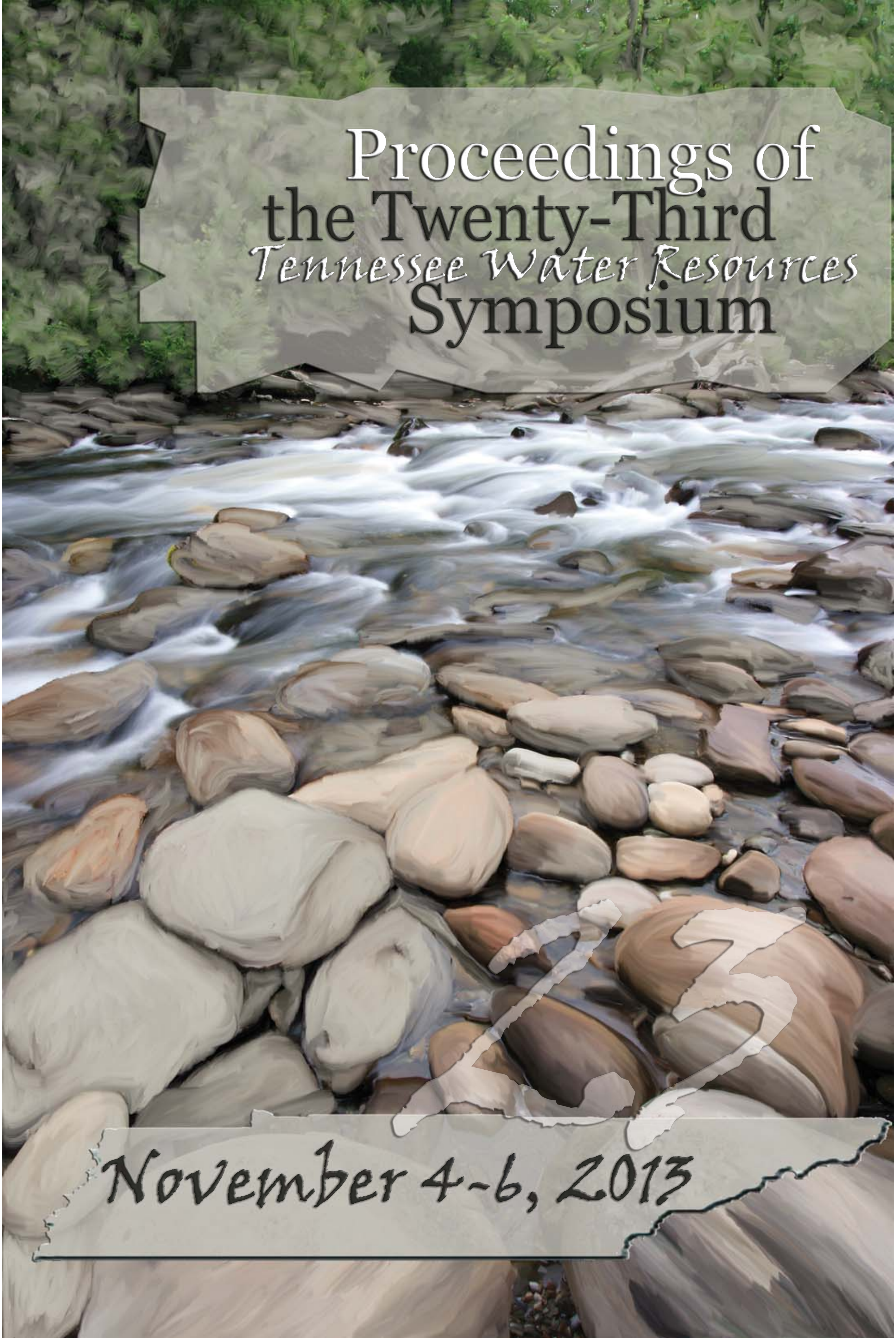
Proceedings of the Twenty-Third *Tennessee Water Resources* Symposium



November 4-6, 2013

Proceedings from the

23rd Tennessee Water Resources Symposium

Montgomery Bell State Park
Burns, Tennessee

November 4-6, 2013

Sponsored by

Tennessee Section of the American Water Resources Association

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PREFACE

Welcome to the 23rd Tennessee Water Resources Symposium sponsored by the Tennessee Section of the American Water Resources Association (TNAWRA). I am excited that you have chosen to join us this year. The conference committee this year was composed of a group of experienced, hard working water resources professionals who crafted an Agenda with excellent speakers and fun social activities just for you – the attendee. I am honored and humbled to be serving as President during this conference.

Welcome to the Civil Engineers who have chosen to attend the Tennessee Water Resources Symposium. Several years ago, the conference committee realized that water resources engineers especially appreciated the symposium. As we have for the past 2 years, we have again partnered with the Environment Water Resources Institute of the Tennessee Section of the American Society of Civil Engineers to offer an "Engineering Track" of presentations that the conference committee felt would be of special interest to engineers. The "Engineering Track" is indicated on the Agenda, but of course, all attendees are welcome to attend any track that is of interest to them. Be sure to attend the Keynote talk at lunch on Monday to hear Bob Hirsh of the USGS speak about "Changing Hydraulic Systems." I am also looking forward to hearing David Haskell's talk on "The Forest Unseen: A Year's Watch of One Square Meter of Forest" at the luncheon on Tuesday.

Almost everyone who knows me has heard my TNAWRA story. When I moved back to Tennessee and began working in water resources, I was looking for a meeting to keep abreast of the current state of the field. I attended the TNAWRA symposium in 2000. When I attended the symposium, I attended as many sessions as possible in order to learn as much as I could (and to get those ever important Professional Development Hours that Engineers need!). I work in the field of water quality protection. At my first symposium, I attended presentations on storm water pollution prevention, groundwater remediation, reservoir hydraulics and operations, flooding, source water protection, wetlands, water monitoring and stream restoration. As I continued to work in the water resources field over the next year, I realized that I had come to use something I learned from every presentation I attended. Therefore I encourage you to attend a presentation that seems to be outside of your field to see if you learn something that you can use later in your work.

The other thing I liked about the symposium is that it is really friendly. I knew no one the first time I went to the symposium in 2000, but by the end of the symposium, I knew many people and each year I return, I meet more people and get to catch up with those I met last year. If you do not know anyone or would just like to meet someone new, I challenge you to step outside of your comfort zone. Say "hello" to someone. If you don't know what to say next try "what kind of work do you do?" or "did you see the presentation about (fill in the blank)?" Also, be sure to come up to me and say hello.

I have the dubious honor of being the longest serving single term President, having a term of almost 19 months. The symposium is usually held in the Spring of each year and the President is sworn in on the last day of the symposium. Due to Federal budget issues in the early Spring of 2013, the symposium was moved to November 2013, which is where we are today. We are back on track and the next symposium will be on April 1-3 of 2015, a mere 17 months away. Mark your calendars and plan to come back.

Attend – Learn – Participate

Thomas B. Lawrence, PE, President, Tennessee Section AWRA, 2013 Conference Chair

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- Randy Kerr, Tennessee Valley Authority
- Amy Knox, Center for the Management, Utilization and Protection of Water Resources-TTU
- Daniel Saint, Tennessee Valley Authority

12:00 – 1:30 p.m.
Monday, November 4
Keynote Address *by* Robert Hirsch, U.S. Geological Survey

"CHANGING HYDROLOGIC SYSTEMS—THINKING ABOUT NON-STATIONARITY OF STREAMFLOW AND WATER QUALITY"

12:00 – 1:30 p.m.
Tuesday, November 5
Luncheon Presentation *by* David G. Haskell, Sewanee, The University of the South

"THE FOREST UNSEEN: A YEAR'S WATCH OF ONE SQUARE METER OF FOREST"

I discuss my year's watch of a small area of forest in southeastern Tennessee. Through a calendar year I returned to observe the one square meter of forest, paying attention to the ecological interactions happening within its bounds. In this talk I will share both scientific and personal insights from the project and give short readings from resulting book, *The Forest Unseen*.

SESSION 1A

ENERGY

FLOOD

SESSION 1B

ENVIRONMENTAL MODELING FOR HABITAT

BEAVER CREEK RESTORATION

SESSION 1C

ECOLOGY/BIOLOGY

RESERVOIR

SESSION 2A

WATER SUPPLY

STREAM DETERMINATION

LID

LID APPLICATIONS

SESSION 2B

ENGINEERING APPLICATIONS

STORMWATER BMPS

MODELING TOOLS I

EDUCATION IN THE AG COMMUNITY

SESSION 3A

TDEC

SESSION 3B

GIS TECHNIQUES AND TOOLS

SESSION 3C

EROSION

PROFESSIONAL POSTERS

STUDENT POSTERS

<u>*High School*</u>

Doctoral Candidate

ABSTRACTS IN ABSENTIA

SESSION 1A

ENERGY
1:30 p.m. – 3:00 p.m.

Water Management and Power Production in East Tennessee: An Assessment of Water-Energy Interactions and Policy
Christopher Clark, Carol Harden, William Park, John Schwartz, Caroline Ellis, Julie McKnight, Evan Betterton, Hope Tracy, and Kelly VanCor

Tennessee Utilities Plug-In for Energy Savings at Their Wastewater Facilities
Jennifer Dodd

Reported Versus Estimated Water-Use Data at Thermoelectric Power Plants in the Southeastern United States
Melissa A. Harris

FLOOD
3:30 p.m. – 5:00 p.m.

Establishing Design Basis Flood Levels at TVA Dams
Michael A. Eiffe

A Record of Sediment Erosion, Flood Frequency, and Sediment Contamination Analyzed from Fine Sediment Deposited in Caves and Sinkholes Draining an Urban Area
Evan A. Hart

Lowering Flood Elevations on the Alabama River
Patrick A. Dobbs

WATER MANAGEMENT AND POWER PRODUCTION IN EAST TENNESSEE: AN ASSESSMENT OF WATER-ENERGY INTERACTIONS AND POLICY

Christopher Clark[1], Carol Harden[2], William Park[1], John Schwartz[3], Caroline Ellis[1], Julie McKnight[2], Evan Betterton[1], Hope Tracy[2], and Kelly VanCor[1]

ABSTRACT

Effective water management is crucial to meeting changing energy and water needs. In the southeastern U.S., recent drought and water conflicts have illuminated the need to evaluate impacts of increasing power production on water quantity and quality. The scale of water use and various types of power production in East Tennessee (TN) make this an ideal location to study water-energy management, policy, and trade-offs. We assessed available water use and quality data and water policy in East TN. While water use per unit energy data are well expressed at the national level, a regional quantification of actual water use is lacking. Permits are required for water withdrawals exceeding 10,000 gallons per day; however, actual water use is unclear as there is no reporting requirement or maximum withdrawal amount. In terms of water quality, thresholds are defined for regional water resources, though operational allowances in water use permits for power facilities often extend beyond these limits. Increases in water temperatures with regional climate change also emerged as a critical concern for both power production and ecosystem health. Intake of warmer waters reduces effectiveness of thermoelectric cooling towers while waters discharged downstream of a facility may exceed biological temperature thresholds. To better integrate science and policy, we recommend future work which quantifies water use per energy unit in East TN, specifies water use reporting guidelines and maximum withdrawals under varying water level conditions, and develops optimal water temperature thresholds for both power plant operation and ecosystem health.

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TENNESSEE UTILITIES PLUG-IN FOR ENERGY SAVINGS AT THEIR WASTEWATER FACILITIES

Jennifer Dodd[1]

In late 2011, staff from EPA Region 4 and TDEC Division of Water Resources began conversation that lead to the formation of the Tennessee Water and Wastewater Energy Efficiency Partnership. The Partnership is a collaboration of staff from EPA Region 4, TDEC, TVA, the University of Memphis, University of Tennessee – Municipal Technical Advisory Service, the Environmental Finance Center (University of North Carolina) and Schneider Electric. Tennessee is the first state in Region 4 to participate in such a program with EPA.

Patterned after an EPA Region 7 initiative, the Tennessee program consisted of an individual energy assessment for each facility and a series of four workshops that facilitated action plans and funding options for capital improvements. The participants in the program were Nashville, Columbia, Fayetteville, Franklin, Caryville-Jacksboro, Lenoir City, and First UD Knox County.

All seven participants found potential energy savings at their wastewater treatment plants. Additionally, Lenoir City Utility Board found potential energy savings at its water treatment plant. The combined potential savings for all eight facilities is over 7 million kilowatt hours per year, which would reduce CO_2 emissions by 6,696 tons, equivalent to 1,190 cars removed from the road for a year or 739 homes powered for a year. Projected annual savings ranged from $15,750 to $210,000, with the average facility having a potential reduction of 17.8%.

Discussions are ongoing for a second round of energy assessments and workshops, beginning in the spring or early summer 2013.

[1] TDEC Division of Water Resources

REPORTED VERSUS ESTIMATED WATER-USE DATA AT THERMOELECTRIC POWER PLANTS IN THE SOUTHEASTERN UNITED STATES

Melissa A. Harris[1]

The U.S. Geological Survey (USGS) compiles and publishes national water-withdrawal estimates for various uses on a five-year cycle. Thermoelectric power plants have accounted for the largest water withdrawals since 1965. In the past, thermoelectric water use has been compiled from regulatory data provided by facility operators to State and Federal agencies. Analysis of published data revealed inconsistencies and reported water-use values that were thermodynamically unrealistic. The USGS has developed a method for estimating water withdrawal and consumption at power plants based on an energy budget constrained by power plant generation, cooling technologies, and environmental variables such as air temperature and wind speed. Water-use estimates were calculated for approximately 1,300 thermoelectric plants in the United States with generating capacities of at least one megawatt, 240 of which are located in the southeast. The estimates include ranges of plausible water withdrawal and consumption rates for each plant. Reported water-use data were compared to estimated plausible ranges for quality assurance. Of the 180 plants in the southeast that reported water-use data, 61 percent reported plausible withdrawal data, but only 27 percent reported plausible consumption data. Some of the discrepancies in the consumption data are likely due to the lack of reported consumption data by thermoelectric plants with once-through cooling systems. For once-through cooled plants, most of the consumption happens outside the plant boundaries in the form of forced evaporation of surface waters due to added heat load.

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ESTABLISHING DESIGN BASIS FLOOD LEVELS AT TVA DAMS

Michael A. Eiffe, Program Manager, Hydrology, TVA

TVA has for many decades used the Probable Maximum Flood (PMF) as the hydrologic design basis for its high hazard dams. The PMF is determined by assessing the flood runoff associated with maximum design storm rainfall published by the National Weather Service. For most TVA projects, previous analyses establishing maximum flood levels and discharges had been completed in the 1980's. Changes in reservoir operating policy, both in operating levels and operational rules, revised dam spillway rating curves, and developments in hydrologic modeling techniques led to a revised analysis to re-establish design basis flood levels. In particular, the legacy TVA code used for unsteady flow simulations was replaced by the industry standard HEC-RAS model. This analysis was comprehensive, and included all TVA projects, even those for which the design basis flood is an event smaller than the PMF. The analysis has now been completed. The presentation will describe how the analysis was done, and present both results and expected future directions in hydrologic assessment.

A RECORD OF SEDIMENT EROSION, FLOOD FREQUENCY, AND SEDIMENT CONTAMINATION ANALYZED FROM FINE SEDIMENT DEPOSITED IN CAVES AND SINKHOLES DRAINING AN URBAN AREA

Evan A. Hart[1]

EXTENDED ABSTRACT

Fluvial sediment deposited in caves often remains preserved for long time periods. Analysis of cave sediments can reveal important clues about the environmental history of the surrounding watershed. For example, valuable information about paleoclimate has been extracted from chemically deposited cave sediments (White, 2007; Sasowsky and Mylroie, 2007). Cave sediments have also allowed researchers to estimate river incision rates on the Cumberland Plateau and in other localities. Less research has focused on contemporary cave sediments, one reason being is that recently deposited cave sediment do not survive long in one location and are continuously swept downstream. However, hydraulic conditions vary widely from one cave to another based on the morphology of the cave. Some caves have high velocity flows during floods, while others back up during floods, leading to periods when very low velocities prevail. Thus a wide range of sedimentary deposits are expected in caves due to the high variability of flow conditions.

We discovered a 2-meter sequence of fine sediment preserved in Capshaw Cave, Cookeville, TN and analyzed these sediments for particle size and heavy metal concentrations. The sequence shows at least 50 alternating layers of silt/clay (dark color) and fine sand (light color). Silt/clay layers range in thickness from 2 to 10 cm, while fine sand layers are all less than 2 cm in thickness. These alternating layers are the result of flooding in the cave. The silt/clay layers are deposited at peak flood stage, when the cave is completely filled, and water velocities are minimal. The thickness of the silt/clay layers suggests the length of time the cave was flooded. The fine sand layers are deposited in the waning stages of each flood as the cave drains out and water velocities increase. Lead concentrations in the sediments ranged from 80 to 130 ppm and were significantly higher than background soil lead concentrations measured in nearby rural areas. Chromium concentrations in the cave sediments were also higher than background samples. Lead in cave sediments likely comes from the surrounding urban area and leakage from the city's sanitary sewer system may be the main source of chromium. The presence of heavy metals suggests that deposition of cave sediments occurred after the urbanization of the watershed (< 100 yr).

These results have further implications for the movement of sediment through watersheds over historic timescales. Human impacts on soil redistribution within watersheds have been widely studied in many different environments. In the eastern US, land clearing for agriculture after European settlement led to increased rates of hillslope erosion and floodplain sedimentation. The magnitude of increased erosion rates has been deduced by analysis of so-called 'legacy' sediments, found today deposited along streams and on floodplains, and where present, behind

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mill dams (Walter and Merritts, 2008). The widespread occurrence of legacy sediments has led to questions about the natural state of stream channels before European settlement and to management questions regarding stream restoration. Analysis of legacy sediments has revealed valuable information about flood frequency, sediment budgets, and the storage and release of contaminated sediment along floodplains. Another form of legacy sediments are those derived from land disturbance during periods of urban growth. In some areas, urbanization produced a sharp increase in sediment delivered to streams (during the construction phase), then a rapid decline in sediment erosion due to covering of impervious surfaces.

In addition to cave sediments, sinkhole sediments were also examined in this study. In karst regions, runoff of water and sediment is strongly controlled by the presence of closed depressions (dolines, sinkholes, pjoles, etc.) that effectively partition the landscape into sub-watersheds, a pattern that has been referred to as polygonal karst (Williams, 1972). Hydrologic connections between sub-watersheds and master streams in karst areas are not immediately apparent from topographic maps, resulting in uncertainties in drainage pathways, the delineation of which require tracing techniques. With respect to sediment, closed depressions, such as sinkholes, act as 'gate-keepers' by restricting or delaying the passage of sediment from sub-watersheds area to master streams. The degree to which sediment is trapped in sinkholes depends on the size of sinkholes and the presence of swallet openings that may connect to cave systems. While some sinkholes have large swallet openings that permit sediment transport directly to subsurface passages, many sinkholes are efficient or indefinite sediment traps. Despite the widespread occurrence of karst terrain, few studies have documented sediment deposition or the residence time of sediment within sinkholes. Data about this 'gate-keeping' function of sinkholes would be useful in determining, for instance, the impacts of disturbances (e.g., forest clearing, urbanization) on downstream sediment flux. In addition, sediment deposited in sinkholes provides a potential record of erosion and environmental conditions in the watershed. Based on field data we were able to quantify historic sedimentation rates for selected sinkholes.

Previous research on sinkhole sediments has focused on the origin of the sediments, rates of deposition within sinkholes, and paleoclimate studies. The origin of sinkhole sediments and soils has been debated. For example, Hall (1976) showed that terra rosa soils, contained within sinkholes in southern Indiana and traditionally interpreted as residual soils, were likely of alluvial origin. He cited several lines of evidence for a fluvial origin of terra rosa, including rounded quartz grains and fine laminations (Hall, 1976). Oh (1992) found that sinkholes in Wisconsin contained an array of colluvium, residuum, alluvium, and loess, dating to between 440 and 6540 ^{14}C ybp. Sedimentation rates for these Wisconsin sinkholes averaged 2 mm yr^{-1}, which is significantly higher than floodplain sedimentation rates in the same region (Oh, 1992). This difference is attributed to a higher trap-efficiency of sinkholes compared to floodplains. Crownover et al. (1994) found alluvial and colluvial soils in sinkholes to be several thousand years old, indicating that sinkholes sediments can be stable for millennia with little or no movement into cave systems. Turnage et al. (1997) used ^{137}Cs to determine sedimentation rates since 1950 for sinkholes in East Tennessee. Their work showed that sedimentation rates were highest for sinkholes with cropland and lowest for sinkholes in forested areas. Stepisnik (2004) found that many collapse sinkholes in Slovenia were filled with loam deposited by overflow flooding from underlying karst systems. This finding suggests that some sinkholes may actually contain sediment derived from cave systems. Goldie and Marker (2001) showed that many sinkholes in the UK are filled with loess overlain by a peat horizon dating to 9000 ^{14}C ybp, denoting a dry-to-humid climate transition at that time. Sediment cores have also been extracted from sinkhole lakes to obtain pollen samples for paleoclimate reconstruction (Wright, 1966; Delcourt, 1979; Hodell et al., 2005). Balbo et al. (2006) used sediment cores from poljes in Croatia to date the onset of human settlement during the Holocene. Bruxelles et al. (2006) found that poljes in France had undergone several meters of infilling with alluvium and colluvium since the Paleolithic times.

The study area lies within the Pigeon Roost Creek watershed near Cookeville, TN, located on the East Highland Rim in northern middle Tennessee. The East Highland Rim is a sinkhole plain underlain by Mississippian limestone, shale, and chert. Variation in bedrock solubility in the area has created a classic fluviokarst landscape. Fluviokarst is thought to be a less well-developed karst landscape where surface streams flow along the surface in areas where insoluble bedrock is found at the surface. Streams often enter the subsurface at accordant elevations which coincide with soluble bedrock layers. Sinkholes in the present study area are formed in two main bedrock units. The St. Louis formation consists chiefly of micro- to medium-grained limestone. The stratigraphically lower Warsaw formation is a heterolithic unit of sandy limestone, calcareous siltstone and shale, and argillaceous limestone. Most streams in the study area sink into caves formed in soluble beds of the middle Warsaw formation. These caves serve as stormwater drains for the city of Cookeville. Cave streams reemerge on the surface at an elevation correspondent to the less-soluble lower Warsaw formation. Many of these sinkholes have slow draining swallets resulting in back-up flooding and damage to structures during heavy rain events.

Approximately half of the land area within the Cookeville city limits drains into one of the 218 sinkholes that have been identified using LiDAR. Land use changes have affected sedimentation and erosion patterns around swallets in the study area. Agricultural activities in the watershed led to severe upland erosion beginning in the 1800s until the early 1900s. The earliest aerial photographs of the area (1938) show a landscape scarred by numerous gullies and bare soil areas. Original soil survey maps show numerous gullies in these watersheds during the early 1900s. Much of the sediment eroded from hillslopes at that time was deposited in sinkholes and caves by tributary streams. Air photos from 1955 and 1972 show evidence of the healing and recovery of upland gullies, which likely led to reduced hillslope erosion rates. Sediment produced in the watershed today originates mainly from construction sites and channel bank erosion (Hart and Schurger, 2005). Land use changes have also affected peak runoff rates in the study watershed. Between 1955 and 1997, commercial land use in the watershed increased nearly 400% and residential land use increased nearly 100% (Hart, 2006). Rainfall-runoff models suggest that the increased percentage of impervious surfaces led to a doubling of peak discharges for tributaries of Pigeon Roost Creek (Hart, 2006). Sediment captured and stored in sinkholes and small floodplains during the agricultural period is now being re-mobilized by channel bank erosion brought on by higher peak discharges.

Many sinkholes were inspected in the field to determine if swallets were present and to observe current sedimentation conditions around swallets. Swallets were classified as either: 1) Open—allow direct passage of water and sediment directly to the subsurface and to points downstream;

2) Closed—swallet openings do not exist or are covered with soil or debris (sediment is retained in these sinkholes while water infiltrates gradually into the subsurface); and 3) Intermittent—swallet openings are evident but are periodically blocked by debris (water and sediment passage is contingent upon swallet conditions which may change from one flood event to the next). For this study, three sinkholes representing each of the swallet conditions listed above were chosen for detailed field analysis (Table 1). All sinkholes examined here are found on the Cookeville East 7.5' USGS topographic quadrangle. Each sinkhole contained alluvial sediments, with vertical stratification evident in many cases. Terry Sink contains a large open swallet (2 m by 10 m) that permits free flow of water and sediment into Terry Cave and does not, at least under present conditions, become clogged with debris. The Terry Cave watershed drains 169 ha and has 30% impervious surfaces. No swallet opening or cave entrance presently exists in Denton Sink. Floodwaters drain more slowly from this sinkhole and sediments cover the sinkhole floor. The drainage area contributing flow to Denton sink is 85 ha and has 46% impervious surfaces. Warehouse Sink (165 ha) drains the most highly urbanized portion of the study area (58 % impervious surfaces) and has an intermittent cave entrance located in the swallet. Debris blocking the swallet changes after each flood event in the sinkhole.

Changes in sedimentation conditions around the three sinkholes were monitored between 2001 and 2010 using repeat surveying and repeat photography. Sediment profiles were described from exposures along entrenched channel banks and from hand-dug pits. Samples were collected for particle size analysis and dating, to a maximum depth of approximately 1.5 m, where refusal was met in the form of large chert fragments. Relative and absolute dating techniques were applied to sinkhole sediments, depending on applicability. For Warehouse Sink, recent trash items washed into the sinkhole from city streets were used to ascertain the relative age of sediment. For example a sediment layer containing an aluminum can copyright dated at 1999, would indicate that the layer was not deposited before 1999. This technique provided a maximum age limit for sediment layers, and thus a minimum estimate of sedimentation rate. This dating technique is similar to those suggested by Trimble (1998) using other available historic artifacts. The results of this study demonstrate the importance of sinkholes as sediment storage sites. The rate of sedimentation in sinkholes can vary from annual, to decadal, to century-long time scales. Rates of sediment deposition over short time periods (e.g., Warehouse Sink) may be extremely high if the measurement period corresponds to land disturbance in the watershed. Over decades and centuries, sedimentation rates are lower and represent long term averages (Terry and Denton Sinks in this study). In karst watersheds, sediment budgets need to recognize the storage potential of sinkholes in order to estimate long-term sediment yields. Sediment yields could easily be overestimated if much of the sediment delivered from hillslopes is stored for long time periods in sinkholes. Additionally, karst processes, such as sinkhole collapses, could release sediment from sinkholes and increase downstream sediment yields, without any changes in upland sediment erosion. Intermittent blockage of sinkhole swallets by debris or sediment, which was apparent at Warehouse sink in this study, can complicate matters by causing sinkholes to cycle through phases of being net sediment trap and net sediment sources.

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APPENDIX: (figures)

Fig. 1. Cave sediment deposit showing alternating light (fine sand) and dark (silt/clay) flood-deposited layers.

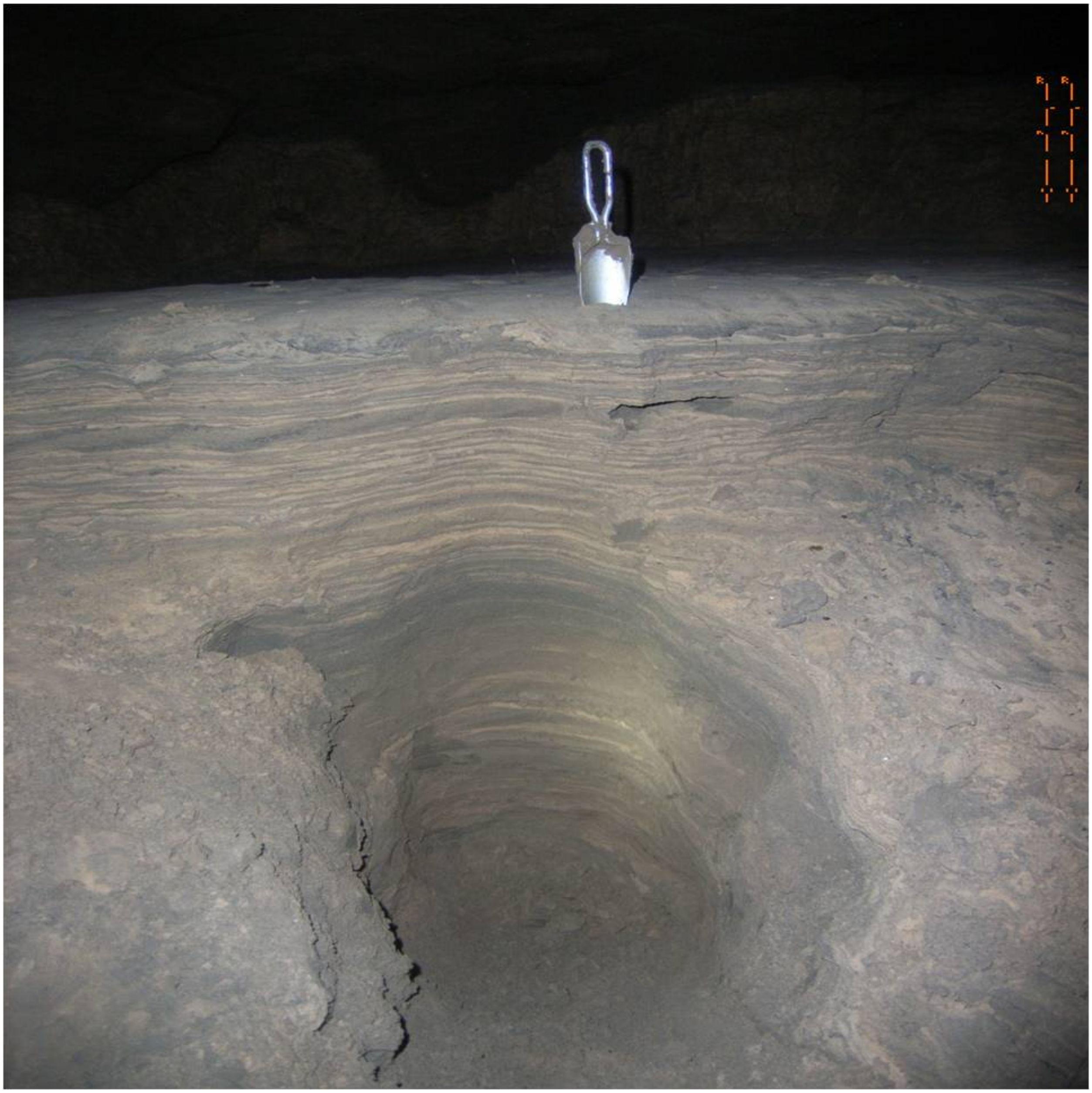

Fig 2. Deposit of sediment in sinkhole. These are recent deposits with trash articles in the lower layers dating to ~1999.

LOWERING FLOOD ELEVATIONS ON THE ALABAMA RIVER

Patrick A. Dobbs[1]

INTRODUCTION

The Alabama River is a large and valuable water resource spanning approximately 320 miles across southern Alabama. The river begins at the Coosa River and Tallapoosa River confluence and ends at the Tombigbee River confluence, where it becomes the Mobile River. The river has three U.S. Army Corps of Engineers navigation dams and flows through a major population center, the City of Montgomery. The last hydrologic and hydraulic study performed on the Alabama River was in 1984, and due to changes in physical watershed characteristics, modeling technology, and regulation, this 25-year-old study is widely accepted to be out-of-date and inaccurate. The inaccuracy claims are validated by USGS gage data and high water marks collected during the 1990 flood. Revered for its navigation, hydroelectric generation, and recreation uses, as well as its scenic value, the entity undertaking a study of the Alabama River must be conscious of technical, political, and social concerns regarding the results of the study.

Through the Fiscal Year 2010 Cooperating Technical Partner agreement, the Alabama Department of Economic and Community Affairs, Office of Water Resources, selected the Upper Alabama Watershed for a Risk MAP study; AMEC Environment & Infrastructure, Inc. is a mapping partner. This study was a perfect opportunity to update the hydrologic and hydraulic analyses of the Alabama River, leading to more accurate base flood elevations, flood hazard delineations, and definition of flood risk. The study reach covers 187 miles, beginning upstream at Jordan Dam on the Coosa River, north of Wetumpka, AL, and ending downstream at Miller's Ferry Lock and Dam, northwest of Camden, AL. Undertaking such a study has required coordination with federal, state, and local agencies, such as the U.S. Army Corps of Engineers, U.S. Geological Survey, Alabama Power, and the Counties bordering the river.

APPROACH

The downstream end of the reach has a drainage area of 20,600 square miles. USGS gage data was used to determine flood discharges. Survey data, bathymetry, LiDAR, and bridge plans were used to develop a HEC-RAS model. From a 1990 flood event, USGS measured high water marks were used for calibration. Updates provided to stakeholders helped manage political and social concerns.

RESULTS AND DISCUSSION

The base flood elevations (BFEs) resulting from the study are, on average, 2.6 feet lower than the 1984 study. The lower BFEs were thoroughly investigated and justified using model calibration and historic documents. The results met community expectations. The presentation will further discuss community responses to the study.

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SESSION 1B

ENVIRONMENTAL MODELING FOR HABITAT
1:30 p.m. – 3:00 p.m.

Estimation of Wetland Elevations Based on Analysis of Daily Stages Using the WETSORT Computer Program
Robert Hunt and Joshua Koontz

Estimation of Fish Spawning and Rearing Habitat Based on Analysis of Daily Stages Using the EnviroFish Computer Program
Barry Bruchman, Joshua Koontz, and L.Y. Lin

Combined Application of Wetland and Fish Habitat Estimation Methods for the Tunica Lake Weir, Tunica, Mississippi
L.Y. Lin and Robert Hunt

BEAVER CREEK RESTORATION
3:30 p.m. – 5:00 p.m.

The Beaver Creek Watershed Restoration Initiative: 2008-2012
Roy A. Arthur and Ruth Anne Hanahan

Restoring Pool-Riffle Structure in Beaver Creek, Knox County, Using a Hydraulic Modeling Approach for Urban Streams
John S. Schwartz and Keil J. Neff

Green Infrastructure Conceptual Planning and Policy Development Using EPA's SUSTAIN Model
Joe Parker, Jean Wodarek, and Roy Arthur

ESTIMATION OF WETLAND ELEVATIONS BASED ON ANALYSIS OF DAILY STAGES USING THE WETSORT COMPUTER PROGRAM

Robert Hunt[1] and Joshua Koontz[2]

ABSTRACT

Whether a surface water project is primarily intended to increase habitat, or has another primary purpose, such as increasing agricultural production, it may be necessary to estimate wetland elevations for both existing conditions and project alternatives, and to evaluate the associated implications for habitat. Wetland elevation is the maximum elevation below which land may be considered a wetland, and so the contour line of the wetland elevation constitutes a boundary line enclosing the potential wetlands at the site. To estimate wetland elevations for project alternatives the Memphis District Corps of Engineers uses a method published by the USDA Natural Resources Conservation Service and implemented in a Vicksburg District computer program named WETSORT. WETSORT analyzes daily stages over a period of years to determine a maximum continuously flooded elevation over a specified duration during the growing season of each year, and reports the median of the annual wetland elevations as the effective wetland elevation for the site. Daily elevations may be historical gage data or simulation model output. The WETSORT algorithm is explained and example input and output is presented.

INTRODUCTION

Engineering projects in channels and floodplains can affect the hydroperiod of streams. Some of these projects are intended to change hydroperiod, while for other projects the change is an unintended side-effect. Whether a project affecting surface water is primarily intended to increase habitat, or has another primary purpose, such as increasing agricultural production, it may be necessary to estimate wetland elevations for both existing conditions and project alternatives, and to evaluate the associated implications for habitat. Assuming a flat pool, once a wetland elevation has been estimated, the area enclosed by that elevation contour is the extent of potential wetlands for that project alternative. For stream reaches where a flat pool concept does not apply, the wetland elevation can be used to delineate the edges of a sloping water surface, so the areal extent of potential wetlands within the stream reach may be determined.

The need to judge wetland extent for proposed projects is based on federal and state laws that require determination of how a project affects wetlands in floodplains and to determine the amount of any needed mitigation.

The three parameters used to determine wetland extent in floodplains includes soil characteristics, type of vegetation, and wetness. However, if a set of potential project

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[1] Hydraulic Engineer, U.S. Army Corps of Engineers, Memphis District
[2] Biologist, U.S. Army Corps of Engineers, Memphis District

alternatives is to be evaluated and compared against existing conditions, simulation of wetness provides a common measure for comparing existing and potential future conditions. Typical project alternatives to consider include existing conditions, future without-project conditions, and multiple project-specific alternatives.

Wetness includes surface water and soil moisture. For projects, surface water extent may be estimated realistically throughout a growing season or project life by referring to historical stream gage records and/or using synthetic records obtained from continuous simulation models. The continuous simulation models may include local rainfall/runoff inflows in addition to the backwater effects from adjacent streams. Although soil moisture may be implicitly reflected in continuous simulation models based on antecedent precipitation index models, or explicitly indicated by soil moisture accounting models, WETSORT only reports statistics for surface water.

Estimation of the absolute extent of wetlands for project alternatives is uncertain by any method. However, if a family of alternatives is modeled using WETSORT, the relative changes in wetland extent present a reliable pattern for decision making. Moreover, the use of data from a multi-year analysis period emphasizes the possible range and variability of wetland elevations.

METHOD

The method used in WETSORT has been published by the USDA National Resources Conservation Service in the *Engineering Field Handbook*, Chapter 19 (1997). WETSORT is simply a utility program to quickly and accurately process many years of water surface elevation data according to the NRCS method. WETSORT is only used to analyze surface water--not shallow groundwater or topsoil moisture.

WETSORT was originally written in the FORTRAN 77 language by the US Army Corps of Engineers, Vicksburg District and run as a command line program in the DOS window of computers operating under Microsoft Windows. A windows version was written later. The WETSORT method is simple enough to apply using an ordinary spreadsheet, although the setup for the running of many alternatives would be tedious.

WETSORT obtains all of its run control input from keyboard and/or mouse entries, but obtains the daily water surface elevation data from a binary file in the Corps HEC-DSS format. The Data Storage System (DSS) is the Corps' water data management software. WETSORT produces an ASCII output file.

Ideally, wetlands are occupied by species of plants that tolerate standing water, or moist soil, or occasional flooding lasting several continuous days during the growing season. Since WETSORT is not applicable to evaluating moist soil or shallow groundwater, the discussion here will focus only on the rise and fall of water surface elevations in a wetland over time.

In a wetland, the general absence of non-water tolerant plant species below a certain elevation is associated with a history of flooding at approximately that elevation during the growing season. The flooding lasts long enough at that elevation to kill non-water tolerant plants. The number of days of flooding sufficient to kill non-water tolerant plants is called the duration. During a single growing season, the highest elevation continuously flooded for the lethal duration is the wetland elevation for that growing season, and also for that calendar year. Of course, over a period of years, the annual wetland elevation varies randomly about some representative elevation.

In Figure 1 below, the dashed water surface elevation represents such a representative wetland elevation. All vegetation rooted below the dashed line is water tolerant. In this figure, the low flow elevation of the stream is somewhat lower than the wetland elevation. Of course, there are degrees of water tolerance among plants, and it is the role of the biologist to identify the marker species for an analysis and the duration to be used in a WETSORT analysis. The vertical bell curve to the right of the figure represents the distribution of annual wetland elevations.

Since flooding varies randomly from year to year, the annual wetland elevation varies randomly also. WETSORT facilitates the identification of a median wetland elevation determined from a multi-year analysis period. The median wetland elevation is considered representative for characterizing the long-term average wetland elevation at a site.

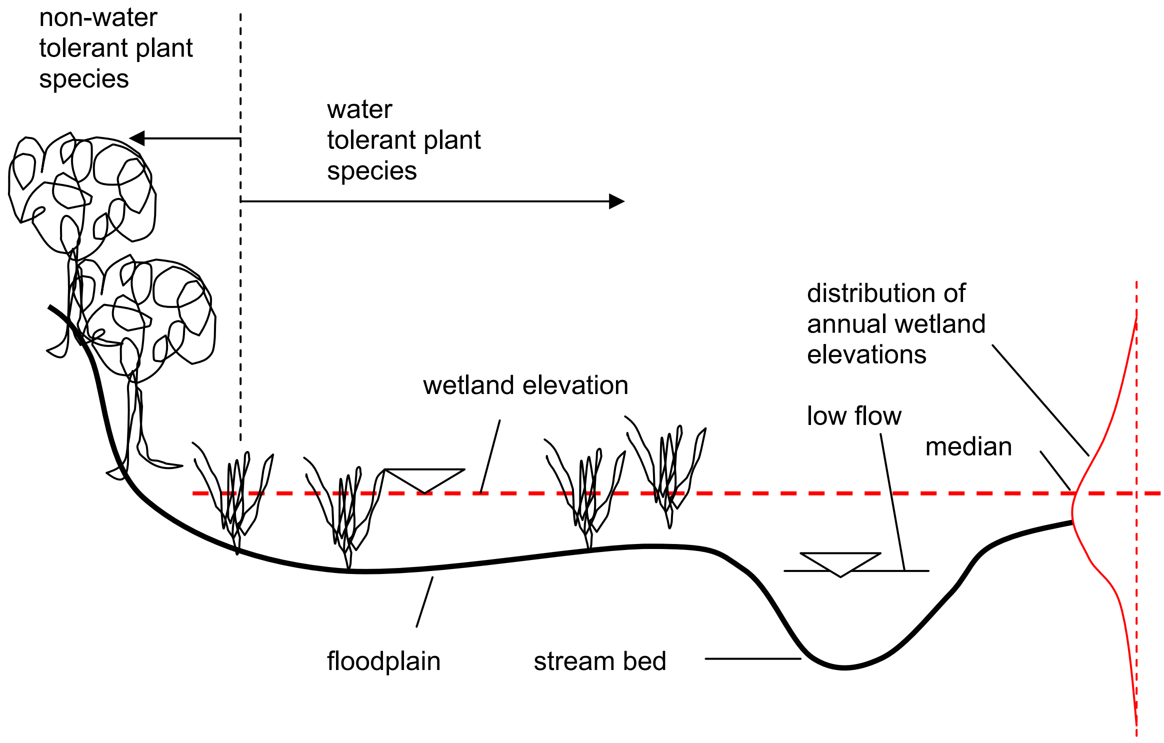

Figure 1. Section of Stream and Floodplain

The growing season is the only part of the year for which WETSORT analyzes water surface elevations. The beginning and ending dates of the growing season must be specified by the user. In Figure 2 the growing season begins on 20MAR and ends on 10NOV (a total of 236 days), and this is the growing season used in the example problem.

In some analyses a flat number of days, such as 15, for example, is specified as the duration--this is how the example problem is set up. However, in some project analyses, percentages of the growing season have been calculated and rounded to the nearest day. For example, percentages of 5 and 12.5 percent have been used in projects, with the intent of bracketing a zone of elevations that may, or may not, be wetlands. Land below the 12.5 percent elevation has been considered definitely a wetland. Land above the 5 percent elevation has been considered definitely not a wetland. The elevation zone between the 5 and 12.5 percent elevations was to be checked to determine if it was a wetland.

If the 5 and 12.5 percent durations had been used in the example problem, the durations would have been 12 and 30 days. For 5 percent of the 236-day growing season, 11.8 days can be rounded to 12 days. For 12.5 percent of the 236-day growing season, 29.5 days can be rounded to 30 days.

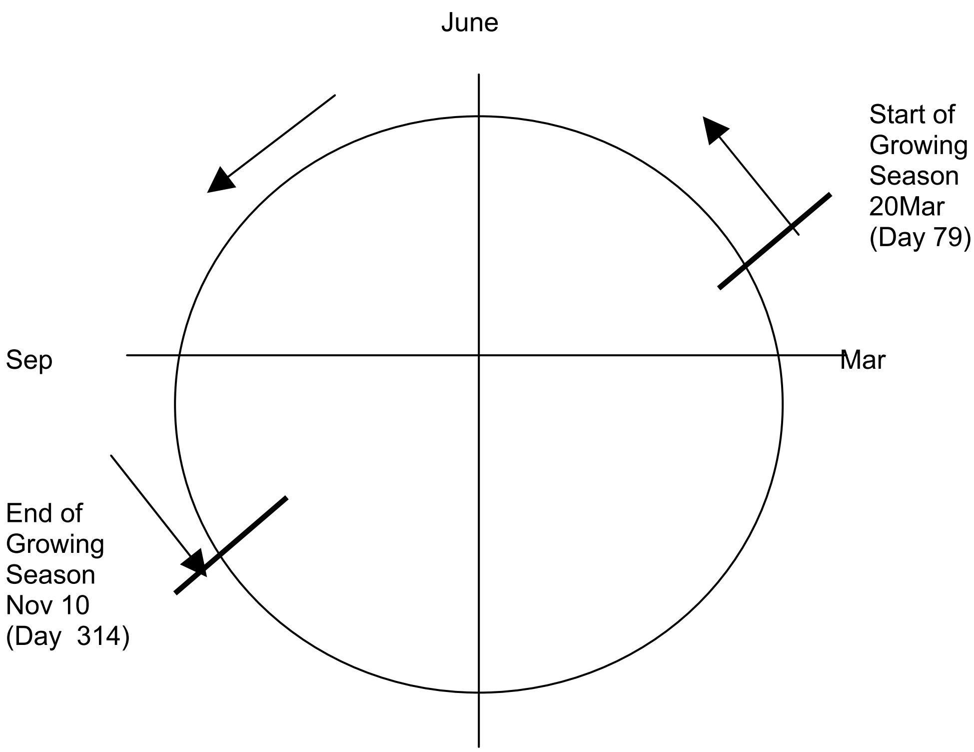

Figure 2. Example Growing Season, 20Mar to 10Nov, Inclusive (236 Days)

Within the growing season of any given year, the duration is stepped through the hydrograph in one-day steps as shown in Figure 3. The single daily stage marked with the red circle is the wetland elevation for the year, because it is the lowest individual elevation within the governing duration.

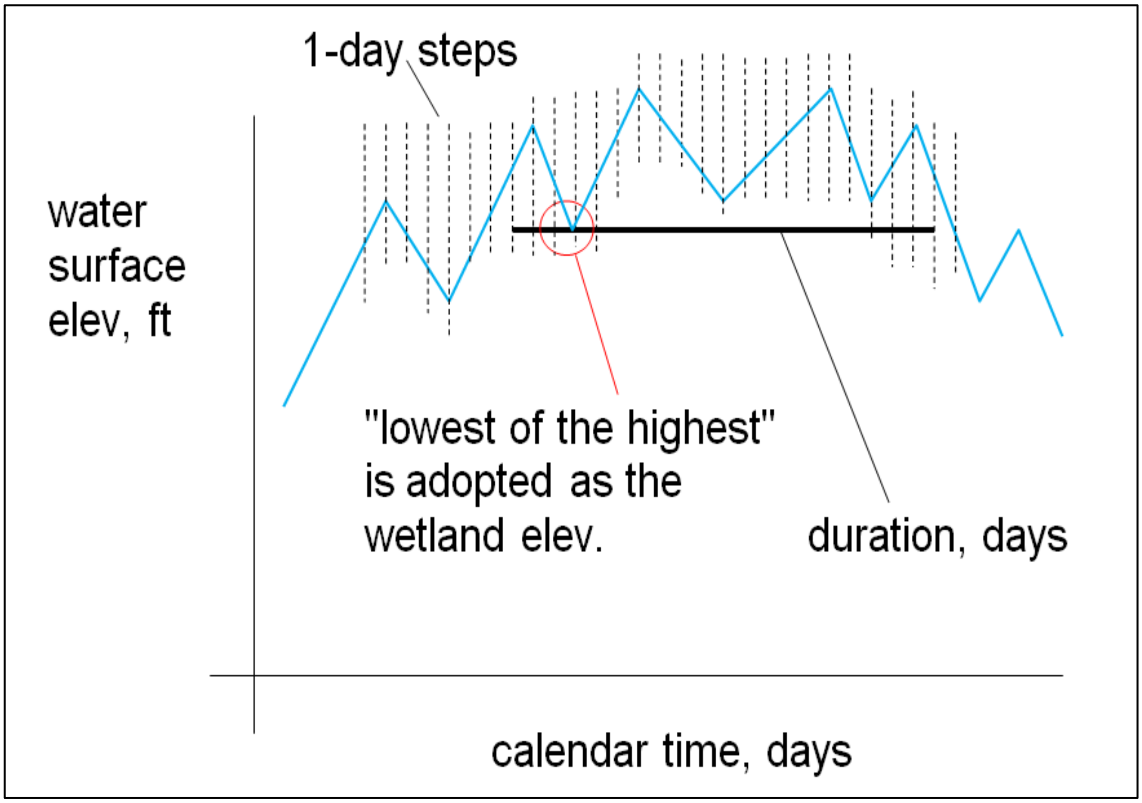

Figure 3. Using Duration to Identify Wetland Elevation for One Year

EXAMPLE PROBLEM

A hypothetical example given below shows the input and output of the WETSORT program. The wetland elevation in this example is 26.55 feet, which is obtained by taking the mean of the ranked elevations listed for the tenth and eleventh years.

<u>Input</u>
Location : Lost Highway bridge on Nowhere River
Analysis period : 1971 - 1990, inclusive
Growing season : 20Mar - 10Nov, inclusive
Duration : 15 days
Gage Zero: 0.0 feet (stages and elevations will print out as if equal)

(Input Continued)
Stage hydrograph of analysis period stored in HEC-DSS (Figure 4):

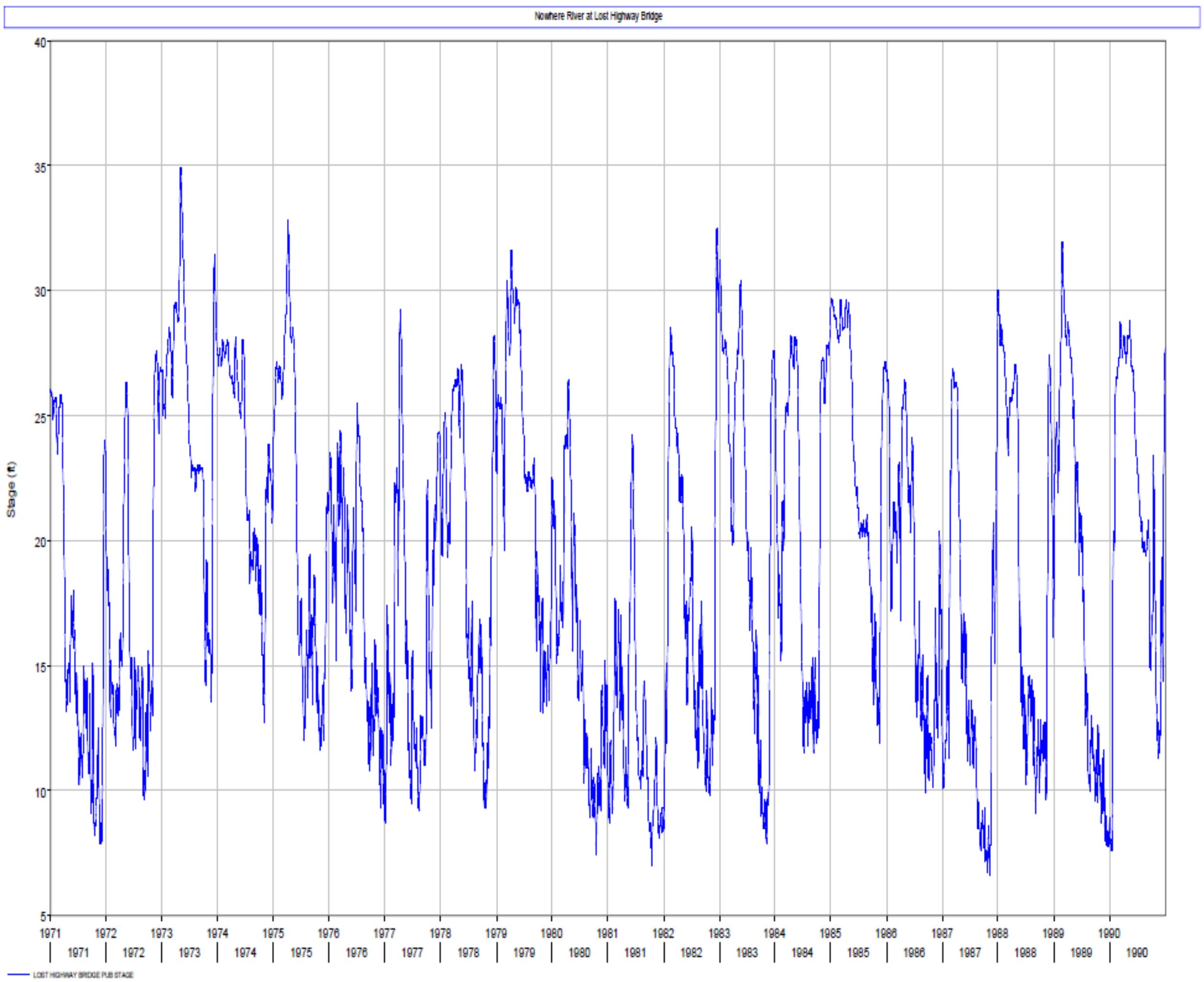

Figure 4. Daily Stage Hydrograph 1971-1990
(Example wetland elev = 26.55 feet plotted as red dashed horizontal line)

<u>Output</u>

WETSORT writes two output tables to an ASCII file. The first table, shown in Exhibit 1, lists annual wetland elevations in chronological order. The input stream, location, growing season dates, and duration are listed at the top of the table. For each year are listed the wetland stage, wetland elevation, and duration starting and ending dates that determine the wetland elevation.

Exhibit 1. WETSORT Annual Output in Chronological Order

```
                    WETEXMPL.OUT

 NOWHERE RIVER
 LOST HIGHWAY BRIDGE

 MONTH/DAY GROWING SEASON BEGINS    3/ 20
 MONTH/DAY GROWING SEASON ENDS   11/ 10
 NUMBER OF DAYS OF FIVE PERCENT DURATION =  15

                         ----STARTING---   -----ENDING----
     STAGE    ELEV     MON   DAY    YR     MON   DAY   YR
    ------   ------    ---   ---   ---     ---   ---  ---
 1   17.70    17.70      3    20  1971       4     3  1971
 2   25.30    25.30      5     6  1972       5    20  1972
 3   32.90    32.90      4    27  1973       5    11  1973
 4   27.00    27.00      6    10  1974       6    24  1974
 5   30.80    30.80      4     1  1975       4    15  1975
 6   24.20    24.20      6    30  1976       7    14  1976
 7   26.60    26.60      4     6  1977       4    20  1977
 8   26.20    26.20      3    31  1978       4    14  1978
 9   29.90    29.90      4     6  1979       4    20  1979
10   24.40    24.40      4    10  1980       4    24  1980
11   22.00    22.00      6     4  1981       6    18  1981
12   23.50    23.50      3    20  1982       4     3  1982
13   29.00    29.00      5    13  1983       5    27  1983
14   27.60    27.60      5     8  1984       5    22  1984
15   28.70    28.70      4     5  1985       4    19  1985
16   25.70    25.70      4    21  1986       5     5  1986
17   26.10    26.10      3    20  1987       4     3  1987
18   26.50    26.50      4    16  1988       4    30  1988
19   28.00    28.00      3    29  1989       4    12  1989
20   28.10    28.10      4    25  1990       5     9  1990
```

The second table, shown in Exhibit 2, repeats the information in the first table, but lists annual wetland elevations in descending elevation order, which facilitates the determination of median elevation. In this example, the mean of the elevations listed on row 10 and 11 is adopted as the median elevation (26.55 feet). Elevation 26.55 feet has been plotted as a horizontal dashed line in Figure 4.

Exhibit 2. WETSORT Annual Output in Elevation Order

```
                         WETEXMPL2.OUT
               -----SORTED TABLE-----

  NOWHERE RIVER
  LOST HIGHWAY BRIDGE

  MONTH/DAY GROWING SEASON BEGINS    3/ 20
  MONTH/DAY GROWING SEASON ENDS   11/ 10
  NUMBER OF DAYS OF FIVE PERCENT DURATION =  15


                          ----STARTING---   -----ENDING----
      STAGE     ELEV    MON    DAY     YR   MON    DAY    YR
     ------   ------    ---    ---    ---   ---    ---   ---
  1   32.90    32.90      4     27   1973     5     11  1973
  2   30.80    30.80      4      1   1975     4     15  1975
  3   29.90    29.90      4      6   1979     4     20  1979
  4   29.00    29.00      5     13   1983     5     27  1983
  5   28.70    28.70      4      5   1985     4     19  1985
  6   28.10    28.10      4     25   1990     5      9  1990
  7   28.00    28.00      3     29   1989     4     12  1989
  8   27.60    27.60      5      8   1984     5     22  1984
  9   27.00    27.00      6     10   1974     6     24  1974
 10   26.60    26.60      4      6   1977     4     20  1977
 11   26.50    26.50      4     16   1988     4     30  1988
 12   26.20    26.20      3     31   1978     4     14  1978
 13   26.10    26.10      3     20   1987     4      3  1987
 14   25.70    25.70      4     21   1986     5      5  1986
 15   25.30    25.30      5      6   1972     5     20  1972
 16   24.40    24.40      4     10   1980     4     24  1980
 17   24.20    24.20      6     30   1976     7     14  1976
 18   23.50    23.50      3     20   1982     4      3  1982
 19   22.00    22.00      6      4   1981     6     18  1981
 20   17.70    17.70      3     20   1971     4      3  1971
```

In Figure 5, the daily elevations are plotted for the year 1971. In addition, the determining 15 day duration of March 20 through April 3, inclusive, is plotted. The 15 day period has the highest continuous elevation within the growing season, while the resultant wetland elevation of 17.7 feet is the lowest elevation of the 15 day period. The value of 17.7 feet marked on the figure is also listed in Exhibits 1 and 2 for the year 1971.

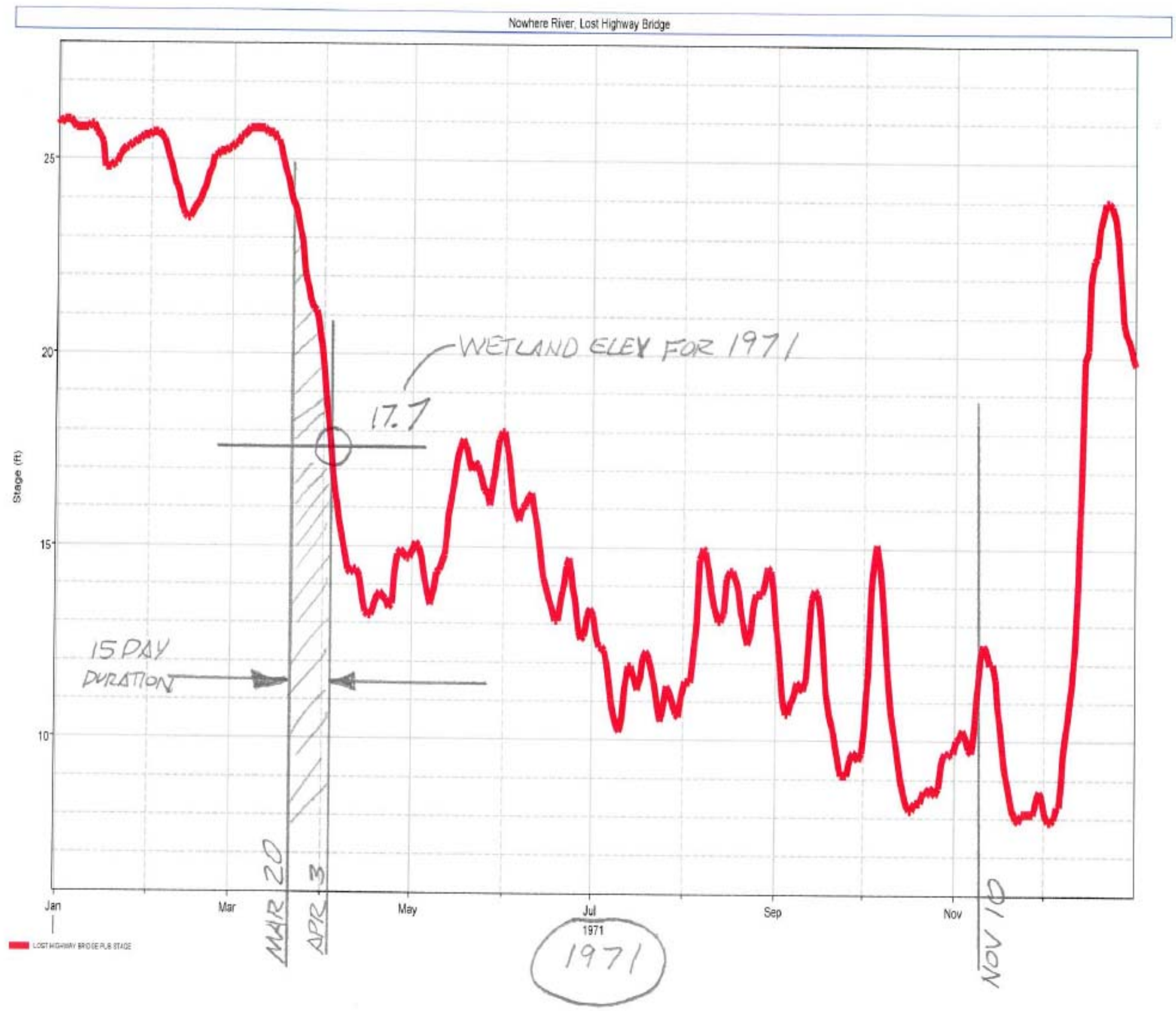

Figure 5. Daily Stage Hydrograph for the Year 1971, Including Identification of the Determining Period and Resultant Wetland Elevation for the Year.

SUMMARY

WETSORT is an implementation of a method described by NRCS to estimate wetland elevation, by analyzing daily surface water elevations throughout the growing seasons of a multi-year analysis period.

The areal extent of potential wetlands can be estimated by plotting the wetland elevation contour on a map of the project area.

Wetland elevation for one year is determined by adopting a multi-day inundation duration and stepping this duration through the growing season in one-day time steps.

The median of ranked annual wetland elevations is adopted as the wetland elevation for the analysis period.

The WETSORT method provides a common basis to compare a wide range of project alternatives.

REFERENCES

US Army Corps of Engineers, Hydrologic Engineering Center, *CPD-79 HEC-DssVue, HEC Data Storage System Visual Utility Engine, Users Manual*, Version 1.2, May, 2005 (Revised Jan, 2006).

US Army Corps of Engineers, Vicksburg District, *WETSORT*, unpublished FORTRAN 77 computer program, circa 1995.

US Department of Agriculture, National Resources Conservation Service, *Part 650 Engineering Field Handbook, Chapter 19, Hydrology Tools for Wetland Determination*, August, 1997.

ESTIMATION OF FISH SPAWNING AND REARING HABITAT BASED ON ANALYSIS OF DAILY STAGES USING THE ENVIROFISH COMPUTER PROGRAM

Barry Bruchman[1], Joshua Koontz[2], and L.Y. Lin[3]

ABSTRACT

Whether a surface water project is primarily intended to increase habitat, or has another primary purpose, such as increasing agricultural production, it may be necessary to estimate fish spawning and rearing habitat for existing conditions and project alternatives. To estimate fish spawning and rearing habitat units for project alternatives, the Memphis District Corps of Engineers uses a model devised by Dr. Jack Killgore of the Corps of Engineers Engineer Research Development Center in Vicksburg, Mississippi and implemented in a computer program named EnviroFish. EnviroFish analyzes daily stages over a period of years to quantify the spawning and rearing habitat in the fluctuating shoreline area of a stream or pool during the spawning season of each year, lists the statistics for each year in the analysis period, and reports the mean of the annual habitat units as the effective habitat measure for the site. Daily elevations may be historical gage data or model output. The habitat quantification is weighted by the vegetative cover of the inundated land. The EnviroFish algorithm is explained and example input and output is presented.

INTRODUCTION

Engineering projects in channels and floodplains can affect the hydroperiod of streams. Some of these projects are intended to change hydroperiod, while for other projects the change is an unintended side-effect. Whether a project affecting surface water is primarily intended to increase habitat, or has another primary purpose, such as increasing agricultural production, it may be necessary to estimate fish spawning or rearing habitat for both existing conditions and project alternatives. The amount of fish spawning or rearing habitat may be estimated for flat pools in floodplains or sloping water surfaces in flowing streams.

The need to estimate the amount of fish spawning or rearing habitat for proposed projects is based on federal and state laws that require determination of how a project affects wetlands in floodplains and to determine the amount of any needed mitigation.

The EnviroFish method of quantifying fish spawning and rearing habitat relies on analysis of multi-year daily water surface elevations within a reproductive season in a project area. If potential project alternatives are to be evaluated and compared against existing conditions, simulation of daily water surface elevations provides a common measure for comparing existing and potential future conditions. Typical project alternatives to consider include existing conditions, future without-project conditions, and multiple project-specific alternatives.

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[1] Hydraulic Engineer, U.S. Army Corps of Engineers, Memphis District
[2] Biologist, U.S. Army Corps of Engineers, Memphis District
[3] Professor of Civil Engineering, Christian Brothers University, Memphis, Tennessee

For projects, surface water elevations may be estimated realistically throughout a reproductive season or project life, by referring to historical stream gage records and/or using synthetic records obtained from continuous simulation models. The continuous simulation models may include local rainfall/runoff inflows in addition to the backwater effects from adjacent streams.

Estimation of the absolute extent of fish reproductive habitat for project alternatives is uncertain by any method. However, if a family of alternatives is modeled using EnviroFish, the relative changes in habitat present a reliable pattern for decision making. Moreover, the use of data from a multi-year analysis period emphasizes the possible range and variability of water surface elevations and associated habitat.

EnviroFish is a Microsoft Windows program written in the Java language. Daily water surface elevations are retrieved from the HEC-DSS database software.

Exhibits presented in this article are taken from the EnviroFish Users Manual.

METHOD

EnviroFish analyzes daily stages over a period of years to quantify the spawning and rearing habitat in the fluctuating shoreline area of a stream or pool during the spawning season of each year. EnviroFish tracks daily water surface elevations throughout a fish spawning or rearing season, lists the statistics for each year in the analysis period, and reports the mean of the annual habitat units as the effective habitat measure for the site.

To build an EnviroFish model to estimate fish spawning or rearing habitat the user needs to:

- select an analysis period of many continuous years

- adopt season, duration, and Habitat Suitability Index values for land use

- determine elevation/area table for each land use on the site

- determine fish species-specific inputs, such as spawning season, durations for spawning or rearing, and limiting maximum or minimum water depths

- determine daily water surface elevations and Average Daily Flooded Area (ADFA)

- determine total Habitat Units for each year

- adopt the mean of the annual Habitat Units as representative of the analysis period.

The EnviroFish method allows the user to set the Habitat Suitability Index (HSI) values for different land uses within the project area. As shown in Exhibit 1, the Users Manual presents sample values for agricultural and fallow land, marsh and bottomland hardwoods, and large and small waterbodies. The natural land uses have a value of unity (1.0), while agricultural land has a value of only 0.2. The user may adopt other values for land uses. However, in the current version, the EnviroFish program does not accept the HSI input. Instead, the program outputs Average Daily Flooded Area for each land use, and the user must post-process the areas to obtain Habitat Units. The spreadsheet shown in Exhibit 11 was used to produce final output for the example problem.

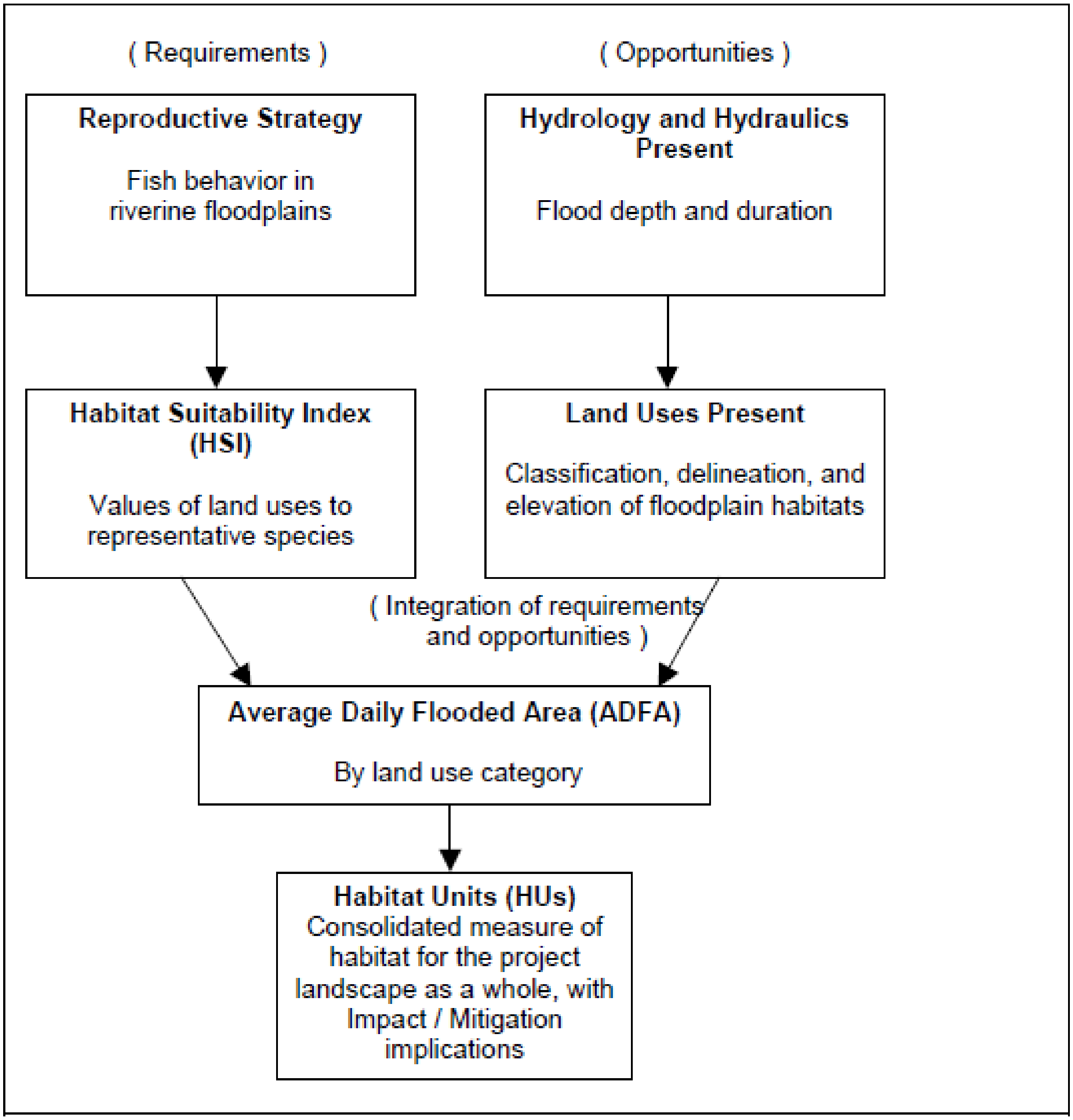
Exhibit 1. Sample Habitat Suitability Index Values

Table 2-1. Habitat Suitability Index (HSI) Values for Spawning and Rearing of Fishes used to Evaluate Riverine Floodplains of the Lower Mississippi River Valley

Land use Category	HSI
Agricultural land	0.2
Fallow	0.5
Herbaceous Marsh	1.0
Bottomland hardwoods	1.0
Large (>1 acre), floodplain waterbodies (e.g., oxbow lakes)	1.0
Small, floodplain waterbodies (e.g. scatters, brakes, sloughs)	1.0

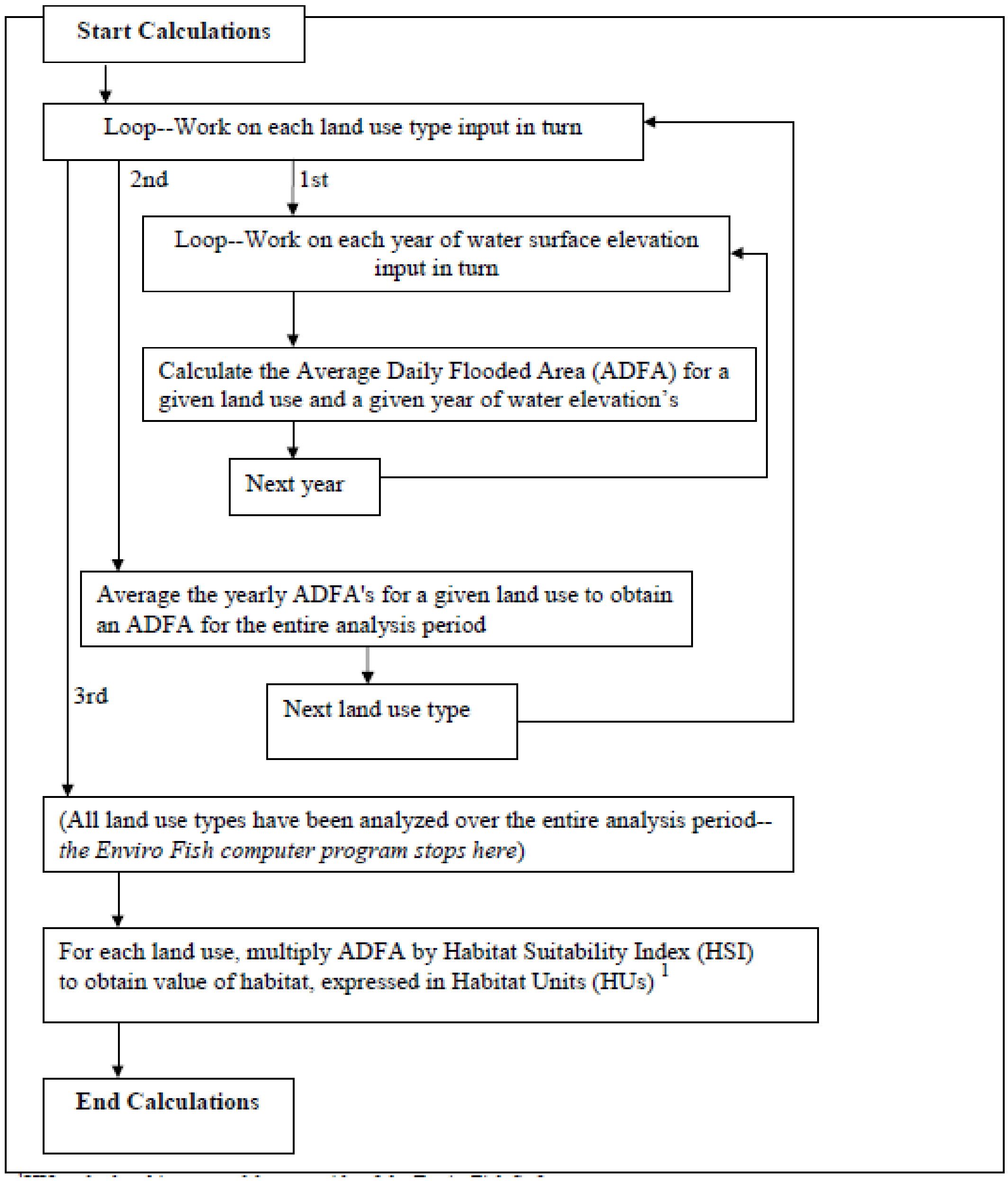
EnviroFish combines biological and hydrologic factors to arrive at an estimate of the total fish reproductive habitat available in the project area. As shown in Exhibit 2, the biological factors of reproductive strategy for fish species and the suitability of land uses are matched with flood depth, duration, and land use to arrive at an average daily flooded area by land use category, and, ultimately, total habitat units for the project area.

Exhibit 2. Flowchart of Habitat Unit Determination



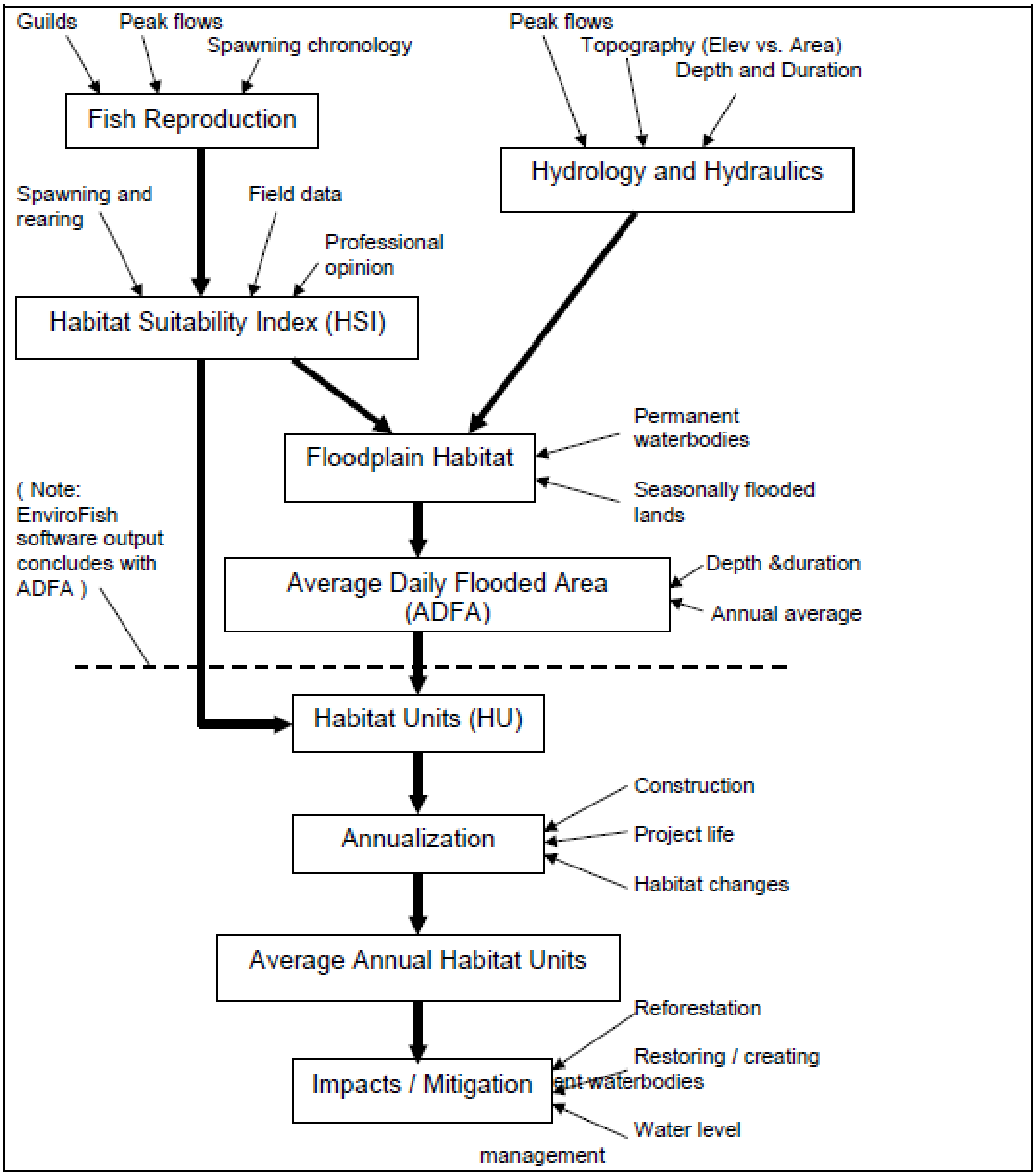
The general concept of EnviroFish gains its modeling power by calculating habitat units for multiple land uses over an analysis period of many years. In addition to the Habitat Suitability Index for each land use, each land use within the project area is described by an elevation versus area table. Therefore the contribution of each land use to total Habitat Units in the project area is estimated for each year, and is reflected in the representative estimate for the analysis period. The calculation cycles required to analyze multiple land uses and years are shown in Exhibit 3.

Exhibit 3. Flowchart of Multi-Landuse and Multi-Year Calculations



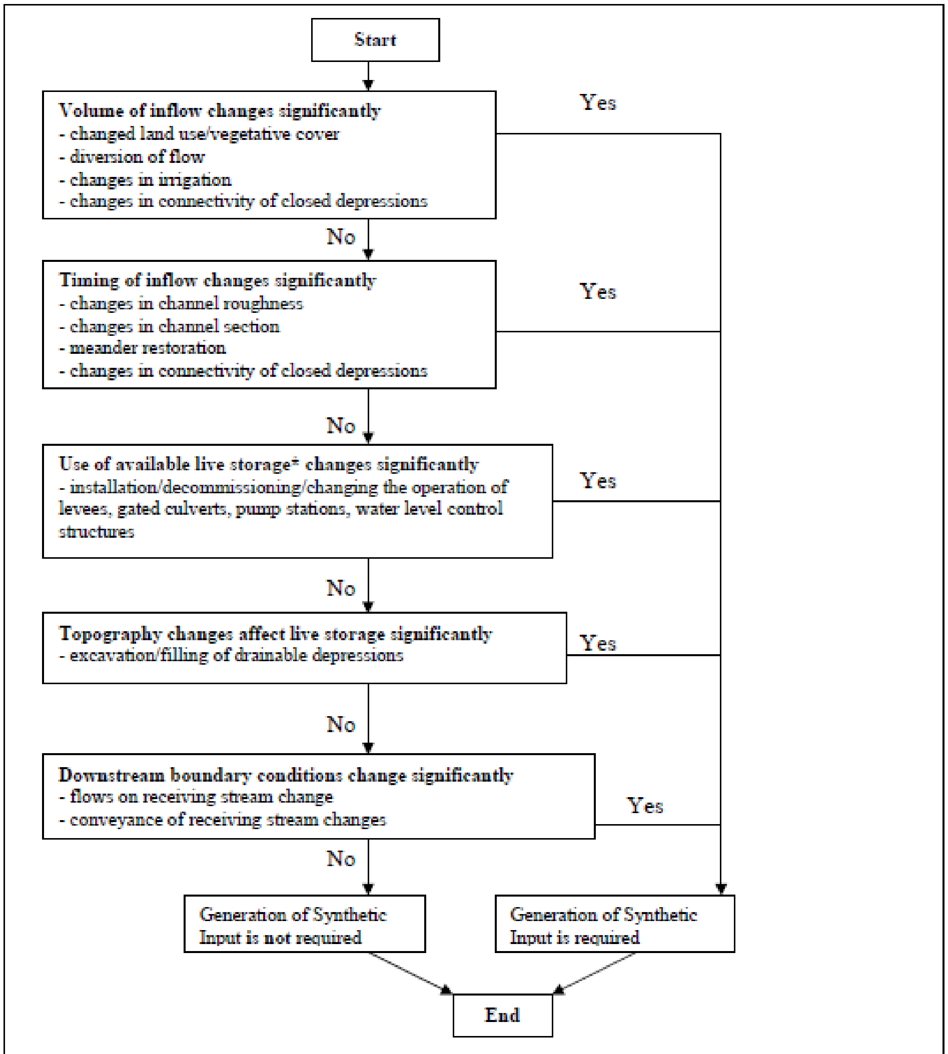
EnviroFish results are used to support judgments about the magnitude of project impacts to fish habitat and the need for mitigation. The factors considered to evaluate habitat and mitigation requirements are shown in Exhibit 4. Just as EnviroFish can estimate project impacts it can also estimate the effectiveness of mitigation areas.

Exhibit 4. Flowchart of Project Impacts and Mitigation



Some projects have the benefit of long and complete stream gage records. However, even projects with extended historical gaging of high quality may require synthetic water surface elevations as input to EnviroFish if future without-project conditions or possible alternatives would change the hydroperiod on the floodplain within the project area. The flowchart shown in Exhibit 5 describes the factors that determine the need to synthetically generate water surface elevations as input to EnviroFish. Those factors are changes in inflow volume, timing of inflow, live storage, topography, and boundary conditions. Typically, synthetic flows from local runoff require continuous rainfall-runoff simulation, based on the land use associated with the alternative. Water surface elevations affected by river backwater, levees, culverts, and pump stations may require use of software such as HEC-HMS, HEC-RAS unsteady, or other programs specifically written to simulate wetland hydroperiod.

Exhibit 5. Flowchart of Determination of Need to Use Synthetic Daily Water Elevations



* The volume of water stored permanently in a depression is *dead storage*, since it does not affect routing–only volumes that can alternately store and release water affect routing computations and are referred to as *live storage*.

Although EnviroFish models both spawning and rearing habitat, for brevity this article focuses primarily on spawning. The modeling of rearing is similar to that of spawning and is described in the Users Manual. EnviroFish typically calculates fish spawning habitat by focusing on a fringe area of a level pool. As shown in Exhibit 6, the fringe area available for spawning is, in general, a ring of submerged shore with user-specified minimum water depth greater than zero and a user-specified maximum depth. As shown in Exhibit 7 and Exhibit 8, eggs deposited within this ring of shore will perish if the water level falls before the eggs hatch.

Exhibit 6. Spawning Depth Constraints

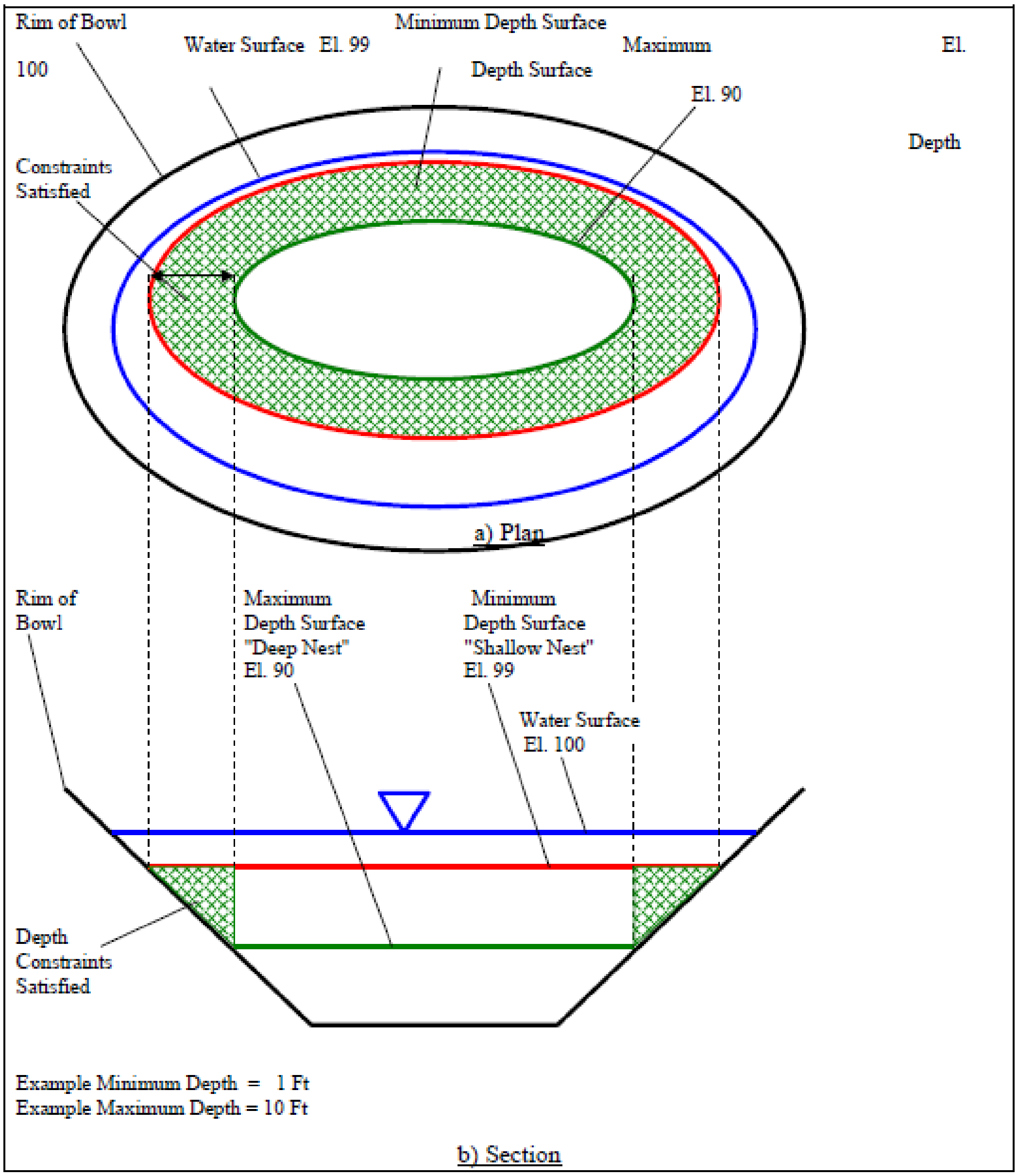
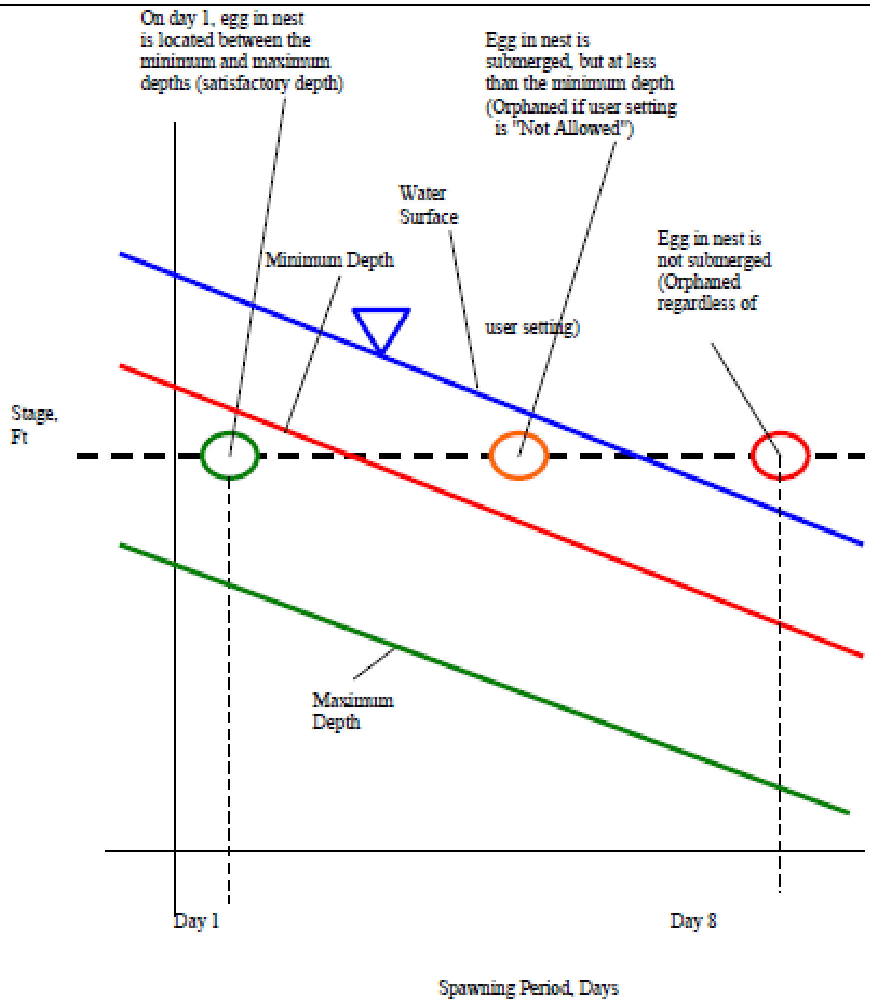


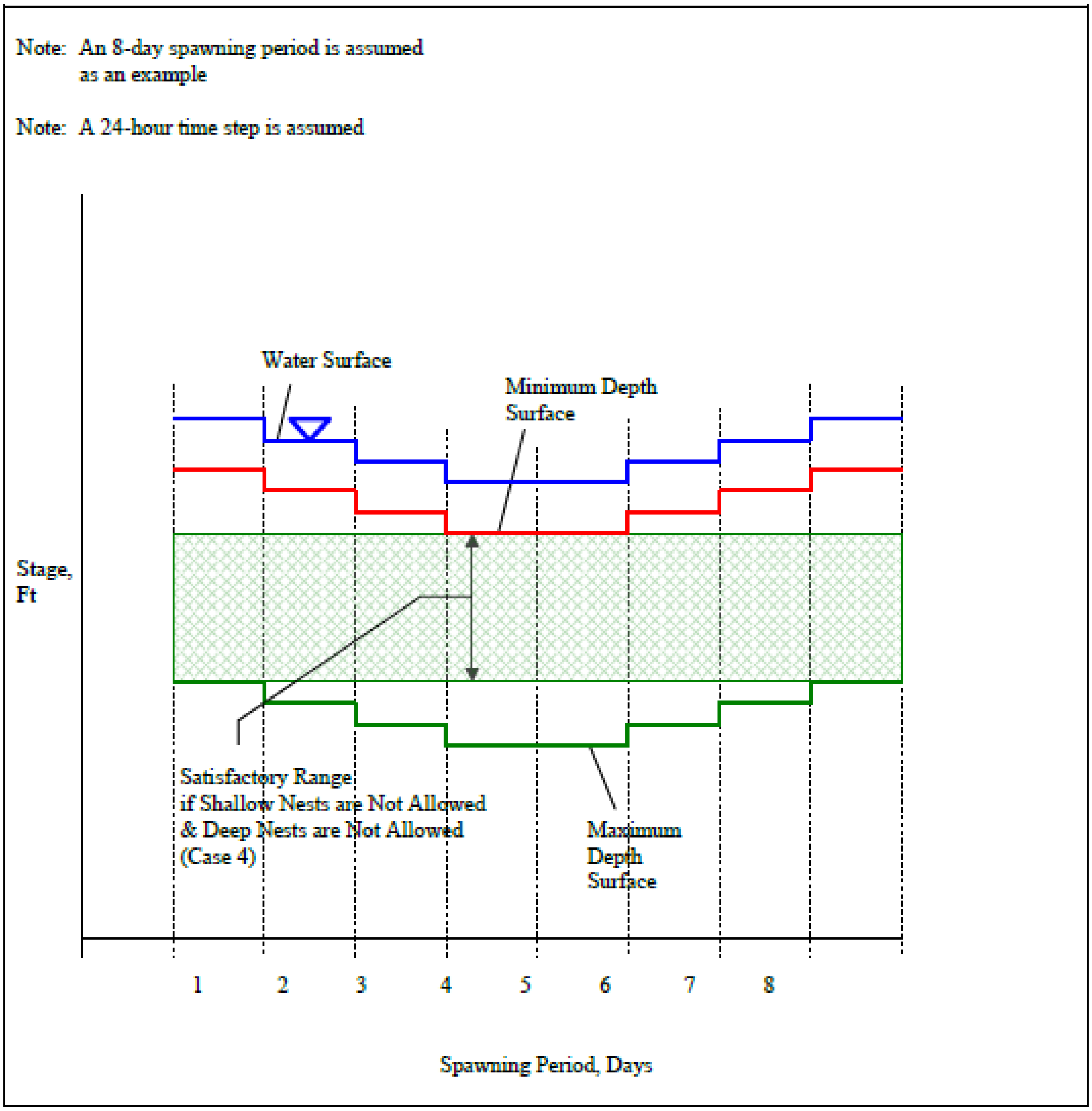
Exhibit 7. Fate of a Fish Egg During Falling Water Levels



Note: An 8-day spawning period is assumed as an example

Note: The stage at which the egg is deposited is constant over time, but the water surface in this example is falling over time.

Exhibit 8. Spawning Depth Constraints through Time



EXAMPLE PROBLEM

This example is presented in full in the EnviroFish Users Manual. For brevity, this article only presents enough material for the reader to get a sense of the results generated by EnviroFish. The 3 year analysis period is much shorter than desirable for a real project, but suffices to show the range of variability possible in calculated habitat units. The essential facts about the example are listed below:

project - flood damage protection for cropland

flooding - river backwater and runoff from project area

analysis period - 3 years (1 dry, 1 average, and 1 wet year)

site location - hypothetical

analysis period daily stream backwater hydrograph - hypothetical

daily local rainfall/runoff inflows - hypothetical

alternative 1 - existing conditions

alternative 2 - levee and gated culvert

alternative 3 - levee, gated culvert, and pump station.

Settings to determine spawning and rearing habitat:

season: 1Mar - 30Jun, inclusive

spawning period: 8 days

spawning depth: 1 ft. min. to 10 ft. max.

restricted rearing : 0.1 ft. min to 11 ft. max.

option to count orphaned areas: no

option to count deep areas: no.

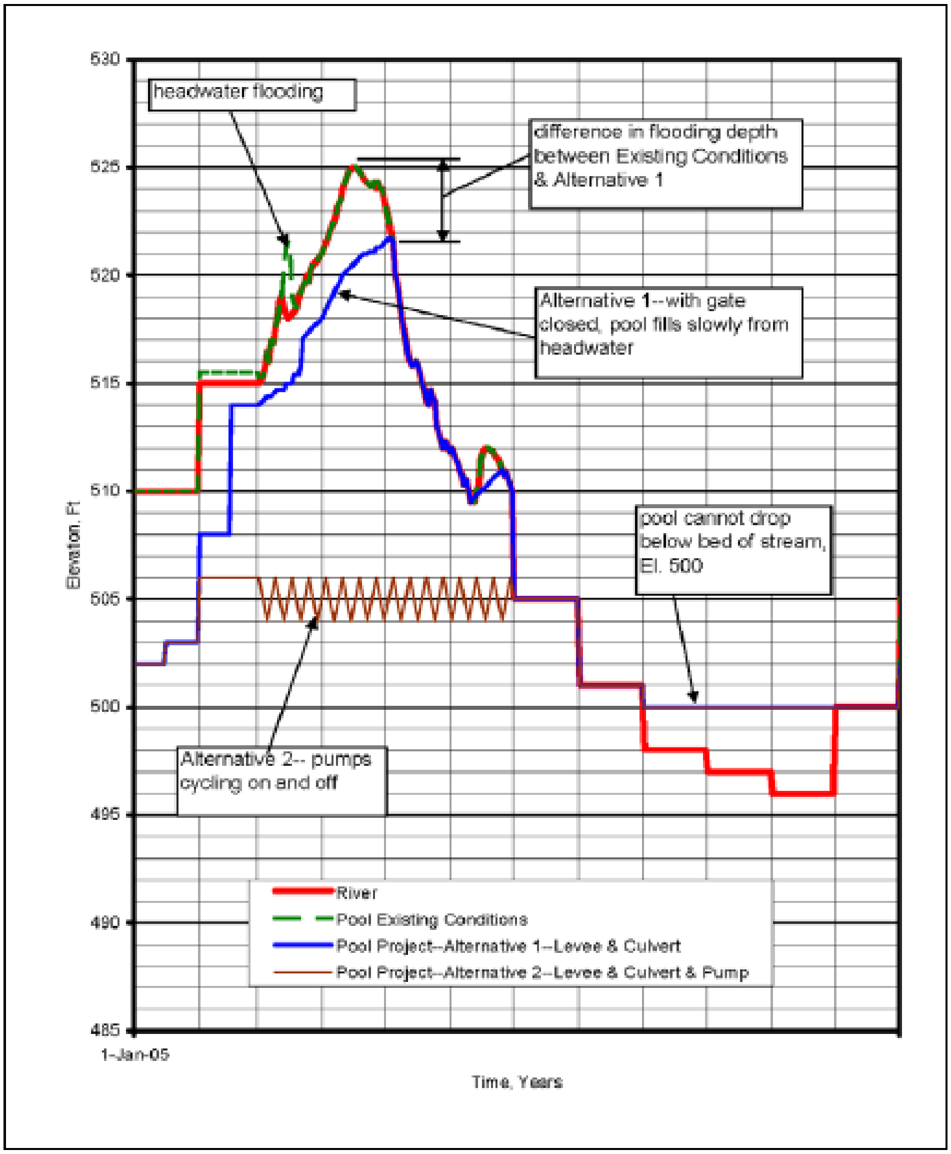
As shown in Exhibit 9, the example problem features five land uses--cypress forest, bottomland hardwood forest, permanent water bodies, stream channel, and cropland. The elevation range that EnviroFish processes is from 500 to 525 feet above seal level. The land use areas are cumulative. These values allow EnviroFish to track the effect of hydroperiod on each land use.

Exhibit 9. Elevation vs. Area for Each Land Use Within Project Area

Elevation Feet	Area					
	Cypress Forest Acre	BLH Forest Acre	Permanent Water Body Acre	Channel Acre	Cropland Acre	Total Acre
500	0	0	0	0.0	0.0	0.0
501	0	0	0	2.5	0.0	2.5
502	0	0	0	5.5	0.0	5.5
503	0	0	0	9.0	0.0	9.0
504	0	0	0	12.9	0.0	12.9
505	0	0	0	17.2	0.0	17.2
506	0	0	0	21.8	54.6	76.4
507	0	0	0	26.4	218.5	244.9
508	0	0	0	31.0	491.7	522.7
509	50	0	0	36.6	823.2	909.8
510	200	0	0	40.2	1165.9	1406.1
511	350	0	0	44.7	1568.5	1963.2
512	400	50	0	49.3	2033.2	2532.5
513	400	200	0	53.9	2460.2	3114.1
514	400	300	0	58.5	2949.4	3707.9
515	400	600	0	63.1	3250.9	4314.0
516	400	800	0	67.7	3664.6	4932.3
517	400	900	0	72.3	4190.5	5562.8
518	400	1000	300	76.9	4428.7	6205.6
519	400	1150	300	81.5	4929.2	6860.7
520	400	1200	300	86.1	5541.8	7527.9
521	400	1200	300	90.6	6216.9	8207.5
522	400	1200	300	95.2	6904.0	8899.2
523	400	1200	300	99.8	7603.4	9603.2
524	400	1200	300	104.4	8315.1	10319.5
525	400	1200	300	109.0	9038.9	11048.0

The annual hydrograph for the wet year in the EnviroFish Users Manual example is presented in Exhibit 10, since it best demonstrates the differences between the three alternatives. The greatest differences between the three alternatives occur in January through June. The Alternative 1 (existing conditions) hydrograph closely follows the river backwater hydrograph. The Alternative 2 (levee and gated culvert) lags the rising river, but closely matches the falling river as the project area drains through the culvert. The Alternative 3 (levee, gated culvert, and pump station) is most independent of the river backwater. The saw-toothed pattern in the Alternative 3 hydrograph is due to the pumps cycling on and off. These differences in hydrographs between alternatives are reflected in the calculations of habitat units by EnviroFish.

Exhibit 10. Comparison of Alternatives in a Wet Year



The results of the EnviroFish run for the example problem are listed in Exhibit 11. In Exhibits 11and 12 the existing conditions alternative is not numbered, the levee and gated culvert are named Alternative 1, and the levee, gated culvert, and pump station are named Alternative 2. Focusing on spawning habitat only, the project area habitat units for existing conditions, Alternative 1, and Alternative 2 are 624.9, 519.4, and 3.2, respectively, which emphasizes how much more impact the pump station alternative has than does the levee and gated culvert only.

The same overall results listed in Exhibit 11 are presented graphically in Exhibit 12. Bear in mind that this example was devised to demonstrate just such a potential difference, and that in practice EnviroFish can be used to guide the operation of flood control projects so that impacts to fish habitat are minimized.

Exhibit 11. Comparison of Habit Units by Alternative and Land Use

Habitat Suitability Indices

Land Use	HSI
cypress	0.9
blh	1.0
water	0.8
channel	0.5
crop	0.2

Spawning Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA acre	HU acre	ADFA acre	HU acre	ADFA acre	HU acre
cypress forest	134.1	120.7	120.4	108.4	0.0	0.0
BLH	192.7	192.7	167.6	167.6	0.0	0.0
permanent water	38.5	30.8	23.2	18.6	0.0	0.0
channel	21.3	10.7	20.0	10.0	6.3	3.2
cropland	1350.2	270.0	1074.4	214.9	0.0	0.0
HU Totals :		624.9		519.4		3.2

Restricted Rearing Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA acre	HU acre	ADFA acre	HU acre	ADFA acre	HU acre
cypress forest	200.1	180.1	178.5	160.7	0.0	0.0
BLH	316.9	316.9	243.9	243.9	0.0	0.0
permanent water	49.8	39.8	35.2	28.2	0.0	0.0
channel	32.2	16.1	28.9	14.5	12.0	6.0
cropland	2069.8	414.0	1576.5	315.3	7.9	1.6
HU Totals :		966.9		762.5		7.6

Total Rearing Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA acre	HU acre	ADFA acre	HU acre	ADFA acre	HU acre
cypress forest	242.9	218.6	194.5	175.1	0.0	0.0
BLH	338.3	338.3	249.5	249.5	0.0	0.0
permanent water	50.1	40.1	36.1	28.9	0.0	0.0
channel	43.5	21.8	36.4	18.2	12.3	6.2
cropland	2370.7	474.1	1704.4	340.9	9.3	1.9
HU Totals :		1092.9		812.5		8.0

Exhibit 12. Comparison of Habit Units by Alternative and Land Use

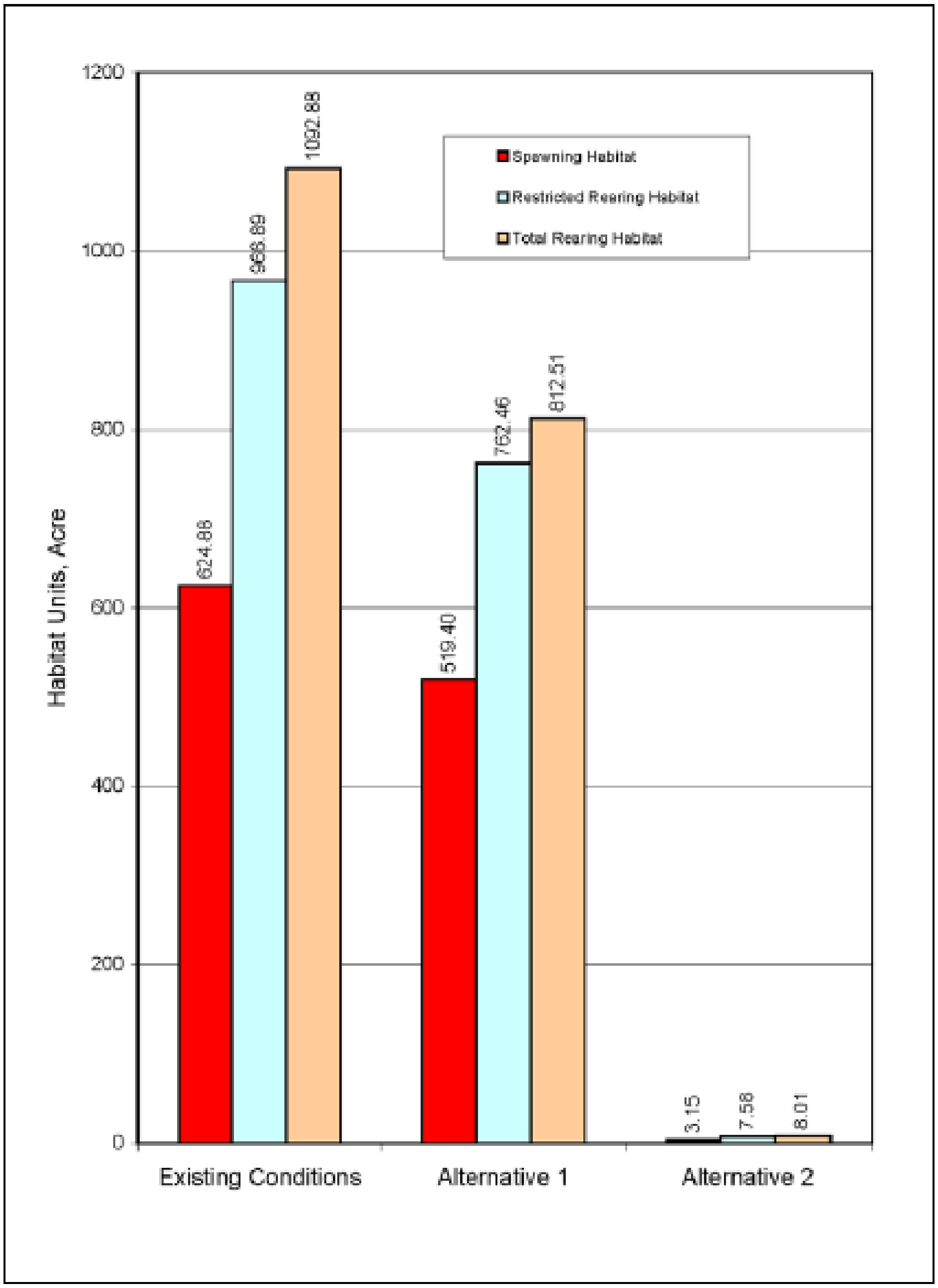


Figure 6-11. Habitat Units for Example Problem Alternatives

SUMMARY

EnviroFish uses topography, daily water surface elevations, and land use value to estimate the fish spawning or rearing habitats in a project area

EnviroFish is a powerful technique for assessing existing conditions and the expected impact of project alternatives on fish reproductive habitat, by examining the effect of varying water surface elevations in the project area over a multi-year analysis period.

REFERENCES

US Army Corps of Engineers, Hydrologic Engineering Center, *CPD-79 HEC-DssVue, HEC Data Storage System Visual Utility Engine, Users Manual*, Version 1.2, May, 2005 (Revised Jan, 2006).

EnviroFish, Version 1.0: User's Manual, Killgore, et al., US Army Corps of Engineers, Engineering Research and Development Center, Vicksburg, Mississippi, 2012.

COMBINED APPLICATION OF WETLAND AND FISH HABITAT ESTIMATION METHODS FOR THE TUNICA LAKE WEIR, TUNICA, MISSISSIPPI

L.Y. Lin[1] and Robert Hunt[2]

ABSTRACT

In 2002 the Memphis District Corps of Engineers installed a riprap weir in the mouth of Tunica Lake to maintain water levels in the lake when the Mississippi River falls below the elevation of the lake outlet. The weir was federally funded under the Section 1135 Environmental Restoration Program, with the State of Mississippi Department of Wildlife, Fisheries, and Parks as the local cost sharing sponsor, to restore the Tunica Lake hydroperiod that existed before man-made cutoffs were installed nearby on the Mississippi River. In recent years the Memphis District has used the WETSORT and EnviroFish computer programs to estimate wetland elevations and fish spawning habitat, respectively. Although these programs were not used in the design of the weir, Tunica Lake is an excellent site to demonstrate the combined use of the WETSORT and EnviroFish computer programs. Therefore a multi-year analysis of the site is presented to illustrate how with- and without-project environmental conditions can be evaluated and compared, as well as how expected environmental performance can be balanced with design constraints.

INTRODUCTION

The WETSORT and EnviroFish computer programs are described in two conference articles accompanying this article. This article illustrates the use of WETSORT and EnviroFish on a site in the Mississippi River floodplain between the main line Arkansas and Mississippi levees.

Shown in Figure 1, Tunica Lake is located about 35 miles south of Memphis, Tennessee and 4 miles west of the city of Tunica, Mississippi. Tunica Lake is the former channel of the Mississippi River prior to the construction of a cutoff by the Corps of Engineers. The lowering of the river channel as a result of the cutoff made Tunica Lake eligible for a Section 1135 environmental restoration project. The red rectangle in Figure 1 is the location of the project weir, which has a footprint of less than 10 acres.

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[2] Hydraulic Engineer, US Army Corps of Engineers, Memphis District

Figure 1. Aerial Photo of Tunica Lake (source Google Earth)

A section through the crest of the installed weir is shown in Figure 2. During a falling river, the broad weir notch helps pull lake levels down quickly to avoid damages to lakeside property, while the narrower notch allows the pool to fall more slowly down to its normal elevation of 159 feet above sea level. Figure 3 is a profile of the riprap weir showing an overall length of 340 feet

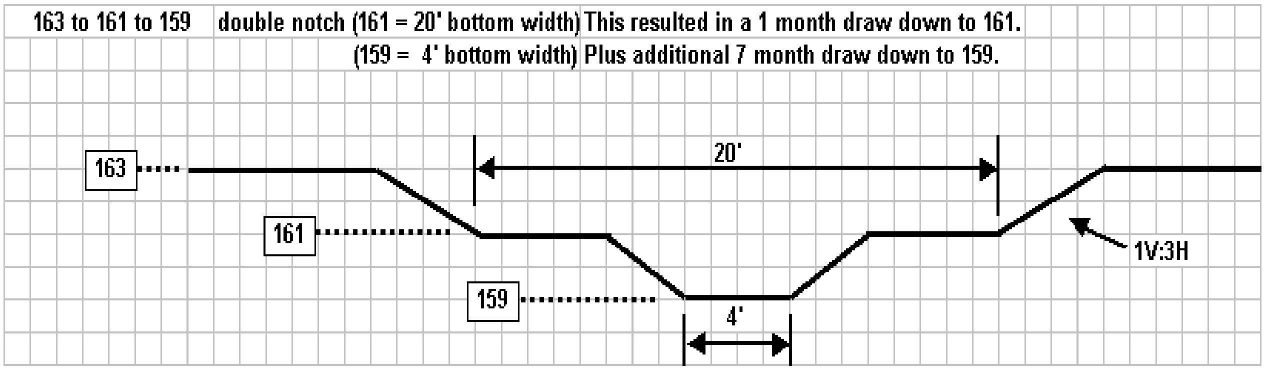

Figure 2. Section Through Crest of Riprap Weir

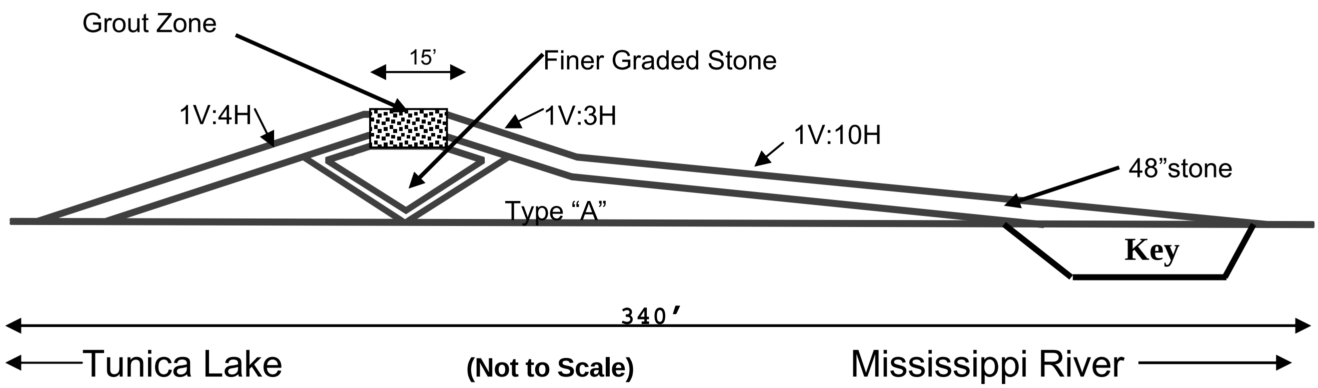

Figure 3. Profile Centerline of Riprap Weir

Figure 4 shows water flowing through Tunica Weir. The flow in the center of the photo is shallow because it is flowing over the broad crest at elevation 161 feet. The flow at the extreme left of the photograph is flowing through the narrow center notch having a crest elevation of 159 feet above sea level. Flow not only leaves Tunica Lake by flowing over the weir, but also flows in the reverse direction from the Mississippi River to the lake when the river is higher than the lake. This allows the sediment and nutrients in the river to enter the lake to support plant and animal life there.

Figure 4. Photograph of Installed Tunica Weir

METHOD

The mouth of Tunica Lake is at mile 677.5 on the Mississippi River, while the location of the closest Mississippi River gage, Helena, is at river mile 663.3, for a distance of 14.2 miles. The approximate typical water surface slope between Helena and Tunica Lake is 0.5 feet per mile. Therefore, the daily water surface elevation of the Mississippi River at the mouth of Tunica Lake was estimated by adding a constant value of 7.0 feet to the water surface elevation at Helena. The Mississippi River hydrograph at the mouth of Tunica Lake is shown in Figure 5. Due to the very high elevations attained by the Mississippi River with respect to the natural ground elevation around Tunica Lake, the river dominates the hydroperiod of Tunica Lake and the land around it.

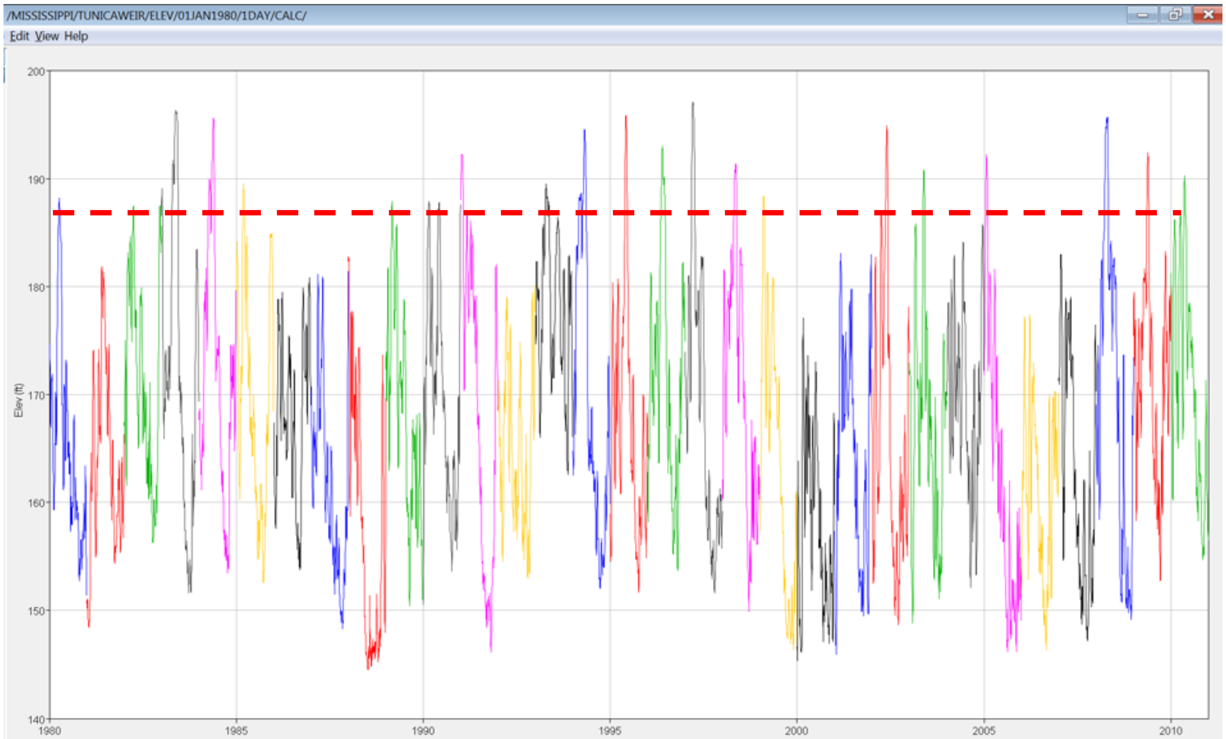

Figure 5. 1980-2010 Hydrograph of Mississippi River at the Mouth of Tunica Lake
(red dashed line is the WETSORT wetland elevation of 186.8 feet)

The natural ground around Tunica Lake is the low, flat land of the Mississippi River floodplain. Figure 6, shows LIDAR mapping of the area that drains into the Lake, and for this analysis the lake and drainage area around it have been modeled as the project area. Within the project area there are only two land uses--permanent water body and bottomland hardwood forest, for a total area of 26,700 acres. Table 1 lists elevation versus area for both land uses. Areas for elevations above 160 feet were obtained from LIDAR, but areas at lower elevations were estimated.

Figure 6. LIDAR Topography of the Floodplain Draining Into Tunica Lake

Table 1. Elevation versus Area of Tunica Lake and Drainage Area by Land Use

Elev Ft	Lake Area Acre	Woods Area Acre	Total Area Acre
140	0	0	0
142	50	0	50
144	200	0	200
146	400	0	400
148	700	0	700
150	1100	0	1100
152	1500	0	1500
154	2000	0	2000
156	2500	0	2500
158	3000	0	3000
160	3500	0	3500
162	3500	500	4000
164	3500	1100	4600
166	3500	1500	5000
168	3500	1900	5400
170	3500	2366	5866
172	3500	3218	6718
174	3500	3997	7497
176	3500	5082	8582
178	3500	6229	9729
180	3500	7483	10983
182	3500	8913	12413
184	3500	10484	13984
186	3500	12225	15725
188	3500	14133	17633
190	3500	16519	20019
192	3500	18838	22338
194	3500	20752	24252
196	3500	21890	25390
198	3500	22549	26049
200	3500	22897	26397
202	3500	23056	26556
204	3500	23141	26641
206	3500	23175	26675
208	3500	23194	26694
210	3500	23204	26704
212	3500	23200	26700
214	3500	23200	26700

Continuous simulation of daily rainfall/runoff was performed to model inflows to Tunica Lake from its surrounding drainage area of bottomland hardwood forest. The local inflow allows the lake level to be higher than the weir crest when the Mississippi River is low. As shown in Figure 7, the weir has a negligible effect on lake levels above 170 feet above sea level and typically affects lake levels only below elevation 165 feet. This performance protects the lake itself without affecting properties that surround the lake. Weir crest elevations of 157, 159, and 161 provide significant boost to lake levels compared to the conditions existing when the weir was installed. Lake levels under future without-project conditions are so low they are almost identical with the Mississippi River water levels.

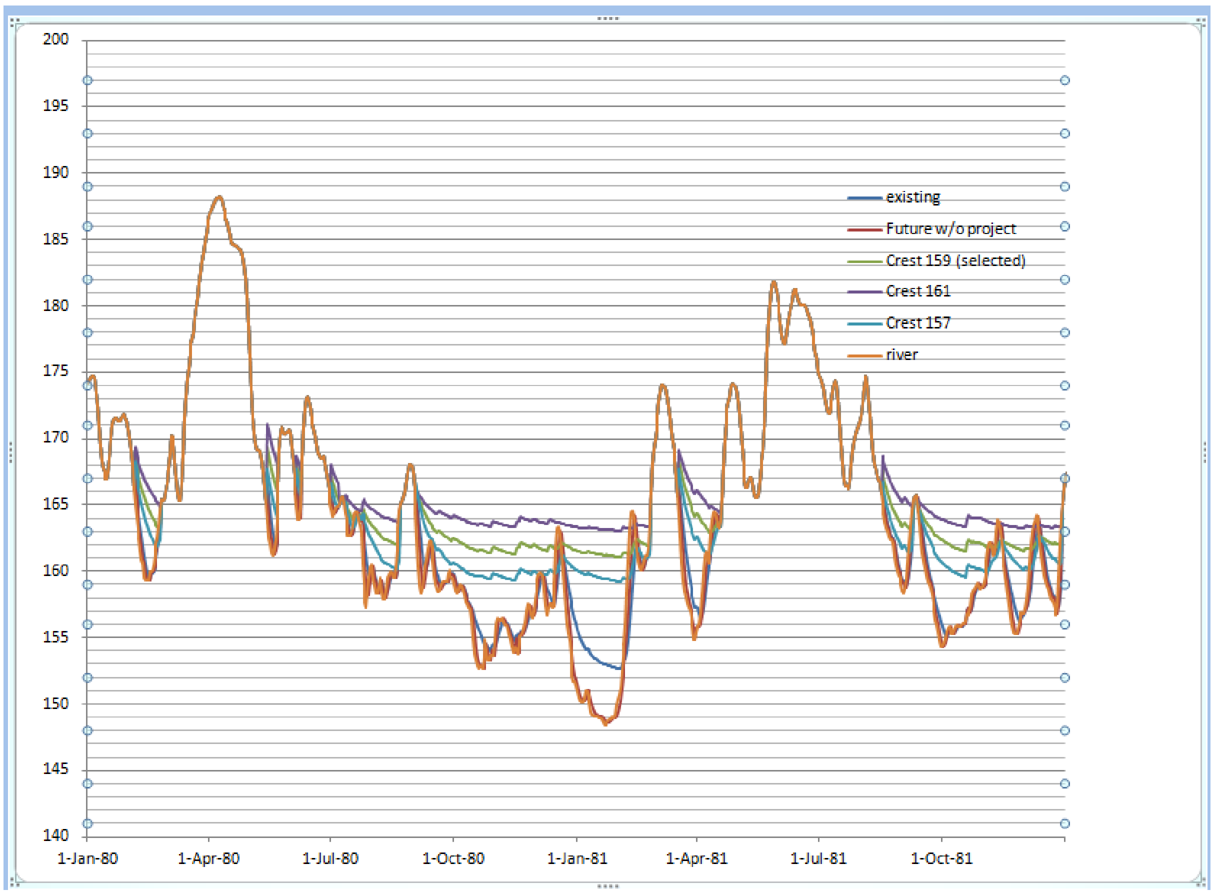

Figure 7. Example Hydrographs for Alternatives, 1980-1981

RESULTS

The results of the WETSORT and EnviroFish analyses are listed in Table 2. The wetland elevation calculated by WETSORT is 186.8 feet regardless of the alternative. This is due to the very high annual Mississippi River water surface elevations, which dominate the hydroperiod of Tunica Lake in the Spring. The EnviroFish estimates of total Habitat Units do vary with alternative, but not greatly. Since the permanent water bodies and bottomland hardwood forests were both weighted with a Habitat Suitability Index of 1.0, the total Habitat Units are simply the sum of the Average Daily Flooded Areas for the two land uses.

What these results mean is that the restoration of Tunica Lake is successful primarily as a year-round volume of water for fish habitat throughout the year, rather than as a major change in the hydrology of the bottomland hardwood habitat or a major addition to fish spawning habitat. As shown in Table 3, the selected weir provides for a normal pool of 3250 acres and 47,000 acre-feet, compared to the future without-project values of only 400 acres and 11,000 acre-feet.

For other projects involving flood control for cropland the differences in wetland elevation and fish reproductive habitat could be significant.

Table 2. WETSORT and EnviroFish Spawning Habitat Results

Alternative	WETSORT Wetland Elev Feet	EnviroFish ADFA Permanent Water Body Acre	EnviroFish ADFA Bottomland Hardwood Forest Acre	EnviroFish Total Habitat Units
existing conditions	186.8	3376	4100	7476
future w/o project	186.8	3328	4089	7417
weir crest 157	186.8	3488	4169	7657
weir crest 159(selected)	186.8	3500	4237	7737
weir crest 161	186.8	3500	4324	7824

Table 3. Tunica Lake Normal Pool Elevation, Area, and Volume with Respect to Alternative

Alternative	Normal Pool Elev Feet	Normal Pool Area Acre	Normal Pool Volume Ac-Ft
existing conditions	152	1500	24000
future w/o project	146	400	11000
weir crest 157	157	2750	39000
weir crest 159(selected)	159	3250	47000
weir crest 161	161	3750	54000

SUMMARY

The Section 1135 Environmental Restoration project installed on Tunica Lake primarily provides a year-round volume of water for fish habitat, but does not affect wetland elevations in the surrounding bottomland hardwood forest, and does not greatly increase fish spawning habitat.

The WETSORT and EnviroFish computer programs facilitate comparisons between alternatives and show the sensitivity of habitat to changes in hydroperiod.

REFERENCES

US Army Corps of Engineers, Hydrologic Engineering Center, *CPD-79 HEC-DssVue, HEC Data Storage System Visual Utility Engine, Users Manual*, Version 1.2, May, 2005 (Revised Jan, 2006).

US Army Corps of Engineers, Vicksburg District, *WETSORT*, unpublished FORTRAN 77 computer program, circa 1995.

EnviroFish, Version 1.0: User's Manual, Killgore, et al., US Army Corps of Engineers, Engineering Research and Development Center, Vicksburg, Mississippi, 2012.

THE BEAVER CREEK WATERSHED RESTORATION INITIATIVE: 2008-2012

Roy A. Arthur[1]* and Ruth Anne Hanahan[2]

INTRODUCTION

The 86 square miles of the Beaver Creek Watershed, located in north Knox County, Tennessee, has been the focal point of the Beaver Creek Task Force (BCTF) partnership for the past 15 years. The entire 44 miles of Beaver Creek and many of its tributaries are on the state's 303(d) list. The primary pollutants are sediment and pathogens. With over 80,000 people living in the watershed addressing these two pollutants has been a challenge to the BCTF. After 10 years of assessment and planning the BCTF received a $919,000 grant in 2008 based on the *Beaver Creek Watershed Restoration Plan,* primarily to address sediment. Using the results of two different models used to prepare the watershed plan, the Task Force developed a four pronged approach to begin restoring Beaver Creek to its intended uses:

- A comprehensive community engagement program
- An agricultural BMP program
- A streambank rehabilitation program in urban areas
- A retrofit program for residential communities

APPROACH

Since its inception the BCTF has operated with a Communication Plan with three main components; watershed awareness, education and involvement. This approach was used for all three restoration components and focused on developing public/private partnerships. The primary BCTF partners participating in projects were Knox County Stormwater Management, the Knox County Soil Conservation District, the Tennessee Water Resources Research Center (TN WRRC), the University of Tennessee, and Hallsdale Powell Utility District. Different partners took the lead on projects allowing the Task Force to focus on multiple projects concurrently.

<u>Agricultural BMP Program</u>: The Ag BMP program was conducted by the Knox County Soil Conservation District (SCD). The BCTF created a brochure for the SCD and a letter announcing the availability of funding for Ag BMPs and touting the economic benefits of installing BMPs on farms. The letter and brochure were sent to all agricultural landowners in the watershed. It was followed by two farm tours, three SCD banquets, and two Farmer's Breakfasts. The Farmer's Breakfasts drew close to 200 participants and resulted in the bulk of projects implemented. I addition all farmers who installed BMPs were given a 4' X 4' "Beaver Creek Conservation Farm" sign to install on their properties.

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Streambank Rehabilitation Program: The Streambank Rehabilitation Program for Urban Areas began with a project in a public park led by UT's Department of Civil and Environmental Engineering was designed to re-create pool/riffle/run sequences in a low gradient, channelized portion of Beaver Creek in the upper third of the watershed. Several newspaper articles about this project led to a 1,400 foot streambank rehabilitation project in the upper portion of Beaver Creek in a subdivision where residents were losing backyards to streambank failure. Led by the Knox County Stormwater Management Division a total of 10 contiguous landowners signed agreements with the County to let the Task Force repair the streambank. An additional 1,000 feet of streambank and the re-connection of a wetland isolated from the creek are planned as funding becomes available.

Retrofit Program: Results from modeling conducted for the watershed plan showed a 20% reduction in sediment input from residential properties was needed to achieve our goal of de-listing Beaver Creek from the 303(d) list. The retrofit program focused on rain gardens, rain barrels, downspout disconnections, bio-retention, and turning eroded ditch lines into grass swales. Three demonstration rain gardens were installed on public property to serve as demonstration sites. Outreach to a Homeowners Association in a subdivision with down slope flooding problems due to inadequate stormwater infrastructure resulted in the installation of 7 rain gardens and several disconnects. A number of rain barrels are scheduled to be installed in the same sub-division this spring. Additionally a bio-retention facility designed to capture and infiltrate a 2.5' storm event has been designed and will be constructed as soon as funding becomes available. UT Extension leads the monitoring effort with TN WRRC providing project management.

RESULTS

Agricultural BMP Program: The Ag program resulted in BMPs installed on 20 properties and included among other practices:

- The installation of over 20 alternative watering systems with Heavy Use Area Protection
- Over 6,000' of exclusion fencing
- 14,500' of cross fencing for rotational grazing
- 15,000 square feet of access road

Streambank Rehabilitation in Urban Areas: The streambank program resulted in:

- 3,000' of streambank repaired
- Another 1,000' planned

Retrofit Program for Residential Communities: Results for the retrofit program are as follows:

- 20 rain gardens
- 2,000 feet of eroded ditch line turned into grass swales
- A planned large bio-retention area in a subdivision

After five years of implementation in the four project areas and ramped up enforcement of the Knox County Stormwater Ordinance by Knox County Stormwater Management, progress in restoring Beaver Creek has been observed. Benthic sampling conducted by Knox County Stormwater in the summer of 2012 at the 11 TDEC monitoring sites on the creek showed 7 of the sites meeting or exceeding TDEC's bio-criteria standard. Additional monitoring for bacteria showed a significant decrease in *E. coli* counts across the watershed. The decrease led to the de-listing of Cox Creek, a Beaver Creek tributary, from the state's 303(d) list.

LESSONS LEARNED

Engaging your community in an effective public/ private partnership to improve water quality can be a daunting but rewarding task. The BCTF has developed a multi-prong approach, engaging youth and adults in a range of projects that hold value on an individual and community-wide level, above and beyond improving the health of our waterways. Over time, these projects have raised awareness of the importance of water quality, instilled pride in those who have been involved, and have led private landowners to seek out public agencies to implement BMPs on their property. There is no magic wand for cleaning up our waterways; what we have learned is threefold:

- The initiative must involve a dedicated group of public and private entities that recognize this will be a long-term effort while also acknowledging the fluidity of the partnership (e.g., Project leadership and partner involvement will fluctuate based on the projects, at hand.);
- Community engagement projects need to hold meaning to those involved beyond the improvement of water quality.
- The community is comprised of multiple audiences with varying motivators and inhibitors that need to be first identified and then accounted for in project planning and implementation.

RESTORING POOL-RIFFLE STRUCTURE IN BEAVER CREEK, KNOX COUNTY USING A HYDRAULIC MODELING APPROACH FOR URBAN STREAMS

John S. Schwartz[1] and Keil J. Neff[2]

Urban and urbanizing streams are impacted by altered watershed runoff hydrology and sediment yields, floodplain modifications, and constrained channel planform from land development. One morphological response to these urbanization impacts is the degradation of pool-riffle sequences. Pool-riffle sequences are fundamental habitat units where many lotic biota have evolved to occupy preferentially. Restoring self-maintaining pool-riffle sequences is essential to the ecological rehabilitation of urban streams when lost. If an urban stream has been straightened from past development, and current infrastructure prevents re-meandering of the channel, restoring pool-riffle structure can be problematic. The goal of this project was to develop a restoration conceptual design through experimental modeling where in-stream hydraulics provides self-maintaining pools and riffles. FLOW-3D®, a three-dimensional CFD model was used to evaluate hydraulic characteristics on Beaver Creek, Knox County, Tennessee. Beaver Creek was a straight urban stream with degraded pool-riffle sequences. Applying geomorphological theory, FLOW-3D® was used to model velocity vector and turbulence patterns in order to assess conceptual restoration design. A final construction design was completed with River2D®, a two dimensional hydrodynamic model that contains an aquatic habitat module. Construction of four pool-riffle sequences was completed in 2012. Hydraulic model development and design concepts applied, a description of project construction, and geomorphic monitoring since construction will be presented.

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[2] Senior Project Engineer, Geosyntec, Knoxville, Tennessee; Assistant Research Professor, University of Tennessee, Department of Civil and Environmental Engineering, 214 Perkins Hall, Knoxville, TN 37996; kneff1@utk.edu

GREEN INFRASTRUCTURE CONCEPTUAL PLANNING AND POLICY DEVELOPMENT USING EPA'S *SUSTAIN* MODEL

Joe Parker[1], Jean Wodarek[2], and Roy Arthur[3]

Knox County is characteristic of many regulated Municipal Separate Storm Sewer Systems (MS4s) in Tennessee; County stormwater management staff struggle to maintain high water quality with limited resources allocated for this purpose. Prioritizing and implementing water quality protection measures can be challenging, especially for areas that were developed at a time when design standards did not have a water quality component.

In early, 2012, Knox County received a 604(b) grant from the USEPA to examine the use of green infrastructure as retrofit solutions to water quality issues with the support of the EPA's *SYSTEM for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model*. *SUSTAIN* was used to assist in the selection and placement of green infrastructure BMPs to achieve stormwater runoff volume and/or water quality targets.

Knox County used the *SUSTAIN* model to develop conceptual Green Infrastructure retrofit plans for two existing developments located within the Beaver Creek Watershed; an aging "big box" commercial retail site; and a 1960's era large subdivision. These locations were chosen to examine potential improvements in runoff water quality and effectiveness in reduction of runoff volume and peak rates. Conceptual plans were developed for each site incorporating a number of potential BMPs with a variety of configurations. The BMPs physical characteristics and arrangements were optimized for effectiveness and cost to meet study objectives.

Knox County will use the findings to support the development of Green Infrastructure policies and design standards that will meet the Runoff Reduction requirements of Tennessee's NPDES Phase II MS4 permit.

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SESSION 1C

ECOLOGY/BIOLOGY
1:30 p.m. – 3:00 p.m.

Watershed-Scale Evaluation of Riparian Vegetation Impacts on Water Quality
Henrique Momm, Ronald L. Bingner, and Yongping Yuan

Hydrology and Soil Microbiology of Cedar Glade Ecosystems
Jennifer M. Cartwright

Structure of Diatom Assemblages and Primary Production in the Nutrient-Impaired Waters of the Red River Watershed in North-Central Tennessee
Jefferson G. Lebkuecher, Stacy M. Rainey, Chelsea B. Williams, and Alex J. Hall

RESERVOIR
3:30 p.m. – 5:00 p.m.

Improving Hydrologic Decision Making for the Tennessee Valley
Curtis M. Jawdy

Hydrothermal Forecasting in the Tennessee Valley
T. Matthew Boyington

Reelfoot Lake Hydrologic Controls and Spillway Operation
Brandon Cobb

WATERSHED-SCALE EVALUATION OF RIPARIAN VEGETATION IMPACTS ON WATER QUALITY

Henrique Momm[1]*, Ronald L. Bingner[2], and Yongping Yuan[3]

ABSTRACT

Riparian vegetation in agricultural watersheds has the potential to act as vegetative buffer filter strips in reducing the amount of sediments and chemicals leaving cropland and reaching downstream lakes and streams. These vegetative zones promote sediment deposition and water infiltration by reducing flow velocity (Yuan et al., 2009). In these natural systems, the amount of sediment trapped is controlled by many parameters, such as terrain topography, surface flow characteristics, soil properties, width of the buffer perpendicular to the flow, and the type of vegetation cover. The performance of vegetative buffers is often expressed by the sediment trapping efficiency (STE), which is defined by the ratio of the mass flowing into the buffer and the mass flowing out of the buffer zone (Dabney et al, 1995).

Over the years, technology has been developed to estimate STE using one-dimensional representations of laboratory experiments and/or small research plots. These studies yielded solutions to estimate STE as a function of key parameters expressed as either empirical relationships (Yuan et al., 2009) or physically-based models; such as the Riparian Ecosystem Management Model-REMM (Lowrance et al., 1998) and the Vegetative Filter Strip Modeling System-VFSMOD (Munoz-Carpena et al., 1999). Despite the utilization of such technology at small-scale research plots and/or individual fields, their utilization at larger scales, such as at a watershed-scale, is still limited. Conversely, conventional watershed-wide simulation tools do not have the necessary detailed components to estimate the contribution of existing riparian vegetation in reducing sediment reaching the aquatic ecosystem.

In this study, a GIS framework was developed to integrate small scale STE models with large scale watershed-wide non-point source pollution models. This integration provides tools for improved evaluation of water quality impacts of conservation practices. The developed distributed technology (GIS-based) characterizes riparian vegetation at the watershed scale, produces key input parameters for STE estimation at individual flow-path level, and reports the results in the necessary format required by existing watershed modeling tools.

A demonstration of such technology is provided by the integration of one-dimensional empirical STE relations (Yuan et al., 2009) with the watershed-scale U.S. Department of Agriculture's Annualized Agriculture Non-Point Source (AnnAGNPS) pollutant-loading model (Bingner and Theurer, 2001). The watershed simulated by AnnAGNPS is spatially subdivided into homogeneous areas referred to as AnnAGNPS cells (red polygons in Figure 1). The developed technology estimates sediment trapping efficiency values for each individual AnnAGNPS cell; provided that a buffer strip GIS layer describing the spatial extent, terrain topographic

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[3] U.S. Environmental Protection Agency, Las Vegas, NV

characteristics, and the vegetation cover type are available. Within each AnnAGNPS cell, individual concentrated flow paths, passing through riparian buffers, are treated as proxy onedimensional profiles utilized in the estimation of STE values by empirical relationships (Figure 1). The set of STE values from all profiles within the AnnAGNPS cell being analyzed are then combined into a single representative STE value specific to that AnnAGNPS cell.

The proposed methodology is demonstrated in a sub-area of the USDA-ARS Goodwin Creek Experimental Watershed, located in Mississippi, and simulated using AnnAGNPS based on the conditions with and without the contribution of riparian vegetation (Figure 2). The empirical relationships proposed by Yuan (2009) to estimate STE values were integrated within the AnnAGNPS pollution model. The AnnAGNPS simulation results indicate a 20% reduction in sediment loads reaching the watershed outlet when accounting for riparian vegetation (Figure 3). Future research efforts will focus on the identification of specific concentrated flow paths passing through buffer zones working as short circuits through the buffer (flow velocity is not reduced) and improvements of empirical models through field experiments.

The developed framework serves as an effective, but simplified spatially distributed approach to evaluating the impact of riparian buffers on watershed sediment loads and downstream water quality through GIS technology that is easily integrated with watershed modeling technology.

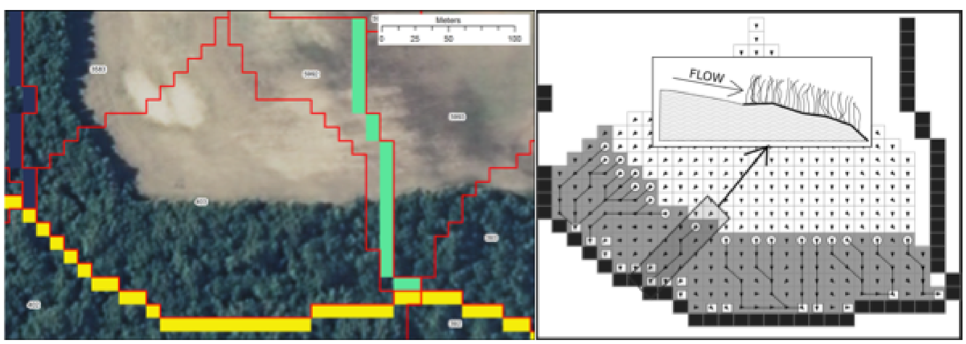

Figure 1. Schematic of GIS technology for the estimation of riparian vegetation sediment trapping efficiency at a watershed scale. Individual concentrated flow paths are represented as one-dimentional profiles into STE models. A weighted average of all flow path profiles generates a representative trapping efficiency value for each AnnAGNPS cell in the watershed.

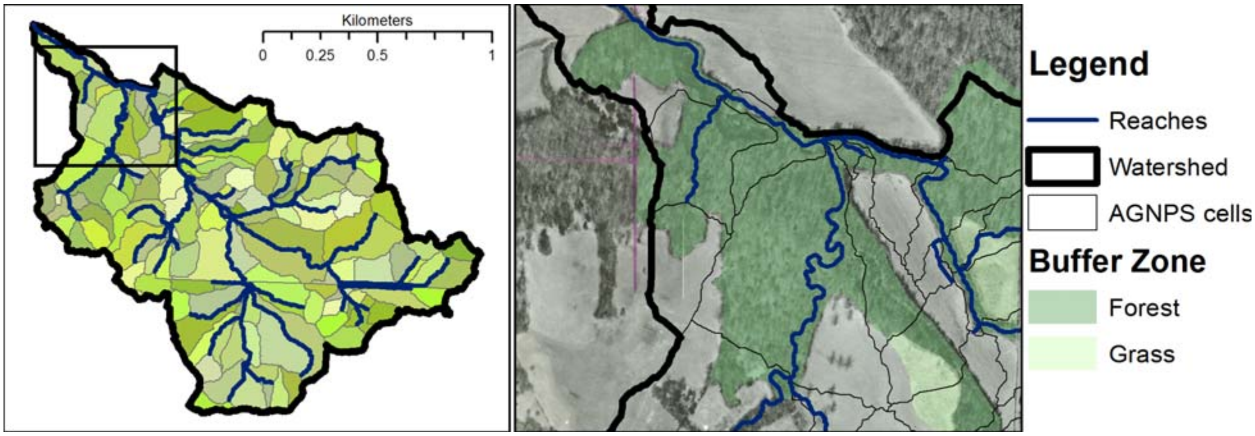

Figure 2. Goodwin Creek Experimental Watershed, located in Panola County, MS. This site was used to demonstrate the riparian buffer GIS technology developed.

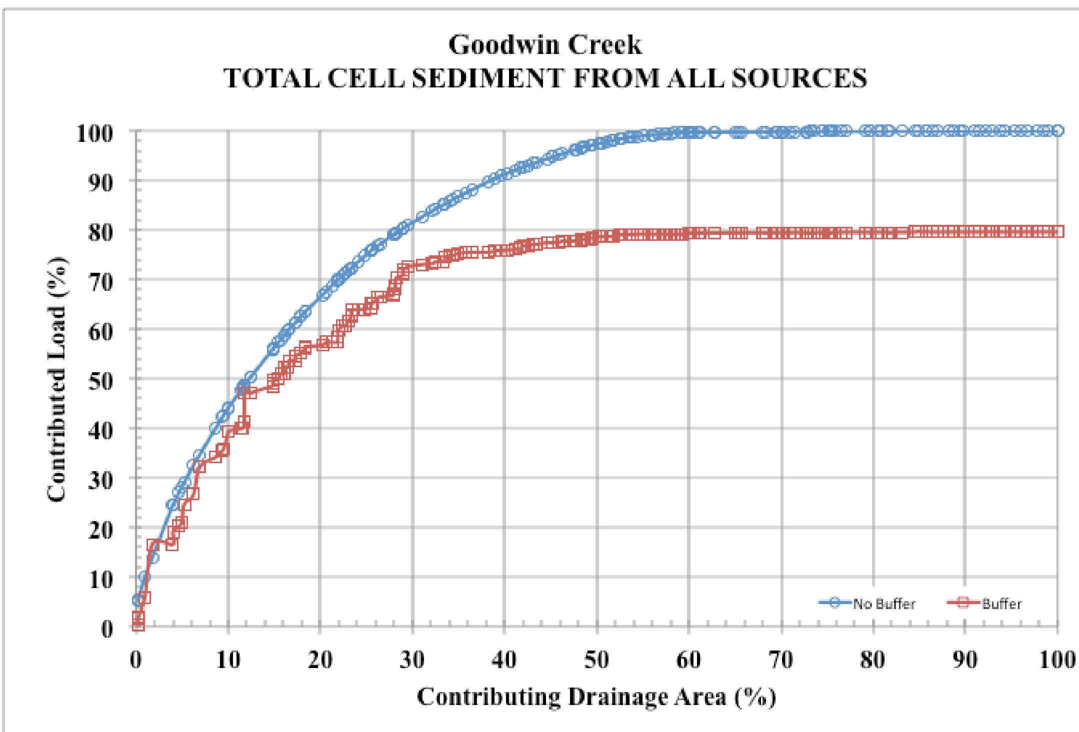

Figure 3. Watershed sediment load ranked by unit drainage area. Two scenarios are illustrated: conventional practice simulation (No Buffer) and simulation considering riparian vegetation as buffer strips (Buffer).

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Yuan, Y., R.L. Bingner, and M.A. Locke, 2009. A Review of effectiveness of vegetative buffers on sediment trapping in agricultural areas, *Ecohydrology* 2**:** 321–336.

HYDROLOGY AND SOIL MICROBIOLOGY OF CEDAR GLADE ECOSYSTEMS

Jennifer M. Cartwright[1]

INTRODUCTION

Limestone cedar glades are distinct ecosystems, characterized by thin (commonly 10 centimeters (cm) or less) soil and extreme hydrologic conditions, ranging seasonally from xeric to saturated, which support a number of critically endangered plant species. The role of hydrology in determining plant community characteristics in cedar glades is still poorly understood. For decades, botanical researchers have speculated that species endemic to cedar glades have a competitive advantage in these ecosystems because of their special adaptations to extreme hydrologic conditions, yet very few quantitative studies of cedar glade hydrology have been published. Even less attention has been paid to the microbiology of cedar glade soils (the presence and function of microscopic life in soil such as bacteria and fungi). The U.S. Geological Survey has partnered with Tennessee State University and the National Park Service to conduct an exploratory study of the hydrology and soil microbiology of cedar glades at Stones River National Battlefield (SRNB) outside Murfreesboro, Tennessee. The cedar glades at SRNB contain high ecological diversity and provide a refuge for endemic glade plants, including two federally endangered species. The goal of this research is to support management decisions concerning the cedar glades at SRNB by providing quantitative analysis of hydrology (including precipitation, soil water content and surface runoff) and soil characteristics (including microbial respiration, microbial metabolic activity, pH, nutrients, and organic matter). Data collection is ongoing and will continue through mid-2013.

APPROACH

Sampling sites were selected using a stratified random sampling and GIS-enabled spatial analysis. Strata used to select sampling points included individual cedar glades (a minimum of 4 points per glade) and glade interior vs. forest buffer; 20 percent of the sites were assigned to a 3-meter forest buffer surrounding glades to allow comparison between glade interior soils vs. forest soils). Soil thickness was measured and the ground surface characterized for 150 randomly located points within 12 glades. For logistical feasibility, 120 of these points were randomly selected for ongoing hydrologic monitoring, consisting of monthly observations of precipitation, soil water content, soil and air temperature, relative humidity, and surface runoff. Where soil thickness was sufficient, soil water content was measured using time-domain reflectometry (TDR); where soils were too thin (less than 8 cm) for TDR measurement, soil water content was measured by oven-drying of soil samples.

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A subset of 36 points was chosen for additional soil analysis. This subset was selected randomly, but with the condition that these points must have at least 4cm of soil thickness to make soil sample collection feasible. At each point, in situ measurements of soil respiration (CO_2 flux) were taken, and one soil sample was obtained using sterile methods. The microbiology of soil samples was analyzed using two techniques: a plate dilution frequency assay which yields a most-probable number of viable, culturable microbial cells per gram of soil, and Community Level Physiological Profiling (CLPP) using Biolog™ plates. The CLPP method allows soil samples to be compared based on substrate utilization profiles, corresponding to the rates at which soil microbial communities catabolize a suite of sole-carbon substrates over a time course of incubation. In addition, soil samples were analyzed to determine water content, pH, nitrate, organic matter and texture.

RESULTS

Preliminary results show that considerable diversity exists within glade habitats for the range of soil properties studied. Also, discernible relations exist between indicators of soil microbial activity and factors including soil thickness, pH, organic matter, water content, microbial respiration, and vegetative cover.

Spatial analysis of soil thickness indicates that glade interiors have much thinner soils than the forest surrounding the glades. An overall positive relation exists between prevalence of vegetation and soil thickness. Relatively little vegetation is supported at locations in glade interiors with soil thickness <5cm. Both *Nostoc commune* (soil-dwelling, nitrogen-fixing cyanobacteria) and biological soil crust (a complex association dominated by foliose lichen) are indicators of shallow soil, typically growing at points in the cedar glades where soil thickness is less than10 cm.

Soil water content varied with season, ranging from a mean of 13.2 percent volumetric soil water content in June 2012 to a mean of 41.8 percent in January 2013. Soil microbial populations (measured by plate dilution frequency assays) and microbial metabolic potential (measured by CLPP) both appear to be constrained by several abiotic factors, including soil thickness, water content and pH. Soil samples from glade locations with very thin soils (less than10cm), which also tend to support less vegetation and have higher pH (often above 8.0), show a marked depression in microbial metabolic response. In addition, CO_2 flux was generally depressed in soil samples with low water content.

STRUCTURE OF DIATOM ASSEMBLAGES AND PRIMARY PRODUCTION IN THE NUTRIENT-IMPAIRED WATERS OF THE RED RIVER WATERSHED IN NORTH-CENTRAL TENNESSEE

Jefferson G. Lebkuecher[1], Stacy M. Rainey[1], Chelsea B. Williams[1], and Alex J. Hall[1]

Six streams in the Red River Watershed were sampled to evaluate the impacts of nonpoint-source pollution on the structure of benthic diatom assemblages and whole-stream oxygen metabolism. The three most abundant taxa sampled in the watershed were *Nitzschia linearis* (16.4 %), *Navicula reichardtiana* (15.4 %), and *Navicula tripunctata* (7.2 %). These taxa are tolerant of habitat degradation due to excessive sediments and nutrient enrichment. Poor quality water in all six streams is indicated by: (1) high Siltation Index values for diatom assemblages which reveal loss of biotic integrity as a result of erosion, (2) high rates of whole-stream oxygen metabolism characteristic of eutrophic conditions, and (3) low ratios of whole-stream gross primary production to respiration typical of heterotroph-dominated habitats associated with poor quality water. The diatom assemblage at Sulphur Fork Creek is most impacted as indicated by the lowest Shannon Diversity Index, highest Siltation Index, and lowest Pollution Tolerance Index. High rates of whole-stream oxygen metabolism and high abundances of diatom taxa tolerant of sediments and eutrophication are hallmarks of stream impairment by erosion and nutrient enrichment. The results reveal the negative impacts of nonpoint-source pollution on the ecological integrity of photoautotrophic peiphyton in streams of the Interior Plateau Level III Ecoregion.

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IMPROVING HYDROLOGIC DECISION MAKING FOR THE TENNESSEE VALLEY

Curtis M. Jawdy[1]*

INTRODUCTION

The TVA River Forecast Center (RFC) is staffed 24x7 to make optimal decisions regarding our 49 dam system. Much of the decisionmaking infrastructure within the RFC was custom-made in the 1970's and 1980's as congressional funding provided for hydrologic R&D. Since then, routing methods have improved considerably, but hydrologic and data management methods less so.

TVA has begun a multi-year effort to modernize our decisionmaking systems. The concepts guiding the modernization are: standard software, model agnosticism, increased collaboration, excellent graphical display, improved forecast accuracy and honest communication of uncertainty.

The first step created a more accurate rainfall tool with redundancy. A custom interpolation with topographic bias removal was created to interpolate gridded rainfall depths based on TVA's rain gages. A second estimation is automatically imported from the Lower Mississippi River Forecast Center, and a third from the National Severe Storms Laboratory. These depth grids are averaged to TVA's basins of interest.

The rainfall tools are built on the Delft-FEWS platform, a standard operational forecast system shared with the National Weather Service. This platform also hosts a pilot rainfall/runoff model for Norris Dam watershed. This model is based on the Sacramento Soil Moisture Accounting methodology and has provided significant improvement over the current Antecedent Precipitation Index methodology. Work is ongoing to calibrate all 140 subbasins within the valley using gage data reaching back to 1950.

The talk will detail these improvements along with TVA's future plans and desire to collaborate with local hydrologists on continued improvement using our new platform.

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HYDROTHERMAL FORECASTING IN THE TENNESSEE VALLEY

T. Matthew Boyington[1]

As part of the ongoing effort to maintain the aquatic habitats of the Tennessee and Cumberland Rivers, the Tennessee Valley Authority (TVA) constantly monitors and manages the thermal discharge from its power plants. To maintain thermal compliance, TVA employs a variety of numeric models, monitoring stations, and operating procedures. This presentation will give an overview of the key thermal concerns in the Tennessee and Cumberland Valleys and detail TVA's hydrothermal forecasting program.

[1] Tennessee Valley Authority

REELFOOT LAKE HYDROLOGIC CONTROLS AND SPILLWAY OPERATION

Brandon Cobb[1]

Reelfoot Lake, located in Obion and Lake Counties, Tennessee, is a shallow natural lake with water levels historically regulated by a stop-log control structure. Stop-log control structures were added or removed to adjust water levels to meet multiple management goals, including mitigation of upstream and downstream flooding, maintaining minimum lake levels to support wildlife habitat, and recreation and tourism. Water levels of Reelfoot Lake reflect the balance between streamflow entering the lake from Reelfoot Creek, Indian Creek, and Bayou du Chien and discharge through the control structure into Running Reelfoot Bayou. In 2013, the stop-log control structure was replaced by a series of computer-controlled lift gates that require a new set of guidelines for operation of the gates to maintain proper water levels in the lake and discharge in streams flowing into and out of the lake. The U.S. Geological Survey, in cooperation with Tennessee Wildlife Resources Agency, is analyzing water movement within the lake and the interactions among tributary inflows, discharge through the new control structure, and water levels in the lake. The resulting understanding will be used to develop operational rules for the new control structure.

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SESSION 2A

WATER SUPPLY
8:30 a.m. – 10:00 a.m.

Water Use in the Tennessee Valley for 2010 and Projected Use in 2035
Amanda K. Bowen and Chuck E. Bohac

Only a Drop to Drink: Potable Water Efficiency Through High Performance Building
Justin Southwick

Determining Optimum Coagulant Dose Using Laboratory Charge Measurement
Alonzo Mancilla

STREAM DETERMINATION
10:30 a.m. – 12:00 p.m.

Background on Tennessee's Use of the Wet Weather Conveyance Concept
Dan Eagar

An Overview of TDEC Hydrologic Determination Procedures
J. Smith (Abstract Not Available)

Current Rules and Technical Criteria for Applying TDEC's Hydrological Determination Certification Program
John S. Schwartz

LID
1:30 p.m. – 3:00 p.m.

The LID Technology Selection Pyramid: Selecting a Green Infrastructure Design Approach
Mark B. Miller

Innovation in Simplified Green Infrastructure Design Criteria
Andrew J. Reese and Sara R. Johnson

Metro Water Service's New Volume (Volume 5) Stormwater Management Manual – First Year Experiences
Michael Hunt

LID APPLICATIONS
3:30 p.m. – 5:00 p.m.

Development and Application of a Low Impact Development Optimization Model to Determine Cost-Effective LID Strategies to Reduce Surface Runoff Volume
Ryan Clark, Frank Ponzio, Dennis George, Yvette Clark, and David Alizandro

State of LID in Tennessee
Andrea Ludwig, M. Patrick Massey, and Keil Neff

City of Chattanooga LID/Green Infrastructure Projects
Don Green

WATER USE IN THE TENNESSEE VALLEY FOR 2010 AND PROJECTED USE IN 2035

Amanda K. Bowen[1]* and Chuck E. Bohac[2]

INTRODUCTION

The quality of life in the Tennessee Valley Region depends on ample water for homes, businesses, farms, meeting places, and recreational activities. Dependable water is fundamental to the economic growth of the region as is dependable, low-cost electricty. It is anticipated that water supply and water-quality issues, coupled with emerging water-use conflict over a fixed supply, will continue to increase across the southeast.

The Tennessee River system is the fifth largest river system in the United States. The Tennessee River watershed drains 40,910 square miles, including portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee and Virginia as shown in Figure 1.

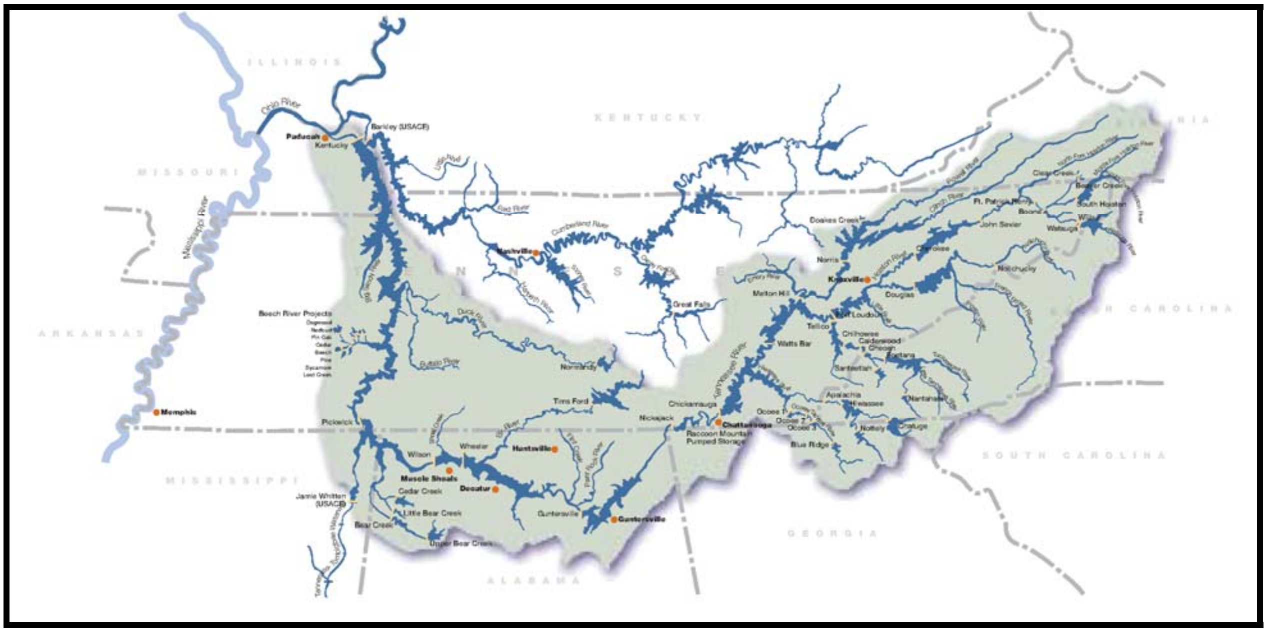

Figure 1. *Tennessee River Watershed*

In 2004, the U.S. Geological Survey (USGS) and the Tennessee Valley Authority (TVA) prepared a water use estimate for the Tennessee River watershed based on data collected in 2000 (Hutson and others, 2004). Utilizing these data, water use estimates were projected to 2030 to aid in the water supply analyses associated with TVA's Reservoir Operations Study (ROS). The ROS was a study conducted by TVA to examine alternative reservoir operations policies in an

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effort to increase overall public value of the reservoir system. The ROS developed a new operating policy that was implemented by TVA in 2004 (Tennessee Valley Authority, 2004). The 2000 water use data were also used by TVA in 2004 to identify areas with potential concerns regarding water supply (Bohac and Koroa, 2004). A second estimate of water use was prepared by Bohac and McCall (2008) using 2005 data. The most recent estimate was prepared using the 2010 data and contains estimates projected to 2035 (Bohac and Bowen, 2012).

APPROACH

TVA implemented a new reservoir operating policy in 2004. One of the objectives of the new operating policy was to meet the off-stream water needs of the Valley until at least 2030. TVA inventories water use every five years to make future projections of water demand in the Valley and to examine trends in water use. These results are used to determine how well the assumptions behind the operating policy are holding up. The data are also used for a variety of purposes including the siting and permitting of new power plants and to aid TVA in its efforts to promote economic development in the Valley.

Water use estimates focus on four categories of off-stream water use: thermoelectric power, industrial, public supply, and irrigation. Each record in the database is labeled as a withdrawal or a return transaction and is also labeled by source of water (surface water or groundwater). Each transaction is assigned to a Water Use Tabulation Area (WUTA), Reservoir Catchment Area (RCA), Hydrologic Unit Code (HUC), state, and county. Water returns to the watershed are used to estimate consumptive use.

RESULTS AND DISCUSSION

Total water withdrawals during 2010 were estimated to average 11,951 million gallons per day (mgd) for off-stream uses. The 2010 total withdrawal was about four percent lower than it was in 2005. This was in large measure due to a reduction in thermoelectric withdrawal of about 5 percent as a result of lower energy generation in the watershed compared to 2005.

Water withdrawals by category, as shown in Figure 2, are:

- Thermoelectric - 10,046 mgd
  (84.1 percent of total use)
- Industrial - 1,148 mgd
  (9.6 percent of total use)
- Public supply - 723 mgd
  (6 percent of total use)
- Irrigation - 34 mgd
  (less than 1 percent of total use)

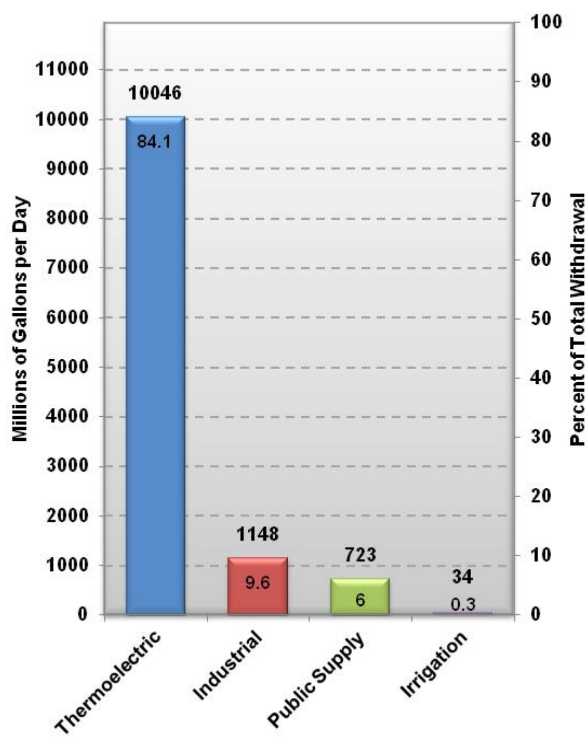

Figure 2. *Water Withdrawals for 2010*

The return flow was estimated at 11,480 mgd or 96.1 percent of the water withdrawn. Net water demand (total withdrawal minus total return) accounts for the other 3.9 percent of total withdrawal, or 471 mgd.

As shown in Figure 3, water returns to the river system were estimated as:

- Thermoelectric - 9,994 mgd
  (99.5 percent of thermoelectric withdrawal, 87.1 percent of total return)
- Industrial - 1,073 mgd
  (93.5 percent of industrial withdrawal, 9.3 percent of total return)
- Public supply - 413 mgd
  (57.2 percent of public supply withdrawal, 3.6 percent of total return)
- Irrigation - 0 mgd

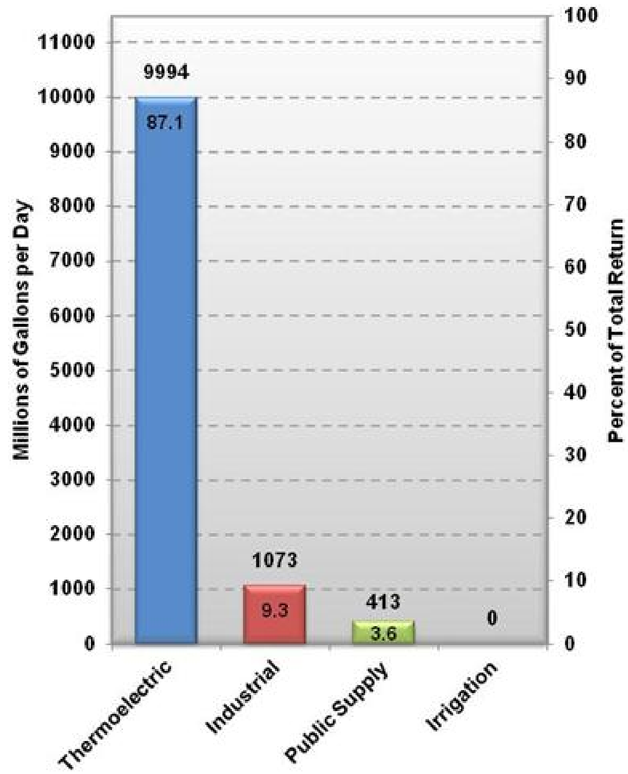

Figure 3. *Water Returns for 2010*

Water that evaporates, transpires, is incorporated into products or crops, or is consumed by humans or livestock is consumptive use. The net water demand is used as an estimate of consumptive use. The net water demands for each category as shown in Figure 4 were estimated as:

- Thermoelectric - 52 mgd
  (11.1 percent of total net water demand)
- Industrial - 75 mgd
  (15.8 percent of total net water demand)
- Public supply - 310 mgd
  (65.7 percent of total net water demand)
- Irrigation - 34 mgd
  (7.2 percent of total net water demand)

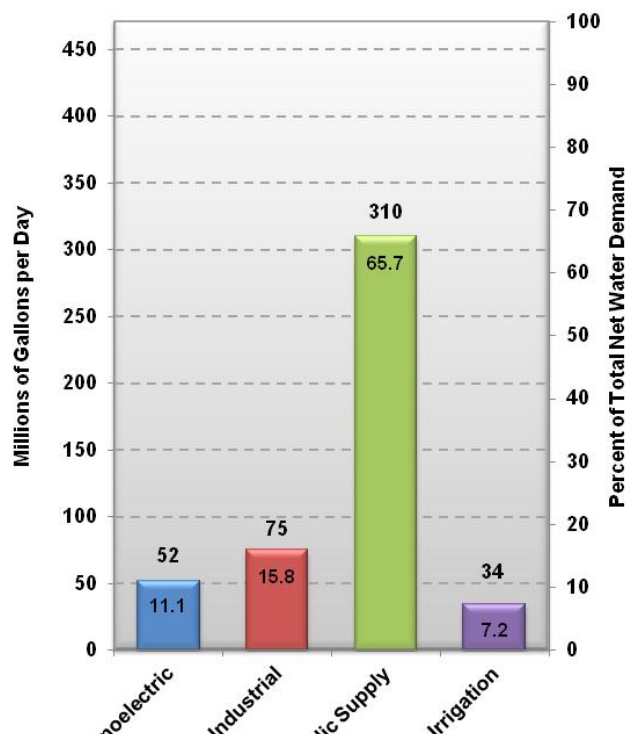

Figure 4. *Net Water Demand in 2010*

Surface water withdrawals were 11,747 mgd or 98.3 percent of total withdrawal with groundwater accounting for the remaining 1.7 percent of total withdrawals or 204 mgd.

By 2035 water withdrawals are projected to decline about 21 percent to 9,449 mgd. By category, water withdrawals are projected to change as follows: industrial will increase by 31 percent to 1,502 mgd, public supply will increase by 30 percent to 938 mgd, and irrigation will increase by 35 percent to 46 mgd. Thermoelectric water withdrawal is expected to decline by 31 percent to 6,963 mgd, reflecting changes in both generating and cooling technologies for power plants. These are shown in Figure 5.

Although total withdrawals are expected to decrease, total net water demand will rise by 51 percent to 712 mgd. This is in large measure due to projected changes in the use of thermolectric generation and power plant cooling technolgies.

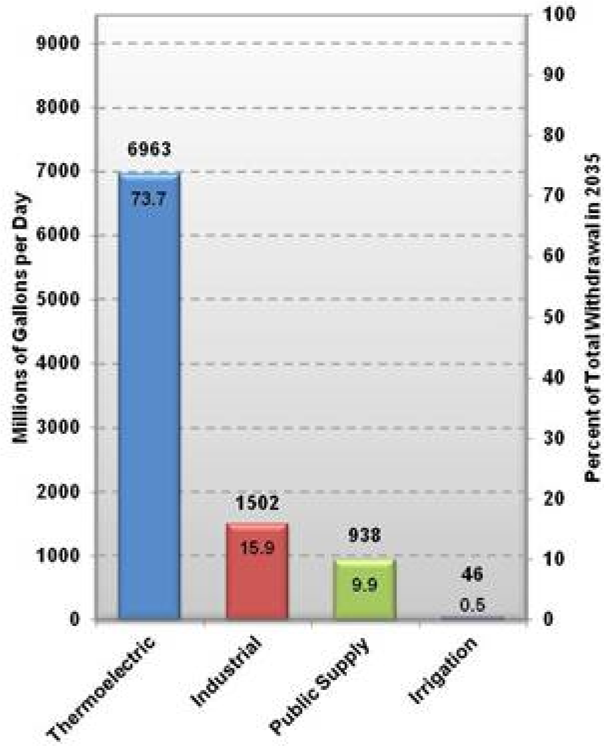

Figure 5. *Projected Withdrawals in 2035*

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ONLY A DROP TO DRINK: WATER EFFICIENCY THROUGH HIGH PERFORMANCE BUILDING

Justin Southwick[1]

Although buildings use a relatively small percentage of the world's fresh water, clean, municipally supplied drinking water is a hallmark of modern societies. The opportunities are extensive to reduce demand for potable water in buildings, while relieving aging sewerage infrastructure at the same time. An often-overlooked benefit from water efficiency is energy efficiency. This presentation will explore how the design and construction community is contributing to water conservation through creative reduction and reuse strategies in high performance buildings and retrofits.

Topics discussed:

1. Need and opportunity for water conservation in buildings
    a. Where does our water go?
        i. Water use by major type
    b. How does it get there?
        i. Energy use from pumping and treating water
    c. How much is used vs. wasted
        i. Water waste at the residential level
2. Strengths and weaknesses of water initiatives in building rating systems
    a. Strengths
        i. Low barriers to entry for initial demand reduction
        ii. Ease of implementation
    b. Weaknesses
        i. Financial
            1. Perceived as a commodity and priced very cheaply
                a. Cheap inputs and outputs (water source & receiving waters)
            2. Limited creativity and need, and grey water reuse
                a. Low price
            3. Weight: By the nature of it's weight it's prohibitive to ship it very far:
                a. Gravity feed
                b. Gravity drainage
                c. Gravity pressure: Water towers
                d. Water towers during low cost power periods
        ii. Cultural
            1. Desire for convenience and reliability
            2. Skills updates for professionals
            3. Codes department comfort levels
            4. Permit limitations

[1] LEED AP, Wilmot, Inc., 615-385-1220, 3654 Knollwood Rd, Nashville TN 37215, www.wilmotinc.com, p. 615.385.1220, f. 615.346.0142

            5. Liability of contamination
        iii. Functional
            1. Need for gravity flow
            2. Need for integrated design
            3. Need for integrated maintenance
    c. Specific Treatment in Rating Systems
        i. LEED
            1. Did not have a Technical Advisory Group for water until several years into program
            2. Focused primarily on flow and flush fixture use
        ii. Energy Star
            1. Increasing focus on water use and water infiltration
        iii. Green Globes
        iv. BREEAM
3. Community-scale program(s)
    a. Municipal government carrots and sticks
        i. Stick: Nashville: 2016 NPDES Permit
            1. Stormwater Management requiring 80% TSS, 1st 1" of rainwater after 72 hours of no rain
                a. Low Impact Development
                    i. Downspout disconnections
                    ii. Rainwater capture
                    iii. Bioswales and other LID
        ii. Stick: Low-water regimes
            1. Restrictions on water use: Atlanta
        iii. Carrot: Nashville: Green Permit requires 20% Water Efficiency Credit regardless of LEED certification level
        iv. Carrot: Fixture retrofit programs, incentives
4. Private sector support
    a. Incentive program(s)
        i. Product manufacturers supporting retrofit programs
        ii. Retrofit programs also support green jobs
    b. "Paid through savings" program(s)
        i. Repeatedly are the quickest return on investment
            1. Are bundled with longer lead time programs
        ii. Tamper-proof retrofits to ensure savings
        iii. Showers & flushing in residential highrises, hospitality
5. Selected case studies to describe efforts in new and/or existing buildings
    a. Rainwater Collection & Reuse: Balzer Theater, Atlanta, GA
    b. 100% on-site stormwater management with LID: NextGen, Nashville, TN
    c. Flow and Flush Fixture Installation: Habitat for Humanity of Greater Nashville
    d. Maple Hills Apartments, Chattanooga Housing Authority
    e. Water use reduction: Bridgeport Housing Authority, Bridgeport, CT
    f. Solar water heating: Jersey City Housing Authority, Jersey City, NJ

DETERMINING OPTIMUM COAGULANT DOSE USING LABORATORY CHARGE MEASUREMENT

Alonzo Mancilla[1]

The one major downside to Jar Testing is the time it takes to complete a test. For many water treatment plants, a simpler, faster, and often more accurate test for determining an optimum coagulant dose can be obtained using a laboratory streaming current device, often referred to as a laboratory charge analyzer. Over the last 7 years, many water treatment plants have adopted this technology and it has become an essential part of their operations. This presentation will review the theory behind the technology, explain where it can be successfully applied, discuss how to properly perform the titration procedure, and end with explaining how to interpret certain responses. This presentation will also be helpful to any operator who has an online Streaming Current device and wants to better understand the technology and learn more about how to interpret the instruments response to certain water quality changes.

[1] Chemtrac Systems, Inc.

BACKGROUND ON TENNESSEE'S USE OF THE WET WEATHER CONVEYANCE CONCEPT

Dan Eagar[1]

The concept of wet weather conveyance has been a part of Tennessee's water pollution control regulatory program since the mid-1980's. The necessity driving the concept was the need for the state, regulated entities, and other interested parties to know when certain regulatory requirements are triggered. *The Tennessee Water Quality Control Act* (Act) defines "waters of the state" as "any and all water, public or private, on or beneath the surface of the ground, that are contained within, flow through, or border upon Tennessee or any portion thereof, except those bodies of water confined to and retained within the limits of private property in single ownership that do not combine or effect a junction with natural surface or underground waters." The Act requires permits for the alteration of the physical, chemical, radiological, biological, or bacteriological properties of any waters of the state. Under these provisions the range of activities potentially subject to permitting or other regulatory provisions is vast. Therefore there is a practical necessity determine which waters are subject to active regulation.

The state water program staff developed the concept of wet weather conveyance to establish a reasonable threshold for applicability of regulatory requirements such as permitting of alterations. A 1988 internal memorandum established a definition of wet weather conveyance and discussed distinguishing characteristics such as persistence of flow and a listing of some indicator aquatic organisms. In 1991, the first set of General Permits for the Aquatic Resource Alteration Permit Program were promulgated as rules of the Water Quality Control Board. They included a General Permit for the Alteration of Wet Weather Conveyances that included a definition of wet weather conveyance, very general limitations or constraints applicable to their alteration, and a provision that the division did not need to be notified or give case-by-case authorization for the alteration of wet weather conveyances. The concept was also incorporated into the state's water quality standard and use classification rules.

As the reach of the water regulatory program grew with federal mandates to control adverse water quality impacts from municipal stormwater system discharges, construction sites, and other sources not previously regulated, the importance of establishing a clear and consistent method for distinguishing between streams and wet weather conveyances became more important. After periodic discussions of the division's approach with legislators and other interested parties and a petition heard by the Water Quality Control Board challenging stream/wet weather conveyance determination for a specific project, a coalition of industry associations launched a legislative initiative addressing the concept. That initiative resulted in legislation re-defining wet weather conveyances, a mandate that the Tennessee Department of Environment and Conservation promulgate rules concerning the identification of wet weather conveyances, and a training and certification program for professionals engaged in making hydrologic determinations.

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[1] Program Manager, Tennessee Stream Mitigation Program

CURRENT RULES AND TECHNICAL CRITERIA FOR APPLYING TDEC'S HYDROLOGICAL DETERMINATION CERTIFICATION PROGRAM

John S. Schwartz[1]

EXTENDED ABSTRACT

Technical criteria for hydrological determinations (HDs) based on scientifically based principles were developed to consistently and accurately determine the jurisdictional status of water features in Tennessee. HDs classify a water feature into two jurisdictional categories; they are a wet-weather conveyance and a stream, and are applicable for the Tennessee Department of Conservation and Environment Water Pollution Control Division (TDEC WPC) permitting purposes, and not for the applicability of federal regulations, local ordinances, real-estate appraisals, or other uses. Technical criteria supplements the standard operating procedures for making stream and wet weather conveyance HDs, as found in Rule 1200-4-03-.05(9) as provided for in Public Chapter 464 of 2009. It should be noted that the HD protocol is specifically designed to address the jurisdictional status of linear watercourses, not other hydrologic features such as wetlands or isolated ponds, although these features may be mentioned as they relate to HDs. HD procedures are based upon concepts and methodologies originally developed and revised by the North Carolina Division of Water Quality (NCDWQ) since 1997, and currently adopted whole or in part by many other state agencies. NCDWQ's documents titled *North Carolina Division of Water Quality Identification Methods for the Origins of Intermittent and Perennial Streams, Version 3.1*, and the *Methodology for Identification of Intermittent and Perennial Streams and Their Origins Version 4.11* can be found online; in addition TDEC WPC's *Hydrological Determination Guidance Manual* can be found on-line.

HDs are completed by desktop and field investigation efforts. First, compilation of basic site information supports a field investigation, and includes site names and location description, 12-digit HUC, latitude/longitude, drainage area, soil, geology, current land use, land/stream disturbance history, and recent precipitation statistics. The HD investigation is hierarchically organized into primary field indicators (assessed first) and secondary indicators. There are nine primary indicators, in which four indicators directly indicate a wet weather conveyance, and five indicators directly indicate a stream (Table 1). Any question on the interpretation of the primary indicators should lead the HD professional to conduct a determination based on secondary indicators. There are 28 secondary indicators based on fluvial geomorphology, hydrology, and biology (Table 1). Indicators are scored based on field observations along a scale from the feature being absent to it being strong with scores ranging from 0 to 3 for each indicator. Thirteen geomorphic indicators include basic features such as continuous bed and bank, sinuosity, pool-riffle sequences or braided bed structures, floodplain surfaces and natural levees, sorting and deposition of alluvial sediment, headcut and grade controls, and channel order. Six hydrologic indicators include observations related to flow duration and interflow transport, hydric soils, and capability to transport organic and inorganic material. Nine biologic indicators include the presence or absence of various biota such as fibrous and rooted plants in channel,

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wetland plants, iron oxidizing bacteria, algae, crayfish, bivalves/ mussels, amphibians, and benthic macroinvertebrates. Species of benthic macroinvertebrates are a key component of the biological assessment. Summing the scores of the 28 secondary indicators, if the total is less than 19, the water feature is classified as a wet-weather conveyance.

This presentation is to provide a general overview of the 9 primary indicators and 28 secondary indicators, and how they relate to the HD of whether a water feature is a wet-weather conveyance or a stream.

Table 1. Tennessee Hydrological Determination Field Data Sheet.
(*field sheet follows*).

Hydrologic Determination Field Data Sheet
Tennessee Division of Water Pollution Control, Version 1.4

County:	Named Waterbody:	Date/Time:
Assessors/Affiliation:		Project ID :
Site Name/Description:		
Site Location:		
USGS quad:	HUC (12 digit):	Lat/Long:
Previous Rainfall (7-days) :		
Precipitation this Season vs. Normal : very wet wet average dry drought unknown Source of recent & seasonal precip data :		
Watershed Size :	Photos: Y or N (circle) Number :	
Soil Type(s) / Geology :		Source:
Surrounding Land Use :		
Degree of historical alteration to natural channel morphology & hydrology (circle one & describe fully in Notes) : Severe Moderate Slight Absent		

Primary Field Indicators Observed

Primary Indicators	NO	YES
1. Hydrologic feature exists solely due to a process discharge		WWC
2. Defined bed and bank absent, dominated by upland vegetation / grass		WWC
3. Watercourse dry anytime during February through April 15th, under normal precipitation / groundwater conditions		WWC
4. Daily flow and precipitation records showing feature only flows in direct response to rainfall		WWC
5. Presence of multiple populations of obligate lotic organisms with ≥ 2 month aquatic phase		Stream
6. Presence of fish (except *Gambusia*)		Stream
7. Presence of naturally occurring ground water table connection		Stream
8. Flowing water in channel and 7 days since last precipitation in local watershed		Stream
9. Evidence watercourse has been used as a supply of drinking water		Stream

NOTE : If any Primary Indicators 1-9 = "Yes", then STOP; absent directly contradictory evidence, determination is complete.

In the absence of a primary indicator, or other definitive evidence, complete the secondary indicator table on page 2 of this sheet, and provide score below.

Guidance for the interpretation and scoring of both the primary & secondary indicators is provided in *TDEC-WPC Guidance For Making Hydrologic Determinations, Version 1.4*

Overall Hydrologic Determination =

Secondary Indicator Score (if applicable) =

Justification / Notes : ______

Secondary Field Indicator Evaluation

A. Geomorphology (Subtotal =)	**Absent**	**Weak**	**Moderate**	**Strong**
1. Continuous bed and bank	0	1	2	3
2. Sinuous channel	0	1	2	3
3. In-channel structure: riffle-pool sequences	0	1	2	3
4. Sorting of soil textures or other substrate	0	1	2	3
5. Active/relic floodplain	0	1	2	3
6. Depositional bars or benches	0	1	2	3
7. Braided channel	0	1	2	3
8. Recent alluvial deposits	0	0.5	1	1.5
9. Natural levees	0	1	2	3
10. Headcuts	0	1	2	3
11. Grade controls	0	0.5	1	1.5
12. Natural valley or drainageway	0	0.5	1	1.5
13. At least second order channel on existing USGS or NRCS map	No = 0		Yes = 3	

B. Hydrology (Subtotal =)	**Absent**	**Weak**	**Moderate**	**Strong**
14. Subsurface flow/discharge into channel	0	1	2	3
15. Water in channel and >48 hours since sig. rain	0	1	2	3
16. Leaf litter in channel (January – September)	1.5	1	0.5	0
17. Sediment on plants or on debris	0	0.5	1	1.5
18. Organic debris lines or piles (wrack lines)	0	0.5	1	1.5
19. Hydric soils in stream bed or sides of channel	No = 0		Yes = 1.5	

C. Biology (Subtotal =)	**Absent**	**Weak**	**Moderate**	**Strong**
20. Fibrous roots in channel [1]	3	2	1	0
21. Rooted plants in channel [1]	3	2	1	0
22. Crayfish in stream (exclude in floodplain)	0	0.5	1	1.5
23. Bivalves/mussels	0	1	2	3
24. Amphibians	0	0.5	1	1.5
25. Macrobenthos (record type & abundance)	0	1	2	3
26. Filamentous algae; periphyton	0	1	2	3
27. Iron oxidizing bacteria/fungus	0	0.5	1	1.5
28.Wetland plants in channel [2]	0	0.5	1	2

[1] Focus is on the presence of upland plants. [2] Focus is on the presence of aquatic or wetland plants.

Total Points = ____________

Under Normal Conditions, Watercourse is a Wet Weather Conveyance if Secondary Indicator Score < 19 points

Notes :

THE LID TECHNOLOGY SELECTION PYRAMID: SELECTING A GREEN INFRASTRUCTURE DESIGN APPROACH

Mark B. Miller[1]

With the expanding demand to implement green infrastructure and low impact development (LID) practices, a variety of innovative site development designs are emerging. Incorporating technically feasible and cost-effective stormwater management practices into these design strategies requires an understanding of the regulatory framework within which LID technologies are selected. Agencies commonly follow a preferred technology selection process instead of simply identifying a given technology and implementing it. If the most preferred technology cannot be installed due to limiting site conditions, then the next technology option should be considered, and so on, until the appropriate technology(s) can be utilized.

A five step LID technology selection pyramid has been developed to illustrate how to select an appropriate green infrastructure approach for site development plans. The five LID technologies are listed below in descending order of selection:

1. Surface Infiltration,
2. Subsurface Infiltration,
3. Rainwater Harvesting,
4. Biofiltration, and
5. Treatment Train Options including Media Filtration, Hydrodynamic Separation, Detention and Storage.

The fundamental goal of LID is to mimic pre-development hydrology by not creating runoff and allowing on-site stormwater to infiltrate to the ground. This presentation explores how the pyramid depicts the LID selection processes and compares those technologies to whether they focus on runoff reduction, stormwater treatment, or a combination of both through treatment train designs. Consideration is also given to whether implementation of any technology is feasible and/or cost-effective given the intended land use(s).

A case installation is described where elements of the LID technology selection process were implemented at the five acre (former) Cavalier Plant Brownfield site near downtown Chattanooga. The property is now used as an operations center for the local electric utility. The stormwater design includes surface infiltration using driveable grass, underground infiltration and detention using modular polyethylene structures, biofiltration using a land based design, and hydrodynamic separation for pretreatment using a manufactured treatment device. These technologies utilize an integrated technology solutions approach to both enhance and complement the principles of LID design goals.

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INNOVATION IN SIMPLIFIED GREEN INFRASTRUCTURE DESIGN CRITERIA

Andrew J. Reese[1] and Sara R. Johnson[2]

Standard depth criteria for green infrastructure leave the designer confused and often leads to an approach that is a mash up of several approaches that defy logic and are hard to apply. However, if the depth criteria are reinterpreted in terms of ability to capture an annual percent of rainfall then possibilities open up for a far more natural and staged approach to site design or retrofit. As well, when this approach is taken then a target land use goal can be established that meets the criteria giving a visual idea of what is acceptable. This approach is applied to Nashville as the first city in the State of Tennessee to adopt such criteria. The criteria was accepted at state and regional level regulators and applauded by designers and developers as well as environmentalists.

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METRO WATER SERVICE'S NEW VOLUME (VOLUME 5) STORMWATER MANAGEMENT MANUAL – FIRST YEAR EXPERIENCES

Michael Hunt[1]

Metro Water Services (MWS) has developed a new Volume (Volume 5) of its Stormwater Management Manual to encourage Low Impact Development (LID) in Nashville. LID is a planning and engineering design approach to land development that includes conservation of natural features and the infiltration, evapotranspiration, and re-use of stormwater on the site where it is generated. LID practices can also be referred to as Green Infrastructure (GI) and include strategies such as green roofs, bioretention, and pervious pavement. The Manual development process included the identification of barriers to the utilization of LID in Metro's existing codes, regulations, and policies. A Stakeholder group consisting of local professionals was convened to evaluate the current utilization of LID in Nashville and brainstorm means to increase its prevalence. The Manual incorporates updated design specifications for green infrastructure BMPs already used in Nashville along with new design specifications for BMPs such as cisterns and reforestation. The design methodology in the new LID Manual will also meet the one inch retention site design requirement of Nashville's new MS4 permit. Incentives will be offered to projects that utilize the new Manual before it becomes mandatory. This voluntary period will be used to identify problems and make any needed adjustments. Metro is providing training and tools to the development community to ease the transition via a dedicated webpage (https://www.nashville.gov/Water-Services/Developers/Low-Impact-Development.aspx).

This presentation will pertain to sites utilizing Vol 5, "lesson's learned", and the vital role contractors play in making LID work.

[1] Program Manager, Metro Water Services, Storm Water Div. – NPDES Office

DEVELOPMENT AND APPLICATION OF A LOW IMPACT DEVELOPMENT OPTIMIZATION MODEL TO DETERMINE COST-EFFECTIVE LID STRATEGIES TO REDUCE SURFACE RUNOFF VOLUME

Ryan Clark[1], Frank Ponzio[3], Dennis George[2,3], Yvette Clark[2] and David Alizandro[4]

Historically, most urban stormwater management plans were concerned with transporting surface runoff away from the area via open and closed conduits that resulted in high energy flows in receiving streams (Burns, Fletcher, Walsh, Ladson & Hatt, 2012). Low impact development (LID) is an alternative, comprehensive approach to stormwater management that incorporates best management practices (BMP) and strategies to reduce the impacts of runoff on surface water quantity and quality. The goal of LID site design is to reduce the hydrologic impact of development and incorporate techniques that maintain or restore the site's hydrologic and hydraulic functions. The optimal LID site design minimizes runoff volume and preserves existing flow paths, which thereby minimizes infrastructural requirements (MDE, 1999). The main motivation for implementing LID strategies in an urban area is to achieve the pre-development hydrologic regime (MDE, 1999). With LID strategies, stormwater runoff is infiltrated closer to its source and can reduce peak discharge volumes which then reduce the amount of nonpoint source pollution (Brown, 2003).

An optimization model was developed to meet curve number constraints at minimum cost for determining low impact development (LID) strategies that could be applicable to reduce surface water runoff from the campus of Tennessee Technological University. The hydrology of the project catchment was examined and the surface water outfalls for the entire catchment were determined. Specific land uses were delineated and integrated with existing soil information to find corresponding curve numbers. The land cover was also evaluated for the implementation of various LID practices. The optimization model was employed and successfully produced much of each LID should be constructed to reduce flow a specified amount at a minimum cost. The LID implementation was simulated in a hydrologic model and a reduction in flow was verified.

REFERENCES

Brown, F. X. (2003). Using low impact development methods to maintain natural site hydrology. Proceedings of the World water and environmental resources congress ASCE.

Burns, M. J., Fletcher, T. D., Walsh, C. J., Ladson, A.R., & Hatt, B. E. (2012). Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landscape and Urban Planning, (105), 230-240.

Maryland Department of the Environment (MDE), (1999). Low-impact development hydrologic analysis. Prince George's County, Maryland.

[1] U.S. Army Corps of Engineers, Nashville District
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[3] Tennessee Technological University, Department of Civil and Environmental Engineering
[4] Tennessee Technological University, Department of Computer Science

STATE OF LID IN TENNESSEE

Andrea Ludwig[1], M. Patrick Massey[2], and Keil Neff[2]

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, the USEPA has implemented pollution control programs including water quality standards for all contaminants in surface waters. Polluted stormwater runoff is commonly transported through Municipal Separate Storm Sewer Systems (MS4s), from which it is often discharged untreated into local waterbodies. Section 402 specifically grants EPA the authority to issue permits for discharges of municipal stormwater, provided such permits include controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and systems, design and engineering methods, and other such provisions as the Administrator or the State determines appropriate for the control of such pollutants. The MS4 must develop, implement, and enforce a permanent stormwater management program (as part of their NPDES permit) designed to reduce the discharge of pollutants from the MS4 to protect water quality.

In Tennessee, runoff reduction has been proposed to be included in the next Phase II permit cycle. As such, "site design standards for all new and redevelopment require, in combination or alone, management measures that are designed, built and maintained to infiltrate, evapotranspire, harvest and/or use, at a minimum, the first inch of every rainfall event preceded by 72 hours of no measurable precipitation" (Section 4.2.5.2.1). An effective way to infiltrate the first one inch of precipitation includes implementing onsite Low Impact Development (LID) Best Management Practices (BMPs).

Multiple Tennessee Phase I and Phase II MS4s stormwater program managers were interviewed to ascertain how they are implementing their stormwater management program considering current and anticipated regulation. This presentation will describe how these Tennessee MS4s are funded, how they implement or anticipate implementing the anticipated 1-inch infiltration requirement into their programs, preferred LID BMPs, and the biggest challenges they currently face in their programs.

ADDITIONAL INFORMATION: Tennessee Runoff Reduction Performance Standards
Karina Bynum, MSCE, P.E., TDEC Division of Water Resources

Permanent stormwater control as specified in the phase II municipal stormwater permit establishes performance standards for volume reduction and pollutant removal for new development and redevelopment projects within the MS4 jurisdiction. Runoff reduction requirement is the regulatory basis for Green Infrastructure in Tennessee. Scenarios of meeting the performance standards are explained and incentive for preservation of natural green space or improved management practices is incorporated into the design options for site.

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CITY OF CHATTANOOGA LID/GREEN INFRASTRUCTURE PROJECTS

Don Green

The City of Chattanooga is undertaking a strategic approach to implement green infrastructure retrofit projects. In most cases, the cost to retrofit a site with green infrastructure is impeding its application. Therefore, the City of Chattanooga is partnering with more than a dozen entities in the development and implementation of green infrastructure improvement projects. In some cases, the City is taking the lead, but in other cases the City is providing the support and guidance during the planning, design, and construction phases of the projects. The collaboration among various entities has been driven by: 1) need for infrastructure improvement, 2) increasing storm water fee, 3) offering alternative green solutions, 4) identifying multiple benefits of green infrastructure and 5) increased awareness of the importance of green infrastructure.

The projects that are undergoing have various land usage: 1) Revitalization of a commercial mid-town area that includes public and private properties, 2) Public school infrastructure improvement, 3) Commercial redevelopment and roadway improvement, and 4) Residential revitalization and institutional improvement area.

The opportunity to conduct these infrastructure improvements is coinciding with the development of new volume reduction standards for development and redevelopment that will be implemented in December 2014. Chattanooga is also addressing existing properties through retrofitting with green infrastructures as a way to achieve improvements in water quality.

This presentation will focus on the commercial redevelopment and roadway improvement and mid-town public/private properties.

SESSION 2B

ENGINEERING APPLICATIONS
8:30 a.m. – 10:00 a.m.

The Use of Polymer Enhanced Best Management Practices (PEBMPS) to Combat Soil Erosion, Eutrophication, and to Meet Water Quality Standards
Kyla J. Iwinski

Sidestream Treatment Alternatives for Nutrient Removal and Recovery at Wastewater Treatment Facilities
Tania Datta

Low Impact Design and the Soil Conundrum
Chuck T. Lacey, Jr.

STORMWATER BMPs
10:30 a.m. – 12:00 p.m.

A Comprehensive Watershed Assessment Program for Northern Kentucky Streams and the Communication Tool Developed for Better Public Understanding
Matthew S. Wooten, Douglas Bradley, David Dilks, and Robert J. Hawley

Genetta Ditch Stormwater Treatment Wetland Design and Construction
Brent C. Wood, Charles R. Oligee, Tommy Oliver, William K. Barry, and Judd Langham

Retrofitting Stormwater Infrastructure and Perceptions in a Conventional Suburban Residential Development in East Tennessee
Andrea Ludwig, Ruth Anne Hanahan, Roy Arthur, and Tim Gangaware

MODELING TOOLS I
1:30 P.M. – 3:00 P.M.

Evaluating the Performance of AnnAGNPS Model in Simulating Runoff: Case Study of Obed River Watershed
Nasrin Alamdari, Alfred Kalyanapu, Dennis George, and Yvette Clark

Applying DEM Correction Algorithm to Derive Synthetic Cross Sections for Flood Inundation Modeling for Cumberland River Near Nashville
Md Nowfel Mahmud Bhuyian and Alfred Kalyanapu

GIS Spatial Modeling of Flow Alteration in SE United States
Peter Li and Rick Kittrell

MODELING TOOLS II
3:30 p.m. – 5:00 p.m.

The Annual Update: Nashville SAFE – It Gets Better Every Year!
Roger D. Lindsey

Conversion from a Legacy Stream Course Mode to an Industry Standard Model
Adrian Ward

Concentration-Discharge Relationships in the Coal Mined Region of the New River Basin and Indian Fork Sub-Basin, Tennessee
J.C. Murphy, G.M. Hornberger and R.G. Liddle

THE USE OF POLYMER ENHANCED BEST MANAGEMENT PRACTICES (PEBMPS) TO COMBAT SOIL EROSION, EUTROPHICATION, AND TO MEET WATER QUALITY STANDARDS

Kyla J. Iwinski[1]

Erosion causes sediment and excess nutrients to enter water bodies. The nutrients eroded along with the soil originate from fertilizer, manure, crop runoff, and urban and industrial activities. This not only causes excessive sedimentation of water bodies, but also results in soil and land loss. The washing of nutrients causes eutrophic conditions leading to algal blooms and water quality degradation.

Turbidity levels have varying impacts on aquatic life causing decreased light, food, and oxygen, as well as mechanical effects and temperature increases. In addition to problems created by turbidity, excess nutrients can lead to harmful algal blooms. Algal blooms not only cause aesthetic, odor, and, taste problems, but many species of algae produce toxins that may be harmful to domestic animals and people.

Enhanced Best Management Practices (PEBMP's) involves using anionic, water soluble polymer technologies to enhance current best management practices (BMPs) and greatly reduce sediment loss as well as the amount of sediment and nutrients entering a water body. Two possible solutions are: (1) capture or retain the sediment and nutrients before it can wash into a water body or (2) use polymer enhancement in conjunction with other BMPs to remove nutrients and turbidity. In various tests and case studies using PEBMPs, a 75-85% reduction in phosphorous has been found as well as a 95+ percent reduction in total suspended solids (TSS) and NTU's.

We will look at the most common and effective PEBMPs currently in use to control sedimentation and eutrophication. These include soil stabilization, bank stabilization, polymer enhanced soft armoring applications, de-watering systems, pond and lake clarification including nutrient (primarily phosphorous) reductions, de-mucking, and SRBs (Sediment Retention Barriers).

[1] Applied Polymer Systems, Inc.

SIDESTREAM TREATMENT ALTERNATIVES FOR NUTRIENT REMOVAL AND RECOVERY AT WASTEWATER TREATMENT FACILITIES

Tania Datta[1]

While on one hand the wastewater industry throughout the United States is challenged with meeting stringent nutrient limits to protect receiving water quality, on the other hand, a shifting paradigm within the industry is emphasizing the importance of sustainable treatment practices and management. Sustainable practices include recovering resources, such as water, energy and nutrients from wastewater and reducing greenhouse gas emissions. Thus, implementing anaerobic digestion for biogas production is becoming a norm in most facilities treating wastewater above 10 million gallons per day (mgd). Many facilities are also digesting high strength organic feedstocks from other waste streams to boost biogas production to generate more energy.

The anaerobic digestion process however, results in significant amounts of soluble nitrogen and phosphorus that is recycled back to be treated in the mainstream biological process. This nutrient-rich stream can contain up to 50 percent of the influent nitrogen and phosphorus loads, and treating it to meet the low effluent nutrient limits, can be energy, resource and capital intensive. Sidestream treatment technologies provide alternatives that are able to fulfill the objectives of meeting stringent nutrient limits, as well as being sustainable. In the recent years, researchers from both the industry and academia have developed a number of innovative treatment approaches that specifically target these recycle flows. Some approaches are physical–chemical in nature and others biologically based. They have garnered interest due to their potential cost-effectiveness and ability to recover valuable resources that are marketable. This presentation will provide a review of these treatment approaches.

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LOW IMPACT DESIGN AND THE SOIL CONUNDRUM

Chuck T. Lacey, Jr.

Regulations for water quality and quantity are ever evolving and numerous best management practices (BMPs) are adopted without regard for the native soils. Most low impact design (LID) practices involve the use of natural vegetation such as bio-swales and rain gardens to enhance the landscaping of a site, and more importantly, reduce the runoff that leaves a site thru infiltration. While these BMP's work well on sites having free draining native soils, there are significant limitations to implementing these practices in areas where rock is close to the surface or sites that have poor infiltration rates. Of even greater concern for the engineer of record, is the potential liability for not adequately managing the larger 90+ percentile storm on these sites.
This presentation will:

- Help familiarize attendees with the best practices for reducing runoff (infiltrating) on sites having poor in situ soils.
- Teach attendees how to incorporate structural underground detention systems into bio-retention practices and other BMP's to control both runoff and significantly reduce the amount of sediment, nitrogen and phosphorous (TMDL's) that leaves a developed site.
- Highlight specific projects where underground products have been used in conjunction with natural BMPs as part of the treatment train.
- Provide design professionals and regulators with more tools for their tool belt in keeping our waterways clean.

A COMPREHENSIVE WATERSHED ASSESSMENT PROGRAM FOR NORTHERN KENTUCKY STREAMS AND THE COMMUNICATION TOOL DEVELOPED FOR BETTER PUBLIC UNDERSTANDING

Matthew S. Wooten[1], Douglas Bradley[2], David Dilks[2], and Robert J. Hawley[3]

ABSTRACT

Sanitation District No. 1 (SD1) is a regional utility charged with the management of both sanitary and storm water systems in Northern Kentucky. In order to make informed, data-driven decisions regarding impacts to local streams and watersheds (as opposed to "presumptive" decisions common to past management strategies), SD1 initiated a comprehensive (biological, chemical, physical habitat, and hydromodification) data collection effort to establish current baseline conditions. Biological, habitat and water chemistry samples have been collected through the nearly 600 mi^2 Northern Kentucky region (~80 sites) following protocols outlined by US Environmental Protection Agency and Kentucky Division of Water (Barbour et al 1999, KDOW 2008), while geomorphic surveys were conducted following Harrelson et al. (1994) and SD1 Standard Operating Procedures (2009). Analysis of stream data indicates clear associations with watershed imperviousness and poor stream quality, such as lower biological scores, separation of community structure, loss of riffle habitat and destabilization of stream bed material. In response to rate-payer and/or stakeholders requests, SD1 has also developed a Stream Condition Index (SCI) to facilitate better understanding of monitoring data to the non-scientific audience. The SCI, although not a regulatory tool, provides a summary of large amounts of complex data into four manageable categories (biology, chemistry, habitat, hydromodification), places each on a scale from 0-10 and provides an overall stream condition score at each sampling location. In addition to this simplified ten point scale, color-coded maps of monitoring locations provide residents information on the current condition of their nearby stream for easy interpretation.

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GENETTA DITCH STORMWATER TREATMENT WETLAND DESIGN AND CONSTRUCTION

Brent C. Wood, PE[1]*; Charles R. Oligee, PE[2]; Tommy Oliver, PE[3]; William K. Barry, PE, D. WRE[4]; and Judd Langham, ASLA, LEED AP[5]

ABSTRACT

Phase 1 of the Genetta Ditch project in Montgomery, Alabama, a stormwater treatment wetland, was designed in 2011 and constructed during 2012. The 7.7 square mile watershed comprises a portion of downtown Montgomery, moderate to high density residential areas, commercial areas, parks, and some wooded areas in its downstream portions. Genetta Ditch is culverted for the upper half of its approximately four mile length. The stormwater treatment wetland was designed to divert first flush flow from the end of this existing box culvert (consisting of three 7'x13' barrels), route this flow through an engineered treatment wetland, and return it to the box culvert. This presentation will discuss the history of Genetta Ditch; design options evaluation; the hydraulic, hydrologic,soil, grading, and plantings aspects of the design; anticipated stormwater benefits; and report on lessons learned during the construction. Future plans for stormwater management in the watershed will also be presented.

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RETROFITTING STORMWATER INFRASTRUCTURE AND PERCEPTIONS IN A CONVENTIONAL SUBURBAN RESIDENTIAL DEVELOPMENT IN EAST TENNESSEE

Andrea Ludwig[1], Ruth Anne Hanahan[2], Roy Arthur[2], and Tim Gangaware[2]

ABSTRACT

The Cedar Crossing Subdivision was developed in the mid to late 1990s using a traditional gray stormwater drainage infrastructure. Currently, there are visible failures of this infrastructure that are exacerbating existing urban water quality issues, threatening sanitary sewer and road infrastructure, and creating unappealing aesthetic problems for the residents. The Tennessee Yards and Neighborhoods Management Team has been working within this community of single-family homeowners and condo owners to retrofit their stormwater infrastructure using low impact development techniques. Our goals are to create a demonstration neighborhood to showcase a variety of single-lot best management practices (bmps) and attempt to evaluate the effectiveness of retrofitting by collecting runoff volume and quality data. Through this integrated research and Extension project, we have 1) collected 18 months of baseline runoff volume and water quality data from the existing gray infrastructure, 2) provided a TYN homeowners workshop for interested participants, 3) partnered with other organizations to cost share with homeowners on single lot runoff reduction practices, which has lead to the installation of 6 rain gardens and rain barrels, 4) developed a homeowner- targeted residential stormwater mapping activity, and 5) developed a plan for a large-scale bioretention facility to be implemented in a common use area of the subdivision. We will continue to work with the residents and facilitate bmp adoption while continuing to collect runoff data for the foreseeable future.

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EVALUATING THE PERFORMANCE OF AnnAGNPS MODEL IN SIMULATING RUNOFF: CASE STUDY OF OBED RIVER WATERSHED

Nasrin Alamdari[1], Alfred Kalyanapu,[2] Dennis George,[3] and Yvette Clark[4]

The Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) is an effective distributed model developed by the USDA-ARS and USDA- NRCS. It is well suited to evaluate agricultural best management practices and to estimate pollutant loadings within a watershed. It has been widely used in different water quality modeling studies due to its simplicity and broad capabilities. The objective of this study is to evaluate the performance of AnnAGNPS to estimate runoff for the Obed River watershed (drainage area of 520 mi^2) in Cumberland Plateau region in Tennessee. To achieve this objective, AnnAGNPS model is developed for the watershed and the model is calibrated for curve numbers (CN). Observed runoff data of 2001 to 2006 were compared with simulated runoff using three measures of fit including: Nash-Sutcliffe efficiency (NSE) coefficient, R-squared (R^2) and percent bias (PBIAS) to assess the model performance. Calibration process resulted in NSE, R^2 and PBIAS of 0.71, 0.7 and -0.45%, indicating good match in both monthly and annual time scales and implying a successful calibration process . Calibration processes at different spatial resolutions for runoff has been processed and for two other parameters including sediment yield and nutrients is ongoing and expected to be done in early future.

Key Words: Non-point source pollution, AnnAGNPS, Obed River Watershed, Runoff, Curve Number, Spatial Resolution

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APPLYING DEM CORRECTION ALGORITHM TO DERIVE SYNTHETIC CROSS SECTIONS FOR FLOOD INUNDATION MODELING FOR CUMBERLAND RIVER NEAR NASHVILLE

Md Nowfel Mahmud Bhuyian[1] and Alfred Kalyanapu[2]

ABSTRACT

Digital Elevation Model (DEM) is a source of topographic data for the purpose of flood modeling. Online archives have elevation data available that cover almost entire world. Recently the use of DEM has made it easy to simulate floods in remote and inaccessible regions. DEMs currently available vary both in spatial coverage and interpolation techniques. Although DEMs provide fairly good representation of the land areas, it often lacks in accuracy on waterbodies. National Elevation Dataset (NED) which is the most commonly used DEM in USA shows plain surface over such location. In this study it was hypothesized that this plain surface represents the water surface instead of the river bed. An algorithm was proposed based on the local morphology and the historical hydrologic data to predict the thalweg location and depth of a river. It was assumed that the thalweg tend to locate near the outer bank of a meander and side slopes follow the sinuosity of the river. The depth at thalweg was calculated using Manning's formula for a reference discharge using reasonable Manning's roughness factors. Reference discharge is the flow that corresponds to the elevation available in DEM adjacent to any gaging station within the study reach. Cumberland River at Tennessee was selected as the study area. The base and modified DEM were used to produce geometric data for 1D HEC-RAS model. The model was calibrated for a moderately high flood event (May 2003) and later tested for a high flood (May 2010) and low flood event (May 2013). It was found that the model with base DEM is capable to simulate when the stage is very high but fails during low and intermediate stages. The applicability of base DEM is also limited for any event above 127 m and 3000 m3/s. The modified DEM could be used for simulating both high and low flood events. The RMSE for simulated stage for 2010 and 2013 with the observed stage was 0.404 m and 0.196 m respectively. Comparison of simulated flood map for May 2010 flood event using base and modified DEM with observed flood extent showed error of -3.87% (underestimate) and 16.63% (overestimate) respectively. This algorithm is applicable for single channel river.

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GIS SPATIAL MODELING OF FLOW ALTERATION IN SE UNITED STATES

Peter Li[1] and Rick Kittrell[1]

ABSTRACT

There are more than 7,500 dams in the U.S. Dams serving as a tool for controlling flood, providing irrigation, and navigation purpose. However, dams may also cause flow alternations which in turn has impaired riverine ecosystems. The study use GIS to model the potential of flow alterations due to dams. Information based on NHDPlus (National Hydrography Dataset) and NID (National Inventory of Dams) were used in processing the GIS layers. Stream flows, mean annual flows and stream orders are the main attributes used for developing flow alteration ratio (FAR). Regional variations of FAR are analyzed and patterns were investigated. Stream orders between 4 and 6 show highest FAR in areas closer to Mississippi River, South Carolina and Texas. Texas, Oklahoma, Louisiana, and Arkansas are found to have higher percentage of streams where accumulated dam storage volume exceeding mean annual flow of the streams. Results from the analysis show lower stream orders have higher percent of reaches above 50th percentile of FAR while higher ordered streams show higher percentage of reaches above 90th percentile of FAR. The regression patterns indicate streams with higher accumulated storage have higher FAR. Results from this study can provide insights to the regional variation of stream alterations and relationship between stream orders and FAR, which in turn to help policy makers in identifying the impaired streams due to flow alteration in southeastern United States.

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THE ANNUAL UPDATE: NASHVILLE SAFE – IT GETS BETTER EVERY YEAR!

Roger D. Lindsey[1]

Following the historical flood in middle Tennessee on May 1 and 2, 2010, the Metro Government of Nashville and Davidson County embarked upon the creation of a flood forecasting and prediction system that would enable effective decision-making in the Emergency Operations Center during a similar flooding emergency. Initial efforts resulted in the development of a functional forecasting tool that has come to be known as "Nashville SAFE". While presentations have addressed the functional features of the Nashville SAFE tool at prior conferences, subsequent phases of development have added additional features that make this model even more effective. Additionally, the tool is being adopted to provide similar capability for flood forecasting in Chattanooga, following the model that underlies the Nashville SAFE tool.

This presentation is intended to provide an update of the subsequent phases of development of the Nashville SAFE Tool, as well as to present the features of the new Nashville NERVE (Nashville Emergency Response Viewing Engine) which has been developed to provide flood and other emergency response information for the citizens of the Nashville and Davidson County area.

(If appropriate, we would be glad to assemble a series of related Nashville Flood-related topics that could be presented during a single session.)

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CONVERSION FROM A LEGACY STREAM COURSE MODEL TO AN INDUSTRY STANDARD MODEL

Adrian Ward[1]

In response to the US Nuclear Regulatory Commission Post-Fukushima Request for Information Letter in accordance with 10CFR50.54 (f) received from the Nuclear Regulatory Commission (NRC) on March 9, 2012, legacy stream course models used in the utility industry are required to be updated to industry standard models. The 50.54(f) letter requires the applicant to complete evaluation of the flood hazards based on present-day methodologies and regulatory guidance. The guidance document, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America, NUREG/CR-7046 published November 2011, specifies use of present day methodologies including current techniques and software. This abstract provides an overview of the conversion from a Fortran-based model used for large-scale reservoir system modeling to a United States Army Corps of Engineers (USACE) Hydrologic Engineering Center-River Analysis System (HEC-RAS) model.

The Fortran-based program was developed in the 1970's to route discharges through a network of open channels and reservoirs in an expansive reservoir system. While the legacy codes have the ability to accurately model storms with varying magnitude, the codes require the use of text input files to describe the channel geometry, inflows, and boundary conditions. Manipulation of these input files, especially during a Probable Maximum Flood (PMF) event, to adjust geometry data, discharge coefficients, and other factors often requires an iterative process that is cumbersome and requires significant time to determine flood levels at a location of interest. Recent conversion to a HEC-RAS model allows a continuous simulation of the same river system to be performed in a matter of minutes by taking advantage of the use of user-defined unsteady flow rules.

Some of the obstacles in making this conversion from the legacy code to HEC-RAS include the following:

- Validating and verifying the HEC-RAS software. Due to the quality assurance (QA) requirements for developing safety-related calculations, software must be put through a series of tests to ensure the software produces accurate results before it can be used to determine flood elevations for nuclear facilities. Examples of the applications that HEC-RAS was evaluated for includes testing the effects of abrupt changes in discharge, slope and channel width and dam failures. The validation and verification process also included testing to confirm that the HEC-RAS software performed correctly with the computer's operating system.

- Developing a set of HEC-RAS geometry files. The legacy code required that hydraulic properties of channel cross-sections be represented by a text file that contained predetermined values of area, conveyance and storage. These geometry files were

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compiled using other legacy codes. Errors could easily occur during development of these files since there is not a graphical interface to help the user identify errors. Also, these codes could not easily account for features such as ineffective flow areas, levees and obstructions, which HEC-RAS easily handles.

- Developing a set of unsteady flow rules. A set of unsteady flow rules had to be developed for each of the eight dams on the river. Use of the legacy code required that portions of the river be broken into sections in order to solve for the looped tailwater effect, which occurs during large volume storm events, such as a PMF. The looped tailwater effect is a storm specific phenomenon that must be solved for each storm event. During the simulations performed with the legacy code, this effect was solved by an iterative process of running a simulation, extracting results, modifying rating curves for changes in coefficients and flow and re-running the simulation until convergence of the headwater/tailwater/discharge relationship. The most current version of HEC-RAS allows the user to solve for this looped tailwater effect with a single simulation by using a set of scripting rules to describe the discharge through the dam.

The main benefit from this conversion process is efficiency. A process that previously took weeks to determine the water surface elevation at an area of interest can be done in a matter of minutes. Data extraction and plots are more readily accessible which allows calculations and engineering reports to be developed more quickly.

CONCENTRATION-DISCHARGE RELATIONSHIPS IN THE COAL MINED REGION OF THE NEW RIVER BASIN AND INDIAN FORK SUB-BASIN, TENNESSEE

J.C. Murphy, G.M. Hornberger, and R.G. Liddle

ABSTRACT

For many basins, identifying changes to water quality over time and understanding current hydrologic processes are hindered by fragmented and discontinuous water-quality and hydrology data. In the coal mined region of the New River basin and Indian Fork sub-basin, muted and pronounced changes, respectively, to concentration-discharge relationships were identified using linear regression on log-transformed historical (1970s-1980s) and recent (2000s) water-quality and streamflow data. Changes to concentration-discharge relationships were related to coal mining histories and shifts in land use. Hysteresis plots of individual storms from 2007 (New River) and the fall of 2009 (Indian Fork) were used to understand current hydrologic processes in the basins. In the New River, a peak-flow threshold of 25 cubic meters per second (m^3/s) segregates hysteresis patterns into clockwise and counterclockwise rotational groups. Small storms with peak flow less than 25 m^3/s often resulted in dilution of constituent concentrations in headwater tributaries like Indian Fork and concentration of constituents downstream in the main stem of the New River. Conceptual two or three component mixing models for the basins were used to infer the influence of water derived from spoil material on water quality.

SESSION 2C

RESTORATION
8:30 a.m. – 10:00 a.m.

Urban Stream Restoration Design Utilizing a Threshold Channel Approach and Habitat Evaluation
William K. Barry, Keil Neff, Charles R. Oligee, and Michael K. Pannell

Stream Restoration in an Urban Watershed: Short Story, Small Town
Karina Bynum

Improving Water Quality Through Stream Restoration at Town Branch: An Urban Watershed Case Study
Russ Turpin and Arthur Parola

STREAM CHANNEL EROSION
10:30 a.m. – 12:00 p.m.

A Review of Erosional Processes Along a River Continuum: Watershed-Scale Implications for River Restoration Planning
Zachariah T. Seiden and John S. Schwartz

Predicting Site-Specific Daily Streambank Erosion Using GPS-Based Watershed Scale Video Mapping and EPA BANCS
Kelsey Hensley, Paul Ayers, Ken Swinson, and Brett Connell

Streambank Erosivity and Substrate Mapping Using SVMS on the East Fork Poplar Creek
Daniel Wade, Paul Ayers, Kelsey Hensley, and Scott Brooks

SURFACE WATER
1:30 p.m. – 3:00 p.m.

Use of Continuous Turbidity Monitoring Data to Identify Biological Impairment Due to Suspended Sediment in East Tennessee Streams
Robert Woockman, John Schwartz, and Carol Harden

Stories of Change: The Tennessee Healthy Watershed Initiative
Trisha D. Johnson

Analytical Determination of Sources of Organic Pollution in Natural Waters
John Harwood, Sreedharan Lakshmi Narayanan, and Sushma Meka

EDUCATION IN THE AG COMMUNITY
3:30 p.m. – 5:00 p.m.

The USGS Velocity Mapping Toolbox, an Overview of How VMT Can Improve the Data Processing and Presentation of ADCP Transects
Daniel Saint

A Study of Cattle Producer Preferences for Best Management Practices in an East Tennessee Watershed
Dayton M. Lambert, Christopher D. Clark, Shawn Hawkins, Forbes R. Walker, and Alice C. Layton

Oostanaula Creek Watershed Restoration Project: The Worst Best Worst Project Completed in Years
Lena Beth Reynolds

URBAN STREAM RESTORATION DESIGN UTILIZING A THRESHOLD CHANNEL APPROACH AND HABITAT EVALUATION

William K. Barry, PE, D. WRE[1]; Keil Neff, PhD., PE[2]; Charles R. Oligee, PE[3]; and Michael K. Pannell, CPESC[4]

The successful restoration of streams in urban areas is challenging due to the complexity associated with constraints including roads, buildings, flood regulations, utility infrastructure and multiple landowners. Efforts are currently underway to rehabilitate an urban reach of Genetta Ditch, a stream draining a large portion of Montgomery, Alabama. The Genetta Ditch watershed is comprised of a portion of downtown, moderate to high density residential areas, commercial areas, and parks, with limited forested areas downstream of the project area. Genetta Ditch is culverted for the upper half of its approximately four mile length. Immediately downstream is the subject project, an approximately 2,700 foot trapezoidal concrete channel that is parallel to, and within the right of way of, Interstate 65. To complement a threshold stream restoration design of the concrete lined stream section, *River2D*, a two-dimensional, depth averaged, finite element model, was utilized to provide guidance for geomorphic stability and placement of in-stream structures. Additionally, *River2D's* implementation of the US Fish and Wildlife Service's Physical Habitat Simulation System (*PHABSIM*) was utilized to evaluate the physical habitat of the restored channel design. Connection of tributaries to the restored channel also presented unique challenges requiring use of a stepped chute design. The use of *River2D* and the stepped chute design approach will be discussed.

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STREAM RESTORATION IN AN URBAN WATERSHED: SHORT STORY, SMALL TOWN

Karina Bynum[1]

Stream restoration in small towns faces a shortage of funds and resources as well as the typical constrains of a built environment and urban runoff effects. In Crossville, TN, integrated approach to stream restoration includes stormwater and land management practices of the contributing watershed as well as infrastructure rehabilitation of walkways and sewer lines. On a single project, improvements to water quality and water quantity were a part of the design from the start. Integration allows for true optimization of resources and maximal use of expended funds. Success hinges on personal communication and free cooperation of the sewer project manager, stormwater coordinator, community leaders in stream restoration and the manager of the municipal park lands. Such environment must be created from within the community of the watershed and be supported by a chief executive sponsor within the governing municipal authority. Crossville project in the Centennial Park serves as an ongoing example of the new paradigm of restoring and managing urban ecosystems and the city infrastructure.

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IMPROVING WATER QUALITY THROUGH STREAM RESTORATION AT TOWN BRANCH: AN URBAN WATERSHED CASE STUDY

Russ Turpin[1] and Dr. Arthur Parola[2]

Improving stream water quality and restoring physical stream stability and habitat have both been shown to increase aquatic life and stream health. However, physically degraded, urban streams with poor water quality from non-point source pollution have often been excluded from receiving regulatory agency and/or funding support due to concerns that restoring the physical habitat could be in vain if the water quality is too poor to support robust aquatic life.

Town Branch (a tributary to Strodes Creek in Clark County), is a typical stream for the Bluegrass Region in Central Kentucky. It has many of the issues and ailments of urban waterways in this area including anthropogenic alterations such as channel straightening and dredging, draining of adjacent wetlands, sewer/utility lines, non-point source pollution from urban runoff, and limited riparian forest buffer.

The Kentucky Transportation Cabinet (KYTC) partnered with the Strodes Creek Conservancy to restore approximately 7,000 feet of degraded Town Branch channel on City of Winchester property as an advance stream mitigation site. Due to concerns that the runoff from the mostly urban watershed would cause poor water quality in the stream, the U.S. Army Corps of Engineers and Kentucky Division of Water set high standards for biological success for the project.

To ensure the project met the biological success criteria, KYTC incorporated several measures into the stream restoration project to improve stream water quality, in addition to restoring the physical stability and habitat of the stream. This presentation highlights innovative features and techniques used to improve stream water quality, as well as stream stability and habitat, as part of stream restoration in an urban watershed.

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A REVIEW OF EROSIONAL PROCESSES ALONG A RIVER CONTINUUM: WATERSHED-SCALE IMPLICATIONS FOR RIVER RESTORATION PLANNING

Zachariah T. Seiden[1] and John S. Schwartz[2]

ABSTRACT

Management of sediment within watersheds disturbed by human activates is vital for the biological protection of our nation's waterways. Excessive fine sediment in rivers and streams is the most cited cause for water quality impairment in most states, leading to the development of total maximum daily loads (TMDLs) for 303d listed waterbodies. Understanding the potential sources of fine sediment generated by erosion processes that change from headwater areas to lower river reaches is important in the development of effective watershed management strategies. These strategies need to regulate sediment transport within natural ranges that support native lotic biota. Reviews of the erosion processes from field-scale overland (sheet) flow, shallow concentrated flow, first-order gully and headcuts, and stream channel bed and bank were examined, and differences defined. Recognizing the process differences and the potential sediment yields per watershed location provides a mean to assess whether restoration efforts are best implemented. Overall, this paper summarizes different erosional processes along a river continuum, describes how scale can skew sediment yield estimation, and elaborates on how scale can alter which best management practices are used.

INTRODUCTION

The management of sediment within watersheds disturbed by human activities is critical for the protection of national waterways. Excessive fine sediment in rivers and streams is the most cited cause for water quality impairment in most states. In order to better link sediment source generation and watershed sediment yields, a better understanding of how different erosional processes and their spatial distribution within a watershed can affect the character of sediment export. Four main types of erosional processes are identified in this paper; they are uplands, rills, gullies, and stream. Processes are positioned hierarchically in a watershed in various sequential orders depending on the land disturbance regime (Figure 1). The sequential order, number of stream linkages, and size of watershed all influence the observed sediment yields and composition transported. It is necessary to understand the impact of scale and disturbance on sediment yields. Sediment yields from watersheds with undisturbed land cover can generally be attributed to uplands and stream erosion, where the land may consist of natural runoff flows through dense vegetative cover. As land cover in the watershed is disturbed a hierarchical nature is created for streams within a watershed, as illustrated by Figure 1, below.

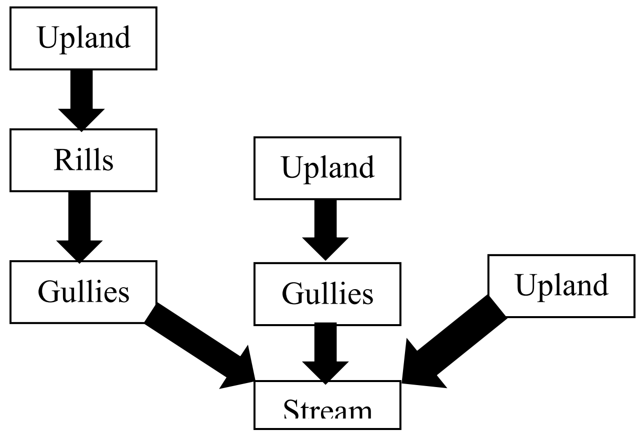

Figure 6. Hierarchy of a River Continuum

As Figure 2 indicates below, greater disturbances increase the definition of this hierarchy and cause the erosional processes contributing to the sediment yield in the stream grow more complex. With undisturbed lands, the uplands erosional processes are primarily gravity driven, with detachment and transport carried out by raindrop impact and sheet flow; the erosional processes in the stream are driven from velocity and shear stress. With increased disturbance, rills and gullies begin to develop. With the development of these rills and gullies, there becomes a transition from erosion governed by gravity to erosion governed by velocity. This transition becomes the most notable when rill erosion gives way to ephemeral gully erosion. Because raindrop impact and shear stress both yield sediment erosion at this point, it becomes very difficult to tell which forces are the more dominant. As the river continuum continues to evolve, the velocity forces grow stronger, with increased flow. This in turn allows for greater variation in particle size and characteristics. With uplands and rill erosion, only small particles that can be easily cleaved from raindrop impact will detach and transport. Due to dominance of shear stress in gullies and streams, combines with increased stream power, larger particles can be detached and entrained. As a result of this variation, it becomes difficult to know the best management practices required to mitigate the sediment yield of the watershed.

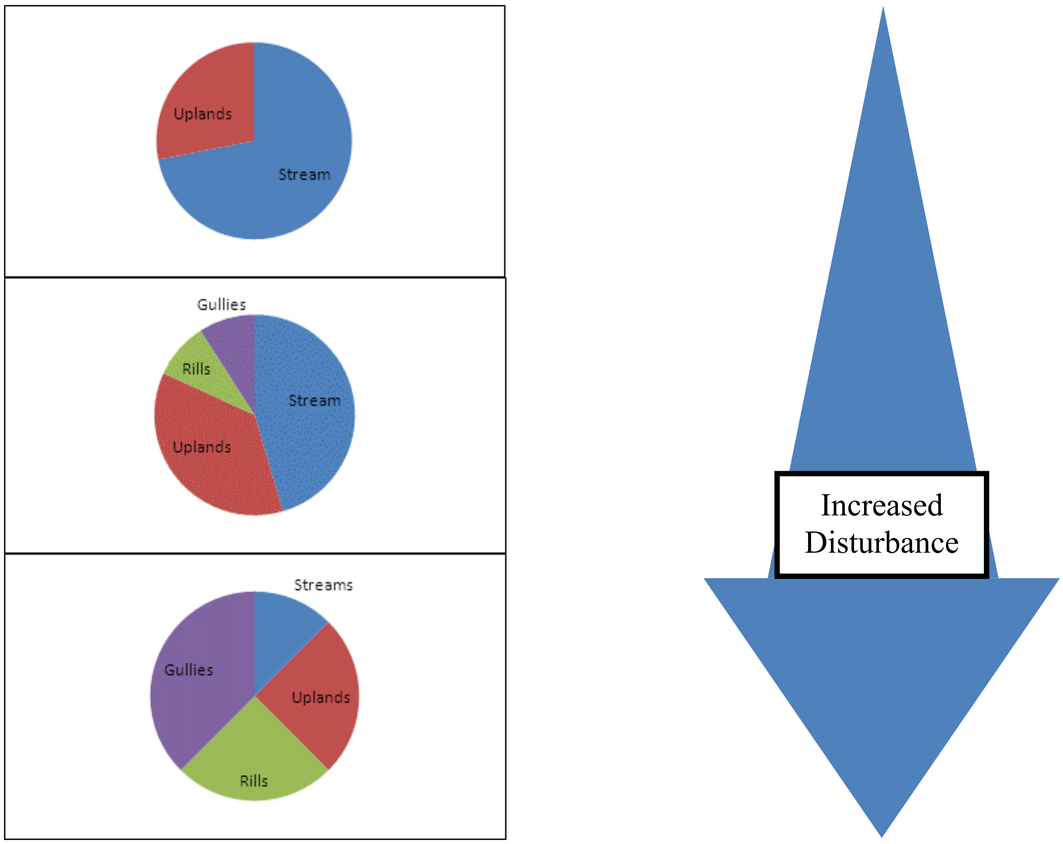

Figure 7. Hypothetical Erosional Contribution as Disturbance Increases in a Watershed

The purpose of this paper is to describe the governing factors for four erosional processes along a river continuum; they are uplands, rill, gully, and stream bed/bank. In addition this will set the stage for development of a conceptual framework to better predict sediment yield, and link in-stream sediment size, composition, and transport characteristics to the dominant sources in a watershed. Coupled with remote sensing and/or field survey, land managers could target restoration funds to the dominant sediment source, whether it is disturbed uplands fields with gullies, or stream bank. As a result, the type of BMPs deployed may change, depending on if resources are to be expended for uplands stormwater controls or stream restoration.

DEFINITION OF EROSION ALONG THE RIVER CONTINUUM

The River Continuum

The river continuum is the developmental gradient by which streams not only form, but also facilitate the transport of water. This continuum begins with the overland sheet flow from storm and irrigation runoff. In areas where the land has been greatly disturbed, this runoff will often cause shallow concentrated formations known as rills. These rills drain into larger channels, often creating ephemeral gullies. As gullies drain increasing amounts of water, they discharge into larger streams that often have consistent base/stream flow present regardless of precipitation events. As this continuum evolves, so do the erosional processes that govern sediment yields; not only do the governing processes vary, but the particle size and characteristics vary as well. To better understand how these variations impact best management practices, it is necessary to understand the physical processes that govern erosion throughout this continuum.

Erosion

As the river continuum progresses, different factors and processes govern the rate and extent of erosion. Erosion is defined by two characteristics. The first is the sediment capacity. The sediment capacity can be defined as the amount of sediment that a given flow can theoretically transport. This sediment capacity is dependent on the physical characteristics over which the water flows. This includes geometry, channel depth/width, wetted perimeter, alignment, slope, vegetation, roughness, velocity distribution, turbulence, etc. (Julien, 2010). The second characteristic is that of the sediment load, the actual sediment available for transport. The available sediment will vary based on watershed characteristics such as topography, vegetation, land use, soil types, etc. Along with this, the sediment load is dependent on hydrological processes and soil characteristic. Hydrological processes include the intensity and duration of a storm as well as the erosion from water flow. The soil characteristics that most impact the soil load are the specific gravity, cohesion, and mineralogy of the soil particles.

If the sediment load is less than the sediment capacity, the sediment transport will occur. Transport of sediment depends on two factors, the detachment of the soil particles and the transport of the particles downstream. Detachment is the process by which particles are separated from the bulk soil. In fields, this will often occur with rainfall. As rain reaches terminal velocity and strikes the ground, the power density (Power/area) is strong enough shear cleave the particles from the bulk soil. According to Julien, this power can be as high as 10 Pa (Julien, 2010). As the water continues to flow, shear stress of the fluid will approach and surpass the critical shear of the soil at the point of incipient motion. This also results in soil particle detachment. As the flow stage increases, the raindrop impact begins to diminish and the shear stress becomes the dominant detaching mechanism. Once the sediment is detached, transport can occur. Partial transport occurs from the raindrop impact on bare soil. As particles are detached from the bulk soil, they are launched into the air and transported by gravity and winds. The dominant form of transport is entrainment/re-entrainment.

Entrainment is when particles are carried by the stream. During this time, gravitational force will cause the particles to settle. Turbulent kinetic energy from the water flow prevents settling from occurring. As a result, the particles are dragged down slope. Re-entrainment is when particles that have settle are swept back into the fluid flow due to the shearing stresses and turbulent kinetic energy. If the sediment load exceeds the sediment capacity, then entrainment fails and deposition occurs. While the general erosion process is described above, there are specific characteristics and micro-processes that govern the erosion rates in different stages of the river continuum. For the purpose of this paper, the river continuum is categorized into several different segments: sheet/rill erosion, ephemeral gully erosion, and stream erosion. By gaining deeper knowledge of erosion in these segments, it is possible to better understand how implementation of best management practices must be targeted.

Sheet/Rill Erosion

In disturbed lands, one of the initial sources of sediment comes from sheet and rill erosion. Sheet flow is the uninhibited flow of water over a field. In sheet flow, the depth of the water is often shallow enough that the primary detachment mechanism is raindrop impact. This combined with the entrainment of the particles will often result in rill formation. Rills are defined as “small, ephemeral concentrated flow paths which function as both sediment source and sediment delivery systems for erosion on hillslope” (Nearing et al., 1997). With sheet and rill erosion, the drainage area is can vary greatly within the watershed. The contributing areas can range from a several acres to several hundred acres. These contributing areas will be near the top of the topographic slope that drains into the larger stream. As a result, sheet and rill erosion are the first contributing sources to sediment yield in a stream. In Figure 3, sheet flow is represented by the area in red, while rills are represented in green.

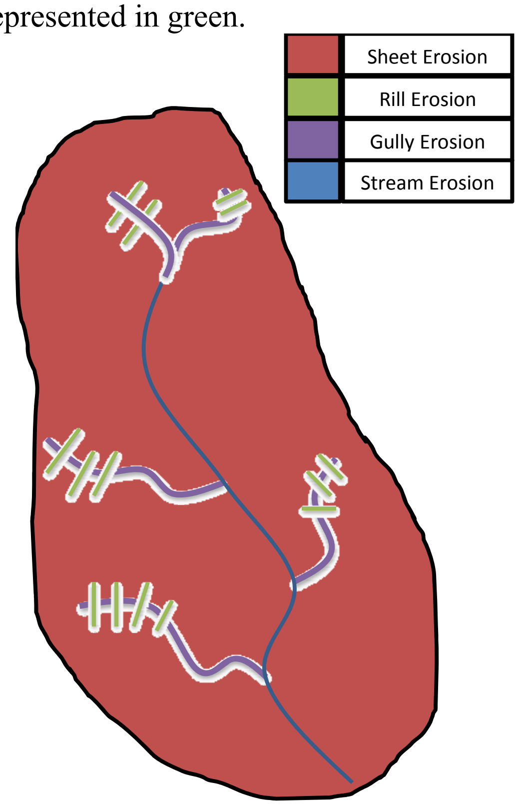

Figure 8. Synthetic Watershed Indicating Erosional Sources

There are several trains of thought when it comes to the governing processes of rill erosion. These models can be summarized into three specific categories (Govers, Giménez, & Van Oost, 2007). The first is that the detachment and sediment load are treated independently. In this model, shear stress is used for detachment, occurring as the path length grows. Once the sediment capacity is met, however, detachment no longer occurs (Elliot & Laflen, 1993). The second modeling concept is defined as detachment-transport coupling (Foster & Meyer, 1971). In this model, detachment and sediment loading are proportionally related. In particular, detachment is proportional to the loading capacity, time of concentration, and the sediment load itself. This relationship suggests that as the sediment load increases, turbulent kinetic energy is dissipated and the detachment within the rill decreases (Govers et al., 2007).

The third field of thought is that detachment and loading are a balance of sub-processes. In this model, stream power is used for four processes. The first is to overcome the cohesion mechanism and thus cause detachment. The second is to cause entrainment of the sediment. The third is re-entrainment of deposited sediment. The fourth is to dissipate energy in the form of heat and noise. In this model, detachment is a result of entrainment of particles from the flow bed, deposition of particles in transport, and re-entrainment of previously deposited particles. Note that rainfall impact is neglected. Finally, detachment changes as a result of "sediment shielding", thus causing an increase in deposition and re-entrainment in greater concentrations. The logic behind this is that sediment transport along the flow bed prevents further detachment. The deposition and remixing of sediment prevents new detachment/transport.

In a comparative analysis of these models yielded interesting results. Yao was able suggest that slope plays a critical role in rill erosion (Yao et al., 2008). This is sound, from the standpoint that the greater slope will increase the flow velocity and thus the shearing force. In addition, a greater slope will decrease the critical shear required for detachment.   Another study, performed by Govers, et al indicates that erosion is independent of slope. Their study suggests that flow velocities are correlated to the bed morphology and flow conditions. Along with this, they found an average Froude number near critical value. In addition, there was consistency in the results yield from mountain flow as well as non-mountainous flow. This indicates that the use of a constant manning's n is not appropriate. In reality, the manning's n must increase with slope gradient, thus accounting for slope independence. In both cases, slope dependency occurs when the flow bed is fixed and the manning's n assumed constant.

This indicates that the interaction is dependent on morphology, not slope (Govers et al., 2007). These results are supported by Nearing, who discovered that slope does not greatly impact the flow velocity. In this study, it was determined that stream power is a strong indicator for rill erosion. This study also indicated that transport capacity may be the limiting factor in rill erosion, as opposed to detachment. Finally, Nearing discovered that head cuts were sediment sources in the rills. Plunge pools serve as sinks for sediment deposition. These sinks then become sediment sources when flow increases (Nearing et al., 1997). Along with this, Govers et al studied the governing processes in detachment. They found that detachment is connected to excess shear stress. Shear stress accounts for the presence of various bed materials and can be calibrated for the land cover. The other contributing factor to detachment is stream power (Govers et al., 2007). In this case, they only evaluated the flow rate and slope. Calibration is still required to account for the geometry and bed material.

An evaluation of the capacity-transport coupling method indicated that while there is a correlation, they two should not be treated as a couple (Govers et al., 2007). Flume studies indicated an increase in sediment load as the capacity was reached. As the sediment load increase, the maximum capacity also increased. This directly contradicts the sediment capacity concept. In gully studies, transport limited systems had upstream degradation. Detachment limited systems had uniform degradation throughout the gully. This suggests that while there is a connection between capacity and loading, it is not a first-order or direct relationship. The results of this testing indicates that models dependent on slope are not necessarily applicable in nature and that the relationship between sediment load and detachment is ambiguous at best. With sheet and rill erosion, the sediment that is transported has characteristics that make it prone to detachment through raindrop impact, including particle size. Sediment yield from sheet and rill erosion is often consistent of smaller particle sizes. If the sediment load in a stream contains small particles, then sheet and rill erosion must considered for implementation of best management practices.

<u>Ephemeral Gully Erosion</u>

As rills continue to develop, they may discharge into the next part of the river continuum: gullies. In slope gully systems, there are ephemeral gullies, which serve as the transitional step between rills and regular gullies (Gong et al., 2011). Ephemeral gullies are defined as “small channels eroded by concentrated flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events (America, 2010). These lead into larger gullies, which are too large to be destroyed by normal tillage operations (Le Roux & Sumner, 2012). While rills run down slope, ephemeral gullies will typically develop in low topographic regions, collecting the discharge from rills. Gullies are more prevalent in areas that have had approximately 100 years of intense cultivation (Zhang, Wu, Lin, Zheng, & Yin, 2007). In Figure 3, gullies are represented in purple. The greatest differences between these and rills are that they allow for a greater flow depth, lower velocity, greater resistance, and their primary input energy is gravity. As a result of this, gullies tend to resemble streams more than they do rills when discussing erosion.

With ephemeral gully erosion, several factors have critical impacts with the detachment and entrainment processes. While the gullies are ephemeral, the primary detachment mechanism will be raindrop impact. This will be the case until the gully starts draining the upland fields and rills. Once the gully starts to show consistent flow, the rainfall impact will have significantly less erosional contribution than the surface flow and upstream erosion. At the point that the gully is flowing consistently, the hydrodynamic elements and processes will better reflect those of stream flows. At this point, factors such as discharge, flow shear stress, runoff kinetic energy, unit stream power, and the Froude number become driving components in the erosional process. Because there is this transition, gully erosion is classified as having an initial adjustment period, leading into a somewhat stable period afterward (Gong et al., 2011).

Along with the transition from upland flow to stream flow, gullies have added depth and complexity due to temporal and spatial changes. Temporally, gully erosion will vary depending on the season. According to Zhang et al, gullies that develop in the summer will be wider than those in winter (Zhang et al., 2007). This is likely due to frozen soil resisting erosion, while summer soils will allow for greater initial sheet erosion. Spatially, gully erosion will vary in relation to the channel cutting that occurs. Many gullies will have “step-pools”, where the water will erode small pools, with a sediment “step” leading into them (Gong et al., 2011). As sediment is transported along the gully system, deposition will fill these pools and head cuts will make their way up the channel.

While ephemeral gully systems are the transition between rill and stream systems in the river continuum, the majority of sediment loading is attributed to them. In several, it is estimated that gullies contribute as much as 70-85% of the total sediment load in a system (diCenzo & Luk, 1997; Gong et al., 2011; Zhang et al., 2007). There are two key factors that contribute to this conclusion. The first is that there is significant deposition within the gully. As a result, much of the clay and silt transported from rills will experience re-entrainment from within the gully. Along with this, there is the fact that gullies are subject to stream bed erosional processes. Because of this, they have a tendency to contribute coarser materials than upland and rill erosion to downstream flows (Guo, Zhang, Wang, Yao, & Ma, 2012). This results in a total load contributing both upland soils such as silt and clay, as well as larger materials including sand and larger stones and debris.

Stream Flow Erosion

As gullies continue to flow, they eventually discharge into streams. As this river continuum progresses, the scale of the flow continues to increase. While sheet and rill flow are localized to fields, and gullies while gullies connect various fields and hillslopes, streams expand to a much larger scale. On this scale, the contributing area is large enough that there can be hydrological variations along the stream itself, causing erosional processes to vary as well.

Despite having this inherent variability along the stream, erosion can still be summarized by two processes: bed erosion or bank erosion. In each case, the raindrop impact has very little contribution to detachment. Bed erosion is characterized by cohesionless sediment being transported in a manner uninfluenced by raindrop impact (Hairsine & Rose, 1992). The physical forces causing detachment are the same that occur in rill and gully erosion. This is when the shear stress of the water surpasses the critical shear stress of the bed. At this point, the soil particles detach and flow downstream. River bank erosion, however, can occur in different manners. One method of bank erosion is due to fluvial entrainment, which is the same process as bed erosion (Veihe, Jensen, Schiotz, & Nielsen, 2011). This causes the river bank to steepen, thus causing instability(Osman & Thorne, 1988). In some cases, side wall erosion will occur in a manner that creates a soil bank shelf. Over time, the weight of the bank shelf will grow too great and the overhang will give way. This is largely dependent on the physical and chemical composition of the bulk soil (Osman & Thorne, 1988). The final method is when the cohesive forces in the bank are too weak and the bank collapses in a landslide fashion (Veihe et al., 2011). In a study carried out by Osman and Thorne, it was determined that nearly half of the sediment load from a stream was contributed from the steam bank, rather than the stream bed (Thorne & Osman, 1988). As a result of this, it was shown that a widening stream is able to transport larger amounts of sediment from upstream sources (Thorne & Osman, 1988). It should be noted that in the case of larger streams, large rocks and debris can be transported downstream along with the sediment.

Stream erosion can vary greatly both temporally and spatially. The erosional processes that streams undergo will vary with time. This could be due to changes in scale, climate, land use, etc. Along with this, there is spatial variability in the erosional processes that will occur. If an are upstream has a heavily vegetated and protected riparian zone, it will have significantly less bank erosion than an area downstream that may be exposed. It should be noted that while small rooted vegetation will strengthen a stream bank, the weight of large trees can actually weaken a stream bank, making it more susceptible to failure (Thorne & Osman, 1988). Along with this, variation in the bed form will lend itself to different erosional processes. In particular, the presence of bends, pools, and riffles will greatly impact sediment transport. As flow enters into a bend, sediment will deposit along the outer edge of the bend, while the water will erode the inner bank. As time continues, the deposited sediments will protect the outer bank, diverting the flows towards the inner bank; this causes that bank to erode (Thorne & Osman, 1988). This will result in the bend inverting, giving the appearance of the bend “moving” downstream. With pool and riffle sequences, high flow rates will cause sediment from shallow riffles to detach and flow downstream. This sediment will settle out in pools, resulting in deposition. As a result, pool-riffle sequences will lend themselves to spatial variation. Along with this, Thorne and Osman noted that, in large watersheds, stream banks will cyclically surpass the threshold for incision, thus causing spiked sediment discharge(Thorne & Osman, 1988). After this occurs, there is a period where the stream bank levels out and the sediment yields return to normal.

Because streams have the capability of transporting larger volumes of water, the stream power generated allows for larger sediment and debris to be transported. Because streams continue to grow with erosion, and transport sediment in the process, they allow for larger particles and debris to transport downstream. While this is the case, streams still transport sediment of smaller particle size. Because of this, it is difficult to know whether the primary sediment source is from upland rills and gullies, or from stream beds and banks. Because best management practices differ greatly when addressing uplands and streams, this matter of scale becomes a major concern.

SPATIAL SCALE AND WATERSHED MANAGEMENT PRACTICES

With the different erosional processes defined for sheet/rill, gully, and stream erosion, the issue of spatial variability makes determining the best land management practices a complicated situation. Figure 4, below, shows the same synthetic watershed as in Figure 3, with several hypothetical sampling locations marked.

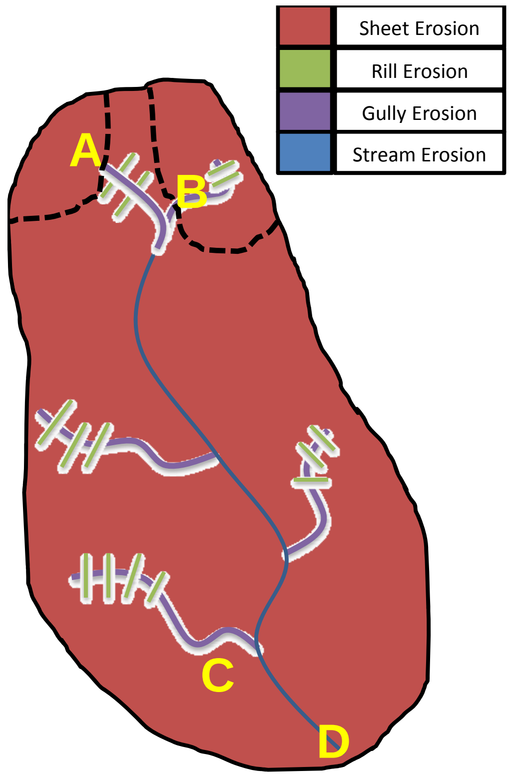

Figure 9. Synthetic Watershed with Hypothetical Sampling Locations

In the case of sampling point A, any sediment yield that is measured can easily be attributed to sheet erosion, as noted by the dashed line. As a result of this, it can be assumed that the primary source of sediment detachment is raindrop impact. This indicates that the best way to limit the sediment yield would be to increase ground cover and thus interception of the raindrops. Sample point B, if located in a gully, becomes more complicated. At sample point B, it is now necessary to evaluate what sediment is contributed from the uplands, rills, or the gully itself. By increasing the spatial scale, the matter of land management has become far more complicated. If the gully is the leading sediment contributor, then it may be possible to stabilize the gully banks and bed and ignore the sheet/rill erosion upslope. If, in this same situation, the sheet and rill erosion is occurring in an agricultural field, then it could be that the sheet and rill erosion may be the primary sediment sources. As a result, conservative farming practice may be more important than stabilizing the ephemeral gully.

Where the greatest difficulty in assessing land management occurs is when sediment yield in a watershed is measured at the outlet, as is in sampling point D. At this point in the watershed, it becomes difficult to determine the primary sources of sediment yield. As discussed in the erosional summaries, gullies can account for as much as 80% of sediment erosion in a basin. At the same time, if the soil at location C is very loose, then it is possible that the sheet erosion from this point is the primary source of the sediment yield at point D. At the same time, it is possible that one or more areas of the upstream banks have surpassed their incision threshold. If this is the case, then bank erosion could be the primary sediment source at point D.

The key question then boils down to what management practice is best used, and where? If the stream banks are yielding the most sediment, then a simple riprap or riparian buffer zone may reduce the sediment to environmentally safe levels. At the same time, if the banks are stable, then it may be that the sheet erosion is the primary cause. If this is the case then better land management, such as no till or vegetative buffer strips, would be more effective than any stream bank stabilization.

As it is now, there are different methods of determining the primary source of sediment and the best way to mitigate the sediment loading. A very popular method is through the use of computer modeling. Programs such as the Soil Water Assessment Tool (SWAT), Agricultural Non-Point Source Pollution (AGNPS) model, and the Water Erosion Prediction Project (WEPP) model are used to estimate erosion in a watershed and the impact of various land management regimes. While these can be used to create targeted best management practices, they require “ground-truthing” in the form of data collection to verify their accuracy. This can be costly both financially and temporally. Another approach that is often used is a “wide-net” approach, where any number of best management practices are used with the hopes that one or more will reduce erosion in the watershed. The issue with this is that it can be difficult and expensive to implement multiple land management practices across a large watershed. Furthermore, because the exact sediment source is not identified, implementation of a land management practice where one is not needed may exasperate the problem rather than fix it.

CONCLUSION

As land is disturbed more and more, erosion increases dramatically. In particular, rills tend to develop in lands that are highly disturbed. As rills discharge into gullies, and gullies into larger streams, erosional processes continue to transform and evolve. On a field and rill scale, raindrop impact is responsible for the majority of detachment, while detachment in the stream scale occurs due to shear stress of the water surpassing the critical shear stress of incipient motion. In gully erosion, there is a transition from rill processes to stream processes. As a result of these processes, sediment loading in streams can cause significant impairment. While best management practices can be used to mitigate these sediment yields, accounting for the spatial scale of the erosion has become a critical concern. Depending on where the sediment loads are being measured, it can be very difficult to know which part of a river continuum is making the most significant contributions. Currently, different computer models are used to estimate the impacts of best management practices on sediment yields. Along with this, a popular practice is to implement multiple best management practices with the hopes that one will address the erosional problems within the watershed. Even though these approaches each have their strengths, the complexity of spatial scale still makes it difficult to effectively address the specific source of erosion.

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PREDICTING SITE-SPECIFIC DAILY STREAMBANK EROSION USING GPS-BASED WATERSHED SCALE VIDEO MAPPING AND EPA BANCS

Kelsey Hensley[1], Paul Ayers[1], Ken Swinson[1], and Brett Connell[1]

According to the US Environmental Protection Agency (EPA), sediment is the most common water pollutant in US rivers. Consequently, the identification of areas with high erosion potential along streambanks is important to reducing sediment input. Furthermore, the prediction of total daily sediment load (TDSL) as a result of streambank erodibility and stream erosivity can assist in the development of novel management and monitoring practices. A new method for visually assessing streambanks has been developed using video footage and a modified version of the EPA-recommended Bank Erosion Hazard Index (http://water.epa.gov). The Streambank Video Mapping System (SVMS) was implemented to collect georeferenced video footage of streambank conditions using three above water cameras mounted on a kayak. In addition, GPS, stream depth and stream width are concurrently recorded. The video was evaluated using four parameters from the Bank Erosion Susceptibility Index (BESI) method: bank angle, bank height to bankfull ratio, surface protection, and riparian diversity. BESI is an ocular estimate of the BEHI. The BESI values were used to develop GIS-based streambank erodibility maps in order to identify areas of high erosion potential. The EPA Bank Assessment for Non-point source Consequences of Sediment (BANCS) method involves utilizing BESI and stream erosivity (by evaluating near bank stress from stream radius of curvature) to predict annual Bank Erosion Rates (BER). Using USGS stream gage discharge data, total daily sediment loads (TDSL) can be predicted. The objective of this study was to develop a method for predicting site specific daily streambank erosion rates using GPS-based watershed scale video mapping. The method was implemented on a 12 mile section of the Driftwood River in Indiana. Total annual and daily streambank erosion was estimated. River sections with high erosion rates were identified. The advantage of video mapping every foot of stream and bank is that 1) the total streambank erosion can be determined, and 2) the locations of high erosion and streambank rescission can be identified and managed.

KEYWORDS: streambank erosion, sediment load, near bank stress, GIS-based, video mapping system.

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STREAMBANK EROSIVITY AND SUBSTRATE MAPPING USING SVMS ON THE EAST FORK POPLAR CREEK

Daniel Wade, Dr. Paul Ayers, Kelsey Hensley, Scott Brooks

Sediment deposition due to bank erosion is a prominent source of the total sediment load in a stream or river. Current techniques used to measure and estimate this sediment load can be time consuming, physically taxing, and the results can vary widely due to small sample sizes. Additionally, there is no way to visually document increases or decreases in the health and erosivity of the water source. The Streambank Video Mapping System (SVMS) is a technique developed to visually capture streambank conditions on a continual foot by foot basis using georeferenced video. Visually documenting streambank health is a way to predict areas of high erosion as well as determine total sedimentation more accurately. The SVMS system was used to assess the condition of a 14 mile stretch of the East Fork Poplar Creek in and around the Oak Ridge Reservation. Mercury contamination by sediment transport is a concern along this segment of the creek so both streambank and substrate mapping was done. By knowing the concentration of mercury in the soil and determining the amount of bank erosion we can estimate the mercury load in the creek. Substrate mapping is done using underwater cameras attached to the bottom of the kayak as well as laser depth sensors and GPS tracking. A modified version of the Wentworth scale is used to classify the substrate particles. Streambank erosivity using above water camera is assessed using the Bank Erosion Susceptibility Index (BESI); which accounts for factors such as bank angle, riparian diversity, surface protection, and bank height to bankfull ratio to assist in determining site-specific Bank Erosion Rate (BER) along the entire 14 mile reach. Mercury contamination is predicted using the sediment load values gained through the BER estimates as well as in situ monitoring. GIS-based analysis of site-specific and total sediment loading allows for the prioritization of streambank restoration efforts to reduce Mercury contamination. The kayak-based videomapping approach expands the EPA-approved streambank erosion prediction methodology to the entire stream reach.

USE OF CONTINUOUS TURBIDITY MONITORING DATA TO IDENTIFY BIOLOGICAL IMPAIRMENT DUE TO SUSPENDED SEDIMENT IN EAST TENNESSEE STREAMS

Robert Woockman[1], John Schwartz[1], and Carol Harden[2]

Siltation is often cited as a cause of biological impairment for streams placed on the 303d list. Once cited, total maximum daily loads (TMDLs) for sediment must be generated to meet state water quality criteria. Although 32 states have developed numeric criteria for turbidity or suspended sediment concentrations (SSC) or both, these criteria are typically written as a percent exceedance above background, and what constitutes background is not well defined. Defining a background level is problematic, considering SSC and related turbidity levels change with location, flow stage, and season. As well, there is limited scientific data available regarding relationships between sediment exposure and biotic response. Turbidity, a well-established surrogate measure of SSC, can be measured and logged continuously by a sonde. The sonde data can then be converted into concentration-duration-frequency relationships (CDF Curves) over a range of flows providing a means for comparison to biotic response measures. This study investigates the use of turbidity sondes to characterize concentration-duration-frequency relationships at ten Tennessee Macroinvertebrate Index (TMI) sites. This presentation reports the status of the project and summarizes common technical issues associated with collecting field data using sondes. It also illustrates how fine sediment transport in disturbed watersheds is potentially influenced by location and contributing drainage area size.

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STORIES OF CHANGE: THE TENNESSEE HEALTHY WATERSHED INITIATIVE

Trisha D. Johnson[1]*

The founding members of the Tennessee Healthy Watershed Initiative (THWI) would like to share our successes of the past year. Our group of MOU and charter signatories, The Nature Conservancy; Tennessee Department of Environment and Conservation (TDEC); Tennessee Valley Authority (TVA) and West Tennessee River Basin Authority, have worked together to engage a wide variety of local stakeholders across Tennessee to apply for strategic funding.

We are currently supporting 11 projects that demonstrate innovative approaches to protecting and improving Tennessee's waters across the state. With an original investment of $850,000 from TVA and $230,200 from TDEC, an unprecedented amount of leverage from awardees has brought in over $675,000 of in-kind match, with over 70 partners statewide combining efforts to implement the projects. The THWI currently is developing funding strategies to enable the Initiative to continue acting as a leader in the state for providing stakeholder-led opportunities for implementing projects in strategic locations using innovative methods.

Also this year, the charter signatories approved a 3-year strategic plan to expand engagement with additional government and non-governmental organizations beyond this launch phase of the initiative. In the coming year we will focus on identifying those water quality protection and restoration activities which demonstrate a high level of cooperation and innovation which can be replicated to address our most pressing water quality challenges. Additionally, the THWI has identified the need to develop and utilize available watershed assessment and prioritization tools to consistently guide our investments in the future.

The THWI is excited about the success of our launch year and would like to introduce stakeholders to our successes focusing on the 11 initial projects that will be implemented over the next 18 months.

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ANALYTICAL DETERMINATION OF SOURCES OF ORGANIC POLLUTION IN NATURAL WATERS

John Harwood*[1,2], Sreedharan Lakshmi Narayanan[2], Sushma Meka[2]

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INTRODUCTION

Pollution of water supplies by sewage is of special concern. Molecular markers have been studied as indicators of potential contamination by human pathogens and by emerging contaminants, as well as of indicators of gross organic pollution which can impact aquatic organisms. Our research presently focuses on analysis of bile acids, fecal sterols, and artificial sweeteners to identify pollution sources. These markers can distinguish between municipal and domestic wastewater, and agricultural animal production sources of organic pollution. Murtaugh and Bunch first suggested the fecal sterol coprostanol be used as an indicator of sewage contamination (Murtaugh and Bunch, 1967). This fecal sterol is product of the bacterial degradation of cholesterol in the human gut. Measurement of fecal sterols overcomes shortcomings of classical microbiological indicators, which include bacterial die-off and lack of correlation with human sewage (Leeming et al., 1997). Isobe et al. measured fecal pollution in Malaysia and Viet Nam (Isobe et al., 2002). Comparing coprostanol concentration with fecal bacteria concentration, the group was able to set standards for coprostanol concentration as an indicator of fecal pollution. A strong linear relationship was observed between concentrations of coprostanol and *E. coli* in both Malaysia and Vietnam. In performing regional monitoring of sewage impact, sterols as molecular markers have two great advantages: the compounds are more stable in storage than are bacteria, and, as sterols concentrate in particulates, they can be collected from water samples and on filters which can be easily transported. Analytical profiles of fecal sterols have been found to distinguish between sewage and runoff from agricultural production (Leeming et al., 1997; Jaffé, 2004).

Recently, sweeteners have been suggested as “ideal markers” of sewage contamination of surface and ground waters. Sucralose and acesulfame-K are both very stable and water soluble, resisting metabolism, decomposition and loss through adsorption in wastewater treatment and in the environment. In a large sampling of Swiss WWTPs, rivers, lakes, and groundwater, acesulfame-K was consistently detected in untreated and treated wastewater (12 – 46 μg/L), in most surface waters, in 65% of the investigated groundwater samples, and even in several tap water samples (up to 2.6 μg/L) (Buerge et al., 2009). Scheurer, et al. tested for seven artificial sweeteners in German wastewater, surface water and soil aquifer treatment waters (Scheurer et

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al., 2009). In the surface water samples, acesulfame-K was the predominant artificial sweetener, while the other sweeteners detected at up to several hundred nanograms per liter in the order saccharin ≈ cyclamate > sucralose. Loos et al. report that sucralose has been measured in surface waters of 27 European countries (Loos et al., 2009). The compound has also been measured in river, marine and coastal waters of the United States, and in U.S. drinking water systems (Mead et al., 2009; Mawhinney et al., 2011).

Many other compounds have been studied as markers of pollution. These candidates include linear alkylbenzenes (LABs), which are impurities in linear alkylbenzenesulfonate detergent formulations, fluorescent laundry whiteners, and the trialkylamine 1-aminopropanone, which is believed to be produced exclusively by humans. Various emerging contaminants, pharmaceuticals and personal care products, are being evaluated as candidates as sewage markers. Caffeine has been monitored in many studies, including using the co-occurance of caffeine and nitrate as an indicator of leaching from household septic systems. These and other potential markers have limited utility for many reasons including instability in water and difficulty in analysis.

APPROACH

We hope to develop an analytical scheme to identify and apportion organic source loadings to natural waters (Figure 1). The advent of liquid chromatography mass spectrometry promises to greatly facilitate analysis of molecular markers in water. Our work to date has focused on developing LC-MS methods for analysis of bile acids, fecal sterols, and artificial sweeteners. We are also determining the most suitable means of sampling and preconcentrating samples for analysis of these compounds.

Bile acids and fecal sterols have traditionally been analyzed by GC-MS, with procedures involving extensive sample extraction, purification, and derivitization. LC-MS promises to afford a much more direct and rapid means of analyzing for both classes of compounds. LC-MS analysis of bile acids is relatively straightforward. Sterols present a special analytical challenge, as these compounds are neutral and do not yield to ionization by the commonly used electrospray interface (ESI) in LC-MS. We have found the alternative atmospheric pressure chemical ionization (APCI) interface allows MS analysis of both fecal sterols and bile acids in a single analysis.

We have selected acesulfame-K and sucralose sweeteners as most promising candidates to selectively identify human municipal and domestic wastewater. While LC-MS with solid phase extraction pretreatment has been employed by others in analysing for these compounds, there is much room for improvement in the analysis of these compounds. Acesulfame-K is very polar, and is not retained in conventional reverse phase chromatography. This low retention is also problematic in sample clean-up and preconcentration by solid phase extraction (SPE). We have tested a series of chromatographic systems to attempt to achieve retention of this compound. Sucralose is poorly ionized in the ESI interface. Following Scheurer, we have found addition of TRIS buffer following chromatography to significantly enhance retention of this compound (Scheurer, 2009).

RESULTS AND DISCUSSION

A review of the literature on molecular markers of water pollution suggests the following scheme for rapid source identification and estimation of organic pollution loads:

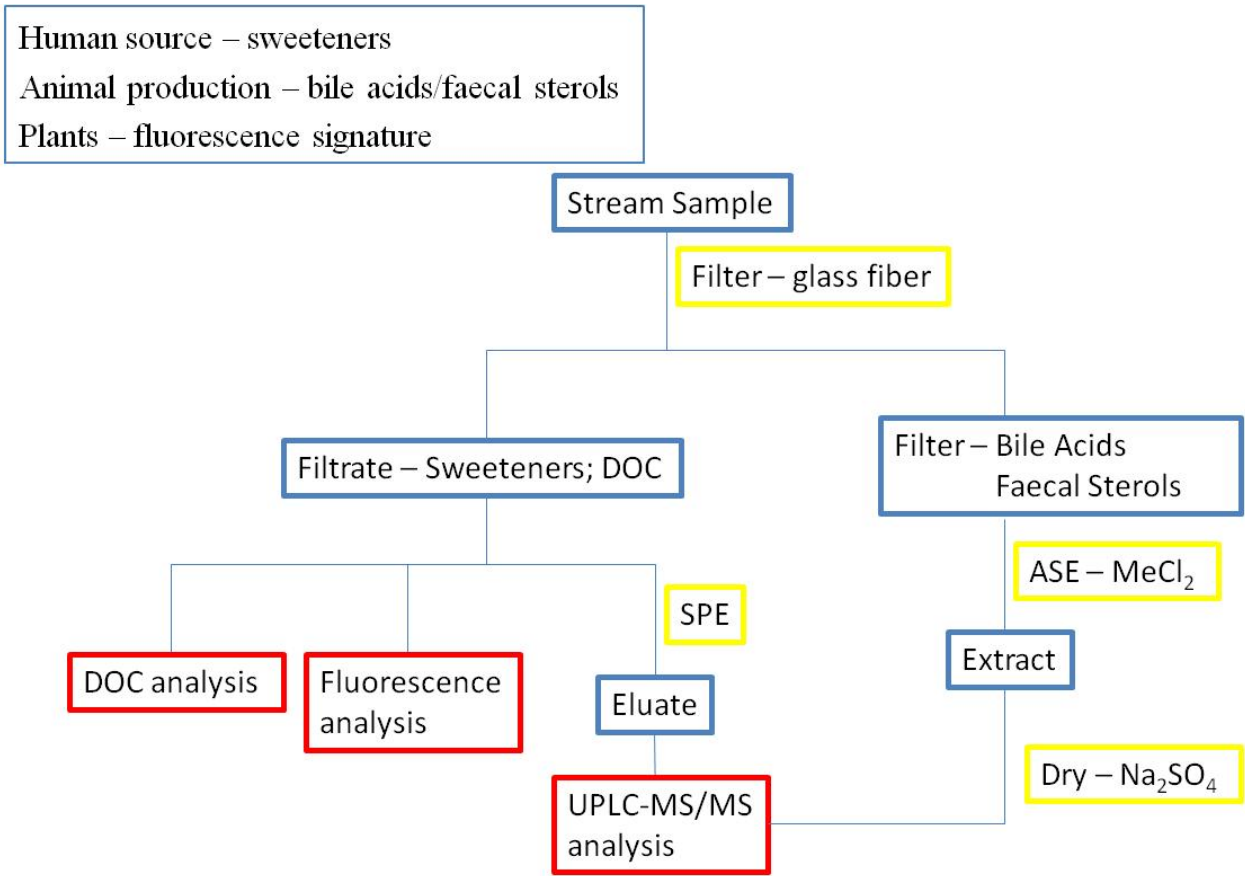

Figure 1. Comprehensive analysis of molecular markers of organic pollution in streams.

To assess the contribution of domesticated animal sources of fecal pollution, Tyagi et al. derived a multiple regression model with selected fecal sterols and bile acids (Tyagi et al., 2007). Five compounds were determined to identify pollution sources efficiently: epicoprostanol, cholesterol, cholestanol, chenodeoxycholic acid, and hyodeoxycholic acid. Our LC-MS development has focused on these selected indicators. The APCI LC-MS interface allows analysis of the compounds in a single analysis, varying the analysis polarity between (+) ion mode for sterols and (-) ion mode for bile acids, and with a mobile phase of methanol, water, and acetonitrile. The compounds are all resolved on either a C-8 or C-18 chromatography column. We obtain detection limits for these compounds comparable to those which have been reported for GC-MS methods (ca. 0.2 µM).

Sucralose and acesulfame-K both produce negative ions for analysis in the ESI MS interface. To date, our attempts have failed to produce chromatographic retention of acesulfame-K; elution of the compound at the unretained time prohibits accurate quantitation. We have tried both nonpolar and very polar stationary phases (C-18, Hypersil Gold, C-8, and P-5). Retention of this compound may be achievable with ion-pair chromatography, or with hydrophobic interaction chromatography (HILIC). We also have obtained only low retention of acesulfame-K on SPE stationary phases, 6% and 13 % on Oasis HLB and Strata X SPE columns, respectively. Sucralose chromatographs well, and we obtain promising recoveries of the compound with SPE, 67% and 126% on Oasis HLB and Strata X columns, respectively. In preliminary study, we have found TRIS buffer to enhance MS response to sucralose by a factor of six.

CONCLUSION AND FUTURE STUDY

The LC-MS method we have developed to analyze bile acids and fecal sterols will greatly facilitate use of these compounds as markers of contamination in research and regulation. Our next study will be to evaluate sampling methods for the compounds, comparing extraction of particulate and sediment with passive sampling (POCIS).

Sucralose is more commonly used than acesulfame-K in the U.S. and in European, and it may be sufficient to analyze this marker alone to estimate wastewater organic loads. We will continue to explore approaches to the analytical challenge of analyzing acesulfame-K by LC-MS. Rapid, quantitative analysis of these markers will allow us to evaluate the possibility of quantitatively assigning source loadings. We will measure the markers in samples with known, individual organic pollution sources, and attempt to mathematically correlate marker concentrations with dissolved organic carbon concentrations in streams.

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THE USGS VELOCITY MAPPING TOOLBOX, AN OVERVIEW OF HOW VMT CAN IMPROVE THE DATA PROCESSING AND PRESENTATION OF ADCP TRANSECTS

Daniel Saint

An Acoustic Doppler Current Profiler (ADCP) is used extensively to collect water velocity and discharge measurements. Although the manufacturer, *Teledyne*, has a program, *WinRiver*, to view the collected data, it is very limited in processing and plotting the data. In order to format the ADCP data into forms that can be processed or plotted by other programs extensive calculations and transformations needed to be performed on the original data. The USGS took notice of these issues and created a tool that has proven very useful in processing and plotting the data into forms that are acceptable for analysis and presentation. This presentation will provide an introduction and an overview of the Velocity Mapping Toolbox (VMT) including how the VMT can "straighten" river transects, create plan views, create various cross sectional views, and the various different forms of data files the VMT is capable of outputting. The various methods of calculations that the VMT uses will be presented, and the various plotting outputs will be shown. The intent of this presentation is to expose fellow ADCP users to the valuable capabilities of the VMT and how this simple toolbox could potentially improve their data handling capabilities as well as save them insurmountable valuable time in processing their data.

A STUDY OF CATTLE PRODUCER PREFERENCES FOR BEST MANAGEMENT PRACTICES IN AN EAST TENNESSEE WATERSHED

Dayton M. Lambert, Christopher D. Clark, Shawn Hawkins, Forbes R. Walker and Alice C. Layton[1]

This research analyzes the preferences of agricultural producers in the Oostanaula Creek and surrounding watersheds for the adoption of Best Management Practices (BMPs) designed to reduce sediment, nutrient, and fecal coliform contamination of surface waters by limiting cattle access to streams. Data on producer preferences were collected using a survey in which respondents were asked to indicate their willingness to participate in a hypothetical cost-share program promoting BMP adoption. The BMPs analyzed include stream crossings, rotational grazing, pasture improvement, and cattle water tanks. The physical and economic constraints faced by producers and the incentives provided by state and federal programs influence the decision to adopt BMPs. There was a clear preference for combinations of BMPs that did not include stream crossings, reinforcing anecdotal evidence from producers in the watershed that the maintenance associated with frequent high flow events may reduce willingness to install stream crossings. Younger, more educated producers with higher income levels that plan to pass the farm onto family members were more willing to adopt certain BMPs. Cattle owners were also more willing to implement management activities designed to improve pasture productivity. The extensive distribution of pastureland in the region analyzed, the relatively inexpensive costs of adopting practices supporting pasture improvement, and higher quality forage correlated with improved pastures suggest a win-win outcome for cattle owners and efforts to enhance water quality. The behavioral information obtained will be used to supplement a long-term biophysical modeling project.

[1] Lambert and Clark are Department of Agricultural & Resource Economics, Hawkins and Walker are Biosystems Engineering and Soil Science and Layton is Center for Environmental Technology, University of Tennessee, Knoxville, Tennessee.

OOSTANAULA CREEK WATERSHED RESTORATION PROJECT THE WORST BEST WORST PROJECT COMPLETED IN YEARS

Lena Beth Reynolds
University of Tennessee Extension

ABSTRACT

Oostanaula Creek is located in McMinn County in southeast Tennessee, running north to south, spilling into the Hiwassee River at Calhoun, Tennessee. The watershed has rural farms in the north, the City of Athens near the center, and rural farmland to the south. Several active dairies lie within the watershed, with others converted to beef and/or crop operations.

Oostanaula Creek Watershed Restoration Project is managed by Dr. Forbes Walker of the UT CASNR, Biosystems Engineering and Soil Science Department. The project involves faculty and extension personnel from UT Microbiology, Civil Engineering, Biosystems, and Agricultural Economics. Lena Beth Reynolds is the Extension Area Specialist working with farmers and landowners to improve water quality in the Oostanaula by lowering bacteria levels and sediment.

Projects designers have been farmers to engineers. BMPs have been installed by farmers and by excavation contractors. A few have been a mixture of both, and involved trading stream mitigation credits with the City of Athens.

This presentation will provide photos, narrative, and details on site determination, recruiting farmers, funding, installing BMPs, and the finished projects. The presentation will accurately describe what went wrong, faults found, mistakes made, and the outcomes of the project on the farmers and agency personnel. There will be lots of photos, anecdotes, and honest descriptions of what happened especially during the massive “Worst Best Worst Project” completed in years.

SESSION 3A

TDEC
8:30 a.m. – 10:00 a.m.

Interpretation of Tennessee's Narrative Color Criterion in a Blue Ridge Mountain Stream in East Tennessee
Greg Denton

Recovery Potential Screening Tool
Regan W. McGahen, David Duhl, and Sherry Wang

GIS Integration and Data Management at TDEC
Richard Cochran

PANEL: CONNECTING WATER SCIENCE TO DECISIONS
10:30 a.m. – 12:00 p.m.

INTERPRETATION OF TENNESSEE'S NARRATIVE COLOR CRITERION IN A BLUE RIDGE MOUNTAIN STREAM IN EAST TENNESSEE

Greg Denton[1]

Tennessee's water quality criteria are specific to the use being protected. Criteria can be either numeric (a specific number or formula) or narrative (a verbal description), but in either case, criteria establish the level of quality needed to protect that use. The most stringent criterion for the uses assigned to a particular stream for a specific parameter is often referred to as the water quality standard for that waterbody.

For protection of the recreational use, the criterion for color is narrative and establishes that the water should be free of "any objectionable" amounts. The wording of the criterion suggests that if the color is ever objectionable, the criterion has been violated. However, such a potentially subjective criterion provides challenges when Tennessee must determine if the frequency, duration, and intensity of violations equals loss of the use.

In this presentation, the author will describe the deliberative process used to make the determination that a Blue Ridge mountain stream (Ecoregion 66) fails to support the recreational use due to color.

[1] Tennessee Department of Environment and Conservation

RECOVERY POTENTIAL SCREENING TOOL

Regan W. McGahen[1], David M. Duhl[1], and Sherry H. Wang[1]

Effective watershed management involves not only protection of resources, but also a plan for restoration of resources that have been impaired. An integral and often difficult part of the decision making process involves determining where to invest efforts for the greatest potential success. A watershed's recovery potential is the likelihood of an impaired water to re-attain a desired condition, given its ecological capacity, exposure to stressors, and the social context affecting efforts to improve its condition.

The Tennessee Department of Environment and Conservation has been collaborating with the Tennessee Department of Agriculture, the Natural Resources Conservation Service, and the Environmental Protection Agency to develop a Tennessee-specific Recovery Potential Screening Tool that will help Tennessee compare restorability across watersheds in a systematic but flexible way. This science-based process to rank and prioritize watersheds has many applications such as prioritization of restoration projects, nonpoint source projects, water quality monitoring, watershed protection, TMDL plan implementation and other prioritization needs. The tool also has applications for EPA's Healthy Watershed Initiative and for the Watershed Report Card. Each set of metrics contain multiple data sets that can be combined in different ways to meet site-specific needs. Additionally, the tool provides three different methods for communicating the findings. Results can be expressed as a rank order, a GIS interpretation, or a three-variable bubble plot.

More information is available at:
http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index

[1] Tennessee Department of Environment and Conservation, Division of Water Resources

GIS INTEGRATION AND DATA MANAGEMENT AT TDEC

Richard Cochran[1]

TDEC has been using GIS technologies to map environmental data for over 20 years. During this period, very few improvements or advancements were made to the Department's GIS infrastructure. GIS was not centrally organized or integrated with the Department's data management plans. Over the past 5 years, TDEC has worked to upgrade the IT infrastructure for GIS technologies. These upgrades include purchasing ArcGIS Server, moving GIS data into a centralized Oracle system, staffing, and more attention and involvement from TDEC's Information Systems Division.

The GIS upgrades have allowed TDEC to integrate more of this technology into both its data management and business functions. Staff has better data quality control using embedded GIS to check information as it's added to central databases. These data are immediately available to GIS users and can be included in desktop analysis as well as web mapping applications. TDEC is now able to create GIS based web mapping applications for the intranet and internet allowing better communication and decision making for staff as well as providing information to the public and other TDEC customers. TDEC's Water Permits, Division of Water Resources staff, Oil and Gas well location, and Mining Section GIS web applications will be showcased during the presentation and the data management behind the scenes will be discussed.

[1] Tennessee Department of Environment and Conservation Division of Water Resources

CONNECTING WATER SCIENCE TO DECISIONS

Every day in Tennessee decisions are made that affect the use and protection of water resources for the good of our people and our environment. In principle, these decisions can be most effective when based on an appropriate and correct understanding of the natural and human systems they concern. Though specific information to address specific decisions is always ideal, this kind of detailed understanding may require investments in research and monitoring that go beyond the resources of any one individual or organization. In practice, numerous organizations working in different ways and with different mission imperatives contribute individually to produce an aggregate informational environment in which most resource management decisions must be made. Although this approach has been adequate for many generalized needs, greater emphasis on strategic planning among multiple organizations may help to ensure that this information is sufficient to address the specific requirements of many new issues and complex decisions in the future.

This panel will serve to initiate a general discussion of science planning to support decisions related water resources management in Tennessee. It pulls together representatives of five organizations working in various different technical capacities and geographic scopes in the state. After a brief introduction to each organization, describing mission goals and operations, we will discuss the technical issues typically of concern to each organization and the ways in which science and technical information fit within and support other organizational needs. As part of this discussion each member of the panel has been asked to address in general terms the following four basic questions. 1. How does your organization identify principal scientific and informational needs to support mission objectives and decision making? 2. What are some of the greatest scientific and informational needs you see developing for your organization over the next 5-10 years? 3. In what ways can existing science and information be adapted or enhanced to more directly support the decisions you and others must make? 4. How do you see your organization working with others to leverage investments in science and information to better support water resources management?

SESSION 3B

GIS TECHNIQUES AND TOOLS
8:30 a.m. – 10:00 a.m.

Applying Geographic Information System Techniques to Hydrologic Analysis
David E. Ladd

Using a Digital Smartpen for Map Markups
David C. Greene

Slap Your Field Crew in the Face
Cliff Hoeffner

APPLYING GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES TO HYDROLOGIC ANALYSIS

David E. Ladd[1]

The U.S. Geological Survey (USGS) Tennessee Water Science Center collects and analyzes hydrologic data to help local, State, and other Federal agencies make decisions that affect citizens across Tennessee. Many hydrologic analyses require the calculation and aggregation of terrain and sub-surface characteristics that may improve our understanding of hydrologic response, contaminant transport, or groundwater/surface-water flow and interaction. Manual calculation of such characteristics requires substantial time and effort for small areas and may be impractical or impossible at a state-wide or regional scale. Time and resources can be saved, and more precise and consistent results produced, by using geographic information system (GIS) methods to calculate hydrologic and hydrogeologic characteristics. Recent applications of GIS methods by the Tennessee Water Science Center include middle and western Tennessee flood-inundation mapping and state-wide analyses of basin characteristics, streamflow statistics, and karst terrain.

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USING A DIGITAL SMARTPEN FOR MAP MARKUPS

David C. Greene[1]

ABSTRACT

A consistent issue in the GIS industry is transferring data from paper maps and field observations to a readily useable digital format. A typical workflow might start with a GIS technician printing a series of maps for field personnel to markup and give back to the technician for any combination of scanning, georeferencing, digitizing, or manual creation. Technically advantaged agencies might use mobile devices with database syncing through wireless broadband internet connections. The mobile solutions are the most versatile solutions providing the agency has the resources to develop the applications, maintain the database, and provide secure internet access to the data. This presentation will explore an alternative method using printed paper maps and a digital smartpen. The process starts with the GIS coordinator using a custom tool for ArcMap to generate a PDF of the work area and base data that works with the pen. Field personnel use the pen to markup the printed PDF while recording audio notation. When finished for the day, another utility extracts the data from the pen as shapefiles and audio files which can then be emailed to the GIS coordinator. Finally, the GIS coordinator uses the markups to create or modify features in the database using the audio for additional information.

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SLAP YOUR FIELD CREW IN THE FACE

Cliff Hoeffner – GEO-Jobe GIS Consulting

If you're organization is anything like Harpeth Valley Utility District, you're interesting in equipping your field crew with easy to use mobile apps. In this presentation, we will uncover how Esri's ArcGIS Online has provided a platform for organizations to extend the reach of their GIS through secure mobile apps and in-office dashboards specifically designed for water organizations.

SESSION 3C

EROSION
8:30 a.m. – 10:00 a.m.

Monitoring and Research to Evaluate Sediment Transport
William J. Wolfe

The Effects of Highway Construction and a Major Flood on Benthic Invertebrate Communities in Middle Tennessee
R. Deedee Kathman

Erosion and Sediment Control: A Linear Project Success Story – SR-840 from SR-100 to Columbia Pike
Jeffrey T. Hoilman

MONITORING AND RESEARCH TO EVALUATE SEDIMENT TRANSPORT

William J. Wolfe[1]

From 2003 through 2012, the U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Transportation (TDOT), conducted a program of research and monitoring to evaluate sediment transport from highway construction sites to Tennessee streams. The evaluation focused on the construction right of way (ROW) for State Route (SR) 840 and streams draining the SR 840 right of way but included selected construction sites elsewhere in Middle Tennessee and ecological reference streams. Monitoring included: (1) continuous and discrete measurement of turbidity, temperature, conductivity, and suspended-sediment concentration (SSC) at construction outfalls and receiving streams; (2) visual inspection of conditions along the right of way and in receiving streams following storms or other indicators of elevated sediment transport, and (3) repeat surveys of fish, invertebrates, and geomorphic channel units in selected receiving streams. Research centered on three key questions: (1) How effective are erosion-prevention and sediment-control (EPSC) measures applied to highway construction zones in Tennessee? (2) How does sediment from highway construction affect biota and channel conditions in Tennessee streams? (3) What are the most cost-effective ways to monitor EPSC performance and the geomorphic and biological integrity of streams draining Tennessee construction sites?

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THE EFFECTS OF HIGHWAY CONSTRUCTION AND A MAJOR FLOOD ON BENTHIC INVERTEBRATE COMMUNITIES IN MIDDLE TENNESSEE

Dr. R. Deedee Kathman[1]

Key Words: construction, benthic invertebrates, flood, drought

Erosion from State Route 840 road construction activities in the early 2000s causing excessive sediments in several streams in Williamson County resulted in Tennessee Department of Transportation (TDOT) and Tennessee Department of Environment and Conservation (TDEC) entering into an Agreed Order in 2003. Part of the Order was to establish criteria that would be put in place to ensure that streams would not be affected by runoff. Stringent Erosion Prevention and Sediment Control (EPSC) measures were used at all locations adjacent to streams and wet weather conveyances. Also as a condition of the Order, TDOT and United States Geological Survey conducted a multiyear interdisciplinary study of sediment transport, and geomorphic and ecological responses of headwater streams in middle Tennessee to better understand physical and biological effects of road construction on receiving streams. Six riffle sites on two streams, Copperas Branch and Greens Hollow Branch, were sampled for benthic invertebrates in November 2005, April 2006 (pre-construction), November 2007 (during construction), and November 2010 (post construction). One site on Copperas was upstream of the construction; the other five were downstream of construction (Figure 1). Middle Tennessee experienced a severe to extreme drought from February to September 2007 (NOAA); in May 2010, the same area experienced catastrophic flooding, receiving 15-19 inches of rain in two days, with high water marks up to 12 feet above normal. Several of the riffles previously sampled were destroyed during the flooding, but nearby similar sites were found within 50 feet upstream or downstream, except for Site 6 in Greens Hollow. The foot-thick cobbles and pebbles at that site were washed away, leaving a bedrock channel for at least 100 feet downstream. The samples were collected along the banks and in small pockets of gravel in proximity to the original site. This site also received runoff from agricultural practices.

Methods followed TDEC (2011) protocols, using habitat assessments and the following seven biometrics: Taxa Richness, EPT (Ephemeroptera, Plecoptera, Trichoptera) Richness, Percent EPT Abundance excluding *Cheumatopsyche*, Percent OC (Oligochaeta and Chironomidae), NCBI (North Carolina Biotic Index), Percent Clingers, and Percent TNUTOL (abundance of nutrient tolerant organisms). Biometric scores (Tennessee Macroinvertebrate Index, TMI) of 40 or 42 indicate Exceptional Tennessee Waters (ETWs), while a value of 32 or above indicates a supporting stream with a healthy, diverse benthic community for this ecoregion. Hierarchical (cluster) analyses compared abundance and taxa similarity among sites and years (Bray and Curtis 1957, Nemec 1991).

Data from the two pre-construction surveys (2005, 2006) indicate that the metric scores for all sites were either equal to or lower compared to the 2007 (during construction) data, the year

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Tennessee experienced the drought. Five of the six sites in 2007 received scores indicating Exceptional Tennessee Waters (ETWs), compared with two in 2005 and two in 2006. Site 3, located below a silt-laden pond, never achieved ETW status during any of the surveys. All sites except Site 5 in 2006 and Site 6 in 2006 and 2010 were considered fully supporting for all four years. See Table 1.

Data from 2010, post construction and post flood surveys, indicated that only two sites (Site 1, Site 5) rated ETW status, both of which were downstream of construction. These same two sites did not attain ETW status during the 2005 or 2006 surveys. All sites in 2010 remained fully supporting except for Site 6 with limited habitat and continued agricultural inputs.

Habitat assessment scores were lowest in 2010 for all sites, but only Site 6 was considered impaired (Table 2). Most scores for 2010 would most likely have been lower if the assessment had been performed at the exact same sites as in previous years instead of at the shifted benthic sampling locations.

The total numbers of taxa remained high throughout the three years, generally with >27 per sample, except for years 2005 and 2007 at Site 3, the site below a pond which never achieved ETW status (Table 3). Site 6, considered non-supporting in 2006 and 2010, had the lowest percentages of EPT individuals (excluding *Cheumatopyshce*, one of the biometrics) and highest percentages of chironomids during those two years compared to all other samples. The lowest percentages of EPT - *Cheumatopsyche* occurred in 2010 for all sites except Site 5, which had a lower percentage in 2006.

Bray-Curtis cluster analysis comparing the similarity among sites and years using numerical abundance per taxon indicated three distinct groupings (Figure 2a). All of the sites from the spring (2006) survey grouped as a distinct set (Group 1), all of the benthos from Sites 3, 4, and 6 clustered into Group 2 regardless of year, and Group 3 was comprised of all the benthos from Sites 1, 2, and 5. Group 3 was further broken down into three smaller distinct groupings based on years. The Group 1 cluster, from the spring 2006 data, indicates that seasonality appears to be the overriding factor separating the benthic assemblages from the other sample data. There were no distinct patterns separating pre-, during-, and post-construction samples.

Jaccard analysis for taxa similarities followed a similar pattern as Bray-Curtis (Figure 2b). The taxa from the spring sampling period were more similar to each other in all samples than to any other sample or year (Group C), having a similar pattern to the abundance data. Samples from Sites 3, 4, and 6 grouped together at a low level of similarity, showing no consistent pattern among sites or years (Group B), and were joined by Group A, the two Site 6 samples from 2005 and 2006. Group D again clustered as a large grouping, with three subsets differentiated by each of the years 2005, 2007, and 2010. One Site 3 sample was also found within the 2005 Group D cluster based on taxa similarity.

The benthic data metrics for each of Sites 1-4 indicate only slight differences in the TMI scores, never changing more than four points among the four years, with no consistent pattern between pre- and post-construction. The scores for Sites 5 and 6 increased in 2007 compared to the two previous years, while Site 5 was only slightly lower in 2010 compared to 2007, and Site 6 was distinctly lower in 2010. The low score at Site 6 in 2010 is also reflected in the low habitat assessment score. It appears that the variability at this site is a factor of both habitat and agricultural practices. The data show a diverse benthic community persisting through several years of construction in the basins, extreme drought, and catastrophic flooding, reflecting the resiliency of benthic communities in these streams. The flood eliminated long sections of benthic habitat in these predominantly bedrock streams, yet diverse communities existed wherever habitat was available. Although diversity remained consistently high, it appeared that the abundances shifted among taxa following the flood in 2010, but could easily be recovered since individuals were still present. This brings into question the usefulness of benthic community analysis for determining stream health during construction when rigorously-applied EPSCs exist throughout the project duration. Future research should be directed towards the effects of construction when rigorous EPSC measures are absent.

FIGURE 2a: BRAY-CURTIS HIERARCHICAL CLASSIFICATION OF BENTHIC INVERTEBRATES WILLIAMSON COUNTY, TENNESSEE

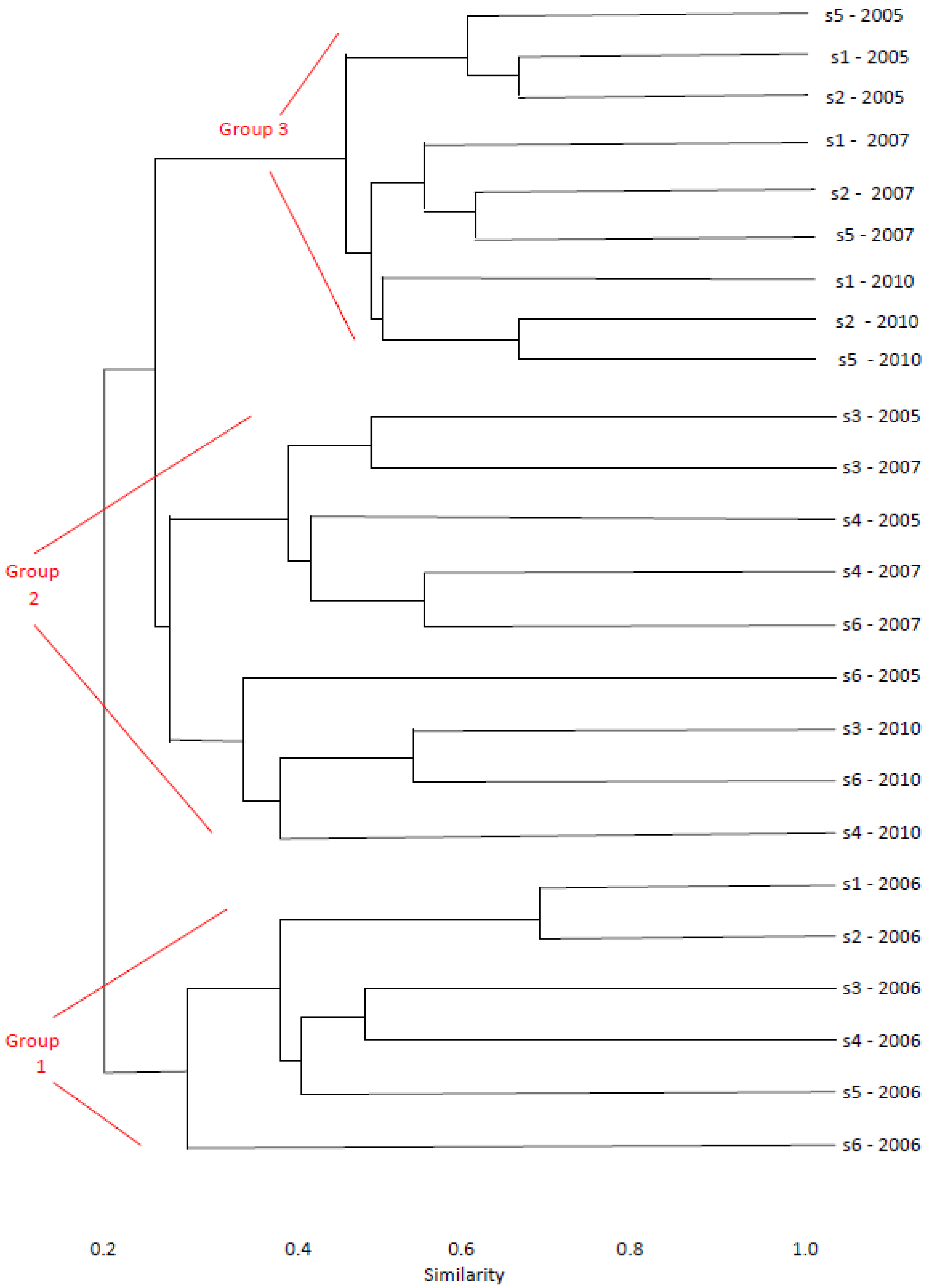

FIGURE 2b: JACCARD HIERARCHICAL CLASSIFICATION OF BENTHIC INVERTEBRATES
WILLIAMSON COUNTY, TENNESSEE

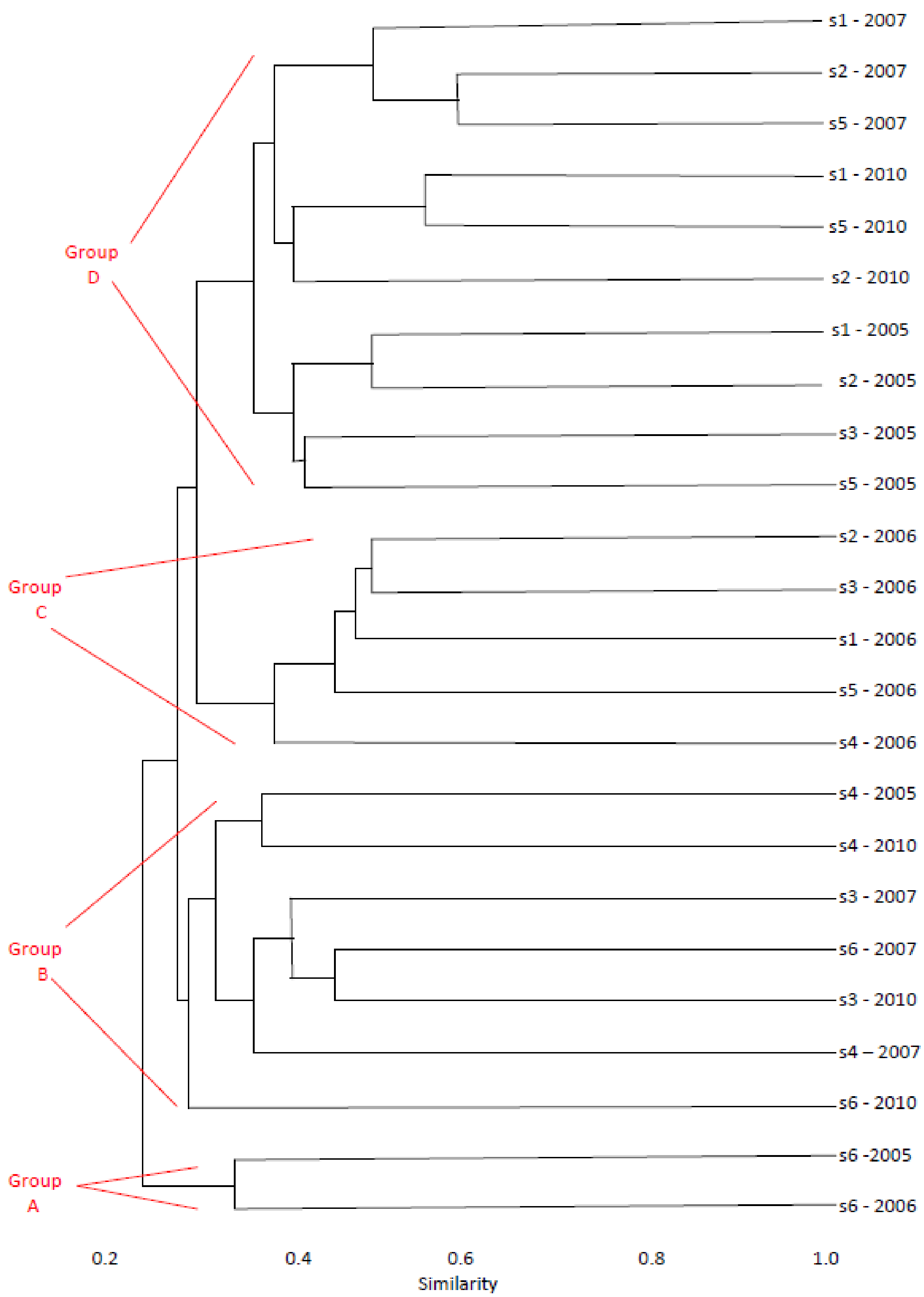

TABLE 1

TDEC BIOMETRIC SCORES (TENNESSEE MACROINVERTEBRATE INDEX) FROM BENTHIC INVERTEBRATE SURVEYS ON COPPERAS BRANCH AND GREENS HOLLOW BRANCH; WILLIAMSON COUNTY, TENNESSEE

Drought: February – September 2007
Construction: started July 2007
Flood: May 2010

Score of ≥32 = fully supporting
Score of 40 or 42 = Exceptional Tennessee Water (ETW)

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	38	42	34	40	36	36
April 2006	38	40	36	42	28	28
November 2007	40	42	38	42	42	40
November 2010	40	38	34	38	40	22

[1] u/s = upstream; d/s = downstream

TABLE 2

HABITAT ASSESSMENT SCORES ON COPPERAS BRANCH AND GREENS HOLLOW BRANCH
WILLIAMSON COUNTY, TENNESSEE

Drought: February – September 2007
Construction: started July 2007
Flood: May 2010

Score of ≥128 = not impaired for streams with > 2 square miles drainage
Score of ≥133 = not impaired for streams with ≤2 square miles drainage

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	173	175	162	168	174	164
April 2006	178	183	179	174	178	169
November 2007	173	178	163	158	176	149
November 2010	170	155	148	146	157	122

[1] u/s = upstream; d/s = downstream

TABLE 3

TAXA AND ABUNDANCE DATA FROM BENTHIC INVERTEBRATE SURVEYS ON COPPERAS BRANCH AND GREENS HOLLOW BRANCH; WILLIAMSON COUNTY, TENNESSEE

(Based on 200±20% number of individuals per sample)

Drought: February – September 2007 **Construction: started July 2007** **Flood: May 2010**

Total Number of Taxa

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	28	32	24	32	28	37
April 2006	37	29	29	30	32	36
November 2007	34	33	26	33	32	28
November 2010	29	28	31	36	39	33

Number of EPT (Ephemeroptera, Plecoptera, Trichoptera) Taxa

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	11	16	10	14	10	12
April 2006	14	11	14	12	10	12
November 2007	14	14	12	15	16	11
November 2010	12	12	11	13	16	7

Total Number of Chironomidae Taxa

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	8	4	7	9	10	6
April 2006	14	9	8	11	13	12
November 2007	10	8	8	11	8	7
November 2010	9	6	10	13	9	11

TABLE 3 (continued)

Abundance of EPT (Ephemeroptera, Plecoptera, Trichoptera) excluding *Cheumatopsyche*

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	101	119	169	145	118	109
April 2006	97	98	121	135	57	56
November 2007	105	76	141	87	109	112
November 2010	76	52	84	90	80	28

Abundance of Oligochaeta + Chironomidae[2]

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	32	13	13	20	63	61
April 2006	62	45	56	47	104	103
November 2007	23	30	13	32	33	47
November 2010	32	45	91	35	41	118

Total number of organisms sorted in laboratory

Month/ Year	SITES					
	1 – Copperas mainstem	2 – Copperas u/s of Greens Hollow[1]	3 – Copperas d/s of pond[1]	4 – Copperas u/s of pond	5 – Greens Hollow u/s of Copperas confluence	6 – Greens Hollow d/s of ROW
November 2005	174	181	199	176	168	208
April 2006	183	200	201	204	191	192
November 2007	188	181	198	182	189	187
November 2010	189	183	184	191	206	177

[1] u/s = upstream; d/s = downstream
[2] Oligochaetes comprise <3% of total number of these 2 groups.

ACKNOWLEDGMENTS

The author thanks the following people who have been invaluable during these surveys: Dr. Bill Wolfe and Dr. Tim Diehl (USGS), and Todd Askegaard (Aquatic Resources Center). I appreciate the support of TDOT and TDEC during all of these studies.

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EROSION AND SEDIMENT CONTROL A LINEAR PROJECT SUCCESS STORY SR-840 FROM SR-100 TO COLUMBIA PIKE

Jeffery T. Hoilman[1]

INTRODUCTION

The vision for a major roadway encircling the Nashville metropolitan area had its roots in 1975 when recommendations in the 1975-1995 Tennessee Highway System Plan proposed by Tennessee Department of Transportation (TDOT) included a principal circumferential highway around Nashville. This highway was eventually identified as SR-840 and was described as the Middle Tennessee Parkway, a four-lane divided highway connecting I-40 west of Nashville, extending south of Nashville and crossing I-65 and I-24, and connecting I-40 east of Nashville. SR-840 was to provide economic development opportunities in Middle Tennessee and relieve traffic congestion on the Nashville interstate system. After 26 years in the making, the 78-mile half circle around southern Middle Tennessee was opened to the public on November 2, 2012. However, this project did not come without environmental controversies for the last remaining sections to be constructed in Williamson County starting in the summer of 2002. Following site visits by Tennessee Department of Environment and Conservation (TDEC) and numerous citizen complaints, Notices of Violation and fines were issued for environmental and National Pollutant Discharge Elimination System (NPDES) permit conditions for the project. These violations led to construction being halted on the project and a Consent Order being issued to TDOT. The Consent Order specified guidelines and restrictions related to erosion prevention and sediment control (EPSC) that TDOT and its contractors would be required to follow for the last remaining sections of SR-840. The purpose of this paper is to describe, at a high level, an overview of the techniques and steps necessary to ensure project success in regards to EPSC and the NPDES permit on linear construction projects.

APPROACH

With approximately 17.6 miles of roadway remaining to be constructed in Williamson County under Consent Order, TDOT began re-evaluating the roadway design and construction approach for the project. Following is a list of procedures taken by TDOT to ensure that the project would maintain NPDES and environmental permit compliance:

1. Develop a grading plan and schedule that are most efficient in reducing land disturbance but yet are feasible to construct while maintaining compliance.
2. Prepare site-specific EPSC plans and coordinate environmental permits on the front end. Site-specific EPSC plans should incorporate multiple phases of EPSC, including clearing and grubbing, mass grading and final stabilization to address the different stages of construction. Additional EPSC phases provide the ability for on-site personnel to handle the various stages of construction and have the EPSC pay items and quantities available to build the project in compliance. Coordination of the design and EPSC plans with the environmental permit writer in regards to streams, wetlands and construction stormwater

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runoff on the front end saves time and ensures that items being permitted can be built in compliance.

3. Create a site-specific storm water pollution prevention plan (SWPPP) to ensure NPDES permit compliance. The site-specific SWPPP provides information on soil types, classifications and erodibility; total and disturbed area acreages; sequence of construction; EPSC measures and stormwater management; outfall, stream, wetland, TMDL and ecology information; maintenance and inspection of EPSC measures; spill prevention, management and notification; non-stormwater discharges and good housekeeping; record-keeping; certifications; and special EPSC items including notes, details, the use of polyacrylamide (PAM) and passive treatment systems for the treatment of stormwater runoff to reduce turbidity.
4. Conduct an environmental pre-construction meeting and walk-through inspection of the project with the contractor prior to construction. Establish expectations, environmental priorities, EPSC inspection coordination and communication protocols during the pre-construction meeting. Additionally, reviewing environmental permitted activities and EPSC stewardship requirements to ensure all involved parties are informed. Conduct a pre-construction walk-through of the project with the contractor and project personnel to document existing conditions and review the constructability of environmental permitted areas.
5. Maintain a good attitude, commitment and flexibility towards EPSC. Those involved must follow the EPSC plan and notes at a minimum but yet be flexible and/or creative to enhance or install additional EPSC measures as needed during construction. All team members must have a good attitude, work together, and trust each other in order to be successful.
6. Maintain good communication. Communication is the overall key. Do not to assume that someone else will take care of the EPSC and environmental permitting requirements.

RESULTS AND DISCUSSION

In July 2007, after redesigning the project and developing site-specific SWPPP and EPSC plans, construction resumed on the last remaining sections of SR-840 in Williamson County. The Consent Order mandated that TDOT develop a Quality Assurance / Quality Control (QA/QC) site assessment program to audit the project twice monthly to ensure that the contractors, subcontractors, TDOT and its consultants (CE&I and EPSC) were abiding by the environmental and NPDES permits for the project. ARCADIS was asked by the Comprehensive Inspections Office of TDOT to assist in providing the QA/QC site assessments for the remaining sections of SR-840. Through the initial QA/QC site assessments, TDOT demonstrated to TDEC and the public that the roadway project could be built in compliance following the steps previously described. The last two remaining sections in Williamson County were eventually let for construction. Over the next 5.5 years, approximately 17.6 miles of roadway were successfully constructed. On November 2, 2012, the 78-mile half circle around southern Middle Tennessee was complete and opened to the public.

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PROFESSIONAL POSTERS

Water Use Studies in Tennessee, 2013 to 2015
John A. Robinson, USGS

WATER USE STUDIES IN TENNESSEE, 2013 to 2015

John A. Robinson[1]

Quantifying water-use information and understanding the effects of water use on water resources and natural hydrologic systems is important for the public and policy makers. The water resources in Tennessee are impacted by population increases, land use changes, climate variability and competing needs for the same resource. As these various stressors on water resources change, water-resource managers and policy makers need quality, timely, and accurate water-use information to assess current and future water supply and availability, water conservation and efficiency, expanding and aging infrastructures, and pricing schedules.

The U.S. Geological Survey is currently conducting two water-use studies in cooperation with the Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources and the U.S. Army Corps of Engineers (USACE), Nashville District to collect and provide water-use information.

The USGS and TDEC-Division of Water Resources are conducting a study to define the 2010 water use for public water-supply systems and self-supplied industry in Tennessee, to define water-use coefficients for public-supply water-use, and to project water-use through 2030 by county in Tennessee. The water-use coefficients for public supply will include domestic, commercial, and industrial water-use sectors.

The USGS and the USACE, Nashville District are conducting a water-use study to document public water-supply, self-supplied industrial, agricultural, and thermoelectric water use in 2010 for the Cumberland River basin in Tennessee and Kentucky. The investigation will compile water use data by sub-watershed and reservoir catchment area. Trends in public-water supply will be estimated through 2040 based on projected population growth. An additional element of the study will include estimates of consumptive use, wastewater releases, and return flows from thermoelectric and industrial use. The results of the investigations will benefit agencies, water-supply systems, economic development districts, environmental groups, and other stakeholders across Tennessee and Kentucky.

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STUDENT POSTERS

<u>High School</u>

Biodegradation of Quaternary Ammonia Compounds by Biofilm and Free-Living Bacteria
Zheer Ahmed, Martin Luther King Jr. Academic Magnet High School

Antibiotic Resistance and Substrate Utilization by Bacteria Affiliated with Cave Streams at Different Levels of Mammoth Cave
Petra K. Byl, Richard Toomey, Jacob Byl, David Solomon, and Shannon Trimboli, Acknowledgement Tom Byl, Hume Fogg Academic Magnet High School

Water Quality Testing at Cooper Creek
Desiree Schutt, Destinee Schutt, and Shelby Seaborn, Stratford STEM Magnet High School

<u>Undergraduate</u>

Reduction of Selected Chemicals from Storm Runoff by Filters and Biodegradation
JeTara Brown, D. Solomon, A. West, Lonnie Sharpe, and acknowledgement Tom Byl, TSU

Feasibility Study for Stream Restoration of Breedings Mill Branch, Cookeville, TN
Alex Burton, TTU

Possible Influence of Cropping Practices on In-Stream Nutrient Concentrations in a Red River SubWatershed
Taylor C. Fleet, David M. Duhl, and Sherry H. Wang

Solute Transport in Karst, a Dual Continuum Model
Justin Harris, Roger Painter, and Lonnie Sharpe, acknowledgement Tom Byl, TSU

Characteristics of Bedload in a Karst Stream System
Kyle Long, TTU

Determination of Sources of Organic Pollution in Natural Waters by Liquid Chromatography-Mass Spectrometry
Sreedharan Lakshmi Narayanan and John Harwood, TTU

Regression Analysis to Determine Correlations Between Environment and Storm Runoff Water Quality
David Solomon and Lonnie Sharpe, acknowledgement Thomas Byl, TSU

Fate and Transport of Chemicals at Mammoth Cave National Park, Kentucky
Ashley West, David Solomon, Sean McMillan, Hung-Wai Ho, Victor Roland, Irucka Embry, Rick Toomey, Roger Painter, Lonnie Sharpe, and Dafeng Hui, acknowledgement Thomas Byl, TSU

Graduate

Integrated 2D Flood Simulation and Spatial Compromise Programming for Assessment of Flood Control Alternatives
Ebrahim Ahmadisharaf and Alfred Kalyanapu, TTU

Hydraulic Connections Between the Cumberland River and Nearby Wells in Nashville, TN
Aras Barzanji, acknowledgement Tom Byl, and Mike Bradley, TSU

Use of Sorption Isotherms to Improve the Efficacy of the Stormwater Filters
Hung-Wai Ho and Rick Toomey, acknowledgement Thomas Byl, TSU

Enhancing the Design of Microbial Batteries in Wetlands
Lina S. Khoury and acknowledgement Tom Byl, TSU

Artificial Sweeteners as Chemical Markers of Organic Water Pollution
Sushma Meka and John Harwood, TTU

Current Trends in Stream Water Quality in the Great Smoky Mountains National Park
Tim Pobst and John Schwartz, UT

Development of a Stormwater/LID Master Plan for the University of Tennessee at Knoxville
Paul Simmons, John Schwartz, and Andrea Ludwig, UT

Evaluation of Green Remediation Strategies at the Velsicol Landfill, Hardeman County, Tennessee
Lore'al K. Spear, Roger Painter, and acknowledgement Tom Byl, TSU

Characterizing the Hydrostratigraphic Controls on Groundwater Discharge into the Harpeth River Using Thermal Signatures and Electromagnetic Induction
Scott C. Worland, VU

Doctoral Candidate

Precise Control of Synthetic Sediment Characteristics for Hexagenia Habitat
Adrian M. Gonzalez, UT, Civil and Environmental Engineering; Envonyx Independent R&D

BIODEGRADATION OF QUATERNARY AMMONIA COMPOUNDS BY BIOFILM AND FREE-LIVING BACTERIA

Zheer Ahmed[1]

Quaternary Ammonia Compounds (QAC) are ubiquitous and commonly used in industrial, domestic, agricultural, and healthcare related fields, QACs are used in surfactants, fabric softeners, disinfectants and even pesticides. One consequence of its widespread use, however, is that 75% of these compounds are discharged into wastewater and little is known about their environmental fate or consequence to ecosystems. Despite their strong bacteriocide characteristics, QACs are vulnerable to the process of biodegradation. The objective of this project was to determine the role of surface area and biofilm development on biodegradation rates of QACs (didecyl dimethyl ammonium chloride and dimethyl benzyl ammonium chloride). To achieve this objective, bacteria resistant to QAC's were collected from a WNS decontamination station at Mammoth Cave saturated with QACs. An experiment was designed to test whether bacteria provided approximately 2.6 times (527 cm^2) more surface area for biofilm development were more efficient at biodegrading QACs than free-living bacteria. Previous research has shown that biofilm formation enhances certain biodegradation pathways. . The microcosms containing QAC solution and bacteria were allowed to equilibrate for 4 weeks to account for sorption and the attachment of bio-film. Then negligibly sized samples were taken periodically to assess biodegradation rates under the different conditions. Preliminary results show that the microcosms with 2.6 times more surface area improved degradation rates with a 48% reduction as opposed to a 38% reduction over a two week period. The results indicated that providing more surface area for biofilm development is something that wastewater engineers should consider if they are targeting biodegradation of QACs.

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ANTIBIOTIC RESISTANCE AND SUBSTRATE UTILIZATION BY BACTERIA AFFILIATED WITH CAVE STREAMS AT DIFFERENT LEVELS OF MAMMOTH CAVE

Petra K. Byl[1], Rickard Toomey[2], Jacob Byl[3], David Solomon[4], Shannon Trimboli[5], acknowledgement - Tom Byl[6]

INTRODUCTION

Located in south-central Kentucky, Mammoth Cave is one of the most unique National Parks in the United States. The surface landscape includes complex relationships between the flora and fauna along with human influences. However, the primary ecological focus is concealed below ground. Over four-hundred miles of cave passages, created by flowing groundwater over millions of years, host a variety of macro and micro organisms. The Green River has cut into the limestone formation over geologic time, creating a complex network of passages that are stacked, one below the other, with the newer levels of cave lying near the bottom. Palmer (2007, 1987) describes 4 levels of cave passages in the Mammoth Cave system. A detailed discussion of the geology and conditions that formed the cave levels can be found in several reports (Palmer, 1987; Palmer 1989; White and White, 1989; Granger, et al, 2001). Precipitation continues to provide water that traverses from the surface, through the unsaturated vadose levels of the cave, and down to the water table in the lower level. Water enters the cave system through direct recharge at sinkholes and through diffuse percolation. The rapid infiltration of stormwater often exceeds the carrying capacity of the upper cave passages and excess water is pushed into void pore-spaces near the top of bedrock. This stored water is slowly released and provides base-flow to cave streams that replenish the pools and streams in the lowest level of the cave (Ryan and Meimen, 1996).

These perennial cave streams carry many of the organic compounds that provide energy to the cave ecosystem (Barr, 1976). The base flow of these streams is punctuated by rapid recharge from sinkholes during storm events. Evidence for sudden influx of rain water is found by changes in the specific conductance of the subsurface streams during heavy rain events (Figure 1) and increased flow (Photos 1a-b). The rapid mixing of storm and base flow water is short lived and subsides comparable to surface runoff after a storm.

During May 2011 to August 2012, the Park endeavored to prevent the spread of *Geomyces destructans* spores by using mats that were saturated with a quaternary ammonia compound (QAC) solution to disinfect the foot wear of everyone who entered the cave. QAC residue on the ground near the disinfection stations was visibly evident during prime tourist season. This heavy use of QACs raised concern about the potential for the disinfectant to be carried into the cave via storm runoff. Also, there was concern about QACs in accidental leaks associated with the

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recreational vehicle wastewater disposal (Diehl and others, 2012). These potential QAC sources were all within the small

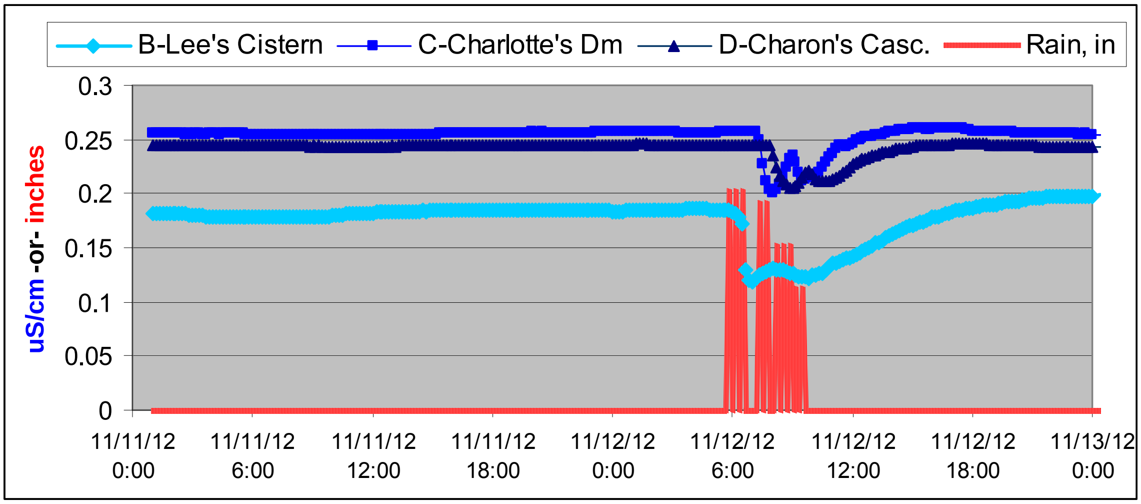

Figure 1. Specific conductance of three vadose streams in Mammoth Cave, November 11-13, 2012. The three streams represent the 3 levels of the cave system, B=mid-level, C=lower level, and D=bottom level. The 0.7-inch rain lasted approximately 4 hours (rainfall data courtesy B. Carson, Mammoth Cave NPS.)

Photo 1a. Flow into the Devil's Cooling Tub, in Gratz Avenue, cave level B, during a storm (discharge is approximately 250 liters per minute).
Photo 1b (right). Flow at the same location, approximately 20 hours after the storm subsided (discharge is approximately 78 liters per minute).

River Styx watershed boundary. One potential consequence of QAC in the River Styx watershed was that it could lead to selection of QAC-resistance in the microbial community. Previous research found that bacteria resistant to QACs were likely to be resistant to other antibiotics (Chapman, 2003). Accordingly, it was possible that repeated exposure to QACs could also lead to resistance of medical antibiotics. There was additional concern that QACs may inadvertently act as microbial signals (Keller and Surette, 2006) or disrupt natural biogeochemical cycles (Underwood and others, 2011) at sublethal concentrations.

Microorganisms play an essential role in the health of Mammoth Cave's ecosystem, yet the ecology of microbial communities in the cave streams has been largely neglected (Barton and Northup, 2007). Most of the scientific literature concerning cave microbiology addresses microbes that live on the cave walls and sediments (Rusterholtz and Mallory, 1995; Northup and Lavoie, 2001; Barton, and others, 2007) or speleothems (Palmer 2007). This project begins to address the gap in microbial ecology of cave streams.

This collaborative project focused on the microbial communities associated with the perennial cave streams in four levels of Mammoth Cave. The objective of this project was to determine the substrate utilization and dose-response to five antibiotic compounds in the microbial communities of cave streams. Sites selected for the study correspond to perennial water from three different levels of the cave within the River Styx Spring basin. The River Styx basin is a small, 1.2 square mile watershed, located beneath the campgrounds to the Visitors Center. Water samples used for microbial analysis were collected during the summer of 2012. Base-flow samples were used for most of the analysis since that would reflect the ambient condition in the cave streams. It should be noted that Central Kentucky experienced a severe drought during the summer of 2012, which also affected our ability to collect storm samples.

METHODS and MATERIALS

Site description - The sampling sites were selected to represent different levels in the cave system (Figure 2). The Post Office parking lot was selected as a surface site for storm sampling. Previous storm sampling had found QACs associated with the RV wastewater disposal system (Diehl and others, 2012). A quantitative dye study in December of 2011 found that it took approximately 75 minutes for the tracer from the parking lot storm filter discharge to reach Shaler's Brook in Annette's Dome located in the upper part of the mid-level cave (Embry and others, 2012). Another tracer study found that it took another 20 minutes to reach Lee's Cistern in the lower mid-level cave. The tracer study failed to show that water flowed from Lee's Cistern to Charlotte's Dome in the lower level and Charon's Cascade at the bottom level. However, a third tracer study found Charlotte's Dome and Charon's Cascade were hydraulically linked and that it took approximately 20 minutes for the tracer to migrate from Charlotte's down to Charon's Cascade during baseflow.

Additional water samples were collected on the surface, at the Historical Entrance disinfection mat, and, at 2 locations in the mid-level cave passage called Gratz Avenue. The footwear disinfection mat was kept saturated with a QAC solution containing 1.33 grams QAC /liter and was a prime candidate for multi-antibiotic resistant bacteria. The Devil's Cooling Tub, located near the south-east end of Gratz Avenue, mid-level passage, was also found to be hydraulically connected to the Post Office runoff. However, it took approximately a month for the tracer released at the Post Office to reach the Devil's Cooling Tub. A stagnant pool mid-way along Gratz Avenue (mid-level) was selected because it represented a different hydrologic setting from Annette's Dome, Lee's Cistern and Devil's Cooling Tub. It did not experience measurable flow velocity (even during storms), nor changes in specific conductance or water-levels. Figure 2 displays the cave routes and sampling sites. Different cave-passage levels are indicated by different colors.

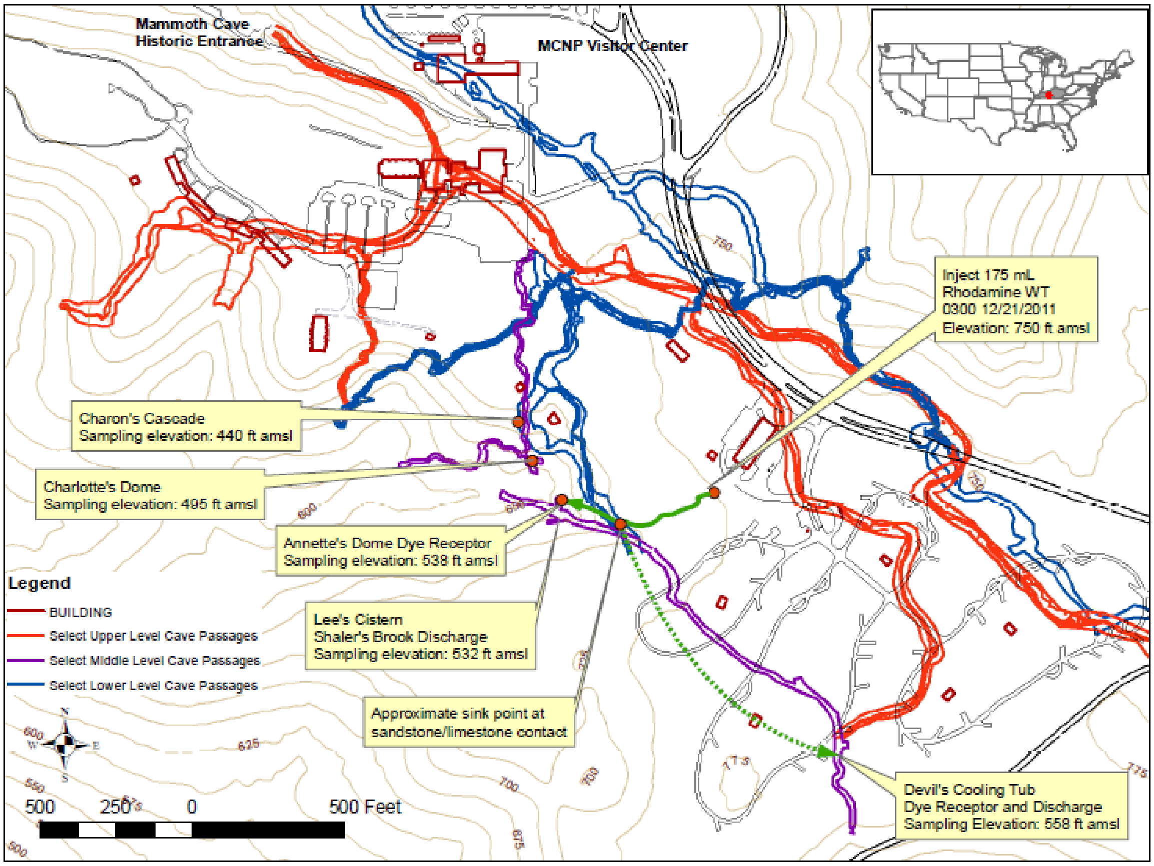

Figure 2. Map depicting sampling sites. Surface water samples were collected at the dye injection point by the Post Office storm filter. Three levels of the cave are represented in this study, upper levels (red), mid-levels (purple) and lower levels (blue). Rhodamine-WT tracer is represented in green.

Water samples for microbial analysis were collected approximately every 2 to 3 weeks in the summer of 2012. Grab samples were collected during base flow using clean sterile 250 mL bottles. A first flush storm sampler (Diehl, 2008) was also used at the Post Office filter discharge pipe and in Annette's Dome. The water samples were brought back to the lab in Nashville and stored at 5°C until analysis was done.

Analysis included bacteria plate counts using 2% agar containing 10% strength Tryptic Soy nutrients (10% TSA). Previous work by Byl and others (2002) found karst groundwater bacteria grew better on low strength media than full strength TSA. Known concentrations of the antibiotics QAC, tetracycline, gentamicin, kanomycin, and erythromycin, were mixed into the

10% TSA just prior to pouring the plates. The cave water samples were hand shaken for a minute to re-suspend the bacteria, and a 10 uL aliquot of raw water was placed on the agar. The cave water containing bacteria was evenly spread over the plate using a sterile bent glass rod. Innoculated plates were inverted and placed in an incubator at 25°C. The bacteria colonies were counted at 1, 2, and 3 days. The results are reported as colony forming units per 10 uL.

The microbial metabolic capabilities were characterized using Biolog's Ecolog™ plates to determine community-level physiological profiles. The plate has 31 different substrates, and three replicates of each substrate (Stefanomicz, 2006). The strength of the bacteria inoculums were normalized by diluting the cave waters with sterile distilled water to a standard turbidity of 1 nephelometric turbidity unit. Standardizing the inoculum, as described in Haack and others (1995), assured that observed differences in community-level physiological profiles were not simply due to differences in bacteria concentration (Figure 3). Readings of the plates were taken at 12, 24, 48, 72, 96, and 120 hours. Analysis included richness, Average Well Color Development (AWCD) (Stefanowicz, 2006), and, Gini coefficient (Harch and others, 1997). Stata™ statistical package was used to calculate the Gini coefficient. The richness is a measure of how many substrates the bacteria community used. AWCD is an indicator of community metabolic rate. The Gini coefficient is a measure of how evenly the bacteria used the 31 substrates.

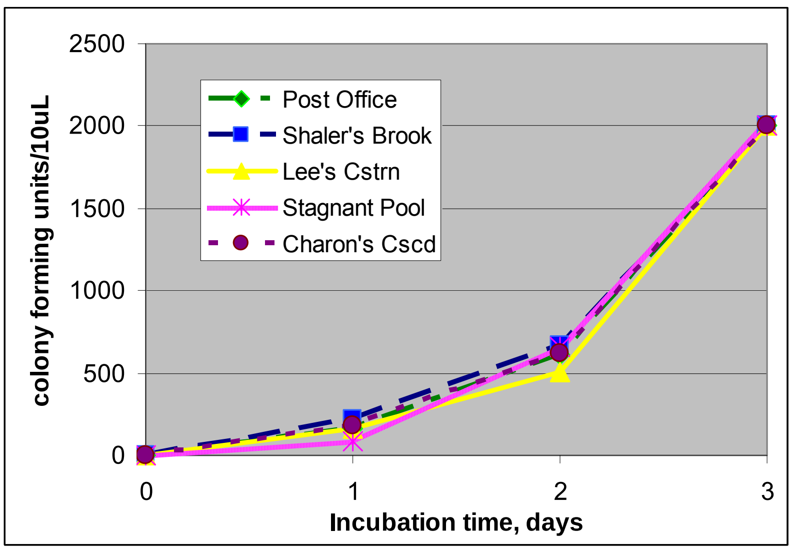

Figure 3. The water used to inoculate the Biolog™ plates was standardized by diluting with sterile distilled water to a turbidity of 1 NTU. This assured that the number of bacteria used in each inoculum was equal.

RESULTS and DISCUSSION

The results of this project are split into two subsections, antibiotic resistance and substrate utilization by the microbial communities. Antibiotic resistance evaluations were achieved by running dose-response tests on 10% TSA plates dosed with increasing concentrations of antibiotics. The substrate utilization tests used Ecolog™ plates to quantify community-level physiological profiling by providing 31 potential food substrates for the bacteria communities to consume over a 5 day period.

Antibiotic resistance – Figures 4 through 9 present the bacteria plate counts for samples collected during base flow. The antibiotics used included QAC, tetracycline, gentamicin, kanamycin, and erythromycin. Antibiotic resistance bioassays included water from the six sampling sites indicated on Figure 2.

Bacteria collected from cave stream at different levels within the River Styx basin of Mammoth Cave were sensitive to QACs with the exception of the sample collected from the Historic Entrance disinfection mat (Figure 4). Bacteria from the mat were resistant to full strength 1.33 mg/L QAC. Bacteria collected at Devil's Cooling Tub, Shaler's Brook, Lee's Cistern and Charon's Cascade were slightly resistant at 1/10th this concentration. But, bacteria from Stagnant Pool were vulnerable to all levels of QACs tested. The product label recommends QAC concentrations around 0.665 mg/L.

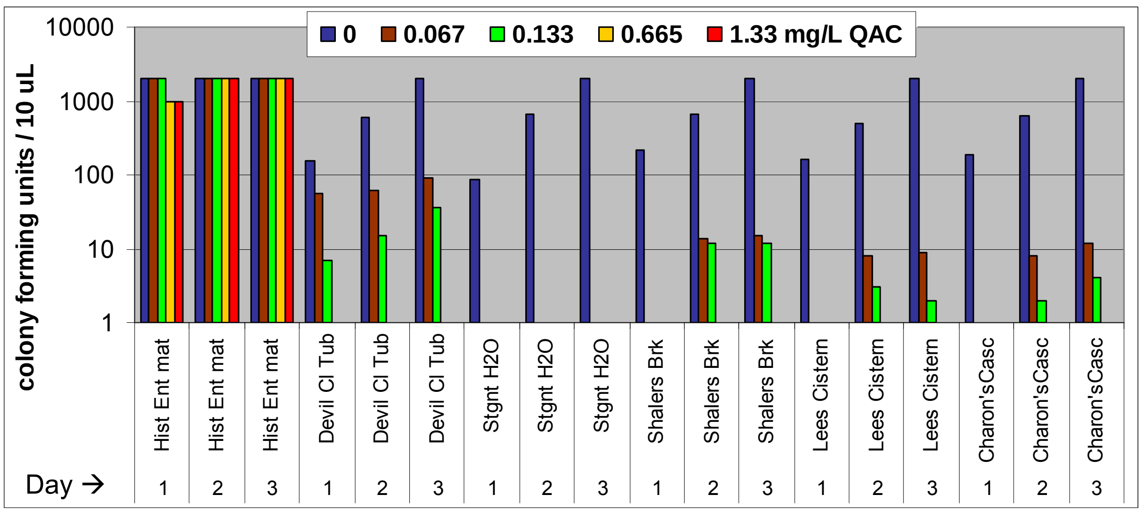

Figure 4. Number of colony forming units that grew on 10% TSA supplemented with increasing concentrations of quaternary ammonia compounds (QAC). Counts are the average of 2 plates from days 1, 2, and 3. [Historic Entrance disinfection mat (Hist Ent mat), Devil's Cooling Tub (Devil Cl Tub), Stagnant Pool (Stgnt H2O), Annette's Dome at the beginning of Shaler's Brook (Shalers Brk), Lee's Cistern (Lees Cistern) and Charon's Cascade (Charon's Casc)].

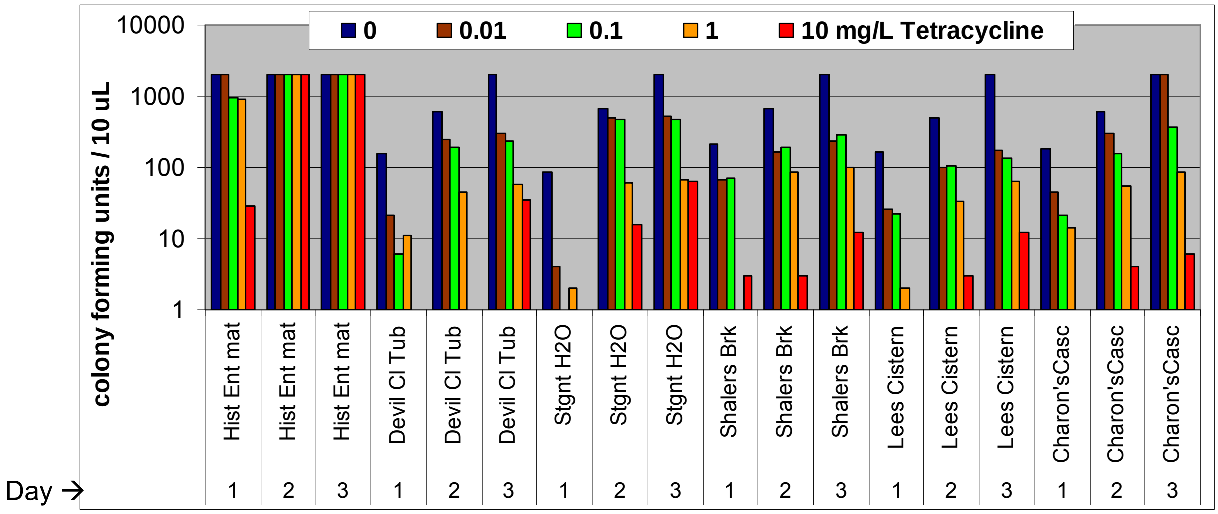

Figure 5. Number of colony forming units that grew on 10% TSA supplemented with increasing concentrations of Tetracycline. Counts are the average of 2 plates from days 1, 2, and 3. [Historic Entrance disinfection mat (Hist Ent mat), Devil's Cooling Tub (Devil Cl Tub), Stagnant Pool (Stgnt H2O), Annette's Dome at the beginning of Shaler's Brook (Shalers Brk), Lee's Cistern (Lees Cistern) and Charon's Cascade (Charon's Casc)]

Cave bacteria exhibited a typical dose-response when exposed to tetracycline (Figure 5) or gentamicin (Figure 6). There was a decrease in the number of colony forming units in response to increasing tetracycline or gentamicin concentrations with the exception of the Historic Entrance mat. Bacteria from the Historic Entrance mat were resistant to 10 mg/L antibiotic. Medicinal concentrations routinely range from 1 to 10 mg/L.

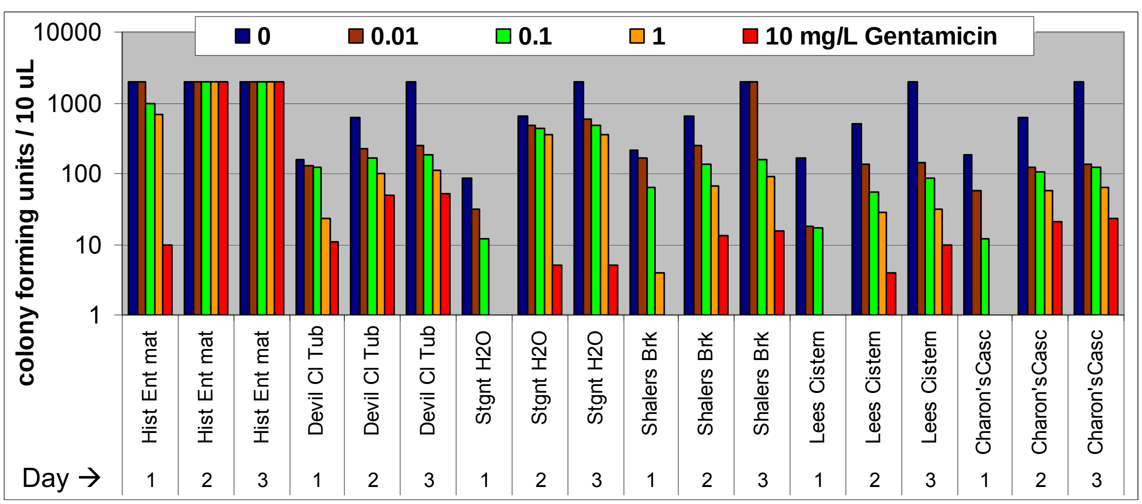

Figure 6. Number of colony forming units that grew on 10% TSA supplemented with increasing concentrations of Gentamicin. Counts are the average of 2 plates from days 1, 2, and 3. [Historic Entrance disinfection mat (Hist Ent mat), Devil's Cooling Tub (Devil Cl Tub), Stagnant Pool (Stgnt H2O), Annette's Dome at the beginning of Shaler's Brook (Shalers Brk), Lee's Cistern (Lees Cistern) and Charon's Cascade (Charon's Casc)]

Bacteria from all the sites showed some resistance to the antibiotic kanamycin, but the bacteria from the Historic Entrance disinfection mat were resistant to all doses tested (Figure 7). Medicinal concentrations of kanamycin range up to 10 mg/L.

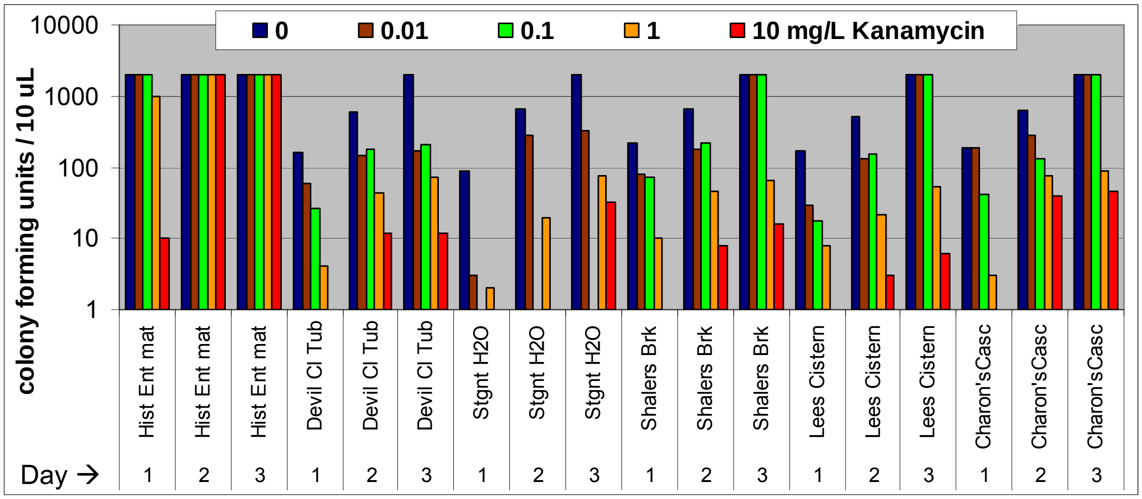

Figure 7. Number of colony forming units that grew on 10% TSA supplemented with increasing concentrations of Kanamycin. Counts are the average of 2 plates from days 1, 2, and 3. [Note - The 0.1 mg/L Stgnt H2O plates were contaminated with fungus. Those cfu data were not included here. Historic Entrance disinfection mat (Hist Ent mat), Devil's Cooling Tub (Devil Cl Tub), Stagnant Pool (Stgnt H2O), Annette's Dome at the beginning of Shaler's Brook (Shalers Brk), Lee's Cistern (Lees Cistern) and Charon's Cascade (Charon's Casc).]

The fifth antibiotic tested was erythromycin, a macrolide antibiotic synthesized by an Actinomycete bacterium, *Saccharopolyspora erythraea*. Actinomycetes are very widespread in Mammoth Cave (Rusterholtz and Mallory, 1995), which might explain why the cave bacteria appear to be resistant to it (Figure 8). In fact, 0.01 to 1 mg/L doses of erythromycin stimulated colony forming units in water from Lee's Cistern, intimating it may be a microbial signal in the cave system (Keller and Surette, 2006).

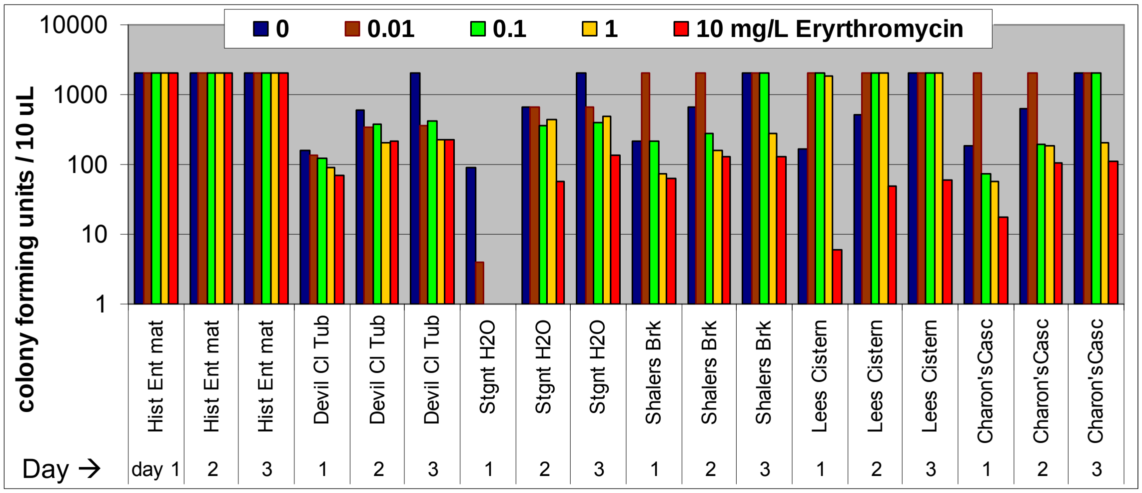

Figure 8. Number of colony forming units that grew on 10% TSA supplemented with increasing concentrations of Erythromycin. Counts are the average of 2 plates from days 1, 2, and 3.

An additional erythromycin test was done using water collected July 20, 2012 from Lee's Cistern. Three replicate plates were used to permit statistical analysis. A Student T-test was used to ascertain significant differences in colony forming units between treatments (p-value = 0.05). There were statistically significant increases in cfu after 48 hours (Figure 9).

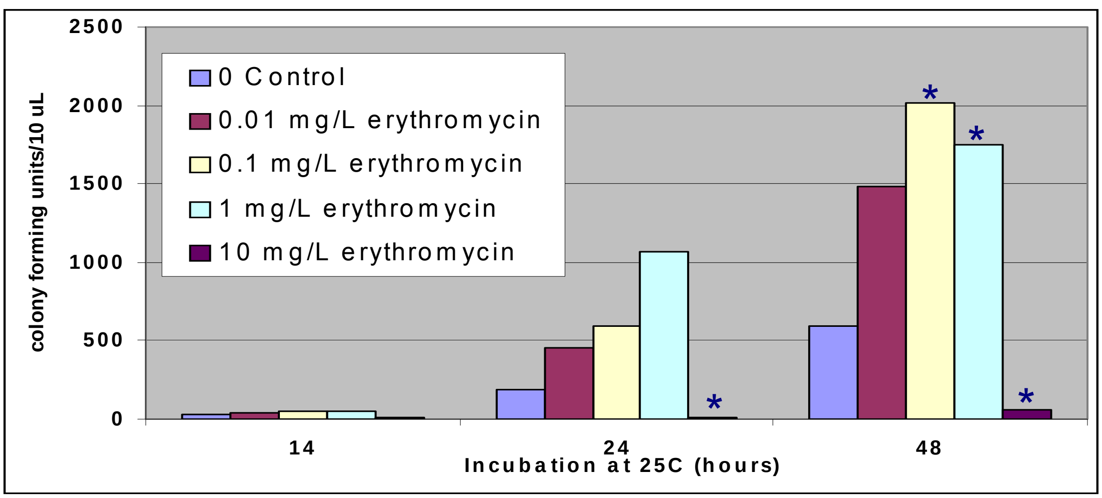

Figure 9. Number of colony forming units on 10% TSA supplemented with increasing concentrations of Erythromycin. Counts are the average of 3 plates at 14, 24 and 48 hours. [an * indicates the bacteria count was significantly different from the controls as determined by a Student T-test with a p-value = 0.05]

Substrate utilization tests –The Biolog™ results from the Post Office storm drain (surface), Shaler's Brook (upper mid-level), Lee's Cistern (lower mid-level), Charlotte's Dome (upper-lower level), and Charon's Cascade (bottom level) are provided in this section. The data analyses include substrate diversity (substrate richness), an indicator of metabolic rate (Average Well Color Development), and substrate evenness (Gini coefficient).

The samples collected on the surface and in the upper levels of the cave had the greatest initial substrate richness values (Figure 10). Charlotte's Dome (lower level) was an exception and had relatively high richness. However, the rate at which the microbial community from Charlotte's Dome used the substrates was slow (Figure 11). After 72 hours, the richness values for all the sites tested were similar (Figure 10). This indicates there was an initial preference for certain substrates, but given time, the bacteria communities can utilize almost all 31 substrates to some extent.

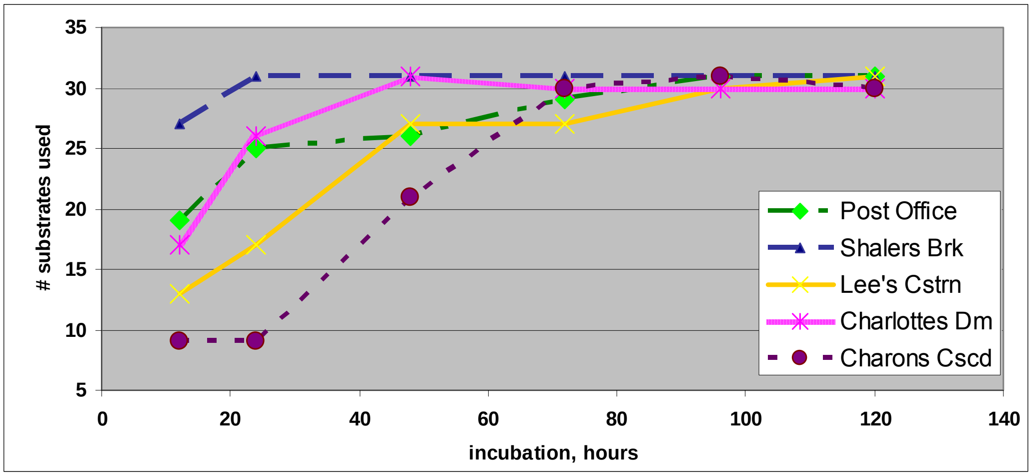

Figure 10. Substrate richness for the different bacteria communities through time.

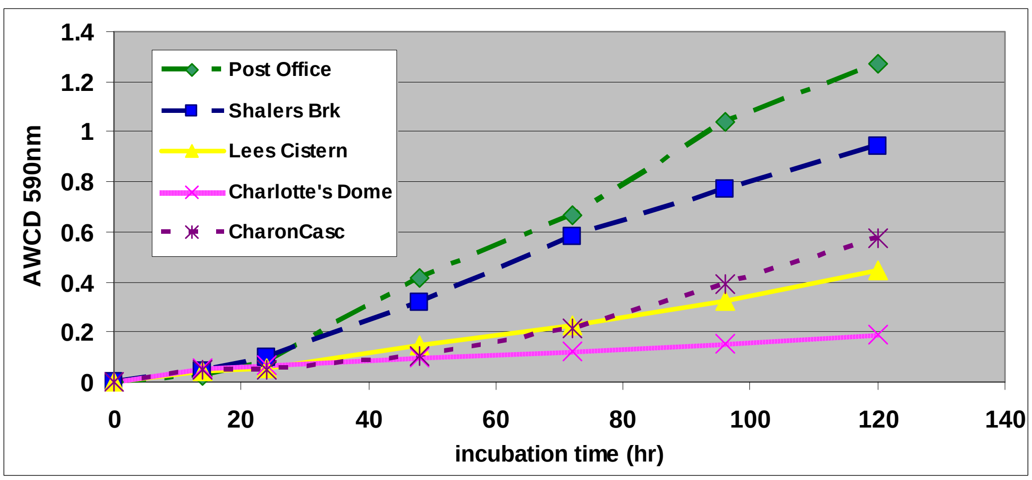

Figure 11. The Average Well Color Development (AWCD) is an indicator of metabolic rates; the steeper the slope, the faster the metabolic rate of the microbial community.

The average well color development (AWCD) is a measure of the rate of substrate consumption in the Ecolog™ plates. As can be seen from the slope of the lines in Figure 11, the AWCD is greatest for the microbial community from the surface site and decreases with the microbial communities deeper into the cave. The exception is Charon's Cascade, which starts off slow, but accelerates after 2 days. Generally, these results indicate that the microbial-community metabolic rates are greatest at the surface and progressively decrease as one goes into the lower sections of the cave.

As noted in the bacteria plate counts, erythromycin stimulated the growth of cfu. We used the Biolog system to determine if a community-level physiological profile change was noticeable when erythromycin was added before inoculating the Ecolog™ plates. A 1 mg/L nominal concentration of erythromycin was added to the waters from Lee's Cistern and Charon's prior to inoculating the plates. The results (Figure 12) indicate that exposure to 1 mg/L erythromycin increased the substrate richness 45-66% in the first 12 hours. Despite a much greater richness in the first 24 hours, there was no statistically significant increase in metabolic rate, as indicated by AWCD data.

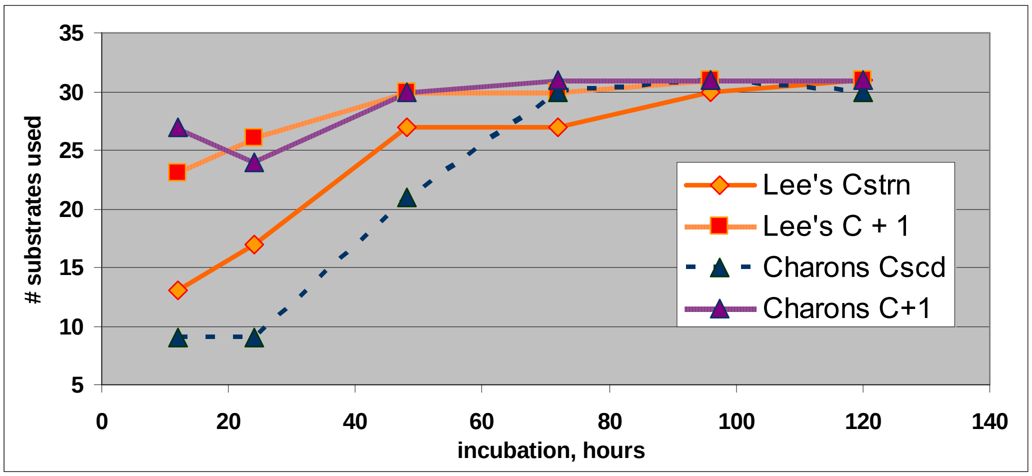

Figure 12. Bacteria from Lee's Cistern and Charon's Cascade treated with 1 mg/L erythromycin had greater initial substrate-richness values than untreated bacteria.

Substrate richness and AWCD are useful measures of microbial ecology, but do not provide information about how evenly the microbial community utilized the 31 substrates. The Gini coefficient is a statistical measure of evenness in a population, ranging from 0 to 1, with 1 being the most uneven and 0 being perfectly equal use of all the substrates. The Gini coefficient values decreased in the first 72 hours, indicating that substrate utilization became more even (Figure 13). However, the Gini coefficient from samples collected from deeper in the cave (Charlotte's Dome, lower level, and Charon's Cascade, bottom level) leveled off after 72 hours, indicating that a steady state had been reached. After 120 hours incubation, it was evident that the microbial communities from or near the surface used the substrates more evenly than the communities deeper in the cave.

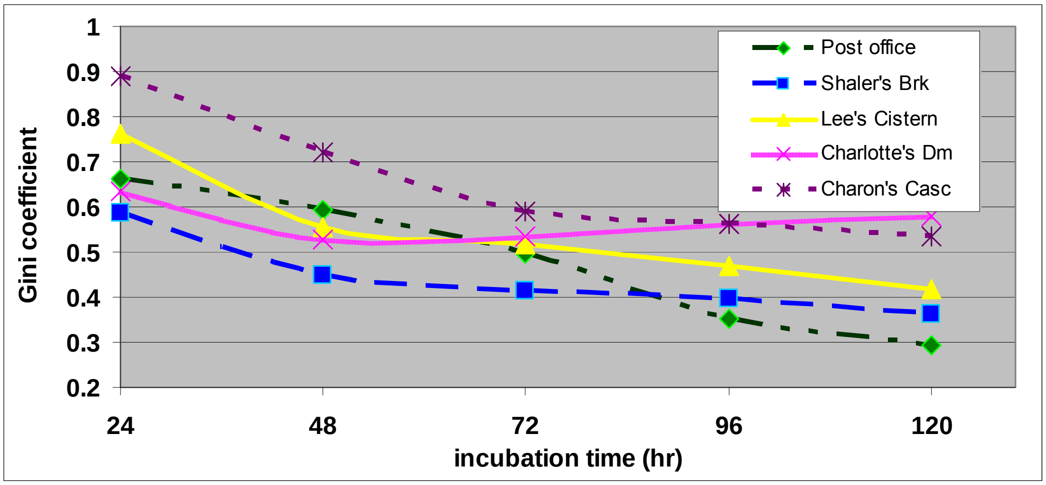

Figure 13. The evenness of substrate use was measured using Gini coefficients. The scal is 0-1, with 0 indicating equal use of all the substrates, and, a value of 1 indicating that only 1 of the 31 substrates was used.

It was evident that the microbial communities did not necessarily share similar physiological profiles. The microbes in the surface runoff or in the upper levels of the cave tended to have greater richness, higher metabolic rates and more evenness of substrate use. Four of the 31 substrates were plotted to visualize their utilization pattern from the surface to the bottom of the cave, using the 120 hour data (Figure 15). The four substrates selected were hydroxybenzoic acid, galacturonic acid, acetyl glucosamine, and Tween 40. Hydroxybenzoic acid is a common leaf compound and can be leached out by rain. Galacturonic acid is the carbohydrate molecule found in pectin polymers, common in plant cell walls and fruits. *N*-acetylglucosamine is the main component of the chitin polymer in insects and arthropods and is also in the biopolymer of bacterial cell walls. Tween-40 is a fatty oil compound similar to fatty acids in biological membranes. The microbial community in the surface runoff waters was more efficient at using hydroxybenzoic acid and N-acetylglucosamine than galacturonic acid and Tween-40. The microbial community in the upper cave (level B) preferred galacturonic acid to the other substrates. Moving deeper into the cave system (levels C and D), there is a major shift from using the simple carbohydrates (hydrobenzoic acid, N-acetylglucosamine, galacturonic acid) to using the lipid Tween-40.

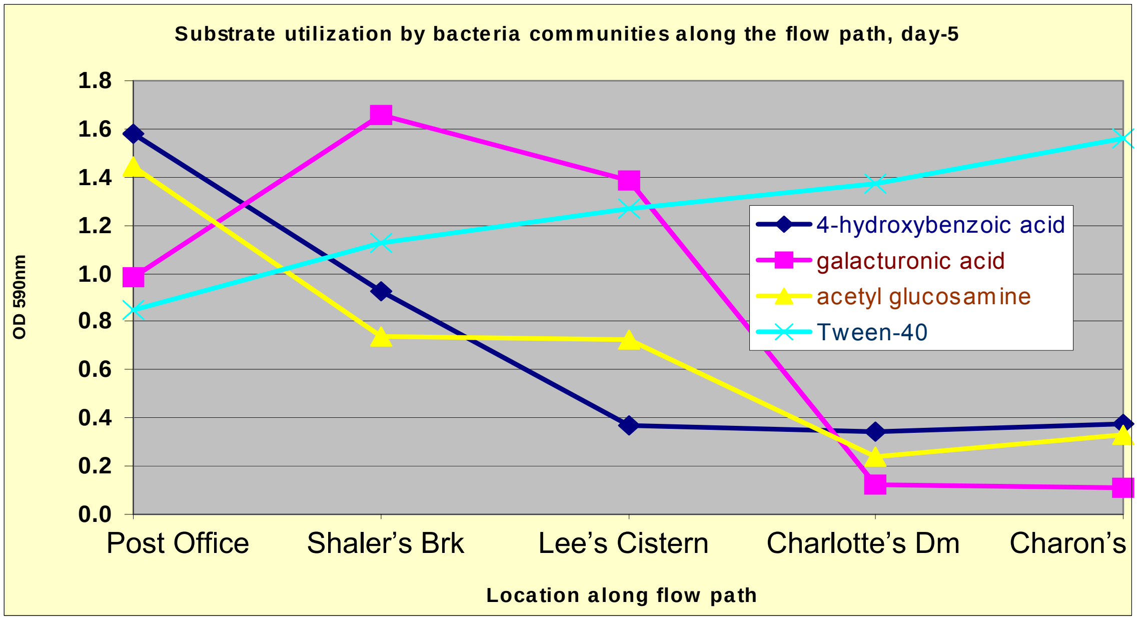

Figure 15 (note – this graph is just a place holder) – Substrate preference at 5 locations in the cave.

In summary, this project looked at the response of cave microbial communities to five antibiotics and their substrate utilization patterns. The cave bacteria appear to be sensitive to QACs, with a slight resistance at the upper cave levels. The footwear decontamination mats soaked with QACs have selected for multi-antibiotic resistant bacteria. Fortunately, the use of QACs in the decontamination mats has been discontinued for other reasons. As other microbicides are being considered, care must be given to prevent the re-establishment of multi-antibiotic resistant bacteria. The bacteria communities in the cave have varying levels of natural resistance to the four antibiotics tested. This resistance is probably due to exposure to similar molecules naturally secreted by the ubiquitous cave bacteria actinomycetes. The data further suggests low doses of erythromycin may act as a microbial messenger and stimulate bacteria growth and substrate richness. Further studies are needed to determine if erythromycin occurs in this environment to determine if it is a microbial messenger in this environment. Using the Ecolog substrate utilization plates, we found that substrate richness, metabolic rates and evenness of substrate use tend to decrease in communities deeper in the cave, with some exceptions. Community preference for certain substrates changed as the water moved from the surface into the cave. Small carbohydrates derived from plants and insects were preferred at or near the surface. The microbial communities deeper in the cave favored the lipid molecule. These results suggest there is a shift in microbial physiological capabilities associated with the different levels in the cave system. The sampling for this study took place during a particularly hard drought (summer of 2012). Thus, the distinct microbial community patterns described here may vary under different seasonal or hydrological conditions.

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WATER QUALITY TESTING AT COOPER CREEK

Desiree Schutt[1], Destinee Schutt[1], and Shelby Seaborn[1]

Understanding the chemical, physical and biological characteristics of water is important because clean water is essential for human consumption and maintaining healthy ecosystems. The goal of this project was to understand the overall water quality of Cooper Creek, a tributary of the Cumberland River that runs near Stratford High School in Nashville, TN. The Cumberland is the source of drinking water for Davidson County, therefore understanding the quality of its water is important. Tests were performed to analyze levels of the chemical components of the creek, including nitrates, phosphates and ammonia. Further tests were performed to analyze the levels of bacteria from fecal contaminations, as well as animals living within the creek. Moderate levels of fecal bacterial contamination were found in the creek. Upon discovering this contamination, microbial source tracking was performed to identify the animal(s) from which the fecal matter came because understanding the source is necessary to design possible preventions to block future contamination. In conclusion, the quality of water in Cooper Creek was suitable for recreational use, but not for potable water. Based on these results future directions include further microbial source tracking as well as identifying specific locations along the creek where fecal contamination is occurring.

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REDUCTION OF SELECTED CHEMICALS FROM STORM RUNOFF BY FILTERS AND BIODEGRADATION

JeTara Brown[1], D. Solomon[1], A. West[1], Lonnie Sharpe[1]
Acknowledgement - Dr. Tom Byl[1,2]

Mammoth Cave National Park was designated an International Biosphere Reserve in 1990 because of the unique environment with many rare and endangered species in the cave system. The ecosystem in the cave is linked to the surface through groundwater recharge; hence the Park's concern for maintaining high quality storm runoff from their parking lots. The Park Service was concerned about fuel compounds and metals from vehicles, quaternary ammonia compounds from recreational vehicle waste transfers, and linear alkyl benzene sulfonates (anionic detergents) from the White Nose Syndrome disinfection stations. The objective of this study was to evaluate the ZPG storm-water filters. The sampling focused on the first-flush runoff waters during the storms. The filters removed approximately greater than 90 % of the fuel compounds. The filters removed 30-90% of the quaternary ammonia compounds from storm runoff. The filters appear to do nothing to remove anionic detergents from storm runoff. Fortunately, we found that the bacteria in the soils and cave streams readily biodegrade the detergents under aerobic conditions. Most filters removed 10-50% of the sulfate, nitrate and ammonia in the runoff. Unfortunately, one filter system near a construction site (Visitor's Center storm filter) became filled with sediments and actually released more nutrients at the beginning of storms than it captured. With the exception of this sediment-filled filter system, the other ZPG filters appeared to improve water quality. Additional studies must be done to improve the efficiency of the filters to remove linear alkyl benzene sulfonates and other chemicals that are toxic to the aquatic organisms in the cave.

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FEASIBILITY STUDY FOR STREAM RESTORATION OF BREEDINGS MILL BRANCH, COOKEVILLE, TN

Alex Burton[1]

Stream restoration involves sets of activities and designs that intend to help improve the health of a river or stream system. The purpose of this research is to conduct a feasibility study for restoring Breedings Mill Branch, a stream in Cookeville, Tennessee. Breedings Mill Branch is a tributary within the Pigeon Roost Creek drainage basin (drainage area = 3.76 km^2, 930 acres), and has been modified so that portions of the stream flow beneath the surface, under businesses, streets, and parking lots. The surface stream portions flow through a concrete channel that was constructed in the 1980s. The concrete channel has a bank-full width of 3 meters and a channel depth of 1.2 meters. The 1.8 km reach of Breedings Mill Branch that is being assessed for restoration has a channel slope of 0.0093. Recommendations for restoration will be based on a reference reach located on Danner Creek. Final recommendations may include re-meandering of the channel, addition of fine and coarse material, and planting of riparian vegetation. To ensure that a restoration will be feasible, not only as proper flood control, but also as a social and economical catalyst, a demographic study will be done to see if the residents surrounding the area will have a better quality of life post restoration.

[1] Tennessee Tech University

POSSIBLE INFLUENCE OF CROPPING PRACTICES ON IN-STREAM NUTRIENT CONCENTRATIONS IN A RED RIVER SUBWATERSHED

Taylor C. Fleet[1,2], David M. Duhl[1], and Sherry H. Wang[1]

High nutrients in surface waters result in impaired local water quality and contribute to hypoxia in the Northern Gulf of Mexico. We analyzed nutrient (nitrogen and phosphorus) concentrations at various sites in the Red River Watershed (05130206). Site RED025.5MT is typical in that concentrations of nitrate-nitrite changed over the years while total phosphorus did not exhibit a similar pattern. Analysis by growing season (March-June) and by calendar season revealed that phosphorus is highest in fall, while nitrate-nitrite is highest in spring. Comparisons to cropping patterns showed that these results are typical of sites near land that is double-cropped. The results help to identify potential solutions including opportunities for additional agricultural conservation practices that can be implemented to reduce nutrient loadings in order to improve water quality.

[1] Tennessee Department of Environment and Conservation, Division of Water Resources
[2] Summer intern

SOLUTE TRANSPORT IN KARST, A DUAL CONTINUUM MODEL

Justin Harris[1], Roger Painter[1], and Lonnie Sharpe[1]
Acknowledgement – Tom Byl[1,2]

The advection dispersion equation (ADE) applied to pipe flow often successfully models solute transport between major karst features, since flow within these reaches is predominately conduit flow. However, the slower solute transport associated with flow in the diffuse continuum may explain the tendency of tracer response concentration data to have a long upper tail compared to the prediction of the ADE. The hydraulic response of karst to a rain event also reflects the dual continuum for karst flow. The high permeability of the conduit network allows for a subsequent quick response at the spring to a rain event, and a slow recession to pre-rain event spring flows is often related to water being released from storage in the fractured media. It is in this context that the case is made for a dual continuum transport model for karst.

In existing double continuum models the matrix and the conduit network are each represented by a continuum; this exchange of water between the two continua is governed by lumped exchange parameters. This paper presents a dual continuum model for karst based on the finite element solution of the rigorous model in terms of the Navier-Stokes, continuity equations describing conduit flow, and a modified Darcy equation describing the diffuse phase flow, which are then used in the transient ADE describing solute concentration. In the model, the two adjacent continua share a common boundary. Due to the extreme differences in the flow regimes near the common boundary, the boundary conditions are characterized by very steep gradients. Furthermore, the hydraulic characteristics are independent of the concentration of the contaminant. Logically conservation of mass and momentum require that the gradients be continuous and in this model the continuity at the common interface was achieved computationally using smooth Heaviside unit functions in a finite element model.

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CHARACTERISTICS OF BEDLOAD IN A KARST STREAM SYSTEM

Kyle Long[1]

ABSTRACT

Despite the widespread occurrence of karst terrain, few studies have examined bedload transport in caves. Bedload size and roundness are likely to be affected by abrasion inside caves. This study examines bedload characteristics including size, roundness, and lithology in the Pigeon Roost watershed, Cookeville, TN. Data were collected from stream reaches upstream from, within, and downstream from Capshaw Cave. Data were also collected from a control stream, Hudgens Creek, which does not flow through a cave. Nine random samples were taken from within Capshaw Cave, six at the resurgence, and 6 from the swallet and 4 random samples were taken from Hudgens creek. Samples were also collected along the length of Hudgens Creek, the control stream. Samples were processed through sieves ranging from 5.6mm to 25mm. Clasts were examined for degree of rounding or angularity and for lithology (acid test for limestone). Nine roundness classes were recognized: very angular (1,2), angular (3,4), sub-angular (5), sub-rounded (6), rounded (7), and well-rounded (8,9). (Krumbein,1941). Particle size for samples along Hudgens Creek were smaller and had a lower mean roundness (4.0) than Capshaw Cave stream (6.6). The higher the number the rounder the bedload is. These results show that before streams enter the cave, the sediments are more angular and rapidly become rounded within the cave. Bedload in the control stream does not show the same rate of downstream rounding. Thus, bedload in karst watersheds may have greater transport distances due to smaller particles sizes. For both streams, fewer than 10% of all particles were limestone and most were chert, but no difference was found in lithology between the two study streams. Data collected for mean roundness from the control stream Hudgens and Capshaw cave stream are starkly different. Shown here, Terry creek a swallet for Capshaw Cave received a mean roundness of 0.49, inside the cave roundness is 0.50, the resurgence for the cave is 0.54. Further past the resurgence the stream goes underground again and reamerges as Pigeon Roost Creek samples of bedload taken here show a higher roundness of 0.55. Hudgens roundness is less, showing upstream 0.43, center 0.49, and downstream from Capshaw Cave (0.52, 0.50). The distance for the nine sites are shown here (figure 1) along with the aggregate mean roundness for each sample. Blue shading represents sites from Capshaw Cave and the Purple shading represents Hudgens sites.

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Mean Roundness	Bedload Sites	Distance(km)
0.49	Terry Creek Swallet	2.1
0.50	Capshaw cave Center	3.2
0.54	Capshaw Resurgence	4.5
0.55	Pigeon Roost Creek 1	10.1
0.48	Pigeon Roost Creek 2	12.6
0.43	Hudgens upsteam	1.9
0.49	Hudgens Center	4.4
0.52	Hudgens Downstream 1	6.2
0.50	Hudgens Downstream 2	7.4

Figure 1

Abrasion plays a big role in bedload roundness it scours the edges smoothing but not loosing shape. Within a cave system we see bedload has a higher mean roundness as for the control stream Hudgens has a lower mean roundness. Distances that are longer show higher rounding this is true because the more stream area the higher abrasion. The lithology of bedload sampled from both streams was very different. More limestone clasts were found within Hudgens than in Capshaw. Whareas, in Capshaw Cave chert bedload was more abundant than limestone. This finding suggests that abrasion in the cave has reduced the number of limestone clasts in the bedload. The bedload limestone had time to dissolve with the increase in abrasion from the cave walls.

DETERMINATION OF SOURCES OF ORGANIC POLLUTION IN NATURAL WATERS BY LIQUID CHROMATOGRAPHY-MASS SPECTROMETRY

Sreedharan Lakshmi Narayanan[1*] and John Harwood[1,2]

ABSTRACT

Identifying the sources of organic matter in streams is important in pollution identification and remediation efforts, and in understanding stream ecology. These compounds are very stable; they collect in suspended particles and sediment in streams, rivers, and estuaries. Coprostanol has been used to positively identify sewage contamination in natural waters (1). The profile of bile acids and fecal sterols in animal excreta can be linked to individual animal species, and these compounds are being studied as source markers of organic pollution from animal production (2). For instance, the major sterols in chicken feces are cholesterol and stigmastanol, while coprostanol and cholesterol are predominant markers of cattle waste (3). Pollution from swine production may be indicated by the presence of hyodeoxycholic acid and lithocholic acid (4). We are focusing our method development on compounds which have been identified by Tyagi et al as sufficient to distinguish among different animal waste sources. These compounds are cholesterol, coprostanol, stigmasterol, stigmastanol, deoxycholic acid, and lithocholic acid (3).

Analysis of bile acids and fecal sterols presently relies on analysis by gas chromatography-mass spectrometry, which requires complicated and time consuming sample preparation. We are developing more rapid and direct procedures to analyze for the compounds by liquid chromatrography-mass spectrometry.

Analysis of sterols by electrospray mass spectrometer (ESI-MS) is technically challenging because the compounds are not easily ionized by the ESI interface. Both bile acids and fecal sterols are ionized in atmospheric pressure chemical ionization (APCI) with negative and positive ionization mode respectively. With the Varian 325-MS instrument, we have found the following optimized operating parameters for analysis of bile acids and fecal sterols by APCI-MS: corona discharge, 4 μA; shield potential, 600 V; housing temperature, 50 ^{o}C; drying gas temp, 325 ^{o}C; vaporizer gas temp, 350 ^{o}C; drying gas pressure, 12.0 psi; nebulizing gas pressure, 55.0 psi; and vaporizer gas pressure, 17.0 psi.

To positively identify compounds in LC-MS, the initial "parent ions" are fragmented by collision with a low pressure of inert gas, and the "daughter" ion spectra are measured. We attempted to identify daughter ions of fecal sterols and bile acids. The parent ion of sterols in LC-MS is the $M+H-H_2O$ ion (i.e., the molecular ion minus 17 amu). We verified that the sterols are so stable that no daughter ions can be produced from them (5). Deoxycholic acid does produce a usable daughter ion (345.2 amu), but none is obtained from lithocholic acid.

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Having developed MS/MS analysis of these markers, next we developed reverse-phase liquid chromatography separations of the combined bile acids and fecal sterols. The compounds are separated by the Zorbax Eclipse XDB-C8 column, at ambient temperature. Several combinations of mobile phase and sample compositions were tested. Finally, a combination of gradient method (0.2 mM ammonium acetate in water as aqueous phase and 80:20 % of acetonitrile and methanol as organic phase were selected as mobile phase; a flow rate of 0.50 mL/min provides good sensitivity with the APCI interface, and allows separation of the bile acids and fecal sterols in less than 30 minutes.

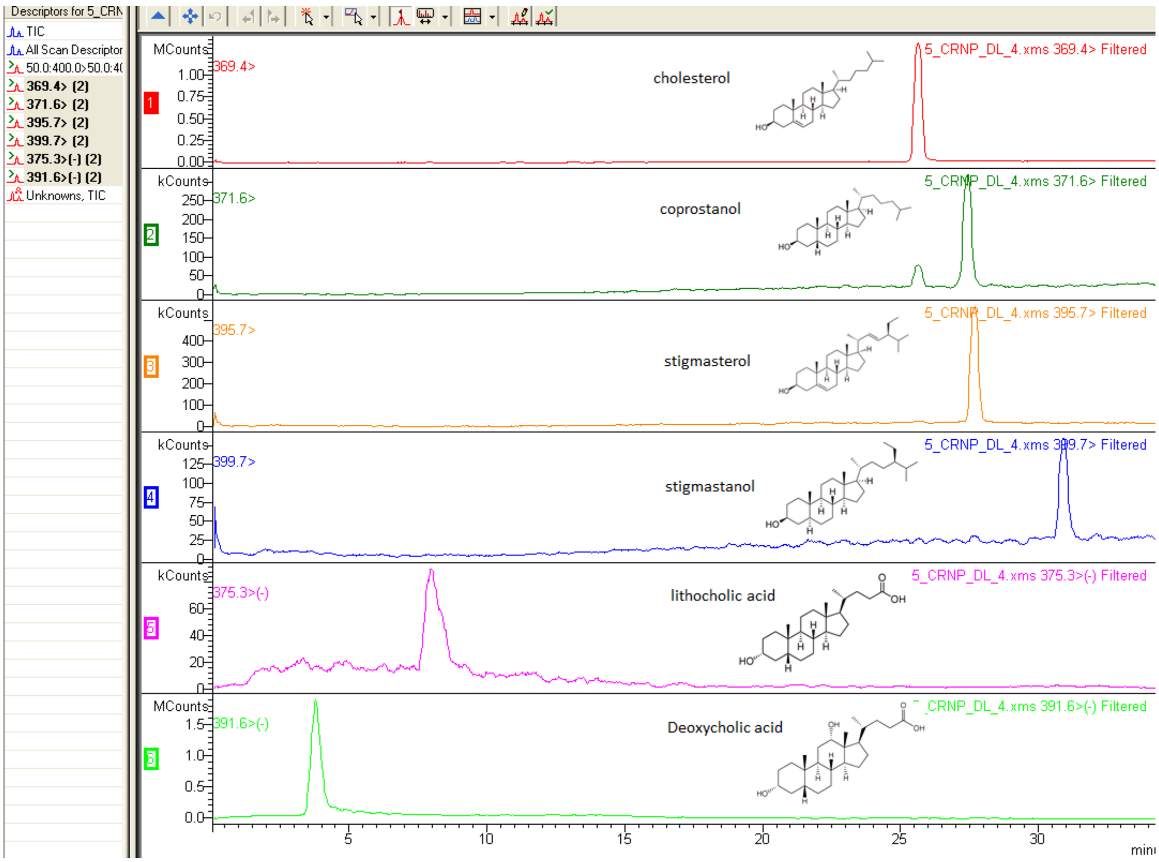

Figure 1. Chromatographic separation of bile acids and fecal sterols using Zorbax Eclipse XDB-C8 (3.0 × 150 mm × 3.5µm) column.

We have also achieved the separation with a conventional C-18 reverse phase column and mobile phase combination of ACN, 0.2 mM NH_4AC in MeOH and 0.2 mM NH_4AC in water.

In conclusion, we have found that atmospheric pressure chemical ionization (APCI) is necessary to ionize fecal sterols for mass spectrometric detection. Bile acids can be ionized both in ESI and APCI.

This work will greatly facilitate use of bile acids and fecal sterols as source markers of organic pollution in natural waters, analysis of the compounds in other applications. The LC-MS/MS analysis is much more direct and rapid than the previously used GC-MS analysis. Our next challenge will be to test the method with field samples, comparing solvent extraction of the compounds from particles and sediment with passive sampling with the polar organic chemical integrative sampler (POCIS).

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REGRESSION ANALYSIS TO DETERMINE CORRELATIONS BETWEEN ENVIRONMENT AND STORM RUNOFF WATER QUALITY

David Solomon[1] and Dr. Lonnie Sharpe, acknowledgement Dr. Tom Byl
Sponsored by Mammoth Cave National Park

The troglobites that live in Mammoth Cave National Park, Kentucky, depend on clean water and can be harmed by contaminants carried into the cave system during storm events. Potential threats to the quality of water include fuel leaks, improperly discarded batteries, the QACs from disinfection stations, road salts in the winter, and general parking lot runoff. The Park Service originally installed storm filters packed with leaf material (2001). In 2009, they switched to zeolite-perlite-activated carbon systems. The objective of this research was to design a contaminant reduction system at Mammoth Cave. It is intended to give state and local government officials, soil scientists, consulting engineers, Extension agents, and citizens a basic understanding of onsite wastewater treatment and the behavior of different wastewater-borne contaminants coming runoff water and waste trucks. Also, we used the data to determine what variables, such as parking lot size, rain intensity, and time-between-rains, influenced the efficiency of the filters. We sampled each filter system a minimum of 3 storms or more. We used first flush samplers and ran analysis on fuel compounds, QAC, COD, Zn, Cu, and NH_4. We found that filter efficiency was often influenced by the size of the parking lot. Frequently, it appeared the filter systems were designed too small for the larger parking lots. The filters had little effect on removing metals (Zn & Cu), but were adequate at removing fuel, QAC and COD. Ammonia was influenced by time between storms. Additional lab studies are being conducted to determine load capacity and interference by natural suspended solids in the runoff. These results will help the Park management use their limited resources more efficiently.

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FATE AND TRANSPORT OF CHEMICALS AT MAMMOTH CAVE NATIONAL PARK, KENTUCKY

Ashley West[1], David Solomon[1], Sean McMillan[1], Hung-Wai Ho[1], Victor Roland[1], Irucka Embry[1], Rick Toomey[2], Roger Painter[1], Lonnie Sharpe[1], Dafeng Hui[1],
acknowledgement - Thomas Byl[1,3]

Abstract - The karst landscape at Mammoth Cave National Park, Kentucky, was formed by water through the dissolution of soluble rocks, forming sinkholes, disappearing streams, emerging springs, closed depressions, and a combination of wet and dry caves. The Park's cave streams and pools provide a home to unique organisms. Surface waters in the Park tend to rapidly drain into subsurface geologic features and caves. This rapid infiltration makes the subsurface vulnerable to contamination. The objective of this investigation was to characterize chemical transport from the surface into the cave. The preliminary results were achieved by tracer studies and monitoring water chemistry along known flowpaths. The results presented in this paper are the outcome of several studies occurring between 2009 – 2012 in a partnership between Mammoth Cave National Park, Tennessee State University, Mammoth Cave International Center for Science and Learning, and U.S. Geological Survey. Processes that influenced chemical transport included storm intensity, time between storms, epikarst saturation, dispersion, dilution, and complex flow paths in the geology.

Introduction - The ecosystem within Mammoth Cave is dependant on adequate clean water for survival. To protect the waters, the Park has addressed the intense vehicle traffic in the parking areas with storm runoff filters. However, they are still concerned about surface chemicals entering the cave ecosystem. Currently, the National Park Service, in agreement with US Fish and Wildlife and Kentucky environmental regulators, has approved the limited application of road deicers on primary roads through the Park during snow or ice storms. However, the NPS lacks some essential quantitative information with regards to salt transport from land surface into the cave ecosystem. The chemical transport mechanisms, including timing, contaminant load and concentration, and hydrologic response are not fully understood. The transport of contaminants into surface water and into the cave ecosystem could adversely impact the aquatic habitat of the rare and endangered species. The objective of this project was to identify and quantify processes important to chemical transport at Mammoth Cave National Park. The approach included monitoring water quality and quantity at points along selected flow routes into the cave.

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MATERIALS AND METHODOLOGY

Three sites were selected for surface and subsurface monitoring stations (Figure 1). Site 1, Silent Grove sinking creek, is near the west edge of the Park. This site is adjacent to an off-park road that receives salt treatment during inclement weather. Site 2 was located near the south entrance to the Park coming from Interstate 65, at the private cave called Diamond Caverns. This site was selected because Diamond Cavern staff have observed rapid flow response during storms, and, the road is expected to be salted during snow events. Site 3, starts at the Post Office parking lot, which has been affiliated with quaternary ammonia compounds (Diehl, et al., 2012), and flows into the historic section of the cave.

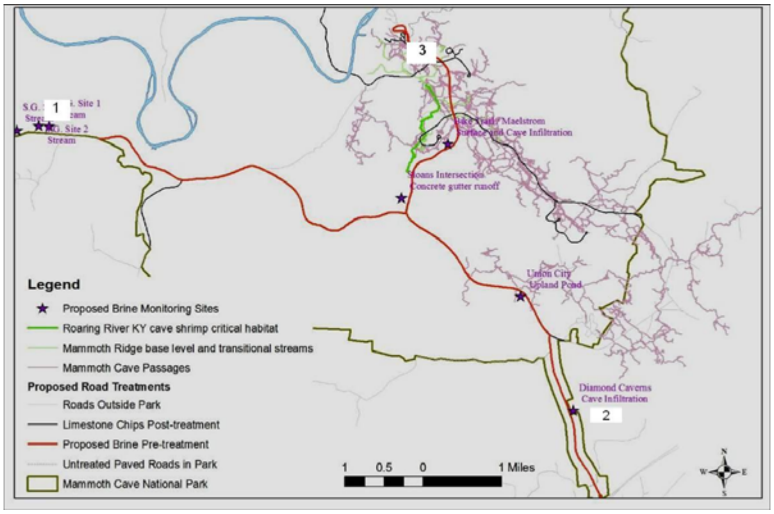

Figure 1. Three monitoring sites selected for monitoring in response to potential road brine application. 1. Silent Grove sinking stream, 2. Diamond Caverns, 3. Post Office-RV dump station. Roads and critical cave habitat are indicated on the map.

Monitoring - YSI datasondes equipped with temperature, specific conductance, pH, dissolved oxygen, turbidity, Rhodamine-WT, and / or water depth probes were deployed along the flow paths at the monitoring sites. The sondes were serviced (calibrated, data uploaded, batteries replaced) every 2-3 weeks. Water samples were collected and analyzed for quaternary ammonia compounds (Hach, 2005) and/or chloride (Hach, 2012).

RESULTS AND DISCUSSION

The transport of chemicals, such as salts, from the surface to the caves was studied at Mammoth Cave National Park, KY. Results from three sites are presented here. Site 1, Silent Grove sinking stream is a road adjacent to the Park and was treated with rock-salt in the winter of 2011 and 2012. Two monitoring stations in the stream, one within 50 feet of the road and another one ~500 feet downstream, were instrumented with datasondes to monitor salt concentration in the stream. Salt spread during a cold spell was washed into the creek during a subsequent rain event (Figure 2). The salt concentration was diluted and dispersed as the water flowed from the road to the sink 500 feet downstream. A calibrated regression curve comparing known concentrations of salt to conductivity measures allowed us to extrapolate the chloride concentration in the stream. The highest chloride concentration was observed at the upstream site (76 mg/L). The chloride concentration was well below the action level of 600 mg/L.

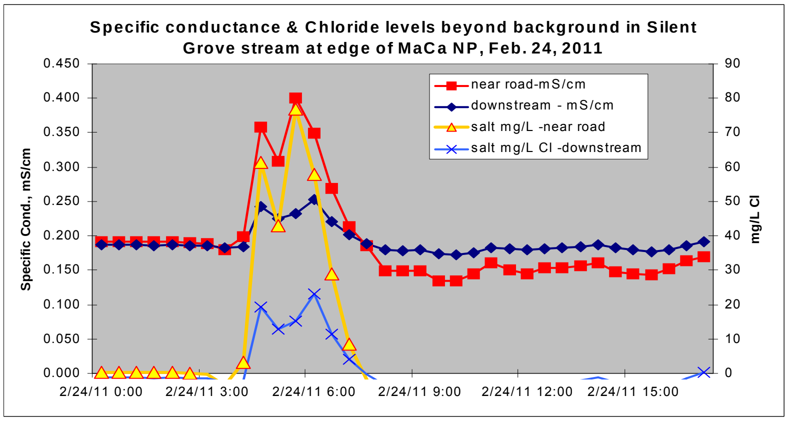

Figure 2. The conductivity and estimated chloride levels in Silent Grove sinking stream following a road salting in February, 2011. The upstream station is 50-feet from the road, and the downstream station is ~500 feet downstream, near the sink.

Data compiled from several sites and summer storm-events were used to run correlations between specific conductance values in the first runoff and time-intervals between the storm events. We observed a weak correlation between increasing time intervals and increasing specific conductance. Although correlation does not imply cause and effect; it is reasonable to assume longer intervals between rain events allows for greater build up of potential dissolved solids.

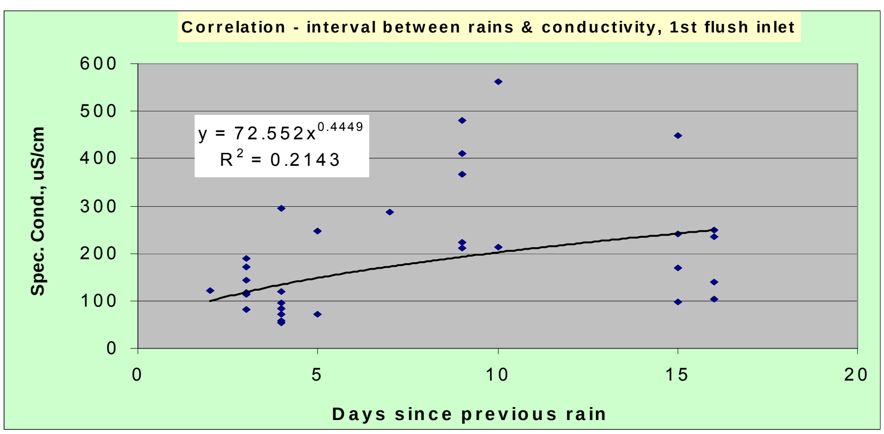

Figure 3. Scatter plot and regression analysis comparing time interval between storms and specific conductance in the first runoff waters from the storms. Data were compiled from several monitoring stations around Mammoth Cave National Park, 2010-2012.

Monitoring stations were set up at the road drainage ditch entering Diamond Caverns parking lot and in a cave pool below the tour route. A winter storm in February 2011 produced runoff that entered the cave and generated a decrease in the specific conductance of the cave pool (Figure 4). There was a short time period (<30 minutes) between the start of the rain and water entering the ditch. The specific conductance in the cave pool, which is an indicator of dilution, responded almost 5 hours later. This time lag was partly due to the flow path length and the head pressure needed to push water to the pool. A second wave of precipitation eight hours later evoked a conductivity response in the pool within a 2-hour time period. A third wave of rain evoked a cave-pool response in one hour. These data suggest that the response time in the cave to storms is partially a function of regolith and epikarst saturation.

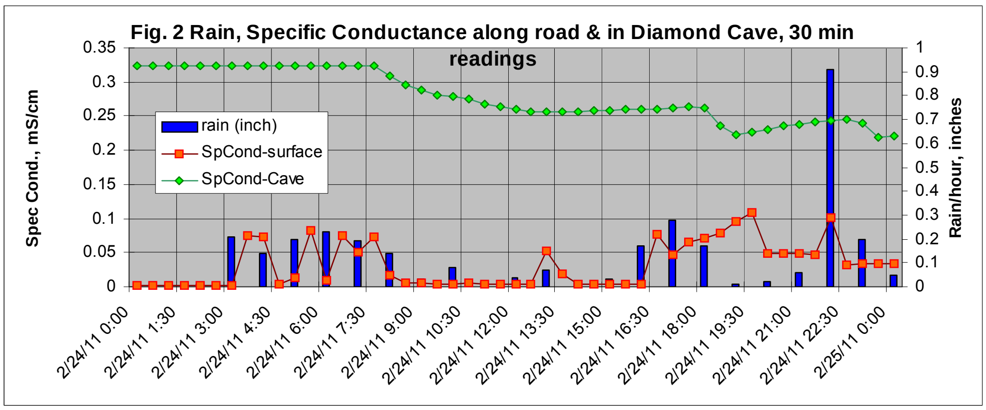

Figure 4. Rain and specific conductance at two monitoring stations at Diamond Caverns by Mammoth Cave, KY. The surface conductivity was zero until the runoff entered the ditch.

A tracer study was conducted at the outfall of the Post Office parking lot storm filter (Embry, et al, 2012). This parking lot was the source of quaternary ammonia compounds (QAC) during several storms (Diehl, et al, 2012). The 175 mL of Rhodamine-WT tracer was released by storm runoff. It took approximately 1 hour and 15 minutes to travel from the discharge of the parking lot filter into Annette's Dome off Gratz Avenue (Figure 5). A monitoring station in the Devil's Cooling Tub at the other end of Gratz Avenue detected a smaller quantity of Rhodamine approximately 1 month and 2 days after tracer release (Figure 6). The average velocity of the tracer transport was estimated by dividing the relative distance from injection point (meters) by the time (minutes). The tracer traveled at an estimated speed of 3.3 meters per minute to reach Annette's Dome and Shaler's Brook. In comparison, the dye traveled at an average velocity of 0.01 meters per minute to reach the Devil's Cooling Tub. Another interesting fact was that the dye had to travel across a surface basin divide (Styx spring and Echo spring) to reach the Devil's Cooling Tub. This transport of dye across a basin boundary illustrates how complicated karst hydrology can be.

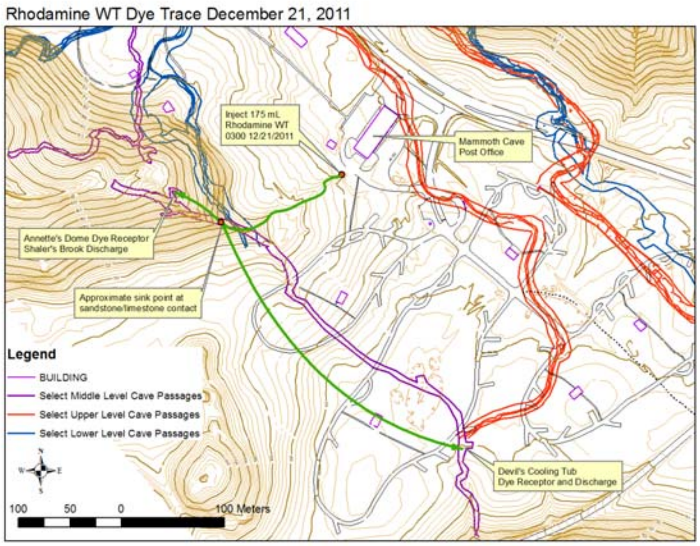

Figure 5. Map showing tracer release point and areas within the cave where it was detected.

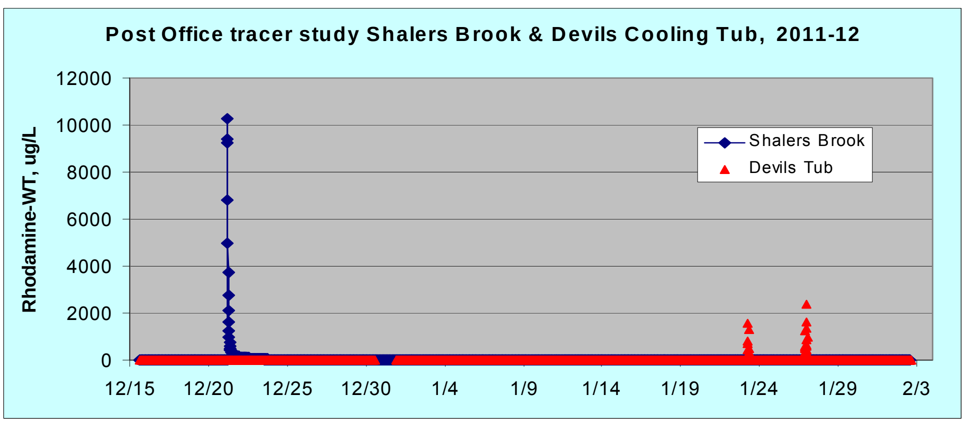

Figure 6. Results of the tracer study conducted at the park Post Office, December 2011. The dye was detected 1.25 hours after release in Annette's Dome, and, a month later in Devil's Cooling Tub.

SUMMARY

This project evaluated the transport of chemicals during storms at three locations. Data from Silent Grove sinking stream show that significant dilution and dispersion can occur within a 500-ft reach of surface stream. These dilution and dispersion processes are important factors for attenuating salt in road runoff. Additional data is being collected at other sites to determine if this pattern is applicable to other areas in the Park. Monitoring activities at Diamond Cavern area found that the response time in the cave was partially a function of epikarst saturation; the more saturated the epikarst, the quicker the response. Studies characterizing the transport from the Post Office into the cave reveal that surface chemicals can arrive in the cave in minutes or weeks after being released. Also, the tracer study illustrates how complicated karst hydrology can be when the dye moved across a surface basin divide.

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INTEGRATED 2D FLOOD SIMULATION AND SPATIAL COMPROMISE PROGRAMMING FOR ASSESSMENT OF FLOOD CONTROL ALTERNATIVES

Ebrahim Ahmadisharaf[1] and Alfred Kalyanapu[2]

ABSTRACT

Comparison of flood control options in space provides floodplain managers and decision makers with more insight about impacts of flood control projects in a watershed. In this study, an integrated approach is represented for assessment of flood control options. The approach employs a two-dimensional flood model, Flood2D-GPU, for flood modeling and a spatial multi-objective decision analysis (SMODA) tool, spatial compromise programming (SCP) for evaluating flood control alternatives. Applying Flood2D-GPU provides decision-maker with not only flood depths, but also other unsteady flood parameters, including velocity and duration of flooding. Here, three attributes, including flood depths, velocities and damages are considered in the assessing most suitable flood control alternative. Simulated depths and velocities are used to estimate flood damages using depth-damage relationships and land use type. The presented SMODA is demonstrated on the Swannanoa River Watershed, located in the upper Tennessee River region in Buncombe County, NC. The study will also discuss improvements the assessment procedures in flood risk management.

Key Words: Flood2D-GPU, Spatial multi-objective decision analysis, Spatial Compromise Programming, Flood Control Assessment, Flood risk management, Swannanoa Watershed.

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HYDRAULIC CONNECTIONS BETWEEN THE CUMBERLAND RIVER & NEARBY WELLS IN NASHVILLE, TN

Aras Barzanji[1], acknowledgement Dr. Tom Byl[2], Mike Bradley[2]

INTRODUCTION

This study was conducted to determine the hydraulic gradient of groundwater in the limestone-bedrock aquifer and to ascertain groundwater flow directions during different weather conditions in Nashville, TN. The three wells used in this study are located along the flood plain, approximately 0.5 mile east of the Cumberland River near river mile 185 on the TSU Research Farm and range from 200 to 250 feet deep. The wells are constructed of 6-inch steel casings that extend to the top of rock, with open boreholes in the bedrock. Geophysical logging of the wells indicates the top of bedrock in the wells at approximately 40 to 60 feet below ground surface, as well as the presence of two sets of primary openings in the bedrock at approximately 72- and 108-feet below land surface. Water elevations were measured in the wells and compared to Cumberland River elevations as reported by the U.S. Geological Survey gage near Bordeaux, TN. The hydraulic gradient was calculated using the triangulation or “three-point” method based on the water elevations in the three TSU wells. Water levels, measured under different weather conditions, ranged from 6 to 22 feet below land surface in the three wells. Continuous water levels also were monitored at 1 hour intervals during the winter and spring of 2010 in one of the wells, using a pressure transducer and data recorder. Results indicate recharge from rainfall events rapidly influenced the hydraulic gradients and flow directions of groundwater beneath the study site. Less than 24 hours after a 1.5 inch rain event, groundwater levels rose from 1 to 3 feet in the wells. The rain event increased the groundwater hydraulic gradient by 11 percent and changed the flow direction from north to northwest across the site. Water elevations in the well with the continuous monitor were compared to the Cumberland River stage data (USGS, Bordeaux). It was apparent that water in the well and river would rise and fall almost simultaneously. The general water gradients suggest groundwater in the study area is moving toward the Cumberland River. On rare occasions, such as the flood of May 2010, the river rises faster than the groundwater and the gradient reverses.

APPROACH

Geophysical logs were employed to determine the characteristics of the regional geology. A gamma log and caliper log were performed on the central well, known as the research well. Well water levels were monitored and measured continuously in the 3 wells. This data was compared to the nearby gage on the Cumberland River. The gage is maintained by the USGS. A pump test was performed to determine the aquifer properties. Cooper Jacob method was used to calculate the transmissivity and storage capacity of the aquifer.

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[2] U.S. Geological Survey, Nashville, TN

RESULTS AND DISCUSSION

Water was transmitted through the openings that were determined by the geophyical logging. Similar openings were found in each of the wells indicating an extensive network of conduits in this area. Water levels from a USGS gage at Woodland St. bridge (Bordeaux), compared to water levels in the TSU show good connection as water levels rise and fall with weather events. The water levels in the well are generally 2 feet higher than water levels in the river, indicating groundwater flows toward the river.During the 100-year flood in May, 2010 (20-25 inches of rain in 48 hours), water levels in the Cumberland actually got ~6 ft higher than water levels in the well. Under those conditions water flowed from the river toward the wells. Results of pump test & Cooper-Jacob calculations Transmissivity of aquifer = 705 sq ft / day Storativity = 2.1 x 10-4 gal/ft. Using GIS data, water level data, & the triangulation method, the ground- water flow direction was found to be north-northwest. This is a different direction compared to the surface flow.

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USE OF SORPTION ISOTHERMS TO IMPROVE THE EFFICACY OF THE STORM-WATER FILTERS

Hung-Wai "Wayman" Ho[1]* and Rick Toomey[2], Acknowledgement - Thomas Byl[1,3]

ABSTRACT

Sorption has been widely used as an inexpensive and environmental friendly water treatment technology. A large variety of adsorbents with different adsorption mechanisms have drawn interests, and combinations of adsorbents will enhance sorption of mixed solutions. However, current sorption research tends to focus on single material. The objective of this study was to develop sorption isotherms for ZPG®, (Zeolite, Perlite, Granular Activated Carbon), used in a stormwater filter cartridge. Contaminants of concern include Cu^{2+} and quaternary ammonia compounds (QAC). Adsorption isotherms were established for Cu^{2+} and QAC, and the best fit for the isotherm data was a Langmuir isotherm for Cu^{2+} and Freundlich isotherm for QAC. The Empirical Constant for Cu^{2+}, Q_o, which represents the maximum adsorption capacity, was 4.61µg/L. The equilibrium constant *K*, which represents the distribution of the contaminants between water and ZPG particles, was 11µg/g for Cu^{2+} and 8µg/g for QAC. Adsorption rates of Cu^{2+} and Zn^{2+} were determined to decrease with time, and Adsorption rate of QAC increases with time. The adsorption isotherm, adsorption rate, and maximum adsorption capacity are used as the criteria, and the result can be used for performance evaluation with the safety limits for the aquatic organisms presented in the Mammoth Cave National Park.

PROJECT LOCATION

Mammoth Cave National Park is located in central Kentucky about 8 miles away from the closest highway, I-65. The park is the home of the longest cave in the world with more than 360 miles of mapped passages, and one of the most diverse cave species and biotic cave communities in the world. More than half a million visitors are attracted annually. The two parking lots, hotel, and visitors are the main stormwater runoff contributors, and the four stormwater treatment systems in this main visitor area are under study. (Figure 1) 4 acres of land around the hotel east stormwater treatment is selected as the design watershed. Stormwater are collected from curb-opening inlet and manholes in the parking lot as well as above the treatment system. Treated water is drained directly to nearby streams. The geology at the park is a deposition of seven hundred feet of limestone and shale followed by sixty feet of sandstone. Dye studies was performed at park surface, and the dye took about 1.5 hours to infiltrate from surface into karst system Therefore, pollutants can follow surface water infiltrating into the cave easily.

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[2] Mammoth Cave National Park, Mammoth Cave, KY
[3] U.S. Geological Survey, Nashville, TN

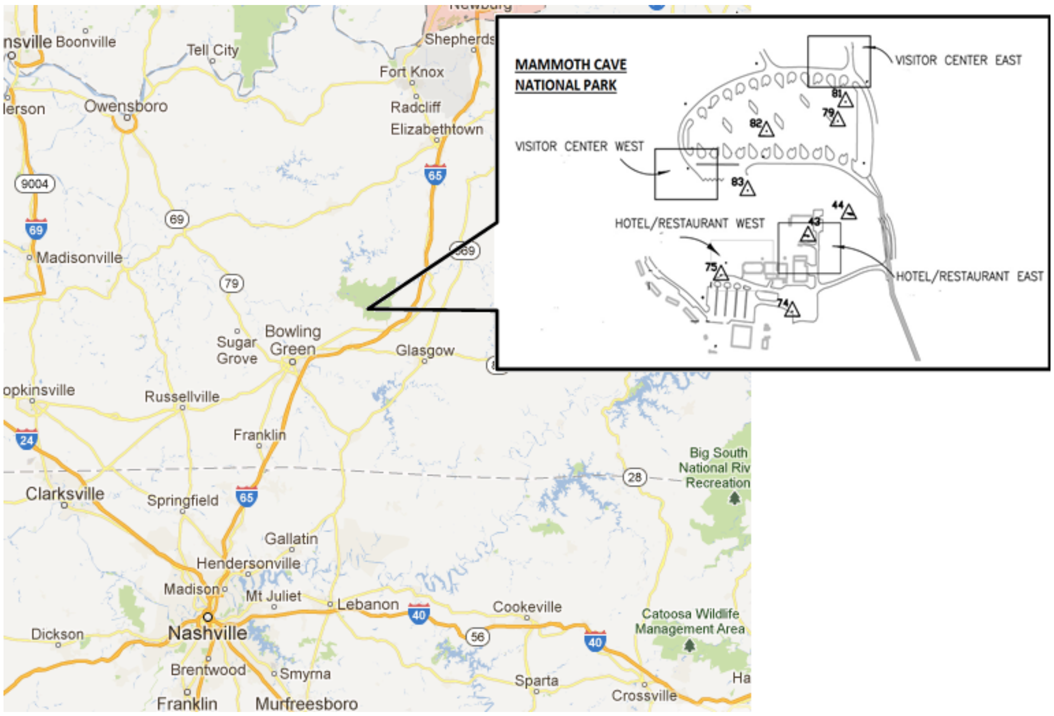

Figure 1. Location of Existing Stormwater Treatment Systems.

BACKGROUND AND CRITERIA

Mammoth Cave National Park is the home of the longest cave and one of the most diverse cave species and biotic cave communities in the world. With more than half a million visitors are attracted annually, stormwater filters are addressed in the park area to prevent anthropogenic contaminants from entering into groundwater and into the cave, and to protects the aquatic habitat of rare and endangered species. However, field data has shown that the performance of the stormwater filters fluctuates. Toxic contaminants with concentrations higher than chronic effects level are found at the filter effluent. Three major contaminants are considered in this study, Copper, Zinc and Quaternary Ammonium Compounds.

Copper is a common contaminant found in vehicles, tires, and especially from parking lot runoff. Field concentration of Copper(II) ion is found to be between 2.8 to 92.0 µg/L. Cave fish, and invertebrates such as isopod and amphipods are vulnerable to copper in which copper can bind to gill membranes, and cause damage and interferes with osmoregulatory processes. Chronic Limits of copper for aquatic organisms ranges from 2.5 to 104µg/L.

Zinc is also a common contaminant found in parking lot runoff released from vehicles, tires, pesticides and cement. Field concentration of Zinc is found to have an average of 0.256 mg/L at filter outlets. Zn has been shown to cause a range of reproductive, developmental, behavioral, and toxic responses in a variety of aquatic organisms. EPA set the maximum permissible concentrations of Zn in water, based upon toxicity to aquatic organisms is 120 µg/L as dissolved Zn.

High concentration of Lysol ® Disinfectant Cleaner is used all over the park for treatments to reduce risk of transferring Geomyces Destructans which is the cause of White Nose Syndrome , a disease that has threatened bat population in eastern North America. Quaternary Ammonium Compounds are one of the major chemicals in Lysol ® , and they are toxic to fishes and aquatic invertebrates.

MATERIALS AND METHODOLOGY

The filters used a zeolite-perlite-activated carbon granules (ZPG®) to sorb dissolved contaminants in the sotrm runoff. The ZPG used in the isotherm studies was provided by Mammoth Cave facilities management from the Stormwater Management StormFilter® used by the Park. Each constituent in the ZPG media has different properties, and a combination of media provide a more effective configuration than single media, and meet a wide range of treatment goals (Table 1).

Constituent	Properties
Zeolite	used in the water filter. Clinoptilolite ($Na_7.3Si_{29}Al_7O_{72}\cdot 23.9H_2O$), a sodium rich zeolites. The enrichment of sodium and the small pore size provide the clinoptilolite high cation exchange capacity (CEC). Cations of heavy metals such as zinc, copper, and lead are removed from water by displacement of light metal cations, Na^+, in the zeolite matrix.
Perlite	pretreated Expanded Perlite, EP, is used in the water filter. It is mainly composed of Silicon dioxide, SiO_2, and Aluminum Oxide Al_2O. EP has high porosity, low density, high surface area, and inert chemical property, which give EP excellent ability to trap sediments and adsorb oil and organic pollutants
Granular Activated Carbon	is one of the most widely used materials to remove organic contaminants from water through adsorption. It has an extensive internal surface area with high porosity and high carbon content which provides high adsorption capacity.

Batch method was used to establish sorption isotherms. Batches were set up with 20g of ZPG® filter media and different concentrations. Composition of each media in volume was about 50% Zeolite, 40% Perlite, and 10% GAC. The bottles containing the ZPG and solution waters were put into a shaker at 25°C, and rotated at 75 rpm for known lengths of time. Initial concentrations of Cu2+ or QAC were measured. The amount remaining in solution were measured at various time periods. The copper concentration was measured using the Hach Porphyrin method (Hach, 2005). The QAC concentrations were analyzed using the Hach direct binary complex method and measured on a spectrophotometer (Hach, 2005).

RESULTS AND DISCUSSION

Adsorption of Copper – Results of the copper studies are shown in figures 2 through 4.

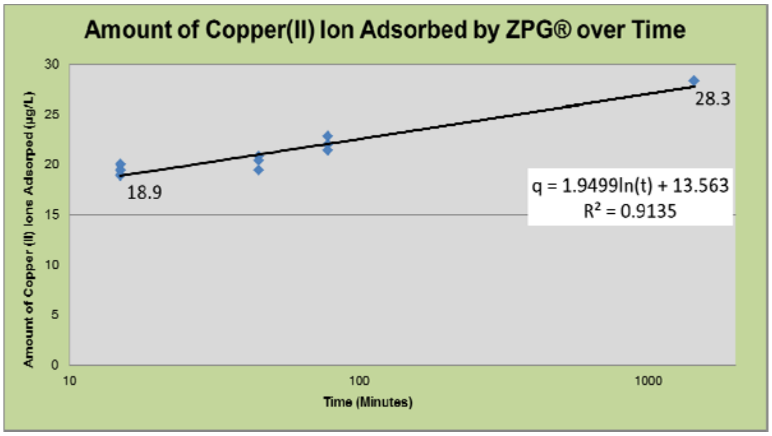

Figure 2. Initial concentration of 40µg/L of Copper(II) ion is used to determine the amount of Cu^{2+} adsorbed to ZPG®. The nature logarithm curve indicates that the adsorption rate decreases over time, $dq/dt = 1.95/t$.

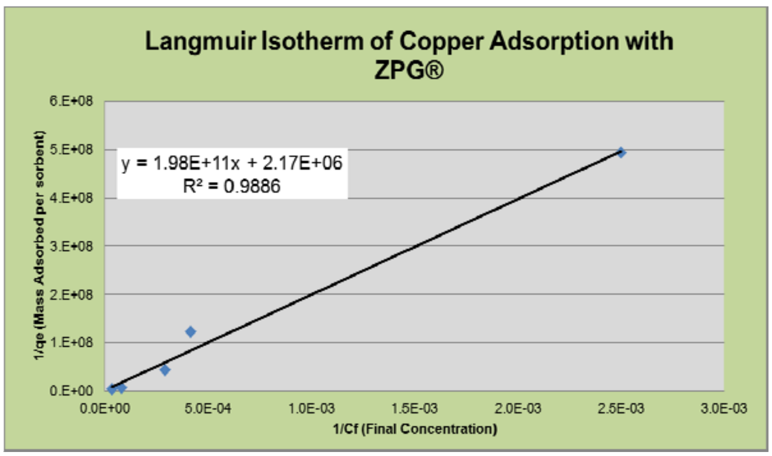

Figure 3. Langmuir isotherm is found to best describe the Cu^{2+} adsortion process onto ZPG®, Physisorption and chemisorption are both expected to contribute in the treatment process. Equilibrium oncentration of Cu^{2+} in solution, C_e, is 4.61µg/L. The adsorption capacity of ZPG®, K_d is 11µg/g.

The relationship between the adsorbed Cu concentration and Cu concentration in solution can be described by the equation, $q = 5.06 \times 10^{-12}\, C / 1 + 1.10 \times 10^{-5}\, C$.

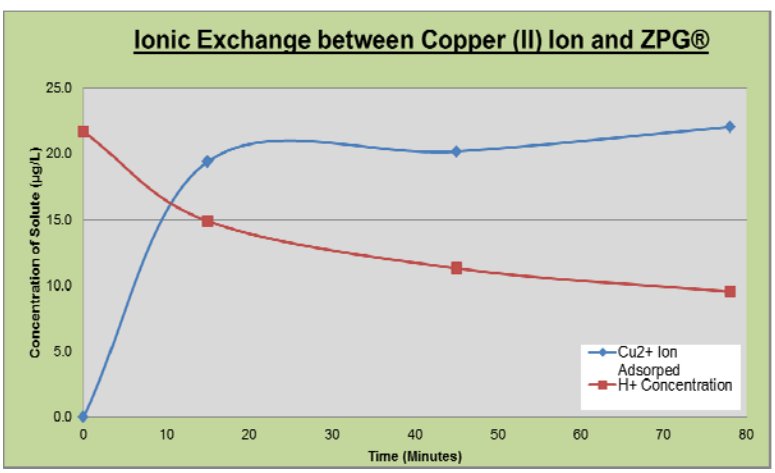

Figure 4. Langmuir isotherms indicate that chemisorption occurs, ionic exchange is expected between the dissolved Cu ion and sodium ion in zeolite. The exchange process can be determined by the change in pH value. An increase in pH value is found during the adsorption process. It agrees with the assumption that ionic exchange occurs. The increase in pH is due to the dissolution of sodium ion and the formation of NaOH, which is indicated by the decrease in H^+ concentration. The adsorption process seems to be a fast process in which the process slows down after a rapid

increase in Cu^{2+} ion adsorbed in the first 15 minutes. Hydrogen concentration also slows down after about 45minutes.

Adsorption of Zinc – Results of the Zinc sorption isotherm tests are shown in Figures 5.

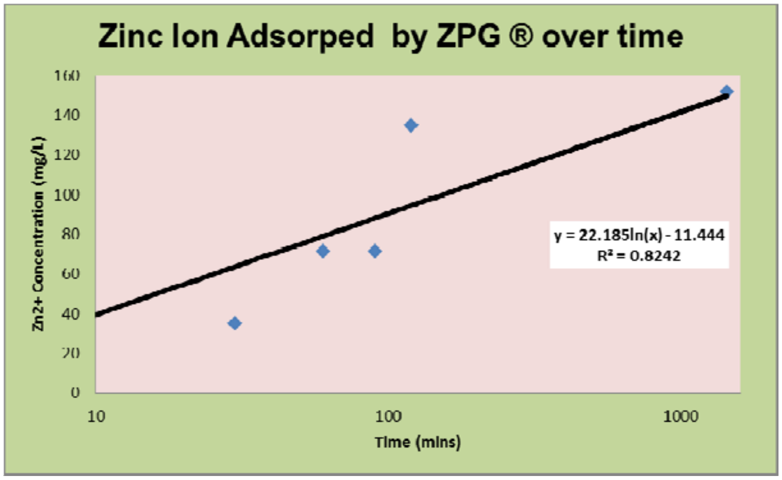

Figure 5. Initial concentration of 227mg/L of Zinc ion is used to determine the amount of Zn2+ adsorbed to ZPG®. The nature logarithm curve indicates that the adsorption rate decreases over time, dq/dt = 22.19/t.

Adsorption of QAC – Results of the QAC sorption isotherm tests are shown in Figures 6 and 7.

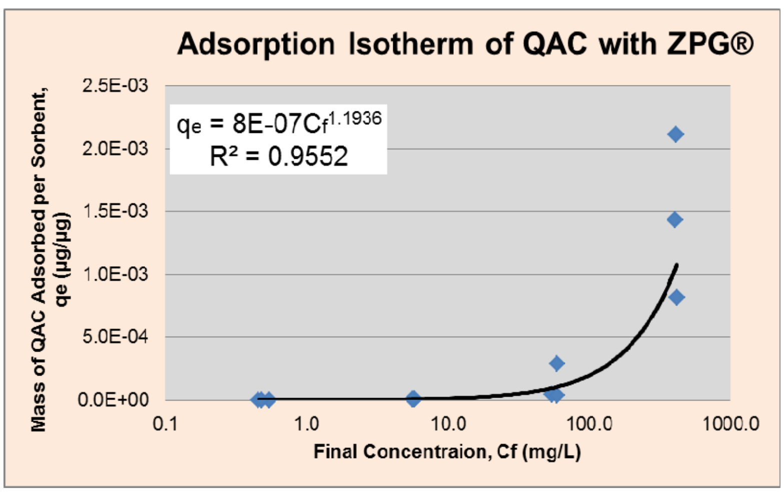

Figure 6. Freundlich isotherm is found to best describe the QAC adsorption process onto ZPG®. Chemisorption is negligible because QAC does not dissolve in water, and no ionic exchanged is expected. Physisorption is expected be the major contributing process in treatment. Granular Activated Carbon and Perlite are the major contributors in the adsorption process. The adsorption capacity of QAC onto ZPG®, K_d is 0.8µg/g.

The relationship between the adsorbed QAC concentration and QAC concentration in solution can be described by the equation, $q_e = 8 \times 10^{-7} C_f^{1.1936}$.

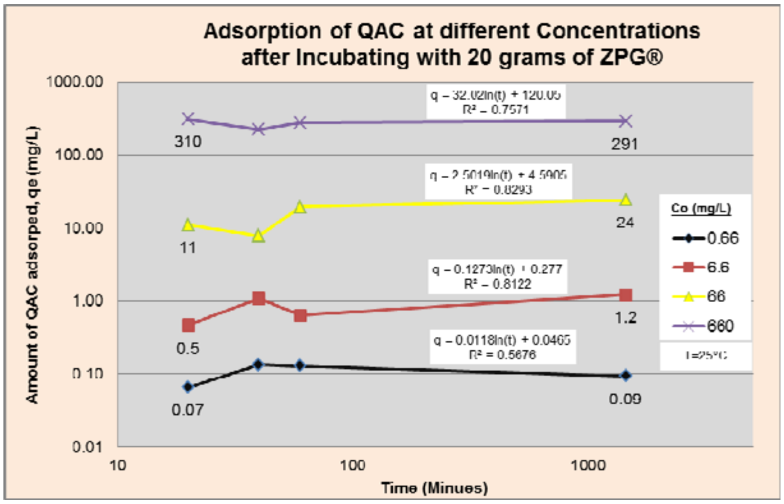

Figure 7. The amount of QAC adsorbed over time with different concentrations was compared. The process is best described by natural logarithm which means the rate of change of QAC adsorbed decreases over time. Also, the adsorption rate is higher with higher initial concentration. The difference in adsorption rate is due to the diffusion effect. The higher concentration of QAC has higher possibility to be adsorbed onto the filter media.

SUMMARY

The sorption of Cu^{2+} from water by ZPG® is best described by the Langmuir isotherm. The Freundlich Isotherm best describes the QAC sorption to ZPG®. Adsorption rates for Cu^{2+} and Zn^{2+}, and QAC have rapid start, decreases over time, and reach the maximum sorption rate within 24 hrs. The experiment result indicates that the percentage reduction of the contaminants is underachieved, with 57% of Cu^{2+} and 64% of Zn^{2+}, and 26% of QAC reduced within 24 hours. The bottom line of these results indicates that when the contaminant concentration is high in the rain water, it will not be treated effectively in a short period of time, and may be released out the discharge effluent pipe.

Additional acknowledgements – the authors wish to thank Steve Kovar, MACA NPS Chief of Facilities Management; Bobby Carson, MACA Chief of Science & Resources Management; Eddie Wells, MACA Volunteer Coordinator; Shannon Trimboli, MACA International Center for Science and Learning; Dr. Malkani, Assistant Dean, TSU College of Engineering, for resources and support.

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ENHANCING THE DESIGN OF MICROBIAL BATTERIES IN WETLANDS

Lina S. Khoury[1] and acknowledgment Tom Byl[1,2]

ABSTRACT

The discovery that microorganisms can oxidize organic compounds to carbon dioxide and transfer electrons to electrodes opened the possibility to consider organic wastes or biomass as a renewable energy source. Microbiologists have been working on finding and classifying different types of electrogenic microorganisms in sediments. However, very little research has been conducted on designing engineered systems to harvest the electricity generated by these organisms. Finding a relation between electrical current generation and design parameters for the electricity harvesting mechanism are the goal of this project. A simple electricity-harvesting cell was designed to test the response of bacteria to different design parameters. A wetland mesocosm (36” long x 24” wide x 24” deep) was established in the campus greenhouse using sediments and water from the TSU wetland, Nashville, TN. Three conductive materials were tested as electrodes; aluminum, galvanized steel, and graphite. The anodes were placed in the anaerobic wetland sediments, and the cathode was in the overlying water. The three different metals started showing results in 48 hours. Graphite electrodes showed the best results and reached a maximum current of 0.5 mA after 28 days. Temperature, pH and specific conductance of the overlying water did not fluctuate over the 2 months of monitoring. Oxygen concentrations in the overlying waters decreased after 45 days due to warm temperature and eutrophication. Preliminary results showed that dissolved oxygen levels in the overlying water and organic compounds in sediments play a major role in electricity production, as well as material and surface area of electrodes. The results of this project may be used to improve the efficiency of electricity generation from wetland sediments.

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ARTIFICIAL SWEETENERS AS CHEMICAL MARKERS OF ORGANIC WATER POLLUTION

Sushma Meka[1*] and Dr. John Harwood[1,2]

ABSTRACT

Water pollution is the common problem all over the world in present day. The pollution may be caused by the organic, chemical or inorganic pollutants. Our project focuses on the determination of sources of organic water pollution using chemical markers. Markers are substances which do not react with water, but stay in the water as pollutants and are characteristic of individual sources of pollution. An ideal marker is source specific, and gives reproducible analytical results (1). We selected the artificial sweeteners Sucralose and Acesulfame-K as our chemical markers of organic pollution from wastewater treatment plants and other domestic sources. These sweeteners are not metabolized in the body and are proved to be present in water after waste water treatment (2). Research is going on using these artificial sweeteners as the markers of organic pollution in US, UK, and Western Europe (1-4).

For this purpose, we are trying to develop a method on liquid chromatography-mass spectrometry (LC-MS/MS) to analyze the water samples for the presence of Sucralose and Acesulfame-K. Because of the high polarity, Acesulfame-K is not retained in the usual reverse-phase liquid chromatography. We have attempted chromatography with a series different stationary phases including C-8, C-18, and P-5. Acesulfame-K was not retained in many of the columns. Acesulfame-K and Sucralose were first tested for their retention times on HPLC using C18 column. As Acesulfame-K is anionic, we are presently investigating ion-pair chromatography, using a quaternary amine counter ion in the eluent, to obtain retention of the compound.

Also, we have analyzed standard solutions by mass spectrometry with methanol as solvent. We are using the electrospray interface in the negative mode (ESI(!)). The detectable mass ranges were set to 30-500 to avoid the detection of methanol fragments. The highest mass was set to 500 to detect any complexes which may have formed. Sucralose, a neutral molecule, by itself shows poor sensitivity with ESI in mass spectra. We have confirmed the finding of Sheurer et al. that post-column addition of TRIS buffer significantly enhances sensitivity of ESI(!) for Sucralose (4).

Also, analysis of the sweeteners in natural waters will require that samples be pre-concentrated. We are comparing the sample pre-concentration by different solid phase extraction (SPE) media. Again, retention of Acesulfame-K by SPE is challenging; to date, no group has reported quantitative recovery of this compound. We will compare SPE recoveries with the commonly used Waters Oasis HLB polymeric column, styrene-divinylbenzene polymer (Jordi Hydroclean RP DVB), and a conventional C-18 SPE column (Alltech).

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When we have developed the preconcentration and analysis by SPE LC-MS/MS, our procedure will be tested with samples collected from the Cookeville waste water treatment plant and downstream of the plant. Future work will focus on correlating the concentration of sweeteners in waters with the concentration of dissolved organic carbon from domestic pollution sources.

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CURRENT TRENDS IN STREAM WATER QUALITY IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Tim Pobst[1] and John Schwartz[2]

Stream water quality sampling in the Great Smoky Mountains National Park began in 1993, and continues through to today. The number of sample sites has varied over time, and the current program consists of 43 streams sites sampled bimonthly. Water quality data from 1993 to 2002 was assessed per elevation from 1,000 ft to 5,500 ft on 500-ft intervals. A range of stream pH estimates based on elevation was found to be declining at a rate of 0.013 to 0.091 units per year. ANC was found to also be declining in the range of 0.0 to 5.91 μeq/L. No trends were observed with nitrate and sulfate. An assessment of water quality data from 2003 through 2009 found different temporal trends. Stream pH was found to be increasing at a rate of 0.01 to 0.02 units per year. ANC was also found to be increasing form most elevational ranges. Nitrate continued to show no trends, or results were mixed amongst the elevational ranges. Sulfate was found to be increasing at the higher elevations above 4,000 ft, which could indicate soil desorption is occurring influencing water chemistry. The increase in stream pH appears to coincide with the observed increase in base cations during this period 2003 to 2009.

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DEVELOPMENT OF A STORMWATER/LID MASTER PLAN FOR THE UNIVERSITY OF TENNESSEE AT KNOXVILLE

Paul Simmons[1], John Schwartz[1], and Andrea Ludwig[2]

In 2012, the University of Tennessee Knoxville (UTK) Campus submitted their application notice of intent for Municipal Separate Storm Sewer System (MS4) permit to the Tennessee Department of Environment and Conservation (TDEC). Prior to which, the UTK Campus was under the City of Knoxville MS4 permit. Complete mapping of the stormwater drainage system was completed, and about 20 sub-basin management units were identified. In addition, hydrologically modeling of each sub-basin was completed, estimating runoff and infiltration potentials. Based on available space, and UTK's facilities master plan, locations for stormwater best management practices (BMPs) were proposed, including bioretention ponds and grassy swales. Low-impact development (LID) facilities were also proposed including rain gardens and pervious pavement. A summary of planning issues are discussed including retrofitting land areas with high-density urban infrastructure and multi-objective development space constraints.

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EVALUATION OF GREEN REMEDIATION STRATEGIES AT THE VELSICOL LANDFILL, HARDEMAN COUNTY, TENNESSEE

Lore'al K. Spear[1], Roger Painter[1]
Acknowledgement – Tom Byl[1,2]

Remedial designs are created to optimize contaminate remediation time and meet environmental regulations; unfortunately, most remediation methods are not environmentally sustainable. The process of cleaning up a hazardous waste site uses energy, natural resources and materials, which consequently creates an environmental "footprint" of its own. The Environmental Protection Agency (EPA) is establishing a program referred to as Green Remediation certification to promote sustainable and environmentally friendly approaches to cleaning contaminated sites. By utilizing the holistic approach of Green Remediation practices, the negative impacts associated with traditional remediation activities are identified, scored and considered in terms of sustainability and impact on climate change. The protocols for scoring remediation strategies are in their beta stage. The objective of this project was to apply the Green Remediation rubric to the Hardeman County landfill used by the Velsicol Chemical Corporation from 1964 to 1973 to dispose of industrial waste. The site is listed as a Superfund site and has had failed remediation of pump-and-treat. More recently, two remediation strategies are being evaluated for the removal of chlorinated solvents from the subsurface – soil vapor extraction and natural attenuation. These three approaches are very different and have different energy requirements. They also represent different time frames. The investigation of three different remediation strategies, pump-and-treat, natural attenuation, and soil vapor extraction, also provides a unique opportunity to incorporate the Green Remediation rubric into the decision making process. This will allow us to determine if reducing the environmental footprint of the remediation strategy is high enough to warrant a green remediation approach.

CHARACTERIZING THE HYDROSTRATIGRAPHIC CONTROLS ON GROUNDWATER DISCHARGE INTO THE HARPETH RIVER USING THERMAL SIGNATURES AND ELECTROMAGNETIC INDUCTION

Scott C. Worland[1]

ABSTRACT

The hydrostratigraphic structure of the subsurface informs groundwater flow paths, and as the water flows through the ground it equilibrates to the relatively constant temperature of the shallow subsurface. This important thermal property allows heat to be used as a groundwater tracer. In the winter months, where the surface water is cooler than the groundwater, temperature fluctuations can delineate groundwater inflows in the hyporheic zone. Our research consists of thermal transects taken down the length of the Harpeth River where temperature measurements were recorded along both banks. The results were mapped using an inverse distance weighted interpolation technique in ArcGIS. The spatial analysis allowed us to recognize hotspots along the river banks where groundwater was most likely to be entering and mixing with the surface water. We then used an infrared camera to further locate groundwater seeps into the river. Where sites demonstrated high temperatures we used electromagnetic induction to characterize the hydrogeologic characteristics of the shallow subsurface for ~100 meter transects running perpendicular to the river bank. It was then possible to use the inverted GEM data to infer hydraulic conductivity and model the steady state transport of fluid in two dimensions using TopoDrive and MATLAB. The conductivity profiles and computer models demonstrate how the local stratigraphy dictates the groundwater flow into the river. Understanding stratigraphic controls on groundwater flow paths and flow rates has implications for the prevention and mitigation of contaminated groundwater entering surface water bodies.

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PRECISE CONTROL OF SYNTHETIC SEDIMENT CHARACTERISTICS FOR HEXAGENIA HABITAT

Mr. Adrian Gonzalez[1], QEP, EIT

Sediment quality assessment seeks to relate lab-based evaluations to conditions in the field. The strength of that relationship depends on the quality of sediment assessment data. Macro-invertebrates, like Hexagenia spp., are used in lab tests to strengthen lab-field relevance, but using locally collected natural sediment as a "reference" treatment or as culture substrate for Hexagenia work can have the opposite effect. The batch-to-batch or location-to-location consistency of natural sediment quality is impossible to ensure or predict. Synthetic sediment has been touted as a way to strengthen the consistency of sediment assessment data, but current recipes suffer from poor realism. As part of a larger development project, this study explores the effects surrogate components can have on bulk characteristics of synthetic sediment. Specifically, cohesiveness and plasticity are critical factors for habitat conditions specific to Hexagenia (burrow stability and ease of penetration). The study demonstrated the strong influence of that silt composition and concentrations have on physical structure (cohesion, adhesion, compactness) and pore water chemistry (conductivity and pH) of the bulk substrate. The same total mass of different particle types and sizes yielded substrates with different texture and pore water properties merely by adjusting their relative proportions. Hexagenia spp. were exposed to different synthetic sediment formulations and observed for survival and burrow construction efficiency. Preliminary results from the Hexagenia exposures to synthetic sediment with varying textures support the study's findings.

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ABSTRACTS IN ABSENTIA

The Symposium had to be rescheduled this year from April to November. These students' work was accepted for the April Symposium, but they were unable attend in November.

Measuring Lag Times and Suspended Sediment Concentration in an Urbanized Karst Watershed
Kolbe D. Andrzejewski

Perception Studies to Determine Receiving-Stream Color Objectionability Due to Effluent Discharge
Sarah Girdner, Brian Waldron, Max Louwerse, Stephanie Ivey, and Jeremy Luno, GWI

Redesigning the RV Waste-Transfer Station at MACA to Avoid Spills
Sean McMillan, TSU

Using NEXRAD Data as Precipitation Input for WinHSPF Modeling
Jaron S. Rottman-Yang, Will Scheidt, Dennis Borders, and Sherry H. Wang

Microbial Risks in Drinking Water Distribution Systems: Persistent Bacterial Populations
Yan Zhang, Joshua Frerichs, and Qiang He, UT

MEASURING LAG TIMES AND SUSPENDED SEDIMENT CONCENTRATION IN AN URBANIZED KARST WATERSHED

Kolbe D. Andrzejewski[1]*

The city of Cookeville, TN lies within a karst watershed where the city's stormwater runoff passes through a series of sinkholes and caves. Sinkhole flooding is a common occurrence in the city and floodplains have been delineated for over 200 sinkholes. Sinkhole flooding occurs when runoff arrives to the sinkhole at a rate that exceeds the drainage rate out of the sinkhole. Sinkhole drainage rates and relationships between rainfall and sinkhole flooding have been determined by previous research. However, the effects of sinkholes and caves on downstream flood stages and lag times have not been studied. We hypothesize that sinkholes act as detention basins, reducing peak runoff rates. The cave system below the sinkholes may also act as a storage reservoir during floods. To test this hypothesis, we instrumented sinkholes, the cave, and downstream resurgence points with automatic stage recorders to determine lag times through the cave. For comparison, we also instrumented and measured lag times in a neighboring watershed without a cave. We also measured suspended sediment concentrations at these locations in order to determine the effects of the cave on sediment transport. Preliminary results indicate lag times between 200 and 330 minutes for the cave stream and between 25 and 65 minutes for the non-cave stream. Suspended sediment concentrations ranged from 200 to 1800 mg/l for both the cave stream and non-cave stream systems. These results indicate that lag times are longer for the cave stream; however, suspended sediment concentrations are similar for both stream systems.

Research for determining lag times, peak runoff differences, and suspended sediment concentrations is ongoing. Lag times are being calculated by computing a centroid for the rainfall data of one day while doing the same for the water depth of the cave, resurgence, creek, and sinkhole then subtracting the two centroids. Unlike analyzing the lag times, measuring the peak runoff differences only contains the cave, resurgence, creek, and sinkhole data. We took the highest peak depth of that day's storm for the cave, resurgence, creek, and sinkhole then compared the differences. For more severe storms suspended sediment samples are gathered and then analyzed based on concentration with emphasis placed on what time the sample was gathered during the storm. More data are needed to strengthen the hypothesis that sinkholes and caves act as sediment reservoirs. Thus, in the upcoming months we will continue analyzing and collecting data for the approaching spring storms.

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PERCEPTION STUDIES TO DETERMINE RECEIVING-STREAM COLOR OBJECTIONABILITY DUE TO EFFLUENT DISCHARGE

Sarah Girdner[1], Brian Waldron[2], Max Louwerse[3], Stephanie Ivey[4], and Jeremy Luno[5]

The City of Memphis' Division of Public Works has partnered with the University of Memphis to develop a decision mechanism to address objectionability of the mixed effluent-river water color at the M.C. Stiles wastewater treatment facility as its discharge enters the Mississippi River. Pursuant to the Tennessee Department of Environment and Conservation (TDEC) General Water Quality Criteria Ch. 1200-4-3-.03[6] (d), the City of Memphis is required to monitor and take corrective action when "…total suspended solids, turbidity or color in such amounts or character…result in any objectionable appearance to the water, considering the nature and location of the water." The term "objectionable", however, is subjective. The project goal is to develop algorithms that provide a more objective measure of objectionability, thereby extending the findings from the limited studies that exist on water color perception. Different than previous studies, the project is interdisciplinary, combining experimental methods and analyses from engineering, psychology and computer science. Our research investigates to what extent Mississippi River water color downstream of the effluent discharge is objectionable when: (a) a change in a color becomes objectionable to the viewer; (b) the color is considered in combination with the Mississippi River scenery; (c) the color is considered in combination with environmental variables (time of day, sunny versus cloudy, rain, and wind); and (d) on-site participant visual assessment. Two wildlife cameras at 8 megapixel resolution capture the scenery once an hour for twelve hours during the pre-dawn and post dusk times of day. One camera is located upstream of the effluent outfall and the second is located downstream of the effluent outfall. Pictures will be taken for one year resulting in approximately 3,650 photos that will be judged on measures of objectionability by participants in a large perception experiment. Weekly effluent, upstream, and downstream water samples are collected and analyzed for tri-stimulus color and Platinum-Cobalt apparent and true color. As river stage in reference to the outfall structure impacts the mixing regime of the effluent stream, river levels are recorded daily in 15-minute intervals using a transducer. To ascertain climatic conditions, a weather station has been installed and records wind speed and direction, temperature and precipitation in 15-minute intervals. The merged findings from the engineering and psychology sections of the research will be incorporated into a decision algorithm that will provide an estimation of objectionability of river water color.

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[3] Full Professor, Department of Psychology / Institute for Intelligent Systems.
[4] Associate Professor, Department of Civil Engineering.
[5] Graduate Research Assistant, Department of Psychology / Institute for Intelligent Systems
[6] TDEC, 2008. Rules of Tennessee Department of Environment and Conservation Tennessee water quality control board, Division of Water Pollution Control, Chapter 1200-4-3, General water quality criteria, 35 p.

RE-DESIGNING THE RV WASTE-TRANSFER STATION AT MACA TO AVOID SPILLS

Sean McMillan[1]

Mammoth Cave in Central Kentucky is the world's largest cave system and has been designated an international biosphere. It has unique organisms that live in the cave system and they are dependent upon high quality water supplied through rain recharge. We have documented quaternary ammonia compounds (QAC) levels ranging from 0.2 to 22 mg/L in storm flow, as well as, other chemicals coming from a poorly drained RV dump station. The objective of this project is to re-design the drain system around the dump station to prevent spillage from washing down into the cave. The first option is a u-shaped trench to catch storm runoff and redirect it into the sanitary sewer. The second option is a gently elevated barrier that will impede the flow of runoff from the impacted area. Additional background, IDF calculations and design parameters will be provided in the poster.

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USING NEXRAD DATA AS PRECIPITATION INPUT FOR WINHSPF MODELING

Jaron S. Rottman-Yang[1,2], Will Scheidt[1], Dennis Borders[1], and Sherry H. Wang[1]

ABSTRACT

Currently, WinHSPF modeling relies on meteorological stations packaged with BASINS 4 to provide precipitation data input. However, the BASINS meteorological database may provide a lower spatial resolution of precipitation data than is desired. This report investigates the usage of NEXRAD measurements to increase the resolution of precipitation data available to WinHSPF. WinHSPF models using both the BASINS meteorological database and NEXRAD precipitation data were created for the Harpeth River 8-digit Hydrologic Unit Code (HUC) watershed (05130204) in Middle Tennessee. A preliminary comparison of the results obtained by the two models suggests the level of resolution provided by NEXRAD data does not increase the accuracy of WinHSPF models of HUC-8 watersheds.

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[2] Summer volunteer intern, Stanford University

MICROBIAL RISKS IN DRINKING WATER DISTRIBUTION SYSTEMS: PERSISTENT BACTERIAL POPULATIONS

Yan Zhang[1], Joshua Frerichs[1], and Qiang He[1]

Microbial populations present in drinking water represent poorly-understood public health risks despite their extremely low concentrations. Indeed, data on waterborne disease outbreaks suggest that drinking water continues to be one of the most import media for infectious diseases worldwide. Previous studies have revealed substantial microbial diversity in drinking water from various water distribution systems. Thus, one major challenge is to identify the mechanisms supporting the survival and growth of these microorganisms in drinking water distribution systems. Toward overcoming this challenge, the specific objective of this study is to identify bacterial populations common in drinking water with high-throughput sequencing. Drinking water was collected from five water distribution systems supplied by five different water treatment utilities. Microbial biomass was harvested with ultrafiltration followed by centrifugal concentration. High-throughput sequencing revealed that a common feature of the drinking water microbial communities was the dominance of *Proteobacteria*, particularly *Alphaproteobacteria* and *Betaproteobacteria*. *Actinobacteria* was also identified as a common member of the drinking water communities with significant abundance. At the family level, the common microbial populations were represented by *Oxalobacteraceae*, *Sphingomonadaceae*, *Caulobacteraceae*, *Mycobacteriaceae,* and *Methylobacteriaceae*. Phylogenetic analysis revealed that bacterial populations with high relative abundance in drinking water were closely related to metabolically versatile bacterial species broadly distributed in natural environments, suggesting a link between environmental distribution, metabolic trait, and presence in drinking water. A good fit with the Zipf-Mandelbrot model suggests multiple factors acting sequentially in shaping the bacterial community in drinking water. PCA and cluster analysis further indicate that bacterial community compositions were influenced by characteristics of source water and treatment options, providing important insight into potential strategies for the control of microbial persistence in drinking water.

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