Proceedings of

the Nineteenth Tennessee Water Resources Symposium

April 15-17, 2009

Photo courtesy of Alan Cressler, USGS

Proceedings from the

Nineteenth Tennessee Water Resources Symposium

Montgomery Bell State Park
Burns, Tennessee

April 15-17, 2009

Sponsored by

Tennessee Section of the American Water Resources Association

In cooperation with

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Cover Design by Amy Knox, Center for the Management, Utilization & Protection of Water Resources—Tennessee Technological University, with photo courtesy of Alan Cressler, U.S. Geological Survey
Symposium Contest Guess-the-Picture Question:
The picture on the cover of the proceedings and on all the symposium publicity was taken on the Duck River. Guess, without going over, the amount of discharge on the day this picture was taken.

PREFACE

Welcome to the Nineteenth Tennessee Water Resources Symposium sponsored by the Tennessee Section of the American Water Resources Association. We have come together again this year, as we have for eighteen years before, to share insight, perspectives, and a common concern for the future of Tennessee's environment and its people.

In coming to these meetings year after year, each of us has helped to shape a creative environment much greater in effect than the many technical presentations, posters, exhibits, and demonstrations we have seen and discussed here. Whether we come to represent federal, state, or local government, private engineering firms, watershed groups and other nonprofit organizations, universities, or just ourselves, all of us who participate in these meetings have shared in a creative process that has opened new possibilities for synergy and collaboration—making everything else we do in our organizations that much more relevant and effective in achieving the best we can for Tennessee and the nation. I complement off of you for your consistent dedication and continued willingness to be part of that conversation we started here nineteen year ago.

Over these many years, our Section of AWRA has held many great meetings; I and the other members of this year's organizing committee hope that what you experience here this week reflects well on that excellent history. We have again assembled, with your help, a comprehensive series of relevant and informative presentations and posters that capture the sweep of science, policy and outreach important to water issues in our state today. And, we hope that we have helped to provoke thought and discussion on some of the most important issues arising for the future. We hope also, that you will take full advantage of all this conference has to offer, including a range of technical programs and exhibits; opportunities to network with other professionals who share common interests; and the entertainment offered by our evening socials, golf tournament, and Fun Run.

The larger technical theme for this year's meeting is the connection of energy to water—specifically, the energy we use to provide water; the water we use to provide energy; and the consequence of this linkage for our environment. We open our meeting with a keynote address that provides a global perspective on how energy and water availability may be connected in the future. Following that, we continue on this theme with a plenary panel presentation and discussion of energy-water concerns from local, state, and regional perspectives. Then, on Friday we wrap up our meeting with a breakout panel discussion on one very real example of the energy-water connection for our environment: monitoring and cleanup of the Kingston fly-ash spill.

Putting together a meeting like this requires considerable investment in time and attention throughout the year by a great many people who freely give their time and talent to make our time together both engaging and productive. I want to thank everyone who has contributed to this effort, from those who help at our registration table to the folks who set up our computers and projectors to those who help serve our food here at Montgomery Bell State Park. Thank you, also, to our loyal sponsors and exhibitors who consistently support this symposium with their time and their money. Without their support, our meetings would not be as interesting or fulfilling. Please express your appreciation to our sponsors by visiting their displays. And, thank you to all of you, our conference participants, presenters and moderators who year after year contribute to making this meeting a rewarding and enriching event.

I especially want to thank Lori Weir (USGS) for her careful attention to the many details large and small that make a meeting like this come together. Lori has once again borne most all of the burden of setting schedules, planning logistics and communicating to our membership. Without Lori's continuing guidance and overall leadership, few of us could hope to be in the right place at the right time. It is clear that the success of this organization over many years would not have happened without her. We are also very indebted to Amy Knox at the TTU Water Center who has served as Secretary for our Section over the last year and who produces our proceedings. It is rarely easy and never fun to get busy people to meet deadlines. Amy does this year after year without complaint.

Finally, I want to thank Dennis George, director of the TTU Water Center, for his service to this organization over the last several years. Dennis will be rotating off of the leadership team at the end of this year after serving for three years as President-Elect, President, and President Emeritus. His energy and enthusiasm have made the work lighter and more enjoyable for all of us involved.

Scott Gain, President, Tennessee Section AWRA, 2008 Conference Chair

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PLANNING COMMITTEE FOR THE NINETEENTH
TENNESSEE WATER RESOURCES SYMPOSIUM

- Scott Gain, U.S. Geological Survey
- George Garden, Barge, Waggoner, Sumner & Cannon, Inc.
- Dennis George, Center for the Management, Utilization and Protection of Water Resources – Tennessee Technological University
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- Forbes Walker, University of Tennessee, Biosystems Engineering & Soil Science
- Sherry Wang, Tennessee Department of Environment and Conservation
- Derek Willis, City of Memphis

1:30 – 3:00 p.m.
Wednesday, April 15
Keynote Address *by* Dr. Michael Webber, Associate Director, Center for the International Energy and Environmental Policy - University of Texas, Austin
Thirst for Power: The Global Nexus of Energy and Water

Energy and water are precious, global, and interconnected resources. Water provides electric power directly and plays a growing role for irrigation of energy crops. At the same time, the thermoelectric sector is the largest user of water in the U.S., withdrawing 200 billion gallons daily for powerplant cooling. And while the energy sector uses water, the water sector uses energy for moving, pumping, treating, and heating. Given recent trends toward water-intensive fuels and energy-intensive water production, the problems might only become worse. However, despite the close relationship of energy and water, the funding, policymaking, and oversight of these resources are typically performed by different people in separate agencies. Energy planners often assume they will have the water they need and water planners often assume they will have the energy they need: if one of these assumptions fails, the consequences will be dramatic. But, by bringing scientific and engineering expertise to bear on this vastly understudied problem, this scenario might be avoided. For this talk, Dr. Webber will build from his lectures in his courses and some of his recently published technical journal articles to share his perspective on the nexus of energy and water in America. In particular, he will discuss the water impacts of various alternative fuels that might potentially grow in use, including unconventional fossil fuels, electricity, and biofuels.

12:30 – 1:30 p.m.
Thursday, April 16
Luncheon Presentation *by* Tiffany Wilmot (LEED AP), of Wilmot Inc.
From the Gore Residence to LP Field — How Green are Tennessee's Buildings?

You can't pick up a magazine or turn the dial without hearing about new efforts to build green. Why is it happening and why is it important? What does green cost and how does it pay? Where should we go from here ("green building's" dirty little secret)? With a review of her experience on showcase projects, Ms. Wilmot will discuss motivations, challenges and opportunities for high performance building in Tennessee.

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SESSION 1A

WATER AND ENERGY PANEL
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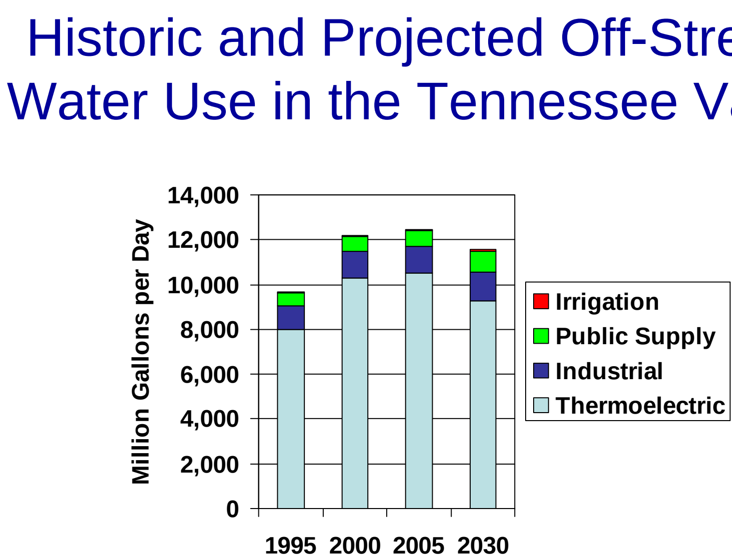
Water Use for Electrical Energy Production in the Tennessee River Valley
Charles E. Bohac

Sustainability Science: Perspectives on the Energy-Water Nexus
Randy Gentry

WATER USE FOR ELECTRICAL ENERGY PRODUCTION IN THE TENNESSEE RIVER VALLEY

Charles E. Bohac, Ph.D., P.E., CGWP[1]

The Tennessee River is the fifth largest river system in the Nation with a watershed that covers 40,900 square miles in seven southeastern states. In 2005, withdrawals for off-stream water use totaled over 12 billion gallons per day with almost 85 percent used for electrical energy generation. The presentation describes how water is used in the Tennessee River Valley and examines potential changes in water use as the result of changes in demand for electrical energy and in generation technology.



[1] Water Supply Specialist, Tennessee Valley Authority, 1102 Market Street, Chattanooga, TN 37402, 423-751-7319, cebohac@tva.gov

SUSTAINABILITY SCIENCE: PERSPECTIVES ON THE ENERGY-WATER NEXUS

Randy Gentry, Ph.D., P.E.

We are in an era of unprecedented pressure on natural resources to meet the demands of continued industrial development globally, and continued population growth. More locally "With U.S. policymakers struggling to contemplate a future where oil pipelines sputter and water wells come up empty, panelists at the recently concluded American Association for the Advancement of Science meeting in Boston urged a rethink of the connection between these two crucial resources.[1]"

The debate over the past few years has focused on the lack of coordinated planning in order to answer the difficult question of resource availability and sharing. Recently, "In late 2006, the Department of Energy delivered a report to Congress on the interdependence of energy and water. This was complemented by the Energy-Water Roadmap, a series of workshops that solicited opinions from over 300 water managers and regulators on where the gaps lie in efforts to sustain future supplies of these precious resources. Now, the 2009 budget contains US$8 million earmarked to help fund a Department of the Interior census of domestic water supplies — the first in 30 years.[1]"

The Energy-Water Nexus national laboratory working group recognized in their report "To sustain energy production, the United States must gain a detailed understanding of the interdependencies of water-reliant systems, balance the needs of all users, and develop technologies to reduce water use and loss. These goals can be achieved through a focused research and development program that integrates the following three components: (1) prediction and decision support, (2) science and technological innovation, and (3) technology transfer and implementation.[2]"

The sustainability science paradigm focuses on all of the energy-water nexus working groups identified goals. A perspective of how a sustainability science research program in this area might work will be provided in the presentation.

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[1] Hoyle, Brian (2009) "The energy-water nexus: deja-vu all over again?" Nature Climate Reports/ doi:10.1038/climate.2008.22.

[2] March 9, 2009: http://www.sandia.gov/energy-water/nexus_overview.htm.

SESSION 2A

GEOMORPHOLOGY — CHANNELS
8:30 a.m. – 10:00 a.m.

Coherent Structure Model for Gravel-Bed Rivers: A Backdrop for Natural Channel Design
Brian Belcher

Geomorphic Observations Along the Clinch River in Tennessee and Virginia
William J. Wolfe, Timothy H. Diehl, Gregory C. Johnson, and Jennifer L. Krstolic

Restoration of the Flat Fork Valley
Andrew Bick

GEOMORPHOLOGY — BIOTA
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Evaluation of CADDIS Stressor Analysis for Tennessee – Progress, and Request for Your Input
John Harwood and Bonnie Newby

COHERENT STRUCTURE MODEL FOR GRAVEL-BED RIVERS: A BACKDROP FOR NATURAL CHANNEL DESIGN

Brian Belcher, PhD, PE[1]

GEOMORPHOLOGY

Turbulent bursting and associated fluid motions are important physical processes in gravel-bed rivers termed coherent structures. A number of limitations exist that prohibit the incorporation of these physical processes associated with turbulent velocity field structures for use in understanding and predicting the evolution of gravel-bed rivers. A goal of stream restoration is to control the dynamics of coherent structures, e.g. to make them slow moving with low energy such that banks are not eroded due to eddy scour. Experimental measurements of velocity fields in gravel-bed flow conditions in the laboratory were used to characterize temporal and spatial structure which may be attributed to coherent vortex structures. Flow visualization techniques were developed to characterize the size, shape and spatial patterns of turbulent structures which exist under equilibrium flow conditions and to accurately determine velocity distributions for the gravel-bed conditions. Coherent structures were observed to be arranged into knot patterns which exhibit reconnection to vortex tubes having origin at the bed. Under the specific conditions of a particularly violent turbulent burst, the fluid domain may be modeled as a flux-conserving flow of prime knots formed of thin-cored flux tubes embedded on an abstract vortex surface itself having topology of a Klein manifold. This model includes reconnection to the vortices shed from individual gravel particles on the bed and describes the evolution of the divergence-free field which has minimal energy, i.e. an equilibrium solution of the governing laws which is the backdrop for understanding velocity distributions and the concept of natural channel design.

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GEOMORPHIC OBSERVATIONS ALONG THE CLINCH RIVER IN TENNESSEE AND VIRGINIA

William J. Wolfe*[1], Timothy H. Diehl[1], Gregory C. Johnson[2], Jennifer L. Krstolic[3]

Reconnaissance-level field observations were made along the Clinch River in winter 2007 and summer 2008 to establish the geomorphic context for a study of land use, water quality, and mussel habitat. Field observations covered the Clinch main stem between Tazewell, Tennessee (river kilometer 257) and Cleveland, Virginia (river kilometer 436) and were supplemented with analysis of historical maps and aerial photographs. Field observations and examination of maps and photographs indicate that the Clinch River channel has been stable for the past 80 years, with the channel location essentially unchanged between 1925 and 2007. Several old fords retain parts of their boulder and timber road beds, even though maintenance ended many decades ago. The persistence of these artificially placed boulder structures is notable because they have been subjected to high flood flows, including one flood in 1977 with a recurrence interval of 100 years.

Prominent geomorphic features include two depositional surfaces that run along the channel throughout the study reach. The lower of these surfaces is a narrow flood plain about 2 meters above typical low water. This floodplain surface is bounded by a terrace about 6 meters above typical low water, which extends away from the channel to the valley wall. Substrate in several mussel-habitat areas included lateral and midchannel alluvial bars with composition ranging from silt and fine sand to small boulders. Boulders and cobbles dominate the bed in many reaches, interspersed with bedrock ledges that control grade at numerous points. Coal fragments, ranging in size from sand to cobbles, were noted at on the bed and bar surfaces at several sites.

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RESTORATION OF THE FLAT FORK VALLEY

Andrew Bick, PE[1]

When completed, the Flat Fork restoration project will be the largest of its kind in Tennessee, with nearly 19,000 linear feet of restored stream, over 70 acres of planted riparian buffer and over four acres of enhanced wetland. Flat Fork and its four tributaries within the project limits drain a 15 square mile watershed at the edge of the Cumberland Plateau, about 20 miles northwest of Oak Ridge.

This presentation will summarize the site assessment and design phases and provide lessons learned from the construction phase, expected to be complete in April 2009. The discussion will include highlights of sediment transport evaluations, which used data collected from an in-stream stage recorder, pebble counts, bar sampling and two pit samplers. Sediment movement from the relatively steep supply reach through the relatively flat project reach on the plateau was evaluated using a variety of critical shear stress and multi-fraction relationships. Details of how HEC-RAS hydraulic modeling was used to support the analyses will also be presented.

Flat Fork, included on Tennessee's 2006 303(d) list for numerous impairments, has been impacted by decades of livestock grazing, row crop cultivation and dredging. A primary project goal is to remove Flat Fork from the 303(d) list. A post construction monitoring program, supported by the Tennessee Department of Environment & Conservation, will build on nearly a decade of ongoing biological and chemical monitoring on Flat Fork. This restoration effort will provide an important connection from the protected headwaters in Frozen Head State Park to Crooked Fork.

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USE OF INDICATORS OF HYDROLOGIC ALTERATION FROM HSPF SIMULATED HYDROGRAPHS TO ASSESS THE IMPACT OF FLOODS AND DROUGHTS ON TROUT POPULATIONS IN UNGAGED STREAMS OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Keil J. Neff*[1], Joseph Parker[2], John Schwartz[3], Matt Kulp[4], Steve Moore[5], and Meijun Cai[6]

Hydrological processes impact the functioning of ecosystems and influence fish population dynamics. The flow regime of a stream affects the structure, composition, and productivity of fish communities by regulating abiotic habitat conditions and biotic processes. In the Great Smoky Mountains National Park (GRSM), native brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) populations have declined in some watersheds over the past two decades. Although it is believed that trout have primarily been impacted by episodic acidification, the effect of natural hydrological extremes or disturbances on brook trout populations in GRSM watersheds is examined in this research. The current GRSM fish-sampling program was established in 1986 in which 69 streams (369 sites) are routinely sampled by GRSM fisheries biologists with standard electroshocking protocols, in which detailed data are collected on fish condition (length, weight), abundance, year class strength, and biomass. To evaluate the impact of hydrological disturbances on trout, indicators of hydrologic alteration (IHA) were computed for a select number of the total fish sampling sites between 1990 and 2007. Because fish sites were located in ungaged watersheds, the Hydrological Simulation Program - FORTRAN (HSPF) was used to model flows. Outlets were defined for each fish-sampling site and flow was calculated for the period of record. The model was calibrated by adjusting parameters including storage, infiltration, runoff, and ground water for three elevation classes (low < 800 m $\leq$ medium < 1200 m $\leq$ high) to fit flow output from model with two USGS gaging stations and one NPS gaging station (Figure 1). IHA software was used to define hydrological alteration including the a) magnitude, b) frequency, c) duration, d) time, and e) rate of change for 1) extreme low flow, 2) low flow, 3) high flow pulse, 4) small floods, and 5) large floods. Figure 2 illustrates an example of environmental flow components defined in IHA software of a HSPF hydrograph for one study site. The ecohydrologic regimes, characterized using the IHA method, were compared with trout abundance and biomass at each site. Results indicated

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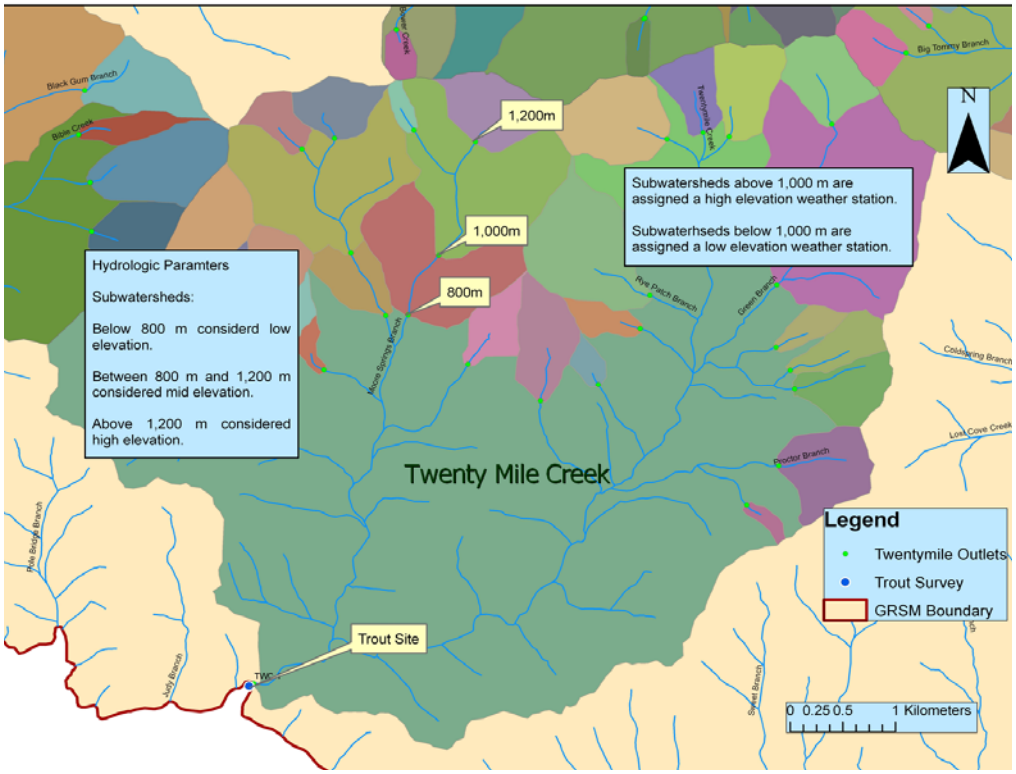

Figure 1. HSPF parameterization.

the abundance of young-of-the-year brook and rainbow trout significantly declined after extreme floods and droughts. In particular, low-flows during droughts significantly reduced recruitment for both brook and rainbow trout, which is likely due to decreased spawning habitat. Brook trout populations in larger low-elevation streams showed more stability compared to smaller headwater streams. Extreme flood conditions significantly lowered young of year (YOY) trout abundance, particularly rainbow trout populations. Low flow (drought) conditions reduced fish biomass and were highly correlated with lower abundance and biomass of brook trout. These impacts were most pronounced in low elevation streams, which provide less temperature refugia and increased competition from rainbow trout. Brook trout repopulated stream reaches in 2-3 years following low flow regimes. This study provides a valuable tool to watershed managers and fishery biologists of the GRSM to understand the effects of hydrologic disturbances on trout population dynamics, and contributes a unique hydrology model for GRSM watersheds to be used for future research.

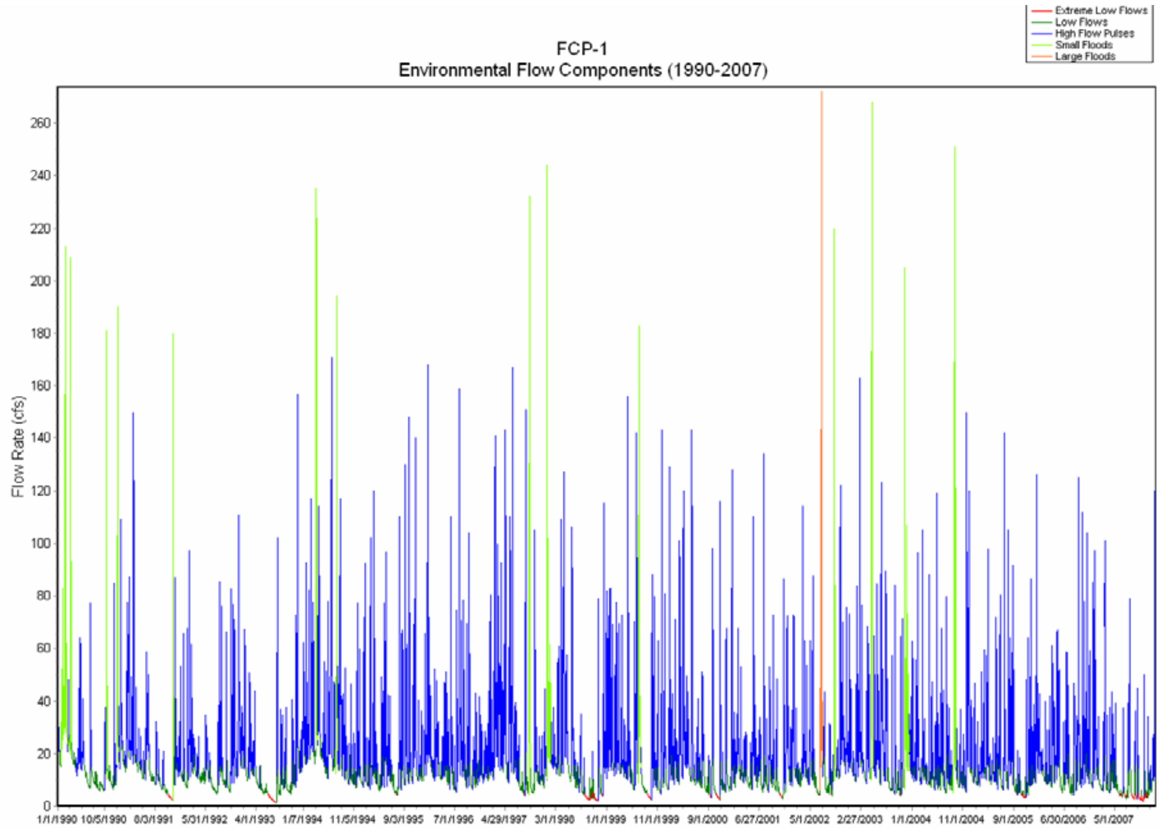

Figure 2. Environmental flow components example.

EVALUATING SUSPENDED SOLIDS IMPACTS USING SPECIES AND TOXICITY DATA

Robert Liddle[1]* and Steve Bakaletz[2]

ABSTRACT

This paper summarizes the major factors involved with assessing suspended sediment impacts on aquatic life and presents a method to relate Total Suspended Solids (TSS) and duration of exposure to specific aquatic effects. The procedures are a modification of the Newcombe and MacDonald (1991) method, where toxicity effects were ranked and statistically related to concentration and duration of exposure using linear regression. "Rank" is an integer from 1 - 14 based on the degree of effect measured during the toxicity study. A rank of one means the study species had an increase in coughing rate, whereas a rank of fifteen means 80 to 100 % mortality occurred. In our procedure, an inventory is made of benthic invertebrates and natural fish species present in the target stream. Sediment toxicity data in the literature is assimilated to tabulate sediment concentration, duration of exposure, the aquatic species tested, and the degree of effects. Multiple regression and other statistical tests are used to assess the methodology. The procedure was tested on a tributary to the Cumberland River in Tennessee. This procedure can be used in lieu of a site-specific toxicity study. Our hypothesis was that the revised methodology would give better results than the Newcombe and MacDonald method because it is tailored to the aquatic species present in the stream and because we included all current toxicity research. Our results were unsatisfactory. The only relationship between rank and TSS/duration was with the dataset for fish species only. The advantages and problems with the method are discussed.

INTRODUCTION

A common task of resource managers is to assess the impacts of sediment to aquatic life. Toxicity is generally related to the *concentration* of the sediment, the *duration* of exposure, and the *frequency* of exposure (Schwartz, and others, 2008). A general procedure is to characterize the sediment, select an indicator species representative of the stream life, and conduct toxicity tests. Fisheries biologists often have to determine what species to test, the duration of the test, and the level of stress to the fish that is acceptable. For example, an unacceptable effect may be habitat degradation, inhibition of reproduction, behavioral effects on juveniles, 20% mortality, 50% mortality, etc. Or, a regulatory authority may make a specific procedure mandatory. Toxicity tests are expensive, time consuming, and sometimes arbitrary or irreproducible. In a landmark paper, Newcombe and MacDonald (1991) tried to solve this dilemma by relating the affect of sediment to the concentration and duration of exposure. In this paper, we refine the method, adapt the procedure to a stream in Tennessee, and discuss the advantages and shortcomings of the method.

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The Newcombe and MacDonald (1991) article is still the most requested article on the American Fisheries Society web page (http://afs.allenpress.com/perlserv/?request=get-archive accessed 2/25/2009). These authors inventoried over 70 toxicity studies on "natural" (uncontaminated) sediments and their effects on freshwater and saltwater fishes. They recorded the sediment concentration listed in the study, the duration of exposure, and the toxicological response of the species. Toxicological effects were grouped into 14 classes (see table 1).

Table 1	
RANK	**TSS Effects on fish and aquatic Life**
14	> 80 to 100% mortality
13	> 60 to 80% mortality
12	> 40 to 60% mortality, severe habitat degradation
11	> 20 to 40% mortality
10	0 to 20% mortality
9	Reduction in growth rates
8	Physiological stress and histological changes
7	Moderate habitat degradation
6	Poor condition of organism
5	Impaired homing
4	Reduction in feeding rates
3	Avoidance response, abandonment of cover
2	Alarm reaction, avoidance reaction
1	Increased coughing rate

Newcombe and MacDonald (1991) formulated a table of toxicity tests from the literature and listed the concentration used in the test, the duration of the test, and the result of the exposure along with the rank (from table 1 above). An example of the data is included in table 2 below:

Table 2. Summary of data on exposures to suspended sediment that resulted in lethal responses in fishes. C = concentration (mg/L) and D = duration (h)

	Exposure		**Stress index**		**Rank of**	
Species	**C**	**D**	**Log(e)*(C*D)**	**Effect**	**Effect**	**Source**
Trout	8	24	5.257	Avoidance	4	Hughes 1974
Plankton	1700	2	8.132	Lethal 50%	12	Rosen 1977
Plankton	5000	168	13.641	Lethal 80%	14	Rosen 1977
Etc.						

They did not find a correlation between concentration and the ranking system they developed, nor between duration of exposure and the ranking system. However, when they combined concentration and duration, they found a statistically significant correlation. One of the final models developed is listed below:

Severity of effect (Rank of Effect) = 0.738 $\log_e$ [C * D] + 2.179; $r^2 = 0.638$

Later, Newcombe (2000, 2003) developed several additional models using a more familiar regression technique that does not combine concentration and duration into one variable. In our study, we also kept the two variables of concentration and duration of exposure separate and used multiple linear regression.

REVIEW OF LITERATURE

Sedimentation is the detachment, transport, and deposition of inorganic particles by water. Numerous publications discuss the difficulty in characterizing sediment (Edwards and Glysson, 1999; Guy, 1969, 1970; Horowitz, 1991; Kondolf and Piefay, 2003, Chapter 5 & 6; Leopold and Wolman, 1992, Chapter 6 & 7; Porterfield, 1972; Simons and Sentürk, 1992, Chapter 4, 8, and 10; and Radtke, 2005, p. 11-36); a summary follows:

ISSUES WITH SEDIMENT PHYSICAL PROPERTIES:
- Dealing with assorted grain sizes (clay, silt, sand, gravel, pebble, cobble, and boulders)
- Solid verses dissolved particles (nanoparticles, colloids, and filter pore-size ambiguity)
- Considering sediment-like material (floating material, organic matter, colored water, ice)
- Turbidity not always related to sediment concentration

SEDIMENT CHEMISTRY ISSUES:
- Contaminated sediment verses “natural sediment”
- Redox variation in bottom sediments changes solubility and chemistry
- Precipitation/dissolution kinetics may need to be considered
- Sediment chemistry differs between particle sizes and source material geochemistry
- Synergistic or antagonistic effects of dissolved solids, water temperature, etc.

SEDIMENT TRANSPORT ISSUES:
- Different “sediment” transport categories (bedload, wash load, and suspended sediment)
- Geomorphic issues (streams incised in bedrock, sand-bottom channels, gravel bars, etc)
- Cohesive vs. non-cohesive stream banks
- Changes in stream bottom vegetation, channel configuration, roughness, H.R., etc
- Settling depends on sediment weight, size, shape, density, charge, and the fluid properties.
- Sediment concentration is not always proportional to flow
- Similar precipitation events may not produce similar sediment-graphs
- Sedimentation varies with precipitation amount, type (snow, ice, rain), distribution (areal and temporal), and rainfall intensity

SEDIMENT SAMPLING ISSUES:
- Sampling equipment is specialized, expensive, and requires expertise
- Location issues: riffles vs. pools, curved vs. straight segments, lentic vs. lotic systems
- Width, depth, and time-integrated sampling is usually necessary
- Sampling sediment and measuring flows may take up to an hour (non-instantaneous)
- Collection and subsequent compositing requires knowledge and judgment
- High flows and floods are difficult to sample for safety and other reasons
- Temporal, seasonal, and diurnal changes in sediment can occur
- Land use, wet-dry years, and climate may change during the monitoring period
- Sampling for concentration verses sediment load requires different considerations
- Dilution of sediment may need to be considered (baseflow, reservoirs, and other discharges)
- Sediment may change during transport to the laboratory (microbial, redox, etc)
- Assorted laboratory techniques are used (SS, TSS, SSC, pebble counts, turbidity, etc)
- Statistical analysis varies by reviewer, particularly for load or flow-adjusted concentration

An understanding of how sediment affects aquatic life is important in assessing impacts. Most effects have been proven, while others have just been postulated. These effects have been discussed in the literature by Waters (1995, p. 173-175) and are summarized below:

SEDIMENT CAN AFFECT TURBIDITY and REDUCE LIGHT PENETRATION:
- Reduction of photosynthesis affects algae
- Impairment of visual feeding efficiency
- Increased invertebrate drift
- Prey is less able to avoid predators
- Changes in fish migration patterns as fish avoid turbid tributaries
- Sediment may favor some adaptable fish, leading to changes in diversity and structure

SMOTHERING or ABRASION OF AQUATIC PLANTS, ANIMALS, EGGS, or FRY:
- This affects filter feeders, fish, benthic macroinvertebrates, mussels, and amphibians
- Reduced food gathering by filter feeding insects (net-spinning caddis fly)
- Abrasion injures fish and makes them susceptible to infection, disease, parasites, etc
- Lowered body condition, slower growth, reduced productivity may occur

SEDIMENT DEPOSITED ON THE RIVER BOTTOM AFFECTS AQUATIC LIFE:
- This changes embededness and particle size distribution, thus a change in habitat
- Change in embededness is habitat reduction; inundation by sediment is habitat change
- Stream bottom can become armored by ferric and other metallic oxyhydroxides
- Coating of river bottom by sediment can change redox and dissolved oxygen conditions
- Low oxygen inhibits obligate aerobes
- Heterotrophic microorganisms are smothered by fine sediment
- Particle size is directly proportional to abundance of benthic invertebrates (EPT taxa)
- Aquatic life may be adapted to high sedimentation during spring, but not during other seasons
- Fish that lay eggs under rocks experience unsuccessful recruitment

Often the goal of aquatic resource protection is to preserve or enhance the entire aquatic ecosystem. However, regulators may measure this in several ways. They may look at a single species (an endangered fish), or the goal may be to protect 85% of the major aquatic groups. The important point is to understand that not all aquatic plants and animals are tested for toxicity, nor are all species necessarily protected. Nonetheless, they are all important in maintaining a stable ecosystem. Below is one grouping of aquatic life taken primarily from Hauer and Lamberti (1996); there are many others.

RIPARIAN AND AQUATIC PLANTS:
- Bryophytes - mosses and liverworts
- Vascular plants
- These serve as food, cover, may increase dissolved oxygen, and provide organic matter.

HETEROTROPHIC MICROORGANISMS:
- Fungi, bacteria, and protists
- Bacteria and protists decompose dissolved and particulate organic matter; then are consumed by higher trophic levels.

BENTHIC ALGAE:
- Plants - green algae
- Animals - diatoms and blue-green algae
- Periphyton (“biofilm”) - the mixed mass of algae, microorganisms, etc
- Some conduct photosynthesis, serve as a food source, provide organic matter, or habitat

MEIOFAUNA:
- Mostly obligate aerobes (rotifers, copepods, nematodes, etc)
- They are seldom studied, but may be the most abundant animal in the river
- May dominate benthic communities in terms of numbers and diversity
- Most live within the top few centimeters of the sediment
- Many are sensitive to pollution, and sediment quality dictates species

BENTHIC MACROINVERTEBRATES:
- Invertebrate fauna retained by a 500 um sieve
- Can include hundreds of species from numerous phyla
- Arthropods - insects (ex. shredders or scrapers), mites, scuds, and crayfish
- Mollusks - mussels, snails, and clams
- Worms - segmented, roundworms, flatworms
- Aquatic insects - dragonflies, mayflies (E), stoneflies (P), and caddisflies (T)
- EPT taxa are sediment intolerant

FISH:
- The top of the underwater food chain; many species and classifications
- Some are sediment intolerant and some tolerate sediment only when adult

In-situ sediment toxicity testing is difficult. As stated above, characterizing sediment is difficult and tracking mobile aquatic life is not practical. If dead fish are found after a sediment event and an autopsy concludes death was by suffocation or consumption, perhaps this is evidence enough. Stationary indicator species such as freshwater mussels may be a good in-situ test organism. However, separating out the impacts from sediment may be difficult. For example, after a storm event, nutrients from farms, feedlot waste, and urban runoff may contribute to toxicity in addition to the sediment. For these reasons, sediment toxicity tests are usually conducted in the laboratory. Most of the toxicity data is from "contaminated sediments," natural eroded sediments that have been mixed with organic pollutants, nutrients, metal waste, or other anthropogenic pollutants. This paper is only concerned with "natural sediments" that have no anthropogenic pollutants of significance as opposed to "contaminated sediments." In practice, it is often difficult to distinguish between the two.

In the past, toxicity tests consisted of placing the test organism(s) into a tank, exposing them to various sediment concentrations, and counting the number of dead according to protocol (ex. Lethal Concentration where 50 % of the organisms died or "LC-50"). Later, the concentration and duration of the exposure was varied to determine the response of the organism to varying real-life sediment events. Below is a short summary of the shortcomings of toxicity tests.

TOXICITY TEST CONSIDERATIONS:
- Deciding what organisms to test
- Testing for the effects of increased frequency of sedimentation
- Using tap water, filtered stream water, unfiltered water, or synthesized water
- Whether to include or exclude the bottom sediments during the test
- Using actual bottom sediment or synthesized sediment in the lab
- Use of actual river sediment, natural clays, or synthesized sediment
- Prevention of river sediment undergoing biochemical change during transport to the lab
- Do you filter out organic matter, worms, insects, etc. from your field sediment sample
- How to keep the sediment in suspension during the test
- Will the velocity of the sediment be similar to that experienced during a storm event
- Eggs, juveniles, adults, and reproducing adults may have different sediment tolerance.

- Evaluating the effects on sediment on various stages in the life cycle of the fish
- The distinction between natural sedimentation and contaminated sediment
- Accounting for the antagonistic and synergistic effects of the river water
- How is dissolved oxygen levels controlled and maintained during sediment circulation
- What are the end points of the test
- Selection of acute or chronic toxicity test
- Determining the appropriate duration for the test
- How do you account for sediment that modifies the aquatic habitat
- Evaluating interstitial (pore) water within the sediments
- How do you set up a control experiment, and what criteria does the control have to meet
- Testing for avoidance, visual impairment, or other behavioral effects to fish

The newer toxicity test methods address many of the problems noted above. Toxicity assessments such as the EPA Sediment Toxicity Identification Evaluation (TIE) procedure (Ho and Mount, 2007) provide guidance to help overcome the shortcomings of sediment toxicity tests. EPA TIE procedures have been structured around three elements: characterization (Phase I), identification (Phase II), and confirmation (Phase III). Procedures include:

- Evaluation of the water, sediment, and interstitial (pore) water
- Evaluating volatile compounds by aeration
- Manipulating pH and ammonia in increments
- Evaluating cationic metals
- Identifying organic compounds in the sediment
- Manipulating the test under acid and basic conditions
- Evaluating sulfide effects
- And several other issues

Numerous test organisms and fish have been used over the years during toxicity tests. Table 3 (below) lists some of the more common test species. A recent EPA document (Berry and others, 2003) discusses the biological effects of "natural" suspended and bedded sediment and summarizes over 300 toxicity tests that have been conducted on over 50 different species of freshwater and marine fish and other aquatic life.

Table 3. Typical test organisms in sediment toxicity tests.

Scientific Name	Common Name
Chironomus dilutus	Chironomid, midge larvae
Chironomus riparius	Chironomid, midge larvae
Hyalella azteca	Amphipod, scud
Lumbriculus variegatus	Oligochaete, "worm"
Gammarus pulex	Amphipod
Hexagenia limbata	Ephemeroptera, mayfly
Tubifex tubifex	Oligochaete
Diporeia sp	Amphipod, Great Lakes
Ceriodaphnia dubia	Cladoceran, water flea
Daphnia magna	Cladoceran, water flea
Daphnia pulex	Cladoceran, water flea
Pimephales promelas	Fish, fathead minnow
alvelinus fontinalis	Fish, brook trout
Oncorhynchus mykiss	Fish, rainbow trout
Modified from Ho, 2007, P. 18-19	

STUDY SITE

The method we used was tested on the Big South Fork of the Cumberland River in northeast central Tennessee and southeast central Kentucky. The watershed contains the Big South Fork National River and Recreation Area (See Figure 1):

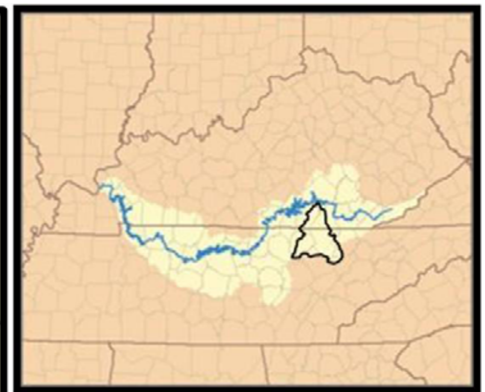


FIGURE 1
LOCATION MAP

METHODOLOGY

We hypothesized that a better correlation between sediment concentration, duration, and effect could be obtained by using only the toxicity test species found in the river being evaluated. Our null hypothesis was that there was no correlation between the three variables at $\propto = 0.05$. We also felt that by updating the list of toxicity results we could improve the reliability of the method. Our revised procedure is as follows:

1) Inventory the river and list all species present (we exclude introduced species)
2) Obtain a current list of toxicity tests conducted on the species found in the river
3) Modify the ranking of effects (Table 1) to match the objectives of the assessment

The inventory of aquatic life found in the river is listed in table 4 below and the toxicity tests found for these species is listed in table 5 below:

Table 4. Aquatic species found at study site.

1	Atherinopsidae	Brook Silverside	Labidesthes sicculus
2	Centrarchidae	Bluegill	Lepomis macrochirus (Rafinesque)
3	(Sunfish)	Green Sunfish	Lepomis cyanellus
4		Largemouth Bass	Micropterus salmoides (Lacepede)
5		Longear Sunfish	Lepomis megalotis (Rafinesque)
6		Rock Bass	Ambloplites rupestris (Rafinesque)
7		Smallmouth Bass	Micropterus dolomieui (Lacepede)
8		Spotted Bass	Micropterus punctulatus (Rafinesque)
9	Catostomidae	Black Redhorse	Moxostoma duquesnei (Lesueur)
10	(suckers)	Golden Redhorse	Moxostoma erythrurum
11		Northern Hog Sucker	Hypentelium nigricans (Lesueur)
12		Quillback	Carpisodes cyprinus (Lesuer)
13		White Sucker	Catostomus commersoni (Lacepede)
14	Cyprinidae	Blacknose Dace	Rhinichthys atratulus (Hermann)
15	(Minnows or Carp)	Blackside Dace	Phoxinus cumberlandensis
16		Carp	Cyprinus carpio Linnaeus
17		Creek Chub	Semotilus atromaculatus (Mitchell)
18		Golden Shiner	Notemigonus crysoleucas (Mitchell)
19		Mimic Shiner	Notropis volucellus
20		River chub	Nocomis micropogon
21		Rosefin Shiner	Notropis ardens (Cope)
22		Rosyface Shiner	Notropis rubellus (Agassiz)
23		Sand Shiner	Notrospis stramineus (Cope)
24		Spotfin shiner	Notropis spilopterus
25		Stoneroller	Campostoma anomalum (Rafinesque)
26		Striped Shiner	Notropis chrysocephalus) (Rafinesque)
27		Whitetail Shiner	Notropis galacturus (Cope)
28	Esocidae (Pikes)	Muskellung	Esox masquinongy ohioensis
29	Ictaluridae	Channel Catfish	Ictalurus punctatus (Rafinesque)
30	(North American freshwater Catfish)	Flathead Catfish	Polydictis olivaris
31		Stonecat	Noturus flavus

32		Yellow Bullhead	Ictalurus natalis (Lesueur)
33	Pecidae	Banded darter	Etheostoma zonale
34	(Perches)	Blackside Darter	Percina maculata (Girard)
35		Bluebreast Darter	Etheostoma camurum (Cope)
36		Channel darter	Percina copelandi
37		Emerald Darter	Etheostoma (Ulocentra) sp.
38		Greenside Darter	Etheostoma blenniodes (Rafinesque)
39		Logperch	Percina caprodes (Rafinesque)
40		Olive darter	Percina squamata
41		Rainbow Darter	Etheostoma caeruleum (Storer)
42		Spotted Darter	Etheostoma maculatum (Kirtland)
43		Walleye	Stizostedion vitreum
44	Unionids	Mussels	various
45	Algae	Green, diatoms, etc.	various
46	Other	undetermined	

Table 5. Published sediment toxicity test data (C = concentration, D = duration of test).

	TAXON	C in mg/L	D in hours	Effect	Rank	Source
1	Zooplankton	24	0.15	Reduced capacity to assimilate food	4	Newcombe
2	Benthic Invertebrates	8	2.5	Lethal: increased rate of drift	11	Newcombe
3	Macro invertebrates	82.5	24	Lethal: reduction in population size	11	Newcombe
4	Benthic Invertebrates	1700	2	Lethal: alteration in community structure and drift patterns	11	Newcombe
5	Zoobenthos	12.5	720	Lethal: reduction in standing crop	11	Newcombe
6	Benthic Invertebrates	8	1440	Lethal: up to 50% reduction in standing crop	13	Newcombe
7	Cladocera	237	72	Lethal: survival and reproduction harmed	13	Newcombe
8	Benthic Fauna	29	720	Lethal: to Trichoptcra, Ephemeroptera, Crustacea, and Mollusca	15	Newcombe
9	Benthic Invertebrates	116	1440	Lethal: reduction in standing crop	13	Newcombe
10	Cladocera & Copepoda	400	72	Lethal: gills and gut clogged	15	Newcombe
11	Benthic Invertebrates	32	1440	Lethal: reduction in standing crop	13	Newcombe
12	Zoobenthos	100	672	Lethal: reduction in standing crop	13	Newcombe
13	Benthic Invertebrates	62	2400	Lethal: 77% reduction in population size	14	Newcombe
14	Benthic Invertebrates	77	2400	Lethal: 53% reduction in population size	13	Newcombe
15	Bottom Fauna	325.5	720	Lethal: reduction in population size	13	Newcombe
16	Benthic Invertebrates	390	720	Lethal: reduction in population size	13	Newcombe
17	Benthic Invertebrates	278	2400	Lethal: 80% reduction in population size	14	Newcombe
18	Stream Invertebrates	130	8.76	Lethal: 40% reduction in species diversity	15	Newcombe
19	Benthic Invertebrates	743	2400	Lethal: 85% reduction in population size	15	Newcombe
20	Benthic Invertebrates	5108	2400	Lethal: 94% reduction in population size	15	Newcombe
21	Stream Invertebrates	25000	8760	Lethal: reduction or elimination of populations	15	Newcombe
22	Daphnids	75	432	Reduced Feeding	4	Berry
23	Red Algae Lemanea	5000	504	Reduced Primary Production	9	Berry
24	Red Algae Egaria	35	960	Reduced Growth	9	Berry
25	Bass - Striped (Larval)	200	0.42	Feeding Rate Reduced 40%	4	Berry
26	Bass - Striped	800	24	Development rate slowed significantly	8	Berry
27	Bass - Striped	100	24	Hatching delayed	10	Berry
28	Bass - Striped	1000	168	Reduced hatching success	10	Berry

29	Bass - Striped (Larval)	1000	68	Mortality rate 35%	12	Berry
30	Bass - Striped (Larval)	500	72	Mortality rate 42%	13	Berry
31	Bass - Striped (Larval)	485	24	Mortality rate 50%	14	Berry
32	Perch (Yellow)	500	96	Mortality rate 37%	12	Berry
33	Perch (Yellow)	1000	96	Mortality rate 38%	12	Berry
34	Bass - Striped	1500	336	Haematocrit increased (FE)	8	Berry
35	Bass - Striped	1500	336	Plasma osmolality increased (FE)	8	Berry
36	Darters	2045	8760	Darters absent	15	Berry
37	Bass (largemouth)	62.5	720	Weight gain reduced 50%	4	Berry
38	Bass (largemouth)	144.5	720	Growth retarded	9	Berry
39	Bass (largemouth)	144.5	720	Unable to reproduce	10	Berry
40	Bluegill	423	0.05	Rate of feeding reduced	4	Berry
41	Bluegill	15	1	Reduced capacity to locate prey	2	Berry
42	Bluegill	144.5	720	Growth retarded	9	Berry
43	Bluegill	62.5	720	Weight gain reduced 50%	9	Berry
44	Bluegill	144.5	720	Fish unable to reproduce	10	Berry
45	Freshwater Mussels	675	1	Decreased filter clearance	8	Berry

Table 6 below lists the modified rank factors. Our change was to add another category for unsuccessful recruitment.

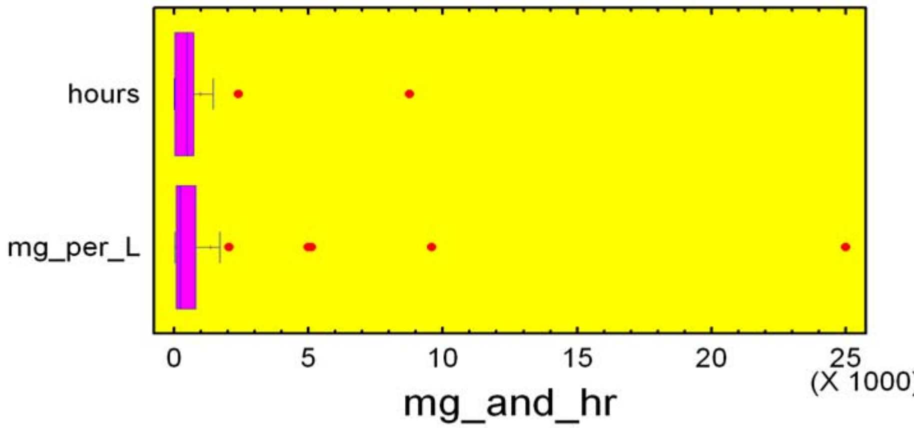
Table 6. Sedimentation response ranking values.

Original RANK	TSS Effects on fish and aquatic Life	New RANK	TSS Effects on fish and aquatic Life
14	> 80 to 100% mortality	15	> 80 to 100% mortality
13	> 60 to 80% mortality	14	> 60 to 80% mortality
12	> 40 to 60% mortality, severe habitat degradation	13	>40 to 60% mortality, severe habitat degradation
11	> 20 to 40% mortality	12	> 20 to 40% mortality
10	0 to 20% mortality	11	0 to 20% mortality
9	Reduction in growth rates	10	**Unsuccessful Recruitment**
8	Physiological stress and histological changes	9	Reduction in growth rates
7	Moderate habitat degradation	8	Physiological stress and histological changes
6	Poor condition of organism	7	Moderate habitat degradation
5	Impaired homing	6	Poor condition of organism
4	Reduction in feeding rates	5	Impaired homing
3	Avoidance response, abandonment of cover	4	Reduction in feeding rates
2	Alarm reaction, avoidance reaction	3	Avoidance response, abandonment of cover
1	Increased coughing rate	2	Alarm reaction, avoidance reaction
From:	*Newcombe and MacDonald, 1991*	1	Increased coughing rate

STATISTICAL ANALYSIS:

Data was plotted for outliers in Figure 2 and to assess distribution:

Figure 2: Box-and-Whisker Plot



Our dataset contained studies with a sediment concentration of 25,000 mg/L and durations of 8750 hours or one year. We eliminated these datum because it was unrealistic for sediment concentrations to remain this high in our watershed for this length of time. This also solved the problem of having an extreme outlier that would skew the distribution of our data and violate some of the assumptions used in linear regression (We were not able to transform our data when these outliers were included). This gave us 43 data points to evaluate. Tests showed the distributions to be skewed (std. skewness = 9.2 and std. kurtosis = 16.5). A Box-Cox transformation was conducted on each variable. This resulted in a normal distribution (std. skewness = -0.01 and std. kurtosis = -0.57) for concentration in mg/L. However the transformed duration variable was marginally normal (std. skewness = -0.59 and std. kurtosis = -2.4) when you consider values within + or - 2 to be a normal distribution. Pearson product moment correlations were run on the three untransformed variables. The only significant correlation was between rank and duration (Corr = 0.4298, p-value 0.0040).

The results, using Statgraphics software by Statistical Graphics Corporation follows:

Multiple Regression Analysis

Dependent variable: Rank

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	6.22642	1.82137	3.41854	0.0015
transformed_C	0.00189	0.00160	1.17929	0.2452
transformed_hr	0.00559	0.00168	3.31556	0.0020

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	120.577	2	60.2887	6.00	0.0053
Residual	402.12	40	10.053		
Total (Corr.)	522.698	42			

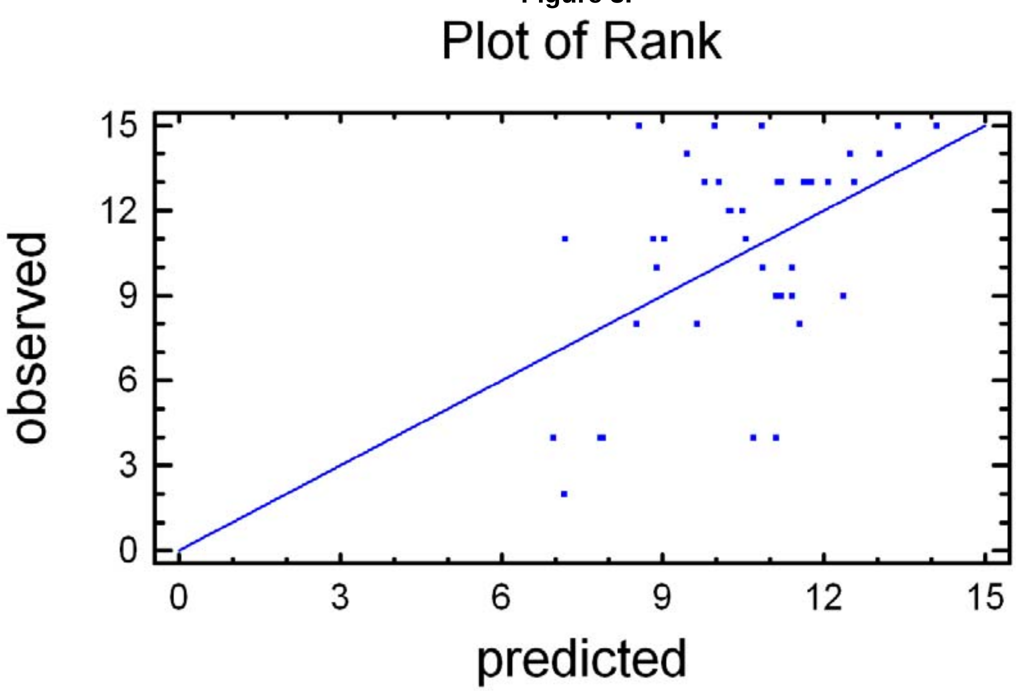
R-squared = 23.0683 percent
R-squared (adjusted for d.f.) = 19.2217 percent
Standard Error of Est. = 3.17065
Mean absolute error = 2.55718
Durbin-Watson statistic = 0.841902 (P=0.0000)
Lag 1 residual autocorrelation = 0.567788

The equation of the fitted model is

Rank = 6.22642 + 0.00188887*transformed_C + 0.0055859*transformed_hr

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. The R-Squared statistic indicates that the model as fitted explains 23.0683% of the variability in Rank. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 19.2217%. The standard error shows the standard deviation of the residuals to be 3.17065. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is less than 0.05, there is an indication of possible serial correlation. We will discuss this issue later. The P-value on the independent variables transformed_C, is 0.2452. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level.

Figure 3.



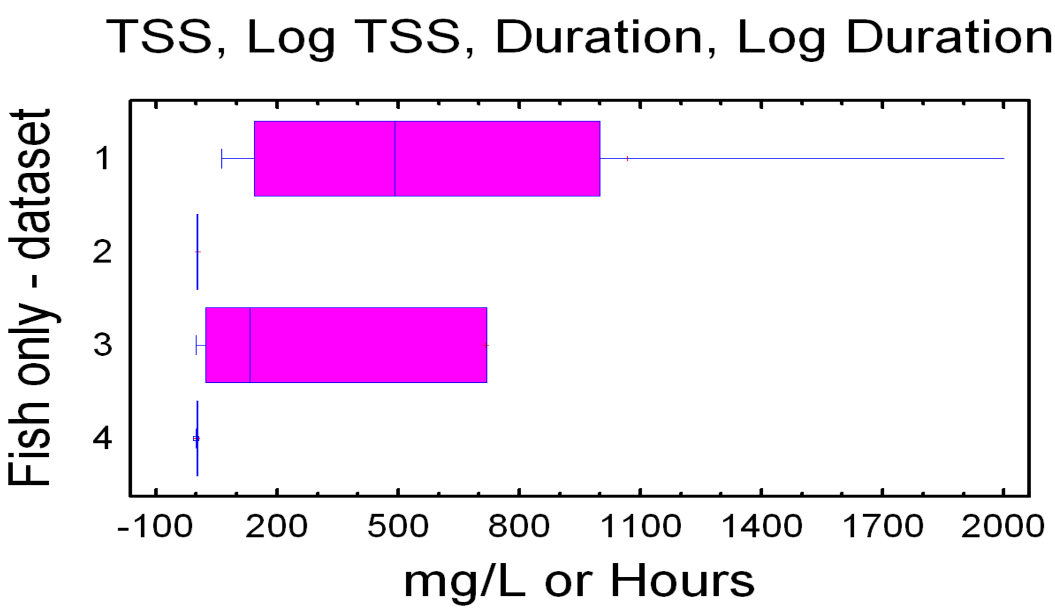
The results of our multiple regression were unsuccessful. We decided to subdivide our dataset into another subset that just represented the fish that were found in our river. Our only rationale was that the non-fish data were mostly macroinvertebrates that would be affected by bottom, or settled sediment rather than suspended sediment.

In order to obtain a normal distribution, our data had to be transformed using log base 10 (See figure 4 below). This figure has four datasets: 1) was the concentration of TSS in mg/L, 2) Log base 10 of TSS, 3) Duration of exposure in hours, and 4) Log base 10 exposure. We ran Pearson correlation calculations on the three variables for the fish-only dataset. See table 7 below:

Table 7 - Pearson Correlation Coefficients

	Hours	TSS	Log_Hour	Log_TSS
Rank	0.395 (p = 0.085)	-0.0069 (p = 0.977)	0.469 (p = 0.036	0.265 (p = 0.259)
TSS	0.060 (p = 0.800)			

Figure 4.



The results of the regression analysis follow:

Multiple Regression Analysis No 2.

Dependent variable: Rank

Parameter	Estimate	Standard Error	T Statistic	P-Value

CONSTANT	1.40948	3.23992	0.435036	0.6690
LogHOUR	1.34573	0.487159	2.76241	0.0133
LogTSS	2.06523	1.08212	1.9085	0.0734

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	65.5389	2	32.7695	4.74	0.0231
Residual	117.411	17	6.90653		
Total (Corr.)	182.95	19			

R-squared = 35.8234 percent
R-squared (adjusted for d.f.) = 28.2732 percent
Standard Error of Est. = 2.62803
Mean absolute error = 1.93646
Durbin-Watson statistic = 1.37225 (P=0.0543)
Lag 1 residual autocorrelation = 0.290849

The equation for this model is:

Rank = 1.40948 + 1.34573*LogHOUR + 2.06523*LogTSS

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between the variables at the 95% confidence level. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals. Notice that the P-value on the independent variables LogTSS is 0.0734. Since the P-value is less than 0.10, that term is not statistically significant at the 95% confidence level (But is significant at the 90% level). Figure 5 below shows the plot of observed values verses predicted, Figure 6 shows the residuals plot.

Figure 5.

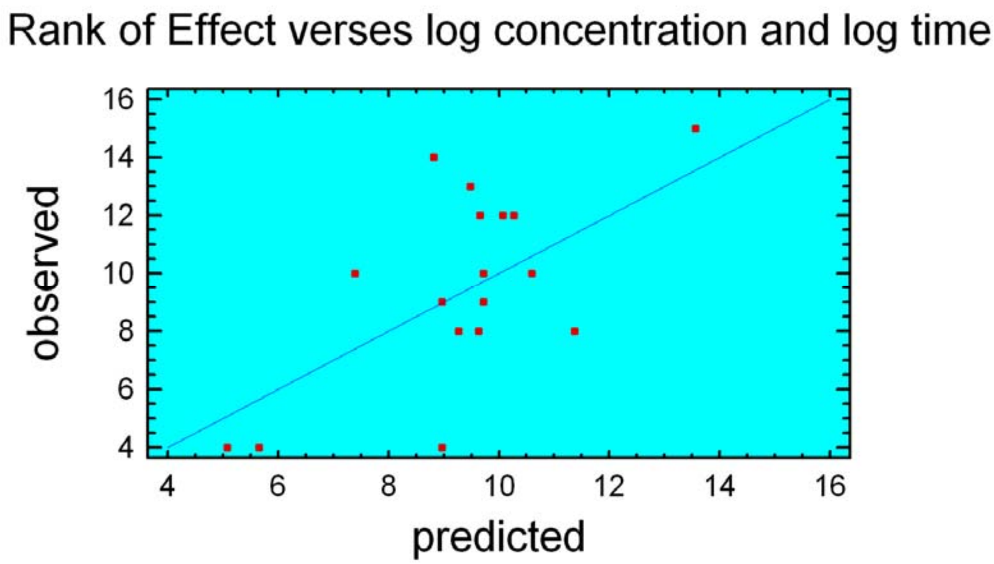
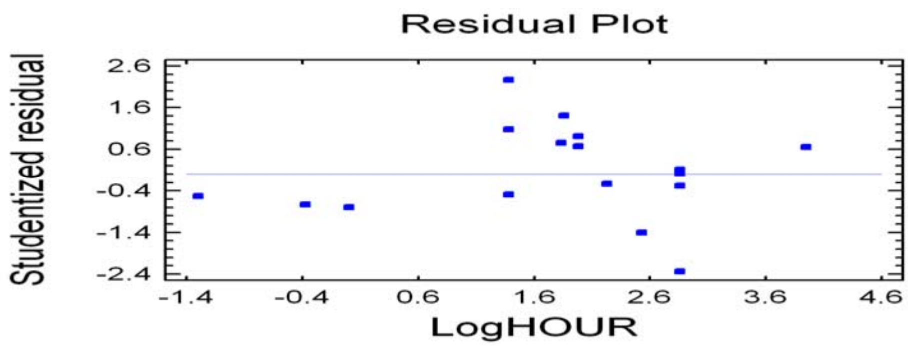


Figure 6.



The correlations between rank and duration were acceptable at the 95% level. However, there was no correlation or significance for TSS and rank. The residuals plot for duration was less than optimum, with significant spread in median durations.

RESULTS AND DISCUSSION

Our hypothesis was that by reducing the list of species to the fish found in the study area we could improve on the model presented by Newcombe and MacDonald. Results for the site-specific dataset were unacceptable. Correlation was significant only for rank verses duration of exposure. Since we could not obtain a normal distribution, even after eliminating outliers and using various transformations, we did not have an optimal dataset for a linear regression. This leads us to believe either there is no linear relationship between effects and concentration/duration, or the relationship is not linear. We had a statistically significant relation between effect and duration, but not statistically significant for concentration. Without considering sediment concentration, our model is worthless in our opinion.

The second model using the subset of data relating to fish-only had marginally better results. We were able to transform the data using logarithms into a normal distribution. However, the correlation between the variables was either weak, or not statistically significant. There was a statistically significant relation between duration and rank when running the regression, but the relation between concentration and rank was only significant at the 90% confidence level.

One of the problems with our method was with the toxicity studies. Many date back into the 1960 - 1970 time when laboratory protocols were not well established. The other problem is with in-situ studies. It is very difficult to measure sediment concentration in the field yet most of the toxicity studies we looked at so far give a finite number, rather than a range of concentration that is more realistic in stream situations. It is not known in some of the studies whether antagonistic or synergistic effects were considered in the toxicity test such as dissolved solids levels, changes in redox of the sediment, temperature changes, etc. We also noted some of the studies used "synthetic" sediment. One study used ferric hydroxide as the sediment source; making its use as a natural sediment questionable in our opinion (since it tends to co-precipitate other metals).

Autocorrelation of some of the toxicity data is likely. When a researcher exposes a fish to a constant sediment source and has multiple duration endpoints, autocorrelation may result. For example, a researcher exposes bass to 1000 mg/L TSS for 24 hours and he reports 10% mortality occurred after 6 hours, 30% mortality occurred after 12 hours, and 70% mortality occurred after 24 hours. The 30% and 70% mortality may have occurred because of exposure during the first 6 hours of the test. To know for certain, you would have to conduct a separate test where some fish were removed from the sediment after 6 hours and then see whether they all survived. We also found that information on the control group was either lacking or non-existent in some of the studies.

The problem with benthic macroinvertebrate data was that it is difficult to know if the sediment was kept in suspension or allowed to settle to the bottom of the test chamber for some of the cases. This data had significant scatter, indicating we needed much more data or the testing methods were flawed. By eliminating the benthic macroinvertebrate data from our study, we violate one of the concerns with toxicity tests - that they often do not include all types of aquatic species necessary for the health of the ecosystem.

Relationships using regression are assumed in our study at a statistical level of 95%. This means we wanted to be 95% certain that the relationship was not happening just by chance. However, we ended up doing several analysis: 1) with the entire group of data, that we were unable to transform, 2) with outliers removed, and 3) with a subset of fish-only data. This leaves us with at least three separate tests, which could be considered "data-fishing" or "data-snooping" as statisticians like to call it. The effect is that our confidence level has now dropped by 3 * 0.05 or 85% confidence. This level is not very useful for setting any kind of sediment criteria. The other problem is that by using a subset of the data, we lowered our type 2 error, which means we really needed to use a higher confidence level.

CONCLUSIONS AND FURTHER STUDY

We conclude that the modification of the Newcombe and MacDonald method led to unsatisfactory results for the watershed we selected. We are now investigating the entire sediment dataset to determine whether some studies were not properly conducted. By refining the list, we hope to improve on the methodology.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Bill Winters and Earl Bandy of the Office of Surface Mining as well as Tom Blount, of the National Park Service for their support of this effort.

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STREAM CHANNELS, DISCHARGE MEASUREMENTS, AND MINIMUM FLOWS

W. Scott Gain and Rodney Knight

Streamflow management for the protection of ecological health will require a thorough understanding of a variety of stream discharge characteristics. Among these is the minimum flow below which water withdrawal could negatively affect the health of aquatic ecosystems. Historically, one of the most widely used of such measures has been an empirical statistic describing the lowest sustained flow likely for seven consecutive days straight once every 10 years. This quantity (the 7Q10) is employed most appropriately as a constraint on the ability of a stream to either assimilate pollutant load or provide a sustainable source of water without storage.

The widespread use of the 7Q10 in water planning has lead to extension of its use for purposes of ecological assessment even though aquatic biologists recognize that the 7Q10 reveals little with respect to the quantity or quality of aquatic habitat in any given channel. In cases where the 7Q10 has seemed an oversimplification, other related statistics such as median-August or September flows, various multiples of the 7Q10, or percentages of mean annual flow have sometimes been tried. Statistical metrics such as these, however, all suffer from the same basic limitations as a minimum flow standard; they accurately represent only a fraction of the total underlying flow record. In general, statistical summaries cannot properly describe the volumes of water moving through a given channel or the amount of habitat provided.

Statistical percentages and return intervals at the low end of water availability may provide measures of stress in aquatic communities (for example, richness scores), but only in conjunction with other more physically-based measures (for example, runoff). Multiple lines of evidence suggest that first order estimates of ecological stress thresholds for streams in Tennessee could be based on combination of 7Q10s with simple physical criteria. For example, area-weighted 7Q10s computed for streams in Tennessee vary regionally with patterns in fish community health across the state. Cross-sectional surveys, as part of thousands of discharge measurements in Tennessee, also show that most channels reach their greatest width-to-depth ratios in a range of discharges from about 0.05 to 0.2 cubic feet per second per square mile.

EFFECTS OF WATERSHED URBANIZATION ON STREAM CHANNEL STABILITY IN KNOX COUNTY, TENNESSEE

Bart Keaney[1], John Schwartz, and Qiang He

In Tennessee, sedimentation is among the leading causes of stream impairment. While a certain amount of sediment will naturally be transported in streams, excessive loads of alluvium are detrimental to the health and use of these resources. Urbanization in a stream's watershed impacts the concentration of stream sediment by increasing the peak stormwater runoff rates. If a stream channel cannot accommodate these rates, it should begin to adjust in a pattern, described in the Channel Evolution Model developed by the USDA National Sedimentation Laboratory, that proceeds through periods of degradation and aggradation until a new, stable channel form is attained. According to the model, channel adjustment will follow a pattern, responding differently upstream and downstream of the area of maximum disturbance. Theoretically, it would be possible to use an evaluation of the stage of channel evolution at several sites along a disturbed stream to predict the response of the entire stream network in the watershed. However, this can only happen in streams in which further disturbances and channel gradient controls are not present, which is not the case in urbanizing watersheds. A semi-quantitative Rapid Geomorphic Assessment, also introduced by Andrew Simon was used to evaluate channel stability at sites throughout the watershed of Beaver Creek, a tributary of the Clinch River in Knox County. Instead of following patterns of adjustment, or being controlled, per expectation, by channel gradient or upstream development, statistical analysis showed that channel response appeared to be most heavily influenced by the ability of the channel material to resist erosion.

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EFFECTS OF WATERSHED URBANIZATION ON BEDLOAD CHARACTERISTICS

William Cantrell*[1], John Schwartz, and Ken Barry

A central problem in the field of stream restoration is that of designing a stable channel that supports a healthy benthic population. Many stream restoration projects take place in urban or urbanizing watersheds. The relationship between changing watershed characteristics and local channel conditions within that watershed is poorly understood. This study consists of a field study of bedload flux in watersheds representing rural, urban, and developing conditions. Study sites were selected in Knox County, Tennessee including twelve sites for the different watershed conditions. The bedload flux portion of the study combines field collection of bedload via Bunte bedload net traps, and estimate of energy slope with peak stage recorders. Information derived from the field collection will be combined with watershed data via geographic information system (GIS) analysis. Watershed metrics including percent impervious area, roadways adjacent to streams, and average watershed slope determined via GIS will be correlated with the measured bedload mass and composition for each research site. The combination of this information will provide a valuable tool in stream restoration design in allowing practitioners to have an empirical metric with which to design/predict channel substrate composition.

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MEASURING STREAMBANK EROSION: LESSONS AND INSIGHTS

Carol P. Harden*[1], Keri Chartrand[2], Erich Henry[3]

ABSTRACT

Streambanks are potential sources of stream-borne sediment, but streambank erosion is poorly understood and infrequently documented. We have completed two years of a three-year effort to monitor bank erosion pins at 17 sites on five tributaries of the Little River in Blount County, TN. Observed rates of bank erosion exceed expected rates and document widespread bank instability. As the project has progressed, we have improved the field procedures and gained interesting insights regarding the behavior of streambanks in the region. To maximize success in relocating pins and confidence in the measurements obtained, we recommend taking photographs, making very careful measurements of pin locations, marking each pin at each (quarterly) visit with spray paint, and having multiple individuals repeat each measurement. Banks of Little River tributaries, especially those in the Valley and Ridge, are typically steep and composed of fine-grained materials. In two years of monitoring, mass movements have been negligible. Streambanks lose material throughout the year via processes of granular disintegration, even without high-discharge flows. During the drought, we observed that fine-grained banks are very susceptible to loss of strength and loss of material just above the water line and we found bank undercutting to occur at low flow. The preliminary findings have important implications for modeling and for identifying and reducing stream sediment sources.

INTRODUCTION

Streambanks are potential sources of stream-borne sediment, but streambank erosion is poorly understood and infrequently documented (Duijsings, 1987; Stott, 1997; Prosser et al., 2000; Couper and Maddock, 2001). Given the importance of siltation as a problem in streams in Tennessee (TDEC 2008), determining the extent to which streambanks contribute sediment to streams merits further attention.

The 980 km^2 Little River watershed, in east Tennessee, offers an excellent living laboratory for a study of streambanks. In 2006, the Environmental Protection Agency selected the Little River watershed as one of its Targeted Watersheds (USEPA, 2008). One of the monitoring projects undertaken as part of the Targeted Watershed Initiative has been a study of streambank erosion at 17 sites (32 banks) on five tributaries listed on the state's 303(d)-list for siltation: Carr, Crooked, Ellejoy, Nails, and Pistol Creeks. Objectives of the streambank monitoring are to determine whether streambanks are actively changing and, if so, to quantify streambank change. In this paper, we present practical details for working with erosion pins, lessons learned that have improved the study methods, and insights gained in the first two years of monitoring.

The Little River (HUC 06010201) watershed lies almost entirely in Blount County and extends from the Great Smoky Mountains to the Tennessee River (Figure 1). At the study reaches, the streams are wadable. Streambanks are steep and bank heights are typically 1–2 m, with a defined

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break in slope at the top. The 32 banks studied have a median angle at mid-bank of 56º, and half of the mid-bank angles are between 40º and 70º. The banks are composed of fine materials. A hand test of 112 samples from 32 banks determined that most samples (46%) are clay loam and that only 20% of the samples had textures coarser than loam (Harden et al., 2009). The coarsest was sand. Most bank surfaces are partly vegetated. Plant cover changes seasonally, but the steepest banks have remained bare throughout the study.

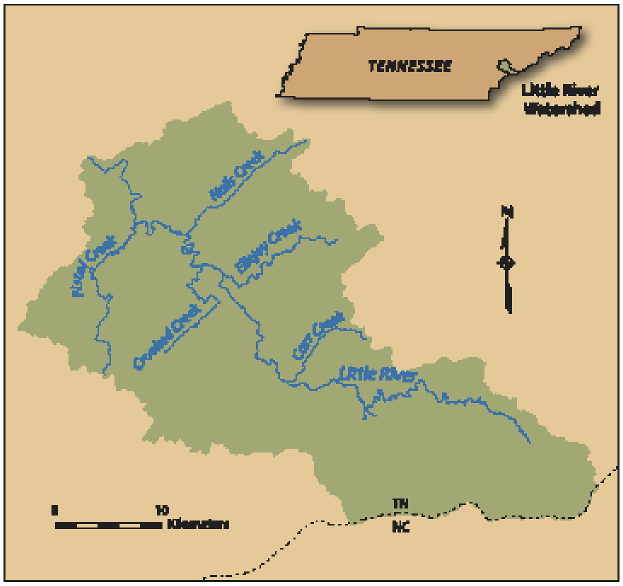

Figure 1. Little River watershed, showing the five tributaries with streambank erosion pins.

EROSION PIN METHOD

Erosion pins provide points of reference from which erosion and deposition can be documented over time. We cut 3.2 mm (1/8”) diameter steel rods into 25-cm segments to make erosion pins and painted the end of each pin white. Our approach was similar to that used by the Tennessee Valley Authority (TVA) and by the U.S. Forest Service (Harrelson et al., 1994). We installed four erosion pins on each streambank, each pin perpendicular to the slope (Figure 2), with 2 cm remaining exposed.

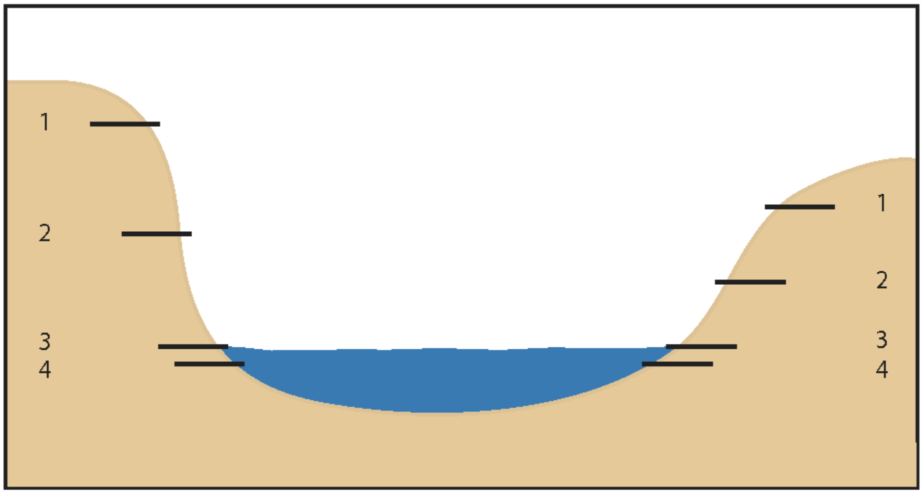

Figure 2. Diagram of arrangement of erosion pins at a cross-section.

The uppermost erosion pin (#1) was placed near the top of the bank, just below the break in slope; the second (#2) erosion pin was placed halfway between the first and the third; the third (#3) erosion pin was placed just above the ordinary water line; and the fourth (#4) was set ~15 cm below the ordinary water line. The location of the ordinary water line was a judgment made in the field based on the shape of the bank, the condition of vegetation and leaf litter, and the actual elevation of water observed over repeated visits to the site. At five locations, rocks or the lack of stable substrate prohibited the placement of a #4 erosion pin. We carefully measured, recorded, and photographed the location of each erosion pin relative to nearby landmarks and to a small flag or piece of surveyors' tape tied to a tree or root to mark the location of the line of erosion pins.

Site selection depends on the research objective. In this case most (27) of the 32 streambanks were chosen along straight reaches to represent "typical" conditions. Five visibly eroding banks were also monitored to document maximum rates of erosion. Erosion pin sites were a subset of those being monitored for flow and water quality in the Little River watershed and some were also sites regularly monitored by TDEC.

A total of 123 erosion pins were installed between December 18, 2006 and February 14, 2007. In the first year (2007), we measured erosion-pin exposures in June and in December. Finding higher-than-expected rates of streambank erosion, we switched to quarterly monitoring (March, June, October, December) in 2008. Quarterly monitoring continues through 2009. We used a ruler to measure erosion pin exposures to the nearest millimeter, and sprayed each erosion pin and about a 5-cm radius of the surrounding bank with brightly colored paint following each measurement.

 

Figure 3. Spray-painted erosion pins on banks of Nails Creek (left) and Ellejoy Creek (right).

LESSONS

As in most field-based studies, many lessons have been learned along the way, and those may be valuable to those undertaking similar studies. In this streambank erosion study, a ruler proved easier to use and provided more reproducible results than a laser range finder. Potential gains in precision of the laser were offset by the irregularity of the bank surface, the occasional interference of leaves or litter, and the difficulty of positioning the instrument exactly at the end of the erosion pin. When using a ruler, care must be taken to not depress the bank surface, especially in very soft, underwater sediments.

During the first two rounds of measurements, we noticed that different persons obtained slightly different readings. Subsequently, we instituted the practice of always having at least two persons make independent measurements of each erosion pin. If a measurement differs by more than 2 mm, the discrepancy is discussed and pin exposure re-measured until agreement is reached.

Photographs have been extremely valuable. Those taken of the initial erosion pin placements have helped us relocate pins. Photographs taken earlier in the study are now being used to document the vegetative cover on streambanks throughout the year and the extent of bank undercutting.

Spraying bright yellow or orange paint on each pin, a step we added to the erosion-pin measurement protocol as an afterthought, turns out to be extremely useful. First, it has greatly helped relocate erosion pins. Second, if the painted surface remains undisturbed between monitoring visits, we can say with confidence that no erosion has occurred. In 12 instances, eight of which were at mid-bank (pin #2), intact paint surrounding a less exposed erosion pin allowed us to determine that the bank had expanded. Flecks of paint mixed with loose sediment serves as evidence that a deposit originated higher on that bank, and intact paint under a fresh deposit provides a record of the former surface. Bank surfaces in the study area tend to be crumbly and granular in texture, and most have a clay loam texture (Harden et al. in press). Repeated observations confirmed that our application of a thin coat of paint did not noticeably change the cohesion of the soil.

After re-setting pins back to a 2-cm exposure at a few sites in the first year, we adopted the practice of re-setting erosion pins only when they seemed likely to fall or to disappear in a deposit. Although it is occasionally necessary, re-setting erosion pins has the potential to disturb bank surfaces and complicates the processes of data entry and analysis.

If finding exposed erosion pins is difficult, finding buried erosion pins is especially challenging. Without digging to find a buried erosion pin, one cannot be sure that it is actually buried, but digging disturbs the bank surface. If we are very sure the pin is buried, we poke around in a small deposit to re-locate and re-expose it. Whether depositional or erosional processes have caused an erosion pin to disappear from view is usually evident. We assigned an estimated exposure value of 20 cm to a completely eroded (25-cm) pin and an estimated exposure value of -5 cm to an unexcavated pin in an obvious deposit. At the end of the second year of monitoring, the fates of four missing erosion pins, all in the #4 position, were uncertain. To avoid disturbance, no excavation will be attempted at these places until our monitoring of the bank has been completed.

INSIGHTS FROM THE LITTLE RIVER TRIBUTARIES

As expected, the lowest part of the streambank, usually or always underwater, has the highest erosion rate. More surprising was the measurable quantity of erosion from the upper parts of streambanks, including changes during time intervals when the depth of flow remained low. Subaerial processes of granular disintegration, including wetting/drying and freezing/thawing were sufficient to release particles from streambanks. Streambanks were steep enough to allow those particles to fall into the water. Although these processes have often been considered preparatory to erosion, subaerial erosion on streambanks has been reported, even as the dominant process, at other locations (Couper and Maddock, 2001; Prosser et al., 2000). Like Wynn et al. (2008) in southern Virginia, we found the incidence of mass movement to be rare compared to the widespread occurrence of subaerial erosion processes, at least in a 2-year period.

All the tributary reaches under study are eroding. With 17% of the erosion pins registering gains rather than losses, the median rate of erosion for “typical” sites (n=102 pins) was 0.9 cm per bank over a 2-year period. The mean was 1.4 cm per bank. The median and mean erosional losses for visibly eroding banks (n=17 pins) were 8.0 cm and 9.2 cm, respectively. This demonstrates that, collectively, the most visibly eroding streambanks have the highest rates of sediment loss. However, of the 16 individual erosion pins showing losses $\geq$ 8 cm (exposures $\geq$ 10 cm), 10 were at sites initially categorized as “typical.”

The monitoring period of calendar years 2007–2008 included a severe drought. During the drought, streambank undercutting was active at 14 of the 32 monitored banks and at many other reaches seen in passing in the tributary streams. Bank undercutting during drought appears to be caused by the wetting of moderately fine-textured bank sediments, with a resulting loss of cohesion and increase in mass. Root structures did not protect banks from being increasingly undercut by wetting (Figure 4). We did not measure soil moisture in this study, but observed that fine-grained bank materials just above the water remained visibly moist. Capillary movement of water into fine sediments and/or minor fluctuations in water level could contribute to high moisture contents of the undercut banks. An undercut streambank becomes vulnerable to further loss from the overhanging portion. It has been difficult to quantify rates of undercutting with erosion pins because stable pin placements were hard or impossible to find.

Figure 4. Undercut bank in a nearly zero velocity zone of Pitner Creek.

Overall, our ongoing use of erosion pins to monitor streambank erosion in five wadable tributaries of the Little River has generated more than the expected results. The magnitude of erosional change, on the order of 1–2 cm over 2 years and with a maximum of 26 cm, is greater than expected and far greater than the error associated with individual measurements. Contributions of sediment to streams from streambanks in the absence of either the hydraulic force of flowing water or mass movements adds a new dimension of complexity and interest to the study of streambank erosion processes. Lessons learned to date in this project should aid others interested in using erosion pins to quantify rates of streambank erosion in other locations.

ACKNOWLEDGMENTS

The authors thank EPA for funding the Little River Targeted Watershed Initiative, W. Ryan Foster for his work on bank angles, Christopher Morris for determining the textures of bank particles, and many individuals who have helped prepare and measures erosion pins. We also thank Kevin Russell and the Cartographic Services Laboratory of the Geography Department at the University of Tennessee for drafting figures 1 and 2.

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WATERSHED PLANNING TO MEET TOTAL MAXIMUM DAILY LOAD (TMDL) WATER QUALITY GOALS IN THE HARPETH RIVER WATERSHED

Dorene Bolze* and Lindsay Gardner*[1]

In Williamson County, one of the nation's fastest growing counties, first-generation pollution reduction goals have been quantified in the TMDLs for the Harpeth River to address intense stormwater, sewer discharge and development challenges. With an EPA Consolidated Watershed Initiative Grant, the Harpeth River Watershed Association (HRWA) and its municipal partners, the City of Franklin and Williamson County, focused on using readily available tools for municipalities and watershed managers to develop planning approaches and implement various strategies to meet these targets for pollution reduction levels for stream health.

HRWA will present findings from a watershed planning process in Fivemile Creek Subwatershed, including discussion of key off-the-shelf decision-support tools that can be used by stormwater coordinators, planning staff, watershed groups or consultants. These include visual stream assessment protocols to make correlations between water quality and land use and models to calculate load reduction estimates and project pollution load increases associated with growth and changes in land use at the subwatershed level, as well as evaluate stormwater runoff and the water quality performance of stormwater management plans for proposed land development projects. HRWA's EPA project experience demonstrates the potential for significant strides toward meeting pollution goals and water quality standards with easily accessible tools designed for knowledgeable municipal stormwater and planning staff and important opportunities to coordinate among jurisdictions for large-scale watershed planning.

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IMPERVIOUS AREA ANALYSIS FOR THE HARPETH RIVER WATERSHED BASED ON ANALYSIS OF 1997 AND 2007 ORTHO PHOTOS AND LOCAL PARCEL MAPS AND COMPARED TO CUMBERLAND REGION TOMORROW'S 2001 GROWTH PROJECTIONS FOR 2020

Michael Cain*[1], Joel Peters, GISP*[2]

Much of the Harpeth River Watershed is in one of the fastest growing counties in the country[3], with a 10 year population increase above 20%. To assess changes associated with development, and vulnerabilities and threats to the watershed, HRWA conducted an Impervious Area Analysis of the entire watershed. This was done using data from a 2001 Cumberland Region Tomorrow (CRT) study that compiled existing data (1997-2001) and produced two scenarios of population growth and impervious cover to 2020. CRT's "Base Case" projects growth following current sprawl patterns and the "Vision" projects growth if concentrated in existing town centers. By comparing ortho photos from 1997 and 2007, ground truthing by staff, and consulting parcel data to determine actual changes in the watershed, HRWA created a GIS layer of imperviousness changes that was added the existing CRT data layer. Maps were made that allowed comparisons of impervious cover between 2001 and 2008, and to see how 2008 compares with the CRT 2020 projections.

The analysis indicates that development is occurring at a fast pace though not necessarily in ways predicted by the CRT study. Areas around the I-65 corridor have already developed to the point that impervious percentage cover is greater than that of the "Vision" projection, while along the I-40W corridor, impervious cover has not changed significantly yet. HRWA plans to update and publish this information as part of a "State of the Harpeth" report biennially. This analysis was part of an EPA Consolidated Watershed Initiatives Grant from the EPA.

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[3] Williamson County was Rated 95th in the country, with Rutherford County (Harpeth Headwaters) rated 37th, http://www.housingbubblebust.com/PopHsgRates/Top100Counties.html

EVALUATION OF CADDIS STRESSOR ANALYSIS FOR TENNESSEE – PROGRESS, AND REQUEST FOR YOUR INPUT

John Harwood[1]* and Bonnie Newby[2]

We are mid-way through our project evaluating of the usefulness of the Web-based EPA Causal Analysis/Diagnosis Decision Information System (CADDIS) in identifying stressors causing impairment of waters of Tennessee. The evaluation consists of evaluating four test cases in order to discover advantages and difficulties in applying the CADDIS procedure. We are evaluating the involvement of stakeholders in identifying stressors, an important component of CADDIS. Additionally, we are producing a summary of information needed to apply the procedure, documentation to facilitate performing CADDIS stressor identification in Tennessee, guidelines as to what impairment scenarios might be successfully approached with the CADDIS process, and suggestions as to what scenarios might be better approached using alternative means of stressor identification.

We will present a brief overview of results obtained to date in our test case analyses. We will discuss the effectiveness of CADDIS in identifying stressors in these cases, and how water monitoring procedures in Tennessee could be modified so as to facilitate stressor identification. We will discuss our success in engaging stakeholders in the analyses, and questions stakeholders have had in the CADDIS procedure. We will outline the tools we plan to prepare to assist TDEC regulators and others in performing CADDIS analyses. Finally, we will ask those attending the presentation to share questions, observations, reservations, and suggestions they may have in this initial phase of applying CADDIS stressor identification in Tennessee.

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SESSION 2B

STREAM EVALUATION I
8:30 a.m. – 10:00 a.m.

Assessing Fish Density within Pleasant Grove Creek, An Impaired Watershed, Logan County, Kentucky
Dereck L. Eison and Andrew N. Barrass

The Wild and Wacky World of NPDES and TMDL Compliance: Approaches and Regulatory Options
Dustin G. Bambic

Development of a Reservoir Embayment Characterization Process to Prioritize Water Quality Improvement Efforts
T. Shannon O'Quinn and Yongli Gao

STREAM EVALUATION II
10:30 a.m. – 12:00 p.m.

Use of Fish Autecology Data to Link Biological Impairment to Stream Siltation
John S. Schwartz, Andrew Simon, and Lauren Klimetz

Impaired River – What Impaired River? The Resilient Little Pigeon River in Sevier County, Tennessee
Christian Crow, Martin Melville, and Jeff Pittman

Continuous Durations of Exceedances of Turbidity and Suspended-Sediment Concentration in Tennessee Reference Streams
Timothy H. Diehl

STORMWATER
1:30 p.m. – 3:00 p.m.

Turbidity Reduction Using Flocculation Enhanced Filtration Technology for Construction Sites and Dewatering Programs
Mark B. Miller

Water Quality Snapshots in Three Urban Storm Sewers, Memphis, TN: The Good, The Bad, and The Ugly
Daniel Larsen, Delphia Harris, and Rhonda Kuykindoll

Green Building and Water Quality. How Green is "Green"?
Don Green

FLOODING
3:30 p.m. – 5:00 p.m.

Is Stream Discharge Fractal? A Comparison of Watauga River Discharge Before and After Construction of Watauga Dam
Ingrid Luffman

Santa Barbara Urban Hydrograph Method: Should It Be the Preferred Method for the Southeast?
Michael Clay and Jerry Anderson

Automated Determination of Potential Flood Damages for a Complex Downtown Flooding Area
Curt Jawdy and Jonnathan Owens

ASSESSING FISH DENSITY WITHIN PLEASANT GROVE CREEK, AN IMPAIRED WATERSHED, LOGAN COUNTY, KENTUCKY

Dereck L. Eison[1]* and Andrew N. Barrass[2]

BIOASSESSMENT

Pleasant Grove Creek is located within the Western Pennyroyal Karst Plain Ecoregion north of Tennessee. The watershed is the focus of several surveys by the Kentucky Division of Water, Environmental Protection Agency, and Austin Peay State University. Pleasant Grove Creek has been identified as an impaired water body on the Environmental Protection Agency's 303(d) list since 2002. The watershed is located in the northern portion of the Red River, which both are regional and national priority watersheds. The topography is an area composed of karst fractures and caves. Ninety-five percent of the land is allocated to agricultural practices. In 1994 and 1998, the Kentucky Department of Water sampled Pleasant Grove Creek for macroinvertebrates and fish. Although a limited number of fish were collected during these studies, little fish data exists in technical reports or journals for this region. Objectives of this study were to assess the environmental health of Pleasant Grove Creek utilizing the Kentucky Index of Biotic Integrity and by comparing historical data with data collected in 2007and 2008. Fish assemblages were compared to habitat changes and an adjacent watershed, Whippoorwill Creek, a creek identified by Kentucky as an exceptional water resource. All protocols for sampling surface waters set forth by the state of Kentucky were followed except for electroshocking. Data indicate that Pleasant Grove Creek continues to be an impaired stream with diminished species richness.

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THE WILD AND WACKY WORLD OF NPDES AND TMDL COMPLIANCE: APPROACHES AND REGULATORY OPTIONS

Dustin G. Bambic, PH[1]

The Clean Water Act requires NPDES permits (Permits) for discharges of pollutants to navigable waterbodies. In cases when these waterbodies are categorized as "impaired", total maximum daily loads (TMDLs) must be developed by the responsible regulatory agency (i.e., the State or USEPA). A component of TMDL development includes calculation of allocations for permitted and non-permitted discharges. These allocations are generally determined in units of allowable mass discharge per day (e.g., pounds of pollutant per day). For wastewater discharges, wasteload allocations (WLAs) are often translated directly into the Permit as effluent limitations. For stormwater Permittees, however, WLAs tend to be implemented as best management practices (BMPs). For instance, for an MS4 that is implicated by a bacteria TMDL, the Permit can contain provisions requiring BMPs that reduce loading of bacteria to receiving waters. Each five-year cycle of the NPDES permit tends to become more stringent with regards to TMDL implementation requirements. There are instances, however, when the Permittees determine that either (1) the permit requirements are not feasible or attainable or (2) the applied water quality standards are not appropriate. In these cases, dischargers can conduct special studies to support revisions to effluent limitations, water quality criteria, or beneficial uses. Revisions of wastewater effluent limitations can be supported by dilution studies that account for volumetric assimilative capacity of the receiving water. Water quality criteria can be adjusted through site-specific objectives (SSOs) that account for the natural attenuation downstream of the discharge site. For instance, metals criteria can be adjusted according to USEPA guidance for Water Effects Ratios (WERs). Finally, beneficial uses can be removed or re-categorized with a Use Attainability Analysis (UAA). In the case of waterbodies that are designated as recreational waters (and protected with bacteria criteria), it may be determined that flow or access conditions do not allow for full body water contact. This presentation will review these various options and provide examples of how Permittees have worked with State agencies to ensure receiving waters are adequately protected based on the best available science.

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DEVELOPMENT OF A RESERVOIR EMBAYMENT CHARACTERIZATION PROCESS TO PRIORITIZE WATER QUALITY IMPROVEMENT EFFORTS

*T. Shannon O'Quinn[1] and Yongli Gao[2]

To simplify water quality improvement in reservoirs, it has been suggested that efforts should be focused on smaller and more manageable units such as reservoir embayment areas. Embayments are prime locations to locate marinas, parks, beaches, and residential homes. To begin testing this hypothesis, current data and information on reservoir embayments in Tennessee have been compiled and assembled into a GIS-based database. Embayments of 11 reservoirs have been mapped and digitized in ArcGIS. GIS based data models have been developed and used to characterize these embayments. Initial characterization criteria included stream presence, watershed size, embayment/watershed ratio, and water quality influences. The characterization process was applied to the mapped reservoir embayments in Tennessee to identify and prioritize embayments that are most likely to be affected by watershed restoration efforts. If effective, this process can be used by resource agencies and stakeholders to prioritize water quality improvements in reservoir embayments.

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USE OF FISH AUTECOLOGY DATA TO LINK BIOLOGICAL IMPAIRMENT TO STREAM SILTATION

John S. Schwartz[1], Andrew Simon, and Lauren Klimetz

Loss of biological integrity due to rivers and stream siltation is a major cause of water quality impairment in the United States. Siltation-impaired streams on Clean Water Act §303(d) lists require development and implement sediment TMDLs, however existing analytical tools for development lack a means to link siltation with loss of biological integrity. This study located in Northern Great Plains Ecoregion co-located 77 USGS gauging stations with flow and suspended sediment data, and fish data from federal and state agencies. Among a broader set of 183 sites, field-based rapid geomorphic assessments were conducted to determine whether the channels were stable or unstable. Suspended-sediment yields were computed for each site, and yields were found to be significantly different between stable and unstable sites. Autecological data was summarized by fish species found in this ecoregion, including attributes on mesohabitat preferences, water quality tolerance, trophic structure, and feeding, diet, and spawning behaviors. An autecological data matrix was created using the species autecological information and site fish presence/absence data, forming a matrix that included, per site, the number of occurrences an autecological attribute occurred for fish species present. Ecological analysis found significant differences for several autecological attributes between stable and unstable channels. Fish located at unstable sites tended to: 1) prefer open-water mesohabitat, 2) be dominated by herbivores with algae diet, and 3) exhibit non-guarding spawning behavior. Use of autecological data and the protocols applied in this study provide evidence of potential causes for biological impairment supporting development of sediment TMDLs.

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IMPAIRED RIVER – WHAT IMPAIRED RIVER? THE RESILIENT LITTLE PIGEON RIVER IN SEVIER COUNTY, TENNESSEE

Christian Crow*[1], Martin Melville, and Jeff Pittman

The Little Pigeon River (2.4 miles) is listed on TDEC's draft 2008 303(d) list for *Escherichia coli* and its major tributary, West Prong Little Pigeon River (8.1 miles), is listed for *E. coli*, total phosphorus, and loss of biological integrity due to siltation. We performed a mollusk and fish survey in the Little Pigeon River just downstream (approximately 3,000 feet) of its confluence with the West Prong Little Pigeon River. The survey was conducted to determine potential impacts of a proposed waterline crossing of the river on the federally endangered oyster mussel, *Epioblasma capsaeformis*, which historically occurred in the area.

The survey was performed in April of 2008. The river was low and clear. A 3-person crew surveyed nearly 1,000 feet (approximately 700 downstream and 300 feet upstream) of the river in the vicinity of the proposed crossing. Despite known water quality degradation, extensive upstream watershed development, and a complete of riparian buffer, a fairly good mollusk and fish community were observed in the survey area. While no federally protected species were found, 7 species of live mussel (plus additional 1 species as relic only), 6 species of darters (including the redline darter, a known host for the oyster mussel), and at least 5 species of snails were observed through snorkeling and tactile searches of the site. Two large riffle areas were present within the survey reach, and in-stream aquatic habitat quality/conditions were moderate to good with a mixture of rocky substrate in areas with moderate to strong current. Riparian conditions along the Little Pigeon River in the study area were severely impacted due to anthropogenic activities (i.e., land clearing, removal of riparian vegetation, grading of bank slopes, etc.), canopy cover was absent, and sedimentation and silt deposits were extensive along the margins of the river and in areas with low current velocities. Most of the substrate and rooted vegetation within the project area was covered with a thick filamentous algae, especially in areas of lower velocities. These degraded riparian conditions offer an excellent enhancement opportunity for protecting the fairly diverse aquatic community that still survives in the area.

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CONTINUOUS DURATIONS OF EXCEEDANCES OF TURBIDITY AND SUSPENDED-SEDIMENT CONCENTRATION IN TENNESSEE REFERENCE STREAMS

Timothy H. Diehl[1]

Continuous durations of elevated turbidity and suspended-sediment concentration (SSC) in reference streams provide a basis for evaluating biological impairment. This approach complements the use of similar exceedance-duration relations developed by Charles Newcombe and others based on toxicological studies. Continuous durations of exceedance were generated at selected values of turbidity and SSC in Copperas Branch and Kelley Creek, small streams in the Western Highland Rim ecoregion, an area with very diverse fish fauna, and in the Wolf River at Lagrange, the Harpeth River at McDaniel, and Spring Creek near Dodson Chapel, ecoregion reference sites with diverse aquatic invertebrates.

In Copperas Branch and Kelley Creek, Newcombe's turbidity threshold for slight impairment was exceeded by one or more storms in water year 2005 but not in water year 2006, which is consistent with reference biology. Turbidity durations were similar in these two streams.
Models of sediment effects based on toxicological studies placed Copperas Branch and Kelley Creek above thresholds for significant impairment of aquatic invertebrates and fish eggs and larvae, and close to the thresholds of lethal effects. These estimates of impairment are inconsistent with local biological data and suggest that the toxicologically derived thresholds are overly conservative in this ecoregion.

In the Wolf River at Lagrange, the Harpeth River at McDaniel, and Spring Creek near Dodson Chapel, both turbidity and SSC were higher than in Copperas Branch and Kelley Creek. Lethal SSC effects predicted by Newcombe's model are inconsistent with observed macroinvertebrate diversity.

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TURBIDITY REDUCTION USING FLOCCULATION ENHANCED FILTRATION TECHNOLOGY FOR CONSTRUCTION SITES AND DEWATERING PROGRAMS

Mark B. Miller*[1]

Clay and silt particles contained in stormwater discharges from construction and development (C&D) sites typically cannot be effectively removed by conventional BMPs such as sediment basins or traps that rely solely on settling. Sediment removal can be improved when sufficient detention time or additives are implemented for those BMPs. An increasing need for active treatment systems (ATS) is especially evident in light of the recent EPA proposed turbidity effluent limit guidelines and standards for C&D sites that could require stormwater discharges to meet an effluent limit as low as 13 NTUs. Use of ATS technology using flocculation enhanced filtration can effectively reduce turbidity levels in runoff from C&D sites and dewatering programs. An innovative ATS technology has been developed that utilizes a treatment train approach consisting of a collection pond followed by a mobile flocculation enhanced filtration system. Runoff water that accumulates in the collection pond is plumbed to the treatment unit without the need for extended detention. Three stages of treatment are provided in the mobile unit: (a) initial hydrodynamic separation to remove debris and coarse material, (b) introduction of a flocculation agent, and (c) filtration of the coagulated material and other fine particles prior to discharge. Treatment flow rates per unit range from 1.0 to 1.5 cfs (450 to 675 gpm). This flocculation enhanced filtration approach provides for a reduction in treatment time due to less detention, a decrease in the treatment footprint, and reduction in associated time and materials costs.

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WATER QUALITY SNAPSHOTS IN THREE URBAN STORM SEWERS, MEMPHIS, TN: THE GOOD, THE BAD, AND THE UGLY

Daniel Larsen[1*], Delphia Harris[2], and Rhonda Kuykindoll[2]

Water from three urban storm sewers (Black Bayou, Cane Creek, and North Cypress Creek) in Memphis were sampled at multiple locations along their courses on one or more dates during the past five years by faculty and students from the University of Memphis and LeMoyne-Owen College. The land use in the watersheds varies from dominantly residential to mixed commercial-residential-industrial. Field physical and chemical data were determined in the waters as well as general environmental conditions at the sampling locations. All waters were analyzed for inorganic ions and selected organic constituents; however, microbiological tests were also conducted on several samples from two of the streams. Black Bayou was dominated by municipal-sourced runoff (fluoride ~1 mg/L, conductance = 90 to 150 µS/cm) along its course and showed the least degree of organic and inorganic pollution. Along most of its course, Cane Creek discharge and water quality are dominated by a permitted discharge of Memphis aquifer water (presumably used for industrial cooling), but the stream shows diminished water quality and undesirable environmental conditions downstream where an old landfill is eroding into the stream bed. North Cypress Creek shows a general decline in water quality (conductance up to 326 µS/cm) downstream. Dissolved oxygen shows a pronounced decrease along a reach with deplorable environmental conditions, black water, and several possible pollution sources; samples at this location contain substantial *E. coli* contamination. The results of these studies indicate the breadth of variability in sources of urban runoff and potential pollution in urban storm sewers.

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GREEN BUILDING AND WATER QUALITY
HOW GREEN IS "GREEN?"

Don Green[1]

The design and construction of our 'built environment' creates enormous pressure on our environment, especially on our water resources. There have been a few developments in the area that focused on better site design which includes water issues as a part of their results, if not part of their focus, and other developments which had water issues as a definite focus of their sustainable efforts.

Post World War II suburban sprawl changed the landscape of the U.S. One result of the sprawl is our growing dependence on energy such as gasoline and electricity. These energy sources are dependent on water and it has become a major limiting factor for alternative energies such as biodiesel and ethanol and the expansion of existing nuclear and coal power generation facilities especially with the continuing drought.

Over the last few years, with our seemingly abundant source of cheap electricity and fuel, we have not put an emphasis on conservation of these resources. Things have changed. As of late, many have put an emphasis on 'green building' examining how we can better develop our built environment with a focus on conserving resources, but how green is "green?"

Several organizations have developed certifications to better define our "green buildings;" a few of these are: EPA: EnergyStar and WaterSense, National Home Builders Association, U. S. Green Building Council's: Leadership in Energy and Environmental Design, LEED Green Building Rating System, TVA: Energy Right Program and the Greater Atlanta Home Builders Association in partnership with Southface: EarthCraft Program.

There are a few local organizations that are focused on water related issues for land development such as Cumberland River Compact's Building Outside The Box programs, U.S. Green Building Council's LEED Green Building Rating System™. Some home builders and developers have stepped up realizing the connection with changes in the landscape and water issues.

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IS STREAM DISCHARGE FRACTAL? A COMPARISON OF WATAUGA RIVER DISCHARGE BEFORE AND AFTER CONSTRUCTION OF WATAUGA DAM

Ingrid Luffman[1]

Discharge from northeast Tennessee's Watauga River is analyzed over two sixteen-year periods, one before the construction of Watauga Dam, and one after construction of the dam. A comparison of river discharge pre- and post-construction can assist in understanding the statistical characteristics of discharge for modeling purposes. Stream discharge is impacted by a number of storage and runoff processes operating at several temporal scales (Hurst, 1951). An unregulated stream may have discharge varying over several orders of magnitude, yet a stream in which flow has been regulated by a dam may have discharge varying over fewer orders of magnitude, but at higher frequencies.

Spectral analysis of hydrologic time series has been used to identify a power-law statistical relationship in both rainfall and discharge (De Vries et al., 1994; Pelletier & Turcotte, 1997; Radziejewski & Zbigniew, 1997). Previous studies of stream discharge have focused on identifying the fractal behavior of natural systems, yet many rivers are regulated by a system of dams and reservoirs. A comparison of flow on an unregulated river to flow on a regulated river contributes to the understanding of the impact of regulation on stream discharge variability. The purpose of this research is two-fold: First, to determine whether stream discharge on Watauga River during the study period is fractal, and second to examine differences in discharge variability between regulated and non-regulated streams. In other words, can regulated, unregulated, or both types of discharge be modeled using a self-affine fractal time series, and what are the implications?

Stream discharge for USGS gauge 03486000 (Watauga River at Elizabethton, TN) from 1926-1941 and 1953-1969 was log-transformed and long term trends were removed. I used an approach similar to Radziejewski & Zbigniew (1997), first log-transforming the discharge, second removing the long-term trend using regression and third normalizing the dataset using the overall variance, which allows for comparison between the pre-and post-dam datasets (Figure 1).

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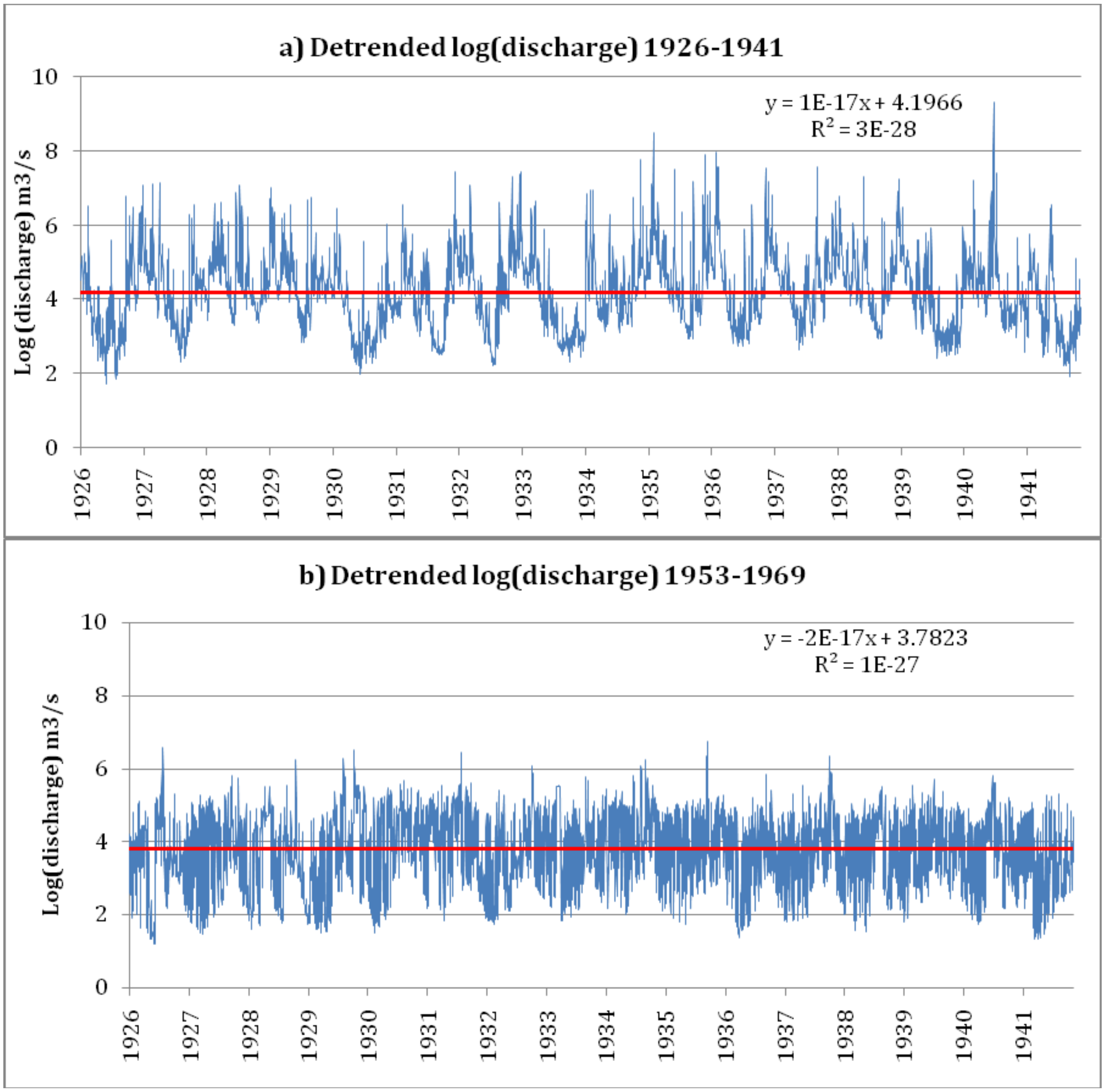
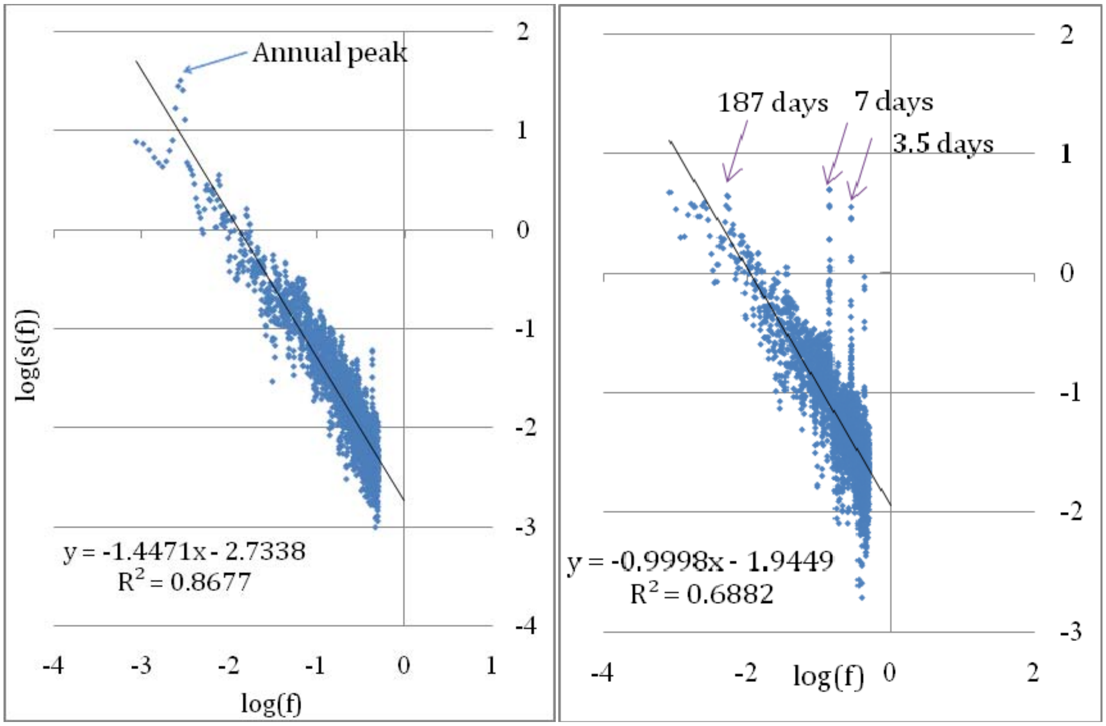


Figure 1. Watauga River detrended log (discharge) for (a) 1926-1941 and (b) 1953-1969.

After detrending, I used the Fast Fourier Transform to deconstruct the time series into a set of sine waves. A plot of amplitude versus frequency of the set of sine waves is the power spectrum of the time series, and a smoothed plot is the spectral density. When a power law relationship exists between amplitude and frequency, a scatterplot of spectral density versus frequency on a log-log scale can be approximated by a straight line, and the dataset is fractal. In this case, the slope of the regression line can be used to estimate the fractal dimension (Turcotte, 1997).

The scatterplots of the pre- and post-dam discharge displayed a number of peaks, indicating periodicity in the discharge time series. Seasonal periodicity can be identified in the pre-dam plot by the annual peak (Figure 2a), while periodicity of approximately 6 months, 7 days and 3.5 days can be identified from peaks in the post-dam scatterplot (Figure 2b).



b) 1953-1969

a) 1926-1941

Figure 2. Plot of log(spectral density) vs. log(frequency) for (a) 1926-1941 and (b) 1953-1969.

The positive slope of the regression line (β is used to estimate the Hausdorff measure (H) and the fractal dimension (D) using the relationship

$$\beta = 2H + 1 = 5 - 2D \qquad (1)$$

which is applicable for one-dimensional self-affine fractals (Turcotte, 1997). Substitution of β in (1) gives estimates of D = 1.78 for the pre-dam discharge (1926-1941) and D=2.0 for the post-dam discharge (1953-1969). The smaller fractal dimension for the pre-dam discharge indicates more autocorrelation (more persistence). In other words, discharge on any given day is more correlated to discharge on nearby days due to common factors influencing discharge (for example, contributions from precipitation, runoff and groundwater).

Because the fractal dimension, D, of the time series is an indicator of tortuosity (and thus the small-scale variability of the dataset), the higher D-value obtained for the regulated stream indicates that high frequency variability increases after construction of the dam. The 1953-1969 discharge data are less auto-correlated at low lags, in other words, the data are more anti-persistent due to frequent daily discharge fluctuations. A likely explanation is that discharge fluctuations are related to regular releases for power generation. In addition, Watauga Reservoir's position at the top of the Tennessee Valley Authority's Tennessee River valley system requires that water be discharged not only to meet power requirements, but also to meet the water needs of the downstream reservoirs. Because controls on discharge may vary without autocorrelation, it follows that the Watauga River discharge data exhibit the same statistical behavior. This result has important implications for discharge modeling, because is underscores the importance of reservoir releases as a control for discharge.

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SANTA BARBARA URBAN HYDROGRAPH METHOD: SHOULD IT BE THE PREFERRED METHOD FOR THE SOUTHEAST?

Michael Clay[1]* and Dr. Jerry Anderson[2]

APPROACH

The purpose of this study was to evaluate the current engineering practices related to estimating peak flows and runoff hydrographs for small urban catchments. Observed rainfall and flow data was collected for eight months for a 3.35 acre parking lot on the University of Memphis campus in Memphis, TN. Using the observed rainfall data as input, various methods of estimating the peak flow and runoff hydrograph were compared against observed peak flows and runoff hydrographs. Three hydrograph estimation procedures were evaluated: the Rational Hydrograph Method, the NRCS (SCS) Dimensionless Unit Hydrograph Procedure, and the Santa Barbara Urban Hydrograph (SBUH) Procedure. Based on the root mean square error and percent difference in estimated peak flows to observed peak flows, the SBUH provided the best estimation of the runoff hydrograph.

RESULTS AND DISCUSSION

Although the SBUH method is not commonly used in the southeastern United States, its runoff and routing procedures are well suited for this area. The SBUH employs the same effective rainfall calculations as outlined in the SCS method, using a curve number to convert rainfall to runoff. However, rather than using a unit hydrograph, the SBUH uses instantaneous hydrographs for each time step routed by use of the time of concentration. The time of concentration is used to provide the attenuation offered by basin storage effects. Thus, in the opinion of the authors, the SBUH method is capable of providing a more accurate estimation with less computational effort than the SCS method.

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AUTOMATED DETERMINATION OF POTENTIAL FLOOD DAMAGES FOR A COMPLEX DOWNTOWN FLOODING AREA

Curt Jawdy*[1] and Jonnathan Owens[2]

Johnson City desired a cost effective solution for a severe flooding problem in the historic downtown. AMEC was tasked with creating and evaluating several flood abatement alternatives in order to develop such a solution. Estimating the financial impact of flood events in an area with many buildings and complex flow patterns was made possible using a link-node hydraulics model and custom GIS tools.

The first phase of the project required modification of an EPA SWMM 4 model that had already been developed. The model was converted to the latest version of SWMM software and a significant amount of new detail was added. To simulate the deep overland flow through downtown that occurred during flood events, streets were modeled as channels and the intersections were modeled as junctions.

The existing conditions model was completed and verified against rough high water marks. Abatement concept models were then created, providing peak water levels throughout the downtown.

The task of calculating flood damages for 150 buildings over 6 storms and 4 concepts was automated using Visual Basic programming as follows. GIS building data provided by the City was joined to the most appropriate (usually nearest) node from the hydraulic models. Subtracting the building's finished floor elevation from the node's peak flood elevation provided a depth of flooding for each building-storm-concept combination. This depth of flooding was then used to calculate a percent damage using a published depth-damage function. Finally, the damage percent was multiplied by the appraised value to determine storm damage.

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SESSION 2C

DATABASE MANAGEMENT
8:30 a.m. – 10:00 a.m.

A HEC-RAS Model Developed by Synthesization of Surveyed and GIS Elevation Data
Gregory H. Nail

Implementing and Interfacing with EPA's Water Quality Exchange Network
Gerald Burnette

Wolf Creek Dam Integrated GIS Database, Web Site, and 3D Model
L. Benneyworth, D. Greene, B. Shah, T. Johanboeke, M. Elson, T. Haskins, and M. Zoccola

BACTERIA
10:30 a.m. – 12:00 p.m.

The Link Between Groundwater Geochemistry and Bacteria in Two Karst Springs
Patrice Armstrong, C. Cobb, B. Cobb, M. Martin, and J. Stewart-Wright

Microbial Adaptations to Karst Aquifers with Contaminants
Tom D. Byl and Roger Painter

Bacteria Sources and Load in Duck River Basin
James J. Farmer

TECHNOLOGY I
1:30 p.m. – 3:00 p.m.

Applications of Computer Models for Enhancing Design and Operations of Aeration Systems at Hydropower Projects
Richard J. Ruane, Gary E. Hauser, and Daniel F. McGinnis

Fecal and Hormonally Active Compound Inputs Into an East Tennessee Watershed
Melanie L. DiClaudio, Dan E. Williams, John Sanseverino, Alice C. Layton, James P. Easter, and Gary S. Sayler

Acute and Chronic Toxicity of Nano-Scale TIO_2 Particles to Freshwater Fish, Cladocerans, Green Algae, and Effects of Organic Carbon on TIO_2 Toxicity
Tina Bradley, Scott Hall, Joshua T. Moore, Tunishia Kuykindall, and Lauren Minella

TECHNOLOGY II
3:30 p.m. – 5:00 p.m.

The Evaluation of a Chemical Fingerprinting Technique for Identifying the Sources of In-Stream Sediments
Robert A. Hull, Forbes R. Walker, and Michael E. Essington

Utility of Field Indicators as Screening Tools for Groundwater Contamination Near Landfills in Tennessee
Randy M. Curtis

Watercress as Sentinels of Water Quality
Christopher Beals

A HEC-RAS MODEL DEVELOPED BY SYNTHESIZATION OF SURVEYED AND GIS ELEVATION DATA

Gregory H. Nail, PhD, PE[1]

This paper documents a case study in which the widely applied one-dimensional open channel flow modeling software, Hydrologic Engineering Center – River Analysis System (HEC-RAS), was used to simulate hypothetical unsteady flows from Wappapello Dam, Missouri. Extensive surveyed stationing and ground elevation data exists in the form of a previously developed HEC-2 model. This HEC-2 model has been converted to HEC-RAS, and significantly enhanced by the addition of stationing and ground elevation data obtained using a GIS software application, HEC-GeoRAS. Wappapello Dam controls flow on the St. Francis River, which forms the western boundary between the Missouri bootheel and Arkansas. The reach of the St. Francis below Wappapello Dam is unusual in that previous steady and unsteady flow hydraulic modeling results, including inundation mapping, are available for guidance and comparison.

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Power Point File of Presentation

IMPLEMENTING AND INTERFACING WITH EPA'S WATER QUALITY EXCHANGE NETWORK

Gerald Burnette[1]

EPA has developed a comprehensive approach for sharing all manner of environmental data – the Exchange Network. One of the exchanges on the Network is the Water Quality Exchange (WQX). WQX is replacing the STORET system, and will become the primary repository and distribution center for water quality data managed by EPA throughout the US. HGL has spent several years developing the DASLER water quality data management system for the US Army Corps of Engineers and other organizations, and recently completed an update that allows DASLER to export data to WQX. This presentation will outline the results of our practical experience with WQX. We will examine the structure of the Exchange Network in general, and WQX in particular. We will also discuss options for participating in WQX, methods for obtaining water quality data, and methods for sharing your water quality data with others.

HISTORY OF EPA'S WATER QUALITY DATA MANAGEMENT

EPA has a long history of involvement with all sorts of environmental data in the United States. The organization acts as a clearinghouse for data ranging from air pollution statistics to pesticide characteristics. EPA assumes this role because of its involvement in a wide variety of environmental investigations and activities. In fact, EPA provides monetary support for the monitoring and assessment activities of many, many less-well-funded organizations. Since EPA essentially pays these organizations to collect data, they have a legitimate interest in obtaining the results.

Over the years, each department and activity within EPA developed their own databases and approaches for managing their particular data of concern. Such was the case for the Office of Water with respect to water quality data. Their first widespread system for managing water quality data was STORET (STOrage and RETrieval system). When it first appeared in 1965, STORET resided on a mainframe. The design of this database was very simple: one table recorded information about sampling locations, and another one stored the water quality observations. Interaction with the database was limited to EPA personnel located at the same site as the mainframe. If you wanted to submit data to STORET, you sent ASCII files on a disk and EPA loaded the data. If you wanted to obtain data from STORET, you sent a request and EPA extracted the data from the database, sending you the results in an ASCII file.

In the mid-1990's, EPA decided it was time for a major overhaul of STORET. They completely redesigned the database, adding an incredible array of metadata and supporting tables. The new system overcame the design deficiencies of the original, but it introduced a new problem in its place: the referential rules of the new database made it impossible to allow for submissions using the old ASCII file approach. In order to address this problem, EPA chose to distribute local copies of the database to all interested parties. The modernized STORET system was first released in 1998, and required users to run this local version of the entire database model in order to meet their submission requirements. Uploads to the national STORET data warehouse were

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handled by data dump functions provided with the back end database management software.

The drawback to this approach was that local users now had to interact extensively with the much more complex STORET data model. Due to budget and other constraints, EPA was never able to develop an acceptable user interface for the new STORET. The interface they offered was confusing and difficult to navigate, and it never gained popular acceptance. While the Office of Water pondered how to address this conundrum, a new initiative was taking shape at EPA. The agency began developing a cohesive approach for handling all environmental data in a consistent manner. This approach uses a markup language (XML) as the basis for exchanging data between disparate systems via interchange files that are self-documenting. The overall implementation of this technology within EPA is called the Exchange Network. By creating an exchange for water quality data (the Water Quality Exchange or WQX), EPA could still provide a national data clearinghouse without the need to provide tools specific to the activity. As long as an organization was able to submit data that matched the WQX schema, they could use any system they desired for local management. In 2006, EPA announced that it would phase out STORET in favor of this new paradigm. Support for STORET is due to end in 2009.

HISTORY OF DASLER

The Data Management and Analysis System for Lakes, Estuaries and Rivers (DASLER) is one of the tools that filled the data management gap created by the arcane STORET interface. DASLER was developed originally for the US Army Corps of Engineers in the mid-1990's. Other organizations discovered its utility and adopted or adapted it for their own use. The DASLER data model is similar to that of the modernized STORET in that it contains enough complexity to adequately assess the quality of the data it houses. However, the DASLER database is focused on surface water quality data only; it omits many of the more subtle and obscure data types that STORET includes in order to be compatible with all possible activities. As a result, the DASLER user interface is much more user friendly, which has led to DASLER's widespread acceptance. Many organizations use DASLER to collect and manage their water quality data and then interface with STORET only to provide data to EPA.

From the beginning, DASLER was capable of exporting data to STORET. When the first versions of DASLER appeared, STORET was still in its ASCII file upload mode, and DASLER had export functions that produced the required files. When EPA introduced the modernized STORET, DASLER was modified so that it could export data in a format compatible with STORET's import functions. Now that EPA has introduced the WQX initiative, DASLER has once again been modified in order to maintain the ability to effectively export data in the required format.

THE EXCHANGE NETWORK

Before examining exactly how DASLER interacts with WQX, we should explore the overall structure and operation of the Exchange Network.

The Exchange Network represents the next step in the evolution of truly distributed data. The architecture of the network is well integrated into the Internet, making it possible for any organization with a presence on the Internet to connect in some fashion. The primary components of the Exchange Network are exchanges and nodes. Exchanges are specialized programs that act as gatekeepers to a particular type of data. Each exchange is oriented toward a specific category of environmental data (e.g., water quality data). Each exchange is based on a schema developed for proper management of the data for that exchange. Nodes are smaller programs that interact with the network framework to retrieve data. Nodes are not geared toward any particular type of data, and can generally obtain data from any exchange. Nodes may also submit data to exchanges. Submissions of data to all exchanges are managed through a core process called the Central Data Exchange (CDX). When a node submits data to the Exchange Network, the CDX provides the first level of validation. The CDX ensures that the submission follows the rules of XML so that it may be properly interpreted by the target exchange. If the submission is acceptable to CDX, then it is passed on to the target exchange for validation against the exchange's schema. If it passes this validation, then it is accepted and incorporated into the exchange. The elegance of this system is that, while all the data ultimately reside in a database, the particulars of any one database are hidden from users, obscured by the commonality of the exchange.

Participation in the Exchange Network is available at several levels. As you might imagine, developing an exchange is a serious undertaking. For that matter, so is developing a node. A fully functioning node requires dedicating space on a server and developing programs that interact with the network at a deep level. The advantages are significant – a fully-functioning node has the ability to obtain data from most any exchange and make that data available to consumers of its service. Obviously, not everyone has the resources to develop a full blown node. To satisfy the requirements of mere computing mortals, EPA has promoted the development of simpler node software. A light node client (dubbed "lite" as is common practice these days) has less functionality that a complete node, but it has enough capabilities to be very useful. Of particular note is that it provides the ability to retrieve data from any exchange and to submit data to any exchange. This is the key to providing specialized applications like DASLER with the ability to interact with exchanges such as WQX.

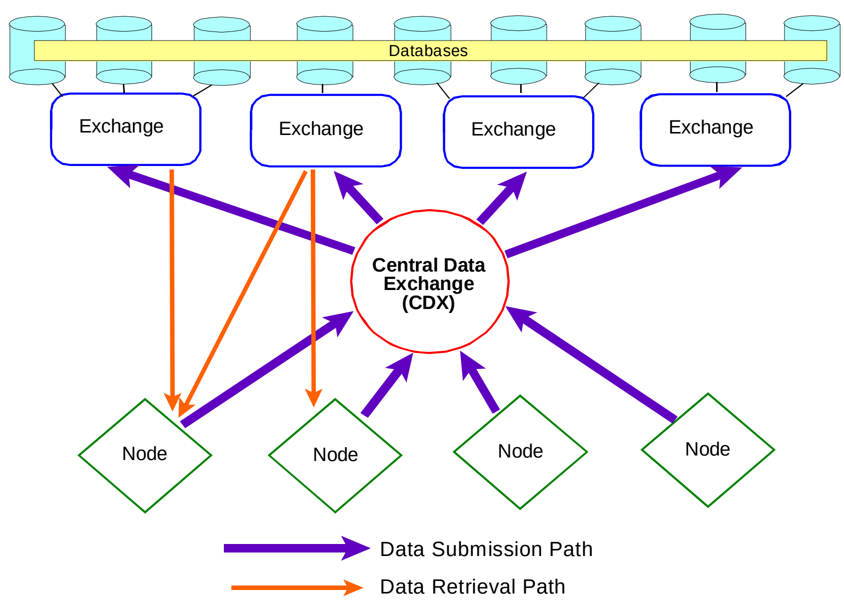

Figure 3. Data flow within the Exchange Network.

EXPORTING DATA TO WQX

We're now ready to explore the main point of our subject – how DASLER interacts with WQX. The focus of DASLER is the local management of the water quality data for a particular organization. In the narrowest sense, it has no use for water quality data from other organizations. Therefore the connection between DASLER and WQX is strictly one-way: from DASLER to WQX. Also, since most organizations that use DASLER lack either the money or the inclination to develop a full Exchange Network node, DASLER utilizes the node client lite software. This greatly simplifies our requirements.

The export process itself couldn't be much simpler: all that is required is identifying the data to be exported, naming the output file, and selecting a few choices regarding special processing. DASLER offers a variety of ways to pick the sample(s) to be exported. Users may choose a single sample, a group of samples related by some common trait (i.e., all samples from location X taken in 2005), all samples for a given project, or other criteria. Files may be given any desired name and may be placed at any location on the local system, but they must have a .xml extension.

The data manipulation options that may be chosen deal with extra items to be included in the export file and the tweaking of sample details. WQX enforces many of the same business rules that were found in the modernized STORET. For instance, before any sampling results will be accepted, you must register information about your organization, describe your sampling program, and provide details about the sampling location. In the modernized STORET these were distinct data submission operations, but in WQX you can submit all of these details in a single operation. DASLER offers a series of check boxes that allow you to select which of these details are included in any particular file. Since these details need only be exported once, DASLER tracks whether or not you've done this previously and modifies the prompts accordingly. Sample and results manipulation options include setting the time zone designation, modifying the collection method, and altering the units for results of each parameter.

While the export itself is simple, arriving at this ability was not. Each change EPA has made in its data acceptance procedures has caused a ripple effect in programs like DASLER. Consider, for instance, how various programs handle parameter identification. The old STORET program identified parameters by a code number. Many people had adopted these code numbers for their own use, and the code numbers soon became synonymous with the parameter. When DASLER was first created, we adopted the same code numbers because they were so well known. When modernized STORET was introduced, EPA abandoned the code numbers, choosing instead to identify all parameters by name only. This placed an additional burden on programs like DASLER, because now every parameter had to have a name that exactly matched what was in STORET. Furthermore, EPA kept tweaking the names, which meant users had to constantly monitor EPA's master list for changes. That trend continued with the introduction of WQX, and once again the names of many parameters were changed. Many parameter names had to be modified in DASLER. [There is hope that this routine will abate. Because the Exchange Network designed around the concept of sharing environmental data, EPA is forcing all exchanges to adhere to a single common parameter naming convention. All exchanges are required to use the names found in EPA's Substance Registry Service.]

Another issue that arose with the introduction of WQX had to do with the amount of detail required in the metadata. At each step in this evolution of EPA's data management, they have imposed greater metadata requirements. While there is a valid argument for the increase – more details about an organization and their sampling program means a better ability to judge the validity of their data – the changes impose more of a burden on other programs. In this case, several DASLER tables had to be augmented by adding new fields to track information that otherwise had little or nothing to do with the focus of the software. Furthermore, organizations that use DASLER now have to actively manage this additional information in order to be compliant with EPA's requirements.

Nonetheless, all the new requirements and changes were accomplished, and DASLER is now capable of producing files that export successfully to WQX. This is not to say that the effort is always flawless. It is probable that all the structural flaws in the XML exports have been resolved. However, users are still discovering new parameter name changes and other nuances that cause problems at the WQX level. As users share their experiences and knowledge, these errors reduce in number.

CONCLUSIONS

The Exchange Network offers great potential for easier sharing of environmental data. With this potential comes increased responsibility on third-party data management programs if they want to participate in the progress. DASLER is one example of such a program that has been adapted to meet the new challenges.

WOLF CREEK DAM INTEGRATED GIS DATABASE, WEBSITE, AND 3D MODEL

L. Benneyworth[1]*, D. Greene; B. Shah; T. Johanboeke; M. Elson[2], P.G.; T. Haskins, P.G.; and M. Zoccola, P.E.

AMEC Earth & Environmental (AMEC) has collaborated with the US Army Corps of Engineers (USACE), Nashville District to manage legacy data associated with the Wolf Creek Dam in Jamestown, KY. AMEC and the USACE are using some of the latest data technologies to provide an integrated project database to assist the USACE in analyzing the vast amount of historical data associated with design, construction, investigations, and rehabilitation of the dam. To this end, AMEC developed a Geographic Information Systems (GIS) database that includes data linked to spatial site features, including CADD drawings, images files, reports, boring logs, spreadsheets, and historical photos. The resulting information is available through a secure, GIS-based Internet data viewer. The integrated project database approach provides USACE with direct access to the database with a dynamic map interface, in a comprehensive, easy to understand, visual format. This integrated database management system provides "real time" access to data, to an unlimited number of users, with no special software or GIS expertise required. In addition to the interactive map viewer, a 3D representation of the data has been created. The model provides a visualization of critical project features in 3D that cannot be viewed effectively in any other way. The technology tools developed for the project provide the USACE a means to quickly evaluate site data, effectively perform analyses, and communicate results.

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THE LINK BETWEEN GROUNDWATER GEOCHEMISTRY AND BACTERIA IN TWO KARST SPRINGS

Patrice Armstrong*[1], C. Cobb[2], B. Cobb[2], M. Martin[2] and J. Stewart-Wright[3]

The objective of the project was to determine if there was a connection between geochemistry and bacteria types in two limestone bedrock springs. The springs are located on the north-east side of Tennessee State University (TSU) main campus in Nashville, TN. Samples were collected from the summer of 2007 through winter of 2009. The TSU springs were sampled approximately every week from June through September, 2007, and then less frequently through March, 2009. Water quality parameters measured include temperature, specific conductance, dissolved oxygen, pH, sulfate, nitrogen, *E. coli*, and other bacteria using Biological Activity Reaction Tests (BART). Continuous water-quality monitoring devices were installed at one of the springs to measure changes associated with different weather patterns. Results of the monitoring activities indicate that the water temperatures were very stable, slowly dropping to 16.5°C in April and rising to 19°C in September. Sulfate concentrations ranged from 57 mg/L during the dry season to 140 mg/L during the wet-spring season. Sulfur-related bacteria followed the same trend as the sulfate concentrations. During January and February 2008, a poultry-research waste storage system approximately 200-300 yards upgradient of the springs was leaking liquefied wastes. The system leaked approximately 2 gallons per minute of high ammonia wastes for 2 months. Three weeks after the leak started, nitrate concentrations rose from 2 mg/L to 8 mg/L in the springs. Approximately a month after the leak was fixed, ammonia levels peaked at 30 mg/L in the springs. Concurrent with these nitrogen patterns we documented a rise in ammonia-oxidizing bacteria from less-than 1000 colony-forming units (CFU) to 100,000 CFU. The ammonia-oxidizing bacteria concentration returned to lower levels as the ammonia was removed from the aquifer. Additional BART tests confirmed the presence of denitrifying, iron-reducing, and slime-producing bacteria at each of the springs. Fecal bacteria were often present in the springs, but there was no discernible pattern to their occurrence or concentrations. These results indicate there is a connection between geochemistry and certain bacteria types in the karst aquifer.

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MICROBIAL ADAPTATIONS TO KARST AQUIFERS WITH CONTAMINANTS

Tom D. Byl[1] and Roger Painter[2]

There is a lack of studies examining biodegradation in karst aquifers, which may be due to the widespread perception that contaminants are rapidly flushed out of karst aquifers. Also, there is reports in the scientific literature about the quantity or types of bacteria that inhabit karst aquifers. The objective of this project was to address these two issues. In highly developed and well-connected conduit systems, the rate of contaminant migration is expected to be much faster than the rate of biodegradation. Field (1993) states that remediation techniques such as ground-water extraction or bioremediation are impractical in karst aquifers dominated by conduit flow; however, he also states that the belief that contaminants are rapidly flushed out of karst aquifers is a popular misconception. Large volumes of water may be trapped in fractures along bedding planes and other features isolated from active ground-water flowpaths in karst aquifers (Wolfe and others, 1997). In areas isolated from the major ground-water flowpaths, contaminant migration may possibly be slow enough that biodegradation could reduce contaminant mass if favorable microorganisms, food sources, and geochemical conditions are present (Byl and Williams, 2000; Byl and others, 2001). The capacity for biodegradation processes in a karst setting was evaluated at sites in Tennessee and Kentucky.

The potential for biodegradation of trichloroethylene (TCE) was studied in a karst aquifer at Lewisburg, Tennessee. This site was selected because of the presence of TCE degradation by-products in the karst aquifer, available site hydrologic and chlorinated-ethene information. Additional chemical, biological and hydrological data were gathered to evaluate if the occurrence of TCE degradation by-products in the karst aquifer was the result of biodegradation in the aquifer or simply transport into the aquifer. Geochemical analysis established that sulfate-reducing conditions, essential for reductive dechlorination of chlorinated solvents, existed in parts of the contaminated karst aquifer. Geochemical conditions in other areas of the aquifer fluctuated between anaerobic and aerobic conditions and contained compounds associated with cometabolism, such as ethane, methane, ammonia and dissolved oxygen. A large, diverse bacteria population inhabits the contaminated aquifer. Bacteria known to biodegrade TCE and other chlorinated solvents, such as sulfate-reducers, methanotrophs, and ammonia-oxidizers, were identified from karst-aquifer water using the RNA-hybridization technique. Results from microcosms using raw karst-aquifer water found that aerobic cometabolism and anaerobic reductive dechlorination degradation processes were possible when appropriate conditions were established in the microcosms. The chemical and biological results provide circumstantial evidence that several biodegradation processes are potentially active in the karst aquifer. Additional site hydrologic information was developed to determine if appropriate conditions persisted long enough in the karst aquifer for these biodegradation processes to be significant. Continuous monitoring devices placed in four wells during the spring of 1998 documented a dual phase ground-water flow system within the karst aquifer. Dynamic areas were present within the karst aquifer where active flow occurred, as well as, stable areas in the karst aquifer that were isolated from active flow. The pH, specific conductance, low dissolved oxygen levels and low oxidation-reduction potentials changed very little in the stable areas isolated from active flow. The stable areas in the karst aquifer had geochemical conditions and bacteria conducive to

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Portions of this abstract were previously published in USGS reports indicated in reference section.

reductive dechlorination of chlorinated ethenes. The dynamic areas of the karst aquifer associated with active flow fluctuated between anaerobic and aerobic conditions in response to rain events. Associated with this dynamic environment were bacteria and geochemical conditions conducive to cometabolism. In summary, multiple lines of evidence developed from biological, chemical and hydrological data demonstrate that a variety of biodegradation processes were active in this karst aquifer.

A second karst-aquifer site contaminated with jet fuel was also investigated. The site is located at an airfield in southern Kentucky. Ground-water samples were collected for bacteria and geochemical analysis from several contaminated monitoring wells in an unconsolidated regolith and karst aquifer that had varying concentrations of dissolved fuel. Bacteria counts ranged from approximately 700,000 bacteria per milliliter to 1.2 million depending on the well and sample collection time. These bacteria counts were derived using two methods, direct counts and BART growth tests, and the results of the two tests were within 20 percent of each other. These numbers are much greater than previously reported when tryptic soy agar was used to quantify heterotrophic bacteria in the same wells (Byl and others, 2001). Bacteria from the fuel-contaminated part of the karst aquifer had a 5% lighter buoyant density and a wider range of sizes than the bacteria from the non-contaminated well. Additionally, bacteria isolated from fuel-contaminated ground-water samples readily grew with dissolved gasoline as the only source of food. Static microcosms (n=3) set up using aerated raw karst water spiked with benzene at 1 mg/L established a biodegradation rate of 50% loss ($T_{1/2}$) in 3 days. Sterile control microcosms had less than 10% benzene loss over the same time period. Additional field evidence that biodegradation was taking place in the aquifer was established by measuring geochemical indicators. The wells with screens intersecting non-contaminated sections of the aquifer had greater dissolved oxygen concentrations (generally above 2 milligrams per liter) than those intersecting more contaminated sections (dissolved oxygen less than 0.1 milligrams per liter). Also, where the oxygen concentrations were diminished, geochemical evidence indicated that anaerobic processes were active. This evidence includes elevated levels of ammonia, sulfide and ferrous iron in the fuel-contaminated ground-water samples. Based on these results, biodegradation of fuel constituents in the karst aquifer is indicated, and therefore, natural attenuation should not be disregarded because of preconceptions about low microbial activity in karst aquifers.

The third set of experiments reported here considers whether free-living bacteria or attached bacteria were responsible for biodegradation processes in karst. In karst aquifers, biodegradation can be accomplished both by surface-attached and free-living bacteria. Biodegradation by attached bacteria is dependent upon and limited by the relatively low surface area to volume ratio (SA/V) of karst aquifers. Biodegradation due to free-living bacteria, however, is not limited by SA/V, but by residence time. The objective of this research was to determine if free-living karst bacteria contributed as much to the removal of ammonia (NH_3) as attached, indigenous karst bacteria. These results were compared with the results of a toluene biodegradation study conducted using the same set up (Painter and others, 2005 KIG). The experimental setup included flow-through karst microcosms with high and low SA/V ratios. The low SA/V ratio system consisted of three 1-L cylinders connected together with non-stick tubing. The high SA/V ratio karst system was similar except the cylinders were packed with glass beads to increase the SA/V ratio by approximately 500%. Microscopic examination confirmed that bacteria colonized the interior surfaces of the lab karst systems. Fresh spring water containing between 10,000 and 20,000 indigenous karst bacteria was continuously pumped through each system. A known quantity of NH_3 was added as a food source and measured at the exit port. Flow rates were similar and residence time differences were compensated for with the residence-time distribution

(RTD) formula described by King and others (2005). First-order NH3-biotransformation rate constants were 0.17 day-1 for the low SA/V system and 0.27 day-1 for the high SA/V system. In the previous toluene study, the first-order rate constants were 0.014 hour-1 for the low SA/V system and 0.016 hour-1 for the high SA/V ratio system leading Painter (2005) to conclude that free-living bacteria contribute as much to toluene biodegradation processes as attached bacteria in karst aquifers. This study suggests that this is not the case with respect to NH_3 biotransformation in karst systems.

ACKNOWLEDGEMENTS

Mike Bradley, Pam Franklin, Kelly Ray, Valetta Watson, Patrice Armstrong, Jim Farmer, Lashun King, Gregg E. Hileman, Shannon D. Williams, David W. Metge, and Ron W. Harvey

PORTIONS OF THIS ABSTRACT WERE PREVIOUSLY PUBLISHED IN

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BACTERIA SOURCES AND LOAD IN DUCK RIVER BASIN

James J. Farmer*[1]

Continuous monitoring of turbidity, streamflow, and specific conductance was initiated at 5 sites in the Fall Creek watershed in Bedford County in the fall of 2008. Weekly counts for *Escherichia coli* were performed at each site. The monitoring is intended to provide information about bacteria loading in relation to land use in the Duck River watershed. Weekly water samples from each site were filtered in succession through 3.0, .45, and .22 micron filters. DNA was extracted from these filters for real-time PCR analysis at the University of Tennessee Center for Environmental Biotechnology. Across a range of flow conditions, turbidity varied from 1 to 276 formazin nephelometric units and *E. coli* most-probable-number (MPN) ranged from 13 to 173,000 organisms per 100 milliliters of water. *E. coli* MPNs for individual streams correlated well with turbidity; Pearson coefficients ranged from .711 to .946. Real-time PCR analysis of filters indicated that more bacteria were retained on the 3µ filter than on the 0.45µ and 0.22µ filters. This result was surprising because the purpose of the 3.0 µ filter was to remove large particles from the water. It was expected that bacteria would be preferentially retained on the 0.45 µ filter. This result suggests that *Bacteroides* and *E. coli* are attached to larger particles or in bacterial clumps. Analysis of DNA from filters for *Bacteroides* molecular markers by real-time PCR indicates both bovine and human signals are present, but no clear trends have been established. Future work includes real-time PCR assays for the pathogens *Salmonella* and *E. coli* 0157:H7.

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APPLICATIONS OF COMPUTER MODELS FOR ENHANCING DESIGN AND OPERATIONS OF AERATION SYSTEMS AT HYDROPOWER PROJECTS

Richard J. Ruane*[1], Gary E. Hauser[2], and Daniel F. McGinnis[3]

Recent developments regarding hydropower projects have led to the need for advancing modeling capabilities of aeration systems.

1. Regulatory requirements by some State agencies are calling for better predictive capability for the performance of turbine venting systems.
2. Power losses are caused by some turbine venting systems, so project owners desire better predictive tools to operate more efficiently and still attain DO objectives.
3. Alternative aeration systems are usually more expensive, so predicting and achieving peak aeration performance of turbine venting systems for attaining DO objectives is important to consider in place of or in combination with alternatives.
4. Total dissolved gases (TDGs) are a concern in some tailwaters, creating the need for the prediction of TDG levels in these hydropower releases.
5. Some hydropower projects are being upgraded with new aerating wheels that can draw much more air into their draft tubes. For these cases, owners often need the best available predictions for the amount of DO uptake that will be attained.
6. Site-specific stream water quality standards for DO can be a consideration for some tailwaters, and the capability to predict future exposure conditions of fish to DO is an important part of establishing better DO standards.
7. Oxygenation of portions or whole reservoirs is being considered at some projects.
8. Lookup tables and operational monitors and controls for aeration systems are being considered for responding to regulatory requirements and reducing power losses.

Commonly used aeration systems for hydropower projects include various approaches to turbine aeration, in-lake diffused air and oxygenation systems, selective withdrawal from the reservoir, and tailrace aeration. For some hydropower projects, a combination of these systems is used. Water quality models are available to significantly enhance the evaluation, design, and operations of these aeration systems for cost-effectiveness, regulatory permitting, and energy conservation.

Significant progress has been made in developing models that can be applied to the following approaches for increasing DO (dissolved oxygen) at hydropower projects: turbine venting using a range of ways to introduce air for both existing and new turbine wheels, compressed air added to draft tubes, tailwater aeration systems including weir aeration, surface water pumps in the forebay, skimmer weirs in the forebay, in-lake diffused air and oxygenation systems in the forebay or upstream from the turbine intake(s), side-stream supersaturation systems, and unit preference for operations where projects have multiple units.

These models can be used for steady-state designs; however, due to the nature of hourly operations for hydropower projects and the variability of DO conditions as well as the use of multiple aeration systems, hourly model simulations over the period of the low DO season are preferable for developing design inputs for aeration systems. Using various approaches the

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integrated effects of multiple aeration systems can be incorporated so that DO at one location can be simulated.

This presentation provides an overview of the modeling approaches that are available and recent applications of these models to attain a range of the objectives for DO using the most cost-effective methods and considering energy conservation.

FECAL AND HORMONALLY-ACTIVE COMPOUND INPUTS INTO AN EAST TENNESSEE WATERSHED

Melanie L. DiClaudio[1], Dan E. Williams[2], John Sanseverino[3], Alice C. Layton[4], James P. Easter[5], Gary S. Sayler[6]

BIOTECHNOLOGY – R&D

New and standard methods are being used to rapidly monitor fecal contamination and hormonally-active compounds in an east Tennessee watershed serviced by a single utility district. The long-range goal is to determine whether wastewater treatment strategies are effective for removal of hormone-active or fecal contaminants and to identify where microbial and chemical contaminants are being introduced. This watershed contains mixed land uses-draining farmland and urban populations incorporating both septic and municipal sewer systems. Yeast-based bioluminescent bioreporters were used to detect environmental estrogens and androgens. In addition, total coliforms and *Escherichia coli* assays were used to monitor fecal contamination. Water samples from four locations (raw and finished wastewater and raw and finished drinking water) were collected three times, as well as samples from upstream and downstream of the effluent pipe on the final sample date. The bioreporters were exposed to concentrated water samples to determine estrogenic or androgenic activity. Potential estrogenic and androgenic activity was found in raw wastewater, however water treatment reduced this activity to below detection. *E. coli*, as well as other coliforms, were found in raw wastewater; while no *E. coli* were detected post-treatment, coliforms were present. Our results demonstrate that these methods can gauge whether wastewater treatment and drinking water samples contain potential EDCs or fecal contamination. Future work will expand the sampling locations to include samples obtained from local watersheds. Data generated, combined with GIS, will map inputs of contaminants and aid watershed regulators in developing remediation strategies for mitigating microbial and chemical inputs.

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ACUTE AND CHRONIC TOXICITY OF NANO-SCALE TiO_2 PARTICLES TO FRESHWATER FISH, CLADOCERANS, GREEN ALGAE, AND EFFECTS OF ORGANIC CARBON ON TiO_2 TOXICITY

Tina Bradley[1*], Scott Hall[1], Joshua T. Moore[2], Tunishia Kuykindall[1], Lauren Minella[1]

This study evaluated the acute and chronic toxicity of 10 nm TiO_2 particles to freshwater aquatic organisms exhibiting varying modes of exposure. The fathead minnow was much less acutely sensitive to TiO_2 (LC50 500 mg/L and higher) than the filter-feeding water fleas *Ceriodaphnia dubia* and *Daphnia pulex* (LC50 approximately 9.5 mg/L). Cerophyll at levels establishing approximately 1.5 mg/L total organic carbon dramatically decreased TiO_2 acute toxicity to *C. dubia* (LC50 > 100 mg/L), whereas 10 mg kaolinite clay decreased the acute toxicity of TiO_2 to *C. dubia* to a lesser extent (LC50 38.6 mg/L) than cerophyll. This indicates that changes in water quality alter the toxicity of TiO_2, and that organic carbon complexation can dramatically alter TiO_2 acute toxicity. In chronic toxicity tests, the green algae *Pseudokirchneriella subcapitata* was more sensitive to TiO_2 (IC25 value 1 to 2 mg/L) than *C. dubia* (IC25 9.4 to 26.4 mg/L) and the fathead minnow (IC25 values over 340 mg/L). The TiO_2 Acute to Chronic Ratio for *C. dubia* was very low, possibly as a result of food-complexation decreasing TiO_2 toxicity in chronic toxicity tests. This study demonstrated that conventional aquatic toxicity test methods are appropriate for evaluation of nano-scale TiO_2, and that algae and filter-feeding invertebrates are much more sensitive to particulate, nano-scale TiO_2 than fish. Additionally, TiO_2 acute toxicity to *C. dubia* is markedly reduced by organic carbon.

THE EVALUATION OF A CHEMICAL FINGERPRINTING TECHNIQUE FOR IDENTIFYING THE SOURCES OF IN-STREAM SEDIMENTS

Robert A. Hull, Forbes R. Walker*, and Michael E. Essington[1]

Sediment is often listed as one of the main contributors to the impairment of surface waters throughout the United States. Sediment source identification is difficult in watersheds with complex combinations of land-uses and non-point sources because of the complexities involved in correlating water quality data, which are relatively easy to collect, to the source of a degrading component. The elemental properties of a particular soil on the landscape may be viewed as a "fingerprint". A comparison of the elemental fingerprints of potential sources and in-stream sediment may be used to establish sediment source. The objectives of this investigation were to characterize the elemental content of suspended stream sediment and potential sources of sediment in an impaired watershed, Pond Creek watershed in east Tennessee (HUC: TN06010201013), and to use multivariate statistical techniques to identify and quantify sediment sources in the watershed. Potential sediment source samples were collected throughout the watershed and suspended sediment samples at two locations. Subsamples of the <53 µm material and suspended sediment were subjected to total dissolution, HNO_3-extraction, and Mehlich 3-extraction. Descriptive statistics suggested that each dataset contained considerable heterogeneity. The source samples were grouped according to land management and position in the landscape. The results of a Kruskal-Wallis rank test and discriminant function analysis indicated that for all three datasets the elemental variability of the samples was not sufficient to differentiate the source and sediment samples and characterize the suspended sediment sources using the initial group definitions. When using all available elemental data from each dataset the groups defined by cluster analysis and canonical discriminant analysis did not match the contents of the initially defined groups. The composition of the clusters varied from one dataset to another, making it difficult to draw conclusions concerning the cluster contents, or to identify sources of suspended sediment. The lack of elemental content variability for differentiating the source and sediment samples and characterizing the suspended sediment sources is likely an artifact of the watershed sampling procedure that was employed, which was directed towards sampling sources likely to be contributing to the suspended sediment load in Pond Creek.

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UTILITY OF FIELD INDICATORS AS SCREENING TOOLS FOR GROUNDWATER CONTAMINATION NEAR LANDFILLS IN TENNESSEE

Randy M. Curtis[1]*

The size and complexity of solid waste disposal facilities causes a different style of contamination for the environment than hazardous waste disposal units. Field indicators have limited utility in evaluating releases from hazardous waste units, particularly when volatile organics are the primary constituents. The release of solid waste constituents from landfills will generate an entire range of environmental effects as the physical, chemical, microbiological, and hydrological conditions in the area of the landfill are affected. Measurments of specific conductance, pH, temperature, and alkalinity can be done in the field, and, more importantly, they can be done quickly and cheaply. While the values obtained have little utility for risk assessment, they can serve as guides for the timing and location of more detailed analyses needed to evaluate potential threats to human health or the environment. Specific conductance, pH, temperature and alkalinity measurments for several landfill monitoring wells were compared using graphs and basic statistical methods to evaluate the screening potential of the indicator parameters. The ease of acquisition and low relative cost of field indicator information would allow more thorough and rapid evaluations of potentially impacted domestic water supplies, which would facilitate delimiting the potential outer limits of the effects of leakage from a landfill.

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WATERCRESS AS SENTINELS OF WATER QUALITY

Christopher Beals*[1]

The oxidase enzyme activity of Watercress (*Nasturtium*) was investigated as a biomarker of oxidative stress due to exposure to aquatic toxins. Watercress is an aquatic plant that has been found to readily bioaccumulate heavy metals that may be found contaminating aquatic systems. Toxic effects of contaminants on plant physiological processes may include changes in enzymatic activity particularly oxidases. Peroxidase and catalase enzymes produce a luminescent reaction as hydrogen peroxide is broken down into water and an oxygen radical. In this investigation, a luminometer was used to quantify the luminescent intensity caused by this reaction as a result of oxidative stress to the plants. Watercress plants were collected from a relatively clean spring on the Tennessee State University campus and were exposed to three different concentrations (10, 100, 1000 ppm) of Et-85, ethanol, and gasoline in order to observe the effects of these chemicals on enzyme activity. A plant slurry was produced using a mortar and pestle, and hydrogen peroxide was injected into the crude enzyme extract with each luminometer reading. Initial experiments determined that a pH 4 buffer provided an increase in enzyme longevity and consistent readings. Whole plants exposed to increasing concentrations of Et-85 biofuel show an incremental increase in chemiluminescence when compared to the control plants (0.0 ppm Et-85). It is hypothesized that the aromatic rings present in the gasoline component of Et-85 may stimulate additional luminescence associated with the catalase reaction. In addition to Et-85, the effects of gasoline and ethanol exposure were examined in separate experiments where plants exhibited oxidative stress when exposed to ethanol, but the reaction occurred after 72 hours whereas plants in the Et-85 experiments showed evidence of oxidative stress after only 24 hours. Fluorometer analysis of unplanted and planted controls will be compared to planted treatments in order to demonstrate Et-85 uptake by watercress plants.

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SESSION 3A

WATERSHED PLANNING II
8:30 a.m. – 10:00 a.m.

Ecological Credit Trading Pilot Study in the Beaver Creek Watershed
Doug Baughman, Roy Arthur, Lisa Bacon, and Rick Brownlow

Aerial Stream Buffer Analysis for Conasauga River TMDL
Frank Sagona and Randy Hale

Site Selection, Modeling, and Design of Sub-Catchment Retrofits for Water Quality and Downstream Channel Protection
Andrew Dodson and Michael Hamrick

POLICY
10:30 a.m. – 12:00 p.m.

EPA Region 4 Inspections at Tennessee Confined Animal Feeding Operations?
Shawn Hawkins and Forbes Walker

A Standardized and Comprehensive Stream Corridor Evaluation Program
Jonathan Hagen, Mounir Minkara, and Rebecca Robinson

The Revised Federal Concentrated Animal Feeding Operation Rule – What Will It Mean for Tennessee?
Forbes Walker and Shawn Hawkins

ECOLOGICAL CREDIT TRADING PILOT STUDY IN THE BEAVER CREEK WATERSHED

Doug Baughman[1], Roy Arthur[2], Lisa Bacon[3], and Rick Brownlow[4]

The Beaver Creek Watershed is located in Knox County, TN and is roughly 25 miles long and 3.5 miles wide, with a total drainage area of approximately 86 square miles. The topography is characterized by a broad floodplain and rolling hills between two ridges, before emptying into the Clinch River. Water quality in the watershed is poor, with the entire length of Beaver Creek on the Tennessee Department of Environment and Conservation (TDEC) 303(d) list. The primary impacts include: sediment, nutrients, and pathogens from agricultural and urban runoff; nutrients and pathogens from municipal point sources; and habitat alteration due to land development.

In conjunction with US Environmental Protection Agency (EPA) Region IV and TDEC, the Beaver Creek Task Force is demonstrating how a credit trading market could be designed to help address the creek's water quality issues. The credit trading market would be an innovative means of effectively balancing economic development objectives with water quality and environmental protection goals in an environmentally challenged watershed. It would support improving and protecting ecological resources in the Beaver Creek watershed.

In particular, the project will propose a framework for a marketplace for investments that implement the watershed plan and Knox County stormwater ordinance. The market analyses will help investors evaluate relative costs and benefits of different control options. Under the framework, market incentives would reward investment in priority watershed plan actions that exceed minimum ordinance standards. Creditable voluntary actions would help leverage financial and other resources for greater environmental returns over a shorter period of time.

Through a marketplace, some developers and other landowners would be able to submit site development plans that comply with stormwater ordinances in one of three ways: they are compliant on-site (i.e., no trading); they are compliant with extra credits (i.e., are sellers); or they are compliant with credit purchases (i.e., are buyers). They would use market tools to trade, bank, and track credits for improving and protecting ecological resources.

The proposed credit accounting system would translate realized benefits into metrics required by the County's stormwater program and provide explicit proof of ordinance compliance. Involvement of the Beaver Creek Task Force leverages a proven partnership between diverse agencies with distinct mandates to achieve the project's success.

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INTRODUCTION

Knox County and the Beaver Creek Task Force (BCTF) are working to restore Beaver Creek in north Knox County, Tennessee to its designated uses specified in the state's water quality standards. The watershed is rapidly urbanizing and facing dramatically increased development pressure (Figure 1). Overall, water quality has declined and the Tennessee Department of Environment and Conservation (TDEC) has included Beaver Creek on the 303(d) list of impaired waterways in 2006 for nutrients, pathogens, sediment, and biotic integrity. Since then, a total maximum daily load (TMDL) was developed for sediment that calls for significant reductions in sediment loading to Beaver Creek to improve stream biotic integrity conditions. There is also a pending TMDL for phosphorus which will likely require loading reductions from the major point sources in the watershed as well as from one or more categories of nonpoint sources.

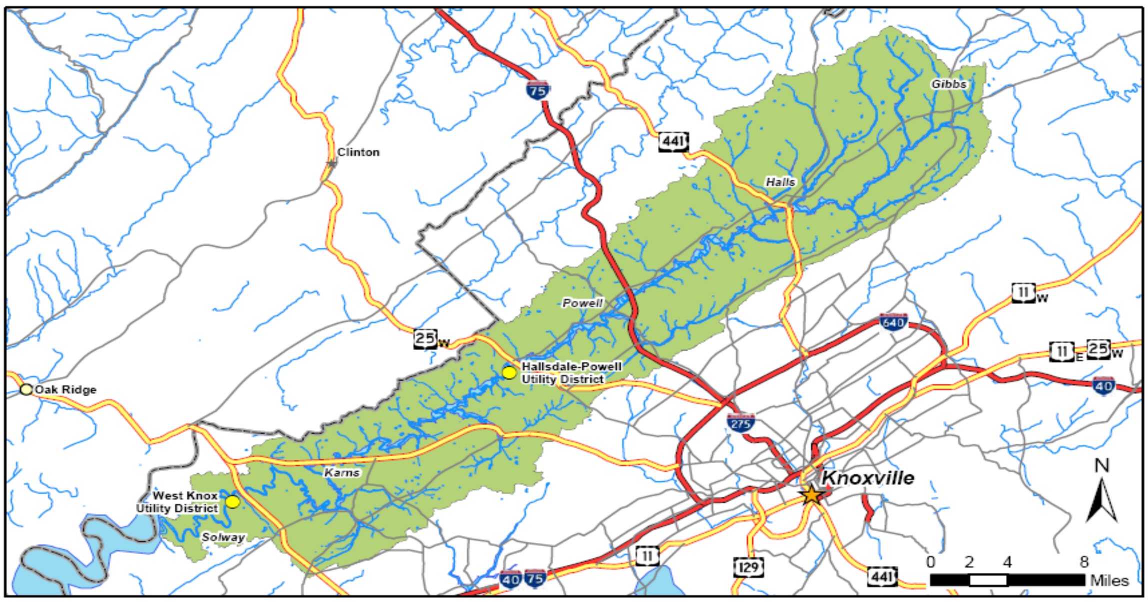

Figure 1. Beaver Creek location map.

To address these challenges, the BCTF has implemented a variety of assessments, studies, and public education and involvement programs in the watershed (Table 1). In 2006, the BCTF was awarded a US Environmental Protection Agency (EPA) Cooperative Agreement Grant to create and test a Pilot Ecological Credit Trading Market. The primary objectives of the pilot were to examine how credit markets for sediment, nutrients, and other ecosystem values can be used to create opportunities for financial rewards and cost-savings that will drive stakeholders to a set of watershed restoration actions that occur more quickly, in more priority locations, and are more cost-effective than would be the case without market-based mechanisms. Concurrently, Knox County was developing, and in 2008 implemented a new ordinance requiring post-development stormwater controls to maintain or improve existing watershed conditions. As such, the credit market evaluations were structured to be consistent with and support the ordinance.

This pilot study was organized into five main tasks:

1. Market Assessment
2. Credit Definition and Development
3. Market Framework
4. Market Transactions
5. Project Evaluation

The following paper is focused on the assessment of a potential multi-credit trading market and the framework for implementation of a trading market in the Beaver Creek watershed.

ASSESSMENT OF CREDIT TRADING OPPORTUNITIES

While addressing sediment and nutrient loadings in the watershed has been the focus of TDEC and the BCTF, other watershed-related improvements will be needed to address the loss of biological integrity.

The summary below addresses the findings relevant to sediment and nutrient credit opportunities associated with the initial market assessment and the cost-effectiveness of future best management practices (BMPs) and provides observations about flow-based credit opportunities that could address biological integrity. Specific mechanisms that could be used to implement multi-credit trading will also be addressed below.

Table 1. Beaver Creek Task Force Accomplishments

- 1998: Beaver Creek Task Force Formed
- 1998: Updated FEMA Flood Study
- 2000: Floodplain no fill line expanded
- 2002: Initial Beaver Creek Watershed Assessment complete
- 2002: Tennessee Growth Readiness
- 2002: Site Planning Roundtable convened
- 2003: Beaver Creek Watershed Association formed
- 2003: Part time Watershed Coordinator hired
- 2003: Intensive Watershed Education initiated
- 2004: Water Quality sampling & analysis
- 2005: Green Infrastructure plan completed
- 2005: GIS Land Use Map update
- 2005: Awarded 604(b) Watershed Planning Grant
- 2005: BMP projects initiated
- 2005: Water quality models developed
- 2005: Watershed Plan process initiated
- 2005: Stakeholder Advisory Council convened
- 2006: Awarded an EPA Cooperative Agreement Grant to create and test a Pilot Ecological Credit Trading Market
- 2006: Models calibrated
  - Hydrologic Simulation Program – Fortran (HSPF) for sediment and nutrients
  - AnnAGNPS for sediment
- 2006: Watershed Plan Complete
- **2007: Awarded $912,000 319h grant from the Tennessee Department of Agriculture**

Sediment Credit Trading Opportunities

The existing TMDL for sediment provides the primary driver for sediment credit trading, and the new Knox County stormwater ordinance provides an additional mechanism/requirement for sediment removal.

Nonpoint-to-nonpoint credit trading for sediment appears feasible with urban sources that are likely to be buyers or sellers (depending on the land use and BMP[s] selected) and agricultural landowners who are likely to be sellers. Results of the BMP cost-effectiveness analysis confirm that application of BMPs on agricultural land for sediment removal is less costly (in dollars per pound [$/lb] removed) than on residential or commercial land. Considering the total sediment reduction goal of 38 percent for the Beaver Creek watershed and the anticipated increases in residential land use (from 35 to 56 percent of the total land area in the watershed), the market for sediment credits is likely to be driven by the potential credit demand from residential development. Based on the BMP cost-effectiveness analysis, it appears that residential developers could be one of the primary buyers in the future market and agricultural landowners could be the primary sellers. Given the range of unit costs estimated for residential BMPs, some economically attractive credits could also be generated in the residential sector.

Nutrient Credit Trading Opportunities

Nutrient reductions will be a secondary benefit of the ordinance implementation as the application of post-development BMPs targeted at sediment control will also provide ancillary nutrient removal for stormwater runoff from new development.

The initial market assessment indicated that point-to-point and/or point-to-nonpoint source trading opportunities could exist if wastewater treatment plants (WWTPs) needed to make nutrient loading reductions, especially considering that the majority of the total phosphorus (TP) loadings to the watershed are from the WWTPs. However, because TDEC has not established the phosphorus TMDL, there is no immediate regulatory driver for nutrient reductions from point sources.

Therefore, the initial nutrient trading opportunities appear to be focused on nonpoint-to-nonpoint transactions. Based on the cost-effectiveness evaluation, the application of BMPs on residential properties appears to be more cost-effective than on agricultural properties. Even so, depending on site conditions and applicability of specific BMPs, there may be potential for credit trading among residential landowners in the watershed.

Other Credit Trading Opportunities: Flow

Design requirements in the ordinance for post-development BMPs require that an additional increment of runoff volume be retained to provide downstream channel protection. This flow volume provides another opportunity for potential ecological credit trading as it is a requirement for future development and can be directly linked to potential improvements in stream habitat conditions and, eventually, biological integrity.

Whereas the new county ordinance requires implementation of post-development BMPs to address both water quality and stream channel protection volume control, there appears to be an opportunity to link multi-credit trading opportunities to this new requirement. This ordinance will provide the mechanism for Knox County to help address the TMDL for sediments and the opportunity for secondary aquatic habitat benefits from the reduction in stormwater flows.

ASSESSMENT OF CURRENT POLICY AND REGULATORY FRAMEWORK

This assessment is framed by the following assumptions:

1. The sediment TMDL for the Beaver Creek watershed requires a 42.8 percent to 48.4 percent reduction in sediment load;
2. The new Knox County Stormwater Ordinance and Stormwater Management Manual places requirements on new development and redevelopment designed to help reduce sediment loadings to the watershed; and

3. An ecological credit market can help achieve these goals more cost-effectively while promoting activities that go beyond minimum compliance and generate measurable pollutant reductions.

To provide the basis for an assessment of the County's current pollutant control requirements to make recommendations regarding a credit market framework, its important to synthesize analyses for the four major source categories—point, agriculture, construction, and urban sources—as they relate to the three types of credits being considered: sediment (TSS), phosphorus, and flow.

Point Source Market Assessment

The two point sources in the watershed-- Hallsdale-Powell Utility District (HPUD) and West Knox Utility District (WKUD)—currently face no requirements to reduce sediment or nutrient loadings below current permitted levels that cannot be readily accomplished with existing treatment technologies. For this reason, they do not appear to be a potential buyer of credits in the near term.

A review of the supply-demand analysis indicates that a point-point trading program would be a more feasible strategy than point-nonpoint source trading, should the WWTPs eventually be interested in trading. Since the WWTPs are estimated to discharge 96% of the current and future phosphorus load, a meaningful point-nonpoint trading program is unlikely. Therefore, the framework design will not consider point-nonpoint source trading involving WWTPs as significant buyers. However, it is possible that one or both of the WWTPs could sell credits to a nonpoint source credit bank, or an individual nonpoint source. This could occur in one of two ways. If a WWTP were under its wasteload allocation (WLA, as could be specified in the TMDL), it could claim credits and sell them. Without WLAs, alternatively mass-based compliance targets would need to be established to support trading. Alternatively, a WWTP could make a financial (or in-kind) investment to a credit bank or individual's credit project and earmark its proportionate share of the credits as its contribution to the watershed restoration plan. Either or both options for point source credit purchases or credit investments could be available under the trading framework.

Agricultural Source Market Assessment

In March of 2006, TDEC completed a siltation and habitat alteration TMDL for the Beaver Creek Watershed which requires a 42.8% to 48.4% overall reduction in sediment loadings. Based on the TMDL, the *Beaver Creek Watershed Restoration Plan* (November 2006) identified a 40% reduction target for agricultural sources. However, there are few mechanisms to force achieving this goal. Even where reductions could be made on a voluntary basis, fairness and the mathematical integrity[1] of the 40% reduction goal suggest establishing a policy requirement that the 40% target be achieved before credits could be generated for use by an entity with a regulatory requirement, such as would exist for urban sources falling under the stormwater ordinance's provisions. The framework will need to address how a 40% reduction requirement (or other baseline) is applied to agriculturalists that have already implemented one or more BMPs,

[1] Mathematically, agricultural sources cannot sell credits for reductions up to the 40% to another source that will count the credit toward its own reduction and have the agricultural sector still collectively achieve its 40% reduction target.

compared to agriculturalists that have no BMPs by establishing rules for calculating baselines for individual sites so as to not unduly penalize good stewards and overly reward laggards.

Agricultural sources could be an important source of credit supply. The preliminary market assessment showed that agricultural sources were estimated at 31% of the total TSS load today, with their contribution decreasing to 21% by 2030 as land is converted to other uses. It was estimated that the agricultural sector could comply with the 40% TSS reduction target if currently installed BMPs were maintained and additional BMPs were placed on 15% of the total agricultural acreage. This would appear to indicate additional capacity for the agricultural sector to create credits even as it complies with the 40% sector reduction goal, potentially generating up to 1,000 tons of reduction annually. This potential supply compares favorably with an estimated maximum urban sector demand of 1,600 tons of TSS per year, without considering any trading ratios, which would likely reduce the creditable supply.

It also appears that agricultural credits could be more cost-effective than urban source controls, on average, assuming trading ratios were not so high as to diminish the cost-effectiveness advantage. Agricultural TSS reductions were estimated to cost between $0.50 and $3.25 per pound per year, compared to urban TSS reductions costing between $2.50 and $30 per pound per year.

Under these circumstances, it seems most likely that agricultural sources would participate in a credit market only as sellers, rather than buyers, unless the 40% reduction requirement was to be strictly enforced. Therefore, the market framework needs to accommodate agricultural credit sellers on a policy and logistical basis, especially where credit sellers are geographically dispersed in the watershed.

Construction Source Market Assessment

The Beaver Creek Watershed Restoration Plan calls for a 70% reduction of TSS from construction sources. This is an important slice of the loading pie, accounting for approximately 40% of the total load over the 2008 to 2030 period. The preliminary market assessment estimated that construction sources would need to place BMPs on 90% of ongoing construction acreage in order to meet the reduction target.

Mathematically, this leaves little room for doing better than required and generating credits for sale, and instead suggests that construction sources could be significant buyers. However both the demand-supply analysis and the cost-effectiveness analysis indicate that, to the contrary, construction sources would be most likely to satisfy their requirements on-site. First, the potential TSS credit demand from construction sources could be as high as 3,400 tons per year, compared to a practical case supply of 1,500 tons per year from other sources. More importantly however, the cost-effectiveness analysis estimated that construction BMPs are among the least expensive on a $/lb/yr basis: only a few agricultural and wood-shrub BMPs are less expensive. Thus, even if credits were available in sufficient supply, the economic analysis indicates construction sources would not find others' credit prices attractive. Therefore, it is not expected that construction sources would be a significant participant in the credit market, either by number of participants or credit volume. However to the extent that individual projects could beat their 70% reduction target, their credits could certainly be price-competitive. The credit framework should therefore accommodate construction sources without making tradeoffs that would make the program less desirable or convenient for potentially more significant participants, including agriculture and urban sources, and third-parties (e.g., not-for-profit or even for-profit organizations).

Urban Source Market Assessment

The *Beaver Creek Watershed Restoration Plan* calls for a reduction of 20% in TSS from urban sources. While this seems moderate, practical mechanisms only exist to secure reductions from new or changing sources—it is very difficult to secure reductions from retrofitting or otherwise changing land use management at existing urban sources. The preliminary market analysis showed that new development controls alone would not be sufficient for urban sources to meet their target on their own; additional retrofits on 40% of the existing urban area would be needed to meet the target. Given the difficulty in requiring retrofits, or even incentivizing them—as retrofits tend to be more expensive on a $/lb/yr basis than controls on new development, or than controls on some other sources—it appears that leveraging requirements on new development and redevelopment will be the only way Knox County can achieve this target.

Under the Knox County Stormwater Management Ordinance, non-exempted[1] development and redevelopment activities that disturb more than 1 acre are required to submit a stormwater management plan that addresses the Integrated Site Design (ISD) criteria. This approach is discussed extensively in the *Knox County Stormwater Management Manual* and the criteria were designed to be, "blended together, enabling the site engineer to size and design structural stormwater controls to address all of these objectives to achieve water quality and quantity goals." The application of these criteria to each development site dictates the size and design of structural stormwater controls. The four criteria are summarized in Table 2 below.

Table 2. Summary of Stormwater Criteria[2]

Sizing Criteria	Description
Water Quality (WQv)	TSS reduction goal of 80% average annual post-development load by treating runoff from 85% of the rainfall events that occur in an average year (1.1").
Channel Protection (CPv)	The runoff volume from the 1-year frequency, 24-hour storm must be captured and discharged over no less than a 24-hour period.
Overbank Flood Protection (Qp_{25})	Provide peak discharge control of the 2, 10 and 25-year return frequency, 24-hour duration storm events such that the post-development peak rate does not exceed the pre-development rate.
Extreme Flood Protection (Qp_{100})	Provide peak discharge control of the 100-year return frequency, 24-hour duration storm event such that the post-development peak rate does not exceed the pre-development rate.

It is presumed that a stormwater management system complies with the 80% TSS removal standard if appropriate structural BMPs are selected, designed, constructed and maintained in accordance with the design criteria specified in the manual.

[1] Knox County Stormwater Ordinance, Sec. 4.1.2
[2] *Knox County Stormwater Management Manual, Sec. 2.1.1*

Knox County staff will be reviewing new developments for compliance with all four of the stormwater criteria. Depending on site conditions, four compliance scenarios are possible:

1. All four criteria met exactly—in a credit trading context, this outcome would neither generate credits nor require offsets;
2. All four criteria bettered—in a credit trading context, this outcome would potentially create credits that could be banked or exchanged, depending on the effect of any trading area restrictions or trading ratio requirements that might diminish or preclude credit trading;
3. Mixed performance where one or more criterion not met, one or more criterion met exactly, and one or more criterion bettered—it is certainly conceivable that in trying to optimize BMP design across all criteria that trade-offs may occur and result in a situation where there could be a demand for one type of credit (sediment or flow), and possibly the creation of the other type of credit (flow or sediment); and
4. No criteria met—a variety of circumstances could make it difficult or impossible to comply with the criteria, on a technical and/or economic basis.

The ordinance recognizes that some potentially meritorious projects may have difficulty meeting one or more criteria and specifically allows for “alternative approaches” to meet the channel protection volume requirement. The alternative approaches are not specified in the ordinance but must provide “adequate channel protection from erosion.” This clause supports the potential for a flow-based credit trading option to meet the channel protection requirement.

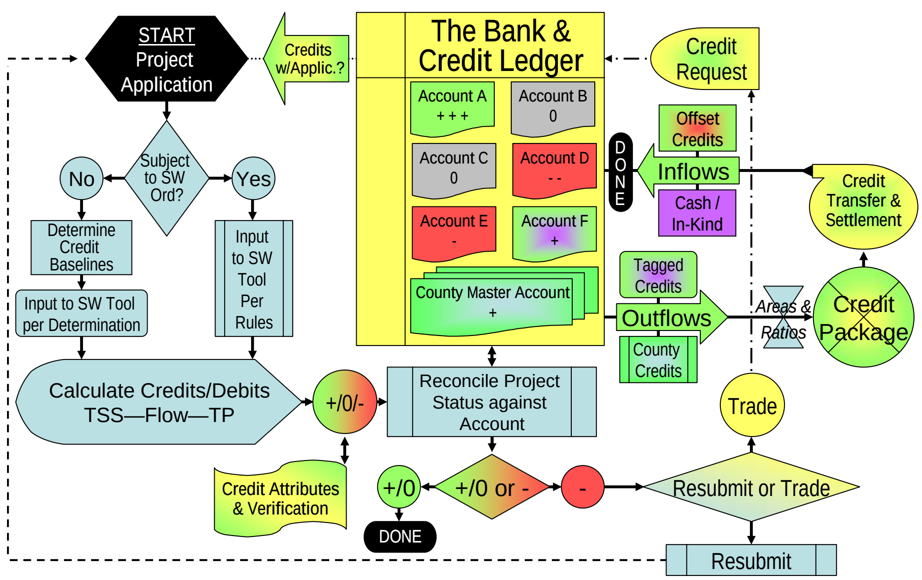

Figure 2. Proposed framework for credit trading in the Beaver Creek Watershed, Knox County, TN.

With respect to sediment, the preliminary demand-supply analysis indicated that urban sources would have to rely on urban controls for a significant proportion but not necessarily the entirety of their mass load reduction obligation. Thus, the credit framework should be optimized to accommodate urban sources as the primary sediment credit buyers—but also potential sellers, agricultural sources as the primary sellers, and landowners from other sectors as less significant participants.

PROPOSED MARKET FRAMEWORK

A *centralized credit bank and exchange*, managed initially and likely into the longer term by Knox County, appears to be the best model to efficiently develop and implement a multi-credit, stormwater-focused trading option as an integrated component of the County's stormwater management program and other watershed-related initiatives. Because the market-based approach is proposed as an expansion of an existing program, it is not necessary to develop the policy and regulatory framework for sediment, flow, and nutrient credit trading from scratch. The existing policy and regulatory framework, including how it drives and defines opportunities and limitations, was described in the previous section. The proposed trading prototype graphically represented in Figure 2 below is designed to fit within the existing policy and regulatory framework, with some enhancements and modifications.

CONCLUSIONS

The proposed credit trading program for Beaver Creek appears feasible for nutrients, sediment, and, potentially, flow. Implementation would be enhanced by utilization of the proposed framework which would be linked to the new Knox County ordinance review process and may facilitate implementation of the new program for post development stormwater controls on a county-wide basis.

AERIAL STREAM BUFFER ANALYSIS FOR CONASAUGA RIVER TMDL

Frank Sagona*[1] and Randy Hale[2]

The 90-mile Conasauga River starts in the Blue Ridge Mountains of Georgia, flows into Tennessee, and then swings back into Georgia. Several stream segments are listed by both states as not supporting beneficial uses, a designation under the Clean Water Act. Fecal coliform bacteria are cited as one cause for impairment. Septic systems and livestock operations are cited as contributing sources of the bacterial impairment. Each state has completed a total maximum daily load (TMDL) allocation to bring the segments back into acceptable water quality standards. The Conasauga River Alliance has submitted a draft watershed plan to initiate the next step of the State's TMDL Implementation plan for the Conasauga. Using aerial remote sensing data and GIS stream buffer analyses, potential bacterial sources to Mill, Ball Play and Coahulla Creeks have been identified. A local stakeholder group has set three goals to initiate a watershed improvement program: 1) direct-mail septic system pumpout voucher program; 2) targeted septic system repairs; and 3) voluntary but targeted demonstrations and workshops for alternative livestock watering practices. Total cost of watershed treatment is estimated at $4.9M; however a targeted approach for treatments based on the aerial stream buffer analyses is $315k.

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SITE SELECTION, MODELING, AND DESIGN OF SUB-CATCHMENT RETROFITS FOR WATER QUALITY AND DOWNSTREAM CHANNEL PROTECTION

Andrew Dodson[1]*, Michael Hamrick[2]

As part of the greater effort to lessen the human impact on the streams of Knox County, the Beaver Creek Task Force is looking for opportunities within the Beaver Creek watershed to increase infiltration, reduce peak flows, decrease stormwater pollution, and help naturalize the stream hydrology. Using a variety of tools, including the Center for Waterhshed Protection's Urban Stormwater Retrofit Practices Manual, and ArcGIS the goal has been to target a specific sub-watershed, inventory the existing drainage structures in the sub-watershed, and compare the existing detention potential with what is required per Knox County's Stormwater Ordinance. Many of the developments in Beaver Creek contain detention ponds that were designed poorly or installed incorrectly. These may provide retrofitting opportunities that are low cost and low impact. A sub-watershed in the headwaters, identified by HSPF modeling used for the Beaver Creek Watershed Restoration Plan and identified as one of the top sediment producing sub-basin, has been chosen to pilot this project. Using EPA's Stormwater Management Model, retrofits are being designed that will meet Knox County standards, increase infiltration, decrease peak flows, protect downstream channels, and decrease the pollutant load.

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EPA REGION 4 INSPECTIONS AT TENNESSEE CONFINED ANIMAL FEEDING OPERATIONS?

Shawn Hawkins[1] and Forbes Walker[2]

On October 7, 2007, the Environmental Protection Agency (EPA) published the National Enforcement and Compliance Priorities for Fiscal Years 2008-2010. In relation to the Clean Water Act, environmental problems exasperated by precipitation were given absolute priority. As in 2004, concentrated animal feeding operations (CAFOs) were listed as a focal point for enforcement, because (1) of the increasing trend toward larger facilities that store huge amounts of animal waste that increase environmental risk, (2) many states identify animal agriculture as a contributing factor to surface water impairment, (3) patterns of noncompliance exits with the industry, and (4) the “need for EPA leadership in implementing federal CAFO regulations.” It’s apparent that the 2007 enforcement strategy is one facet of the response by EPA to the recent *Waterkeeper* court decision to emphasize that federal regulations prohibit *any* discharge of pollutants from CAFOs operating without an NPDES permit. In was in this context that EPA Region 4 conducted enforcement visits at Tennessee animal feeding operations (AFOs) in the Spring of 2008. At least 10 facilities were visited and all but one appeared to be in some state of non-compliance. A wide variety of facilities were visited including permitted and unpermitted facilities, large-medium-small AFOs/CAFOs, and broiler/layer/pullet/dairy farms. This presentation will provide an overview of why CAFOs are listed as a national enforcement priority, interpret data from EPA databases of past CAFO inspections, describe the inspection process, and provide some details of where the inspection took place and the outcome of the inspections to date.

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Power Point File of Presentation

A STANDARDIZED AND COMPREHENSIVE STREAM CORRIDOR EVALUATION PROGRAM

Jonathan Hagen*, Mounir Minkara[1], Rebecca Robinson

Urban watersheds are susceptible to a myriad of water quality impacts, and communities need to systematically assess the range of impacts and restoration opportunities found along stream corridors. The Chattanooga Stream Corridor Evaluation (SCORE) program has been effective at collecting and analyzing comprehensive data to assess local watershed condition so as management and restoration resources may be better allocated.

By following standardized assessment protocols, key physical, hydrologic, geologic, and biologic streambank parameters are evaluated and inventoried. Such metrics allow stream reaches to be ranked based on their respective severity and then transposed into a GIS inventory to subsequently allocate key resources more effectively. Since June 2007, Water Quality personnel have inspected nearly 40 miles of city waterway surveying three major watersheds.

Citico Creek, a highly urbanized basin with many high-density residential communities, consistently ranked low for the various sensitivity metrics. Friar Branch, a developing basin comprised of single unit residences, commercial structures and open space, contained the greatest span of earthen channels, and displayed higher canopy cover and buffer widths; though exhibited the greatest observed erosion. Dobbs Branch, a highly urbanized basin with many aged industrial facilities and residences, exhibited the greatest percentage of concrete-lined channel and the lowest observed streambed erosion. This analysis will specifically be used for 1) developing an inventory of problematic stream banks, 2) identifying and prioritizing stream restoration programs, 3) proper management of activities impacting certain stream reaches, 4) establishing pre- and post-restoration water quality studies within city waters, and 5) inclusion and application in the city's watershed management and modeling programs.

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THE REVISED FEDERAL CONCENTRATED ANIMAL FEEDING OPERATION RULE - WHAT WILL IT MEAN FOR TENNESSEE?

Forbes Walker*[1] and Shawn Hawkins[2]

On November 20, 2008 the United States Environmental Protection Agency (EPA) issued a revised final concentrated animal feeding operation (CAFO) rule. This final rule replaces the previous rule that was released in 2003 and was the basis for the 2004 Tennessee CAFO rule. Under the new revised CAFO rule livestock producers no longer have a "duty to apply" for National Pollution Discharge Elimination System (NPDES) permits when there are no plans to discharge. Nutrient Management Plans (NMPs) will now be part of the permit application & are subject to public review. However, facilities that wish to be considered non- discharging will need to voluntarily certify that they have no potential to discharge by developing a NMP and documenting they are following the plan by keeping records. There is no public review required for the NMPs developed as part of this voluntary certification program. Liquid manure containment structures for swine, poultry, and veal operations that were designed for the 100-year, 24-hour storm will not meet non-discharge criteria so these livestock producers will be required to apply for an NPDES permit and develop and follow a NMP. At the present time it is unsure what changes will be required to the Tennessee CAFO rule. In summary, it appears that all medium and large CAFOs that manage liquid manure will be required to develop and implement NMPs whether or not they are required to apply for an NPDES permit or not.

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SESSION 3B

GROUNDWATER
8:30 a.m. – 10:00 a.m.

Alteration of the Geothermal Gradient Due to Groundwater Withdrawals at Memphis, Tennessee
Michael Bradley and Randy Thomas

Groundwater and Surface Water Interactions in an Active Karst Area Under Low Flow Conditions, Carter County, Tennessee
Yongli Gao

Changes in Shallow Groundwater Quality in the Memphis Area, Tennessee, 1997-2006
James A. Kingsbury and Jeannie Barlow

MONITORING PLAN FOR THE KINGSTON ASH SPILL PANEL
10:30 a.m. – 12:00 p.m.

Surface Water Monitoring in the Aftermath of the December 2008 Kingston Steam Plant Ash Spill
Gregory M. Denton

Biological Monitoring Plans for TWRA
Bobby Brown

Tennessee Valley Authority: What's the Overall Plan?
D. Yankee

ALTERATION OF THE GEOTHERMAL GRADIENT DUE TO GROUND-WATER WITHDRAWALS AT MEMPHIS, TENNESSEE

Michael Bradley[1]* and Randy Thomas[2]

Geothermal gradients in aquifer systems can be affected by the direction and velocity of ground-water flow and can provide information on the vertical movement of ground water. Ground-water withdrawals from the Memphis aquifer at Memphis, Shelby County, Tennessee have resulted in the development of a large cone of depression in the potentiometric surface of the aquifer creating a downward gradient from the overlying water-table aquifer to the Memphis aquifer. The downward movement of water from the water-table aquifer to the Memphis aquifer has altered the geothermal gradient at some of the production well fields resulting in temperature anomalies in the normal gradient that can be identified in temperature logs of the observation wells. Temperature logs were collected from selected observation wells from 1977-1984 as part of an investigation of leakage of water from the water-table aquifer to the Memphis aquifer in the Memphis area and again in 2008 as part of the current Memphis area ground-water investigation. Both sets of temperature logs show alterations to the geothermal gradient in some areas of large ground-water withdrawals from the Memphis aquifer. Changes in ground-water withdrawals from the Memphis aquifer at well fields in Memphis from about 1980 to 2008 appear to have resulted in additional changes to the geothermal gradient. Geothermal anomalies are present at greater depths in areas of increased ground-water withdrawals and at shallower depths in areas of decreased ground-water withdrawals.

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GROUNDWATER AND SURFACE WATER INTERACTIONS IN AN ACTIVE KARST AREA UNDER LOW FLOW CONDITIONS, CARTER COUNTY, TENNESSEE

Yongli Gao*

Many karst features such as caves, sinkholes, springs, and loosing streams are founded to be connected to the Rock House Cave groundwater system in Cater County, northeastern Tennessee. Previous dye-tracing test shows that groundwater velocity is approximately 400-500 m/day during normal-flow conditions. To further investigate the flow conditions during a severe drought year, two different fluorescent dyes were injected simultaneously in Dry Creek and Rock House Cave on December 8, 2008. Both dyes were detected in Cave Spring Cave, which merges into Buffalo Creek. Water samples were collected along cave conduits, surface streams, and springs during the tracing period. Dye analyses of these water samples indicate that this is a highly dendritic conduit flow system. Depending on flow conditions, surface water disappears from different locations along Dry Creek. No dyes were detected at upstream locations and other springs along Buffalo Creek and dye concentration decreases gradually along downstream locations. It takes weeks to months for all the dyes wash into the karst aquifer from the loosing stream - Dry Creek, during low-flow conditions. However, once the dye gets into the karst conduit, it would be transferred very rapidly to its outlet, Cave Spring Cave.

CHANGES IN SHALLOW GROUND-WATER QUALITY IN THE MEMPHIS AREA, TENNESSEE, 1997-2006

James A. Kingsbury[1] and Jeannie Barlow[2]

Samples were collected in 1997 from a network of 32 monitoring wells in the Memphis area for a broad range of constituents to characterize the effect of recent development (post-1970) on shallow ground-water quality in Shelby County, Tennessee. These wells were sampled again in 2006 to characterize changes in shallow ground-water quality in this urban setting. Most of the wells (24) were completed in the terrace deposits aquifer; however, 8 wells in the southeastern part of the county, where the terrace deposits are dry, were screened in the upper part of the underlying Memphis aquifer. At least one pesticide was detected in samples from more than 70 percent of the monitoring wells during both sampling periods. Simazine and atrazine were the most commonly detected pesticides during both sampling periods, but these herbicides were detected nearly twice as frequently in 2006 as in 1997 in water samples from the terrace deposits aquifer. In samples from the upper part of the Memphis aquifer, simazine was detected more frequently in 2006 than in 1997. The detection frequency for atrazine in samples from the upper part of the Memphis aquifer decreased in the second sampling period, but the maximum concentration in 2006 was about an order of magnitude higher than in 1997. Nitrate concentrations varied as well, and in most samples from the terrace deposits concentrations were higher in 2006 than in 1997; the median nitrate concentration in 2006 was 1.5 mg/L compared to 0.7 mg/L in 1997. Ground-water age estimates, changes in inorganic constituent concentrations, physical properties, and environmental conditions also were evaluated to better understand controls affecting variability of these contaminants in shallow ground water.

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SURFACE WATER MONITORING IN THE AFTERMATH OF THE DECEMBER 2008 KINGSTON STEAM PLANT ASH SPILL

Gregory M. Denton[1]

In the early morning hours of December 22, 2008, the retaining wall of a wet ash containment structure failed at the Kingston Steam Plant in Tennessee. The resulting release of over a billion gallons of water and coal ash covered roads and a rail line, seriously damaged several homes, filled two embayments, and almost completely blocked the main channel of the Emory River.

Within a few hours, emergency responders were on the scene, including the Tennessee Department of Environment and Conservation. Following initial efforts to determine the extent of the loss of life and property (gratefully, no one was killed), attention turned to the safety of downstream water supplies. While the Tennessee Valley Authority (TVA) and the U.S. Environmental Protection Agency (EPA) performed the initial rounds of surface water sampling in the Emory, Clinch, and Tennessee rivers, the department sampled raw and finished drinking water daily at Rockwood and Kingston, plus well water at private homes within a 4 mile radius of the spill.

On January 2, the department began its own surface water sampling program at multiple stations above and below the ash spill. Additionally, several environmental groups and universities also reported water data from the area.

Continuing in our traditional role as the agency with primary water quality assessment responsibilities in Tennessee, the department has been compiling and analyzing water quality data from the agencies and third-party entities monitoring in the spill area. Review of these data have been complicated by several factors including the reluctance of samplers to provide data to a state regulatory agency, the reporting of data from multiple labs sometimes utilizing different methodologies, results reported at detection levels above applicable water quality criteria, differing data assessment methods, and nationwide media attention.

The December 2008 ash spill at the Kingston Steam Plant was a catastrophic event of historical magnitude that continues to impact lives, property, and the environment. Data collected thus far have allowed us to conclude that the water supply is safe and other than the direct physical impacts, the ash has not led to acute toxicity in the Emory and Clinch rivers. Violations of Tennessee's chemical water quality standards occurred immediately following the spill and whenever the ash has been resuspended by runoff or boat traffic. Chronic aquatic life effects and biomagnification of heavy metals in the food chain are possible and the monitoring of water, sediment, and fish tissue will need to continue.

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BIOLOGICAL MONITORING PLANS FOR TWRA

Bobby Brown[1]

Discussion will be provided on the following topics:

- Initial damage assessment for fish and aquatic life, aquatic habitat, riparian forest and wetland habitat.
- Initiation of fish collections in the Emory and Clinch Rivers to establish benchmark values for heavy metal contaminants in fish.
- Coordinate research efforts with ORNL, USFWS, and TVA to assess near event mid-term (3-5 years) and long term (5-7 years) response of fish and aquatic life to the fly ash release.
- The role of a cooperating agency for National Environmental Policy Act (NEPA) related activities including preparation of an Emergency Environmental Assessment (EA).
- Participation in coordinated research to evaluate near, mid, and long term response of amphibians, turtles, freshwater mussels and snail, avian species, and water/terrestrial interface wildlife (muskrats, mink, etc.) to the fly ash release.
- The role of an inter-agency coordination work group with USFWS, TDEC, EPA, TVA, ORNL, ORAV, and others to evaluate the near, mid, and long term impacts resulting from the Kingston fly ash release.

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[1] TWRA Region III Habitat Protection Biologist

TENNESSEE VALLEY AUTHORITY: WHAT'S THE OVERALL PLAN?

D. Yankee

On Monday, December 22, 2008, a dike containing the Tennessee Valley Authority (TVA) Kingston Fossil Plant dredge cells collapsed, releasing about 5.4 million $yard^3$ of fly ash and bottom ash into adjacent waterways and over land. TVA responded immediately with a number of emergency response actions and sampling activities, as well as community outreach programs. Subsequently, the Tennessee Department of Environment and Conservation issued a Commissioner's Order requiring action be taken as necessary to respond to the emergency. As part of this Order, TVA was required to prepare and submit a Corrective Action Plan (CAP) within 45 days of receipt of the order. The CAP included a response to the following elements:

A. A plan for the comprehensive assessment of soil, surface water, and groundwater, remediation of impacted media; and, restoration of all natural resources damaged as a result of the coal ash release;

B. A plan for monitoring the air and water in the area during the cleanup process;

C. A plan to ensure that public and private water supplies are protected from contamination and that alternative water supplies are provided if contamination is detected;

D. A plan addressing both the short term and long term management of coal ash at the Kingston Plant, including remediation and stabilization of the failed ash waste cells, proper management of the recovered ash, and a revised closure plan for the Class II ash disposal facility; and,

E. A plan to address any health or safety hazards posed by the ash to workers and the public.

TVA's objectives for recovery of the recovery effort are to ensure the safety of citizens and response personnel, keep the public and stakeholders informed of response activities, maximize the protection of environmentally sensitive areas, and to ultimately return the community to normal conditions. The goal of this presentation is to discuss response activities, results of environmental sampling to-date, as well as long-term monitoring and site plans and options.

SESSION 3C

EDUCATION AND OUTREACH
8:30 a.m. – 10:00 a.m.

Rainy Day Brush-Off: Hands On Stormwater Education for Knox County
Parci Gibson

Days of My Life of a Watershed Coordinator (A.K.A. Was This in My Job Description?)
Lena Beth Carmichael

Metro Nashville Water Services Watershed Management Public Outreach Program
Michelle Barbero

RAINY DAY BRUSH-OFF: HANDS ON STORMWATER EDUCATION FOR KNOX COUNTY

Parci Gibson[1]*

Knox County is like many other phase II NPDES communities across Tennessee. The county's once rural landscape is being transformed into a more metropolitan one due to Tennessee's growing polualtion. This growing popluation has placed a strain on water quality in the fastest growing sub-watersheds in Knox County. Knox County has forty sub-watersheds within its jurisdictional boundaries. Thirty-eigt of the sub-watersheds have been evaluated to determine the percentage of area covered by impervious surfaces. Of the sub-watersheds with data, twenty-six percent have a percent imperviousness of ten to twenty-five percent. Another fifteen percent of those thirty-eight sub-watersheds have a percent imperviousness of twenty-five to sixty percent. Research has shown a direct correlation to percent imperviousness and water quality degredation. An increase in impervious surfaces in Knox County has changed the natural hydrology of the sub-watershed within the county. More water is now flowing as overland runoff, where it once infilrated into the ground. This change in the water cycle has increased the amounts and types of pollutants entering the wateways causing water quality degradation. Both the amount of water and the pollutants in the water are having negative impacts on streams in Knox County as a direct result of increasing impervious cover. In 2007, the Water Quality Forum intitiated an artistic rain barrel competition to bring awareness about stormwater runoff pollution to the citizens in Knox County. This intiative was dubbed the Rainy Day Brush-off event and is intended to be a fun, creative and high-profile project to educate the community about water conservation and stormwater pollution prevention. Knox County Stormwater Management has taken the lead role in implementing this program. The Rainy Day Brush-off initiative is modeled on highly successful projects conducted by Kentucky's Bluegrass PRIDE and Missouri's James River Basin Partnership. The Water Quality Forum's Rainy Day Brush-off uses the Internet, print media, workshops and rain barrel sale days to educate people on the problems associated with polluted runoff along with ways in which individual homeowners can address stormwater on their own property. The 2008 Rainy Day Brush-off event was very much a success. Over one-hundred fifty ready-to-install rain barrels were made over three workshop days. Another one-hundred twenty barrels were given out by Knox County Stormwater Management to area residents interested in making their own barrels. The 2009 Rainy Day Brush-off is currently being planned with the aim of having more attention focused on mass media educational outreach about stormwater pollution and making more rain barrels available for the public. The purpose of this presentation will be to provide an overview of this program and describe our approach to expand the project.

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DAYS OF MY LIFE OF A WATERSHED COORDINATOR (A.K.A. WAS THIS IN MY JOB DESCRIPTION?)

Lena Beth Carmichael*

Pond Creek Watershed is a rural agricultural watershed in McMinn, Monroe, and Loudon Counties in East Tennessee. The watershed work in Pond Creek is a new project for the University of Tennessee, with the goal of improving water quality. Pond Creek is listed on the 303(d) list as being impaired by bacteria from livestock grazing, livestock in the stream, and animal feeding operations. Three graduate studies have been conducted by UT Biosystems Engineering master's degree students. BMPs have been installed, and management practices have also been changed with the goal of minimizing animal waste runoff to the stream. Examples of successful Best Management Practices, challenges encountered while working with the farms, and unsuccessful attempts are included in this presentation. Photographs and learning opportunities will be shown from the Youth Water Day Camp, with youth from farms in the watershed participating. This agricultural valley evolves as dairies go out of business, and develop to produce beef, grain, and switchgrass. During this project, the human dimension in watershed restoration work has been challenging, frustrating, rewarding, and humorous, with multiple examples of "Was this in my Job Description?" and enough real-life events for a soap opera.

METRO NASHVILLE WATER SERVICES WATERSHED MANAGEMENT PUBLIC OUTREACH PROGRAM

Michelle Barbero[1]*

Metro Water Services is improving water quality throughout Metro Nashville Davidson County. The Watershed Group is using baseline data collected from impaired streams to compile a more precise watershed management plan. This plan is tailored to each individual sub-watershed with its respective land use, thus enabling a more effective management approach. Public education is a key component of this watershed plan, targeting widespread education of non-point source pollution prevention. Most of our educational activities to date have been with school-aged children and community environmental events. Metro Water Services is compiling a more aggressive educational outreach program to reach all constituents. The focus of this paper will be to discuss previous successes and future educational outreach goals to better educate the public on ways to improve water quality both individually and collectively.

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PROFESSIONAL POSTERS

Impervious Area Analysis for the Harpeth River Watershed Based on Analysis of 1997 and 2007 Ortho Photos and Local Parcel Maps and Compared to Cumberland Region Tomorrow's 2001 Growth Projections for 2020
Michael Cain and Joel Peters

Evaluation of CADDIS Stressor Analysis for Tennessee – Progress, and Request for Your Input
John Harwood and Bonnie Newby

Factors Affecting Occurrence and Distribution of Selected Contaminants in Groundwater in the Valley and Ridge Aquifers, Eastern United States, 1993-2002
Gregory C. Johnson, Tammy M. Zimmerman, Bruce D. Lindsey, and Eliza Gross

IMPERVIOUS AREA ANALYSIS FOR THE HARPETH RIVER WATERSHED BASED ON ANALYSIS OF 1997 AND 2007 ORTHO PHOTOS AND LOCAL PARCEL MAPS AND COMPARED TO CUMBERLAND REGION TOMORROW'S 2001 GROWTH PROJECTIONS FOR 2020

Michael Cain*[1], Joel Peters, GISP*[2]

Much of the Harpeth River Watershed is in one of the fastest growing counties in the country[3], with a 10 year population increase above 20%. To assess changes associated with development, and vulnerabilities and threats to the watershed, HRWA conducted an Impervious Area Analysis of the entire watershed. This was done using data from a 2001 Cumberland Region Tomorrow (CRT) study that compiled existing data (1997-2001) and produced two scenarios of population growth and impervious cover to 2020. CRT's "Base Case" projects growth following current sprawl patterns and the "Vision" projects growth if concentrated in existing town centers. By comparing ortho photos from 1997 and 2007, ground truthing by staff, and consulting parcel data to determine actual changes in the watershed, HRWA created a GIS layer of imperviousness changes that was added the existing CRT data layer. Maps were made that allowed comparisons of impervious cover between 2001 and 2008, and to see how 2008 compares with the CRT 2020 projections.

The analysis indicates that development is occurring at a fast pace though not necessarily in ways predicted by the CRT study. Areas around the I-65 corridor have already developed to the point that impervious percentage cover is greater than that of the "Vision" projection, while along the I-40W corridor, impervious cover has not changed significantly yet. HRWA plans to update and publish this information as part of a "State of the Harpeth" report biennially. This analysis was part of an EPA Consolidated Watershed Initiatives Grant from the EPA.

[1] Watershed Assessment and Restoration Manager, Harpeth River Watershed Association, michaelcain@harpethriver.org

[2] GIS Analyst, Tetra Tech EM Inc., joel.peters@ttemi.com

[3] Williamson County was Rated 95th in the country, with Rutherford County (Harpeth Headwaters) rated 37th, http://www.housingbubblebust.com/PopHsgRates/Top100Counties.html

EVALUATION OF CADDIS STRESSOR ANALYSIS FOR TENNESSEE – PROGRESS, AND REQUEST FOR YOUR INPUT

John Harwood[1]* and Bonnie Newby[2]

We are mid-way through our project evaluating of the usefulness of the Web-based EPA Causal Analysis/Diagnosis Decision Information System (CADDIS) in identifying stressors causing impairment of waters of Tennessee. The evaluation consists of evaluating four test cases in order to discover advantages and difficulties in applying the CADDIS procedure. We are evaluating the involvement of stakeholders in identifying stressors, an important component of CADDIS. Additionally, we are producing a summary of information needed to apply the procedure, documentation to facilitate performing CADDIS stressor identification in Tennessee, guidelines as to what impairment scenarios might be successfully approached with the CADDIS process, and suggestions as to what scenarios might be better approached using alternative means of stressor identification.

We will present a brief overview of results obtained to date in our test case analyses. We will discuss the effectiveness of CADDIS in identifying stressors in these cases, and how water monitoring procedures in Tennessee could be modified so as to facilitate stressor identification. We will discuss our success in engaging stakeholders in the analyses, and questions stakeholders have had in the CADDIS procedure. We will outline the tools we plan to prepare to assist TDEC regulators and others in performing CADDIS analyses. Finally, we will ask those attending the presentation to share questions, observations, reservations, and suggestions they may have in this initial phase of applying CADDIS stressor identification in Tennessee.

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FACTORS AFFECTING OCCURRENCE AND DISTRIBUTION OF SELECTED CONTAMINANTS IN GROUND WATER IN THE VALLEY AND RIDGE AQUIFERS, EASTERN UNITED STATES, 1993-2002

Gregory C. Johnson[1]*, Tammy M. Zimmerman[2], Bruce D. Lindsey[3] and Eliza Gross[4]

Between 1993 and 2002, the U.S. Geological Survey's National Water-Quality Assessment program sampled 265 wells and springs in the Valley and Ridge physiographic province, extending from Georgia to New Jersey. Water samples were analyzed for pesticides, nutrients, major ions, volatile organic compounds, radon, and fecal-indicator bacteria. Differences in the occurrence and distribution of selected constituents were evaluated using a number of physical setting characteristics including: general lithologic groupings (carbonate, noncarbonate), land use (agricultural, urban, undisturbed and mixed), and relative distance along flowpaths (approximated as distance from a well to the nearest ridge top and the nearest stream).

Position along the flowpath predicted some water quality constituents in both noncarbonate and carbonate settings. The upper portions of flow paths were predominantly forested. The middle portion of flow paths were mixing zones with older water from upgradient forested land use and newer water from overlying agricultural land use. The discharge zone near the end of flowpaths was typically agricultural or urban land. The upper portion of the flow path typically had low alkalinity and few anthropogenic contaminants. A few constituents such as sulfate increased along the flowpath in both aquifer types. Alkalinity and calcium increased along the flowpath in carbonate systems only. Redox conditions were typically oxic higher in the flowpath and anoxic lower down. Samples from noncarbonate aquifers had a higher percentage of anoxic and mixed redox states (35 and 17 percent respectively) compared to carbonate aquifers (6 and 4 percent). In carbonate aquifers, efficient hydraulic connections to the surface and turbulent flow may limit development of anoxic conditions, making degradation of redox-sensitive species such as nitrate less likely than in the noncarbonate aquifers.

Land-use, aquifer type and redox state are strongly related to ground-water concentrations of nutrients and anthropogenic contaminants. Nitrate concentrations were higher in carbonate aquifers (median =3.4 mg/L) compared to noncarbonate aquifers (median = 0.09 mg/L). Nitrate concentrations were also higher in wells with oxic conditions. Occurrence of nitrate and agricultural pesticides were positively correlated to agricultural land use and negatively correlated to forested land use; VOCs were negatively correlated to forested land use. Urban land use had a combination of negative and positive correlations with nutrients and anthropogenic contaminants, possibly due to the urban study being down gradient of agricultural areas. Agricultural wells in carbonate settings had higher median nitrate concentrations (6.85 mg/L) than agricultural wells in noncarbonate settings (0.16 mg/L). Wells sampled in mixed land-use areas (a combination of agricultural, urban or undeveloped land uses) had higher median nitrate concentrations in carbonate settings than in noncarbonate settings (1.23 and <0.05 mg/L respectively).

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STUDENT POSTERS

Student poster presenters will be available to discuss and answer questions about their displays with the judges at 3:30 p.m., Thursday, April 16. All poster presenters will be available to discuss and answer questions about their displays beginning at 5:30 p.m. on Thursday, April 16.

Assessment of Groundwater Leakage Through the Upper Claiborne Confining Unit to the Memphis Aquifer in the Allen Well Field, Memphis, Tennessee
Elizabeth Bradshaw and Daniel Larsen

Applying Geospatial Soil Survey Data to Estimate Stormwater Trapping Efficiencies of West Tennessee Filter Strips
Christopher A. Bridges

Wetlands Improve Water-Quality at Tennessee State University
Brandon Cobb, C. Cobb, P. Armstrong, M. Martin, L. Sharpe, and J. Stewart-Wright

Using Chemographs to Characterize a Karst Spring in Nashville, TN
Carlton Cobb and J. Stewart-Wright

Maintenance Water Quality Structures and Illustrating Water Quality Testing to Undergraduate Students
S. Hovis, W. Anderson, and L. Sizemore

Analysis of Organic Contamination by Coal Mining and Asphalt Production
Jo Meagan Mansfield, Gene Mullins, and John Harwood

Use of Independent Gamma Distribution to Describe Tracer Break-Through Curves
Marquan Martin and Roger Painter

Use of Dynamic Systems Modeling to Conceptualize the Progression of Acidic Deposition to Stream Chemistry in Streams of the Great Smoky Mountains National Park
Lee Mauney and John Schwartz

A Detailed Investigation on the Exchange of Groundwater and Surface Water in a Sand Bottom Stream in West Tennessee
Ryan Pickett, Brian Waldron, Dan Larsen, Jerry Anderson, and David Arellano

Solubility and Biodegradation of ET-85 in Groundwater
Loreal Spear, Christin Staples, B. Kamara, and L. Sharpe

Helping Rural Communities in the Dominican Republic and Guatemala with Low Cost Sources of Clean Drinking Water
Adam Teg, Forbes Walker, John Schwartz, and Neal Eash

ASSESSMENT OF GROUND-WATER LEAKAGE THROUGH THE UPPER CLAIBORNE CONFINING UNIT TO THE MEMPHIS AQUIFER IN THE ALLEN WELL FIELD, MEMPHIS, TENNESSEE

Elizabeth Bradshaw[1*] and Daniel Larsen[1]

The Allen Well Field is a municipal well field located in the southwestern portion of Shelby County, in Memphis, TN that provides drinking water pumped from the Memphis aquifer to the City of Memphis. Past research has identified windows in the upper Claiborne confining unit, which separates the Memphis aquifer from the overlying shallow aquifer in the Memphis area, that provide avenues for leakage of modern water from the shallow aquifer into the Memphis aquifer. This study uses water levels, water quality data, ^{3}H - ^{3}He analysis, and the hydrostratigraphy of the Allen Well Field and the Memphis Depot to assess the source and flow paths of modern water leaking into the Memphis aquifer near the Allen Well Field. ^{3}H - ^{3}He data show that young water (less than 50 yrs) is present in many wells in the Allen Well Field, especially those with higher total dissolved solids and water compositions similar to those of the Mississippi alluvial aquifer water. However, water levels in the shallow aquifer indicate a depression in the northeastern edge of the Allen well field, near the Memphis Depot, a Department of Defense facility with extensive groundwater contamination. Hydrochemical and water-level data, and hydrostratigraphic cross-sections will be presented that evaluate whether the leakage of modern water originates from the shallow aquifer near the Memphis Depot, the Mississippi alluvial aquifer, or some combination of the two.

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APPLYING GEOSPATIAL SOIL SURVEY DATA TO ESTIMATE STORMWATER TRAPPING EFFICIENCIES OF WEST TENNESSEE FILTER STRIPS

Christopher A. Bridges[1,2]

Stormwater biofiltration systems are among the least expensive and most widely used best management practices. However, watershed-scale terrain and soil variability can greatly impact the effectiveness of grass filter strips and riparian forest buffers. Therefore, this project illustrates a simple technique for using readily-available Soil Survey Geographic Database (SSURGO) information to estimate the pollution removal capabilities of soil map units. The model of Dosskey, Helmers, and Eisenhauer (2006) was applied to soil series in the Little Beaver Creek Watershed of West Tennessee, which is impaired due to high nutrient levels. Model inputs include factors of the Universal Soil Loss Equation contained in the SSURGO database, which were analyzed using ESRI ArcMap 9.3.

Findings indicate that the water trapping efficiency (WTE) of a 12 m grass filter strip ranges from six to 64%, while sediment trapping efficiency (STE) ranges from 17 to 99%. As found in similar studies, the capacity of soils to filter sediment was significantly higher than the capacity of soils to effectively filter dissolved pollution. The average stormwater trapping efficiency of streamside management zones increased with Strahler stream order, and with saturated hydraulic conductivity of surface soils. Propagation of both grass and woody plant species in priority locations should aid in stormwater management via infiltration of sediment and utilization of dissolved nutrients.This method presents natural resource managers with new opportunities for rapid evaluation of stormwater pollution control options, which should help to increase both the efficiency and effectiveness of stream restoration projects.

REFERENCES

Dosskey, M.G., M.J. Helmers, and D.E. Eisenhauer. 2006. An approach for using soil surveys to guide the placement of water quality buffers. Journal of Soil and Water Conservation 61(6):344-354.

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WETLANDS IMPROVE WATER-QUALITY AT TENNESSEE STATE UNIVERSITY

Brandon Cobb*[1], C. Cobb[1], P. Armstrong[2], M. Martin[1], L. Sharpe[3], and J. Stewart-Wright[4]

Wetlands have been shown to attenuate suspended sediments and agricultural pollution in rural areas but little work has been conducted regarding the benefits of the wetlands in mitigating urban non-point source pollution (NPS). The objective of this project was to determine if an 80 acre natural wetland located down gradient of bedrock springs, parking lots, city streets and leaky sewer systems in Nashville, Tennessee helped to mitigate urban NPS runoff. The drainage area was estimated to be 2.3 square miles using the USGS Stream Stat program. Sampling points were selected based on reconnaissance during rainfall events to determine general flow paths. Water samples were collected at these sampling points during base-flow and rain runoff events. Water-quality monitors were also placed in the springs and along the flow path during the 12 month period of study. Water samples were analyzed within 48 hours for turbidity, specific conductance, pH, and volatile organic compounds (VOC). Additional analyses were performed for sulfate (SO4), nitrate (NO3) ammonia (NH3) and chemical oxygen demand (COD). It was found that runoff from parking lots and roads during winter storms had relatively high VOC levels (62 µg/L benzene, 132 µg/L toluene, 106 µg/L xylenes, and a number of unidentified compounds). Water samples collected downstream of the wetland, however, had VOC concentrations below detection levels. Water samples collected at the most downstream site also had significantly lower levels of turbidity (90 % lower), NH3 (99% lower), COD (95% lower), NO3, (90% lower), and SO4 (63% lower) on average for the year. The results indicated that routing water through the urban wetland resulted in significant water-quality improvements during the study period.

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USING CHEMOGRAPHS TO CHARACTERIZE A KARST SPRING IN NASHVILLE, TN

Carlton Cobb*[1] and J. Stewart-Wright[2]

Ground water in karst terrains is highly vulnerable to contamination due to the rapid transport of contaminants through the highly conductive conduit system. Karst aquifers in urban locations are considered particularly vulnerable to contamination because of a greater numbers of potential contamination source areas and focused storm runoff from impervious surfaces that can build up rapid pressure change in the aquifer. Altered rain-recharge patterns, such as diversion of recharge into man-made storm systems are common in urban areas. Developing a conceptual model of how the water infiltrates and moves into Nashville's shallow aquifer is essential to understanding the vulnerability of Nashville's shallow aquifer to pollution. The objective of this research was to develop a conceptual model depicting flowpaths of rain recharge to two springs in Nashville, TN. Two years of near continuous temperature and conductivity monitoring was done at Tumbling Rock Spring located on Tennessee State University's campus. Additional synoptic sampling was done to augment the electronic monitoring at Tumbling Rock Spring and nearby Trough Spring during the two-year period. The data include dissolved oxygen, pH, nitrate, sulfate, iron, discharge and turbidity. Also, attention was paid to the weather to ascertain patterns in the spring chemographs associated with rain events. The data show a smooth transition in temperature through the seasons regardless of rain events. Essentially, the springs were 17.5 C +/- 1 degree year round. A noticeable lag of several months was observed between the air temperature and the groundwater temperature. The specific conductance also had a seasonal pattern. The specific conductance of the spring's water would drop during the drier summer months and then rise during the wet winter season. However, this pattern was punctuated by sharp peaks and valleys associated with rain events. The sharp decrease in specific conductance associated with a rain event, followed by a quick rebound indicates that there is relatively rapid infiltration and transport of rain water to the spring by a small portion of recharge. However the lack of concurrent temperature change, and only minor increases in discharge and no major increase in turbidity are evidence that most of the spring flow is due to dispersed recharge. Attempts to use nitrate as a natural tracer as hydrologists have done in Texas karst regions did not work here due to the non-conservative nature of the nitrogen in this ground-water system. Another approach that uses peaks in specific conductance due to rain events is being assessed.

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MAINTENANCE WATER QUALITY STRUCTURES AND ILLUSTRATING WATER QUALITY TESTING TO UNDERGRADUATE STUDENTS

S. Hovis, W. Anderson[1], and L. Sizemore[2], and MTSU undergraduate students enrolled in ABAS 3370 and 4370 for the academic year 2008-2009

In urban areas, organic fluids and particulate from automobiles can be carried off parking lot surfaces and move into water resources. Bioretention ponds (rain gardens) are one way to ameliorate the water quality of runoff while aesthetically enhancing the area. Grading the inflow to construct a rain garden at MTSU, variation in soil colors was seen. This was due to organic material being deposited by parking lot runoff. The organics did not appear to affect plant growth and development in the "polluted" area. Bioassay experiments showed that motor oil at levels of 50 parts per million had little effect on the germinating seeds. Further research was done to observe the effect of 500 parts per million of motor oil on both grasses and broadleaf plants. Constructed rain gardens on the MTSU campus have helped remove pollutants from the surface runoff before it reaches the water storage basin.

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ANALYSIS OF ORGANIC CONTAMINATION BY COAL MINING AND ASPHALT PRODUCTION

Jo Meagan Mansfield[1]*, Gene Mullins, John Harwood

We have developed extraction and analysis methodologies for determination of organic contamination in samples taken from two areas affected by fossil fuel industries. Polynuclear aromatic hydrocarbons (PAHs) and other organic compounds from such operations can contaminate both the water and sediment of receiving streams. Our analysis steps include solid phase extraction and preconcentration of samples, and high-performance liquid chromatography /mass spectrometric analysis utilizing atmospheric pressure chemical ionization. The method provides a useful tool in monitoring streams with potential organic pollution created by coal mining, asphalt production, and other industrial activities. We will analyze samples from the segment of the Emory River which contains coal ash from the recent spill at the Kingston Coal Plant, and drainage from the Horseshoe Mountain coal mine site. We will present our analytical methodology, and results of our initial analyses of environmental samples.

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USE OF INDEPENDENT GAMMA DISTRIBUTION TO DESCRIBE TRACER BREAK-THROUGH CURVES

Marquan Martin*[1] and Roger Painter[1]

The advection-dispersion equation (ADE) is widely used as a predictor of residence time distributions (RTDs) for tracer breakthrough curves for karst systems. Solutions of the ADE for tracer breakthrough studies with near plug flow behavior are characteristically Gaussian in appearance. However, very few, if any, quantitative tracer studies result in tracer concentrations that have symmetrical distribution about the mean residence time. While the symmetry of Gaussian breakthrough curves often correctly predicts finite tracer concentrations at zero time, it generally does not accurately predict actual tracer breakthrough curves, which invariably are characterized by relatively long tails. This suggests that a different conceptual approach may be appropriate for describing tracer breakthrough curves and the hydrologic systems they represent. The objective of this project was to develop a more descriptive approach of tracer break-through data based on the gamma probability density function. The tracer travel distance and tracer linear velocity were assumed to be randomly distributed variables with gamma distributions. The RTD for tracer breakthrough curves was derived from the individual distributions of tracer travel distance and linear velocity. This approach was compared and contrasted with the traditional approach based on the ADE for modeling tracer breakthrough data from tracer studies conducted at Mammoth Cave National Park storm filters.

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USE OF DYNAMIC SYSTEMS MODELING TO CONCEPTUALIZE THE PROGRESSION OF ACIDIC DEPOSITION TO STREAM CHEMISTRY IN STREAMS OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Lee Mauney*[1] and John Schwartz[2]

The Great Smoky Mountains National Park (GRSM) receives some of the highest rates of atmospheric deposition of acid pollutants in the United States. Concerned over potential impacts to water quality from this atmospheric deposition, GRSM implemented a long-term, water quality monitoring program in 1991 with goals to better understand these impacts and improve resource management strategies. This program has produced a substantial data set but no representative model of the processes involved in acidic deposition to actual stream chemistry. To evaluate these processes, an object-based systems dynamics modeling software (STELLA) will be used to produce a representative model of the hydrologic and biogeochemical systems. This model could not only aid in understand complex processes of these systems, but may be used as a watershed management tool for streams with low alkalinity waters.

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A DETAILED INVESTIGATION ON THE EXCHANGE OF GROUND-WATER AND SURFACE WATER IN A SAND BOTTOM STREAM IN WEST TENNESSEE

Ryan Pickett, E.I.[1]*; Brian Waldron, Ph.D. P.E.; Dan Larsen, Ph.D.;
Jerry Anderson, Ph.D. P.E., and David Arellano, Ph.D. P.E.

GROUND WATER: RECHARGE

This study investigates the use of multiple methods to determine stream/aquifer interaction in a sand bottom stream in West Tennessee. These methods are used to produce a quantitative measure of exchange flow between the two systems and the primary hydrogeologic factors governing this exchange. The study site is in a section of the Loosahatchie River, west of the I-70 Bridge and USGS gaging station (#07030240), in the northeastern part of Shelby County. Instrumentation of the site includes falling head permeameters, pressure transducers, and seepage meters. Permeameters, consisting of 2 inch PVC with a 6 inch interval of 0.01 inch slotted screen, were installed in five nests of three across a single transect of the river. Within each nest, the screened intervals were set 1, 3 and 5 ft below the riverbed relative to the same vertical datum. The permeameters were instrumented with pressure transducers (Solinst Gold Levelogger accurate to ± 0.010 ft) to measure head drop during a hydraulic conductivity test and to monitor pressure head and temperature at depth over time. Data collected indicates an irregular variation in the hydraulic gradient where water level within the middle screened interval is typically higher than the shallower and deeper sections (results were corroborated with the seepage meters). Since, the Loosahatchie River is an entrenching channelized system; it is suspected that the wide variation in measured hydraulic conductivity (*K*) is due to fluvial processes creating compartmentalized flow. The values of *K* calculated using Hvorslev's equation with shape factor 8 are: 89 – 828 ft/day for the shallow interval (1 ft), 23 – 270 ft/day for the middle interval (3 ft) and 23 – 305 ft/day for the deep interval (5 ft). The research is ongoing and future plans include utilizing electric resistivity to characterize the riverbed heterogeneity in greater detail. We will also employ a distributed temperature sensing (DTS) survey to monitor temperature variations at high resolution over time.

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SOLUBILITY AND BIODEGRADATION OF ET-85 IN GROUNDWATER

Loreal Spear*[1], Christin Staples[2], B. Kamara[2] and L. Sharpe[2]

The United States government is promoting alternative fuels that reduce our dependency on foreign oil. Tennessee is promoting E-85, a fuel that consists of 85 percent ethanol and 15 percent gasoline. The environmental fate of gas-alcohol mixtures, however, has not been investigated. The consequences of an uncontrolled spill of E-85 or a related mixture would, therefore, be very difficult to predict. The objective of this research was to determine if a commercial grade E-85 mixture would dissolve more readily in water and move faster through water-saturated soil than regular gasoline. A better understanding of E-85 mobility in the subsurface is of practical importance if E-85 is to become widely used and stored in underground storage tanks like conventional fuels. Solubility-in-water studies comparing gasoline with E-85 found that the ethanol component in E-85 acted as a co-solvent and enabled aromatic compounds to dissolve five times more rapidly in water. The enhanced solubility characteristics due to E-85 may allow the aromatic rings to move faster and further through water-saturated soils and karst conduits than regular gasoline. Additional experiments were conducted to determine if regolith soils would affect the dispersal rate of E-85 fuel compounds. Sterile soil-column studies using soils collected from karst regions of Middle Tennessee demonstrated that aromatic compounds, such as benzene, toluene or xylene (BTX), from the E-85 moved 3 to 4 times faster than BTX compounds in regular gasoline when transported by water through the soil. The results suggest that leakage of E-85 from underground storage tanks could result in wider contamination of aquifer materials in a shorter time than regular gasoline. Additional work compared the biodegradation of E-85 with regular gasoline. Using static reactors with bacteria collected from a karst aquifer, aerobic biodegradation of E-85 was almost 5 times faster than biodegradation of regular gasoline. The faster biodegradation is in agreement with previous reports finding that dissolved-phase fuels were more bioavailable and degraded faster. However, under anaerobic conditions, the BTEX compounds from E-85 degraded at $1/10^{th}$ the speed of regular gasoline. It is not known if this was due to the anaerobic bacteria preferring ethanol as a food or if the ethanol had an inhibitory effect on the anaerobic bacteria. Additional studies are needed to more thoroughly address issues concerning E-85 solubility and biodegradation under anaerobic conditions.

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HELPING RURAL COMMUNITIES IN THE DOMINICAN REPUBLIC AND GUATEMALA WITH LOW COST SOURCES OF CLEAN DRINKING WATER

Adam Teg*[1], Forbes Walker[2], John Schwartz[3] and Neal Eash[4]

The Engineers Without Borders student chapter at the University of Tennessee (UT) has partnered with disadvantaged communities in the Dominican Republic and Guatemala to implement sustainable water supply projects.

In March 2006, five students and one faculty member conducted an assessment trip to the village of Los Cerros near the Haiti border in the Dominican Republic. Hand pumps were being used on two wells, but were not working on three other wells. The two operative pumps would nearly dry during droughts. A topographical survey of the village identified locations to construct water storage tanks. In May 2006, the government drilled new, deeper boreholes. A grant provided funds to install an electric pump in a new well, construct two new water storage tanks, and supply pipelines. In December 2006, another team from UT successfully constructed a new water system with the help of the people of Los Cerros.

In May 2007, ten students and three faculty members traveled to Guatemala to construct three prototype rainwater storage tanks in the village of La Fortuna, in western Guatemala. These systems collected rainwater from the roofs of the villager's homes during the rain season (May to October), and provide clean, safe water for each household during the dry season (November to April). A follow-up visit was conducted in March 2008. Water tests showed that the water was still clean (no detectable *E. coli*) compared with a nearby well ($> 10^6$ cfu *E. coli* per 100 ml). A follow-up trip is planned for May 2009.

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The Tennessee Water Resources Research Center (TNWRRC) and the Southeastern Water Resources Institute (SWRI) are the formal water resources research entities under the Institute for a Secure and Sustainable Environment (ISSE) at The University of Tennessee. The two organizations work synergistically together to address water resources research needs to the broad regional community.

The TNWRRC is a federally designated research institute headquartered at the University of Tennessee, Knoxville. The Center was established in 1964 by Governor Clement following the enactment of the Water Resources Research Act of 1964 (PL 88-379) by Congress. TNWRRC's missions include: (1) to assist and support all academic institutions of the state, public and private, in pursuing water resources research programs that address problem areas of concern to the state; (2) to promote education in fields related to water resources and to provide training opportunities for students and professionals in water resources related fields; and (3) to provide information dissemination and technology transfer services to state and local governments, academic institutions, professional groups, businesses and industries, environmental organizations, and others that have an interest in solving water resources problems.

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The University of Tennessee created the Institute for a Secure and Sustainable Environment (ISSE), pronounced ICE, to promote development of policies, technologies, and educational programs that cut across multiple disciplines, engage the university's research faculty and staff, and grow in response to pressing environmental issues facing the state, the nation, and the globe. ISSE became operational on July 1, 2006.

The institute represents a restructuring and expansion of the Waste Management Research and Education Institute—a state Center of Excellence established in 1985—to focus more broadly on environmental challenges. The institute will include programs previously found in two other long-standing organizations housed at the university and devoted to environmental research: the Joint Institute for Energy and Environment and the Energy, Environment and Resources Center. The consolidation of environmental research activities will enhance collaboration, facilitate more efficient administration, and build on existing strengths and on-going research efforts.

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Proceedings compiled by the Center for the Management, Utilization and Protection of Water Resources —
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