the dictates of theory and further research. The sizes of the various NPSs and PSs involved will also be included in future work, since larger buyers and sellers could lead to reduced transactions costs and greater market efficiency.

CONCLUSIONS

This study has produced a rough outline of a methodology that can be used to prioritize watersheds for WQT. It could be extended for use with other pollutants that are commonly produced by different sources with differing costs of pollution abatement. Some refinements should and will be made to the methodology, such as modifying the weighting scheme for the objectives, geospatially locating PSs that discharge into impaired segments, and accounting for the sizes of relevant PSs by quantifying current emissions and maximum allowable emissions. NPS emissions also must be quantified, and potential reductions must be valued on the basis of supply and demand, as well as foregone farm profits due to potentially reduced productive capacity of farmland. Following these further steps will create a more comprehensive system for prioritization of watersheds for WQT, as well as allowing the savings potential to be quantified in potential WQT markets.

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Table 1. 23 Watersheds and Relevant Attributes

WATER-SHED	AG LAND %	SEDIMENT-IMPAIRED METERS	RELATED IMPAIRMENTS METERS	NPDES PERMITS FOR TSS	POTENTIAL BUFFER STRIPS ADJACENT TO POTENTIALLY TRADABLE IMPAIRMENTS (AC)	MULTI-STATE TRADABLE IMPAIRED	TOTAL TOXIC IMPAIRMENT %
08010201	61.44	22,782	0	14	451	NO (KY)	.02
06010201	16.72	71,232	347,655	12	2,272	NO	7.74
08010203	55.30	531,895	216,219	13	9,602	NO	0
05130206	62.53	414,693	243,847	12	3,895	NO	0
06020002	13.65	69,941	0	15	214	NO (NC)	1.03
06030002	34.22	13,407	548,702	30	3,193	YES (2)	1.08
08010205	34.59	188,681	311,370	9	2,472	NO	0
08010208	30.20	872,397	0	10	6,521	NO	4.63
08010204	48.67	712,396	486,347	7	13,887	NO	0
06010108	20.09	708,007	591,102	6	8,590	YES (2)	0
06030003	37.04	199,880	0	10	1,328	NO	3.44
08010202	40.52	822,893	299,268	11	8,997	NO	0
06040001	22.52	571,506	0	9	6,285	NO	0
06040002	37.65	113,075	0	5	5,080	NO	1.38
06010103	10.84	38,355	506,096	4	574	NO	0
08010207	28.68	573,857	34,369	20	5,024	NO	0
05130104	4.12	374,824	0	3	216	NO	0
06010208	9.39	60,726	0	5	370	NO	0
05130203	30.42	116,241	89,847	4	1,017	NO	1.93
06010106	6.25	129,242	55,000	3	310	YES (2)	2.24
06020004	17.24	27,462	0	3	22	NO	7.15
05130101	5.09	66,004	0	63	34	YES (2)	0.03
06030004	32.33	23,234	36,716	4	316	NO	2.40

Table 2. 23 Watersheds and Priority Rankings

WATER-SHED	PRIORITY	RELATIVE SCORE	AG LAND %	SEDIMENT-IMPAIRED METERS	RELATED METERS IMPAIRED	NPDES PERMITS FOR TSS	POTENTIAL BUFFER STRIP ADJACENT TO POTENTIALLY TRADABLE IMPAIRMENT (AC)	MULTI-STATE TRADABLE IMPAIRED	TOTAL TOXIC %
08010204	1	7.8	7.6271	8.13733570	8.227802	0.666667	10	10	10
08010202	2	6.9	6.2318	9.42369527	5.062883	1.333333	6.4731337901	10	10
08010203	3	6.7	8.7621	6.03601905	3.657897	1.666667	6.9094843130	10	10
05130206	4	6.2	10	4.67160270	4.125295	1.500000	2.7933645871	10	10
08010207	5	5.4	4.2047	6.52452299	0.581439	2.833333	3.6076451496	10	10
06010108	6	5.4	2.7341	8.08624082	10	0.500000	6.1795888929	0	10
08010205	7	5.0	5.2165	2.04046613	5.267619	1.000000	1.7670393076	10	10
06040001	8	5.0	3.1501	6.49715363	0	1.000000	4.5171294627	10	10
08010208	9	4.9	4.4650	10	0	1.166667	4.6873422286	10	4.0181
08010201	10	4.6	9.8134	0.10913980	0	1.833333	0.3094121890	10	9.9742
06010103	11	4.4	1.1505	0.29043411	8.561906	0.166667	0.3981247746	10	10
06030002	12	4.3	5.1532	0	9.282696	4.500000	2.2870537324	0	8.6047
06040002	13	4.2	5.7405	1.1602929	0	0.333333	3.6480346195	10	8.2171
05130203	14	3.7	4.5027	1.1971501	1.519991	0.166667	0.7176343310	10	7.5065
06030003	15	3.6	5.6360	2.1708402	0	1.166667	0.9419401370	10	5.5556
05130104	16	3.5	0	4.2074646	0	0	0.1399206635	10	10
06020002	17	3.3	1.6316	0.6581450	0	2.000000	0.1384781825	10	8.6693
06030004	18	3.3	4.8297	0.1144018	0.621145	0.166667	0.2120447169	10	6.8992
06010208	19	3.1	0.9022	0.5508679	0	0.333333	0.2509917057	10	10
06010201	20	3.1	2.1572	0.6731743	5.881472	1.500000	1.6227912009	10	0
05130101	21	3.0	0.1661	0.6123121	0	10	0.0086548864	0	9.9612
06020004	22	1.9	2.2462	0.1636224	0	0	0	10	0.7623
06010106	23	1.4	0.3647	1.3485023	0.930465	0	0.2077172737	0	7.1059

ESTIMATING AGRICULTURAL WATER USE IN A WATERSHED

J. Bert Britton[1]

Currently under the Tennessee's Water Information Act, agricultural operators are not required to report the amount of water used in their operations, unless a particular operation withdraws more than 10,000 gal/day. Numerous agriculture operations throughout Tennessee do not withdraw the specified amount, but use a significant amount of water. This amount of water is unknown and is not estimated at the watershed level. With increasing competition between various economic sectors for water supplies, estimations must be developed to ensure there is sufficient water available for these agricultural operations.

I utilize existing methods for estimating agricultural water use in watersheds along with a Geographic Information System (GIS) to develop an estimation of agricultural water use in the Nolichucky River Watershed (HUC# 06010108). Also, National Land Cover Dataset (NLCD), Digital Elevation Models (DEM), National Elevation Dataset (NED), and State Soil Geographic Database (STATSGO) will be implemented into a GIS. These digital datasets and precipitation data will be analyzed to determine agricultural areas that are probable to use more water.

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WATERSHED CHARACTERISTICS IN KARST AREA

Peter Li[1]

The degree of karstification in central and east Tennessee has dramatically affected the local hydrology. Watershed characteristics, such as stream network, drainage density, and stream order are investigated and compared using hydrological tools in GIS. Digital Elevation Models from four major watersheds, Caney Fork, Emory, Upper Cumberland and Lower Cumberland were processed to digitally produce sub-basins and stream networks inside of each watershed. Total length of stream network are compared from GIS-processed and rf1 (US EPA's River Reach File 1) and NHD (National Hydrography Dataset). The preset minimum cells for a watershed and stream network can be a major factor in determining number of watersheds and total river miles within a watershed. The study shows that higher cell number produced less number of sub-basins and shorter river miles. Karstification factor has various impact in drainage density. Comparisons between less karsted watersheds (Emory and Lower Cumberland) and heavily karsted watersheds (Caney Fork and Upper Cumberland) show the drainage density is in reverse relationship to the karstification levels. A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response.   TR-55 was used to model the peak discharge and hydrograph between karst and non-karst watersheds. The result shows major difference between karst and non-karst watershed due to caves, sinkholes and their impact on local hydrology.

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FACT OR FICTION: THE TRUTH ABOUT WATER CONTAMINATION IN MANCHESTER AND TULLAHOMA, TN

Kelsey Bitting, John Ayers and Kaye Savage

INTRODUCTION

Public opinion in the towns of Manchester and Tullahoma, TN generally holds that the groundwater in the area is thoroughly contaminated as a result of Arnold Air Force Base and Arnold Engineering Development Center (AEDC) operations, and that even the treated tap water in the surrounding areas may be unsafe for consumption. Evidence supporting this theory comes in various forms. First, similar military installations have been known to create contamination issues in other areas (e.g. Oak Ridge National Laboratory, Oak Ridge, TN). Studies conducted in the past found extensive contamination (including aquifer contamination) in the area associated with AEDC (Davis 1996, Battelle 1988 and 1989, Benham Group 1989, Engineering Science 1984, Oak Ridge National Laboratory 1989, Post et al. 1989, Woodward-Clyde Consultants 1990); contaminants included heavy metals such as mercury, arsenic, chromium, copper, cobalt, cadmium, lead, and selenium, as well as a number of volatile organic compounds, such as those marked in Figure 1 with *, as well as trichlorofluoromethane, and 1,1-dichloroethane (Davis, 1996). Davis (1996) found the source of an estimated 60% of the contamination was the landfill, from which the presumed direction of groundwater flow and the flow of surface streams could easily transport the contaminants directly toward the pumping station which supplies the two towns' water. A class-action lawsuit filed in 2000 alleged the misuse and improper disposal of a number of the above-listed and similar chemicals (those marked in Figure 1 with [†], as well as perchloroethylene, mercury, arsenic, methylene chloride, chromium, PCBs, ethylene, and asbestos), but was never resolved (Class Action).

According to this information, contamination in the water seems likely. However, volatile organic compounds often have rapid decay rates once released into the environment, while heavy metals can adsorb to soil particles and settle out in sediment (Alloway and Ayres, 1997). Since all studies cited above were conducted before 2000, the question of the current contamination suspected by citizens remains, prior to this study, unanswered.

Manchester, TN is located about 70 miles southeast of Nashville, TN, on I-24; Tullahoma, TN is located approximately 15 miles southwest of Manchester on state Highway 55 (Figure 2). The AEDC is located on the land adjacent to the two towns. One potential source of contamination from AEDC that will be highlighted in this study is the AEDC landfill.

PROCEDURE

Samples were collected from surface water in a path leading from the landfill to the pumping station on Normandy Reservoir (Figure 2); potential ground water contamination was assumed to be reflected in the surface water, since the limestone strata in the area is known to lend itself to springs, and since the reservoir itself is a reflection of the water table; the well water sample, taken just north of the landfill, also reflects groundwater composition. One exception to the sampling method is a tap water sample, which was also collected just north of the landfill and reflects quality of water from pumping station after processing at water treatment plant. Samples were collected using a Van Dorn-style sampler, allowing samples to be collected at different depths in the reservoir; a variety of information was collected at each stop using a Hydrolab, including pH, temperature, oxygen content, and conductivity.

Samples were filtered to remove suspended sediment, and were preserved using acids to prevent chemicals from decaying prior to analysis. Volatile organic compounds were analyzed using United States EPA VOC method 504.2 (a type of gas chromatography) by Continental Analytical Services, Inc., while heavy metals were analyzed using ICPMS (mass spectrometry); mercury was not analyzed, since it is hazardous in concentrations below the instrument detection limit.

RESULTS

Results for heavy metals are presented in Figure 3, and are plotted as a function of distance from the landfill in Figure 4. No consistent trend of concentration as a function of distance from the landfill is apparent, and all contaminants were present in levels well below United States EPA limits. The most interesting findings were the comparatively-elevated copper levels found in the tap and well water samples, which were elevated although still below EPA limits as well.

No detectable levels of any of the volatile organic compounds analyzed were found in any of the samples except the tap water sample. The tap water was found to contain chloroform and bromodichloromethane, two carcinogenic compounds which are common products of water treatment; the levels of these two compounds were acceptable by EPA standards.

DISCUSSION OF RESULTS

Elevated copper levels found in the tap and well water samples may be an indication of copper pipes used to transport the water, and therefore not a reflection of elevated copper levels in the water at its source (either after water treatment or in the ground).

According to the findings of this study, water contamination of analyzed substances associated with AEDC is no longer a problem for the area in question. However, one possible source of error is that during transportation, VOC samples appear to have reached temperatures above sample handling guidelines, which may have permitted contaminants to decay. Nonetheless, the presence of chloroform and bromodichloromethane in the tap water sample suggests some, if not all VOCs, would have been preserved if present in other samples.

ACKNOWLEDGEMENTS

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Figure 1: List of volatile organic compounds analyzed.

*[†]Benzene	*Ethylbenzene	Bromoform	Bromomethane
[†]Vinyl Chloride	Chlorobenzene	m-Dichlorobenzene	1, 2, 3-Trichloropropane
Carbon Tetrachloride	Styrene	Dibromomethane	1, 1, 1, 2-Tetrachloroethane
*1, 2-Dichloroethane	*Tetrachloroethylene	1, 1-Dichloropropene	
*Trichloroethylene	*[†]Toluene	1, 1-Dichloroethane	Chloroethane
p-Dichlorobenzene	*[†]o-Xylene	1, 1, 2, 2-Tetrachloroethane	2, 2-Dichloropropane
*[†]1, 1-Dichloroethylene	Methylene Chloride	1, 3-Dichloropropane	o-Chlorotoluene
*[†]1, 1, 1-Trichloroethane	*1, 1, 2-Trichloroethane	Chloromethane	p-Chlorotoluene
o-Dichlorobenzene	1, 2, 4-Trichlorobenzene	Bromomethane	Bromobenzene
*cis-1, 2-Dichloroethylene	*Chloroform	1, 2, 3-Trichloropropane	cis-1, 3-Dichloropropene
trans-1, 2-Dichloroethylene	Bromodichloromethane	1, 1, 1, 2-Tetrachloroethane	trans-1, 3-Dichloropropene
1, 2-Dichloropropane	Chlorodibromomethane	Chloromethane	*[†]m+p-Xylene

Figure 2: Map showing locations of samples

Sample Location Map
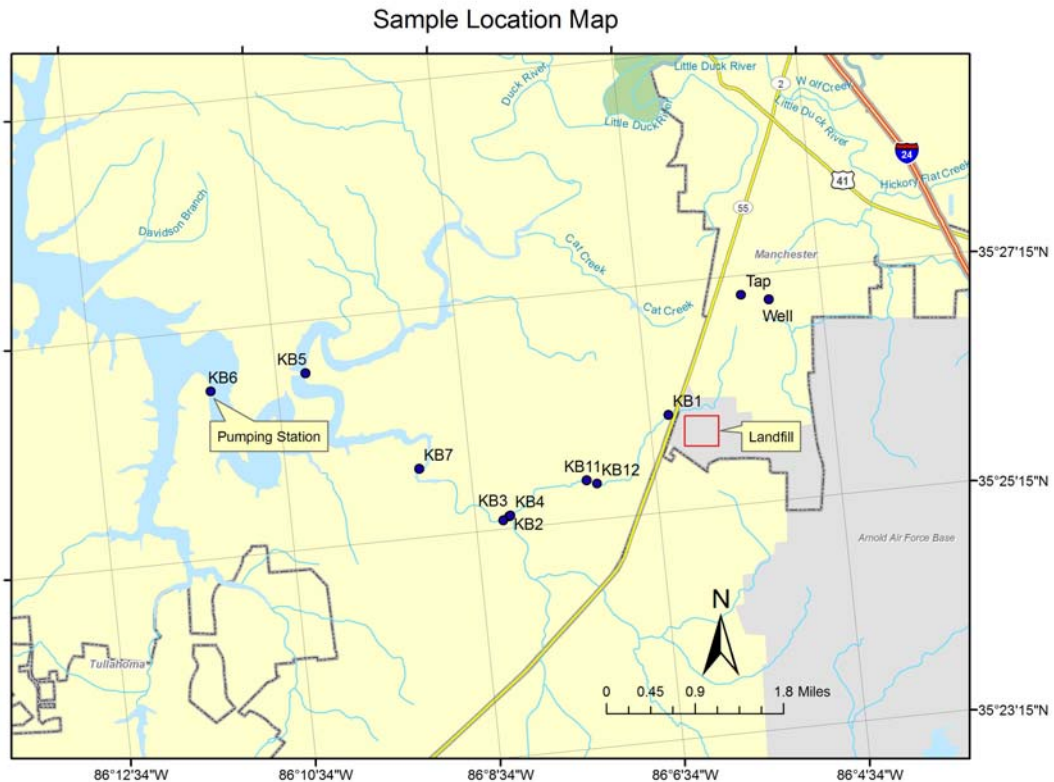
Figure 3: Heavy metal concentrations

Sample	Cr	Cu	Co	Cd	Pb	As	Se
BLANK	3.15	0.483	0.271	0.796	0.246	8.76	19.5
Equipment Blank	3.07	4.63	0.175	0.151	1.1	1.16	1.7
KB1-Blackjack Creek (near landfill)	5.74	9.35	0.456	0.293	1.02	7.4	5.52
KB2-Rutledge Falls	6.61	2.36	0.488	0.137	0.44	3.24	3.57
KB4-Duck River	4.25	4.92	0.465	0.314	1.15	2.84	3.02
KB5- Normandy Lake	4.89	5.19	2.16	0.188	0.737	6.67	3.2
KB6-Pumping Sta.-5 ft.	3.92	3.74	0.668	0.101	0.236	4.12	1.88
KB6-Pumping Sta.-30 ft.	3.58	4.33	0.485	0.119	0.424	3.75	1.5
KB7-Crumpton Creek/Lake	4.78	3.63	0.969	0.157	0.73	5.61	2.05
KB8-Confluence-5 ft.	4.71	3.1	1.01	0.149	0.715	5.75	2.09
KB8-Confluence-15 ft.	3.66	3.21	0.574	0.176	0.676	6.11	2.14
Tap Water	6.1	92.7	0.355	0.248	1.77	4.8	2.52
Well Water	10.4	20.7	0.4	0.555	0.512	1.16	3.49
KB12-Blackjack Creek (near spring)	12.3	1.48	0.338	0.24	0.658	2.48	3.37

Figure 4: Heavy metal concentrations vs. distance from landfill
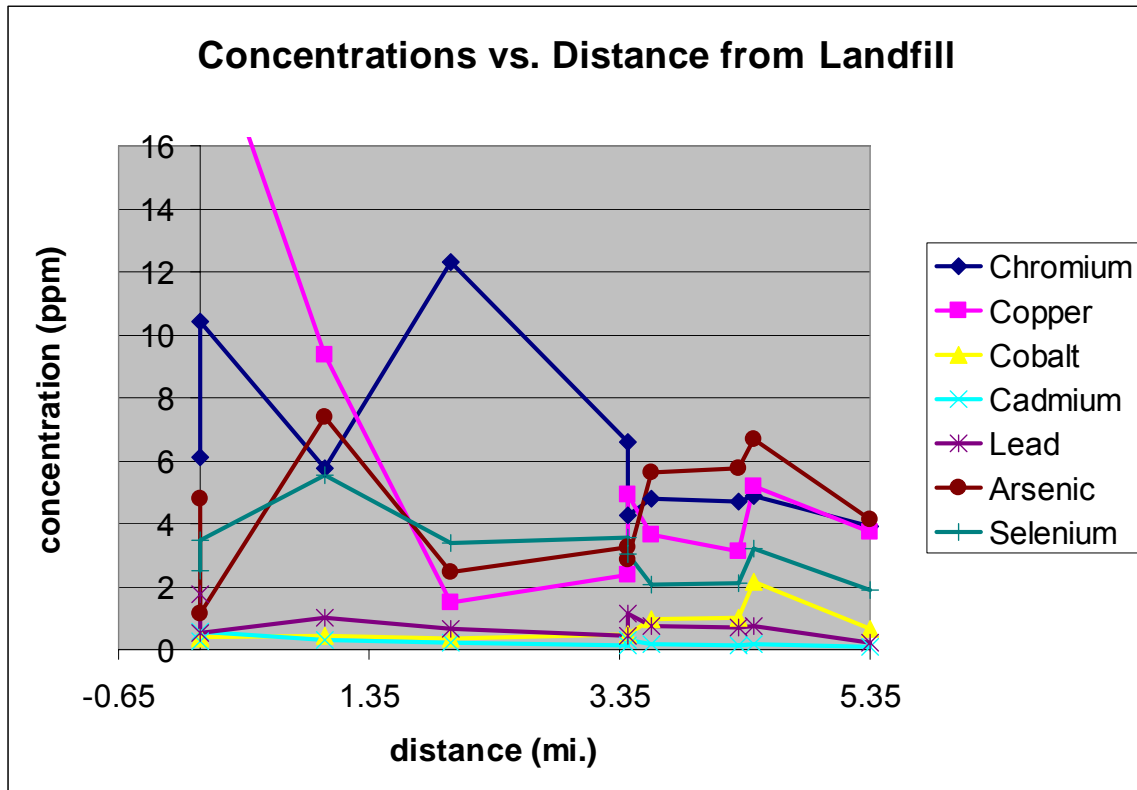
PROFESSIONAL POSTERS

Presenters will be available to answer questions from 5:30 to 6:00 p.m. on Thursday, April 14.

Water Quality in Relation to Stream Flow in the Red River Basin
Steven W. Hamilton and Gregory S. Ridenour

Innovative Approach to Identifying Pollutant Sources in Corbin Reservoir Watershed
Tony Miller

WATER QUALITY IN RELATION TO STREAM FLOW IN THE RED RIVER BASIN

Steven W. Hamilton[1]
Gregory S. Ridenour[2]

Between June 1998 to August 2002 physical and chemical parameters were measured from locations in the Red River watershed. Water temperature, dissolved oxygen, and pH were measured in the field using multiparameter probes (Hydrolab and YSI). Parameters measured in the lab were totals alkalinity, calcium, hardness, nitrate-nitrite nitrogen, orthophosphate, total phosphorus and sulfate. While many of the samples were collected on tributaries of the Red River, six were collected from the Red River at Port Royal where a USGS stream flow gauging station is located. These data are analyzed for this study. The parameters were associated with a stream flow value by downloading flow values and dates from the USGS National Water Information System and matching them with the dates of our samples. A flow duration curve was constructed using software developed by Bruce Cleland of America's Clean Water Association to display the percentage of time that a given flow is equaled or exceeded. Flows were divided into five regimes (high, moist, mid-range, dry, and low) whose midpoints are 5%, 25%, 50%, 75%, and 95%, respectively. Only total alkalinity showed a significant correlation with flow at the 5% significance level. Calcium was just outside the 10% significance level. Perhaps the lack of correlation between flow and the other parameters resulted from sampling at primarily low to dry flow conditions. Collection of data over a wider range of flows should be attempted to better elucidate the relationship between discharge and nutrient concentrations and other physicochemical parameter in this watershed.

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INNOVATIVE APPROACH TO IDENTIFYING POLLUTANT SOURCES IN CORBIN RESERVOIR WATERSHED

Tony Miller[1]

The Corbin City Reservoir is listed as a first priority impaired water body in Kentucky's 2002 303(d) report. The report cites the impaired uses as drinking water supply (non-support) and aquatic life (partial support) with the pollutants of concern being nutrients, organic enrichment, low dissolved oxygen, taste and odor, and algal growth. The purpose of our project is to identify significant sources of nonpoint source pollution, develop practical solutions, and prioritize projects for future funding for both impaired stream reaches and the Corbin City Reservoir. The goal of this project is to make Corbin City Reservoir and the tributaries within Laurel River watershed safe for drinking, overall recreation, and aquatic life. Activities include creation of a project team, selection of eighteen (18) headwater stream segments for assessment, preparation of a sampling plan, field assessment, analysis of data, and consideration of solutions for nonpoint sources identified. In addition, an educational outreach component will involve development of environmental classroom materials in cooperation with staff from the Laurel County school system to present a watershed awareness module to the entire student body. The final project document will be entitled "Watershed Implementation Plan for Highly Impacted Portions of the Corbin City Reservoir Watershed."The project team hopes to locate 10 or more nonpoint sources of impairment in the upper Laurel River watershed, 5 or more nonpoint sources of excess nutrients contributing to impairment in the Corbin City Reservoir; determine links between watershed and reservoir impairments, and develop 5 or more practical plans for reducing found impairments to levels within the range of healthy warm-water aquatic habitats.

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STUDENT POSTERS

Presenters will be available to answer questions from 5:30 to 6:00 p.m. on Thursday, April 14.

Bioluminescent Bacteria as Indicators of Water Quality in a Wastewater-Treatment Plant
Dominic Anako, Janique Suber, Maurico Ricks, Paul Frymier and Tom Byl

Sorption and Desorption Isotherms for Toluene and Karstic Materials and Implications for Transport in Karst Aquifers
Mario Beddingfield, Callandra Collins, Khalid Ahmed, Roger Painter and Tom Byl

Modification of A Numerical Model to Predict Transport and Flux of Fecal Bacteria in a River
James Davis, Tiffany Hines, John Brew, John Finke, Lonnie Sharpe and Tom D. Byl

Free-Living Bacteria Versus Attached Bacteria: Which Contributes More to Bioremediation?
Fuzail Faridi, Tom Byl and Roger Painter

Development of a Computer Program That Uses Residence-Time Distribution and First-Order Biodegradation to Predict BTEX Removal in Karst Aquifers
Ryan Fitzwater, Roger Painter, Valetta Watson and Tom D. Byl

Effects of Land Use on Water Quality of Small Watersheds Atop the Cumberland Plateau, Sewannee, TN
L. Megan Green and Karen Kuers

Lactate Induction of the Ammonia Mono-Oxygenase Enzyme and PCE Cometabolism
LyTreese Hampton, Roneisha Graham and Tom D. Byl

Field Investigation of Water Quality and the Role of Colloids in an Urban Watershed, Mill Creek, Tennessee
Vena Jones and Kaye Savage

Quantifying Peroxide-Enhanced Toluene Biodegradation in a Single-Well Injection
Lashun King, Kendra Smith and Tom D. Byl

Biodegradation of Toluene as It Continuously Enters A 5-Liter Karst System
Shawkat Kochary, Roger Painter and Tom Byl

BIOLUMINESCENT BACTERIA AS INDICATORS OF WATER QUALITY IN A WASTEWATER-TREATMENT PLANT

Dominic Anako[1], Janique Suber [1], Maurico Ricks[1], Paul Frymier[2] and Tom Byl[3, 1]

Toxic compounds in influent wastewater can have a negative effect on the quality and performance of activated sludge systems. Monitoring the influent wastewater by chemical analysis and periodic bioassays is often too slow in response to avoid problems. Bioluminescence in certain bacteria with a luciferase enzyme can provide quick and early toxicity information. The two objectives of this project were to determine if a bioluminescent bacterium could serve as a monitor of water quality for incoming water, and, to design a way to apply this technology to provide a continuous toxicity measure. Two bioluminescent bacteria, Shk1 and PM6, were exposed to increasing concentrations of selected chemicals and their bioluminescence monitored to develop dose-response toxicity curves. Likewise, activated sludge bacteria were exposed to increasing concentrations of the same chemicals and their oxygen consumption measured. The bioluminescence and oxygen consumption responses are both indicators of bacteria activity and health. These responses were compared to determine if the bioluminescent responses were comparable to the oxygen consumption response of activated sludge. A control test done with sodium chloride salt did not cause a noticeable change in bioluminescence or oxygen consumption at any of the test concentrations (10 to 100,000 micrograms per liter). Chemicals that elicited a toxic response were zinc (Zn^{2+}), nickel (Ni^{2+}), silver (Ag^{2+}), quaternary ammonia compounds, toluene, and sodium hypochlorite. The responses of the two bioluminescent bacteria and the oxygen uptake were found to be similar in most cases, with PM6 being the most sensitive and Shk1 being the least sensitive. These results indicate that water quality may be monitored using the bioluminescent response in a way that is protective of the activated sludge chamber of the wastewater-treatment plant. Implementing a continuous water-quality monitoring system in a wastewater-treatment plant using bioluminescent bacteria must include consideration of the volume entering the facility, equipment and placement of the monitoring system in-line, potential toxins, and the system's response to a toxin.

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SORPTION AND DESORPTION ISOTHERMS FOR TOLUENE AND KARSTIC MATERIALS AND IMPLICATIONS FOR TRANSPORT IN KARST AQUIFERS

Mario Beddingfield[1], Callandra Collins[1], Khalid Ahmed[1], Roger Painter [1] and Tom Byl[2, 1]

Karst aquifers dominated by conduit flow are extremely vulnerable to fuel contamination such as from leaky underground storage tanks or spills. Direct flow paths through fractures and sinkholes often allow contaminants to move rapidly into the conduit system. Not much is known about how the fuel will interact with the carbonate rock in the conduit system. The objective of this research was to bridge this information gap by measuring sorption and desorption of fuels to karst materials. The first phase of this study involved the dissolution and desorption processes. Initial experiments (n=5) used karst bedrock fragments of known size soaked in toluene for 24 hours. Then the sterile toluene-soaked rocks were placed in sterile distilled water. The concentration of toluene dissolved in the water was measured over increasing time periods. These data were used to derive a first-order exponential rate of dissolution/desorption [$C_w(t)=C_i e^{kt}$]. The empirical value for k was 0.8958. The toluene concentration in the water reached a maximum carrying capacity in approximately 3 weeks. The second phase of this project involved sorption studies using limestone fragments of known size and water containing a known concentration of dissolved toluene. The empirical value for the sorption k was 1.006. These results show that sorption is faster than desorption and have implications for designing a model that predicts the fate and transport of fuels in karst aquifers.

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MODIFICATION OF A NUMERICAL MODEL TO PREDICT TRANSPORT AND FLUX OF FECAL BACTERIA IN A RIVER

James Davis, III[1], Tiffany Hines[1], John Brew[1], John Finke [1], Lonnie Sharpe [1], and Tom D. Byl[2,1]

Fecal pollution in surface waters is a serious water-quality 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 predict the rate of bacteria removal from the water column based on density, settling rates, and water velocity. Such models, however, do not consider survival and reproduction of bacteria in sediments, or resuspension. Flume and stream experiments were conducted to measure the survival, reproduction, and resuspension of fecal bacteria in sediments. These results can be used to modify a numerical model by incorporating survival of bacteria in bed sediments and resuspension into the water column, in addition to other parameters such as water velocity, initial bacteria concentration, and settling rate. *E. coli* and *Klebsiella* were introduced into the circulating-water flume at known concentrations and monitored as they settled or remained suspended. Bacteria concentrations were measured in the water column and the sediment along the flume to determine bacterial fate and transport. The model accurately predicted bacteria settling from the water column. The sediment fecal bacteria population declined at an exponential rate over several weeks (experimental decay value = -0.2735). This decomposition rate was coupled to the numerical model, and additional tests were done in a small stream contaminated with fecal coliform. Comparison of the model and stream data were mixed due to irregular resuspension of bacteria-contaminated sediments. Additional work is needed on factors that control resuspension of sediments.

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FREE-LIVING BACTERIA VERSUS ATTACHED BACTERIA: WHICH CONTRIBUTES MORE TO BIOREMEDIATION?

Fuzail Faridi[1], Tom Byl[2,1], and Roger Painter[1]

Researchers have implied that natural bioremediation in karst or fractured rock is unlikely to occur because of the lack of bacteria biofilm in karst aquifers. It has been stated that hydrologic and geologic characteristics of fractured rock aquifers are not suited for natural bioremediation because small microbial populations exist. If bioremediation in bedrock aquifers is dependent upon contact between surface-attached bacteria and contaminants, then bioremediation would be limited by the low surface area to volume ratio (SA/V) of karst aquifers. However, a quantitative basis for accepting or rejecting the assumption that attached bacteria dominate bacteria the biodegradation process in karst conduits has not been shown. The objective of this research was to determine if free-living karst bacteria contributed as much to toluene biodegradation as attached bacteria. To accomplish this objective, two flow-through reactor systems were established. One reactor system consisted of three 1-liter cylinders connected together with Teflon® tubing for a total open volume of 3.3 liters. The second reactor system was similar to the open system except the cylinders were filled with flat, circular glass beads that increased surface area to volume ratio approximately 500 percent compared to the open system. Raw karst water containing live indigenous bacteria was pumped through each system. The flow rate was slightly less in the high SA/V system than in the open system to compensate for the reduced volume space. Additionally, the residence-time distribution of each system was established using rhodamine dye in order to calculate biodegradation rates as a function of residence-time distribution. Results from the conservative tracer studies and toluene degradation studies were used to mathematically determine first-order degradation-rate constants for both systems. The resulting first-order rate constants were 0.014 hour^{-1} for the open system and 0.016 hour^{-1} for the high SA/V ratio system, respectively. If surface-attached bacteria were the main contributors to the biodegradation process and the SA/V ratio was increased 500 percent, a significantly higher biodegradation rate should have occurred in the high SA/V reactor. The biodegradation process was predominantly a result of free-living bacteria in the open volume. The 15 percent increase in the degradation rate for a 500 percent increase in SA/V indicates that attached bacteria may have contributed to the observed biodegradation rate.

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DEVELOPMENT OF A COMPUTER PROGRAM THAT USES RESIDENCE-TIME DISTRIBUTION AND FIRST-ORDER BIODEGRADATION TO PREDICT BTEX REMOVAL IN KARST AQUIFERS

Ryan Fitzwater[1], Roger Painter [1], Valetta Watson [1] and Tom D. Byl[2, 1]

Approximately 40 percent of the United States east of the Mississippi River is underlain by karst aquifers. Karst ground-water systems are extremely vulnerable to contamination; however, the fate and transport of contaminants in karst areas are poorly understood because of the complex hydraulic characteristics of karst aquifers. Ground-water models developed using Darcy's Law coupled to rates of biodegradation are useful for predicting the fate of fuels in unconsolidated aquifers, but have little utility in karst conduits. Conceptual models developed for karst aquifers have a consistent theme of non-ideal flow, storage, and active flow components. This research used a residence-time distribution (RTD) model approach that integrated residence times of contaminants isolated in storage areas with the residence time of contaminants moving through conduits coupled to a pseudo-first order rate of biodegradation. The microcosms consisted of four 1-liter chambers connected with small glass tubing. A peristaltic pump provided a consistent flow of karst water from a 10-gallon reservoir. First, a quantitative dye study was done to establish the residence-time distribution of the three systems. This was followed by a sterile toluene run to measure sorption of toluene to the microcosm systems. The third microcosm run incorporated karst bacteria and toluene. The removal of toluene predicted by the RTD-biodegradation model and the experiment were within 2 percent agreement (n=3). The RTD-biodegradation model was transformed into a user-friendly program that utilizes MS Excel® with Visual Basic interfaces. The input sheet of this prototype program requires site information, a biodegradation rate, and the results of a quantitative tracer study. The results, or output pages, provide residence-time distribution graphs and various statistical calculations. The output pages also report the calculated amount of BTEX removed during transport through the karst aquifer based on RTD and biodegradation. Additional work is needed to incorporate dilution into the model.

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EFFECTS OF LAND USE ON WATER QUALITY OF SMALL WATERSHEDS ATOP THE CUMBERLAND PLATEAU, SEWANEE, TN

L. Megan Green[1]* and Karen Kuers[2]

During the fall of 2003 and 2004, water samples were collected and analyzed from 6 streams on the Domain of the University of the South in Sewanee, TN to characterize the effects of land use on water quality on the Cumberland Plateau. The six small first-or second-order streams were categorized as urban or forested based on land use. Forested watersheds consist of mature, upland hardwoods and are used primarily for low impact educational and recreational activities. Urban watersheds, while supporting a significant tree cover, contained impervious surfaces such as roads, buildings, sports fields, and residential houses. Grab samples were collected from the watersheds in the fall of 2003 and 2004 and analyzed for pH, temperature, conductivity, NO_3-N, PO_4-P, *E.coli*, coliform, and total suspended solids (TSS). Initial results indicate several trends associated with land use. The average NO_3-N concentration of the urban streams, while low, was three times that of the forested streams (0.09 vs 0.31 ppm). Conductivity averaged nearly seven times higher for urban streams (134.4 vs 20.8 µS), with the highest values consistently recorded in the watershed with the highest percent impervious cover (approximately 40%). Urban streams also had higher bacterial counts (using 1 ml samples analyzed with Petrifilm™). While average pH was slightly higher for urban than forested streams (6.9 vs 5.8), TSS and PO_4-P were almost undetectable for all streams. Our data suggest small, but statistically significant differences between the water quality of urban and forested watersheds near Sewanee which merit further study.

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LACTATE INDUCTION OF THE AMMONIA MONO-OXYGENASE ENZYME AND PCE COMETABOLISM

LyTreese Hampton[1], Roneisha Graham[1], and Tom D. Byl[2,1]

Water containing bacteria was collected from a PCE-contaminated karst aquifer in north-central Tennessee to establish liquid, 1-liter microcosms. The microcosms were spiked with known concentrations of perchloroethylene (PCE) and 11 different formulations of lactic acid. The ammonia-lactate formulation caused a rapid removal of PCE and oxygen (O_2). Similar results that were achieved by using a second set of microcosms spiked with ammonia-lactate to re-test the removal rate of PCE and O_2 indicated a possible cometabolic PCE-removal process. Although only one report of PCE-cometabolism was found in the literature, ammonia-oxidizing bacteria indigenous to the karst aquifer were hypothesized to be capable of cometabolizing PCE with the ammonia mono-oxygenase (AMO) pathway. To test this hypothesis, microcosms were established using different forms of ammonia (ammonia-lactate, ammonia-chloride, ammonium plus sodium lactate), reference controls (sterile, live without food, sodium lactate, sterile + ammonia lactate), and ammonia mono-oxygenase inhibitors [2-chloro-6-(trichloromethyl) pyridine, azide, and allylthiourea]. Microcosms treated with ammonia-lactate had the most rapid reduction of PCE and O_2, followed by the ammonium + sodium-lactate treatment. The other live microcosms treated with ammonia also experienced significant drops in PCE and O_2 after 24 hours. The control (sterile and live without food) microcosms did not experience a significant drop in PCE in the same time period. After 24 hours, the rapid PCE removal in all the ammonia-treated microcosms decreased due to the consumption of the oxygen. Tests with the AMO inhibitor in the presence of ammonia-lactate did not prevent the PCE removal or O_2 consumption. Lactate may stimulate AMO or protect the enzyme from inhibition. Additional tests need to be conducted to prove that AMO is responsible for the removal of PCE. These preliminary results provide strong evidence that karst bacteria indigenous to this aquifer can cometabolize PCE.

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FIELD INVESTIGATION OF WATER QUALITY AND THE ROLE OF COLLOIDS IN AN URBAN WATERSHED, MILL CREEK, TENNESSEE

Vena Jones[1]* and Kaye Savage

Mill Creek, a watershed in Middle Tennessee that is subject to variable land use practices, is listed with the USEPA as an impaired watercourse [303(d)]. It has exceeded USEPA regulatory levels (>90th percentile of allowable limits for the given ecoregion) for siltation, nutrient load, and pathogens, and failed to reach adequate dissolved oxygen concentrations (TDEC, 2004). Colloidal constituents (particulate matter <1μm) that are permanently dispersed within the water column can contribute to the downstream distribution of pollutants due to their high surface areas and surface charge characteristics. To assess this contribution, grab samples were collected from Mill Creek in its upper, middle, and lower reaches under variable flow conditions between August and November of 2004. Tangential flow filtration was used to filter and fractionate particulates into size ranges of >0.65μm, 0.65μm - 0.45μm, 0.45μm - 0.11μm and < 0.11μm. The resulting permeates were analyzed for total and reactive phosphate and trace metals by spectrophotometer and ICP-MS, respectively. A GIS was generated to illustrate spatial relationships of pollutant loads within the watershed. Phosphate loads increased with increasing discharge. Phosphate loads also increased downstream suggesting additional contributions from runoff especially during high flow events. The majority of the phosphate load is in dissolved form under all flow conditions. Phosphate associated with particulate matter demonstrated different distributions under high and low flow conditions. At low flow, phosphate is associated with colloids in all size fractions, whereas at high flow it is associated predominantly with the smallest colloids.

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QUANTIFYING PEROXIDE-ENHANCED TOLUENE BIODEGRADATION IN A SINGLE-WELL INJECTION

Lashun King[1], Kendra Smith[1] and Tom D. Byl[2, 1]

Microcosm studies indicate that anaerobic biodegradation of toluene is generally 50 times slower than aerobic biodegradation. Because of the potential for the rapid transport of dissolved contaminants in karst conduits, aerobic conditions are needed to enhance bioremediation. This study was divided into two phases. The objective of the first phase was to evaluate oxygen-release compounds (ORCs) to enhance fuel biodegradation by free-living bacteria found in karst aquifers. The objective of the second phase was to develop a numerical method to quantify the rate of enhanced biodegradation using a single well for injection and monitoring.

In the first phase of this study, the ORCs evaluated were hydrogen peroxide (H_2O_2), calcium peroxide (CaO_2), and magnesium peroxide (MgO_2). The H_2O_2 molecules break down into oxygen (O_2) and water (H_2O). The CaO_2 and MgO_2 break down in the presence of water into O_2 and either $CaOH$ or $MgOH$, respectively. In this study, 2.25-liter liquid-karst microcosms (for example, flasks containing water and free-living karst bacteria) were spiked to 100 micrograms per liter (ug/L) toluene, and different ORC concentrations were added. Sterile controls also were established with toluene and ORCs to verify that toluene removal resulted from biological processes. Additional controls with live bacteria, but no ORC supplements, also were established for comparison. Microcosms enriched with 3 milligrams per liter (mg/L) H_2O_2, CaO_2, or MgO_2 all showed greater than 95 percent toluene removal in 7 days, as compared to 45 percent removal in live microcosms with no ORCs. When the microcosms were enriched with 300 mg/L H_2O_2, CaO_2, or MgO_2, only the H_2O_2 treatment elicited a reduction in toluene of greater than 99 percent in 7 days. The other peroxide treatments had slightly enhanced toluene removal compared to the live control, but generally were not effective at this higher concentration. The decline in MgO_2 and CaO_2 performance possibly was caused by the simultaneous release of hydroxide, which was found to inhibit biodegradation processes.

In the second phase of the project, a numerical method capable of quantifying biodegradation was developed by coupling the equation for residence-time distribution to a first-order rate of biodegradation. This numerical method was evaluated in a laboratory simulation. The simulation included a single-well injection of H_2O_2 and sodium chloride (conservative tracer) into a 5-gallon carboy containing karst water with 100 micrograms per liter toluene. The carboy was connected to a pump that delivered a constant flow of fresh bacteria-containing karst water (3 milliliters per minute) through the 5-gallon carboy, thereby diluting and transporting the conservative tracer from the carboy. The toluene was also diluted and transported from the carboy, but was also subject to biodegradation processes since it is a non-conservative chemical. The rate of toluene removal predicted by the numerical model and the observed rate of removal in the experiment were within close agreement (18 percent), confirming the numerical approach.

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BIODEGRADATION OF TOLUENE AS IT CONTINUOUSLY ENTERS A 5-LITER KARST SYSTEM

Shawkat Kochary[1], Roger Painter[1], and Tom Byl[2,1]

Contamination releases can occur as slow, long-term spills rather than as instantaneous spills. These continuous releases can result in a steady state of contaminants that can last months to years. Predicting the fate and transport of these contaminants in a karst aquifer is especially challenging because of the complex hydrogeology and uncertainties in residence time. The objective of this research was to adapt the residence-time distribution (RTD) biodegradation model, which was developed to predict the biotransformation of a single spill in a karst aquifer, for a continuous input of contaminants. Theoretically, the RTD for a karst system calculated from either a pulse- or a continuous-input tracer study would be identical, but mathematical manipulation of the data for the two approaches is quite different. Determination of the RTD from a continuous input requires numerical differentiation of tracer response data as opposed to numerical integration for the pulse approach. Three experimental runs were conducted involving the application of a continuous input: (1) rhodamine dye alone to establish RTDs for the systems, (2) sterile toluene (25 micrograms per liter) to quantify abiotic sorption, and (3) toluene with karst bacteria to quantify biodegradation. The three replicate karst systems were each 5 liters and had a continuous flow rate of 3.3 milliliters per minute. The difference between the RTD-based model prediction and the experimental toluene conversions was 17 percent.   The continuous-input approach (numerical differentiation) had the tendency to magnify experimental and random errors in the tracer response data as compared to the pulse-input method (numerical integration).

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