Proceedings of

The Seventeenth Tennessee Water Resources Symposium

April 17-19, 2007

Proceedings from the

Seventeenth Tennessee Water Resources Symposium

Montgomery Bell State Park
Burns, Tennessee

April 17-19, 2007

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Cover Design by Amy Knox, Center for the Management, Utilization & Protection of Water Resources, Tennessee Technological University with photo courtesy of U.S. Geological Survey

Symposium Contest Question: What is the standard battery charge life of the hazard light shown?

PREFACE

On behalf of this year's planning committee, I am delighted to welcome you to our Seventeenth Tennessee Water Resources Symposium.

I like being part of a good team, so I have particularly enjoyed working with the planning committee for the 2007 meeting. Our planning sessions, always held at the conference room of the Nashville USGS office, have been lively and spirited. Ideas arise, decisions are made, someone volunteers (or if absent, is volunteered) to take on an assignment, and we go on. I very much appreciate the spirit of cooperation and the good humor that each member of the planning committee has brought to this process.

As always, TN AWRA is deeply indebted to Lori Crabtree for her meticulous organization, clear and careful communication, and gentle persuasion. Lori has nurtured and maintained this organization since its birth, and she is primarily responsible for our continuing success. Thanks also to USGS for supporting Lori's work on our behalf and for our Web site.

I owe many thanks to past President Brian Waldron as a gracious and patient mentor and for his wonderful system for organizing and managing the dozens of abstracts we received. If Brian ever leaves groundwater, he can certainly make it as a librarian.

Amy Knox at the TTU Water Center has again produced our proceedings on a pocket-size disk. I know we all appreciate having this material in convenient digital form. Amy has been great to work with.

Our loyal sponsors and exhibitors continue to support our symposium financially and by their attendance. Our meetings benefit greatly from their involvement. Please join me in thanking them as you visit their displays.

Finally, the strength of our annual conference, which is regarded as outstanding by the national officers who have visited, derives not only from the quality of our program but also from the energy and enthusiasm of our participants. Our diverse assembly from business, government, academics, research institutions, and NGOs, our conference organizers, presenters, moderators, attendees, storytellers, and musicians, all contribute richly to our meetings. The education we receive, ideas we exchange, and contacts we make all better prepare us to address Tennessee's water resource challenges.

Paul Davis
2007 President, Tennessee Section, American Water Resources Association

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TENNESSEE WATER RESOURCES SYMPOSIUM

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- Larry McKay, UT, Earth & Planetary Sciences
- Sherry Wang, Tennessee Department of Environment and Conservation

1:30 – 3:00 p.m.
Tuesday, April 17

Keynote Address *by* **Dennis McKenna, Deputy Administrator**
Illinois Department of Agriculture, Division of Natural Resources
50 Minutes to Gulf Hypoxia Literacy

12:30 – 1:30 p.m.
Wednesday, April 18

Luncheon Presentation *by* **Nicholas Crawford, Professor and Director**
Center for Cave and Karst Studies, Western Kentucky University,
Department of Geography and Geology
Environmental Problems Associated with Karst Hydrology in Tennessee

SESSION 1A

NUTRIENTS

SESSION 1B

STREAM ACIDIFICATION

SESSION 1C

EDC AND TOXIC CONTAMINANTS

SESSION 2A

TRACERS I

TRACERS II AND GROUNDWATER

TRACERS III

TRACERS IV

SESSION 2B

WATERSHED STUDIES I

WATERSHED STUDIES II

URBAN WATERSHED PLANNING I

URBAN WATERSHED PLANNING II

SESSION 2C

ENGINEERING DESIGN

WATER QUALITY MANAGEMENT

RESTORATION I

RESTORATION II

SESSION 3A

HYDROLOGIC REQUIREMENTS OF AQUATIC ECOSYSTEMS I

HYDROLOGIC REQUIREMENTS OF AQUATIC ECOSYSTEMS II

SESSION 3B

WETLANDS

STATUS REPORT OF WOLF CREEK AND CENTER HILL DAMS

Session to be moderated by Bob Sneed, U.S. Army Corps of Engineers

SESSION 3C

STORMWATER AND MORE

EDUCATION AND OUTREACH

PROFESSIONAL POSTER

STUDENT POSTERS

SESSION 1A

NUTRIENTS
3:30 p.m. – 5:00 p.m.

Application of Statistical-Regression Modeled Estimates of Stream Nutrient Loads to Support Nutrient-Management Strategies for Estuaries in the Southeastern United States
Anne B. Hoos, Michael Woodside, and Gerard McMahon

Modeling Nutrients in an Urbanizing Watershed Using HSPF
James R. Hagerman

Nutrient Dynamics in Tennessee Reservoirs
S. Qualls (Paper not available)

APPLICATION OF STATISTICAL-REGRESSION MODELED ESTIMATES OF STREAM NUTRIENT LOADS TO SUPPORT NUTRIENT-MANAGEMENT STRATEGIES FOR ESTUARIES IN THE SOUTHEASTERN UNITED STATES

Anne B. Hoos[1], Michael Woodside[1*], Gerard McMahon[2]

The U.S. Geological Survey's National Water-Quality Assessment Program has compiled surface-water quality monitoring data and estimates of nutrient sources (wastewater, agricultural, urban, and atmospheric) from Federal, State, and local water-resource agencies throughout the southeastern region of the United States. These data provide input to the SPARROW (SPAtially-Referenced Regression on Watershed attributes) water-quality model to predict nutrient loads in individual stream reaches and transport and fate of these nutrients as they move through the stream network to coastal water bodies. Application of modeled findings addresses two questions about stream nitrogen loads entering the 17 nitrogen-impaired estuaries in the southeast, with implications for nutrient-management planning. First, what are the proportional contributions of nitrogen delivered to each estuary from point-source wastewater discharges, agricultural and urban land, and atmospheric deposition, and how will changes in inputs from these sources affect the annual load delivered to the estuary? Second, what are the proportional contributions of nitrogen delivered to the estuary from each individual watershed in its drainage basin, and how does annual delivered load respond to incremental change in the amount of nitrogen exported from individual watersheds?

1 U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, Tennessee 37211

2 U.S. Geological Survey, 3916 Sunset Ridge Road, Raleigh, North Carolina, 27607

MODELING NUTRIENTS IN AN URBANIZING WATERSHED USING HSPF

James R. Hagerman[1]

ABSTRACT

Most stream segments in the Beaver Creek watershed are listed for one or more pollutants. To support watershed planning, the Hydrologic Simulation Program – Fortran (HSPF) was used to model hydrology, sediment, and nutrients in the Beaver Creek watershed in Knox County. HSPF simulates detailed hydrologic, erosion, and nutrient cycling processes, and provides time series outputs of concentration as well as total loads. Land use data for the model came from analysis of high-resolution color aerial photography. Model output was calibrated to the USGS gage near the mouth of the watershed and to one year of monthly water quality and discharge measurements at 12 sites throughout the watershed. The model was used to distinguish between the different urban and agricultural nonpoint sources of sediment and nutrients and to determine the relative importance of the point source loadings. The results were used to explore alternative strategies for water quality improvement for inclusion in a watershed plan. In addition, the model was used to project impacts from future development.

INTRODUCTION

The Beaver Creek watershed covers 91 square miles immediately north of Knoxville. It is within Knox County and in the Ridge and Valley ecoregion of east Tennessee. Beaver Creek flows into the Clinch River at Clinch River mile 39.6, within the pool of Melton Hill Reservoir. Most of the stream segments within the watershed are listed for pathogen indicators, nutrients, low dissolved oxygen, and/or sedimentation (Denton, et. al, 2006). Beaver Creek and its tributaries were included in the Lower Clinch TMDLs for pathogens and for siltation (TDEC, 2005 and 2006).

Until the latter part of the twentieth century, land use in the Beaver Creek watershed was predominantly agricultural with a few small communities. In the last few decades, urban development has been rapid, but a significant portion of the watershed is still used for pasture and hay.

Two wastewater treatment plants (WWTPs) discharge to the creek. The Hallsdale Powell Utility District (HPUD) discharge is at Beaver Creek mile 23.5 with a permit limit of 9.0 MGD. West Knox Utility District discharges at Beaver Creek mile 10.7, with a permit limit of 4.0 MGD.

The Beaver Creek Task Force (BCTF) was formed 1998 to begin working to improve Beaver Creek water quality and now consists of 19 local, state, and federal agencies, local utility districts, and grassroots citizens groups. The BCTF started laying the groundwork for developing a watershed restoration plan in 2004 and chose HSPF for the modeling component.

The Hydrological Simulation Program Fortran (HSPF), version 12 is a spatially distributed, lumped parameter watershed model. It simulates nonpoint source runoff and pollutant loadings for a watershed, combines these with point source contributions, and performs flow and water quality routing through stream reaches. Because it accounts for nutrient cycling both in upland

1 Environmental Engineer, Tennessee Valley Authority, 400 W. Summit Hill Drive WT 11B, Knoxville, TN 37902 jrhagerman@tva.gov

areas and within the stream, it is well suited for nutrient studies. HSPF is a component of the BASINS package supplied by the Environmental Protection Agency (EPA).

DATA SOURCES

Water quality data were provided by John Schwartz of the University of Tennessee Department of Civil and Environmental Engineering. Samples were taken at 13 tributary and mainstem sites approximately monthly from March 4, 2004 to January 11, 2005, on a total of 12 sampling dates. Parameters included NH_3-N, NO_2 + NO_3 -N, Total Kjeldahl N, organic N, total phosphorus, total organic carbon, pH; water temperature, indicator bacteria (fecal coliform and E. coli), dissolved oxygen, and discharge.

Land use data were developed from color aerial photography taken in 2003 provided by the Koxville-Knox County Knoxville Utilities Board Geographic Information System (KGIS). The photography was analyzed by students of Carol Harden of the University of Tennessee Department of Geography.

After this land use classification was finished, Tim Kuhn and Alex Zendel of Knoxville-Knox County Metropolitan Planning Commission performed a detailed analysis of impervious area based on existing building footprint and road paved-area data, along with estimated driveway areas. The analysis provided data not only on total imperviousness by land use, but also information about the contribution of road, roof, and parking areas to total imperviousness.

Further processing was done to determine the areas that were not served by sewer. GIS data provided by Hallsdale Powell Utility District (HPUD) that showed sewer system coverage was combined with the land use data to find the residential areas that depend on septic systems for waste treatment.

A detailed land-use classification scheme was used, resulting in 39 classes. These classes were combined into 24 classes for modeling purposes. Classifications included 4 different residential densities and 3 pasture classes based on quality of vegetative cover. Commercial and industrial land uses were combined overall, but “big box” commercial was broken out because of the higher imperviousness. Because HSPF treats pervious and impervious areas separately, the detailed imperviousness data was used to maximize flexibility in treatment scenarios.

Weather data came from the National Oceanic and Atmospheric Administration (NOAA) weather station at Knoxville-McGee Tyson airport (air temperature, dew point, wind speed, sky condition (cloudiness)); the University of Tennessee Agricultural Experiment Station (pan evaporation); and HPUD (hourly rainfall). Utility programs supplied with BASINS were used to calculate solar insolation from the sky-condition data.

U. S. Geological Survey (USGS) gage data was available near the downstream end of the watershed and was used in conjunction with the discharge data gathered during stream monitoring.

CALIBRATION

Hydrologic calibration is the first step in calibrating HSPF because runoff and flow is used for overland and in-stream transport. The USGS gage at the mouth was used as the primary comparison, with monitoring-station observations used for validation. Final calibration attained a

Nash-Sutcliffe efficiency coefficient of 0.74 (Figure 1). Most of the remaining variation can be attributed to uneven rainfall distribution across the watershed.

The rest of the calibration was based on the 12 monitoring days at each site. Only one of these sampling dates was during a rainfall event. This relative lack of data density required a more qualitative "weight of evidence" approach to calibration of the remaining parameters.

Because of the association between sediment and other parameters, erosion and sediment transport was the next calibration step after hydrology. Model factors were selected to generate an erosion rate similar to that predicted by the Universal Soil Loss Equation (USLE), then factors for individual land uses were adjusted so that model results were as close to observations as possible for each subwatershed (Figure 2). A similar process was used to select nutrient application, atmospheric deposition, and cycling factors.

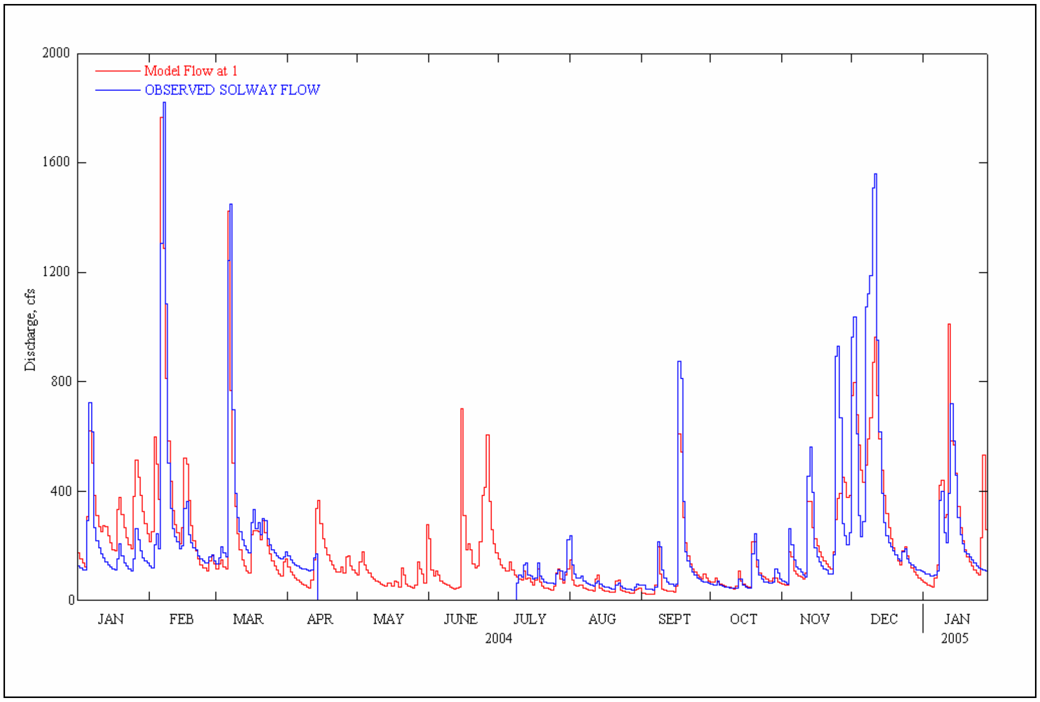

Figure 1. Observed and modeled discharge.

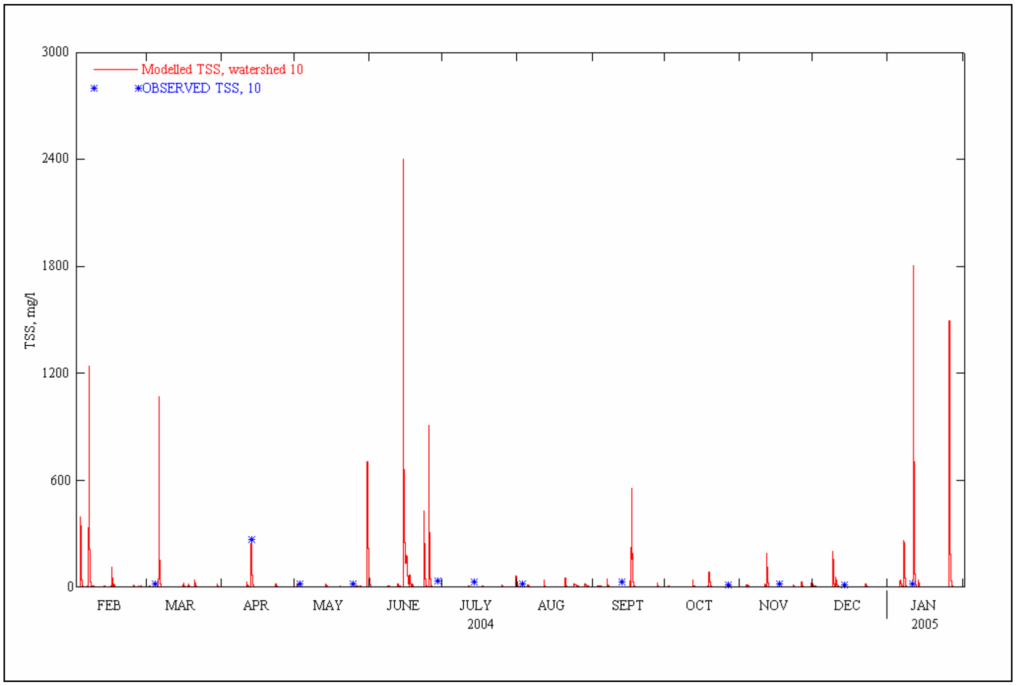

Figure 2. Observed and modeled TSS.

RESULTS

Approximately one third of the watershed is occupied by residential land uses (Table 1). The bulk of this is rural residential (less than 2 units per acre), accounting for 20% of the total area. Most of the rest (13% of the total area) is low-density residential (2 to 5 units per acre) with medium-density residential and apartments each occupying less than 1% of the watershed. Residential areas that are not served by sewers take up 15% of the watershed.

Table 1. Generalized land use.

Land Use	Acres	Percent of watershed
Residential	20223	35%
Commercial/industrial	3589	6%
Agriculture	11986	21%
Forest/shrub	19867	35%
Construction	1555	3%
Total	57220	

Forest and scrub/shrub areas account for another third of the watershed. Shrub land uses include both abandoned agricultural areas and areas cleared for development and subsequently overgrown. Many of the forested areas are steep and rocky and unsuitable for development. Agricultural areas are predominantly pasture, with only about 0.6% of the watershed in row crops.

Although active construction covered only 3% of the watershed at the time of photography, the model estimates that construction sites generate about 41% of the sediment. Agriculture and residential areas account for most of the rest.

Table 2. Sediment load by source.

Land Use	Sediment load, Tons/year	Percent of watershed load
Residential	2205.4	19%
Commercial/industrial	253.8	2%
Agriculture	3572.7	31%
Forest/shrub	661	6%
Construction	4696	41%
Total	**11389**	

According to model estimates, the two WWTPs in the watershed discharge over half of the total nitrogen (Table 3). Residential areas are the next largest contributor, with non-sewered areas generating nitrogen loading at a substantially higher rate than areas with sewers. Forest and shrub areas generate nitrogen at a lower per-acre rate than agricultural areas, but the greater area of forest/scrub produces a greater total load.

Table 3. Total nitrogen load by source.

Land Use	Total nitrogen load, lbs/year	Percent of NPS load	Percent of total load
Residential	85,033	41%	17%
Commercial/industrial	8,833	4%	2%
Agriculture	47,129	23%	10%
Forest/shrub	61,906	30%	13%
Construction	3,529	2%	1%
Total NPS	**206,431**		42%
Point source	**281,598**		58%
Total Load	**488,028**		

The WWTPs dominate the total phosphorus budget in the watershed (Table 4). Most of the nonpoint-source contribution is from residential areas. Non-sewered areas contribute phosphorus at only a slightly higher rate than areas with sewers. Phosphorus is associated with sediment, so construction areas generate phosphorus loadings at a higher rate than other land uses.

Table 4. Total phosphorus load by source.

Land Use	Total nitrogen load, lbs/year	Percent of NPS load	Percent of total load
Residential	2,063	62%	6%
Commercial/industrial	310	9%	1%
Agriculture	428	13%	1%
Forest/shrub	49	1%	0%
Construction	480	14%	1%
Total NPS	**3,331**		9%
Point source	**33,318**		91%
Total Load	**36,649**		

DISCUSSION AND CONCLUSIONS

The model accounted reasonably well for observed variations in in-stream concentrations of sediment and nutrients. However, much of the nonpoint-source loading takes place during storm events, and the monitoring dates included only one small storm. This leaves uncertainty in load generation and transport.

Although HSPF models storage and re-suspension of sediment within stream channels, it does not explicitly account for stream channel erosion. It was assumed that any net stream channel erosion taking place was lumped with erosion rates for the land uses associated with a stream channel. Calculated rates of sediment generation were reasonable and fairly low compared to those calculated with USLE, ranging from 0.001 tons/acre/year for forest with good cover to 3.32 tons/acre/year for construction sites with no visible erosion control. Since sediment loading in the stream can be accounted for with these sediment generation rates, it appears that stream channel erosion is not a large net sediment contributor on an annual basis in this watershed.

Compared with literature values of nutrient export (Reckhow et al., 1980), loading rates generated by this study are reasonable. Nitrogen export rates are mostly close to the averages reported by Reckhow. Modeled phosphorus loading rates are well below Reckhow's averages, and some of the modeled values are below the range of reported values. This may be because of the lack of storm data, but increasing the amount of phosphorus available for transport, either by fertilizer application or atmospheric deposition, generated unrealistically high peak concentrations in the model.

The sediment results of this model have been used to guide selection of treatment practices for the Beaver Creek Watershed Restoration Plan and 319 grant proposal submitted to the Tennessee Department of Agriculture. Further planning will be supported by the results of the nutrient portions of the model.

LITERATURE CITED

Denton, G.M., K.J. Sparks, D.H. Arnwine, R.R. James, and L.K. Cartwright. 2006. 2006 305(b) Report. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, TN.

Reckhow, K.H., N.B. Beulac, and J.T. Simpson. 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. Environmental Protection Agency. EPA 440/5-80-011.

Tennessee Department of Environment and Conservation. 2005. Total Maximum Daily Load (TMDL) for Pathogens in the Lower Clinch Watershed (HUC 06010207) Anderson, Campbell, Grainger, Knox, Loudon, Morgan, Roane, and Union Counties, Tennessee. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, TN

Tennessee Department of Environment and Conservation. 2006. Total Maximum Daily Load (TMDL) for Siltation and Habitat Alteration in the Lower Clinch Watershed (HUC 06010207) Anderson, Campbell, Grainger, Knox, Loudon, Morgan, Roane, and Union Counties, Tennessee. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, TN

SESSION 1B

STREAM ACIDIFICATION
3:30 p.m. – 5:00 p.m.

In Situ Bioassays of Native Brook Trout (Salvelinus fontinalis) in Streams Affected by Episodic Acidification in the Great Smoky Mountains National Park
Keil J. Neff, John Schwartz, R. Bruce Robinson, and Theodore B Henry

Long-Term Trends in Water Quality for a High-Elevation Stream in the Great Smoky Mountains National Park: Impacts of Acid Deposition
Angela Smith

Hydrologic Impacts from a Landslide in the Tennessee Coal Fields
Robert G. Liddle

IN SITU BIOASSAYS OF NATIVE BROOK TROUT (*SALVELINUS FONTINALIS*) IN STREAMS AFFECTED BY EPISODIC ACIDIFICATION IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Keil J. Neff[1], John Schwartz[2], R. Bruce Robinson[3], and Theodore B Henry[4]

INTRODUCTION

It is suspected that acidic runoff episodes are the primary cause of the extirpation of native brook trout (*Salvelinus fontinalis*) in six headwater streams in the Great Smoky Mountains National Park (GRSM). The GRSM receives some of the highest rates of acid deposition in the U.S. in the form of SO_4^{2-} and NO_3^{2-} (Johnson 1992; Shubzda et al. 1995) which contributes to acidic episodes of low pH, low acid neutralizing capacity (ANC) and elevated aluminum (Wigington et al. 1996). Fish and other aquatic animals can experience mortality or sub-lethal physiological stress when exposed to low pH and elevated aluminum as a result of ion-regulation interference (Dennis and Bulger 1995). Changes in stream water chemistry and brook trout physiology were determined during a 36-hour acidic episode at three remote headwater stream sites in the Middle Prong of the Little Pigeon River watershed. Whole-body sodium loss in individual trout sampled from cages was evaluated to determine the physiological response to the acidic episode.

METHODS

Water quality monitoring and native brook trout bioassays were conducted at three remote sites on streams in the GRSM (Figure 1) in east Tennessee: Middle Prong of the Little Pigeon River, Ramsey Prong, and Eagle Rocks Prong. The watersheds selected for study are typical watersheds of the GRSM, and are characterized by steep gradients and thin sandy loams that provide rapid runoff and poor buffering capacity and therefore are sensitive to acidification (MacAvoy and Bulger 1995). The three streams were selected for study on the basis of (i) the presence of trout at the control site, (ii) absence of trout in streams that historically supported trout at treatment sites, (iii) proximity of study sites to laboratory and (iv) lack of anthropogenic effects in watershed. Ramsey Prong and Eagle Rocks Prong historically supported brook trout but currently have no trout species inhabiting the streams. The Middle Prong is inhabited by native brook trout and rainbow trout and has the accumulation of waters from Ramsey Prong and Eagle Rocks Prong, and Buck Prong and Chapman Prong.

Water quality and stage height at the three stream sites were monitored from April 2006 to present. Grab samples were obtained monthly and more frequently during bioassays. Conductivity, pH, turbidity, and temperature were measured continuously at 15 minute intervals with a YSI 6920 data sonde. An ISCO 6712 automated water sampler was used to collect samples during acidic episodes. Chemical analyses were performed at the water quality lab at the University of Tennessee. Water samples were analyzed for the following parameters: conductivity (EPA method 150.1), pH (EPA method 120.1), ANC (Mantech PC-Titration Plus); sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+) (Dionex IC, Standard Methods 4110); Al, Ca, Cu, Fe, K, Mg, Mn, Na, Si, and Zn (Thermo Electron Intrepid II ICP-AES, EPA Method 6010B).

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1 Graduate Research Assistant, University of Tennessee, Department of Civil and Environmental Engineering, 706 S.E.R.F., Knoxville, TN 37996 kneff1@utk.edu

2 Assistant Professor, University of Tennessee, Department of Civil and Environmental Engineering, 63 Perkins Hall, Knoxville, TN 37996 jschwart@utk.edu

3 Emeritus Professor, University of Tennessee, Department of Civil and Environmental Engineering, 73 Perkins Hall, Knoxville, TN 37996 rbr@utk.edu

4 Research Scientist, University of Tennessee, Center for Environmental Biotechnology, 676 Dabney-Buehler Hall, Knoxville, TN 37996 thenry8@utk.edu

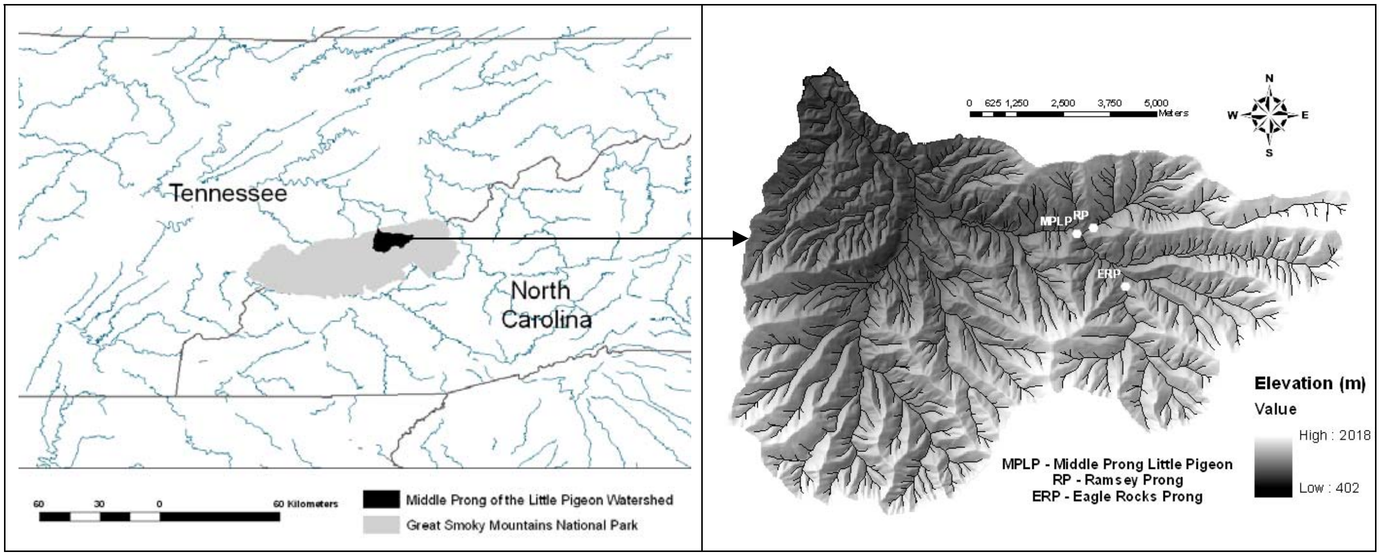

Figure 1: Location of study area and study streams in the GRSM in Tennessee.

The southern strain of native brook trout in the GRSM are taxonomically distinct from northeastern brook trout (McCracken et al. 1993). Trout used in the bioassays were collected using standard electroshocking techniques (Reynolds 1996). 120 test fish were collected from a circum-neutral reach and put into a common pool. Test fish were randomly distributed and transported in aerated backpack tanks to the three sites (40 trout per site). Test fish were held at each stream in cages following the approach of Johnson, et al. (Johnson et al. 1987). Insitu bioassays were conducted during a 9-day testing period from June 20th-June 29th, 2006. Test fish were collected on June 19th, 2006 and given a 24-hour adjustment period before initiation of testing period to ensure recovery from electroshocking and transport stresses. A storm event and subsequent 36-hour acidic runoff episode occurred June 26th-June 27th. Trout were randomly sampled from each of the four testing containers at each site on day 1 of the testing period. Trout were sampled two days before, the day following, and three days after the storm event.

In the laboratory, all trout samples were immediately put in a cold room (4° C) and within one week were oven-dried at 70° Celsius for 5-7 days. Following the procedure of Grippo, et al, (1996), dried trout were put into amounts of trace metal grade nitric acid, appropriately diluted with deionized water and vacuum-filtered through 0.45 μm filter for analysis of whole-body sodium concentrations using an ICP-AES.

RESULTS AND DISCUSSION

At base flow during the study period, the three sites experienced significantly different pH values: Ramsey Prong (mean pH = 5.89) > Middle Prong (mean pH = 5.79) > Eagle Rocks (mean pH = 5.49). During the stormflow, Eagle Rocks was significantly more acidic than the other two sites: Middle Prong (mean pH = 5.38) ≈ Ramsey Prong (mean pH = 5.39) > Eagle Rocks (mean pH = 5.00). Figure 2 illustrates the pH values at the three sites during the study period. It has been documented that pH values less than 5.2 can cause sodium loss and mortality in trout (Gagen and Sharpe 1987). During acidic runoff, all three sites experienced pH values less than 5.2 for the following durations: Middle Prong (8.75 hours), Ramsey Prong (11 hours), and Eagle Rocks (40.75 hours).

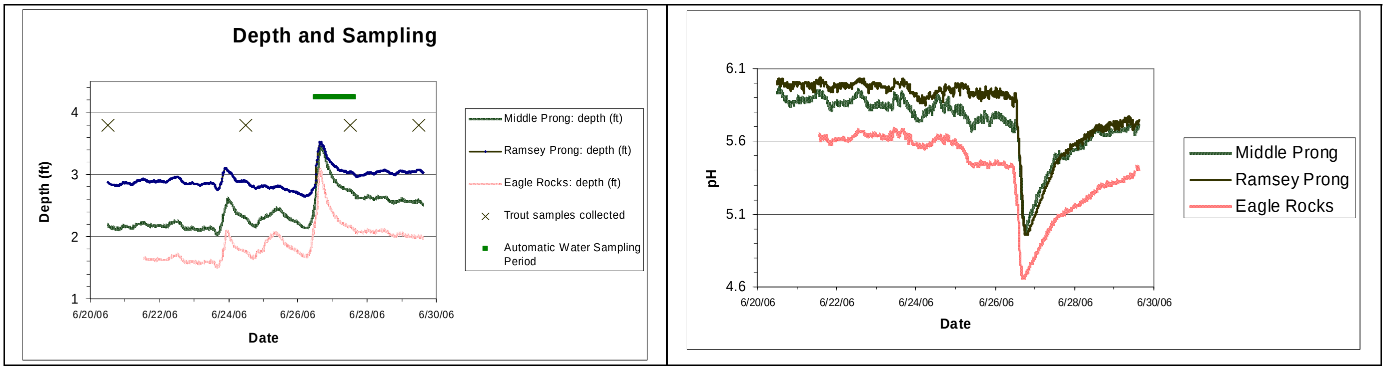

Figure 2: Stage at study sites and sampling sequence during bioassay period.

pH values during testing period at study sites.

To account for differences in trout mass, total body sodium was normalized by dividing by dry mass of trout samples. Considering all 48 samples, there were no statistical differences (ANOVA's and t-tests, $\alpha = 0.05$) between sites or dates (Figure 3). Each site was analyzed independently to determine if there were differences of total body sodium by date. There were no statistical differences by date at the Middle Prong and Ramsey Prong sites. Each sample date was also analyzed independently. Prior to the acidic episode (6/20/06 and 6/24/06) and two days following the event (6/29/06), there were no differences of total body sodium by site.

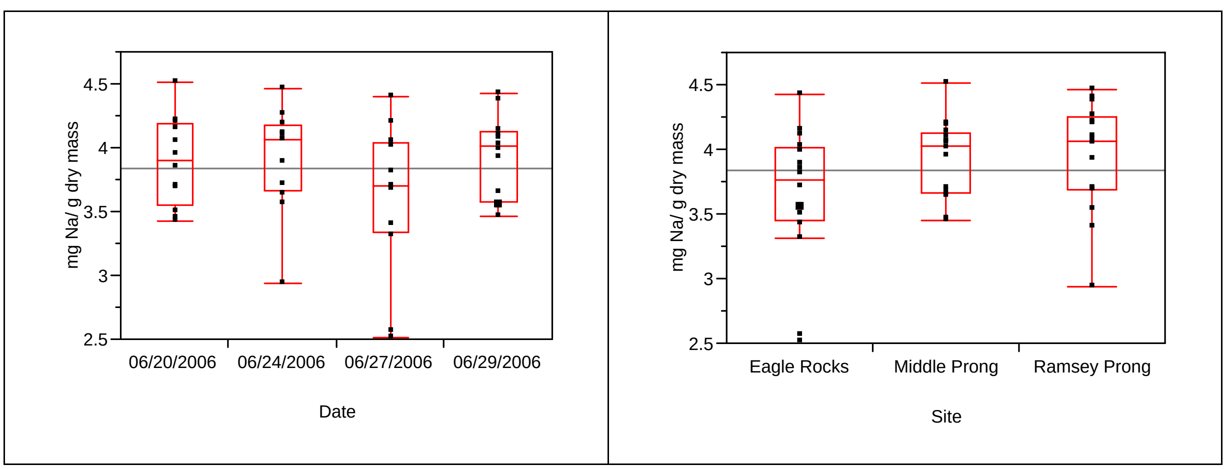

Figure 3: Box plots of total body sodium per dry mass by site and date.

The trout at Eagle Rocks, the site that experienced the lowest pH and longest duration of pH < 5.2, had lower total body sodium immediately following the storm (Figure 4). This was significantly different than the other three sample dates (ANOVA: Prob>F=0.0339; t-test: Prob<t: 6/27/06 to 6/20/06 p=0.0164, 6/27/06 to 6/24/06 p=0.0094, 6/27/06 to 6/29/06 p = 0.0040). The total body sodium of trout samples was also significantly lower at Eagle Rocks than the other

sites on 6/27/06 (Figure 4). An analysis of variance between the sites on this date produced a P-value of the F-statistic of 0.0452. T-tests between the sites also were significant (α = 0.05).

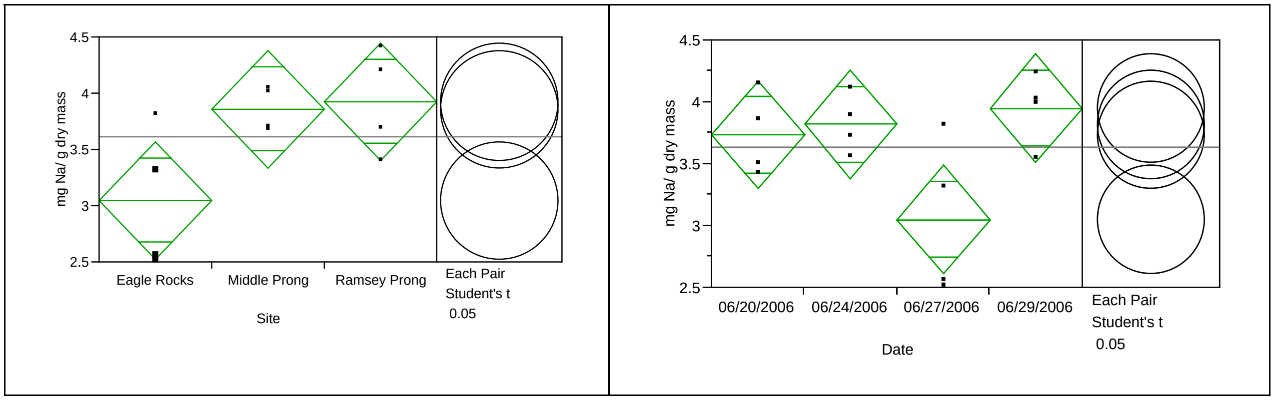

Figure 4: June 27th total body sodium per dry mass by site. Eagle rocks total body sodium per dry mass by date.

In this initial phase of investigating native trout in the GRSM, these results demonstrate that acidic runoff episodes can negatively affect brook trout physiology under actual field conditions. Native brook trout of the GRSM can tolerate pH depressions with a minimum pH = 5.0 and a duration of pH < 5.2 less than 12 hours. Trout lose the ability to regulate critical blood ions, as exemplified by a loss of total body sodium, when pH = 4.66 and pH < 5.2 for 40 hours. There is some evidence that brook trout can recover from an acidic response of this magnitude and duration.

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LONG-TERM TRENDS IN WATER QUALITY FOR A HIGH-ELEVATION STREAM IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK: IMPACTS OF ACID DEPOSITION

Angela Smith[1]*

ABSTRACT

Long-term trends in water quality in a high-elevation stream are compared to open site and through-fall acid deposition trends in the Noland Divide watershed of the Great Smoky Mountain National Park (GRSMNP).

Linear regressions were generated for the15-year data set, which contains the following: pH, conductivity, acid-neutralizing capacity, sulfate, nitrate, and ammonium. Results showed episodic low stream pH events corresponding to high stream stage events. A correlation between the streamwater pH and stage indicates that episodic low pH readings are the result of acid rain and supports the hypothesis that acid rain contributes to the degradation of the water quality in the higher elevations of the GRSMNP.

In keeping with air quality initiatives, linear regressions of the sulfate and nitrate data from precipitation samples show a gradual decrease in deposition. Reduction in acid deposition, however, is not reflected in stream chemistry. Linear regression of the streamwater pH shows a gradual decrease in average daily pH values. These results echo other research findings that reduction in acid deposition is not yet affecting the continuous degradation of streamwater in the GRSMNP.

Other long-term trends identified in the analysis include increases in calcium, magnesium, and ammonium deposition, which could explain part of the increasing pH trend of the precipitation data.

1 *Graduate research assistant; University of Tennessee, Knoxville, Dept of Environmental Engineering; 223 Perkins Hall, 1506 Middle Drive, Knoxville, TN 37996; abrawle1@utk.edu

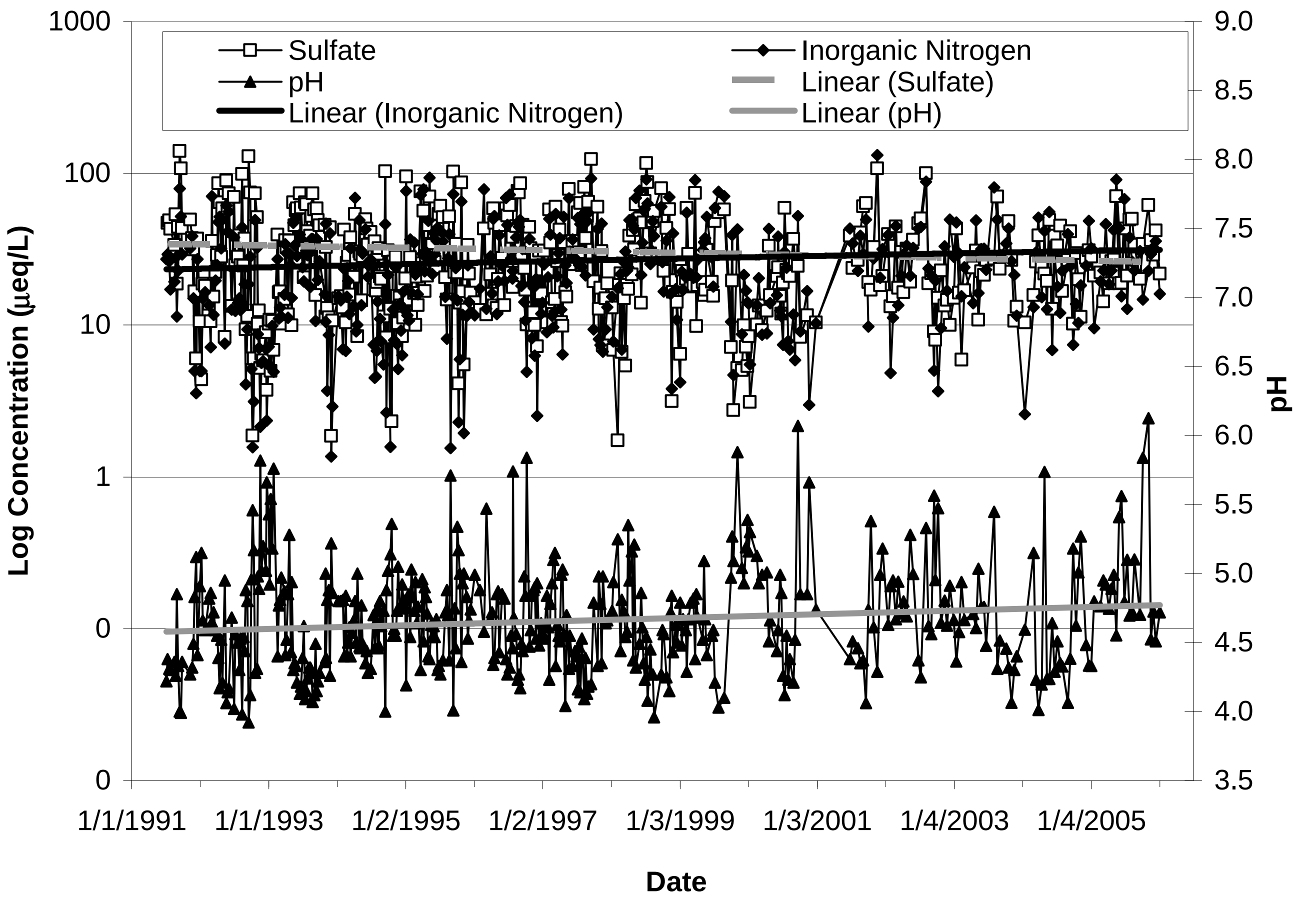

Figure 1 shows the scatter plots and time trends for pH, nitrate, and sulfate for the open site grab samples.

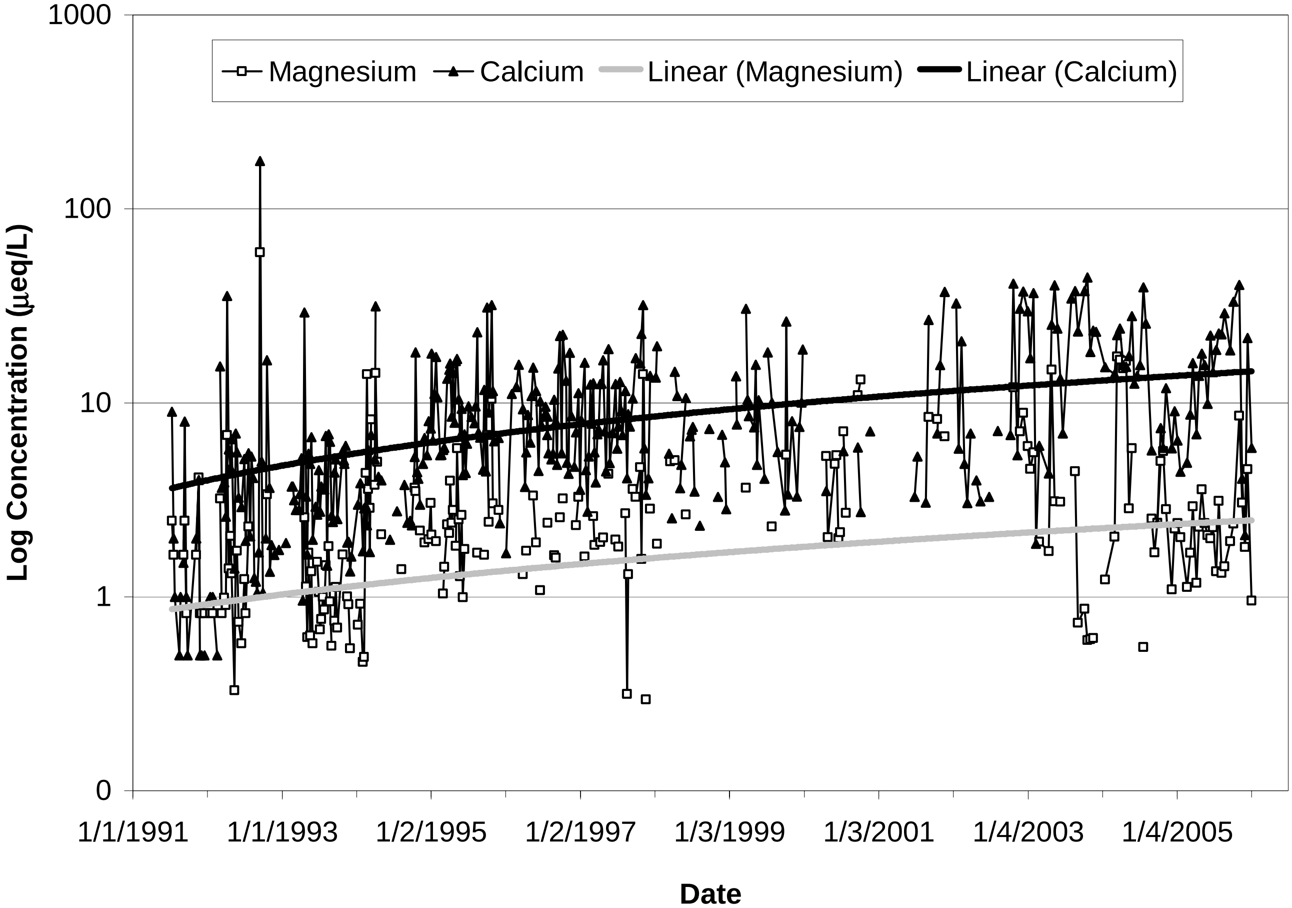

Figure 2 shows the scatter plots and time trends for calcium and magnesium deposition for the open site grab samples.

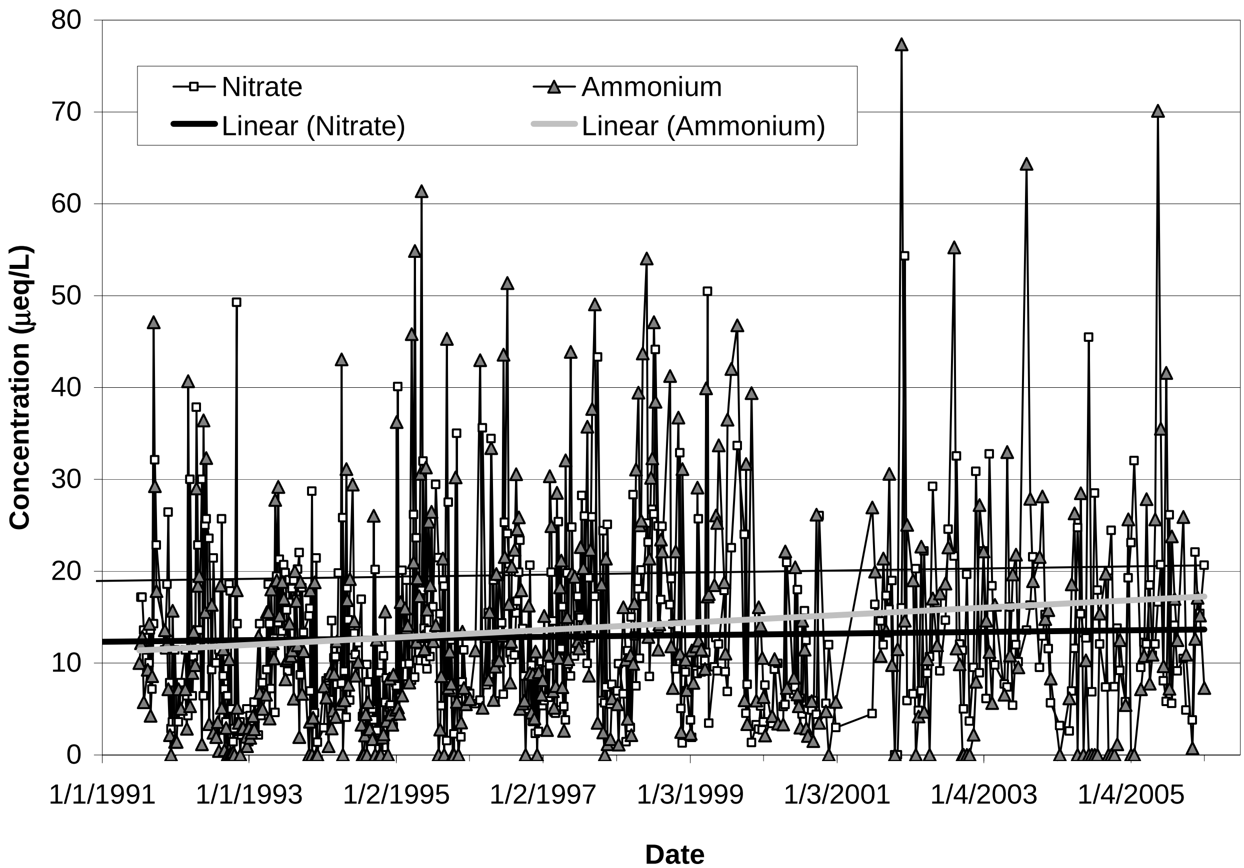

Figure 3 shows the scatter plots and time trends for nitrate and ammonium deposition for the open site grab samples.

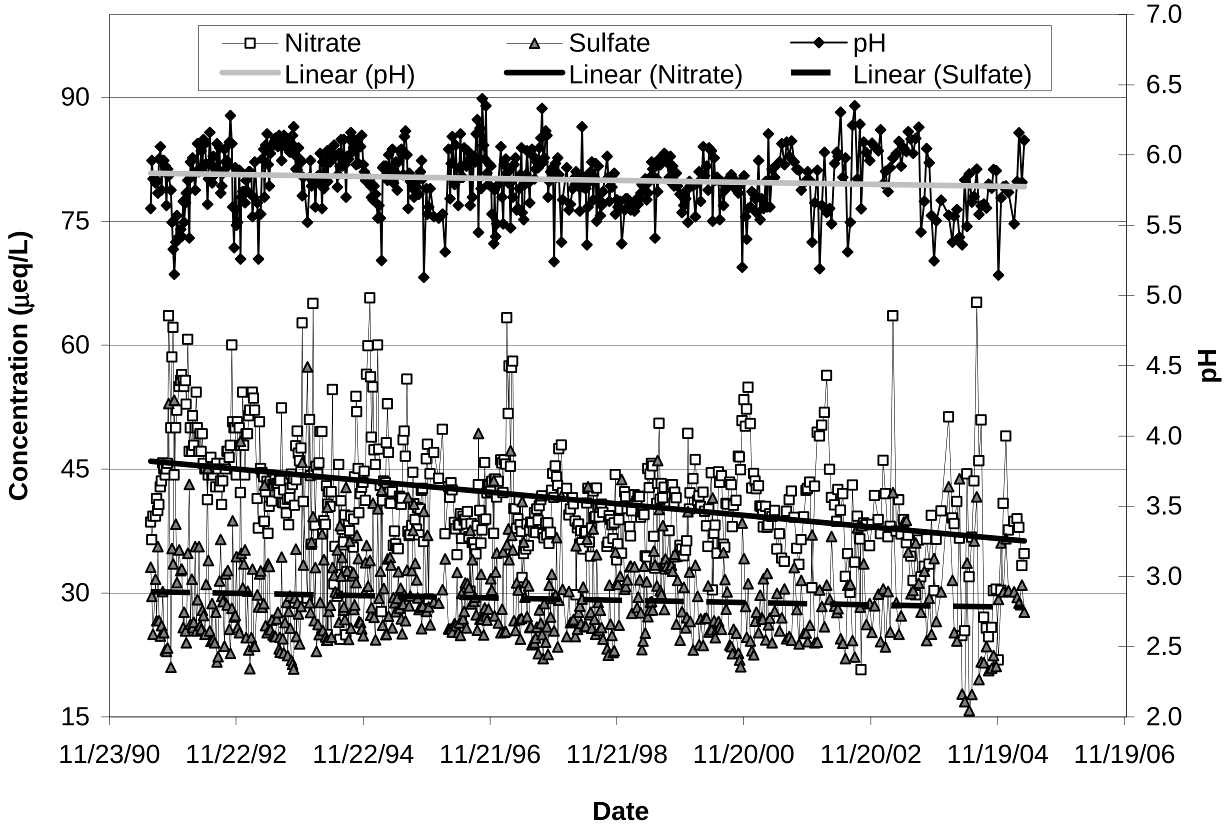

Figure 4 shows the scatter plots and time trends for pH, nitrate, and sulfate values for the southwest stream grab samples.

HYDROLOGIC IMPACTS FROM A LANDSLIDE IN THE TENNESSEE COAL FIELDS

Robert G. Liddle[1]

On January 27, 2005 a 25 acre landslide occurred on a steep mountainside at High Point Mountain in Scott County. A reclaimed contour strip coal mine and a reclaimed mountaintop removal coal mine were partially affected by the landslide. Sediments from the landslide eroded into Smoky Creek, a tributary to New River, within the Big South Fork of the Cumberland River basin. Initial suspended sediment concentrations below the landslide were about 5000 mg/L, while bedload concentrations were about 24,000 mg/L. After 4 months the landslide had stabilized and suspended sediment concentrations fell to less than 10 mg/L. Sand and gravel sized particles settled out within 2000 feet below the landslide tributary, while fine silts and clays were carried over 20 miles downstream. Groundwater from the adjacent mine spoils was modeled using the USGS MODFLOW software; results indicated mine spoil discharges would reach equilibrium within 292 days. Geochemical acid-base accounting accurately predicted no acid mine drainage would occur. Stormwater was modeled using the TVA TENN-I double triangle model, gross sediment erosion was modeled using the ERODE-I model, and net sedimentation was modeled using the LOAD-I watershed model. Model results compared well with actual field data. Mitigation of erosion from the landslide was modeled using the NRCS WEPP model and consisted of seeding the landslide with grasses, planting trees, and implementing vegetative filters. In conclusion, the landslide resulted in an intense short-term release of sediments similar to a construction site, which subsided in about 3 months.

1 Hydrologist, U.S. Department of the Interior, Office of Surface Mining, 710 Locust St., Knoxville, TN 37902 rliddle@osmre.gov

SESSION 1C

EDC AND TOXIC CONTAMINANTS
3:30 p.m. – 5:00 p.m

Endocrine Disrupting Chemicals: How Do We Know Whether There is a Problem in Tennessee?
Alice C. Layton, Melanie L. Eldridge, and John Sanseverino

Expression of Vitellogenin Genes in Fish Following Exposure to Environmental Estrogens
Theodore B. Henry, Jack McPherson, and Emily D. Rogers

Innovative Solution for Chlorinated Solvent Bioremediation at the Groundwater-Surface Water Interface
Duane Graves, Emily Majcher, and Michelle Lorah

ENDOCRINE DISRUPTING CHEMICALS: HOW DO WE KNOW WHETHER THERE IS A PROBLEM IN TENNESSEE?

Alice C. Layton[1]*, Melanie L. Eldridge[2], and John Sanseverino[3]

Over the past decade, water quality surveys indicated that numerous areas of the United States have pharmaceuticals and steroid hormones in their waterways. Additional studies have linked the exposure of fish and amphibians to natural and synthetic steroids to reproductive and endocrine disruption (estrogen and/or androgen). Within the State of Tennessee, little is currently known about the prevalence of endocrine disrupting chemicals in our waterways. Part of this arises from the fact that numerous classes of chemicals can act as endocrine disruptors including: surfactants, plastic precursors, prescription pharmaceuticals, and natural steroids, thus making analytical testing a complicated task. In addition, depending on the class of chemical, endocrine disruption may occur at concentrations in the ng/L of water range. In order to overcome the limitations of analytical analysis, our lab has developed bioluminescent-based yeast (*Saccharomyces cerevisiae)* reporters for the detection and quantification of estrogenic and androgenic chemicals. The combined use of these two strains allows testing of chemicals for estrogenic and androgenic activity as well as rapid assessment of the prevalence of endocrine disrupting chemicals in waterways of concern in Tennessee.

1 Research Associate Professor, Center for Environmental Biotechnology and Department of Microbiology, The University of Tennessee, 676 Dabney Hall, Knoxville, TN, 37996. alayton@utk.edu

2 Postdoctoral Research Scientist, Center for Environmental Biotechnology and Department of Microbiology, The University of Tennessee, 676 Dabney Hall, Knoxville, TN, 37996.

3 Research Associate Professor, Center for Environmental Biotechnology and Department of Microbiology, The University of Tennessee, 676 Dabney Hall, Knoxville, TN, 37996

EXPRESSION OF VITELLOGENIN GENES IN FISH FOLLOWING EXPOSURE TO ENVIRONMENTAL ESTROGENS

Theodore B. Henry*[1], Jack McPherson[1], Emily D. Rogers[1]

The lipoprotein vitellogenin is produced in hepatocytes of female fish in response to estrogen and deposited in developing oocytes where it is cleaved to form yolk proteins. Although vitellogenin is not normally expressed in male fish, vitellogenin genes are present, and production of vitellogenin can be induced by exposure to exogenous estrogenic substances. Detection of vitellogenin in blood plasma of wild-caught male fish has been used as a biomarker of exposure to estrogenic substances for more than 20 years. In most fish investigated, there are multiple genes that code for vitellogenin proteins, and while the biological significance for the multiple genes is unknown, differential expression of the individual genes offers an opportunity to better interpret the exposure of fish to environmental estrogenic substances.

In the present research we have developed a quantitative reverse transcriptase PCR (qRT-PCR) approach to evaluate the expression of seven vitellogenin genes in zebrafish. The primers and probe sets used were developed based on sequences of the individual genes available online (i.e., GenBank) and through molecular biology techniques in the laboratory. Subsequently, zebrafish were exposed in the laboratory to environmental estrogens, total RNA was extracted following exposure, and expression of individual vitellogenin genes was evaluated by qRT-PCR.

Results indicate that expression of individual vitellogenin genes varies according to exposure to estrogenic substances and that qRT-PCR of vitellogenin genes offers a unique tool for evaluation of endocrine disruption in fish.

1 Center for Environmental Biotechnology, University of Tennessee, Knoxville, TN 37996

INNOVATIVE SOLUTION FOR CHLORINATED SOLVENT BIOREMEDIATION AT THE GROUNDWATER-SURFACE WATER INTERFACE

Duane Graves, Ph.D.*[1], Emily Majcher, P.E.[2], and Michelle Lorah, Ph.D.[2]

The remediation of wetlands and groundwater seep areas provides several technical challenges including difficult access; tidally or seasonally influenced water fluxes; sensitive ecological exposure points; and complicated, competitive biological communities. This presentation discusses the use of bioaugmentation with an innovative remediation design for treatment of chlorinated solvents in groundwater that seeps to the surface of a wetland. Both components of the technology, a new bioaugmentation culture and the remediation design, have broad applicability to groundwater treatment. The bioaugmentation culture is currently being tested for effectiveness at a chlorinated solvent contaminated site in Tennessee.

The first demonstration of the technology was accomplished at a location where substantial mass of dissolved chlorinated solvents seeps into a tidal wetland along a creek from an underlying groundwater source at Aberdeen Proving Ground, Maryland. A high efficiency, low maintenance, in situ bioremediation technology that combines bioaugmentation with an engineered mat (reactive mat) to treat contaminated groundwater in this sensitive environment was developed by the U.S. Geological Survey (USGS) and implemented collaboratively by USGS and Geosyntec Consultants.

The reactive mat is an innovative, engineered, permeable barrier designed specifically to function in a wetland to protect surface water by intercepting and treating groundwater as it seeps to the surface. The biologically reactive mat was bioaugmented with a newly developed, robust microbial consortium (WBC-2) capable of dechlorinating a broad range of chlorinated solvents in groundwater (Figure 1). The mat was also amended with an insoluble electron donor. The WBC-2 facilitated the rapid degradation of 1,1,2,2-tetrachloroethane (TeCA), trichloroethene (TCE), carbon tetrachloride (CT), and chloroform (CF). Post-construction performance monitoring for one year demonstrated the physical stability of the reactive mat, persistent methanogenesis and high dissolved hydrogen concentrations suitable to sustain reductive dechlorination, solvent concentration reductions ranging from 100 to greater than 1000-fold within the reactive mat, and an overall reduction in the mass of chlorinated solvents seeping into surface water (Figure 2).

Performance results suggest that the reactive mat design is highly adaptable to installation requirements at groundwater-surface water interfaces in wetland, estuarine, riverine, and lacustrine environments. The combination of rapid biodegradation rates, substantial contaminant concentration reductions, an inconspicuous profile, and low maintenance requirements makes the reactive mat a useful technology for groundwater remediation at the point of exposure. The broad substrate range and robust physiological characteristics of WBC-2 supports its value for chlorinated solvent bioremediation.

1Principal, GeoSyntec Consultants, Knoxville, Tennessee 37909; dgraves@geosyntec.com

2Engineer and Hydrologist, respectively, US Geological Survey, Maryland-Delaware-DC Water Science Center, 8987 Yellow Brick Road, Baltimore, MD 21237; ehmajche@usgs.gov and mmlorah@usgs.gov.

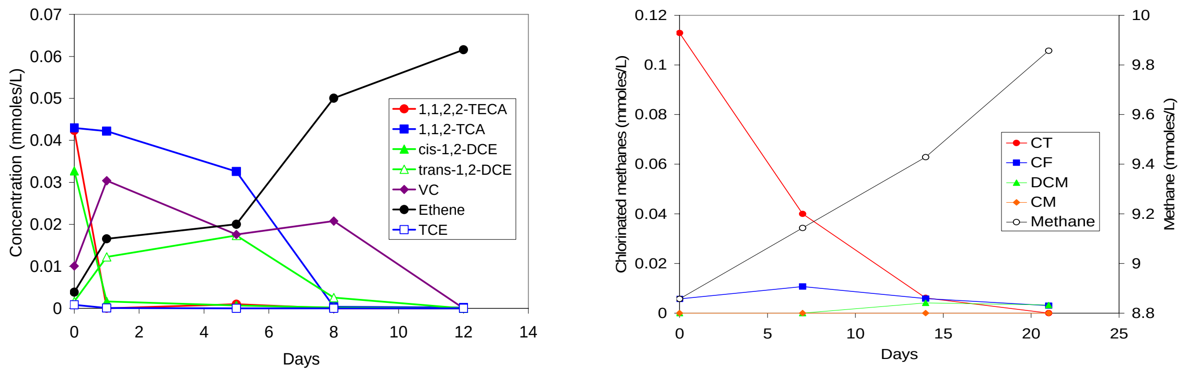

Figure 1. Biodegradation of chlorinated ethenes, ethanes, and methanes by WBC-2. (1,1,2,2-TECA, 1,1,2,2-Tetrachloroethane; 1,1,2-TCA, 1,1,2-Trichloroethane; cis-1,2-DCE, cis-1,2-dichloroethene; trans-1,2-DCE, trans-1,2-dichloroethene; VC, vinyl chloride; TCE, trichloroethene; CT, carbon tetrachloride; CF, chloroform; DCM, dichloromethane [methylene chloride]; CM, chloromethane)

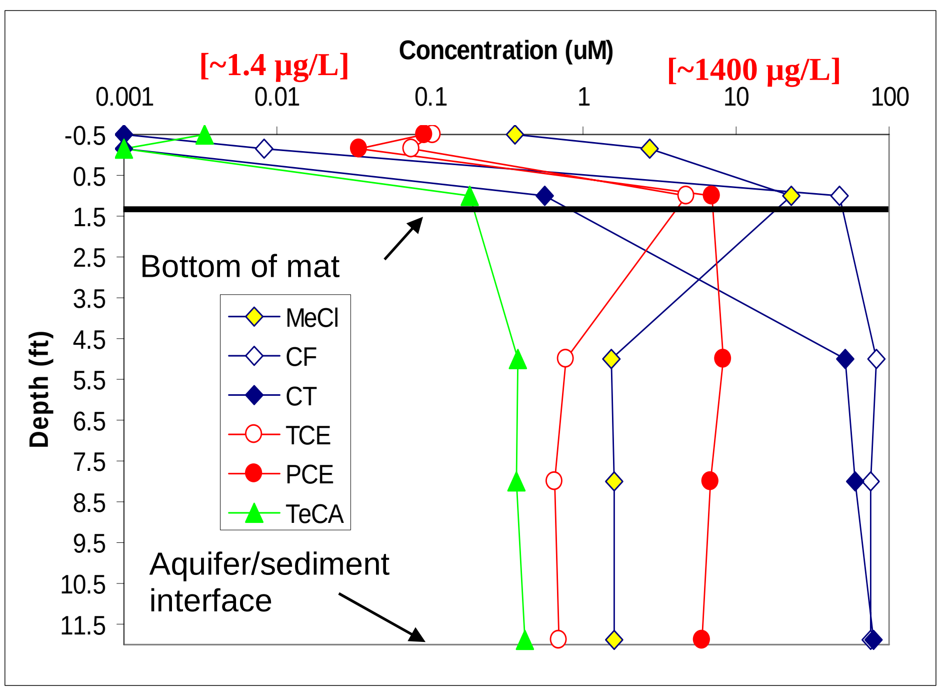

Figure 2. In situ groundwater concentration of chlorinated ethenes, ethanes, and methanes that seep upward in untreated wetland sediments and within in the bioreactive mat. Groundwater flow is from deep to shallow with final expression water from the bioreative mat at the surface of the wetland. (MeCl, methylene chloride; CF, chloroform; CT, carbon tetrachloride; TCE, trichloroethene; PCE, tetrachloroethene; TeCA, 1,1,2,2-tetrachloroethane)

SESSION 2A

TRACERS I
8:30 a.m. – 10:00 a.m.

Estimating Recharge Through Fine-Grained Residuum Overlying a Karst Aquifer Using Tritium/Helium and CFCs
Larry D. McKay, Vijay Vulava, Bryan Schultz, Frank Bogle, and D. Kip Solomon

Use of Tracers and Other Data to Assess Leakage from Nonconnah Creek to the Shallow and Memphis Aquifers in the Vicinity of the Sheahan Well Field, Memphis, Tennessee
Daniel Larsen, Jason Morat, Brian Waldron, Stephanie Ivey, and Jerry Anderson

Using Decay Series Isotopic Tracers to Develop Conceptual Models of Aquifer Behavior
Randall W. Gentry

TRACERS II AND GROUNDWATER
10:30 a.m. – 12:00 p.m.

Recharge Estimation Using Meteoric Chloride as a Tracer within the Vadose Zone
Brian Waldron and Daniel Larsen

Using Groundwater Age Dating and Particle-Tracking to Test a Conceptual Model of Groundwater Flow from a Landfill to a Spring
Connor J. Haugh

Evaluation of Multilevel Monitoring Well Completion Technologies for Karst Dolomite
Todd Kafka, Duane Graves, Peter Zeeb, Duane Wanty, and Steve Sacco

TRACERS III
1:30 p.m. – 3:00 p.m.

Utility of Tracers in Modeling Groundwater Flow in the Sheahan Wellfield Complicated by Inter-aquifer Leakage Owing to Aquitard Breaches
Brian Waldron, Dan Larsen, and Jason Morat

Dual Tracers Used to Evaluate Seepage in a Natural Wetland
Duane Graves, Emily Majcher, and Michelle Lorah

Organic Fluorophores in Drinking Water: Implications for Dye Tracing and Source Characterization
Terri Brown, Larry McKay, John McCarthy, Jie Zhuang, and Randy Gentry

TRACERS IV
3:30 p.m. – 5:00 p.m.

Design Cost-Effective Tracer Tests to Quantify Surface and Groundwater Flow and Contaminant Transport in Karst Areas, Northeastern Tennessee
Yongli Gao

Karst Hydrology and the Interpretation of Negative Results in Tracing Tests: A Theoretical Perspective

Barry F. Beck, Wanfang Zhou, Arthur J. Pettit, Ramona C. Josefczyk, and Jie Wang

ESTIMATING RECHARGE THROUGH FINE-GRAINED RESIDUUM OVERLYING A KARST AQUIFER USING TRITIUM/HELIUM AND CFCS

Larry D. McKay[1*], Vijay Vulava[1], Bryan Schultz [1& formerly 2], Frank Bogle[2] and D. Kip Solomon[3]

A study was carried out to estimate rates of recharge through a 7-40 m thick layer of clay-rich residuum overlying carbonate bedrock using environmental tracers (3H/3He and CFCs). These tracers are present in the atmosphere and in precipitation due to anthropogenic releases, mainly over the past 50 years. Tritium (3H) was released in large quantities by above-ground testing of thermonuclear weapons and reached a peak in the mid-1960s. Helium-3 (3He) is the daughter product of tritium decay. Once tritiated water infiltrates below the water table, it is isolated from the atmosphere and as the 3H content decreases due to radioactive decay, the 3He content increases. By measuring the ratio of 3H/3He in groundwater from a given depth, it's possible to estimate the apparent "groundwater age", meaning the elapsed time since the recharging water entered the water table. Chlorofluorocarbons (CFCs) were used for a variety of industrial purposes, including as compressor fluids in refrigerators and as propellants in spray cans. Concentrations of CFCs increased steadily in the atmosphere throughout most of the latter part of the 20th century and only recently have the values stabilized due to regulations limiting CFC use in many countries. Recharging groundwater contains trace amounts of dissolved CFCs with the concentration related to the initial atmospheric concentration at the time when the recharge became isolated from the atmosphere (typically assumed to occur when the recharge reaches the water table). By measuring CFC concentrations in groundwater samples it's possible to estimate "groundwater age" in much the same manner as used for 3H/3He. Both methods have some limitations, such as uncertainty about possible subsurface sources of 3He and possible biodegradation of some of the CFC compounds and they're often used together to help reduce this uncertainty. However, determination of "groundwater age" with either method requires the assumption of "plug flow" meaning that there is not substantial mixing with older or younger recharge. This has generally been accepted as a reasonable assumption for granular aquifers, but the method has rarely been tried in the fractured, highly weathered materials that are common in east Tennessee and other areas in the southeast.

The main objectives of the present study were to measure 3H/3He and CFC concentrations in typical residuum overlying a karst aquifer and use these values to estimate variability in groundwater age and recharge rates. Limitations on the methods for use in these types of materials were also examined and the results were compared with recharge rates calculated using Darcy's Law and measured values of hydraulic conductivity and hydraulic gradient.

A total of 14 wells (11 in the residuum and 3 in bedrock) were purged and sampled for 3H/3He and CFCs. In the residuum, where hydraulic conductivity values range from 6 x 10-4 to 2 m/day, it was usually necessary to install a dedicated submersible pump and purge the wells in cycles over a period of several days or more (i.e., draw the water level down to 1 m above the screen and then leave it overnight to recover before purging again). Samples for CFC analysis were collected using copper tubing from the pump to prevent loss of gas and were collected with zero headspace in glass vials submerged in a stainless steel vessel. Tritium samples were collected in 1 L

1Department of Earth and Planetary Sciences, Univ. of Tennessee, Knoxville, TN 37996 USA

2Tetra Tech, Inc., 800 Oak Ridge Turnpike, Oak Ridge, TN 37830

3Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112

polyethylene bottles and 3He samples were collected by suspending a diffusion sampler in the middle of the well screen after purging.

Apparent groundwater ages for samples from the 11 residuum wells that were tested for 3H/3He ranged from 5 to 32 years. Ages determined from the CFC values ranged from 17 to 39 years, although many of the CFC samples couldn't be analyzed because of high background concentrations of dissolved organic contaminants. Apparent ages from the 3 bedrock wells tested ranged from 6 to 18 years for the 3H/3He method and 19 to 36 years for the CFC method. Recharge velocities in the residuum were calculated by dividing the distance from the seasonal low water table to the top of the well screen by the apparent age determined using the 3H/3He method. The resulting vertical recharge velocities ranged from 0.03 to 1.1 m/year, with a mean value of 0.30 m/year and a geometric mean of 0.18 m/year. For a few cases, where data was available for both hydraulic conductivity and vertical hydraulic gradient, we calculated values of Darcy velocity assuming the residuum is sufficiently fractured as to present an equivalent porous medium with total porosity (40%) equal to the effective porosity. In these wells, the calculated Darcy velocity was higher than the environmental tracer velocity by factors ranging from 3 to 20 times. This may be due to anisotropy in the residuum, if one assumes that slug tests in the wells mainly measure horizontal hydraulic conductivity, whereas the tracer velocities are more strongly controlled by vertical hydraulic conductivity. However, it could also be due to uncertainty in hydraulic conductivity measurements, the effective porosity or the "average" hydraulic gradient value used in the Darcy calculations. The recharge rates based on the groundwater age dates also have limitations (as discussed earlier), but the biggest advantage is that they are completely independent of Darcy's Law and hence provide an alternative measure of recharge rate. In addition, the recharge rates calculated based on environmental tracers could be used at locations where there was only a single monitoring well (multiple wells are always required to determine vertical hydraulic gradients for Darcy velocity calculations). This allowed us to substantially improve our measure of the geographic variability of recharge rates across the site and provided valuable data for constraining the subsequent flow and transport modeling.

USE OF TRACERS AND OTHER DATA TO ASSESS LEAKAGE FROM NONCONNAH CREEK TO THE SHALLOW AND MEMPHIS AQUIFERS IN THE VICINITY OF THE SHEAHAN WELL FIELD, MEMPHIS, TENNESSEE

Daniel Larsen[1], Jason Morat[2], Brian Waldron[3], Stephanie Ivey[4], and Jerry Anderson[5]

Leakage of water into the semi-confined Memphis aquifer near the Sheahan Well Field in Memphis, Tennessee, has been suggested by many studies extending back to the 1960's, mainly using hydrologic data and isotopic tracers. Most recently, leakage from Nonconnah Creek to the Sheahan well field was investigated over a one-year period using multiple approaches: (1) stream discharge data, (2) hydraulic head data, (3) geochemical and environmental tracer ($^3H/^3He$ and CFC's) studies, and (4) finite-difference computer modeling of stream-aquifer-pumping response. The stream loss and hydraulic head data strongly support the conclusion that losses from the creek contribute approximately 0.5 million gallons per day to the Memphis aquifer. Geochemical data from Nonconnah Creek and wells in the upper part of the Memphis aquifer show substantial similarities and are compatible with creek water contributing to leakage. Tritium-^3He data from shallow aquifer monitoring wells within the Sheahan well field are composed of modern water with ages that generally increase from the creek toward the well field. CFC ages obtained from the same wells are older than the ^3H-^3He ages for chemically reducing waters, but are approximately the same for the one well with more oxidizing waters. Although the monitoring well data collected are consistent with the leakage model, the leakage pathway from the creek to the well field is interpreted to follow a paleovalley feature that has little well control. The results emphasize the utility of tracers in ground-water flow studies, but also illustrate potential problems and the need for multiple investigative approaches.

1Associate Professor, Dept. of Earth Sciences, The University of Memphis, Memphis, TN 38152, Tel: 901-678-4358 Email: dlarsen@memphis.edu

2Graduate Assistant, Dept. of Earth Sciences, The University of Memphis, Memphis, TN 38152, Tel: 901-678-4355 Email: jmorat@memphis.edu

3Assistant Professor, Ground Water Institute, The University of Memphis, 301 Engineering Admin. Bldg., Memphis, TN 38152, Tel: 901-678-3913 Email: bwaldron@memphis.edu

4Assistant Professor, Dept. of Civil Engineering, The University of Memphis, Memphis, TN 38152, Tel: 901-678-3286 Email: ssalyers@memphis.edu

5Director, Ground Water Institute, The University of Memphis, 300 Engineering Admin. Bldg., Memphis, TN 38152, Tel: 901-678-3062 Email: jlandrsn@memphis.edu

USING DECAY SERIES ISOTOPIC TRACERS TO DEVELOP CONCEPTUAL MODELS OF AQUIFER BEHAVIOR

Randall W. Gentry[1]

Aquitard windows are known to occur in unconsolidated aquifer systems and represent areas of focused recharge to otherwise confined underlying aquifers. The study herein focused on a known window site affecting the Memphis aquifer located in the Sheahan well field in Shelby County, Tennessee. Uranium- and thorium-series radioisotopes have been evaluated from production wells sampled in multiple well fields and evaluated for distinct characteristic signatures. From earlier research, a conceptual model was realized whereby higher uranium concentrations from near-surface waters flow through a redox barrier in the aquitard window and become depleted in uranium. Further, $^{234}U/^{238}U$ activity ratio increased down gradient of the recharge source by alpha-recoil mobilization of ^{234}U via ^{234}Th, and possibly leaching of uranium bound by iron hydroxides via dissolution and subsequent precipitation by reducing waters flowing to down gradient wells. The purpose of this research was to explore the difference between conceptual models of differing hydrologic settings, represented by three different well fields in the City of Memphis area.

1 Associate Professor, The University of Tennessee, 62 Perkins Hall, Knoxville, TN 37996; Email: rgentry@utk.edu

RECHARGE ESTIMATION USING METEORIC CHLORIDE AS A TRACER WITHIN THE VADOSE ZONE

Brian Waldron[1*] and Daniel Larsen[2]

Recharge is a critical hydrologic factor for assessing ground-water resource sustainability that is commonly evaluated using mass-balance calculation or a model fudge-factor calibration term. Such recharge estimates are commonly oversimplified rates representative of large areas and not coupled to a watershed's physical heterogeneity, land use, or near-surface soil properties. In an effort to obtain better recharge estimates, the chloride-extraction vadose-zone method, a well-established arid-region recharge estimation methodology, was employed at a site in West Tennessee within the Memphis aquifer recharge area.

Meteoric chloride is used as a tracer within the vadose zone to estimate recharge through a mass balance approach assuming that the sole source of chloride is from wet fall and runoff can be considered negligible. The study area is a recreational field at the Pinecrest Presbyterian camp in Fayette County approximately 4 miles east of Moscow, Tennessee on Highway 57. Continuous soil cores to a depth of 34 m were extracted within the vadose zone using a hollow stem auger before abrupt termination of the drilling processing due to shearing of the drill shaft. Soil samples were collected *in situ* using bicarbonate tubes 76 cm in length. Following tube extraction, aluminum foil was placed over the tube ends, which were then capped with plastic caps and sealed with duct tape.

In the laboratory, soil moisture contents were calculated by oven drying the sample (ASTM D2216-05). For each bicarbonate tube pair, two 400 g soil samples were collected and homogenized. From this 400 g sample, two 100 g subsamples were used for chloride extraction by addition of 100 mL of Millipore deionized water (>17.6 megaohms). The sediment-water mixture was mixed for 24 hours, centrifuged for 45 minutes, and the supernatant collected. The extraction procedure was repeated three times. Chloride concentrations in the supernatant were determined using ion chromatography, with a method detection limit of 0.14 mg/L. Precipitation rates are estimated at 137 cm/yr. Wet-fall chloride concentrations from a nearby National Atmospheric Deposition station on the Hatchie River indicate an average 0.17 mg/l. After adjustment of the soil moisture content for drilling induced anomalies, the average meteoric chloride concentration in the vadose zone soil below the root zone is 14 mg/l. This results in a point-recharge estimation of 1.6 cm/yr, which is at the low range of recharge estimates made using other methods in the region (1.5 to 25 cm/yr). The chloride content of shallow ground water in a well approximately 0.5 km from the borehole site is 1.5 mg/L. Assuming that this value is representative of local ground water, a recharge estimate of 15 cm/yr is obtained. Although the borehole-derived recharge value is within the range of model and measured recharge values, it is actually much lower than expected for the sandy sediments observed at the borehole site. The lowest recharge estimates in the region are generally obtained from areas where recharge occurs through 3 to 15 m of loess, which is not present at the borehole site. The sandy nature of soils at the Pinecrest site should enhance recharge. Possible sources of error in application of the chloride-extraction method include loss of water from cores during storage, input of anthropogenic chloride, experimental error, and analytical error. Rigorous quality control (standard, blank, replicate controls) of the chloride analysis rules out analytical error. However, water contents of samples decrease markedly after approximately one week of storage,

1 University of Memphis, Civil Engineering, 110D ES Building, Memphis, TN, 38152, bwaldron@memphis.edu

2 University of Memphis, Earth Sciences, 001 Johnson Hall, Memphis, TN, 38152, dlarsen@memphis.edu

suggesting that water-loss may be a problem. Custodial personal at the Pinecrest site indicate that no chlorine-based pesticides or herbicides had been applied for the past 20? years. Runoff or through flow at the site may further complicate application of the vadose-zone chloride method; however, both of these processes are believed to be unimportant at the site. Comparison to other tracer-based recharge methods at the Pinecrest site is needed to further evaluate the discrepancy between recharge estimates obtained by extraction-based versus ground-water chloride methods.

USING GROUND-WATER AGE DATING AND PARTICLE-TRACKING TO TEST A CONCEPTUAL MODEL OF GROUND-WATER FLOW FROM A LANDFILL TO A SPRING

Connor J. Haugh[1]

ABSTRACT

A conceptual model of ground-water flow from a landfill to a spring was tested using ground-water age dating and flow-model particle-tracking. The site is located at Arnold Air Force Base in the eastern Highland Rim. Contaminants from the landfill, primarily TCE, have been detected in the spring, which is approximately 5 miles down gradient from the landfill. The conceptual model of the ground-water flow and contaminant transport includes flow in fractured rock, through porous media, and through a highly transmissive zone along an extensive trough in the bedrock surface. In the conceptual model, ground-water flow and contaminants from the landfill move relatively slow until reaching the trough and then relatively rapid along the trough to the spring. The spring and 15 wells located along and near the flow paths from the landfill were sampled to determine the apparent age of the ground water. Water from all of the wells and the spring were analyzed for age determination using the sulfur-hexafluoride (SF_6) technique. In addition, water from the spring and 8 of the wells were analyzed for age determination using the tritium/helium ($^3H/^3He$) technique. Time of travel to each of the sites was also estimated using particle-tracking from a recently updated digital ground-water-flow model. Apparent ground-water ages and particle- tracking travel times agree reasonably well at most of the sites. These data support the conceptual model of ground-water flow from the landfill to the spring.

INTRODUCTION

Contaminants (primarily TCE) from a landfill (SWMU 1&2) at Arnold Air Force Base (AAFB) have been detected in Big Spring at Rutledge Falls, located approximately 5 miles down gradient from the landfill. This study tested the conceptual model of ground-water flow from the landfill to the spring using age-dating samples and particle-tracking from a digital flow model. A correct conceptualization of the ground-water flow, including direction and rate of movement, is needed to plan an efficient remediation strategy for the site.

The landfill is located in the eastern Highland Rim at Arnold Air Force Base (fig. 1). The AAFB area is located in a fractured carbonate terrane covered by regolith derived from in-situ weathering of carbonate rocks of Mississippian age. The base of the flow system is the Chattanooga Shale. The Chattanooga Shale is overlain by the Fort Payne Formation. In the area between the landfill and Big Spring, the Fort Payne Formation as rock ranges from less than 20 to about 60 ft thick and regolith ranges from about 40 to 90 ft thick. The Manchester aquifer, the primary aquifer in the area, consists of gravels and chert rubble at the base of the regolith and solution openings in the upper part of the bedrock (Burchett and Hollyday, 1974).

The conceptual model of the ground-water flow from the landfill to the spring includes flow in fractured rock, through porous media, and through a highly transmissive zone along an extensive gravel-filled bedrock trough (fig. 2) (CH2MHill, 2001). Contaminants migrate vertically downward through the regolith under the landfill to the top of bedrock, and then move under the

1 Hydrologist, U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211 cjhaugh@usgs.gov

retention pond to the northwest through gravels at the top-of-rock and fractures in the bedrock. North of the retention pond, the bedrock thins and the contaminants mainly move through gravel zones near the top of rock. Contaminants continue westward moving through the gravels to the airfield area where a prominent trough in the bedrock surface exists. This bedrock trough is nearly coincident with a trough in the potentiometric surface (fig. 1). This feature is believed to represent a zone of high permeability within the aquifer that is an important regional flow path (CH2M Hill, 1999, 2001; Haugh 2006). In the trough area, many different ground-water flow paths converge and mix. At the down gradient end of this trough is Big Spring at Rutledge Falls which has a steady discharge of about 3.3 cubic feet per second with an average TCE concentration of about 8 micrograms per liter (Williams and Farmer, 2003). Similar troughs in the potentiometric surface exist at other locations in the AAFB area (Haugh, 1996, 2006; ACS 2002; Robinson and others, 2005). In the conceptual flow model, ground water and contaminants move relatively slow through the gravels and bedrock under the retention pond and the gravels northwest of the retention pond and relatively rapid through the trough to Big Spring.

APPROACH

Environmental tracers, such as chlorofluorocarbons (CFCs), tritium (^3H), and sulfur-hexafloride (SF_6), can be used to trace the flow of ground water and to determine the time elapsed since recharge (Plummer and Friedman, 1999). Environmental tracers and numerical simulation in combination are effective tools that complement each other and provide a means to quantitatively estimate the flow rate and path of water moving through a ground-water system (Reilly and others, 1994).

To test the conceptual flow model and the ground-water flow rates implied by it, ground water samples were collected from 16 sites (15 wells and Big Springs) for age-dating. CFCs are a known minor contaminant in the plume, so the CFC technique could not be used for age-dating at this site. Ground water samples from all 16 of the sites were analyzed for SF_6 and ground water samples from 9 of the sites were analyzed for $^3H/^3He$.

Ground water ages also were estimated at each of the sampling sites using a recently updated digital flow model of the ground-water system at AAFB (Haugh, 2006). This model was constructed and calibrated using MODFLOW-2000 (Harbaugh and others, 2000) and incorporates the conceptual model of ground-water flow from the landfill to Big Spring. The model contains 4 layers. Layers 1 and 2 represent the regolith and layers 3 and 4 represent the bedrock. Ground-water ages were determined using MODPATH (Pollock, 1994) by placing 512 particles within model grid cells that represent each site and back tracking the particles to their recharge locations. The average travel time of the particles provides an estimate of the ground-water age at each site. Apparent ages from the ground-water samples and average particle-tracking travel times were then compared to evaluate the conceptual and digital flow models.

RESULTS

Eight of the samples analyzed for SF_6 where considered contaminated with SF_6 meaning the concentrations in the samples were greater than would be present from ambient atmospheric sources alone (table 1). Two highly contaminated samples (well 91 and 92) were located nearest the landfill. SF_6 and TCE concentrations are correlated (fig. 3). This correlation suggests that non-atmospheric SF_6 is present as a waste in the landfill and as a contaminant in the plume. Because of this, the apparent SF_6 age at any site that had detectable TCE is qualified as ‘greater than' the reported value. Age dates for these sites (468, 474, 604, and Big Spring) are believed to be biased young by SF_6 contamination. Apparent ages at the sites believed to be unaffected by SF_6 contamination range from 6 years at well 610 to 51 years at well 609 (table 1). All nine of the sites analyzed for $^3H/^3He$ resulted in valid ages. Apparent ages ranged from 19 years at well 92 to 38 years at Big Spring.

As a result of the SF_6 contamination at many of the sites, no sites had data for SF_6 and $^3H/^3He$ for direct comparison of apparent ages. Three sites (474, 604, and Big Spring) with 'greater than' qualified SF_6 ages also had $^3H/^3He$ ages. At each of these sites, the $^3H/^3He$ ages are 14 or more years greater than the qualified SF_6 ages suggesting that SF_6 ages at these sites are indeed biased young by contamination. Apparent ages of ground water from wells completed in the regolith generally are younger than wells completed in bedrock. Apparent ages from the regolith wells range from 6 to 34 years and apparent ages from the bedrock wells range from 12 to 51 years.

Average travel times at the 16 sites as determined by particle-tracking ranged from 6.4 years at well 504 to 43 years at Big Spring. Average particle-tracking travel times for wells completed in regolith ranged from 6.4 years at well 504 to 24 years at well 450. Average particle-tracking travel times for wells completed in rock ranged from 14 years at well 559 to 40 years at well 609. Big Spring had the longest average particle-tracking travel time at 43 years.

Generally, the apparent ages and average particle-tracking travel times agree reasonably well (table 1, fig 4). Of the 13 sites with an apparent age determination, 8 are within 5 years of the average particle-tracking travel time and 10 are within 8 years of the average particle-tracking travel times. Three sites have age differences of greater than 10 years; 471, 609, and 707. At well 609, the apparent age as determined by SF_6 is 51 years compared to an average particle-tracking travel time of 40 years. Because atmospheric SF_6 concentrations have only increased significantly during the last 30 years, SF_6 age dating is most useful for dating ground water recharged in the last 30 years. Therefore the SF_6 apparent age of 51 years in well 609 has a much higher degree of uncertainty than apparent ages less than 30 years. The uncertainty associated with the apparent age of 51 years may account for some of the differences with the travel time of 40 years.

Wells 471 and 707 have apparent ages that are 15 and 17 years older than average particle-tracking travel times. Both of these wells are screened in the regolith (model layer 2). The particle tracks have flow paths to the wells from layers 1 and 2 only. If these wells actually derived a significant portion of their water from flow paths from rock (layer 3), the particle--tracking ages would be greater. The apparent age of 34 years for water from well 707 is similar to the apparent ages from nearby wells completed in rock (well 305 and 645, table 1). Additionally, the bedrock thins up gradient of well 707, and the conceptual model includes flow paths that move from rock to regolith in this area. The digital flow model may not be adequately representing flow paths that move from rock (layer 3) to regolith (layer 2) in the area up gradient of well 707.

Analyzing the apparent ages and the particle tracks together, the wells can be divided into two groups. Flow paths for wells located outside the trough area are relatively narrow and extend up gradient towards a ground water divide (91, 92, 305, 645, 707, 504, 505, 471, 450, 609, and 610) (fig. 5). Where well pairs are completed in the regolith and rock, the flow paths to the rock wells are longer than flow paths to the regolith wells. Flow paths for wells located inside the trough integrate flow paths that originate over a broad area (468, 474, 559, and 604) (fig. 5). Flow paths to these wells have a much wider range of travel times as indicated by the maximum and minimum travel time (table 1). The mixing of ground water with differing flow paths make interpreting the apparent ages much more difficult.

Interpreting the apparent ages and flow paths together provides evidence to support the conceptual flow model from the landfill to Big Spring. The apparent ages determined for wells located between the landfill and the trough (91, 92, 305, 645, 707, and 450) increase down gradient and range from 19 to 34 years indicating relatively slow ground water movement. Further down gradient, the apparent age decreases in wells located in the trough (468, 474, 559, and 604) varying from 12 to 22 years indicating mixing in the trough area of the older ground water from the landfill with younger ground water from other flow paths. The apparent age of the water discharging at Big Spring is 38 years. Apparent ages for sites in the trough represent a mixed ground-water age due to the convergence of ground water from differing flow paths. However, the apparent ages generally agree with average particle-tracking travel times indicating the digital flow model adequately represents the mixing of differing flow paths in the trough. In the digital flow model, particles placed at the landfill that discharged to Big Spring have an average travel time of 46 years (Haugh, 2006). Additionally, particles placed in the area where the flow paths from the landfill enter the trough (near well 450) and tracked forward to Big Spring have travel times that range from 1 to 5 years with an average of 2 years (Haugh, 2006). These travel times indicate relatively slow ground-water velocities from the landfill to the trough and relatively fast ground-water velocities from the trough to Big Spring.

LIMITATIONS

Ground water age as determined by SF_6 or $^3H/^3He$ is qualified as apparent age because the determined age assumes the tracer moves conservatively with the water and does not take into account factors such as sorption, degradation, dispersion, diffusion, or mixing. All these factors can affect the apparent age. In this study, mixing may be the most important factor affecting ages. Since the atmospheric concentrations of SF_6 do not increase linearly through time a mixed age sample would show some bias. This is especially true when part of the mixture is older water (greater then 30 years).

The flow model is limited by the finite-difference discretization both aerially and vertically and cannot represent features finer than the model discretization. In the digital flow model, aquifer properties within a model cell are homogeneous and cannot represent the heterogeneities that may exist along a well screen. Additionally, in the particle-tracking analysis, particles are evenly distributed within the model cell that contains a well. For most of the regolith wells, the actual well screen extends over the full thickness of layer 2, so the particles occupy the same vertical interval in the model as the actual well screen. In most of the rock wells, the actual well screen only partially penetrates layer 3, layer 4, or both. But the particles in the model are distributed within the full thickness of whatever layer or layers the well screen penetrates. In cases where the well screen penetrates two layers, particles are distributed between the two layers roughly proportional to the flow in each layer. So for some of the rock wells, the particles are distributed in the model over a larger vertical interval than the actual well screen occupies. Therefore, the particle-tracking flow paths may contain shallower or deeper flow paths than the actual well screen would sample.

SUMMARY AND CONCLUSIONS

A conceptual model of ground-water flow from a landfill to Big Spring at Rutledge Falls was tested using ground-water age dating from environmental tracers and particle-tracking from a digital flow model. Apparent ground-water ages and average particle-tracking travel times generally agree well, supporting the conceptual model of ground-water flow from the landfill to Big Spring. Analyzing the apparent ground-water ages and particle flow paths together help interpret the apparent ages, particularly for wells that lie in the trough and draw water from differing flow paths.

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Table 1. Comparison between apparent ground-water age as determined by sulfur-hexafluoride and tritium/helium techniques and flow model travel times, in years

[SF_6, sulfur-hexafluoride; $^3H/^3He$, tritium/helium; HiC, highly contaminated; C, contaminated; --, no data]

		Apparent Age		Flow model particle travel times			Difference
Site	Zone	SF_6	$^3H/^3He$	Minimum	Average	Maximum	(Apparent age - average travel time)
91	Rock	HiC	--	19	30	160	--
92	Regolith	HiC	19	19	21	23	-2
305	Rock	C	33	21	33	72	0
450	Regolith	C	32	12	24	38	8
468	Rock	>15	--	1.1	29	316	--
471	Regolith	C	25	5.6	10	13	15
474	Regolith	> 9	22	1.5	17	38	5
504	Regolith	C	--	4.3	6.4	9.7	--
505	Rock	29	--	10	26	100	3
559	Rock	12	--	1.1	14	327	-2
604	Regolith	> 6	20	1.6	14	36	6
609	Rock	51	--	10	40	192	11
610	Regolith	6	--	5.6	8.6	17	-2.6
645	Rock	C	32	20	32	70	0
707	Regolith	C	34	12	17	26	17
Big Spring	Rock	> 6	38	1.4	43	201	-5

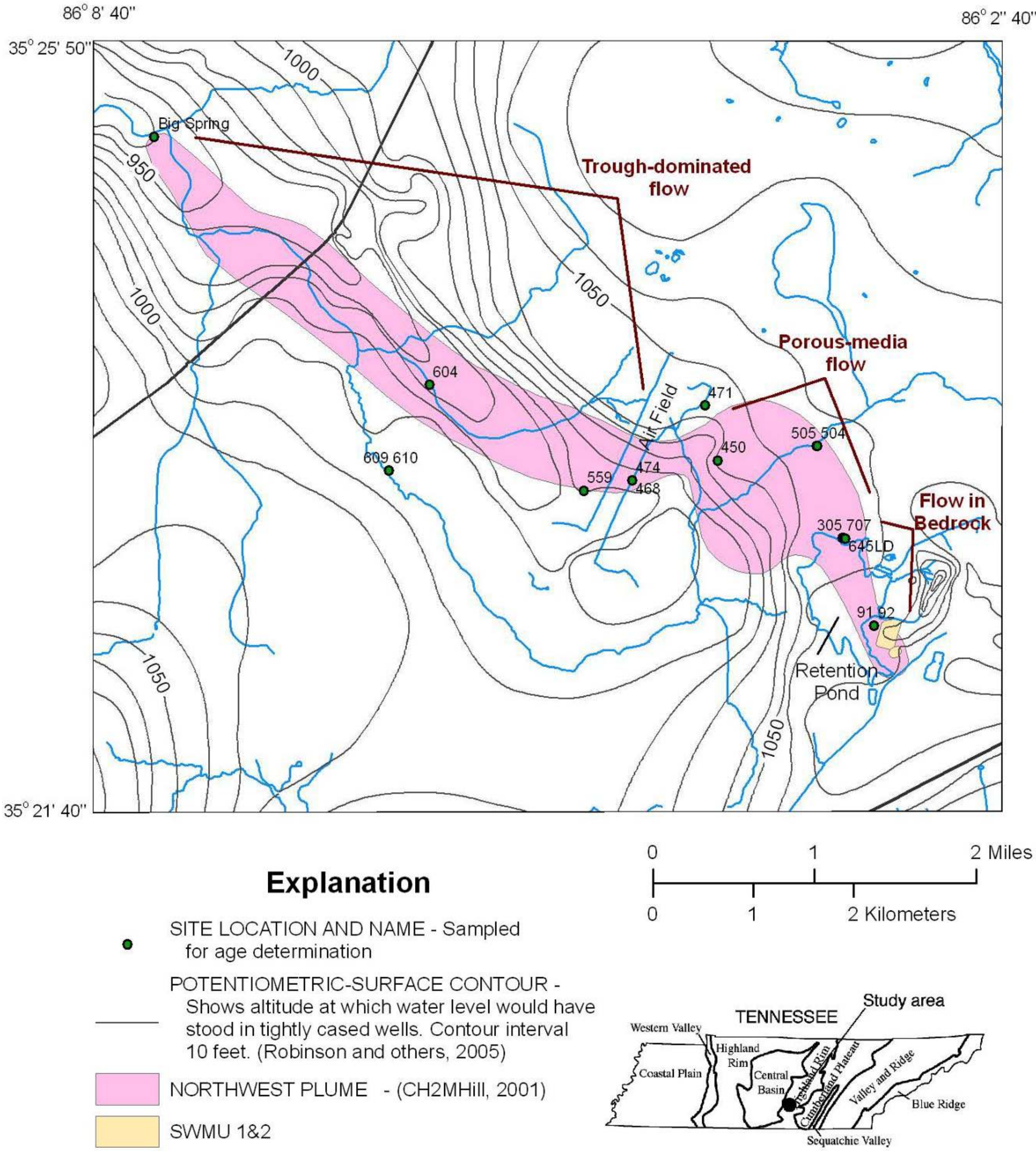

Figure 1. Location of study area and sampling sites.

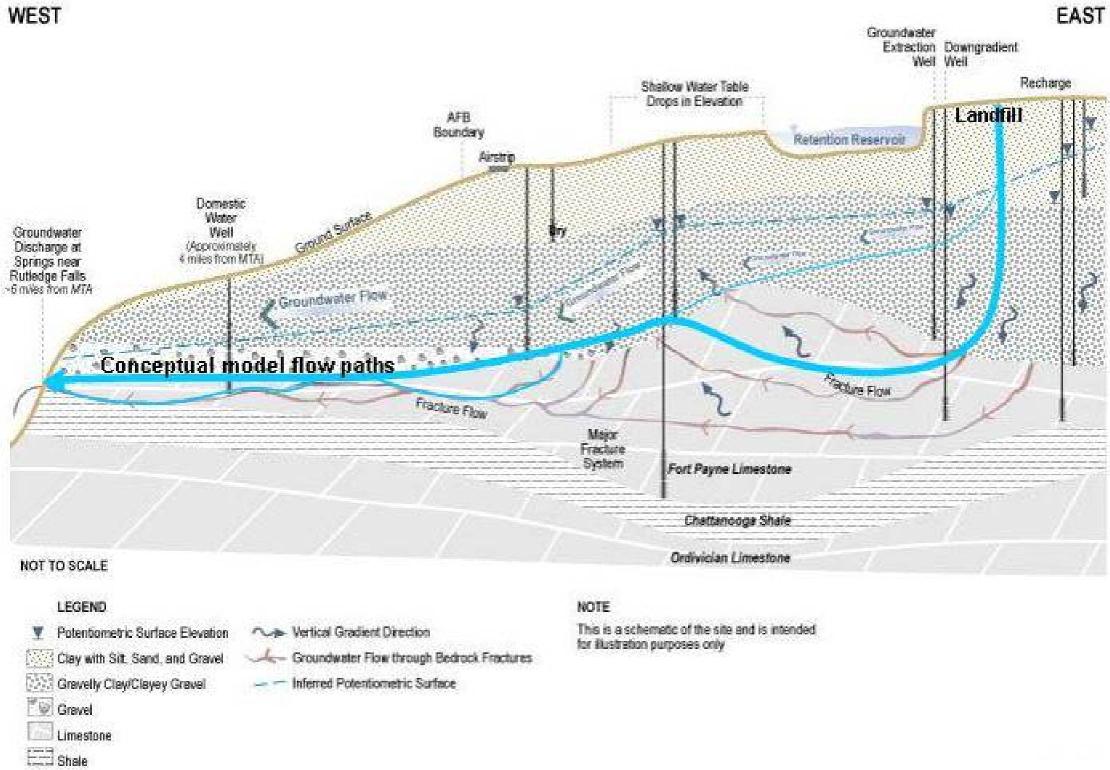

Figure 2. Cross section showing conceptual model of flow paths from the landfill to Big Spring at Rutledge Falls (modified from CH2MHill, 2001.

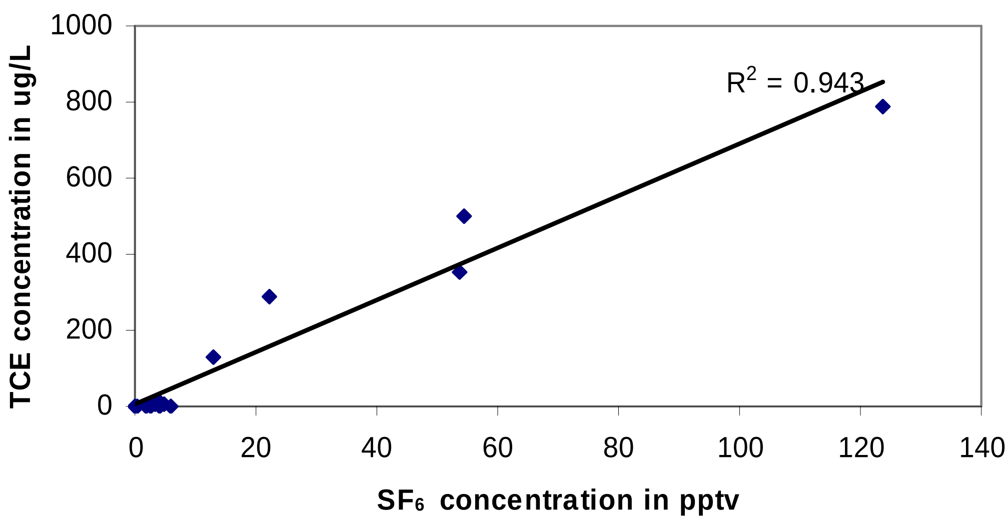

Figure 3. Plot showing relation between SF_6 and TCE concentrations.

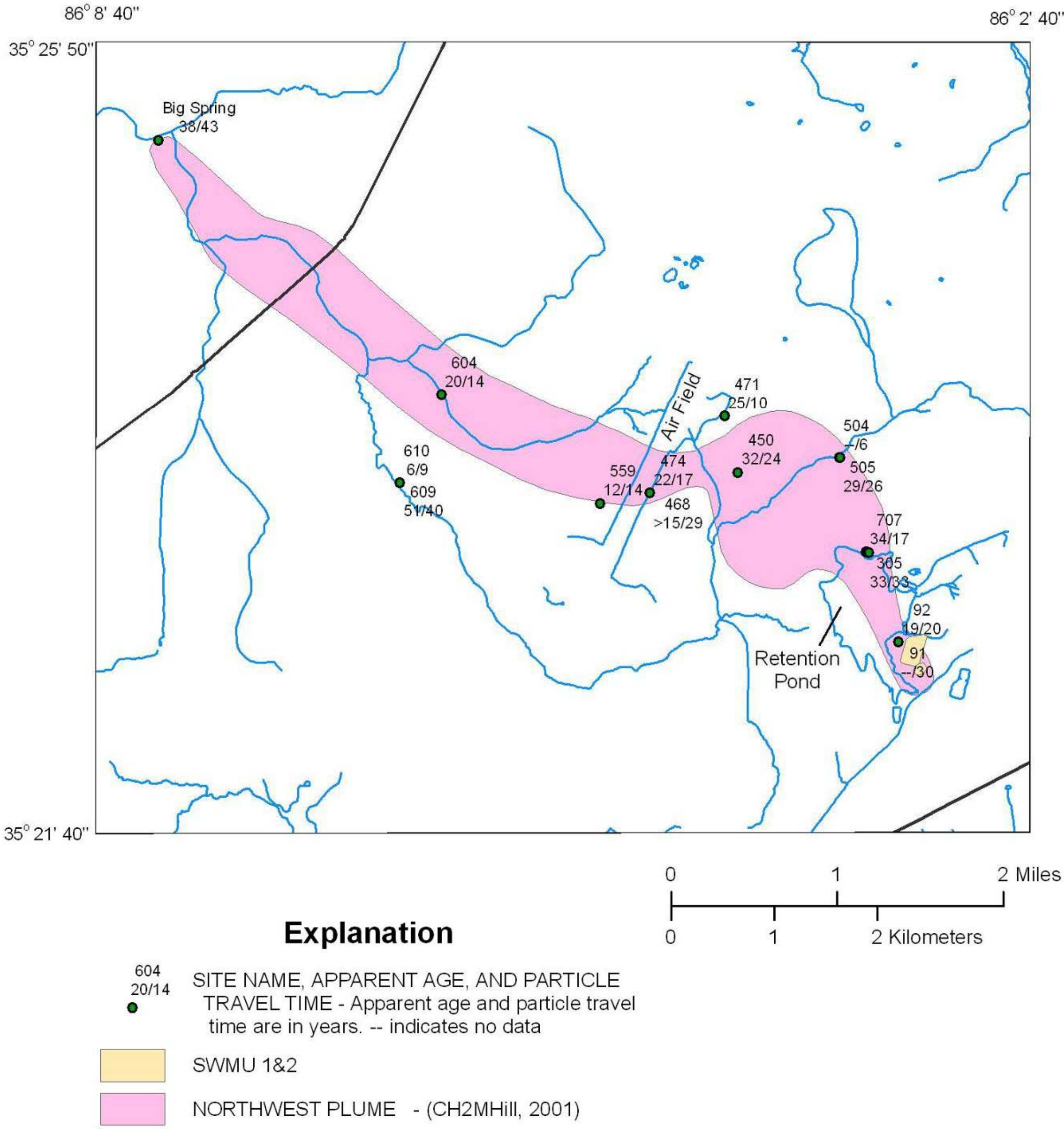

Figure 4. Apparent age and average particle-tracking travel times for sampled sites.

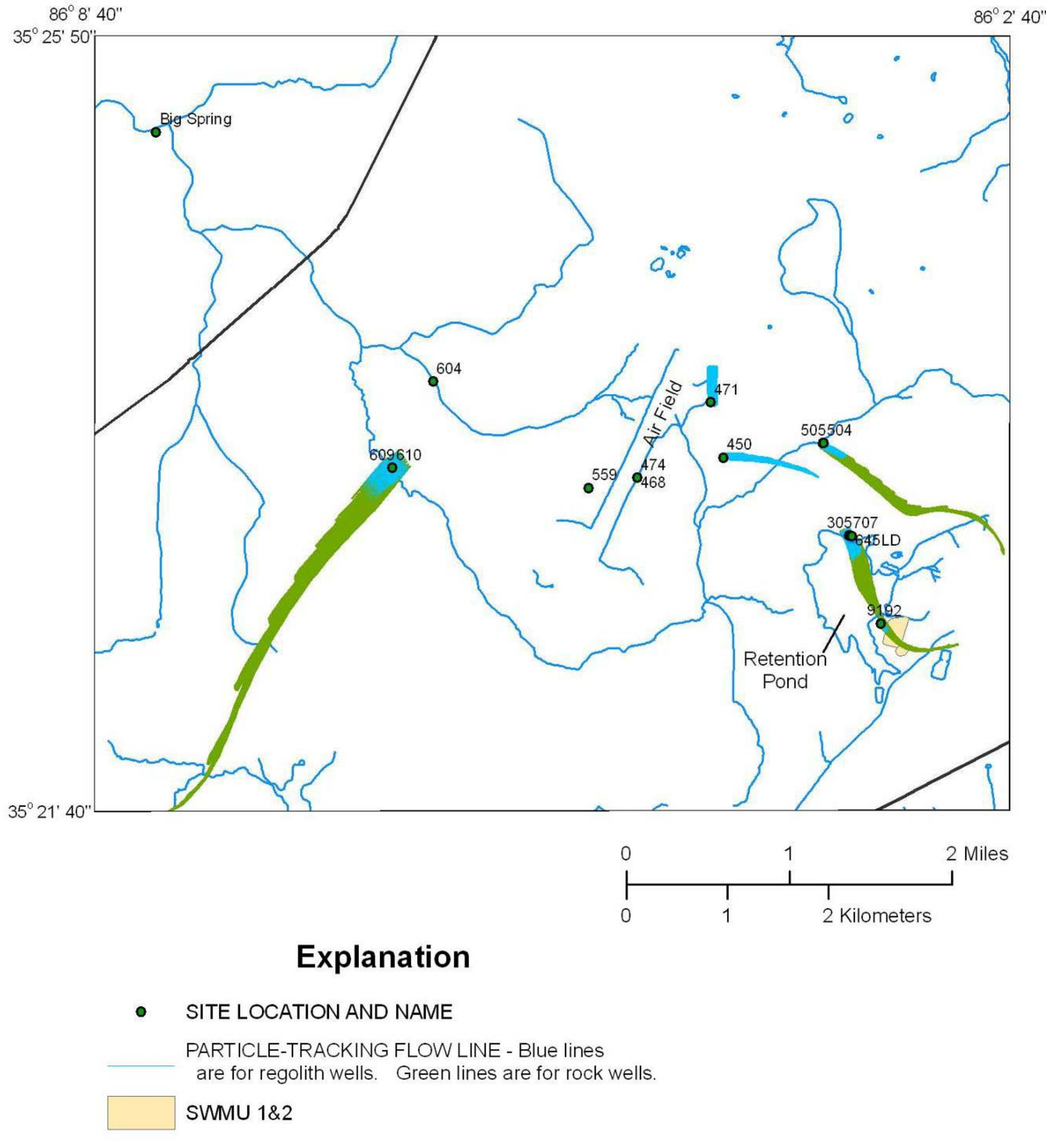

Figure 5. Flow path for wells sampled for age determination located outside trough area.

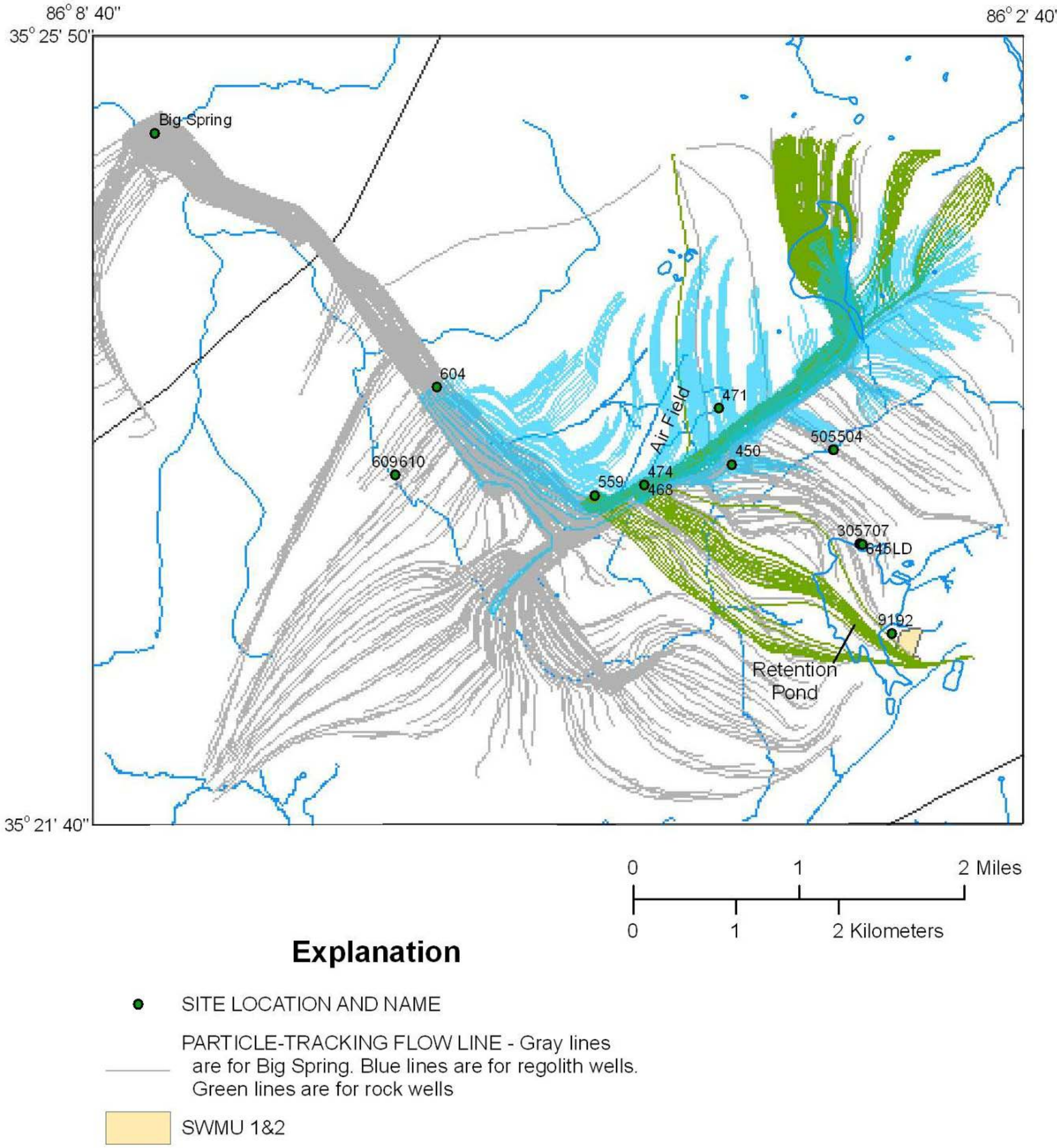

Figure 6. Flow path for sites sampled for age determination located inside trough area.

EVALUATION OF MULTI-LEVEL MONITORING WELL COMPLETION TECHNOLOGIES FOR KARST DOLOMITE

Todd Kafka[1], Duane Graves*[1], Peter Zeeb[2], Duane Wanty[3], and Steve Sacco[4]

As part of an environmental investigation of groundwater impacted with trichloroethene (TCE) and tetrachloroethene (PCE) in the Knox Group dolomite of the Valley and Ridge Province of Eastern Tennessee, seven core holes were advanced to depths ranging from 66 to 176 feet (20.1 to 53.6 meters) below ground surface. Karst features and fractured zones were encountered in each core hole and were found to intersect solvent-impacted groundwater at several depths. The cost and complexity of core hole advancement and challenges of traditional well completion discouraged the drilling of separate core holes to provide vertically discrete monitoring points. A multi-level monitoring system was sought to obtain reliable, depth-discrete groundwater samples from individual core holes.

This paper presents a comprehensive technical and economic review of commercially available multi-level well completion technologies to simplify the selection of a reliable and cost effective, multi-level completion method for karst sites. Several technologies permit the installation of multiple sampling intervals within a single borehole; however, these technologies were initially designed for application in competent bedrock or stable boreholes, and their applicability and functionality in karst formations are not well documented. Karst formations present substantial monitoring well completion challenges, especially when a single core hole spans several distinct zones of secondary porosity, such as micro-scale fracture networks and macro-scale voids. Designing a cost effective well completion strategy that isolates and reliably samples these features is a critical element of detailed environmental investigations in contaminated karst.

Five multi-level well technologies were critically evaluated with regard to site-specific requirements to select the best available technology for the site. Technologies considered included: the Westbay Multi-level Well System, the Solinst Waterloo Multi-Level System, the BarCad III System, Solinst Continuous Multi-channel Tubing (CMT), and the Water FLUTe system. Nesting of traditional small diameter wells was also included in the evaluation. Each technology was evaluated for the ability to isolate multiple sampling zones, ease of installation, requirements for sampling, sample quality, system durability/longevity, material and installation costs, sampling cost and complexity, and potential for repair. The Water FLUTe system was selected as the appropriate technology for monitoring groundwater in karst dolomite at this site for the following reasons: 1) the continuous core hole seal best addressed concerns of vertically isolating intervals without the use of inflatable packers or bentonite, 2) ease of sampling and low waste generation, 3) ease of installation, 4) ability to remove the system for repair or re-accessing the core hole, if necessary, and 5) an acceptable cost.

1Hydrogeologist and Principal, respectively, Geosyntec Consultants, 1351 Dick Lonas Road, Bldg. A, Knoxville, TN 37909, tkafka@geosyntec.com and dgraves@geosyntec.com.

2Principal, Geosyntec Consultants, 289 Great Road, Suite 105, Acton, MA 01720, pzeeb@geosyntec.com.

3Principal, Intensol, LLC, 180 Downer Avenue, Hingham, MA 02043, duane.wanty@comcast.net

4Vice President Environmental Health and Safety, Invensys Process Systems, Inc., 33 Commercial Street, C41-2E Foxboro, MA 02035, steve.sacco@invensys.com.

INTRODUCTION

Ground water monitoring well completion strategies and techniques are critical aspects of groundwater investigations since monitoring well design can dramatically influence data quality and usability. Therefore, reliable, reproducible, and durable well completions are essential. The ability to collect repetitive groundwater samples at multiple depths supports better interpretations of aquifer systems, contaminant distributions, and the performance of remediation programs. Several options are available for installing multi-level monitoring wells. Some multi-level monitoring systems employ traditional completion techniques, requiring multiple sand filter packs and bentonite seals installed in vertical succession, which can be a challenge even in predictable and relatively uncomplicated geologic environments. The added complexity of karst with its small-scale features (fractures and vugs) and large-scale features (cavities, voids, and caves) greatly complicates the installation of multi-level monitoring wells. Nevertheless, the prevalence of vertically stratified contaminants and secondary porosity features in karst aquifers makes multi-level monitoring wells valuable.

SITE SETTING

Multi-level well technologies were evaluated as part of an environmental investigation of chlorinated solvent-impacted groundwater at a former manufacturing plant located in an East Tennessee creek valley. The valley is underlain by the Chepultepec and Longview Dolomite formations of the Knox Group Dolomite. These formations have a northeast strike and dip to the southeast between 30-60 degrees. The bedrock surface ranges between zero and 32 feet (9.7 m) below ground surface (ft bgs) in a “pinnacle and cutter” pattern common in East Tennessee. Overlying soils consist primarily of a silty clay regolith and occasional alluvium.

During the site investigation, seven bedrock core holes were advanced through 6-inch steel surface casing set two to five feet into the uppermost zone of bedrock that appeared competent based on drilling observations. The core holes were advanced using a wire-line core rig equipped with a PQ-sized core bit (nominal 5-inch diameter) to depths between 66 and 176 ft (20.1 to 53.6 m) bgs. Multiple secondary porosity features were encountered in each core hole. Micro-scale karst features, such as fracture networks and vugs, were encountered at multiple depths at each location. Macro-scale karst features, such as cavities (less than one ft [0.30 m]), voids (one to six ft [0.30 to 1.8 m), and caves (six ft [1.8 m] or more), were encountered at multiple depths in five core holes. Drilling water was lost to the formation over nearly the entire depth of each core hole, providing a qualitative indication of overall bedrock permeability. Groundwater screening samples were obtained from the bottom few feet of the advancing corehole. The sample interval was isolated with an inflatable packer. Results indicated vertical stratification of chlorinated solvents in each corehole. Subsequent borehole flowmeter testing in four core holes indicated multiple flow zones.

Evaluating the potential continuity and connectivity of the flow zones at each location and the vertical distribution of chlorinated solvents requires multiple sampling intervals positioned at different depths. Because of access limitations within the creek valley, drilling multiple core holes at each location was cost-prohibitive and impractical. As a result, the installation of multi-level monitoring systems was evaluated. Selecting an appropriate multi-level monitoring system required determining which of the available methods provided the best overall value while still satisfying key investigation objectives and being applicable to karst.

The challenges of discrete, multi-level monitoring in a karst formation are readily apparent in Figure 1, an optical televiewer image (360° view) of the upper 90-ft interval in one corehole. Karst voids and fracture zones are the black zones in the image. Based on solvent screening samples and the vertical location of transmissive intervals, the 19-26 ft, 59-64 ft, 73-78 ft, and 85-

90 ft intervals were identified as targets for long-term monitoring. Thus, it was necessary to identify a multi-level monitoring system capable of being deployed in coreholes similar to the one shown in Figure 1.

TECHNOLOGY EVALUATION CRITERIA

Several criteria were considered during the evaluation of the commercially available methods. The criteria included:

1. **Customizable design** – Factors evaluated included the technology's degree of customization in design and sample collection, applicability to 5-inch diameter core holes, the pumping/water recovery system, and flexibility in design of monitoring intervals.
2. **Constructability and composition** – Considerations included the composition of material components (i.e., chemically inert materials), their durability, manufacturer warranties, and the ease and location of construction (i.e., the completeness of prefabrication and the amount of additional preparation required in the field).
3. **Installation quality and reliability** – The ability of the technology to form reliable well seals (bentonite, grout, or packers) with durable ports, the precision with which the system can be installed to design specifications, the system's reparability, and the need for manufacturer trained installation specialists were used to assess the quality of the finished well and the complexity of installation.
4. **Ease of use** -- This aspect considered the system's usability by field personnel for sampling and measuring water levels and the need for specialized tooling and equipment.
5. **Data quality** – The capacity of each system to provide groundwater samples and hydraulic head measurements that meet data quality objectives was evaluated based on manufacturer's specifications and past experience.
6. **Regulator acceptability –** Documented acceptance by regulatory agencies (federal and state) was essential since the technology must meet state regulatory approval and be accepted for use as a monitoring well.
7. **Long-term performance record** – This criterion attempted to evaluate the failure rate of each technology. Some of the technologies have been practiced for more than 20 years while others are less than 10 years old, complicating direct performance comparisons.
8. **Cost**– The total cost for each technology was determined using material, construction, installation, and sampling costs. Total costs were evaluated two different ways. First, the cost per technology to complete a hypothetical 100 feet (30.5 m) deep well with two sampling intervals was considered. Second, the actual project costs were compared based on estimates of actual well-specific requirements.

These criteria were evaluated for seven well installations with different completion requirements. Some of the technologies were suitable only for a subset of the wells.

TECHNOLOGY REVIEW AND EVALUATION

The six multi-level monitoring well technologies evaluated were:

1. Water FLUTe (FLUTe, LLC., www.flut.com);
2. BarCad System (BESST, INC., www.besstinc.com);
3. Continuous Multi-channel Tubing (CMT) System (Solinst Canada LTD., www.solinst.com);
4. Waterloo Multi-level System (Solinst Canada LTD., www.solinst.com) ;

5. Westbay Multi-level Well System (Model MP38) (Westbay Instruments INC., www.slb.com); and
6. A traditional single core hole well nest using 1-inch (2.5 centimeter) diameter well materials (conventional 2-in-1 nest).

A description of these technologies, their construction, and operation is not provided herein but may be found at the vendor web sites provided above. Technology documentation and specifications were gathered from manufacturer/vendor's web page, conversations with sales and technical representatives, and relevant databases (i.e., EPA's CLU-IN [http://www.clu-in.org/] and CLAIRE [http://www.claire.co.uk]). Each vendor was specifically queried regarding the technology's applicability to karst.

Based on these sources, an assessment of each technology relative to site-specific conditions and requirements was developed. The assessment included an evaluation of hypothetical costs to construct a 100 ft (30.5 m) multi-level monitoring well with two monitoring intervals and to conduct one sampling event. The results of this assessment are summarized in Table 1.

SITE SPECIFIC TECHNOLOGY SELECTION

As shown in Table 1, each of the technologies possessed positive attributes that would recommend them for appropriate site-specific applications. Each technology had disadvantages as well. Table 2 summarizes the monitoring requirements for each of the seven coreholes and the estimated site-specific costs for completion using each technology.

Using the combination of technical features and cost to complete, the Water FLUTe technology was ultimately selected as the best-value option for this site. The following considerations lead to the disqualification of the other technologies:

- The Solinst CMT, Solinst Waterloo, BarCad, and 2-in-1 nest systems were eliminated due to their incorporation of conventional well installation materials such as filter packs and bentonite seals for completion because of the difficulty of accurately emplacing these materials in a karst formation. The ability to verify a reliable installation of these systems was a great concern as was the long-term viability of the bentonite seals to maintain hydraulic separation between monitoring intervals. The CMT and Waterloo systems required the traditional well installation methods in order to address the non-standard 5-inch (12.7 cm) corehole diameter.
- The state regulator would not approve use of conventional nested small diameter wells (i.e., the 2-in-1 nest).
- The Westbay system was not recommended due to high installation and sampling costs, which did not justify, in this case, the system's high reliability and customization to corehole specifications.
- The BarCad was also disqualified from further consideration because only three monitoring zones can be installed in a 5-inch (12.7 cm) corehole.

The Water FLUTe was distinguished from the other technologies for use at this site based on the following features:

- multiple monitoring zones within a 5-inch (12.7 cm) core hole diameter;
- continuous seal against the borehole wall to isolate karst features without the use of packers or bentonite;
- easy installation;
- a simple sampling system with low sampling cost and minimal waste production;
- the capacity to collect groundwater samples and head data from each sampling interval; and

- the ability to remove the liner for repair or replacement, if necessary.

No other technology provided this combination of desirable features. Although the material and installation costs of the Water FLUTe ranked third highest of the technologies (Tables 1 and 2), it best addressed the complications associated with multi-level well construction in karst and provided the best overall value for the project.

Fig. 1 Optical televiewer image of 90-ft corehole in dolomitic bedrock (light intervals). Karst voids are shown as black intervals.

Table 1
Criteria Evaluation of Selected Multi-Level Monitoring Systems

	Customizable design	Constructability and composition	Installation quality and reliability	Ease of Use	Data Quality	Regulator acceptability	Long-term Performance Record	Cost[1]	Other
FLUTe	1. Number of ports limited by borehole diameter. 2. Standard sampling interval 5-ft but other options available. 3. No depth constraints for site coreholes.	1. Prefabrication requires temporary sealing of coreholes. 2. Polyurethane coated nylon liner, teflon and PVDF tubing and seals.	1. High accuracy between design and completion. 2. Unique corehole seal using hydrostatic pressure -- no packers or bentonite. 3. Simple and rapid installation without a drill rig; requires vendor-trained installers. 4. Liner susceptibility to tears from karst formations.	1. Dedicated simple nitrogen displacement pump with no moving parts; requires gas source and regulator. 2. Use of tubing for sampling and head measurement ports make field measurements more cumbersome due to lack of rigidity. 3. Capable of simultaneous multi-level purging.	1. Direct contact with formation allows no to low turbidity and no filter pack issues. 2. Closed system eliminates atmospheric contact with sample. 3. Simple low-flow purging techniques.	1. Limited in Tennessee (second application). 2. Increasing exposure at federal RCRA and CERCLA sites.	1. Limited; liner failure not occurred in material developed since 1999. 2. Urethane coating process found to leach low levels of arsenic and toluene, which usually decline over time. 3. Diffusion of contaminants through liner have been documented.	$ 6,573	1. Installation errors covered by vendor if installed by vendor. 2. Aquifer testing not practical on an installed system.
BarCad	1. No depth constraints for site coreholes. 2. Limited to 3 intervals in a 5-inch corehole. 3. Capable of 6-inch monitoring intervals.	1. Single rigid pipe. 2. Removable pumps available if repairs are projected. 3. Prefabrication requires temporary sealing of coreholes.	1. Inflatable straddle packers required for corehole seals; limited documentation provided for bedrock application. 2. Without use of packers, requires filter packs and bentonite seals. 3. Successful installation depends on the drilling subcontractor's skill and familiarity with the technology.	1. Dedicated, simple sampling system requiring gas source and regulator. 2. Maintenance free pumps with 30-year guarantee. 3. Capable of simultaneous multi-level purging.	1. Closed system eliminates atmospheric contact with sample. 2. Pre-pack sand around pump intake reduces fines.	1. No known applications in Tennessee.	1. 20-year performance record.	$ 6,280	1. Aquifer testing limited to slug tests using specially designed pressure transducers.

Table 1
Criteria Evaluation of Selected Multi-Level Monitoring Systems

	Customizable design	Constructability and composition	Installation quality and reliability	Ease of Use	Data Quality	Regulator acceptability	Long-term Performance Record	Cost[1]	Other
CMT	1. Capable of up to 7 monitoring intervals. 2. Highly discrete sampling intervals (6-inches) 3. Double-acting packers can only be installed in 5" corehole inside 4" diameter well screen/casing, which in turn is installed with filter packs and bentonite seals.	1. Onsite construction with directions; no need to temporarily seal coreholes. 2. Inert and environmentally acceptable components: HPDE tubing, stainless screen mesh and clamps, expandable dielrin and neoprene plugs to seal channels with no joints or connections.	1. Installation accuracy dependent upon skill of drilling subcontractor and flexibility (i.e., coiling) of tubing at time of installation. 2. If double-acting packers not used, installation requires filter packs and bentonite seals inside corehole. 3. Installation labor dependent upon number of ports required.	1. Minimal purge volume of 40 milliliters per foot of channel. 2. Small tubing apertures require peristaltic pump or mini-inertial lift pump if water level is below ~25 ft.	1. High integrity and quality of samples due to continuous tubing design, mesh screens, and optional filter pack. 2. Small port volumes not ideal for some analytical methods.	1. An increasingly visible and acceptable technology in the regulatory community.	1. Limited to late 1990s.	$ 4,909	1. Low material costs per port. 2. Low yield aquifer testing is possible if two channels used per monitoring zone (one for pumping and one for monitoring head). 3. Tubing supplied in 100', 200', and 300' lengths.
Waterloo	1. Three monitoring options -- sample only, head only, or both. 2. Designed for 3" and 4" coreholes -- cannot be used in a 5" corehole without filter packs and bentonite seals. 3. 3 types of packers: permanent, removable, and bentonite filled. 4. Dedicated pumps available.	1. Inert and environmentally acceptable components such as PVC or stainless steel ports, Kevlar/rubber packers, and nylon or Teflon tubing.	1. Constructed to specification in the field, limiting the potential for cross contamination within open boreholes. 2. Installation ease not well known or predictable in karst environment. 3. Construction and installation requires 3-4 person team trained by Solinst without use of a drill rig.	1. Specialized equipment is available for sampling, but is not required. 2. Use of tubing for sampling and head measurement ports make field measurements more cumbersome due to lack of rigidity. 3. Dedicated pumps permit simultaneous sampling of all intervals.	1. Closed system eliminates atmospheric contact with sample.	1. The technology has been used frequently at RCRA and CERCLA sites under substantial regulatory scrutiny.	1. 20-year operational history for performance evaluation.	$ 8,184	1. Double and single valve pneumatic pumps are an available option for sampling deeper groundwater.

Table 1
Criteria Evaluation of Selected Multi-Level Monitoring Systems

	Customizable design	Constructability and composition	Installation quality and reliability	Ease of Use	Data Quality	Regulator acceptability	Long-term Performance Record	Cost[1]	Other
Westbay (MP38)	1. Highly flexible design with no mechanical restrictions on number of intervals.		1. High degree of accuracy between design specifications and completed system; drill rig required for installation.	1. No dedicated pumps.	1. Closed system eliminates atmospheric contact with sample.	1. Successful applications at the Oak Ridge DOE Reservation in a similar geologic setting.			1. Capable of low and high yield aquifer testing.
	2. Multiple packer styles (i.e., normal or stiffened) are available for various pressure differentials and applications.		2. Ease of installation is highly dependent upon skill and experience of certified drilling subcontractor						2. Installation requires Westbay certified subcontractor or oversight by Westbay personnel.
	3. MP38 in situ data collection includes pressure and temperature.	1. Inert and environmentally acceptable components: PVC, stainless steel, Teflon, Viton, Iconel, ceramics, ABS, Buna, polyurethane, and Kevlar.	3. Use of inflatable packers for sealing monitoring intervals requires zones of competent bedrock.	2. Sophistication of system requires onsite training (lump sum cost) of future users by Westbay for use of specialized sampling tools.	2. Ability to obtain insitu data such as temperature and pressure with high accuracy.	2. Numerous high profile applications across US with substantial regulatory approval.	1. Ability to test system integrity throughout its operational life is unmatched by the other technologies.	$ 11,040	3. High sampling costs -- specialized sampling tools rent for $1,700/week or $22,700 for purchase.
			4. The system relies on the long-term effectiveness of inflatable packers, which cannot be repaired.						4. Expensive for shallow applications. The Westbay system is generally considered more cost-effective for deep installations (several hundred feet deep).
2-in-1	1. 5" coreholes limited to 2-3 sampling intervals using 1" diameter well materials.	1. Inert PVC or stainless steel.	1. Technique familiar to drilling subcontractors				1. Durable over long-periods		
	2. Interval lengths based on standard screen lengths (2.5 ft or more)	2. Field construction eliminates cross contamination concerns in open coreholes.	2. Reliability dependent upon seal integrity in karst.	1. Small diameter reduces pump options, particularly if water levels exceed 25 ft and peristaltic pump eliminated.	1. Sample representativeness often questioned with 1" diameter well materials.	1. 1" wells not approved by state regulators.	2. Prone to well fouling over time.	$4,580	1. Capable of low-yield aquifer testing.
			3. Ease of installation dependent upon skill of drilling subcontractor and extent of karst voids.						

Notes:
[1] - 2005 cost for a 2-sampling interval system, 100-ft total depth, and one sampling event.
PVDF Polyvinylidene fluoride

Table 2. Site-Specific Corehole Monitoring Requirements and Estimated Costs

Location	Total Depth in feet (m)	Screened Intervals	2-in-1 nest	Water FLUTe	CMT	BarCad	Waterloo	Westbay MP38
1	106 (32.3)	2	$4,650	$7,060	$5,480	$6,280	$8,200[a]	$9,680
2	66 (20.1)	2	$4,200	$5,770	$4,710	$6,280	NA	$9,680
3	116 (35.4)	4	NA[b]	$10,360	$6,430	$12,560	NA	$12,880
4	101 (30.8)	4	NA	$9,800	$8,880	$12,560	NA	$12,880
5	180 (54.9)	3	$8,440	$10,340	$8,190	$9,890	NA	$13,880
6	160 (48.8)	3	$6,600	$10,250	$5,930	$9,890	NA	$13,880
7	68 (20.7)	2	$5,000	$6,000	$4,750	$6,280	NA	$9,680
Total			$28,890	$59,580	$44,370	$63,740	$8,200	$82,560

[a]The Waterloo system was applicable to for only one borehole that had a six-inch diameter. The rest of the boreholes were five inches (12.7 cm) in diameter.
[b]NA, not applicable for specific borehole characteristics or number of sampling intervals.

UTILITY OF TRACERS IN MODELING GROUND-WATER FLOW IN THE SHEAHAN WELLFIELD COMPLICATED BY INTER-AQUIFER LEAKAGE OWING TO AQUITARD BREACHES

Brian Waldron[1]*, Dan Larsen[2], Jason Morat[3]

The Memphis Light, Gas and Water (MLGW) Sheahan wellfield was modeled using the USGS MODFLOW package within the pre-/post-processor Groundwater Modeling Software (GMS) program. The shallow aquifer (Quaternary), Upper Claiborne confining clay, and the Memphis aquifer (Lower Claiborne) units are modeled explicitly using the MODLFOW LPF package. The MODFLOW grid is 53 rows by 69 columns with regular grid spacing of 500 ft. Two suggested aquitard breach locations in close proximity to the Sheahan wellfield were simulated for comparison reasons. Particle tracking was performed for selected wells for which H^3/He^3 was measured and ground-water ages were calculated. Particle tracking was also performed for flow from the two aquitard breaches. Of the five wells having H^3/He^3 information, wells 78, 87 and 88 had "young" ground-water ages. Only well 87 through particle tracking indicated contribution from the two aquitard breach locations within the wellfield. Capture zones for wells 78 and 88 deviated away from the suggested breach locations. Drainage patterns calculated for the top of the Upper Claiborne unit provide plausible erosional scaring from the deposition of the fluvial/alluvial sands and gravels that comprise the shallow aquifer. This possible paleo-erosional map compliments the young water being received by well 88, but does not corroborate the young water observed in well 78.

1 Associate Director, University of Memphis Ground Water Institute, 301 EA Bldg., Memphis, TN 38152, bwaldron@memphis.edu, 901.678.3913

2 Associate Professor, University of Memphis Dept. of Earth Sciences, 001 Johnson Hall, Memphis, TN 38152, dlarsen@memphis.edu, 901.678.4358

3 Master's student, University of Memphis Dept. of Earth Sciences, 001 Johnson Hall, Memphis, TN 38152, jmorat@memphis.edu

DUAL TRACERS USED TO EVALUATE SEEPAGE IN A NATURAL WETLAND

Duane Graves, Ph.D.*[1], Emily Majcher, P.E.[2], and Michelle Lorah, Ph.D.[2]

Two innovative remediation technologies were planned for the treatment of groundwater containing high concentrations of chlorinated solvents (over 30 mg/L of chlorinated ethanes, ethenes, and methanes). The contaminated groundwater was detected in high velocity groundwater seep areas in a natural wetland. Both technologies considered for the seep areas employed electron donor addition and bioaugmentation for reductive dechlorination. However, before the remedial designs could be finalized, hydraulic characteristics of the seeps required better definition. Therefore, a dual tracer test using FWT Red (a red dye approved for use in drinking water) and bromide ions was devised to assess key seep area characteristics affecting the engineering design of the remediation technologies. These characteristics included:
the mechanism of flow in the seep area—conduit or diffuse;
the flow path of water within the seep area;
and the retention time of water from entry into the wetland sediments from the underlying aquifer to exit at the wetland surface, i.e., seepage velocity.

The tracer test was designed using the Efficient Hydrologic Tracer-Test Design (EHTD) program (US EPA, 2003). The dye tracer assessed preferential water flow that would result in rapid breakthrough of the dye at the surface. The bromide tracer evaluated diffuse flow through the sediment. Following injection of both tracers into the wetland seep area, FWT Red transport was assessed by visual examination of the surface of the seep area while bromide was measured in depth-discrete groundwater samples using an ion selective electrode. The test was designed to evaluate five potential groundwater flow scenarios in the wetland (Figure 1)

The results demonstrated that movement of groundwater through the seep area occurred by diffuse flow rather than rapid transport through preferential flow paths since red dye was not detected at the surface. Bromide slowly migrated away and upward from the injection points. In addition to the dominant upward gradient, a slight horizontal flow to the southeast was also detected in the movement of the bromide tracer (Figure 2). Comparison of modeled breakthrough curves and field measured bromide distribution improved the estimate of groundwater seepage velocity through wetland sediments. The retention time from groundwater entry into wetland sediment to expression at the surface was shown by bromide movement to be 70 days. Tracer test results supported the design of in situ bioaugmentation, groundwater remediation systems.

1Principal, Geosyntec Consultants, Knoxville, Tennessee 37909; dgraves@geosyntec.com

2Engineer and Hydrologist, respectively, US Geological Survey, Maryland-Delaware-DC Water Science Center, 8987 Yellow Brick Road, Baltimore, MD 21237; ehmajche@usgs.gov and mmlorah@usgs.gov.

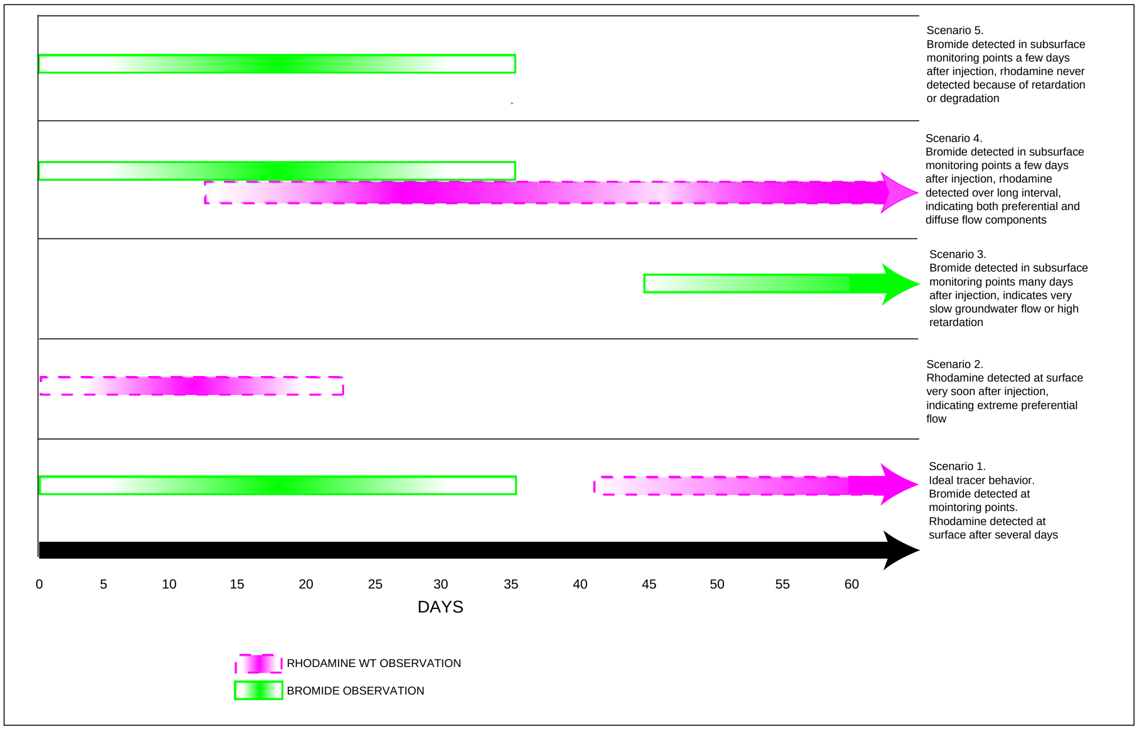

Figure 1. Potential flow scenarios in wetland seep area evaluated by dual tracer test.

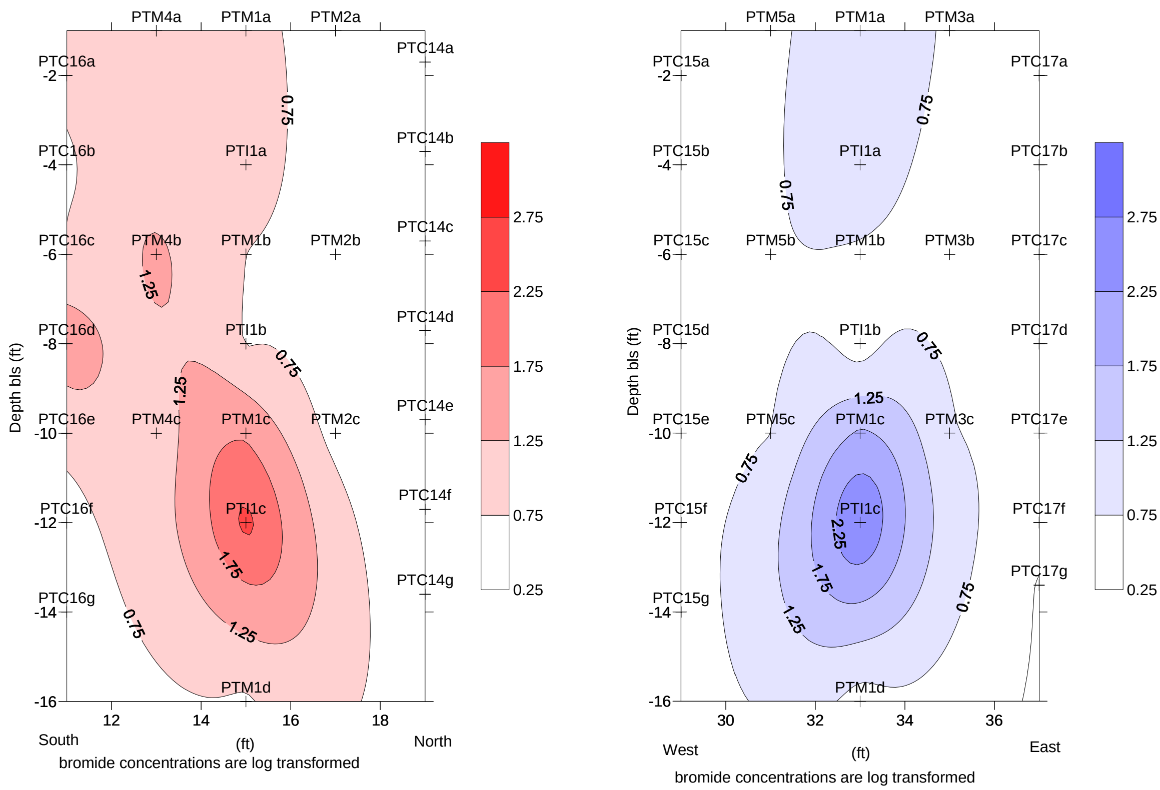

Figure 2. Distribution of bromide tracer eight days after injection at location PTI1c.

ORGANIC FLUOROPHORES IN DRINKING WATER; IMPLICATIONS FOR DYE TRACING AND SOURCE CHARACTERIZATION

Terri Brown[1*], Larry McKay[2], John McCarthy[3], Jie Zhuang[4], and Randy Gentry[5]

Dye tracing for delineating groundwater flow paths and source water protection areas (SWPA) is often underutilized due to concern about the potential for visible color changes in drinking water supplies, streams and springs. This issue could be addressed through the use of low concentration dye solutions, but must be based on better information about background sources of fluorescence, such as fluorescent dissolved organic matter (FDOM). Previous studies of aquatic systems ranging from marine to freshwater have found it possible to differentiate between fluorophores of natural and manmade origin based on their specific spectrometric properties and variations. Naturally-occurring FDOM is ubiquitous and difficult to characterize, consisting of humic and fulvic substances as well as proteins derived from the microbial breakdown and degradation of leaf litter and other organic matter. In infiltrating groundwater, humic substances tend to be detained in the epikarstic zone due to selective adsorption onto clays and calcium carbonate particles, and subsequent precipitation. Therefore, during most of the year, the more mobile, lower molecular weight fulvic substances tend to dominate FDOM in groundwaters.

This study combines the measurement of optical properties and total organic carbon (TOC) to describe the background fluorescent properties of approximately 20 public groundwater supply sources in East Tennessee. Trend analysis and excitation-emission matrices (EEM) are used to provide a snapshot of spatial and temporal variability of FDOM in karst aquifers of the Valley and Ridge. In general, wavelength variations in the fluorescence of fulvic-like substances vary with season and source, with the most important factors governing background fluorescence being depth/type of soils and vegetative cover. Inferences about land use and nonpoint source pollution can also be derived from an examination of FDOM spectra.

When evaluated in combination with water chemistry, rainfall, soils, land use and geologic information, FDOM fingerprinting provide sensitive indices of aquifer vulnerability and may signal long-term water quality trends. Lab work is being followed up with field tests of low level dye injections in typical karst aquifers to evaluate the feasibility of using FDOM fingerprinting in conjunction with low concentration dye tracing to delineate SWPAs.

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1 Hydrogeology Masters student, University of Tennessee, 306 Earth and Planetary Sciences, 1412 Circle Drive, Knoxville TN 37996-1410 tbrown23@utk.edu

2 Professor of Hydrogeology, University of Tennessee, 306 Earth and Planetary Sciences, 1412 Circle Drive, Knoxville TN 37996-1410 lmckay@utk.edu

3 Research Professor, Research Center of Excellence for Biotechnology, University of Tennessee, 676 Dabney-Buehler Hall, 1416 Circle Drive, Knoxville TN 37996-1605 jmccart1@utk.edu

4 Assistant Professor, Research Center of Excellence for Biotechnology, University of Tennessee, 676 Dabney-Buehler Hall, 1416 Circle Drive, Knoxville TN 37996-1605 jzhuang@utk.edu

5 Assistant Professor, Director, Southeastern Water Resources Institute, University of Tennessee, Department of Civil and Environmental Engineering, 62 Perkins Hall, Knoxville TN 37996-2010 rgentry@utk.edu

DESIGN COST-EFFECTIVE TRACER TESTS TO QUANTIFY SURFACE AND GROUND WATER FLOW AND CONTAMINANT TRANSPORT IN KARST AREAS, NORTHEASTERN TENNESSEE

Yongli Gao*[1]

Tracer test is a fundamental tool for measuring flow velocities in the rapid flow portions of karst aquifers. Fluorescent dyes have been widely used to trace flow velocities in karst aquifers. In addition to flow velocities, tracers can yield important information about the mass balance of solutes in groundwater and surface water and the nature of the subsurface flow path. However, dye tracing can be ineffective and expensive if not designed properly. This paper presents an example of dye tracing conducted in Watauga watershed, northeastern Tennessee. The tracer test was designed based on a field inventory of springs, caves, wells, sinkholes and other features such as sinking streams found in the study area. Field observations, in-situ flow measurements, and salt tracing methods were used to estimate flow velocity and discharge in the creek and groundwater conduits. The tracer test was proved to be successful using a very small amount of fluorescent dyes. The single, narrow, asymmetric breakthrough curve of this tracer test revels that this is a dendritic conduit flow system under normal flow condition.

1 Department of Physics, Astronomy, and Geology, Box 70652, East Tennessee State University, Johnson City, TN 37614, gaoy@etsu.edu

KARST HYDROLOGY AND THE INTERPRETATION OF NEGATIVE RESULTS IN TRACING TESTS: A THEORETICAL PERSPECTIVE

Barry F. Beck, Wanfang Zhou, Arthur J. Pettit, Ramona C. Josefczyk, and Jie Wang

Groundwater tracing is a commonly used diagnostic tool in karst investigations. The overall purpose of any tracer test is to maximize the "detection power" while minimizing both the false negative and false positive detection rates. A hydrologic connection between the injection and monitoring sites can be established by a positive detection of the tracer at the monitoring location. A properly and carefully designed tracer test can also provide insightful information on the structure of the karst aquifer and the characteristics of the ground water flow and contaminant transport therein. However, tracing tests are used mainly to investigate the unknowns and/or uncertainties. Negative detections occur, and interpretation of the negative detections has plagued this valuable technique since 1869. Many investigators discredit negative detections and interpret only the positive data. This is partially because there are many sources of false negatives. The interpretation of negative detections in tracing tests is usually more challenging than interpretation of positive results, but it can be valuable. For instance a positive trace conducted in Knoxville, Tennessee in 2002 from a sinkhole to a spring was negative at nearby residential wells. The initial interpretation was that the flow did not go to the wells. However, this interpretation did not take into account the dynamic nature of the karst aquifer, the location of the wells in the multi-porosity aquifer, the structure of the wells, and the way in which the tracer test was performed. The trace was performed in the dry season when the aquifer was recharging the conduit that might connect the sinkhole and the spring. If the trace had been run during a major precipitation event, when sinkholes were backflooding and the conduit was recharging the karstic aquifer, the results might have been different. Appropriate interpretation of negative results requires an understanding of the uniqueness of the karst aquifer and the conduit drainage system and knowledge of a proper tracer test design.

P.E. LaMoreaux & Associates, Inc., 106 Administration Road, Ste. 4, Oak Ridge, TN 37830, Tel: (865) 483-7483, Email: info@pela-tenn.com

SESSION 2B

WATERSHED STUDIES I
8:30 a.m. – 10:00 a.m.

Watershed Plan Development: Lessons Learned in Beaver Creek "The Good, The Bad, and the Ugly"
Roy A. Arthur and Ruth Anne Hanahan

Volunteer Stream Bank Erosion Study: So How Much Sediment Does Bank Erosion Generate?
John McFadden

Managing Nonpoint Source Pollution at the Landscape-Scale: Experiences from Pond Creek Water Quality Improvement Project 2001 to 2006
Forbes Walker, Lena Beth Carmichael, and Jonathan Hagen

WATERSHED STUDIES II
10:30 a.m. – 12:00 p.m.

HEC-RAS Modeling of Dam Break Scenarios
Gregory H. Nail

Hydrologic Analysis of the Obed River Watershed, Cumberland Plateau Physiographic Province, Tennessee
George S. Law

Climate Change in East Tennessee or a "Cool" Place to Look for Global Warming-Evaluating Stream Thermal Variation for Protection of East Tennessee Coldwater Fishery Regimes
Robert C. Benfield

URBAN WATERSHED PLANNING I
1:30 p.m. – 3:00 p.m.

Decentralized Wastewater Treatment in Tennessee: Where Are We and Where Are We Going?
Edward M. Polk and Robert G. O'Dette

Evaluating Management Needs in Water Resources and Spill Response Activities
Janey Smith, Mark D. Abkowitz, and Eugene J. LeBoeuf

Examining the Impacts of Urbanization on Hydrologic Response for the Ensor Sink Watershed, Cookeville, TN
Britton D. Wells and Vincent S. Neary

URBAN WATERSHED PLANNING II
3:30 p.m. – 5:00 p.m.

Headwaters of the Harpeth River: Water Quality and Habitat Study
Mike Cain and John McFadden

A Rational Approach to Predicting the Impact of Water Withdrawal on Watershed Water Quality
Scott Woodard, Art Newby, Edward Thackston, and David Parker

Economic Criteria for Regional Water Supply Planning in Tennessee
William W. Wade

WATERSHED PLAN DEVELOPMENT: LESSONS LEARNED IN BEAVER CREEK "THE GOOD, THE BAD AND THE UGLY"

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

PURPOSE

In 2006, the Beaver Creek Task Force completed a watershed restoration plan for the Beaver Creek Watershed (HUC TN-06010207-011). The Task Force, formed in 1998, is comprised of 19 agencies, utilities, institutions, and non-profits, its mission to protect and restore the health of Beaver Creek. The development of the plan was unquestionably a tremendous learning experience for Task Force members. The purpose of this paper is to share our lessons learned: "the good, the bad and the ugly."

BACKGROUND

The Beaver Creek Watershed is located in the 630-square-mile Lower Clinch River Watershed, covering 86 square miles in the northern portion of Knox County. The main stem of Beaver Creek is 44 miles long and flows through five different communities before emptying into the Clinch River. The watershed is rapidly urbanizing with a current population of approximately 75,000 residents and a projected one of 108,000 by the year 2030, an increase of 45%.

Nearly all of Beaver Creek and its major tributaries are on the State of Tennessee's 303(d) list of impaired streams. Causes of impairment include phosphorus, nitrates, *E. coli*, low dissolved oxygen, loss of biological integrity due to siltation, and physical substrate habitat alteration. Pollution sources include major municipal point sources, pasture grazing, and discharges from Knox County's NPDES-permitted Municipal Separate Storm Sewer System (MS4). The Tennessee Department of Environment and Conservation (TDEC) developed and US Environmental Protection Agency (EPA) approved Total Maximum Daily Loads (TMDLs) for siltation and habitat alteration and pathogens for the Lower Clinch River Watershed. The primary impacts addressed by the restoration plan are siltation and habitat alteration.

The Beaver Creek Restoration Plan was developed over an 18 month period, with funds provided by TDEC through a 604(b) grant. The process used to develop the plan followed the steps described in the new US EPA *Handbook for Developing Watershed Plans to Restore and Protect our Water* (EPA841-B-05-005). Its content encompasses the nine elements required by the US EPA Section 319 Nonpoint Management Program.

LESSONS LEARNED

The development of the Beaver Creek Restoration Plan offered the Task Force an opportunity to evaluate our strengths and limitations in light of the challenges associated with taking on such a

1Watershed Coordinator, Knox County Department of Engineering and Public Works, Stormwater Management Division, 205 West Baxter Avenue, Knoxville, TN 37917, Rarthurroy@aol.com

2 Senior Research Associate, TN Water Resources Research Center, University of Tennessee, 311 Conference Center, Knoxville, TN 37996, rhanahan@utk.edu

project. We have categorized these experiences ("learning opportunities") under four primary areas:

- Partnerships
- Administrative Considerations
- Public Participation
- Technical Challenges

Under each, we were exposed to the potential "good" and "bad" aspects of developing a watershed restoration plan. The "ugly" we define as that which we simply can not control – those circumstances that at times "just happen." Following is an overview of each issue and the lessons we took away from each.

Partnerships

An initial step in the development of a watershed restoration plan is determining who will be involved in its development. This involves evaluating community resources including agencies and organizations that may have a stake in developing the plan and that also have the time and skills to do the work. One option, if resources (e.g., research capabilities) are not available within a community to develop a plan, is to contract the work to an outside consulting firm. Another option, if it is felt local resources are available, is to do it in "in-house." The Task Force opted for the later.

The basis for this decision was three-fold. First, among the agencies, institutions, utilities and nonprofits involved in the Task Force, we have a wide range and breadth of watershed-based project experience. Second, the Task Force includes academic institutions as well as agencies that have and continue to conduct water quality-related research in the Beaver Creek Watershed. We felt our familiarity with the watershed and its communities would give us an advantage in evaluating each of the strategies in terms of its potential for success. Third, we recognized that it will be us -- the Task Force members -- who will ultimately be implementing the restoration strategies set forth in the plan and thus it is well worth our effort to develop the plan ourselves.

That being said, the Beaver Creek Task Force involves numerous agencies and organizations, each with their own mission and goals and professional styles of presenting information and data. In order to provide a more cohesive voice to the plan, we opted to hire a plan writer with the responsibility for compiling data and information provided by our diverse set of partners and synthesizing it into a functional and uniform document.

Lessons learned about partnerships:

- **The Good:**
    - Partners are more willing to make substantive contributions to the watershed restoration plan when responsibilities and costs are spread among multiple parties.
    - Diversity of academic and work experiences among partners can lead to innovative ideas and solutions.
    - Unforeseen knowledge and skills will surface in partnerships comprised of diverse institutions and individuals.
    - Local knowledge of a watershed -- its ecology as well as its communities -- can lead to more pragmatic implementation strategies.

- **The Bad:**
    - Individual partner missions and goals influence the level of priority that is given to the development of the restoration plan.

    - The greater the number of partners, the greater the potential for the project to become unwieldy. This may lead to disorganization if not properly managed.
    - Additional resources may be needed to reduce the overall work load on already overtaxed partners.

- **The Ugly:**
    - Conflicts related to professional and personal agendas among partners are inevitable in a project involving a diversity of agencies, organizations, and institutions. These conflicts may disrupt the progress of the project, if not managed carefully.

Administrative Considerations

The Task Force's administrative structure was fully utilized throughout the development of the restoration plan. This included a five-member Executive Committee that oversees its day to day operations and two standing committees, a Technical Committee charged with oversight of the science necessary to develop the plan and an Education/Outreach Committee with the responsibility for developing and executing the programs necessary to promote watershed restoration. Ad hoc committees are formed as needed. In the case of the Beaver Creek restoration plan project, one was formed to oversee the administration of the 604(b) grant being utilized to support the development of the plan. Task Force committees generally meet monthly, with the entire Task Force coming together on a quarterly basis. The quarterly meeting's agenda includes Committees updating one another on progress being made, with ensuing discussions on how Committee efforts may interface.

Early in the development of the restoration plan, it became apparent that although the Task Force had an administrative structure, the project itself was lacking leadership, creating two notable problems. First, there was a lack of accountability, i.e., "the buck stop here," within the project. Without one person at the helm, we, as Task Force members, were all being held less accountable for our assignments resulting, in, for example, deadlines not being met. Second, information and data were not always being fed back to the plan writer in a timely fashion or in a useable format. Recognizing this deficiency, the Knox County Watershed Coordinator who also serves on the Task Force Executive Committee took the lead on the project, providing timeline oversight and serving as a conduit for the transfer of information from the partners to the plan writer.

An additional organizational tool that was extremely valuable to the plan development process was the compilation of a detailed annotated plan outline based on US EPA guidance documents. The outline provided a way for the Task Force Committees to more readily identify missing information and data gaps. It also provided a transparent means of making work assignments to partners and tracking the portions of the plan that had been completed.

Lessons learned about administration:

- **The Good:**
    - Adding structure to a partnership helps to define roles and responsibilities.
    - The administrative structure of the Task Force – its Executive Committee and Standing Committees – worked well for the project, with the Executive Committee tracking the "big picture" and the Standing Committees focusing on specific issues.
    - The Task Force quarterly meetings provided multiple benefits including time for Committees to update one another and identify tasks requiring joint Committee efforts and providing an opportunity for synergistic ideas to emerge.

    - A detailed outline is a practical way to assign work tasks and monitor their completion.

- **The Bad:**
    - Without a project leader, there is less overall partner accountability.
    - Partner goals and work plans can sometimes conflict with project goals and work plans.
    - A plan writer can reduce the overall work load of the partners, but information must be fed to that person in a timely manner to stay within the project timeline.

- **The Ugly:**
    - Working by committee requires compromise which can lead to interpersonal challenges if not handled with care.

Public Participation:

Education and outreach is a critical part of any watershed effort, starting at its outset and continuing throughout the planning and implementation phases. It is particularly important in the development of a watershed restoration plan which will later require not only the public's buy-in and support, but, in some cases, their participation in its implementation.

The Task Force conducted two primary forms of public outreach related to the plan, one of which we felt was particularly successful and the other less so. The first was the formation of a 19 member Stakeholder Advisory Council that was intentionally selected to provide a broad cross-section of stakeholders. The Council met seven times with Task Force partners over an 18 month period. It was first educated on watershed issues and on the EPA-recommended watershed planning approach. The Council then provided feedback regarding potential general community concerns about plan implementation, ideas to more effectively communicate with the public and their perceptions on community acceptability of proposed restoration strategies. The logistics for these meetings are notable. They were two hours long and held over lunch that was catered by women of the church where we met who provided a truly delicious home-cooked meal.

A series of public meetings were also conducted in each of the primary communities. The meetings were advertised through local papers, schools and other community institutions. They were set up to include Task Force informational booths related to ongoing watershed programs, projects and proposed restoration strategies. A brief presentation of the proposed plan was also provided. Feedback from attendees was positive, as for most it was the first Beaver Creek-related meeting they had attended. However, attendance was extremely low. We attributed this to several possible factors including: 1) competing community events; 2) no one major rallying watershed issue to bring people to the meeting; 3) weather; and 4) over-saturation in the media. A local community paper that is a prime source of information for Beaver Creek communities has over the past two years extensively covered watershed issues which may actually have led to citizens feeling they have heard enough about these issues.

In retrospect of the public meetings, we felt we should have used more innovative means in reaching out to the community in place of employing the conventional public meeting model. With this model, there is often a perception, and rightfully so, that we are asking the public to meet our needs rather than us intentionally working to meet theirs. In more recent watershed outreach efforts we are looking at utilizing a range of social marketing approaches that targets subpopulations and their needs.

Lessons learned about public participation:

- **The Good:**
  - The Stakeholder Advisory Council provided valuable input to the process, in part because of its diverse composition.
  - Home-cooked meals (and the wonderful smell of yeast rolls cooking) created a more positive and relaxed meeting space. It also appeared to be a true draw, helping to consistently keep attendance rates high.
  - Using non-conventional means of conveying information to and seeking input from the public needs to be considered (i.e., better meeting subpopulation needs).
- **The Bad:**
  - Participation in the public process is very unpredictable and can be affected by a range of unforeseen variables.
  - Too much press can sometimes lead to over-saturation.
  - The conventional public meeting model appears primarily to be effective when there is a "hot" publicly-debated topic to be presented.
- **The Ugly:**
  - Bad weather happens.

Technical Issues:

There is a wide range of technical studies that must be completed to develop a watershed restoration plan. These include upland and stream visual assessments, water sampling and analysis, biological assessments, modeling of impacts and the creation of restoration scenarios. With the expertise available in the Task Force, multiple research and collaborative partnerships were formed. In addition Task Force members were able to use data that had been previously collected for other projects.

There was also a challenging research-related situation that proved to be instructive on multiple levels. It involved contradictory results of two separate sediment source models by two different researchers that had differing research project timelines. First, in regards to the conflicting data, several technical meetings were dedicated to determining how the opposing results could be reconciled. In the end, it was deemed that they could not, but that results from both could be field tested partially through additional data collection over the course of the first five years of the implementation of the restoration plan and partially through the evaluation of the effectiveness of the selected restoration strategies. Throughout these discussions, we realized the value of leadership that was adept in the "negotiation process." Second, this situation underscored the reality of models. In short, models are "black boxes" that must have an adequate amount of data to be field tested. Often watershed plan development timelines do not provide the time to collect the needed data. Third, in utilizing two modeling efforts by two separate researchers (one within a federal agency, another within an academic institution); the reality of differing research time tables was driven home. The predominant use of one model over the other in the plan was influenced by our project time line.

- **The Good:**
  - Partnerships can spread the research workload and costs.
  - A partnership comprised of a diverse set of entities are better able to provide the broad range of data needed for a comprehensive watershed restoration plan.
  - Unexpected research results can lead to new directions.
- **The Bad:**

- There never seems to be enough data to fully understand the nature of stream impacts.
- Contradictory research results can lead to a need for adept negotiation skills.
- Governmental agencies often have differing research objectives and timelines than academic institutions. Both need to be accounted for in creating a timeline for the development of a watershed restoration plan.

- **The Ugly:**
    - There never seems to be enough time or money to collect the data needed to fully characterize a watershed.

In summary, we realize that any project utilizing as many partners as we involved in the development of the Beaver Creek Watershed Restoration Plan that the road to completion may not always be smooth. It is a given that each of the partners will have their own individual agendas, missions and timetables. What became clearly evident throughout this project was that it needed strong leadership and a simple but defined structure. With these elements, it then became easier to accommodate individual partner issues, needs and sometimes conflict. In particular, these elements facilitated better communication, clarified roles and responsibilities and kept the planning process moving forward. In the end, we felt the “good” far outweighed the “bad” and “ugly” and that it was well worth “growing the plan” ourselves so that we would then be better prepared for its implementation. Stay tuned for reports on its harvest.

VOLUNTEER STREAM BANK EROSION STUDY: SO HOW MUCH SEDIMENT DOES BANK EROSION GENERATE?

John McFadden

VOLUNTEER STREAM BANK EROSION STUDY INTRODUCTION

The Harpeth River Watershed Association (HRWA) is a 501(c)3 not for profit conservation organization. HRWA's mission is to restore and protect the ecological health and biodiversity of the Harpeth River Watershed for the people, fish and wildlife that depend on it by building an organization that provides scientific and technical foundation to efforts to improve and protect the river system and when applicable to influence statewide water policy.

HRWA's guiding principles establish that all work from outreach to policy is based on scientific and technically accurate understanding of watershed ecology and that it utilizes trained volunteers in every aspect of its work, including data collection and restoration. Finally, HRWA strives to work collaboratively in any area possible with other organizations to further common goals. HRWA with the help of Dr. Dave Wilson, volunteer and retired Vanderbilt professor, designed and carried out the *Volunteer Stream Bank Erosion Study* detailed in this report.

Sediment is the leading cause of water quality degradation in Tennessee (TDEC, 2002). Sediment comes from two major sources: (1) surface erosion off land in the watershed—from construction, agricultural activities, timber cutting etc., and (2) from stream bank and bed erosion, occurring when high velocity water flows scour material from the stream bank and bed, and when supersaturated bank soils, structurally weakened, fall into the stream as water recedes. In 2002, TDEC prepared a sediment Total Maximum Daily Load (TMDL) in an effort to begin the process of addressing sedimentation in the mainstem of the Harpeth River. However, the TMDL did not address sediment from construction runoff or stream bank erosion.

In 2003, HRWA conducted a *Visual Stream Assessment* (VSA) of over 200 sites along 303(d) listed stream segments. Among other things, the survey revealed that over 50% of sites had occasional or common bank erosion, in addition to riparian impairment. As a result of the VSA data and the sediment TMDLs' limitations regarding bank erosion, HRWA made two broad conclusions. First, bank erosion was a significant source of sediment in the system and second, TDEC was unable to include this pollutant source as there was no associated quantifiable data.

Thus, the HRWA's technical advisory committee, led by Dr. Wilson, recommended that HRWA initiate a study to determine the rate of bank erosion at some of these sites. The purpose of this study was to quantify sediment loss associated with stream bank erosion at several sites within the Harpeth River Watershed. The techniques used were low-cost, simple, volunteer oriented and lent themselves to quantitative interpretation.

This project is funded, in part, under an agreement with the Tennessee Department of Agriculture, Nonpoint Source Program and the U.S. Environmental Protection Agency, Assistance Agreement, #C9994674-03-0. Grant contract # GR-04-15878-00.

METHODS AND MATERIALS

Bank erosion can be measured with a number of methods. HRWA utilized trained volunteers to collect the bank erosion data via two simple methods, the knitting needle and stake and tape method. These methods are described in detail in Appendix III.

TRAINING

Volunteer training was conducted in Franklin, Tennessee and included lecture, demonstration, and practice until participant competence was achieved. Once trained, volunteers were instructed to set up their study sites within a two-week period if possible. If the site was not set up within the two week window, HRWA staff or Dr. Wilson assisted the volunteer with site set up provided a review of methodologies.

KNITTING NEEDLE METHOD

The knitting needle method was designed to determine stream bank erosion rates when the rates were thought to be minor. The method involved measuring the length, width and height of the bank and then "nailing" the knitting needles into the face (vertical) of the bank in a grid pattern. Volunteers were instructed to nail the needles in until only the head of the needle was visible. The grid pattern was recorded on the field data sheet. Once a flood event occurred, volunteers went back to the sites and measured the distance from the head of the needle to the new face of the bank (post erosion event). Unfortunately, this method posed two problems: 1) initial bank erosion rates were greater than the length of the needle (1 foot/needle) and 2) needles proved hard to find in the bank following flooding, as leaves and detrital material obscured them. Due to these problems, this method was abandoned.

STAKE AND TAPE METHOD

The stake and tape method was generally designed for larger sites in the range of 1000 to 2000 feet in length and greater than 20 feet in height. Due to their size, these sites were not accessible from the face of the bank, but only from the top of the bank. The stake and tape method involved first collecting the length and height of the area to be studied and then setting up a grid on the top of the bank utilizing wooden stakes. Two stakes were employed, one was the reference stake utilized to measure the distance from the top of bank back and the other stake was deemed auxiliary and placed in between the reference stake and top edge of bank to assure measurements were made at the same location/direction on subsequent data collections. In addition to the auxiliary stake, a compass reading taken along the same line allowed for reestablishing the position in the event the auxiliary stake was lost. This proved helpful as several auxiliary stakes were lost even though they had been placed five to seven feet back from the top edge of the bank. Soil loss rates were calculated by finding the difference between the initial stake to bank distance and final stake to bank distance, multiplying this difference by bank length and bank height to determine soil loss in cubic feet. Soil loss, in cubic feet was divided by 27 (cubic feet per cubic yard) to determine soil loss in cubic yards.

RESULTS

The purpose of the volunteer bank erosion study was to quantify sedimentation associated with stream bank erosion in the Harpeth River Watershed. Volunteers setup and collected data from a total of nine sites (Appendix I, Table 1), including three sites on tributary streams and six sites on the mainstem of the Harpeth River (Appendix II, Map 1). The entire electronic data file can be acquired by emailing hrwa@harpetheriver.org.

Total soil loss was calculated at 1,188.66 cubic yards over 1,918 linear feet of bank with an average bank height of 9.17 feet (Table 2). Soil loss ranged from 1.2 cubic yards (Harpeth River at Brown's Creek off the Natchez Trace) over a 49 ft site (0.75 years of data) to 873.66 cubic yards over 521 ft (4 years of data) along the mainstem in the Morton Mill area of Bellevue. Soil loss over all sites occurred at a rate of 0.57 cubic yards per linear bank foot.

Soil loss ranged from 0.01 cubic yards per foot at Site 2 to 1.68 cubic yards per foot at Site 9 (Figure 1). The greatest loss rates were observed at Site 9 (Figures 2 - 5) and Site 8 (West Harpeth downstream of Highway 96 bridge). Mass bank failure at Site 9 along the Harpeth River at Bellevue is shown in Figure 3. The lowest loss rates were observed at Sites 1 and 2 (Figures 6 and 7).

Site 5 along the South Harpeth at Old Harding Road had one of the middle rates of bank erosion (Figure 8). This was not expected as this subwatershed is one of the least developed, with the primary land uses being agriculture and forestry. This site and one other along the South Harpeth not included in the study due to data record problems, appear to have significant bank erosion issues (Figure 8). As well, the West Harpeth at Leiper's Fork and West Harpeth below Highway 96 had high rates of erosion, as compared to sites along the mainstem (excluding Site 9). Conversely, several sites along the mainstem had lower rates of erosion as compared to the West Harpeth and South Harpeth sites and the site of greatest loss (Site 9). Of the four sites that lost the least amount of soil, three were on the main stem of the river below Franklin.

CONCLUSIONS AND RECOMMENDATIONS

The HRWA carried out a stream bank erosion study in an effort to begin to quantify amounts of sediment loading associated with bank erosion. Sediment is the leading cause of degradation and impairment in the Harpeth River Watershed and as such source determinations are important in corrective actions, permitting and regulatory decisions and structure. The study found that with an average bank height of 9.17 feet, soil was lost at a rate of 0.57 cubic yards per linear foot of eroding bank. HRWA concluded that significant amounts of sedimentation are entering the aquatic system from bank erosion.

It appears from the data that other factors, beyond location in the watershed, are affecting bank stability. For example, adjacent land uses, such as agriculture, specifically beef production alter riparian habitat and may have caused bank instability and bank loss along one site in the South Harpeth. Conversely, Site 8 along the West Harpeth downstream of Highway 96 continues to have a well-developed forest buffer, yet had one of the higher erosion rates as compared to other sites. Since this study, it has been determined that a specific action, the construction of the new highway 96W bridge over the West Harpeth upstream and the removal of a bend in the river, is causing bank erosion downstream of the bridge all the way to the confluence with the main Harpeth. Site 8 became part of the largest stream restoration project of the state's TN Stream Mitigation Program as part of HRWA's efforts. It was during the consulting engineering firms site visits that the cause of the bank erosion along this heavily forested stream cooridor was identified. A tornado in the May of 2005 also damaged some of the forested area in part of this area as well. Thus, HRWA recommendations include increased monitoring and restoration activites.

Monitoring

HRWA recommends carrying out additional monitoring for each site. First, habitat data and watershed imperviousness (upstream of each site) should be determined. Habitat quality at each site (utilizing the Rapid Bioassessment habitat quality protocols) may help explain: 1) if relationships exist between bank erosion rates and riparian condition among other habitat qualities and 2) potential relationships between adjacent land uses and bank erosion rates. In addition, watershed impervious cover above each sampling point should be determined. This determination would help project staff better understand the variability of bank erosion rates and as such the mechanisms that may be employed to reduce bank erosion.

Restoration Activities

Over the past five years, HRWA has carried out a number of restoration projects, the majority of which involved increasing riparian habitat quality and bank stabilization. For example, HRWA along with the City of Brentwood stabilized roughly 200 linear feet of stream bank along the Little Harpeth River in River Park. In addition, HRWA along with volunteers working in the Harpeth and Duck River watersheds, have planted some 20,000 (+/-) seedlings in riparian zones.

Riparian restoration consists of two basic activities including: 1) removal of any cause of degradation and 2) restoration of the vegetative community. In addition, some hydrologic conditions may need to be restored. Removal of the cause of degradation may include livestock or other human use exclusions and provisions for livestock alternative water supply. Once removal of degradation causes occurs, riparian (buffer) re-vegetation can occur.

The Natural Resources Conservation Service (NRCS) guidelines call for a minimum buffer width of 35 feet along rivers and streams, however other sources call for up to 100 feet of buffer (see Wenger, 1999). HRWA should promote as wide a buffer as possible, based on land condition, landowner concerns and other factors that may apply. In an effort to leverage additional (NRCS) funds, buffers would need to be a minimum of 35 feet wide. However, because TDEC biologist (as per communication with James R. Smith) and others have observed improvements in water quality associated with one row of trees along creek banks, and because land owner objections often have to do with loss of land to graze, crop etc. HRWA should advocate for as much width as possible, but in some cases work to reestablish at least minimal riparian zones (e.g. one row of trees) for bank stabilization and shading of the stream.

Finally, it may be necessary to restore natural hydrology to the riparian zone. In cases where aquatic systems are severely down cut, channels have formed through the riparian zone, thus bypassing the beneficial effects of sheet flow. This reduces the pollutant loads associated with riparian zones. In addition, it may be desirable to add in-stream structures to increase a systems ability to carry its bed load. For example a series of check dams, j-vanes or other appropriate structures may be used to increase velocity and/or sinuosity within an existing channel. However, in utilizing these options, one should pay particular attention to opposing banks to ensure structures do not create additional erosion. Proper installation of structures is the key to proper functioning.

Stream bank erosion is a significant problem in the Harpeth River and thus treating all eroding stream banks may not be cost-effective or practical. HRWA recommends the following prioritization scheme: areas where specific ecologic assets, such as mature trees are located should be treated first, and then areas thought to be contributing significant soil to the system, second. For example, streams with one row of scattered trees on a highly erosive stream bank would be treated in an effort to conserve those trees providing shade and detrital material (habitat and food) to the system (ecological asset). In systems affected by sediment, long, highly erosive segments may be treated. This should provide for the greatest load reductions at the least cost. Utilizing the current study’s data the following formula can be utilized to calculate an estimated sediment load (ESL) associated with stream bank erosion:

$$ESL = ((bh/9.17) \times 0.143) \times L$$

Where:
ESL = Sediment loss in cubic yards per foot
bh = bank height to be treated
9.17 feet = average bank height from HRWA Bank Erosion study
0.143 cubic yards = soil loss/foot per year in HRWA Bank Erosion Study
L = Length of bank to be treated

The formula should continue to be refined and validated. For example, estimates of soil erosion should be made on stream banks and then measurements should be collected to determine the accuracy of estimates. Hopefully over time, the formula can be validated as a mechanism utilized to drive sediment load reductions via bank restoration efforts.

The primary method utilized by HRWA to treat eroding stream banks has been placement of cedar revetments, and in many cases reshaping of banks, back fill and re-vegetation. HRWA continues to utilize cedar revetments to treat banks as high as 12 feet and generally found them effective in reducing stream bank erosion (McFadden, 2005). HRWA utilizes a technique developed by Jen-Hill Construction for cedar revetments similar to that recommended by the Natural Resources Conservation Service, except cedar trees are bundled in coir matting or jute, prior to being attached to the stream bank. The matting helps capture sediment through compaction of the branches. In addition, the revetment can be backfilled and replanted immediately following installation.

HRWA believes the habitat restoration activities listed above will do much to help bring the watershed back to an unimpaired state, however if development trends and methods are not modified, the long term implications for the watershed are increased levels of impairment. Thus, HRWA strongly encourages establishment and/or maintenance of riparian buffers in developed and developing areas, maintaining natural hydrology (generally infiltration versus runoff and conveyance) and construction and post construction stormwater treatments. HRWA believes theses techniques, when strictly adhered to, have a tendency to increase water quality specifically in smaller tributaries. Field data collected following development will reflect the nature of the development techniques. For example, one study conducted by HRWA along unnamed tributaries of the Harpeth River documents degraded water quality following development infrastructure implementation (McFadden, 2004). The following development site design changes are made generally and may need to be modified based on site-specific conditions.

The goal of alternative site design is to maintain natural watershed hydrology, allowing rainwater to infiltrate into the ground versus increasing runoff. Stream bank erosion is exacerbated by increased runoff associated with roads, parking lot and rooftops (impervious cover). Reconnecting stormwater flow to ground water is the key to preventing additional bank erosion and associated water quality and habitat degradation, and more importantly, increasing the possibility for water quality enhancement in impaired systems. Thus, inclusion of pervious pavement for driveways, modified road drainage structures, biofiltration islands, and lot level stormwater retention devices can enable developed areas to come closer matching the hydrology similar to natural areas. For example, stormwater from roads can be discharged laterally (as sheet flow) into grassed swales or other permeable materials. An area could still have the curb and gutter appearance without the curb, but with a concrete (pervious or not) ribbon along the edge of roadways. In addition, rooftop drainage should be directed to rain barrels, rain gardens and/or discharged into drain fields as opposed to being directed onto impervious drive and roadways. Parking lots and/or paved areas can be constructed of pervious material for overflow and low use areas. Much information can be found on alternative development site design at www.cwp.org. Finally, and perhaps most importantly, streamside (riparian) buffers are necessary for protecting and enhancing water quality, especially in maintaining bank stabilization and shading to minimize water temperature fluctuations and the effects on water chemistry that affects aquatic life.

Reestablishing and/or maintaining adequate riparian buffers along streams, and wet weather conveyances is imperative to water and habitat quality as they provide water quality treatment, infiltration, increased channel stability and opportunities for wildlife. Natural (no human activity) buffers along perennial streams should be a minimum of 100 feet wide and along all other watercourses a minimum of 75 feet wide. Wenger (1999) suggests a width of 100 feet with an increase of two feet per degree of slope. It may be advantageous for other ecological functions (wildlife, in particular amphibians), along the mainstem of the Harpeth and major tributaries to increase the buffer to 300 feet. HRWA recommends planting buffers with native vegetation including canopy trees, understory trees, shrubs and herbaceous vegetation.

In summary, HRWA carried out the *Volunteer Stream Bank Erosion Study* in an effort to quantify sedimentation associated with stream bank erosion in the Harpeth River Watershed. To that end, the data indicate that 0.39 cubic yards per foot of soil were lost along 1,918 linear feet of stream bank studied. The study was carried out by volunteers over a two year period, however due to mass bank failure and other human activities (i.e. bushogging) most sites were reestablished during the second year by project staff. The data indicate bank erosion is a significant source of sedimentation to the river system. Thus, HRWA recommends conducting additional studies to document and validate methodologies and to carry out bank restoration effectiveness.

Although the activity referenced in this publication has been financed, in part, with the Sate and/or federal fund, the mention of trade names or commercial products does not constitute endorsement or reformation by the State or the Environmental Protection Agency.

ACKNOWLEDGMENTS

This study would not have been possible without the efforts of Dr. Wilson to design the project and the effort of volunteers to identify study sites and contact landowners who were willing to allow volunteers or staff to establish the study sites and do periodic measurements. We would like to thank Conner Haugh and Ed Snyder particularly of the volunteers. Also, thanks to Eddie Bateman and Gwen Blanton who as HRWA staff during the course of the project managed the data gathering and coordination with the volunteers.

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APPENDIX I – TABLES

Table 1 – Site Numbers, Location and Total Soil Loss

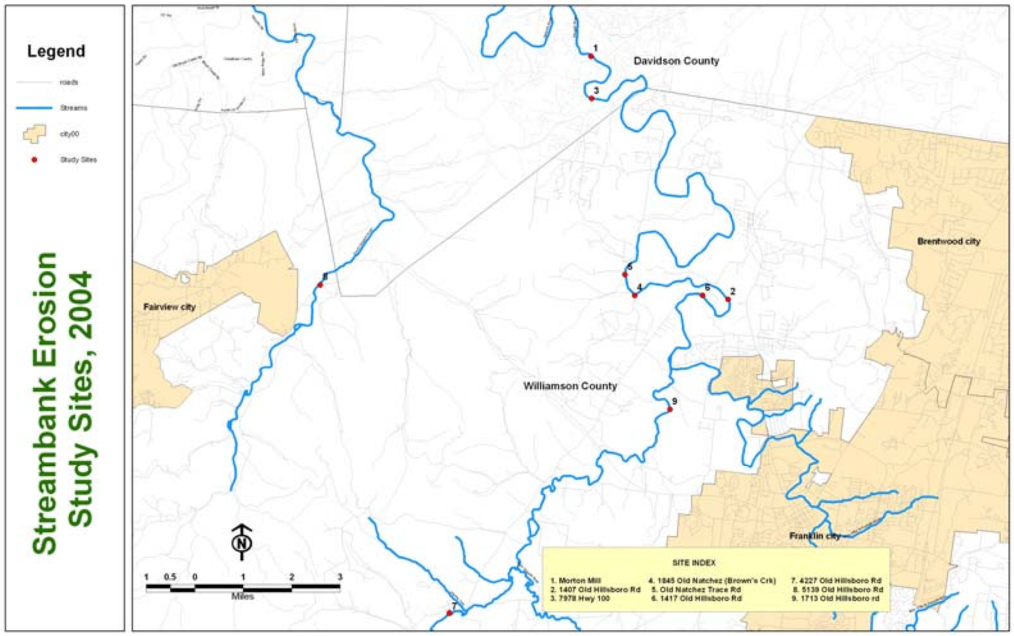
Site #	Location	Method	Stream name	Lat/long. (stake 1)
1	Main stem	Stake and tape	Harpeth River at Browns ck	N 036 03 43.2 W 086 56 56.9
2	Main stem	Stake and tape	Harpeth River – Brockman	N 35 59.362 W 86 53.869
3	Main stem	Stake and tape	Harpeth River - Lewis	N 36 02.954 W 86 56.926
4	Main stem	Stake and tape	Harpeth River Lumsden Bd.	N 35 59.428 W 086 54.428
5	Tributary	Stake and Tape	S Harpeth – Nelson	N35 59.33 W87 02.53
6	Main stem	Stake and tape	Harpeth River – Off Nat. Tr.	N 35 53.666 W 086 59.954
7	Tributary	Stake and tape	West Harpeth - Hood	N 35 57.394 W 086 55.143
8	Tributary	Stake and tape	West Harpeth - Magli	N35 57.375 W86 55.128
9	Main Stem	Stake and tape	Harpeth in Bellevue	N36 03 43.2 W86 56 56.9

Table 2 – Summary Data – least to greatest total soil loss

Site #	Stream	Length (ft)	Bk Ht. (decimal ft)	Soil Lost (cy)*	Time (yrs)	Soil loss per foot (cy)
1	Harpeth River at Browns ck	49.00	10.37	1.20	0.75	0.02
2	Harpeth River	128.00	5.70	1.86	0.60	0.01
3	Harpeth River	88.00	13.00	4.13	0.60	0.05
4	Harpeth River Lumsden Bend	104.00	5.35	5.71	1.00	0.05
7	West Harpeth	146.00	6.66	7.99	0.60	0.05
5	South Harpeth	300.00	5.00	11.84	0.60	0.04
6	Harpeth River	80.00	11.58	29.57	0.60	0.37
8	West Harpeth	503.00	10.52	160.58	2.00	0.32
9	Harpeth in Bellevue	521.00	15.25	873.68	4.25	1.68
	Totals	1919.00	9.27 (Average)	1096.56	1.22 (average)	2.60

CY—cubic yards

APPENDIX II – MAPS AND FIGURES



Map 1

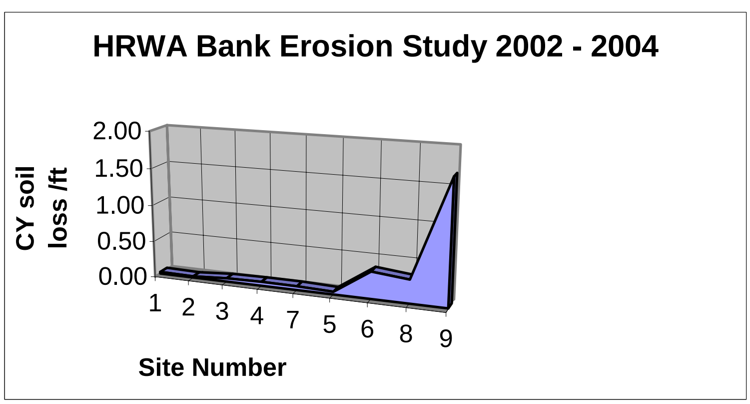


Figure 1 – HRWA bank erosion sites lowest to highest soil loss per linear foot.

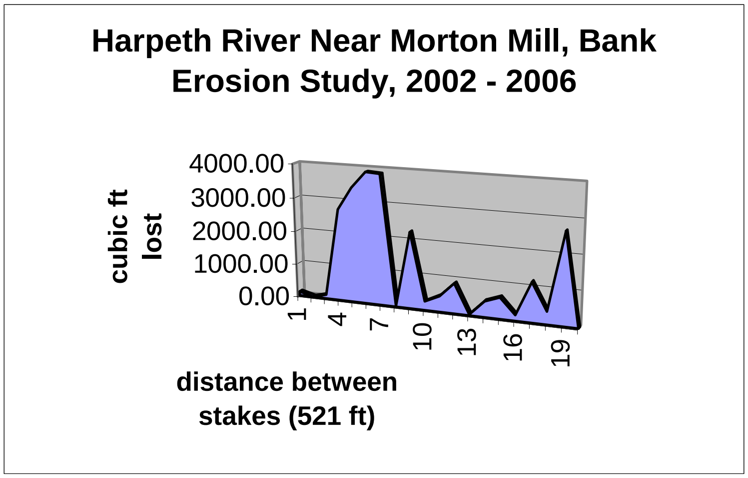


Figure 2 – Harpeth River near Bellevue, TN, Site 9 (site of greatest loss), 873 cubic yards of soil lost from 2002 – 2006.

Figure 3 – Harpeth River near Bellevue, TN, Site 9

Figure 4 – Harpeth River near Bellevue, TN, Site 9 - erosion stake on new bank location.

Figure 5 – Harpeth River near Bellevue, TN, Site 9- erosion stakes during flood stage.

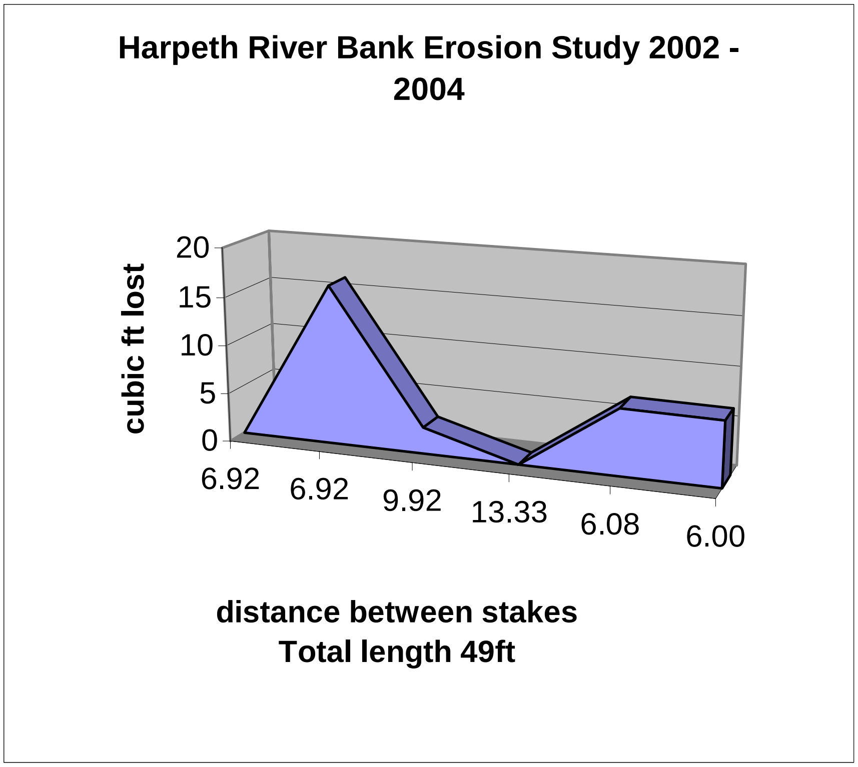


Figure 6 – Harpeth River at Brown's Creek, Site 1, lowest total soil loss.

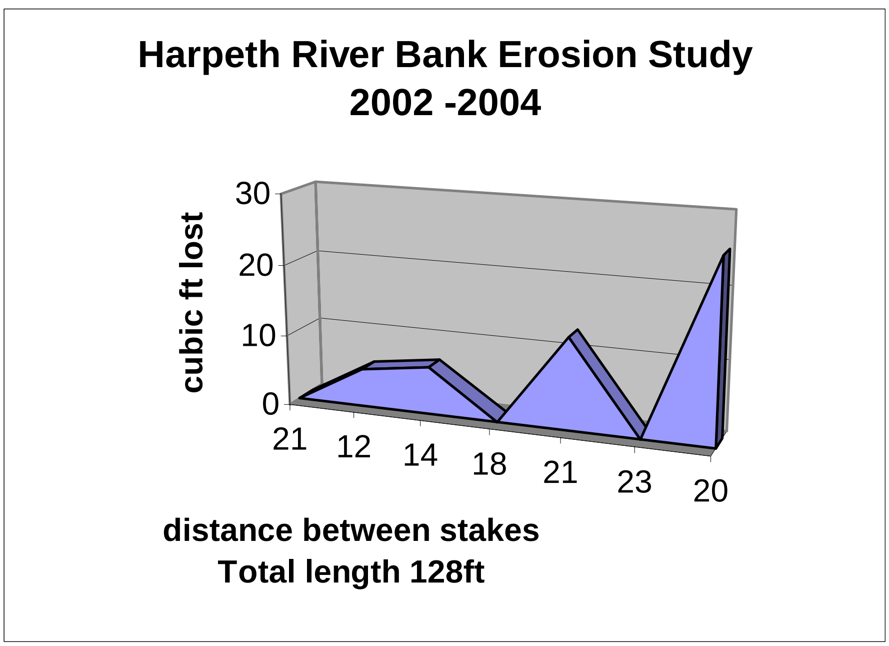


Figure 7 – Site 2, second lowest total soil loss.

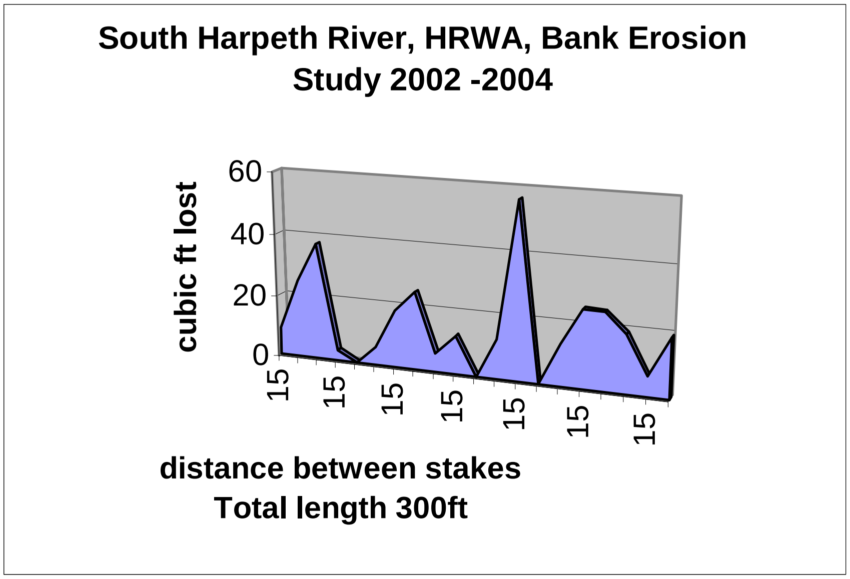


Figure 8 – Site 5 South Harpeth River at Old Harding Road

APPENDIX IV - PROTOCOLS FOR STREAM BANK EROSION STUDY
HARPETH RIVER WATERSHED ASSOCIATION, 05/09/02

"KNITTING NEEDLE" METHOD

For small streams and for large streams having banks that are accessible and are not eroding very rapidly, one can use knitting needles for measuring erosion rates.

Materials Needed

1. field book for recording measurements and observations
2. #2 pencils
3. a measuring tape 16 ft or more in length
4. a map (topo sheet) on which you can mark the location of the site (may use maps available from Topozone web site.)
5. 24 knitting needles (number needed may vary with the site), at least 8" in length, with one capped end. Must be stiff enough to permit insertion into a clay bank. 6-8" pins or nails will also work.
6. a light hammer (tack hammer) or mallet to install needles
7. a 1-ft ruler calibrated in inches and centimeters
8. printed data table form

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Site Set-up

Step 1. Determine the latitude and longitude of your site (degrees, minutes, seconds) using either Topozone on the internet or a GPS; record these in your field book. For help, contact hrwa@harpethriver.org or 615-790-9767.

Step 2. During a period of low water, knitting needles should be driven into the eroding bank on a grid having a spacing of approximately 2 ft. in the vertical/near-vertical direction and approximately 6 ft. in the horizontal direction. Needles should be pushed in at right angles to the bank surface and should be inserted completely, so that only the heads are visible. (This is to reduce the likelihood of their being dislodged by floating logs and other debris during floods.)

Step 3. Measure the distance between the needles with your tape (ft, in). Make an accurate sketch map showing the locations of the needles and record the measured distances between them; this is necessary in order to calculate the area of the bank being studied. Number the needle locations on your sketch map so that each needle can be identified.

Step 3. Record in your field book the date on which the needles were installed. Also record any descriptive information—condition of streamside vegetation, livestock access, obvious signs of erosion, manmade structures causing erosion, etc.

Step 5. Make a table in your field book showing the needle identification numbers in the left column and approximately 20 columns to the right in which to record measurements as they are made. Leave space for the dates of the measurements in the top row of the table. You may use the prepared tables. Data should be turned in on these prepared tables at the end of the project.

Step 6. After each major storm, **allow the stream to subside to a level at which it is safe to work**. Use the ruler to measure the lengths of knitting needles which are exposed (in millimeters), and record these lengths and the identification numbers of the needles in your field book. You may also record the data and the exposed lengths directly on the printed data table you've been given. After you have recorded the exposed length and identification number of each needle, push or drive it into the bank so that the head is flush with the clay surface. If none of the needle has been exposed, record 0 mm for its exposed length. Repeat 20 times at regular intervals.

Step 7. At the end of the study, add up the exposed lengths for each needle recorded in the table; the sum equals the thickness of the layer of soil that was eroded at that location. Add these sums together for all the needles, then divide by the number of needles to obtain the average thickness in mm. Multiply the average thickness by 0.00328 ft/mm to obtain the average thickness in ft. Determine the area of your study site by calculating the product of its height (ft, closest tenth) by its length (ft, closest tenth). (If the area of your bank site is not rectangular, you may want to subdivide it into rectangular units and calculate the area of each, or you can contact a project coordinator to help you determine the area of your site.) The volume of soil lost during the period of the study is given in cubic feet by the product of the total site area and the average thickness of the eroded layer. To obtain cubic yards, multiply this result by 1 cu yd / 27 cu ft.

STAKE AND TAPE METHOD

If you anticipate substantial erosion, it may not be practical to use the knitting needle technique. Also, if the near-vertical face of the bank is not safely accessible, you may not want to use this technique. In that case, the stake and tape method will allow you to get a fairly good estimate of the rate of erosion, although this technique is not as accurate as the knitting needle method. If possible, your site should consist of the full length of bank at which you see signs of active erosion—raw soil, perhaps some exposed tree roots, signs of bank slumping, information from the property owner, etc. **If possible, please use both the knitting needle method and the stake and tape method, as it is helpful to obtain data using both techniques at several sites to compare the two methods.**

Materials Needed

1. field book
2. topographic map segment (from Topozone) for showing site location
3. wooden, metal, or plastic stakes, two for every six feet of bank to be studied. Thus, if your site is 100 ft long, you will need 2 X 16.667 = 34 stakes. Number these with waterproof magic marker or by some other method.
4. waterproof magic marker
5. #2 pencil
6. hammer or mallet for driving the stakes
7. compass
8. measuring tape at least 16 ft in length
9. printed data table form

Site Set-up

Step 1. Determine the latitude and longitude (degrees, minutes, seconds) **of each end of your site** either by using the Topozone site on the internet or by means of a GPS unit. Record this information in your field book, along with any relevant descriptive information about the site—state of riparian vegetation, livestock access to bank, visible signs of erosion, manmade structures causing erosion, best management practices (BMPs), etc. Set up your site when the water is fairly low.

Step 2. Drive stakes into the ground at approximately 6-ft intervals along a line 8-12 ft back from the edge of the stream bank and parallel to it. Number each of these stakes consecutively with waterproof magic marker. Do this along the full length of your study site. **These are your reference stakes**. Leave the tops of the stakes high enough so that they can readily be seen, or put in auxiliary markers (surveyor's tape or something similar) to show you later where the stakes are. Do not put stakes in cultivated land where they may be torn out and/or damage equipment—check with the property owner.

Step 3. Record the number of each stake in Column 1 of the data table provided. For each stake, determine the compass bearing (degrees) of the shortest line to the bank and record this in Column 2 of the printed data table provided. Place an auxiliary stake between the reference stake (the numbered stake) and the bank (about 2 ft from the reference stake) to indicate the compass bearing of this line. Do not number the auxiliary stake, so that you can later distinguish it from the numbered reference stake.

Step 4. Make a sketch map in your field book showing the locations and numbers of the stakes. Measure the distance (feet, inches) between successive stakes (1-2, 2-3, 3-4, etc.) with your tape and record these distances on your sketch map and in Column 3 of your table.

Step 5. For each numbered stake, use your measuring tape to measure the distance (ft, in) from the top of the bank to the bottom of the bank (where it starts to level out and become stream bed). Record this in Column 4 of the table.

Step 6. Measure the distance from the front (streamside) edge of the reference stake over the auxiliary stake to the edge of the bank. Later, in similar fashion, you will use the auxiliary stake to make sure that you always measure in exactly the same direction from the reference stake toward the stream's edge. In Column 5, enter the date in the top row, then enter the distance measured from each reference stake to the bank in the appropriate place.

Step 7. After each major storm, for each reference stake measure the distance (ft, in) between the front edge of the stake over the auxiliary stake to the edge of the streambank. Put the date at the top of the first available blank column, then record the stake-bank distances in that column. Repeat as directed for completion of data gathering.

Step 8. At the end of the study, calculate the volume of soil lost by bank erosion as follows. For each stake, subtract the last stake-to-bank distance from the first (in the fifth column of your data table), and convert this figure from feet and inches to feet (to tenths of a ft, shown as XX.X). This gives the thickness (T) of the volume of soil lost at that stake. For each stake convert the bank height measurement (in Column 4) to ft (XX.X). This gives the height (H) of the volume lost at that stake. For each stake calculate half the distance between the stakes on either side of it (to tenths of a ft) to get the length (L) of the volume lost at that stake. This cannot be done for the two end stakes; for them, use the distance (to tenths of a ft) between the end stake and the adjacent stake for the length (L) of the volume lost by that stake. The volume of soil lost by each stake is then given by $V = T*H*L$. Add the volumes lost by each of the stakes to get the total volume of soil (in cubic ft) lost by the site during the course of the study. If you wish to convert this to cubic yards, multiply by 1 cu yd / 27 cu ft.

Safety Considerations

1. Take care when parking and getting into and out of your car. Traffic accidents are probably the greatest hazard.

2. Sampling in bad weather or in the dark should be avoided.

3. You may be working along near-vertical, muddy, slippery stream banks with deep, fast-moving water below. Be prudent and cautious, particularly when using the knitting needle method. A safety rope and a helper may be in order. Do not attempt to check your knitting needles when the stream is in flood stage; this may be extremely dangerous.

4. Take precautions regarding hornets and wasps, snakes, ticks and chiggers, poison ivy, farm animals (particularly bulls) and dogs.

5. Let someone know where you're going and when you expect to be back.

6. If you should use a canoe or other boat in a knitting needle study, don't go in flooded, raging streams, wear a life jacket, and use caution.

MANAGING NON-POINT SOURCE POLLUTION AT THE LANDSCAPE-SCALE: EXPERIENCES FROM POND CREEK WATER QUALITY IMPROVEMENT PROJECT 2001 TO 2006

Forbes Walker[1], Lena Beth Carmichael[2] and Jonathan Hagen[3]

Pond Creek is an agricultural watershed typical of many in the Southeastern United States. Land use is dominated by pastured based beef cow-calf and dairy operations. Pond Creek (TN06010202013) is part of the Upper Tennessee Basin in east Tennessee in McMinn, Monroe and Loudon counties. In 2006 it was listed on the 303(d) list of impaired water bodies in Tennessee for nitrates, *E. coli* and habitat alteration. The primary causes of impairments were identified as pasture grazing, livestock in stream and animal feeding operations (AFOs). Since 2001, the University of Tennessee Extension has been leading a multi-agency project to improve water quality in the watershed. A land-use inventory of the watershed suggested that major source of non-point sources of pollution were poorly managed pastures, plowed fields and eroding stream banks. The outreach portion of the project has focused on one-on-one meetings with farmers and other stakeholders, pasture management and the demonstration of "engineered" best management practices (BMPs) such as fencing, installation of alternative watering systems and heavy use areas. In 2005 a total maximum daily load (TMDL) for reducing pathogen loads in the Watts Bar watershed (which includes Pond Creek) was developed by the Tennessee Department of Environment and Conservation (TDEC). In 2006 a watershed restoration plan was developed by project personnel and approved by the Tennessee Department of Agriculture. The restoration plan calls for relocating cattle away from stream banks, the installation of buffers, repairing septic systems and manure storage structures.

1 Associate Professor, Biosystems Engineering and Soil Science Department, University of Tennessee, 2506 E J Chapman Drive, Knoxville TN 37996
frwalker@utk.edu

2 Pond Creek Watershed Project Coordinator, McMinn, Monroe, and Loudon Counties
107 West College St. Athens, TN 37303

3 Extension Associate, Biosystems Engineering and Soil Science Department, University of Tennessee, 2506 E J Chapman Drive, Knoxville TN 37996

HEC-RAS MODELING OF DAM BREAK SCENARIOS

Gregory H. Nail, PhD, PE[1]

This presentation documents a successful application of the Hydrologic Engineering Center-River Analysis System (HEC-RAS) software to model dam break scenarios. Recently, a dam break capability has been incorporated into the United States Army Corps of Engineers (USACE) HEC-RAS software. An existing HEC-2 river model was extended to include the entire reach between two artificial reservoirs. This HEC-2 model has been converted to HEC-RAS. A dam and reservoir have been appended to the upstream end of this HEC-RAS model, and dam break scenarios developed. The successfully completed model runs confirm the capabilities of HEC-RAS to model dam break scenarios. Modeling results predict increases in water surface elevations and velocities, as a function of time. These results point to bridges at risk for overtopping, or overbank areas at risk of flooding, in the event of a dam failure. Model predictions also quantify timing of the resulting surge as it moves downstream, and into the downstream reservoir.

1 Assistant Professor, Engineering Department, The University of Tennessee at Martin, Martin, TN 38238 gnail@utm.edu

HYDROLOGIC ANALYSIS OF THE OBED RIVER WATERSHED, CUMBERLAND PLATEAU PHYSIOGRAPHIC PROVINCE, TENNESSEE

George S. Law[1]

The Obed River watershed occupies 520 square miles of the geologically-complex Cumberland Plateau Physiographic Province primarily in Cumberland, Fentress, and Morgan Counties, Tennessee, and drains to the Emory River. The fast growing city of Crossville in Cumberland County is the center of commerce for this area and lies in the headwaters of the watershed. Much of the main stem of the Obed River watershed, in Cumberland and Morgan Counties, is part of the National Wild and Scenic Rivers System. Tennessee's Catoosa Wildlife Management Area surrounds much of the Obed Wild and Scenic River providing environmental protection. As with many areas throughout the United States, a fine balance is developing between regional growth and the protection of the scenic river and its surrounding natural environment.

Approximately 4,000 small impoundments, including agricultural farm ponds and fish ponds, and water supply and recreational lakes have been constructed in the Obed River watershed over the past 50 years. These impoundments have a total surface are of about 6 mi^2 or 3,840 acres, an average depth of about 10 to 15 feet. Analysis of rainfall and streamflow information has found no measurable effect that geology and impoundments might be having on streamflow quantity from the watershed. The continued development of farm ponds and fish ponds, and water supply and recreational lakes, with dams and embankments built atop stream channels could contribute to future measureable changes to the natural streamflow of the Obed River watershed.

The Crossville sewage treatment plant (STP) currently discharges about 2.2 million gallons per day or about 3.5 cubic feet per second of treated effluent to the Obed River upstream of the National Wild and Scenic River. During drought periods and the annual low-flow season, treated effluent may account for over 50 percent of the runoff from the watershed. In addition, the STP effluent augments streamflow quantity throughout the year.

CLIMATE CHANGE IN EAST TENNESSEE OR A "COOL" PLACE TO LOOK FOR GLOBAL WARMING - EVALUATING STREAM THERMAL VARIATION FOR PROTECTION OF EAST TENNESSEE COLDWATER FISHERY REGIMES.

Robert C. Benfield*

INTRODUCTION

Water withdrawal of Trout Belly Spring on Doe Creek located in Johnson County Tennessee provided an opportunity for modeling temperature variation of a protected coldwater fishery. Intensive temperature studies on Doe Creek, a high quality trout stream, are evidence of the diminutive temperature impact resulting from the pumping of the Trout Belly Spring as a public water supply. As a result of a near constant temperature and flow from Trout Belly Spring, predictive temperature modeling can be performed on the receiving stream. The ability to model temperature is just one factor that helped in the protection of this 1998-2002 drought-stressed section of Doe Creek. Likewise, it is encouraging to see that the Tennessee Wildlife Resources Agency (TWRA) has reported substantial increases to rainbow trout density and standing crop in recent years (Habera, Bivins, Carter, & Williams, 2004-5).

Studies of temperature regimes for the smaller flows found in the "cool" East Tennessee mountain spring fed streams are important for several reasons. The Environmental Protection Agency (EPA) has argued that drought and other long-term weather variations as well as geographic distributions influence prototypical temperature ranges for aquatic systems (Poole, Risley, & Hicks, 2001). Synthesis of these variables for East Tennessee would be of considerable value to future decisions.

The Mountain City Water Department performs nocturnal pumping of the Trout Belly Spring to supply water to the Northeast State Correctional Facility. Analysis of the temperature data has shown the need to reevaluate recommended restrictions on time of day pumping. According to US Fish and Wildlife Service (USFWS), species such as rainbow trout utilize acclimation periods leading up to temperature stress as adaptations for their particular niche (Armour 1991). Protection of this coldwater fishery might just be slightly enhanced by utilizing less prescriptive pumping times to facilitate optimized temperatures during acclimation periods. There are also offsetting benefits that may be realized by diurnal pumping. The natural habit of fish is to seek refuge during temperature fluctuations resulting from solar heating. Nocturnal variations are small in comparison to diurnal variation and notably diurnal variation is larger during lower flow conditions. Furthermore, daytime pumping will not adversely alter Doe Creek's use classification.

SETTING

Johnson County Tennessee, located in the Northeastern corner of the state, derives its public and private water supplies from groundwater sources. The two main geologic formations used as aquifers are the Cambrian Shady dolomite and the Rome Formation. Trout Belly Spring's nearly 3000 gallons per minute flow to Doe Creek is found just north of Pandora and forms a short tributary under Highway 67 to Doe Creek. The spring is located in the Rome Formation and has similar characteristics to other Rome Formation karst springs in the Carter and Johnson County areas. The Rome Formation karst springs typically have near constant parameters (flow, temperature, and water chemistry) and lack the magnitude of variation found in typical, younger geologic age karst springs receiving more concentrated recharge (Benfield, Hughes 1999). Doe

Creek is located in the Blue Ridge Province of Tennessee and the mountain trout waters overlap most of the Blue Ridge Province (see Figure 1).

METHODOLOGY

Fishery temperature metrics such as maximum daily maximum temperature (MDMT), maximum weekly maximum temperature (MWMT), and maximum daily average temperature (MDAT), and maximum weekly average temperature (MWAT) are used by federal and some state agencies for regulatory criteria (Essig 2003). These metrics are utilized in the U.S Department of the Interior *Guidance for Evaluating and Recommending Temperature Regimes to Protect Fish* (Biological Report 90 (22), 1991). The shorter diel (diurnal & nocturnal) patterns are thought to be important at the Doe Creek and Trout Belly Spring locations. The guidance metrics are not utilized as Tennessee criteria nor are year-to-year variation in averages.

Prior to consideration of the initial withdrawal permit April 4, 2000, diurnal modeling was used to compare expected temperature variation to Tennessee's Department of Environment and Conservation regulations for “trout waters”. The regulatory criteria state the water temperature change shall not exceed 3 degrees C and rate of change shall not exceed 2 degrees C per hour and not to exceed 20 degrees C maximum. Based on the best available data at that time, the withdrawal of 700 gallons per minute would be consistent with the trout waters criteria. The modeling input parameters used were estimated data and were adjusted to be conservative. The computed value of 1.5 degrees C maximum change was just under the 2 and 20 degrees C criteria. Since 1999, improvements in measurements have tuned the mixing equation-based model to accurately predict temperature to the detection limit (NIST data logger 0.2 degree C).

RESULTS AND DISCUSSION

As an added measure in the permit process the utility’s contractor suggested “night” pumping to avoid the higher daytime stream temperature time periods. This last minute recommendation did not consider scientific research on fish temperature tolerance response to increasing acclimation temperature and the nighttime pumping became a part of the state's permitting. Fortunately, the rate of 700 gallons per minute withdrawal is small in magnitude with respect to temperature and the time of day is of little consequence due to the short duration of pumping.

Approximately 5 cubic feet per second of water from the main Trout Belly Spring tributary flows into Doe Creek during pumping periods. As cited in Tennessee regulations, a “de minimis” change is no degradation (TDEC, 2004). The current rate of pumping does not cause any degradation. Less than 0.5 degrees C change to the temperature regime is evident under the optimum flow conditions to incur a maximum change. Reduced pumping rates, while not currently permitted, would also offset any cumulative effects of thermal stress in the postulated sub-lethal thermal zone. Armour (USFWS) made the relationship of monthly thermal statistics for recommended sub-lethal temperature regimes (as cited in Brett et al. 1982).

Review of TWRA reports and the history of this section of Doe Creek support the management of this fishery. Doe Creek’s history includes: special attention to large “lake-run” trout by TWRA, Field & Stream magazine, and local anglers: a special internal report by R. A. Shields recommending to TWRA that Doe Creek be taken off the trout list due to poor habitat; floods; droughts; and extra efforts to stock catchable fish, plant eggs, and once to make it a hatchery. It is beyond the scope of this investigation to comment on the vitality of the ecosystem and what makes it so outstanding or enhanced. However it is worth noting that natural indicators vary within most natural systems.

Year-to-year variations documented by the Idaho Department of Environmental Quality research (Essig, 2002) and possible climate variation should invoke a closer (or more detailed) look at temperature and acclimation periods. Scientific based metrics should be appropriate for use on these small watersheds. Ecosystem response to variations in physical parameters such as flow and temperature may be quite complex. Nocturnal pumping of Trout Belly Spring minimizes changes in daily maximum temperatures in Doe Creek. However, this nocturnal strategy results in diminished flows and elevated minimum temperatures when fish are not seeking refuge. In the absence of detailed scientific studies of the fishery, much uncertainty will remain concerning optimal time and duration of water withdrawal from the spring. Effects of solar radiation can be seen in Figure 2. Very quickly after sunrise, the temperature starts to rise in a non-smooth fashion. What is the best management in complex dynamic systems?

CONCLUSION

Currently there is a scarcity of surface water and spring temperature data for the mountain streams of East Tennessee. For this reason, it is a conclusion of this report that there needs to be a robust conceptual model developed to become a part of a strategy to protect habitats from further degradation. This model should be preceded with collection of more physical parameters in the environment. Any regional conceptual model should take into account quantity of flow and percentage of groundwater. The University of Tennessee found that spatial distributions of trout species correlate to elevation (Jackson Robinson, Moore, & Kulp. 2006). How much of this distribution is temperature and how much is physical or quality of habitat? Elevation reflects annual temperatures for groundwater springs. Higher elevations have lower groundwater temperatures. While known to karst scientists, this temperature relationship lacks widespread incorporation in biological studies. Synthesis of time and spatial domains are recommended.

TWRA identified water withdrawals, such as on Doe Creek, as a problem (Fiss, Habera 2006). TWRA should be applauded for their conservative approach to changes in the watersheds. There are considerable pressures on the resource that are often best dealt with rigid responses. At the same time, there is continual improvement in the understanding of environmental systems. Technology allows more resolution of dynamic conditions and in this case information to predict the magnitude of physical changes. This is why Trout Belly spring water withdrawal has been a success with respect to temperature criteria. See Figure 3.

ACKNOWLEDGMENTS

Thanks to family and friends who went with me to collect data and see that I did not drown in the creek. Special thanks to those who helped me with fishery biology including: Roger Petrie's rainbow trout temperature research, Dale Rector's expert knowledge of ecology, and Rob Limbom's fish protection work. Thanks to John Wojtowicz, PhD, and Tina Robinson for their help with benthic results interpretations. Thanks to Sid Jones, PhD, Yongli Gao, PhD and East Tennessee State students and friends for their modeling and field work, Thanks to Doug Cornett, the chief water plant operator, who told me of the folk song legend of Tom Dula being caught on Doe Creek as well as the stream alterations and iron-forge history plus local fishing habits.

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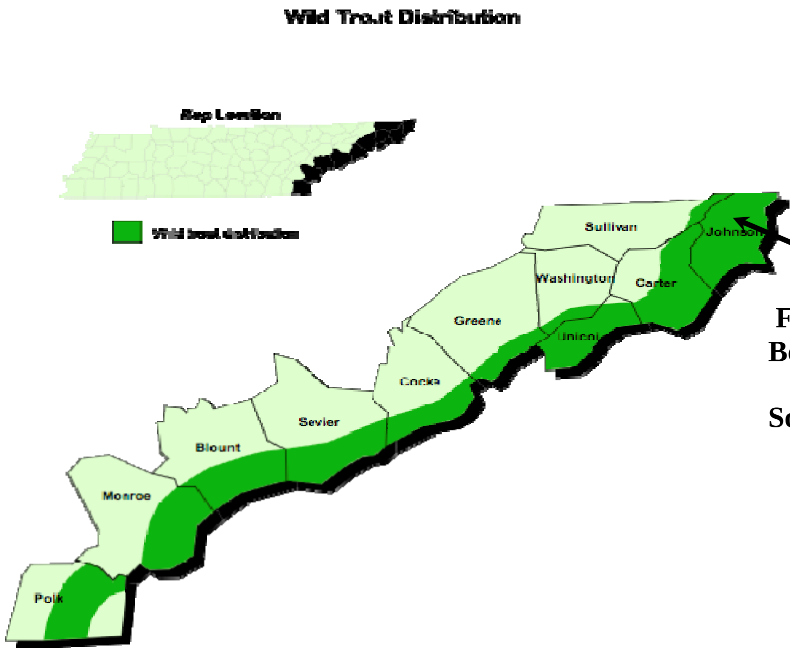

Figure 1. Location of Doe Creek and Trout Belly Spring

Source of map - TWRA

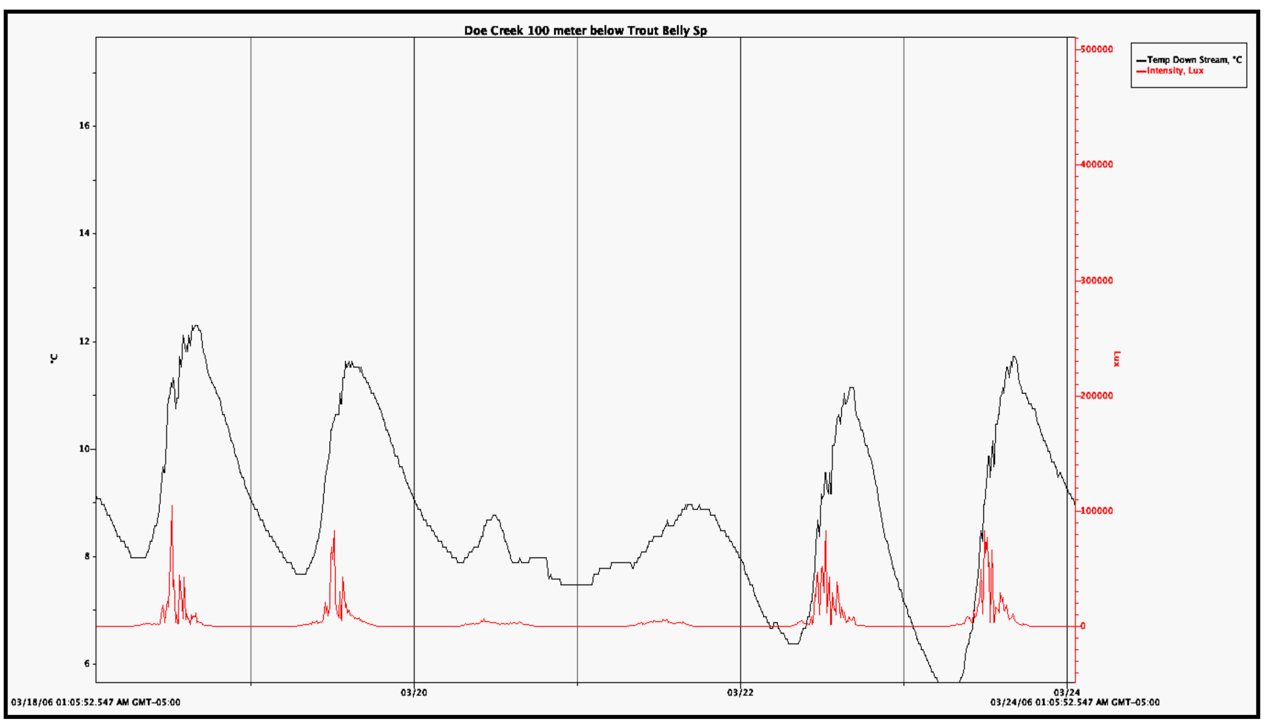

Figure 2. Light intensity (lower line) and temperature (upper line) of Doe Creek. The rising limb is variable and correlates to sun radiation causing 0.5 degrees C temperature spikes during the diurnal cycle. The falling limb is the nocturnal cycle and shows a slightly noticeable change when pumps are started. Note: the down stream temperature is less than 12.5 degrees C, the spring's constant temperature. Pumping lowers creek temperature and improves spawning conditions. Cloudy days in center.

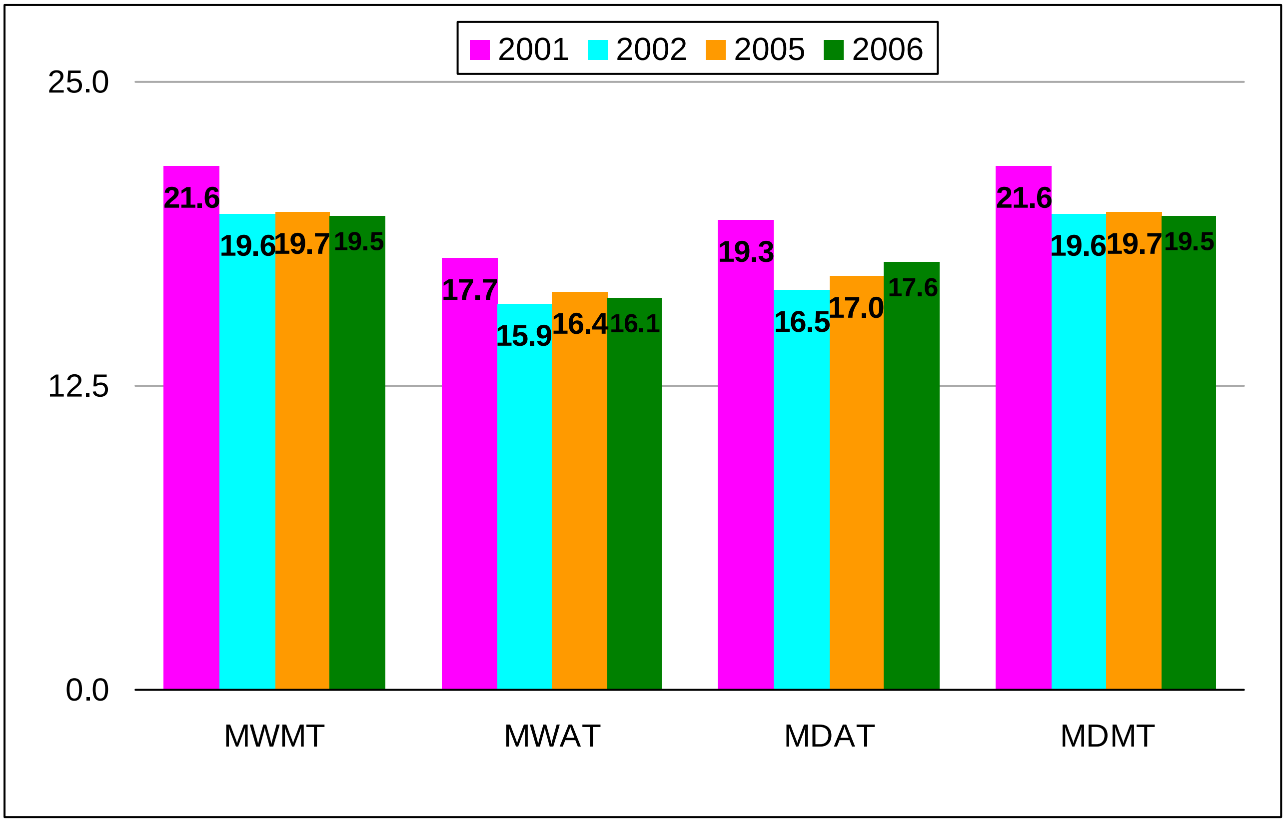

Figure 3. Doe Creek temperature metrics: maximum daily maximum temperature (MDMT), maximum weekly maximum temperature (MWMT), and maximum daily average temperature (MDAT), and the maximum weekly average temperature (MWAT). Water withdrawal started in 2002. Note the EPA monitoring and assessing water quality value for Rainbow trout MWAT average temperature for growth is 19 degrees C. Doe creek is at about 16 since pumping started.

DECENTRALIZED WASTEWATER TREATMENT IN TENNESSEE WHERE ARE WE AND WHERE ARE WE GOING?

Edward M. Polk, P.E.[1]* and Robert G. O'Dette, P.E.[2]

Decentralized wastewater treatment can be defined as small treatment/disposal systems that serve residential or light commercial developments and are located very near the homes or businesses where the wastewater is being generated. It is a rapidly growing and sometimes controversial concept in the wastewater field. Tennessee is getting its share of both the growth and the controversy. The Department of Environment and Conservation (TDEC) is charged with administering permits for such systems and reviewing the plans and specifications for their design. This presentation describes the nature of the treatment processes being utilized, including primary, secondary, and final land application of the treated effluent. A breakdown is given of where the systems are located and who are the private and public entities that are building and operating the systems. Photos of typical design components taken during construction are presented (these systems are mostly underground, thus making it difficult to visualize them once they are constructed and operating). Performance data is presented for typical systems. Effluent limitations, monitoring, and other permit requirements are described. The evolving TDEC regulations, design criteria and permit conditions developed to protect surface and groundwater are also discussed.

1 Manager, Permit Section, Division of Water Pollution Control, Tennessee Department of Environment and Conservation, 6th Floor L & C Annex, 401 Church Street, Nashville, TN 37243-1534, Edward.Polk@state.tn.us.

2 Assistant Manager, Municipal Facilities Section, Division of Water Pollution Control, Tennessee Department of Environment and Conservation, 6th Floor L & C Annex, 401 Church Street, Nashville, TN 37243-1534, Robert.O'Dette@state.tn.us.

EVALUATING MANAGEMENT NEEDS IN WATER RESOURCES AND SPILL RESPONSE ACTIVITIES

Janey Smith[1], Mark D. Abkowitz, and Eugene J. LeBoeuf

ABSTRACT

Inland waterways provide sources for drinking water, hydropower generation, and recreational opportunities for communities, habitats for aquatic species, and navigational pathways for freight transport. Management of these water resources involves the balancing of many competing demands, including the need to provide adequate protection in the event of a chemical spill event. Efforts to assist decision support capabilities of water resource managers include the development of a water quality and spill response system that combines geographic information systems (GIS) with hydrodynamic and water quality modeling. Creation of this Spill Management Information System (SMIS) involves the identification of major information requirements for individuals and agencies involved in water resources management and spill response activities. Among the sources for this information are critical reviews of relevant literature, after action reports from previous spill response activities and surveys of key stakeholders. Furthermore, individuals and agencies acting in specific roles during each of these situations may possess differing priorities. This paper provides results from an analysis of this hierarchy of information needs in water quality management and spill response activities, including the identification of areas of conflicting priorities and.

INTRODUCTION

Management of the nation's inland waterways today includes making difficult decisions and attempting to meet the demands of many. Our inland waters provide drinking water and hydropower for communities, recreational delight for many, habitats for aquatic species, and navigational pathways for freight transport. Each user desires their needs to be met with a certain level of water quality expected. Water resource managers are faced daily with the task of trying to meet many of these expectations.

In 1972, the U.S. Environmental Protection Agency (EPA) Clean Water Act mandated "states, interstate agencies, municipalities, and industries to develop comprehensive programs for preventing, reducing or eliminating pollution, and improving the sanitary condition of surface and underground waters." More recently, the *2006-2011 EPA Strategic Plan* calls for improved standards, protection of source waters, security of water infrastructures, and improved quality of rivers, lakes, and streams (EPA 2006). In addition, mangers must be prepared to protect these valuable resources in the likelihood of a chemical spill. How are the agencies and individuals involved in management of our waterways to meet these many objectives?

In an effort to assist water resource managers in meeting these demands, efforts are underway at Vanderbilt University to develop a similar system that can be used not only for spill response with improved modeling capabilities, but also in water quality management. The system will provide valuable information in a decision supporting capacity. Furthermore, we suggest that this can be accomplished through visual communication using systems such as the Spill Management

1 Vanderbilt University, Department of Civil and Environmental Engineering, Station B # 351831, Nashville, TN 37235. janey.v.smith@vanderbilt.edu

Information System (SMIS) which combines geographical information systems (GIS) with hydrodynamic and water quality modeling to show contaminant plume migration in a riverine system (Martin, LeBoeuf et al. 2004).

To create such a system, the major information needs of individuals and agencies involved in water quality management and spill response activities must be identified. The objectives of this portion of the project were to perform an analysis of the current literature and survey key stakeholders to develop a hierarchy of such needs. Survey results would subsequently direct our efforts in developing a system that is responsive to them. The following is a presentation of preliminary results of our efforts to implement and test a chosen survey procedure and gather information for future work.

LITERATURE REVIEW

The following is a review of the literature pertaining to the goals of this research in areas of water quality management, spill response, stakeholder involvement, and survey techniques. While, it is by no means an all inclusive review, it does represent sufficient coverage to be indicative of the state of the practice.

WATER QUALITY MANAGEMENT

One might ask "What is water quality management?" Biswas suggests that the main objectives of water management include "improved standard and quality of life of the people, poverty alleviation, regional and equitable income distribution, and environmental conservation" (Biswas 2004). Effective water management can include reconciling conflicting interests of conservation, irrigation, drainage, supply, flood control, hydropower, waste, recreation, and others (Grigg 1996). Problems facing management officials consist of greater demands on available resources due to population growth, higher standards of living, and contamination of the current sources (Bouwer 2000).

SPILL RESPONSE ACTIVITIES

Today, the number and severity of oil spills in the U.S. has been reduced thanks to planning and mitigation efforts by the USCG and other agencies (Burns, Pond et al. 2002). However, thousands of inland waterway incidents, including oil spills which threaten water supplies and public health, are still reported in the United States each year (NRC 2005). It is imperative that managers be prepared for emergency accidental or intentional chemical releases in addition to daily operations.

Presently, management of spill response activities in U.S. waters is directed by the National Response Center (NRC). In the event of a spill, an on-scene-coordinator (OSC) is contacted. For inland waterways, an Environmental Protection Agency (EPA) OSC responds, and for coastal regions, a U.S. Coast Guard (USCG) OSC takes control of the situation. He or she is responsible for managing federal spill response actions. After notification of a spill, the OSC assesses the size and nature of the spill along with potential hazards and the necessary resources for containment and clean-up operations. If the incident warrants federal involvement, the appropriate regional response team may be activated to assist in response activities. Additional support from the EPA's Environmental Response Team can be obtained if necessary.

To assist in information handling during response activities, documentation is performed using Incident Command System (ICS) forms. The On Scene Command and Control (OSC^2) system was developed for the use by the USCG in spill response activities. OSC^2 manages ICS forms, a database of spill response resources, oil spill modeling and GIS components (Anderson, Galagan et al. 1999).

Efforts at Vanderbilt University to assist agencies in responding to inland waterway incidents include development of both an inland marine transportation risk management system and an inland marine hazardous materials response database (Dobbins and Abkowitz 2002; Dobbins and Abkowitz 2003; Martin, LeBoeuf et al. 2004), in addition to the Spill Management Information System (SMIS) (Martin, LeBoeuf et al. 2004), which preface the current work.

STAKEHOLDER PARTICIPATION

Participation in the decision making and management processes by stakeholders (whether they be multiple agencies or the general public) on a multitude of issues has increased in recent years. Yosie and Herbst suggest this increase in stakeholder involvement comes from the "lack of public confidence and trust in the environmental decision making of many government agencies and corporations…and the increasing transparency of institutions whose decisions affect environmental quality" (Yosie and Herbst 1998). Government sanctions calling for stakeholder participation. Another explanation is the increasing complexity of water management issues. Today, water quality is more interconnected with social, economic, environmental, and political factors and cannot be necessarily be solved by water professionals alone (Biswas 2004).

Involving stakeholders in the decision making process has many benefits. One such benefit is the acceptance of policies and regulations established by government offices by giving the stakeholders a voice, thus developing their trust in the process. Another benefit from stakeholder involvement is the establishment of a common vocabulary between policy makers, scientists, and the public (Borsuk, Clemen et al. 2001).
A simple way to evaluate the views of stakeholders and gauge their interest in water management issues is through administering surveys to interested and/or invested parties. Borsuk, et al. used surveys, phone and personal interviews, and public meetings to identify stakeholder values and objectives for management of the Neuse estuary (2001).

Stakeholder participation can also play an important role in spill response management activities. In a presentation at a recent meeting of the Region 4 Regional Response Team (RRT4), "Review of Successes/Problems/Ideas for Improvement," they identify the need for "early coordination of stakeholders and clear definitions of roles, responsibilities and needs [in emergency response activities]" (RRT4 February 2006). Action items from the August 2006 meeting include increasing involvement of state and federal agencies in their meetings and activities (RRT4 2006). Both of these calls for action demonstrate the usefulness and necessity of the current research. On a larger scale, USCG is reportedly gathering stakeholder input on oil spill prevention and response through workshops and conferences (Burns, Pond et al. 2002). The authors are unaware of publication of the findings from this effort and are focused on a smaller region and chemical releases including, but not limited to oil.

SURVEY METHODOLOGY

To evaluate common interests and information needs of water quality management and spill response personnel in the southeastern United States, a survey was administered to several individuals in leading roles. Preparatory work included evaluation of online survey systems and identification of possible participants. A discussion follows outlining the steps taken toward administering the water quality management and spill response survey.

ESTABLISHING STAKEHOLDERS

A large percentage of our nation's inland waterways are located within the southeastern region. This fact alone makes the area a useful sampling ground for stakeholders to participate in the project. An initial sweep to identify potential stakeholder agencies was performed via online searches and email requests to identify personnel within these agencies who could provide useful feedback in water quality management and spill response. Individuals with prior knowledge and close working relations to our research group were contacted for information to develop a focus group of supervisory individuals and additional contacts who participate in water quality and spill response activities.

Leading agencies in the region involved in water resource/water quality management include: Tennessee Valley Authority (TVA), U.S. Army Corps of Engineers (USACE), The Environmental Protection Agency Region 4, U.S. Fish and Wildlife, local utilities, and local governments. The Region 4 Regional Response Team (RRT 4), a group of individuals representing many of the aforementioned agencies and responsible for training activities, exercises, and responding to releases of hazardous materials and oil spills in the southeastern United States, was also considered for participation. Supervisory individuals for many of these agencies were contacted and asked to participate in the survey. The final list of participants included at least one highly qualified member of each of the following organizations:

- U.S. Coast Guard (USCG), District 8
- U.S. Environmental Protection Agency (EPA), Region 4
- U.S. Army Corps of Engineers (USACE), Nashville District
- U.S. Fish and Wildlife Service (FWS)
- U.S. Department of Homeland Security (DHS)
- Region 4, Regional Response Team,
- Tennessee Valley Authority (TVA)
- Tennessee Department of Environment and Conservation (TDEC)
- Nashville Metro Water Services
- The O'Brien's Group, an independent emergency response management services company

Personal communication and emails were used to enlist participants and develop repertoire prior to administering the survey. Overall, the expressed interest in the research was positive and participation in the survey was expected to be high.

SURVEY IMPLEMENTATION

The survey consisted of two parts. Part I focused on water quality management issues and Part II focused on spill response activities. Each part consisted of 12 questions (see Appendix A). The questions were aimed at gaining general information about what each participant views as having greatest importance in their role.

A mixture of free-response, rating, and multiple choice questions were used. Free response questions were used to allow participants to openly express their views on issues such as their identification of key challenges in water quality management, where multiple choice questions would not be adequate. The first question of Part II, was used to identify whether or not survey participants were involved in spill response activities. A selection of "not involved," concluded their participation requirements.

Two versions of the survey were provided for participants: (1) online and (2) printable. It has been shown that online surveys are just as effective as paper surveys (Ladner, Wingenbach et al. 2002). Participants were allowed one week to respond to the questionnaire. Hamilton believes that most surveys are completed within the first day after dissemination (Hamilton 2003), so allowing for an extended time period for survey completion may not be effective in increasing response rates. Surveys were sent to participants via an email containing introductory information, instructions, and both a link to the online survey and a pdf file attachment of the printable version.

RESULTS AND DISCUSSION

In total, 22 Phase I surveys were administered and 11 responses were received, resulting in a response rate of 50%. This could be considered a high response rate according to Hamilton (Hamilton 2003). Respondents primarily consisted of individuals that work for a government agency. The roles represented included all of the following: technical support staff, regulations developer, private industry member, utility provider, and environmental manager.

PART I: WATER QUALITY MANAGEMENT

Survey participants were asked what good water quality management meant to them. Several objectives for water quality management were suggested and participants were asked to rank them in order of importance ranging from "not important" to "very important" (Figure 1).

When considering the relative importance of uses of our inland waterways in the management process, i.e. the competing demands that must be met, the distribution became interesting. Each use was ranked from not important to very important by survey participants. A hierarchy of the importance of each use is shown below (Figure 2). Surprisingly, habitat for aquatic species was rated only slightly higher than maintaining public water supplies. Both of these items were considered of high importance in other studies (Borsuk, Clemen et al. 2001). Hydropower, while being considered the nation's leading renewable energy source and contributing nearly 95,000 megawatts of power each year (DOE), was ranked lowest. Surprisingly, recreation was valued higher than hydropower. This may come from lack of knowledge about hydropower or its societal contributions. Further investigation is necessary to determine the causes for this result.

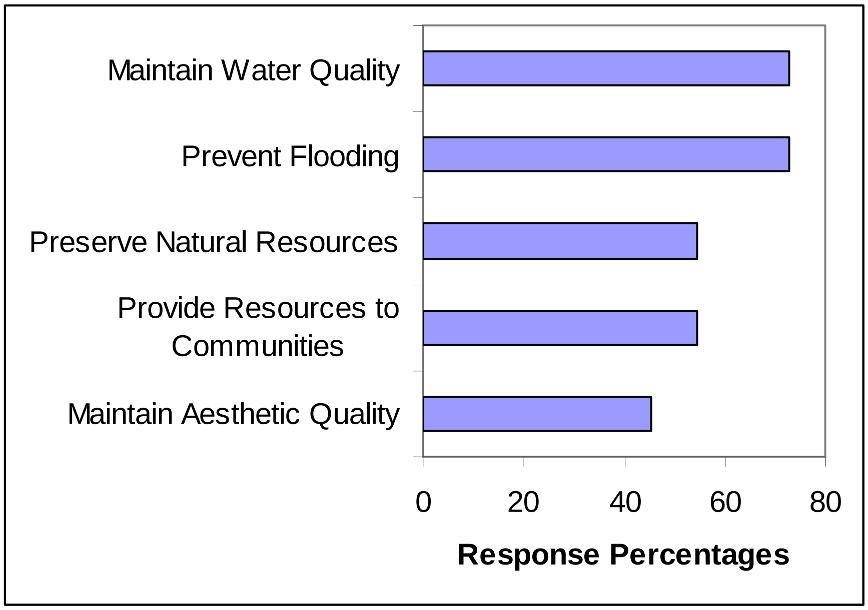

Figure 1: Management Objectives as Percentages Marked as "Very Important"

A similar question was posed about the sources of contamination/dangers to the quality of our inland waterways. Items for consideration included contaminant spills, agricultural and urban runoff, and discharges from both wastewater treatment plants (WWTP) and industries (Figure 3). For this question, an "other" category was included where participants could specify any threat not already considered in the question. Additional responses included silviculture/forestry, overuse, and bypass of sewer systems. Leading concerns are for non-point source pollution from agricultural and urban runoff. One possible explanation is the lack control of discharge from these sources compared to those regulated by the National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act (CWA), where point discharges from industries and wastewater treatment plants are permitted (1972).

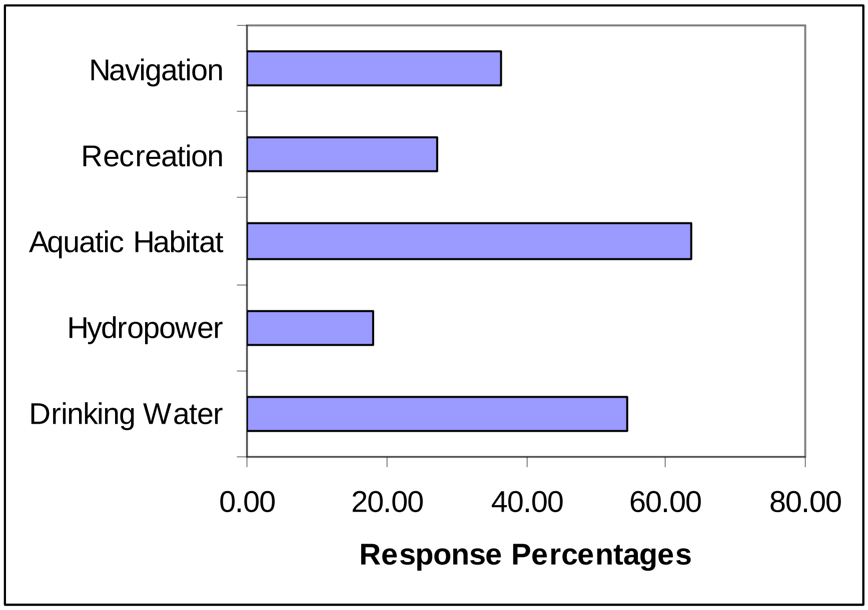

Figure 2: Relative Values of Water Resource Uses Based Upon Selection of "Very Important" Ranking.

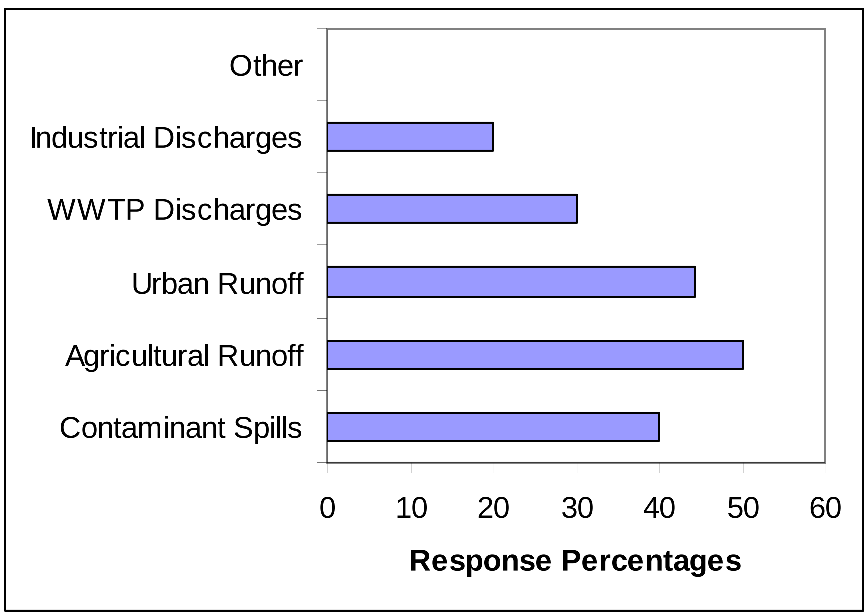

Figure 3: Threats to Water Quality as Percentages of Responses as "Very Important"

Most survey participants said that they are either directly involved in development of water quality standards or have a voice in the establishment of such standards. This indicates that communication in regulation development among agencies exists. However, one respondent listed the greatest challenge faced in water quality management as being the lack of willingness of regulators to work with the public, which suggests that public involvement is lacking or communication bridges must be made.

When asked about the role of public involvement in water quality management, most participants stated that public participation was essential for the success of water quality management. To quote one, "Local watershed groups are an invaluable asset for policy development." Another stated that the only way for a policy to be successful was through public support. On the contrary, one said that he/she felt the public could care less. However, this individual and others commented, even though it was not directly addressed in the survey, that public education is essential in water quality management through active pollution prevention and clean up activities. Overall, management agencies agree that public participation and stakeholder involvement are necessary for effective management. A similar assessment of the perspectives of local and regional government agencies focused on storm water management issues was performed by the Water Management Association of Ohio and Water Resources Foundation of Ohio. They found that collaboration between communities and regulators was essential in good management practices. Furthermore, improved education of the public was identified as a need to improve management of water resources (OHSTF Ohio Storm Water Task Force).

Other challenges mentioned included lack of adequate funding, difficulties in enforcing regulations, managing pollution from agricultural and storm water runoff. The most commonly reported challenge involved balancing the many demands of end users while protecting environmental and water quality interests. This was expected. Furthermore, this is supported by the comments about whether or not a consensus has been reached for practices for maintaining the quality of our inland waterways. Most said that no consensus had been reached and referred to the differing objectives of multiple organizations. While best management practices (BMPs) exist for some water quality issues, the priorities for implementing these vary across organizations. On a positive note, a few respondents felt that coordination of activities between agencies is improving.

To gauge the possible usefulness/comfort level of surveyed individuals in using a system such as the one under development, they were asked about their confidence in use of water quality models for decision support and their personal comfort in use of GIS. Nine out of eleven members stated that they were at least somewhat confident in modeling as a support technology. Similarly, eight of the eleven are knowledgeable in the use of GIS. Therefore, we can expect that individuals acting in water resource management capacities would be able to utilize our system (with minor training).

PART II: SPILL RESPONSE

The majority of survey participants (10 of 11) indicated that they were involved in spill response activities. This level of involvement could explain the high ranking of contaminant spills as a threat to water quality. Participants indicated their roles in spill response activities to be primarily technical support or leadership positions.

Several questions focused on immediate concerns and responses at the onset of a spill response activity. When asked to identify the first question each respondent is required to answer during a spill event, 60% indicated that the location of the spill was the foremost item of consideration. A follow-up question asked about the first answer they must provide to others. Many of the responses centered on human health and safety. Others noted that considerations involve determining whether action is needed, what authorities had been notified, and what are the projected impacts downstream. The leading objectives during response to an inland waterway spill event consisted of protecting the well being of water intakes, responders, and the public.

Beyond the initial objectives and response efforts, participants were asked about their values during a spill event (Figure 4). One question focused on the importance of protecting the uses that were previously considered during normal management operations (Part I) and another focused on the value of various types of information during a spill event. For the first question, water intakes and habitats for sensitive species were given priority, but in opposite ranking from their importance for daily management (Figures 1 and 4). As could be expected, knowing the locations of the contaminant plume and downstream water intakes were of highest importance for the other question (Figure 5).

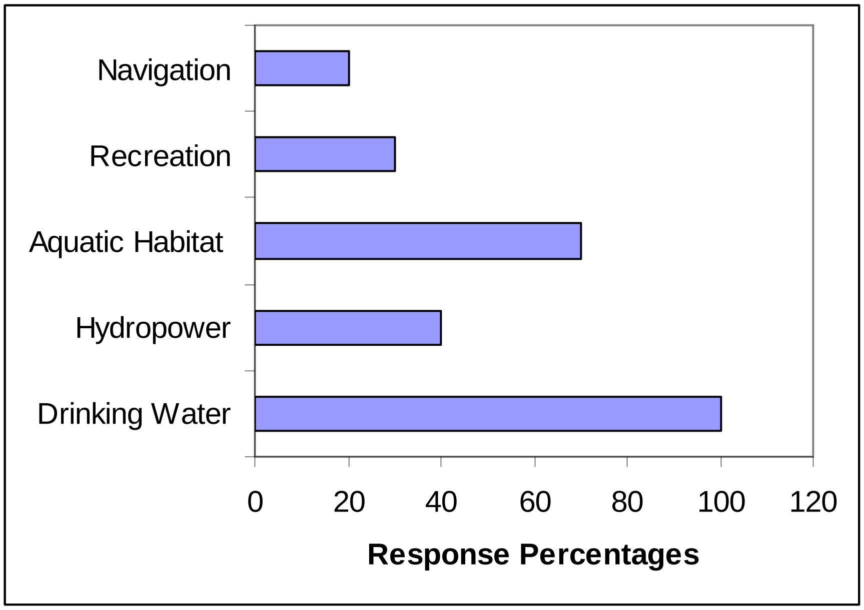

Figure 4: Importance of Uses During Spill Events as Percentages as "Very Important"

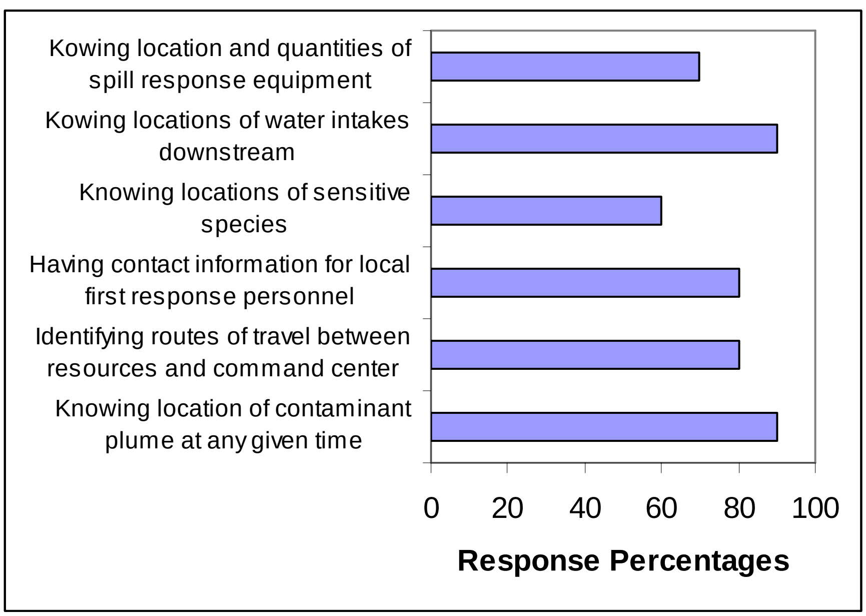

Figure 5: Information Needs During Spill Response Identified as "Very Important"

Further inquiries focused on the preparation of the individuals and their organizations for spill/emergency response efforts. All survey participants, except one, indicated that their organization has an emergency response action plan in place and they are generally aware of the protocols defined in it. Over 80% responded that their organization utilizes each of the following preparation measures: spill response exercises, incident plans, scenario development/modeling, HAZMAT training and first-aid and safety training. One indicated in the "other" option that his organization needs improved emergency response plans and development of scenarios. To further evaluate the benefits of such preparatory efforts, survey participants were asked to rank the effectiveness of planning techniques (Figure 6). According to the responses, having contact information for key response personnel was valued most indicating that communication and organization are key in these activities. Closely related in importance are having available information resources and knowledge of personnel duties/chains-of-command. Again, this shows the necessity of communication during spill events. Overall, 90% of the respondents indicated that they felt reasonably or well prepared to respond to a chemical spill if one were to occur today, which is comforting news. The one who indicated being somewhat prepared and interested in more training may have also been the individual who stated that his organization needed improved emergency planning.

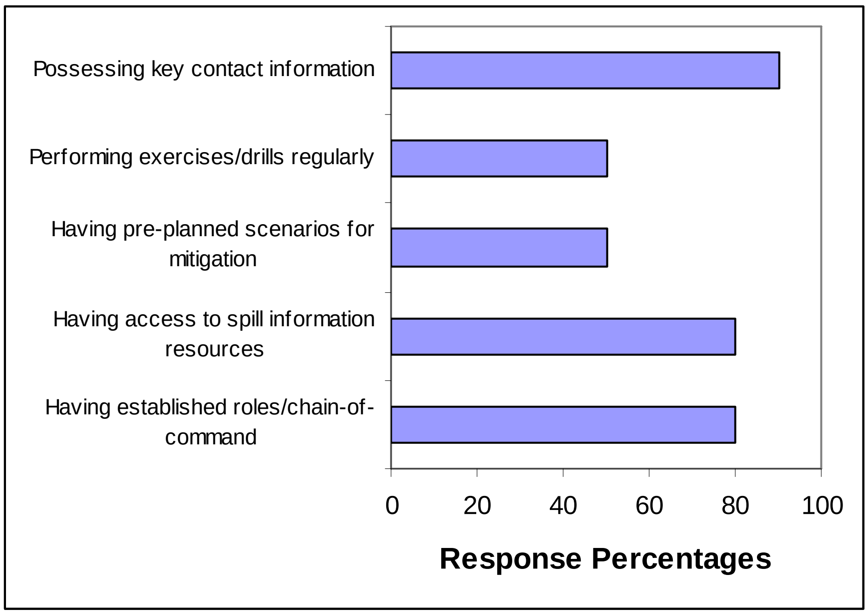

Figure 6: Effectiveness of Preparation Strategies as Percentages Marked "Very Effective"

CONCLUSIONS

Through evaluation of the literature and input via participation in a survey, we have identified issues of key importance during water quality and spill response management of our inland waterways. A small, but highly informed, focus group was asked to provide its views on several issues related to the two fields.

While many indicated that they felt a consensus did not exist among leading agencies on how to manage our water resources, some consensus did exist. Common trends among responses indicated that increased involvement and communication among management agencies and the public are essential to successful management of our water resources. This included the need to educate the public on prevention and environmental issues. Communication was found to be of high importance for both water quality and spill response activities. As expected, one of the major challenges in water quality management is meeting the demands of many end users.

Another key challenge is stakeholder involvement both from the associated agencies and the public sector. Further analysis should be performed to determine possible avenues for public involvement/education and how to best involve parties with differing values/demands to ensure proper management and protection of our waterways.

Hierarchical rankings of values in management objectives, values of resource uses, and threats to water quality were evaluated. Objectives of highest importance were maintaining the quality of our inland waterways as public water supplies and flood prevention. Greatest value was placed upon these waters as sources of drinking water and habitat for aquatic species for both daily management and spill response activities.

Most individuals felt prepared to respond to a chemical spill today. All indications were that the preparation efforts currently used at their organizations such as HAZMAT training, performance of drills/exercises, and scenario development are effective in helping prepare response personnel. Key components of information needed to assist in response activities were identified as locations of the contaminant plume and water intakes. Of utmost importance was consideration for human health and safety.

For the spill response survey (Part II), greater agreement in values and objectives existed than for the management part. The split responses concerning involvement of the participants in establishing water quality standards suggests additional investigation should be performed to identify the causes for lack of involvement and establish ways to improve communication between these agencies. Ideally, the results of this study and future studies in this area will assist in bringing about consensus as well as guiding development of the envisioned water quality management and information system.

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EXAMINING THE IMPACTS OF URBANIZATION ON HYDROLOGIC RESPONSE FOR THE ENSOR SINK WATERSHED, COOKEVILLE, TN

Britton D. Wells[1] and Vincent S. Neary, Ph.D., P.E.[2]

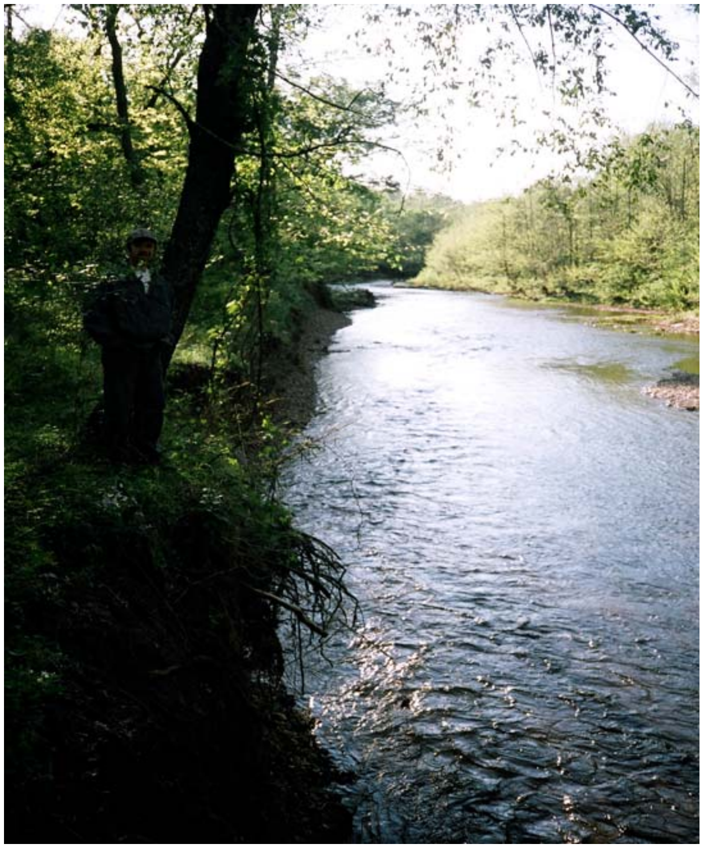
Cookeville, the largest city in the Upper Cumberland, has experienced higher-than-average growth in the past decade. As a result of new industries and businesses moving to the area, urbanization has expanded and natural resources have been adversely impacted. Urbanization of Cookeville has increased paved, impervious land areas in the Pigeon Roost Creek watershed, particularly in the sub-watershed, the Ensor Sink catchment, and has significantly altered the watershed's water budget and hydrologic response. Parking lots, rooftops, and roads have contributed to large areas of impervious land; thereby increasing the volume, flow rate, and rapidity of stormwater runoff. This increases the potential for downstream flooding, channel erosion, and water quality degradation. Many of the developments during the past decade have also filled wetlands, which naturally store stormwater runoff and reduce flooding downstream. The impacts of urbanization on the water budget and hydrologic response of the Ensor Sink catchment were assessed in this study using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). The model was calibrated and validated for existing conditions using precipitation and streamflow measurements collected over a two year period. It was then used to predict the hydrologic response for three design storm events with return periods of 2-, 10- and 50-years. Impacts of urbanization were evaluated by comparing the predicted peak flows, volume and time to peak for these design events with those assuming pre-developed conditions; one in which the watershed is assumed to be completely wooded and the other predominantly pasture.

1 Graduate Student, Tennessee Technological University, Center for the Management, Utilization and Protection of Water Resources, P.O. Box 5033, Cookeville, TN 38505 bdwells21@tntech.edu

2 Associate Professor, Department of Civil & Environmental Engineering, Tennessee Technological University, P.O. Box 5015, Prescott Hall Room 339, 1020 Stadium Drive, Cookeville, TN 38505 vneary@tntech.edu

HEADWATERS OF THE HARPETH RIVER: WATER QUALITY AND HABITAT STUDY

Mike Cain and John McFadden



WATER QUALITY AND HABITAT STUDY INTRODUCTION

The Harpeth River Watershed Association (HRWA) is a 501(c)3 not for profit conservation organization. HRWA's mission is to restore and protect the ecological health and biodiversity of the Harpeth River system for the people, fish and wildlife that depend on it by building an organization that provides scientific and technical foundation to efforts to improve and protect the river system and when applicable to influence statewide water policy. HRWA's guiding principles establish that all work, from outreach to policy and politics, is based on a scientific and technically accurate understanding of watershed ecology and that it utilizes the vast resources of trained volunteers in every aspect of its work, including data collection and restoration. Finally, HRWA strives to work collaboratively in all possible areas with other organizations to further common goals. With the help of its science advisory council, HRWA designed and implemented the *Headwaters of the Harpeth River Water Quality and Habitat Study* detailed in this report.

The Tennessee Department of Environment and Conservation's (TDEC) 2006 303(d) List identifies the cause of degradation in the Harpeth River headwaters generally as alteration in stream-side or littoral vegetative cover, siltation and pollutant sources such as pasture grazing and removal of riparian habitat. The 303(d) List identifies Concord Creek, an unnamed tributary to the Harpeth River, Kelly Creek and Cheatham Branch as being impaired. Following is a brief description of each system's impairment as reported by TDEC's 303(d) List.

Fifteen and one tenth (15.1) miles of Concord Creek (TN13204018-0200) are identified as impaired as a result of "alteration in stream-side or littoral vegetative cover and siltation" with the specific source being identified as "pasture grazing and removal of riparian habitat." One and three tenths miles (1.3) of an unnamed tributary to the Harpeth River (TN05130204018-0300) are identified as impaired as a result of "alteration in stream-side or littoral vegetative cover and siltation" with the specific source being identified as "pasture grazing." Nine and three tenths (9.3) miles of Kelly Creek (TN05130204018-0400) are identified as impaired as a result of "alteration in stream-side or littoral vegetative cover and siltation, *E. coli*" with the specific source being identified as "pasture grazing." Three and four tenths (3.4) miles of Cheatham Branch (TN05130204018-0500) are identified as impaired as a result of "alteration in stream-side or littoral vegetative cover and siltation" with the specific source being identified as "pasture grazing."

In addition to the 303(d) List, HRWA in 2001, conducted a visual stream assessment (VSA) of over 200 sites along 303(d) listed stream segments. Among other things, the VSA revealed that over 50% of sites surveyed had occasional (75% of best case) or common (50% of best case) bank erosion, in addition to riparian impairment. Of the 200 plus sites, seven were in the headwaters area and the data from these sites generally indicated that wide spread habitat degradation and nutrient enrichment (see Figure 2) were problems. For example, riparian scores for the east fork of Kelly Creek were 1 (poor) out of 5 (optimal) for both right and left banks, and there were agricultural land uses noted adjacent to the stream. In addition, quality control data collected by the principle investigator indicated the same.

As a result of the VSA data and the 303 (d) list data, HRWA designed and implemented the *Headwaters of the Harpeth River Water Quality and Habitat Study*. The purpose of the study was 1) to validate the existing HRWA and TDEC data and 2) to begin to identify areas contributing to the identified impairment in an effort to begin the restoration process.

This project is funded, in part, under an agreement with the Tennessee Department of Agriculture, Nonpoint Source Program and the U.S. Environmental Protection Agency, Assistance Agreement, #C9994674-03-0. Grant contract #GR-04-15878-00.

METHODS

HRWA collected physical/chemical data and habitat quality data at 16 locations (Figure 1) in the headwaters located in Eagleville/Rockvale area in Rutherford County, Tennessee. Physical/chemical and algal information were collected nine times from May 2005 to May 2006 and included location (latitude/longitude), total nitrates, reactive phosphorus, pH, turbidity, conductivity, stage and algal growth. Habitat quality data were collected at each site once during the fall of 2005.

Physical/Chemical/Algal Data

HRWA collected one-liter grab samples at each location and utilized a Hach DR/890 Colorimeter for nutrient (TN method #8171, & TP method # 8048) and other parameter analysis as appropriate (e.g. turbidity method #8237). Dissolved oxygen data was acquired via LaMotte chemical test kit (model #5860), while temperature and conductivity (model #HI 8733) and pH (model #HI 93100) were collected utilizing a pair of Hanna instruments. Initially all samples were to be processed in the field, however due to the number of sites and time required to carry out sampling, nutrient samples were placed on ice and processed in the lab. Stage was measured initially in May of 2005 and recorded as base. The subsequent measurements were collected from the same prominent point on the stream overpass and recorded as difference from base. Finally, algae growth was assessed on a scale of 0 to 5 based on estimates of percent of coverage with 0 being no coverage and 5 being 100% coverage.

Habitat Quality Data

The habitat assessment was conducted in accordance with the EPA Rapid Bioassessment Protocols (Barbour et al., 1999) and Tennessee's Standard Operating Protocols (TDEC, 2002). The habitat assessment consisted of 10 parameters measured visually by the investigator. For example, riparian zone, stream bank stability and available cover for aquatic life are scored from 1 – 20 at each sampling station. The total score represents the condition of habitat with reference to the specific site. Individual scores range from 0 – 20, with a maximum possible score of 200. The higher the habitat assessment score, the greater habitat suitability for fish and aquatic life.

RESULTS

The purpose of the study was to further validate existing HRWA and TDEC data and to begin to identify areas contributing to impairment in an effort to begin restoration. HRWA along with TDEC have documented physical/chemical, biological and habitat impairment in the headwaters of the Harpeth River. The results of this study include data on the physical/chemical, habitat and biological characteristics (algae) of these aquatic systems.

Physical/Chemical

Average and minimum/maximums for physical chemical data are included in Table 1 Appendix II. These data sets were collected over a period of one year at 16 different locations. The complete data file can be acquired from hrwa@harpethriver.org. Data for sites 17 and 20, in Table 1 are absent, as these sites were never observed with flowing water. Figures 4–15 (Appendix I) present physical chemical data for sites 5, 10, and 13. The data generally show pollutant loads associated with increased flows as measured by stage. For example, site 13 total phosphate increased from 0.15 mg/l to 0.54 mg/l, while flow increased from 0.2 to 0.5 feet above base from February to March 2006. Turbidity also increased from 8 to 22 NTUs, while temperature almost doubled 7 to 13 degrees C. Dissolved oxygen decreased during this time period from 11.0 to 6.8 mg/l and nitrate levels decreased from 1.9 to 0.5 during the same time period. The decrease in nitrate levels may be due to increased algae activity. However, the algal measurement stayed the same (2) during this time period.

Site 10 data was similar to 13, however total phosphate decreased from 0.33 to 0.26 mg/l, while flow increased from 0.2 to 1.3 feet above base from December 2005 (no sample in January) to March 2006 (February and March flow was 1.3 feet above base). Turbidity increased from 33 to 47 NTUs while temperature increased from 9 to 14 degrees C from February to March 2006. Dissolved oxygen decreased from February to March 2006 from 9.0 to 6.8 mg/l and nitrate levels decreased from 0.5 mg/l to below detection limits during the same time period.

Figures 17 through 20 include data from sites 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 16. These data appear to generally indicate that pollutant loading occurred during the wetter months (November, 2005 – April, 2006). However, during September 2006, turbidity data from site 11 indicate low flow sediment loading (Figure 18). During the fieldwork, it was noted that construction of a gravel road had been completed immediately adjacent to the unnamed tributary. This activity apparently was the cause of the increased turbidity levels.

Habitat Quality

Habitat scores for each site are presented in Figure 3. Scores ranged from about 70 to 140 out of 200 with an average score of 92 or less than 50% of optimal habitat condition. The typical site has a highly impacted riparian zone with little of no forest buffer and failing stream banks, likely associated with livestock access and increased storm flows. In addition, habitat data indicate significant channel modification (channelization) and in-stream sedimentation. The data indicate wide spread riparian, bank and in-stream habitat degradation. Given the historic land use and propensity to channel the streams and tile (drain) surrounding lands this level of habitat degradation is not unexpected.

Algae

Alga percent coverage was estimated by the investigator and recorded utilizing a scale from 1 to 5, with 1 representing less than 20 percent and 5 representing greater than 80 percent surface coverage. Average algal values for each site are included in Table 1 with sites 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 16 data presented in Figure 20. The highest values tended to occur during the month of May 2006 (nine sites), followed by the month of October 2005 (two sites). This may be related to the availability of nitrogen in the water column and associated with agricultural fertilization practices. It also appears from the data as presented in Figures 15.1, 15.2, 15.3 and 20 the level of algal coverage decreased during higher flow periods, higher nitrate and phosphate levels.

CONCLUSIONS AND RECOMMENDATIONS

The Harpeth River Watershed Association (HRWA) initiated the headwaters study to further validate existing HRWA and TDEC data and to identify areas contributing to impairment in an overall restoration effort. The study documents widespread habitat degradation, in addition to indicating existing pollutant loads are generally tied to nonpoint source pollution, however in some cases causes were observed directly related to land use changes adjacent to tributary systems. Unfortunately, the data do not indicate any one area as contributing a mass pollutant load. Conversely, the data indicate impairment appears to be a result of agricultural and municipal land use, in part resulting in wide spread habitat degradation. Habitat degradation seems to be the most obvious and widespread problem related to current land use in the headwaters. Thus, our recommendations focus on habitat restoration and include additional monitoring.

Habitat Restoration

HRWA has, for the past three years, met with landowners, citizens, NRCS employees and government leaders in an effort to develop a stakeholder-based watershed enhancement plan. Stakeholders recognized that channelization of the many tributary streams is not likely to be corrected. Yet, project staff working with the local Watershed Enhancement Committee, have developed a watershed enhancement plan that calls for relatively simple activities designed to increase habitat and bank stability and deal with some of the more obvious problems. The core of the restoration activities called for includes reforestation of riparian zones, stabilization of stream banks and increased sinuosity in existing channels.

Riparian reforestation consists of two basic activities, including: 1) removal of the cause of degradation and 2) restoration of the vegetative community. In addition, some hydrologic conditions may need to be restored. Removal of the cause of degradation includes livestock exclusion and provision for alternative water supply. Alternative water supply may be provided by one of two mechanisms, placement of trough or tank outside the livestock exclusion zone or a limited stable access point allowing livestock to enter the creek. Based on conversations with district conservationists, water supply points should be provided every 2,000 feet. Once livestock are excluded from the riparian zone and alternative water supply provided, riparian (buffer) restoration can occur.

The Natural Resources Conservation Service (NRCS) guidance calls for a minimum 35 foot wide buffer along rivers and streams, however, other sources call for up to a 100 foot buffer (see Wenger, 1999). HRWA should promote as wide a buffer as possible, based on land condition, landowner concerns and other factors that may apply. In an effort to leverage additional (NRCS) funds, buffers would need to be a minimum of 35 feet wide. However, because TDEC biologist (as per communication with James R. Smith) and others have observed improvements in water quality associated with one row of trees along creek banks, and because land owner objections often have to do with loss of land to graze, crop etc. HRWA recommends as much width as possible, but in some cases suggests working to reestablish minimal riparian zones (e.g. one row of trees).

Finally, in some cases it may be necessary to restore natural hydrology to the riparian zone. In cases where aquatic systems are severely down cut or where channels have formed through the riparian zone, bypassing sheet flow and thus pollutant load reductions associated with the filtration capacity of the riparian zone. In addition, it may be desirable to add in stream structures to increase a system's ability to carry its bed load. For example a series of check dams, j-vanes or other appropriate structures may be used to increase velocity and/or sinuosity within an existing channel. However, in doing this one should pay particular attention to opposing banks to make sure the structure does not create additional erosion. Proper installation of structures is the key to proper functioning.

Stream bank stabilization should be carried out along roughly 10% of stream banks. Stream bank erosion is a significant problem in the headwaters of the Harpeth River and thus treating all stream banks is not cost-effective or practical. HRWA recommends the following prioritizing scheme; areas where specific ecological assets, such as mature trees are located should be treated first and then areas thought to be contributing significant soil to the system second. For example, streams with one row or scattered trees on a highly erosive stream bank would be treated in a effort to protect and save those trees providing shade and detrital material (habitat and food) to the system (ecological asset). Secondly, in systems impacted by sediment, long, highly erosive segments may be treated. This should provide for the greatest load reductions at the least cost. Utilizing the HRWA *Bank Erosion Study* (McFadden, 2006) the following formula can be utilized to calculate an estimated sediment load (ESL):

$$ESL = ((bh/9.17) \times 0.143) \times L$$

Where: ESL = Sediment loss in cubic yards per foot
bh = bank height to be treated
9.17 feet = average bank height from HRWA Bank Erosion study
0.143 cubic yards = soil loss/foot per year in HRWA Bank Erosion Study
L = Length of bank to be treated

The primary method utilized to treat eroding stream banks should be placement of cedar revetments, possibly with reshaping of banks, back fill and revegetation. HRWA continues to utilize cedar revetment to treat banks as high as 12 feet and generally found them effective in reducing stream bank erosion. HRWA utilizes a technique developed by Jen-Hill Construction for cedar revetments. The process is the same as Natural Resources Conservation Service, except cedar trees are bundled in coir matting or jute, prior to being attached to the stream bank. The coir matting or jute helps capture sediment by allowing branches to be more compact. In addition, the revetment can be backfilled and re-vegetated immediately following installation promoting bank stability and habitat quality in the short term.

Monitoring

HRWA recommends additional physical/chemical and biological monitoring be carried out. First, it is believed that greater pollutant loads result from non -point source events than were observed during this study. Because the study was carried out during a time of minimal rainfall, high flow data may not reflect the upper end of pollutant loadings associated with storm events.

Thus, additional storm event/high flow sampling should be carried out. One sampling of all sites during the first flush of pollutants would speak volumes relative to pollutant loadings and source. This might be best accomplished with automatic samplers or volunteers.

HRWA recommends that benthic sampling be conducted at all major and minor tributaries. Initially, benthic organisms should be keyed out to the order level, and then selected sites processed to genus level. The initial screening level (order) can be conducted by volunteers and will allow project biologists to begin to assess if all systems are impaired. Areas along Kelly Creek and Concord Branch appear to have sub-optimal to optimal habitat and thus may not have the level of impairment when compared to other sites with poor habitat. Once the order level benthic macro-invertebrate inventory (BMI) survey is conducted, project biologists can carry out genus-level assessment. Once this is done, additional questions relative to source may be answered based on pollutant specific tolerance of benthic organisms thereby driving more specific restoration needs.

Summary

The purpose of the study was to add to an already existing body of information collected by HRWA and TDEC regarding impairment and subsequent 303 (d) listing of the headwaters of the Harpeth River and to begin to identify areas contributing pollutant loadings to impairment in an effort to begin restoration activities. While the study did document higher pollutant loading in headwater tributaries, none stood out as a large single source. However, it was clear from the data large scale in stream, bank, and riparian habitat degradation has occurred over time. This appears to be primarily related to a historical agricultural land use. Fortunately, many of these “sources’ of habitat impairment can be easily and to some degree cost – effectively mitigated.

Although the activity referenced in this publication has been financed, in part, with the Sate and/or federal fund, the mention of trade names or commercial products does not constitute endorsement or reformation by the State or the Environmental Protection Agency.

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Barbour, M., Gerritsen, J., Snyder, B., & Stribling, J. 1999. Rapid Bioassessment Protocols for use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. USEPA Report. EPA 841-B-99-002. Washington, DC.

McFadden. 2006. *"Stream Bank Erosion: So how much sediment does stream bank erosion contribute?"* Presented at the 2006 Kentucky/Tennessee Water Environment Federation meeting. Nashville, Tennessee.

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Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross and R.M. Hughes. 1989. Rapid Bioassessment Protocols For Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. EPA/440/4-89/00/, Washington, D.C.

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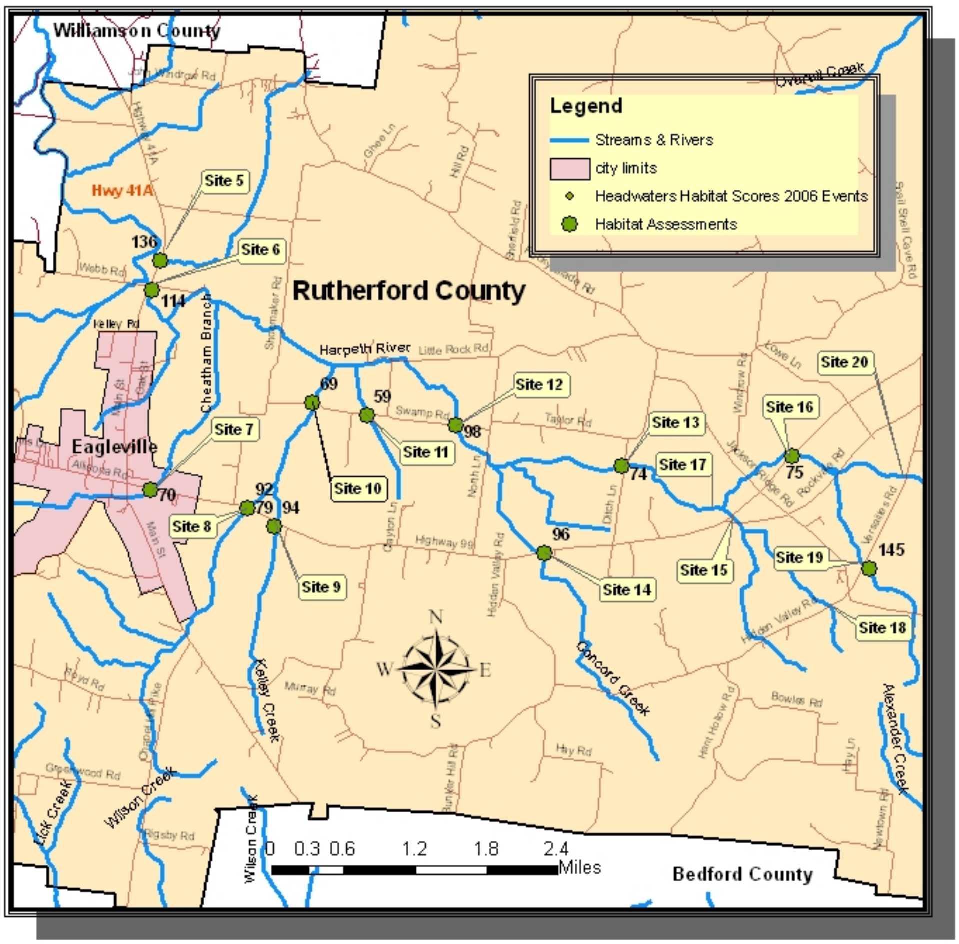
APPENDIX 1 – FIGURES

HRWA Harpeth River Headwaters
Habitat Assessments, Eagleville Area



SITE LOCATION DESCRIPTIONS

Site 5	2.0 mi north of Hwy 99 on Hwt 41A	Site 13	Ditch Laneat Concord Creek
Site 6	1.8 mi north of Hwy 99, Harpeth River	Site 14	Hwy 99 3.1 mi east of Eagleville
Site 7	Hwy 99 next to Community Center	Site 15	Rockvale Road SW of Concord
Site 8	Hwy 99 and Kelly Creek	Site 16	Rockvale Road NE of Concord
Site 9	Hwy 99 pst Kelly Creek	Site 17	Hwy 99
Site 10	Swamp Road at Kelly Creek	Site 18	Mt Pleasant Rd SW of Versailles
Site 11	Swamp Road past Kelly Creek	Site 19	Mt Pleasant Rd NE of Versailles
Site 12	Swamp Road at Harpeth River	Site 20	Versailles Rd N of Versailles

Figure 1- Site Location Descriptions

Figure 2 – Kelly Creek and Highway 99, Rutherford County Tennessee

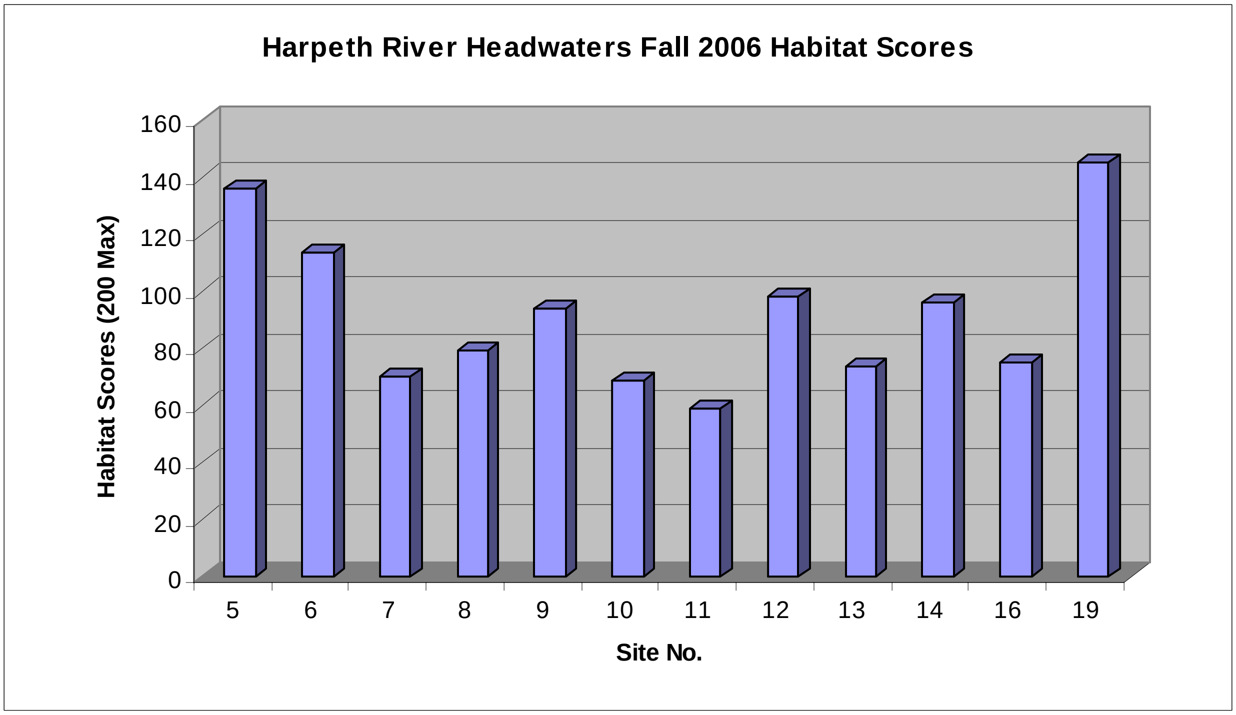


Figure 3 – Habitat scores for sites 5 – 19 (15, 17, 18 and 20 were not scored)

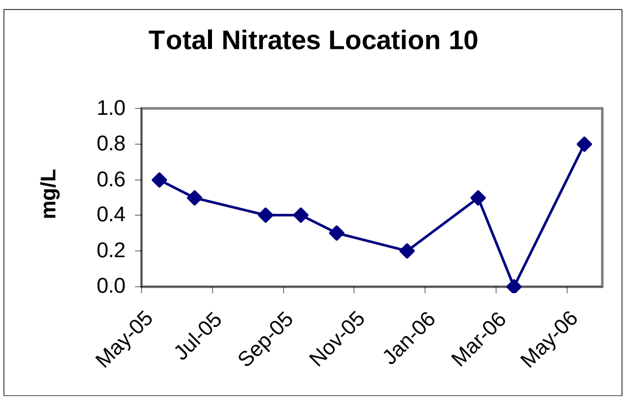


Figure 4 – Site 10 Kelly Creek Total Nitrates

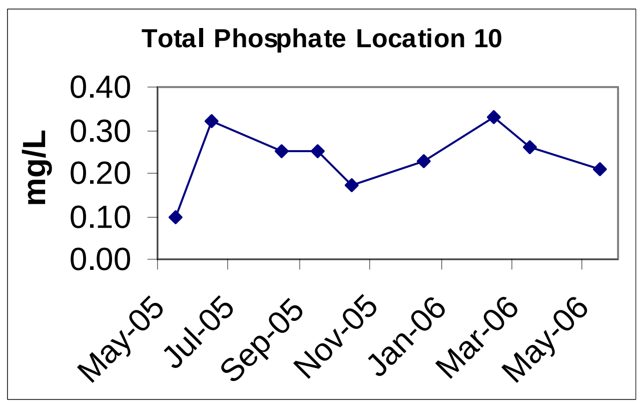
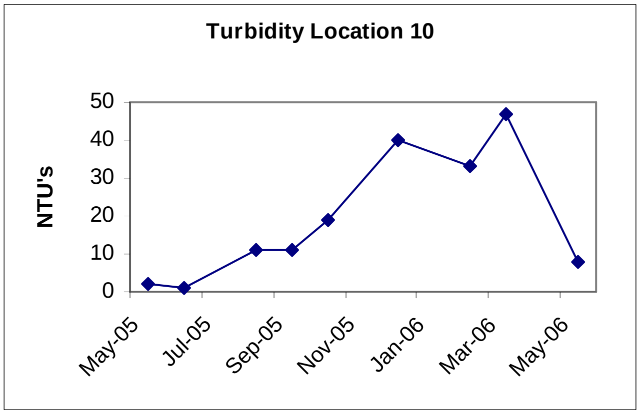


Figure 5 – Site 10 Kelly Creek Total Phosphate



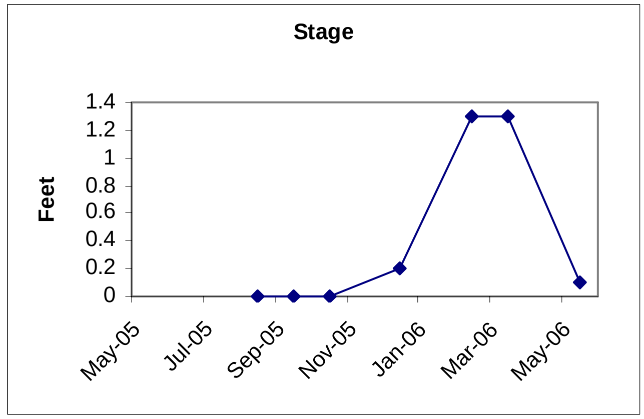


Figure 6 – Site 10 Kelly Creek Turbidity

Figure 7 – Site 10 Kelly Creek Stage

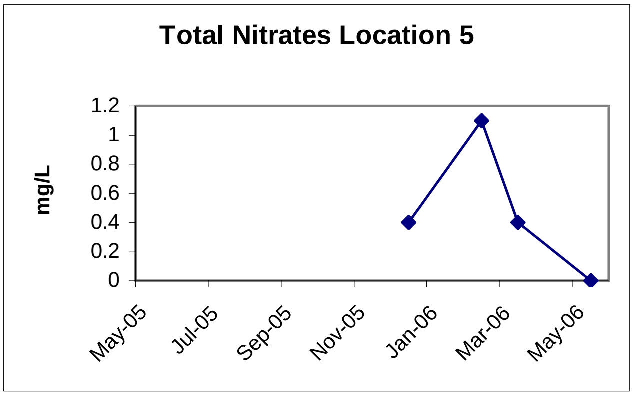


Figure 8 – Site 5 Unnamed Tributary to Harpeth River Total Nitrates

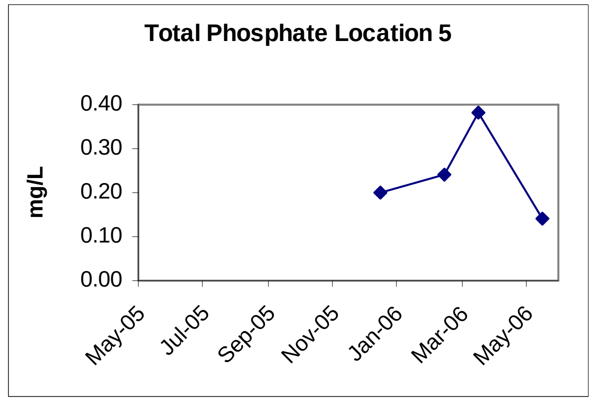


Figure 9 – Site 5 Unnamed Tributary to Harpeth River Total Phosphates

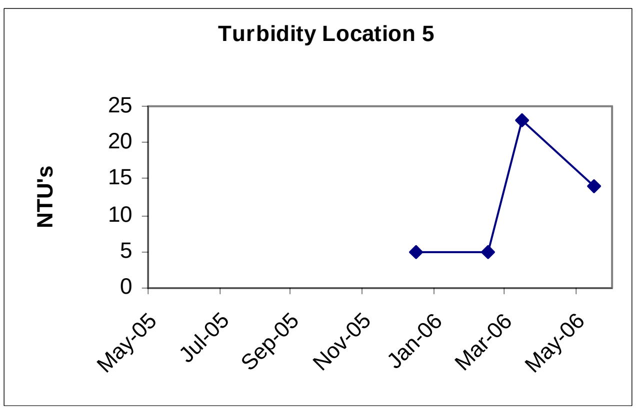


Figure 10 – Site 5 Unnamed Tributary to Harpeth River Turbidity

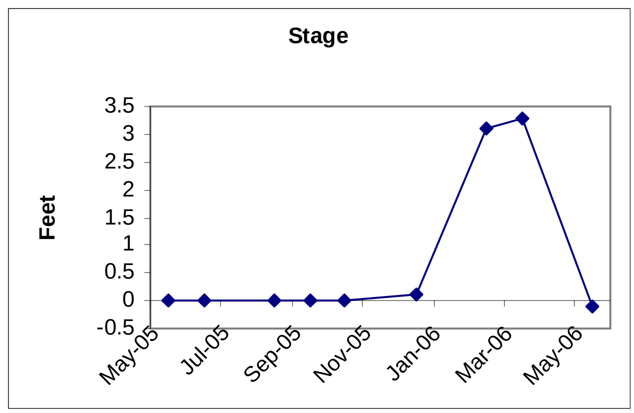
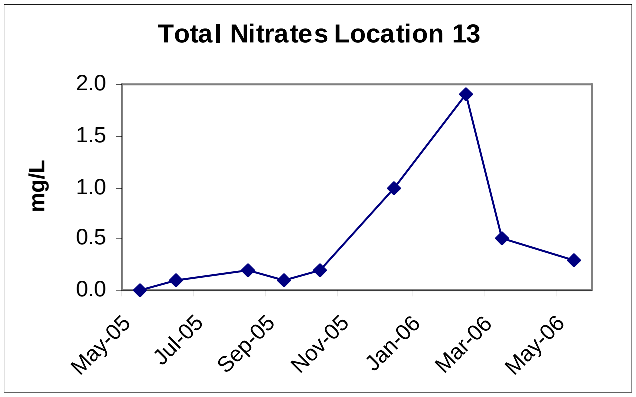


Figure 11 – Site 5 Unnamed Tributary to Harpeth River Stage



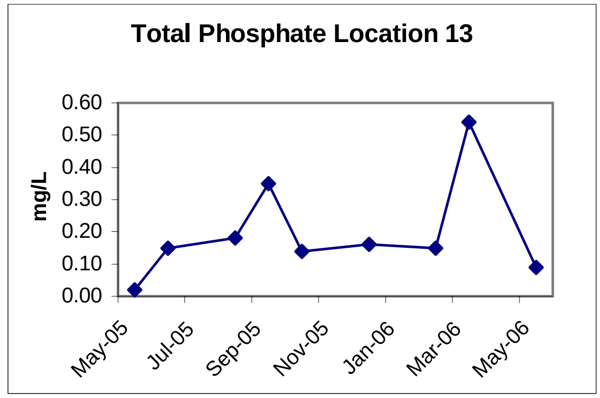
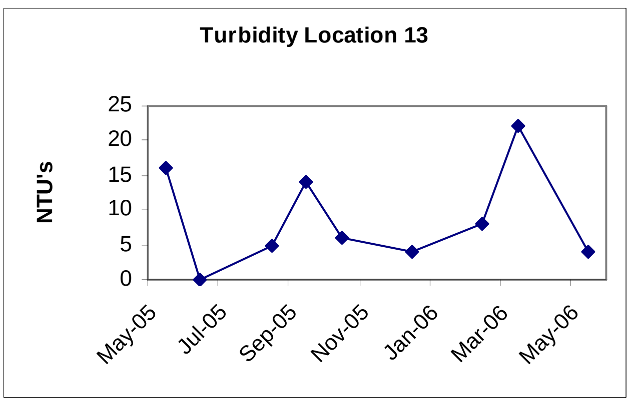


Figure 12 – Site 13 Concord Creek Total Nitrates

Figure 13 – Site 13 Concord Creek Total Phos.



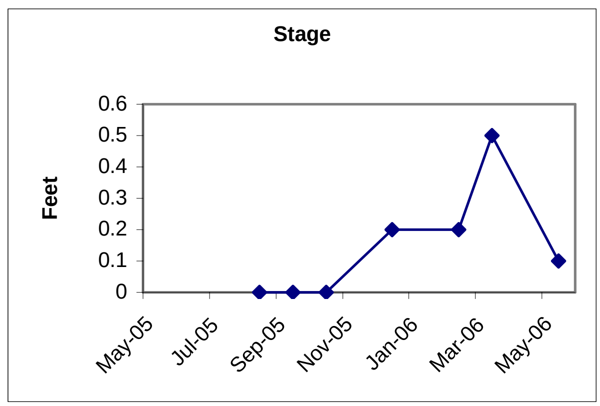


Figure 14 – Site 13 Concord Creek Turbidity

Figure 15 – Site 13 Concord Creek Stage

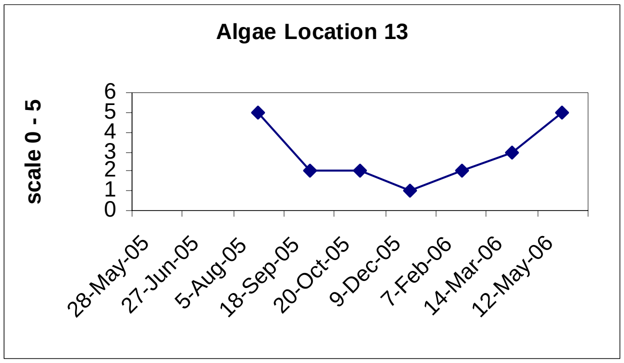


Figure 15.1 – Site 13 Concord Creek Algae

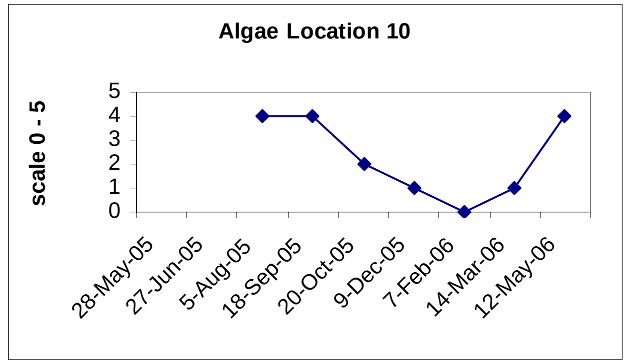


Figure 15.2 – Site 10 Kelly Creek Algae

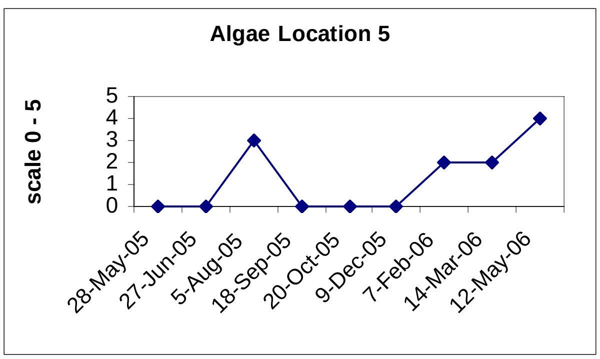


Figure 15.3 – Site 5 Unnamed Tributary to Harpeth River Algae

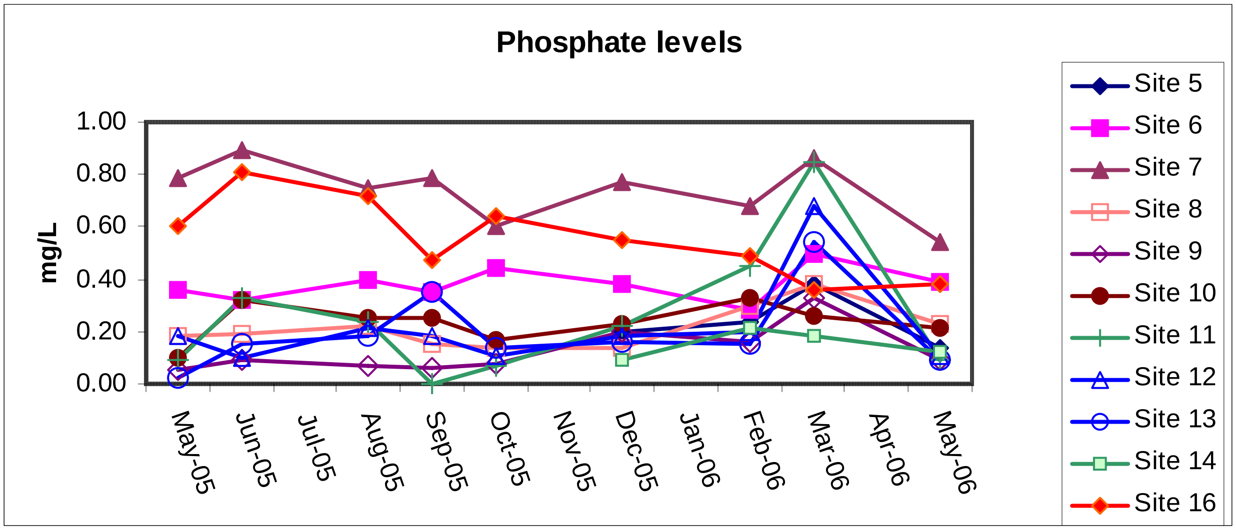


Figure 16 – Harpeth River headwaters' Phosphate levels sites 5 – 16 May 2005 to May 2006.

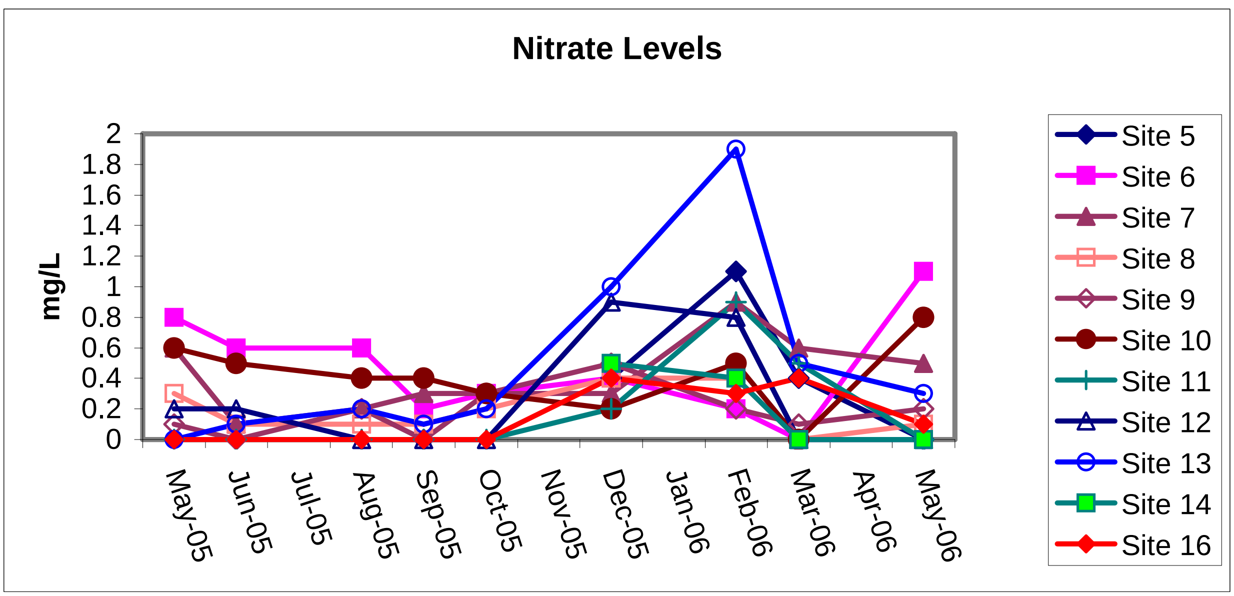


Figure 17 – Harpeth River headwaters' Nitrate levels for site 5 – 16.

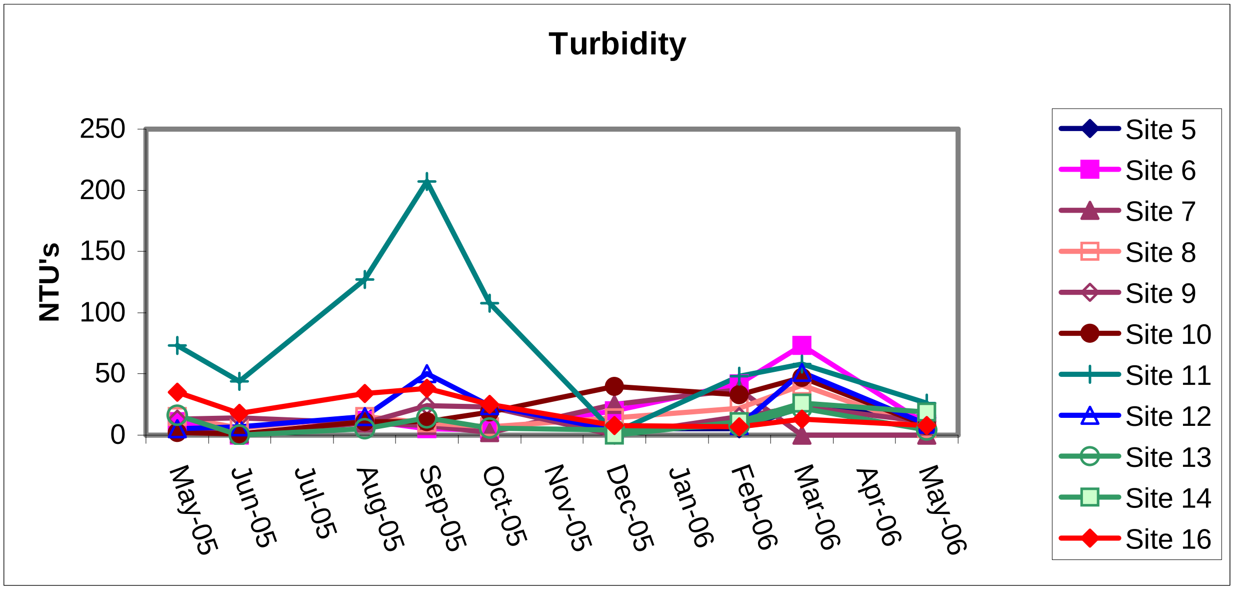


Figure 18 – Harpeth River headwaters' Turbidity levels for site 5 – 16.

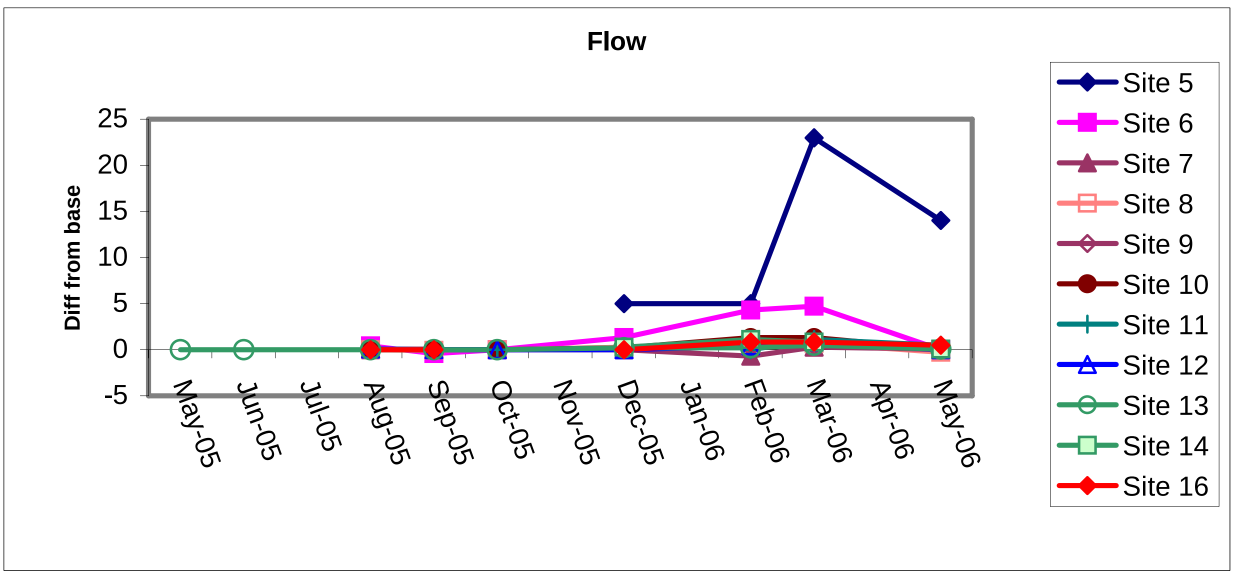


Figure 19 – Harpeth River headwaters' flow levels for site 5 – 16.

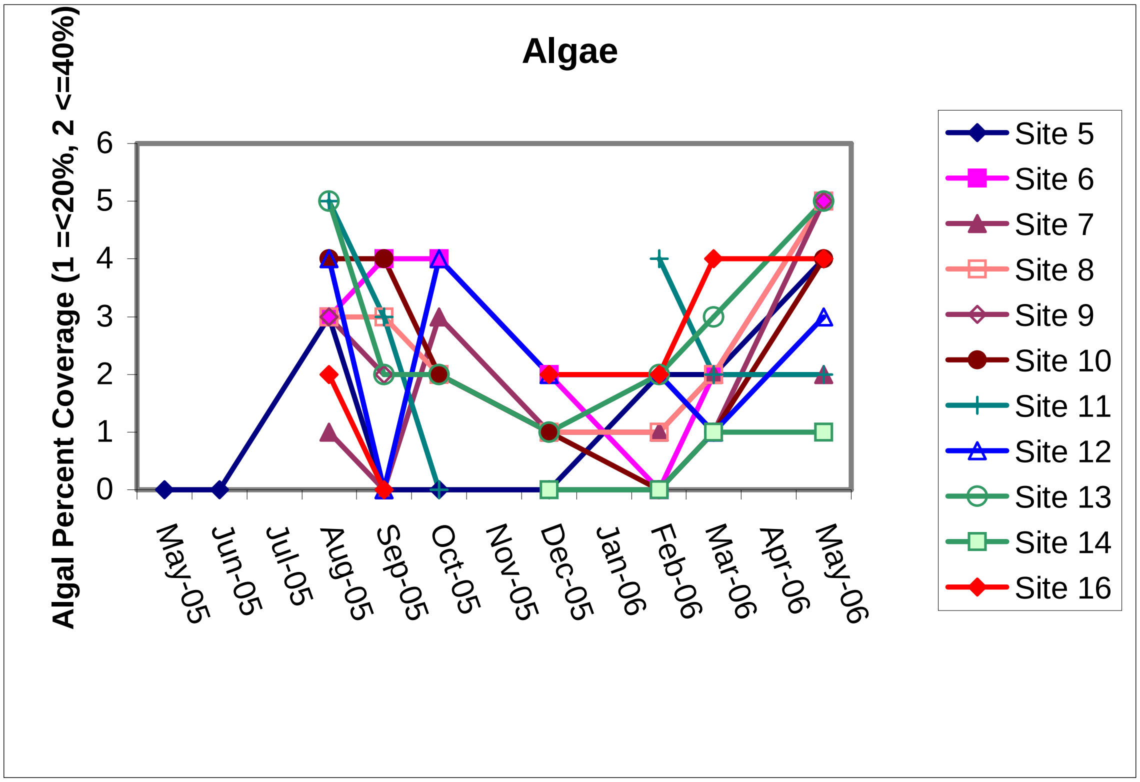


Figure 20 – Harpeth River headwaters' Algae levels for site 5 – 16.

APPENDIX II
TABLES

Table 1 - Average physical / chemical data collected from May 2005 – May 2006 and Habitat data collected fall 2006

Site #/ Parameter	**5***	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17 *3**	**18**	**19**	**20 ****
Stage (ft)	1.65	1.73	-.04	0.14	0.20	0.41	0.28	0.19	0.10	0.58	0.12	0.35		0.08	0.22	
Phosphate (mg/l)	0.24	0.38	0.74	0.21	0.13	0.24	0.26	0.22	0.20	0.15	0.14	0.56		0.73	0.97	
Nitrate (mg/l)	0.5	0.5	0.4	0.2	0.2	0.4	0.2	0.2	0.5	0.2	0.2	0.1		0.5	0.2	
Temp (deg. C)	10.5	17.1	20.9	18.9	18.9	19.3	20.4	17.6	18.1	8.6	6.0	16.9		13.0	11.7	
Turbudity (ntu)	12	20	10	15	15	19	77	19	9	14	4	21		3	8	
pH (SU)	8.34	7.86	8.48	8.12	8.16	7.97	8.70	7.90	8.07	7.89	8.26	8.5		8.53	8.10	
Dissolved Oxygen (mg/l)	7.9	6.5	8.0	7.8	7.9	7.8	8.3	6.7	6.9	7.2	8	7.7		11	8.8	
Condu. (u/S)	376	383	421	367	417	336	266	286	328	302	268	348		492	382	
Habitat scores (/200) *1	136	111	70	79	94	69	59	98	74	96	*2	75		*2	145	
Algae (1 – 5)	2.75	3.3	1.43	2.43	2.5	2.67	3.2	2.29	2.9	0.5	1.0	2.33		0	3	

* Site # 5 – 20 (1 – 4 were in another watershed)

*1 habitat scores are from one sample

*2 not scored

*3 - never scored due to lack of water

A RATIONAL APPROACH TO PREDICTING THE IMPACT OF WATER WITHDRAWAL ON WATERSHED WATER QUALITY

Scott Woodard (CTE), Art Newby (CTE), Dr. Edward Thackston (Vanderbilt University ret.), David Parker (City of Franklin)

The City of Franklin Tennessee currently withdraws water from the Harpeth River. The city is not currently required to hold a permit for water withdrawal. However, the plant is in need of upgrades and possibly expansion. Any modifications to the plant require application and approval of an Aquatic Resource Alteration Permit from the Tennessee Department of Environment and Conservation.

In 2005, the city hired CTE Engineers to develop a study in conjunction with TDEC, TWRA and many other stakeholders including local environmental groups. The project began with a stakeholders planning workshop to identify the concerns and obtain all data available at the time. A plan was then developed and executed to evaluate the potential impact of a managed water withdrawal strategy.

PowerPoint File

ECONOMIC CRITERIA FOR REGIONAL WATER SUPPLY PLANNING IN TENNESSEE

William W. Wade, Ph. D.[1]

City of Franklin filed an application for an Aquatic Resource Alteration Permit (ARAP) in the fall, 2006, to increase withdrawals from the Harpeth River for municipal water supply. The City seeks to replace its 1952 2 mgd water plant and double intake capacity to 4 mgd.

Franklin's ARAP application does not address the questions most relevant to the welfare of Franklin residents and Tennesseans. Regional water supply planning is needed to optimize citizen welfare by managing small river systems to provide services of highest societal value.

Franklin currently buys 67 percent of its water, 4.2 mgd, from Harpeth Valley Utility District (HVUD) and makes 2 mgd in its old plant. Franklin's 1998 30-year contract with HVUD requires 3.3 mgd monthly minimum purchases. Until Franklin's demand growth exceeds 7.3 mgd, the HVUD contract caps the amount of water that can be made in the new plant. I estimate that Franklin's demand will not top 7.3 mgd before 2012. Harpeth flows limit expected operating capacity to 3.7 mgd average after 2012. The early year contract limits, outyear flow constraints and cost reduce plant economics and cause the "build plant" project evaluation to be negative. Franklin residents could get cheaper water from HVUD.[2] More important, the externalities of Harpeth water withdrawals need to become determinant criteria for an ARAP.

Franklin's downstream wastewater plant is running at 6 mgd, but sized for 12 mgd to anticipate growth. Harpeth River flows provide critical dilution service to Franklin's POTW. Its growth <u>must</u> be anticipated and accommodated. Harpeth River below Franklin is effluent dominated during low flow season. Harpeth River has been in violation of the DO standard of 5 mg/L during low-flow warm summer months for at least six years.[3]

My paper will use Franklin's ARAP application as a case study to integrate economic perspectives and analysis into water resource decisionmaking. I will address three questions.

1. What are the instream flow values at stake for existing and expanded Harpeth water withdrawals for drinking water compared to HVUD supplies from the Cumberland?
2. Do withdrawals for the drinking water plant or Harpeth flows left instream for wastewater dilution provide the more valuable services to the residents of the City?
3. How should Franklin evaluate the Harpeth River view shed services for impending downtown Franklin riverfront development and Franklin's Greenbelt system?

I will discuss how to compare the economic benefits of <u>instream water flows</u> versus benefits of <u>water diversion</u> for drinking water to optimize limited river systems within regional water supply planning. The paper will extend the research cited in footnote 2.

1 President, Energy & Water Economics, Columbia TN 38401. wade@energyandwatereconomics.com; 931-490-0060.

2 William Wade, "Water Supply Planning for City of Franklin," Presentation to City of Franklin, October 17, 2006.

3AquaAeTer, "Analysis of the Harpeth River for Water Withdrawals and Wastewater Assimilative Capacity," Presentation to City of Franklin, October 17, 2006.

SESSION 2C

ENGINEERING DESIGN
8:30 a.m. – 10 a.m.

Evaluation of High Density Polyethylene (HDPE) Pipe Use for TDOT Projects
Ali Hangul

Engineering Design Methods to Prevent Stream Base Flow Interception by Gravity Sewer Line Construction
William E. Griggs, Richard D. Martin, and Heather J. Brown

Investigating Sediment Retention in Proprietary Stormwater Treatment Devices
John Dawson and Kwabena Osei

WATER QUALITY MANAGEMENT
10:30 a.m. – 12:00 p.m.

Derivation of Site-Specific NPDES Permit Limits for Copper
L. Heise (Paper not available)

Continuation of Wadeable Streams Assessment Project in Tennessee
Gregory M. Denton

Mercury Levels in Tennessee Fish
Gregory M. Denton

RESTORATION I
1:30 p.m. – 3:00 p.m.

Pavilion Branch Stream Restoration Project
Gary M. Mryncza

Pond Creek Levee Setback and Stream Restoration Project
Michael F. Adams, Robert Bailey, and Aaron J. Kopp

Restoration of Wallens Bend and Clinch Rivers to Reduce Sediment Near Threatened Mussel Shoals
Nick Cammack, Greg Babbit, and Michael F. Adams, Jr.

RESTORATION II
3:30 p.m. – 5:00 p.m.

Stream Restoration in West Tennessee—Crooked Creek
Aaron J. Kopp, Robert Bailey, and Michael F. Adams

Marble Springs: Stream Restoration on Governor John Sevier's Homestead
Ryan V. Smith

Third Creek Restoration Project, Knoxville, Tennessee
Andrew Bick

EVALUATION OF HIGH DENSITY POLYETHYLENE (HDPE) PIPE USE FOR TDOT PROJECTS

Ali Hangul, PE*[1]

The FHWA is revised the regulation 23 CFR part 635 subpart D to address Section 5514 of the **Safe , Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU).** This law requires the FHWA to ensure that States provide for competition with respect to the specification of alternative types of culvert pipes.

The pipe selection criteria currently being used by the Design Division was prepared approximately 15 years ago. TDOT initiated a review of High Density Polyethylene (HDPE) pipe as part of an evaluation of alternative types of culvert pipes. This was done in order to expand the use of HDPE pipe on projects as an alternative drainage structure.

This study was grouped into four categories as follows.

A. HDPE Pipe Review Group Investigation
B. TDOT HDPE Pipe Survey (Research Advisory Committee)
C. Evaluation of results for HDPE Pipes from the National Transportation Product Evaluation Program, AASHTO Test facilities, and other published studies
D. Conclusions

A. HDPE Pipe Review Group Investigation

The HDPE Pipe Review Group identified and determined the following items which needed further investigation.

a. Relation between the backfill density and the fill height.
b. Effect of the backfill material types and the amount of pipe deflection associated with the reported pipe failure locations.
c. Select backfill material and study a new Standard Drawing (D-PB-2)
d. Durability, life expectancy (Accordance with ADS 100 years)
e. Is inside of the pipe corrugated or smooth?
f. UV light resistance; will this make the pipe become brittle?
g. Resistance to fire.
h. Installed HDPE pipe final cost (cost of pipe, trenching, compaction, proctor density test, after installation deflection test and life expectancy).

HDPE PIPE REVIEW GROUP INVESTIGATION RESULTS

A) Relation between the backfill density and the fill height

1 * Civil Engineer Manager, TDOT Design Division, Quality Assurance and Standards Office, J. K. Polk Bldg. Suite 1300, Nashville, TN 37243

A direct relationship is found between the backfill density and the fill height. The increased backfill density is lowered the pipe deflection rate under fill.

Reference:
(Utah State University, Structural Performance of 42" HDPE Pipe.)
(Ohio University w/ODOT, Transportation Research Board Paper #930514)
(Pennsylvania Deep Burial Study, 15 Year Summary Report, Geotechnical Report No. AD588-351F)
(Dept. of Civil & Env. Eng., Univ. of Massachusetts, Transportation Research Record #1541)

B) Effect of the backfill material types and the amount of pipe deflection associated with the reported pipe failure locations.

Slight tensile stresses in the pipe arising from trench anomalies and residual stresses from the manufacturing process are overcome by the large compressive stresses due to the soil overburden. Therefore, the net stress in the pipe is compressive.

Reference:
OHIO University, Civil Engineering Department, November 15, 2001

C) Select backfill material and study a new Standard Drawing (D-PB-2)

The backfill shall be selected granular compactable material. It shall be Type B aggregate, Grading D or E meeting the requirements of Subsection 903.05.

According to the HDPE Pipe manufacturer's recommendations and Univ. of Mass. Study the existing Standard Drawing D-PB-1 cannot be utilized for HDPE pipe. A new standard drawing D-PB-2 is developed for HDPE pipe.

F) Durability, life expectancy

While the HDPE pipe manufactures claim the life expectancy of their pipe is 100 years, the responses to our survey indicated that an average life expectancy of 50 years is adopted by other DOT's.

H) Is inside of the pipe corrugated or smooth?

The HDPE pipe is available in both a single and dual wall configuration. Only the dual wall configuration will be used by the Department. The outer wall is corrugated for the dual wall pipe while the inner wall is smooth. However, after installation of the pipe excessive soil loading will cause some corrugation inside the pipe. A research study has been published on the effects of the subject corrugation to pipe hydraulic capacity.

I) UV light resistance; will this make the pipe become brittle?

Sunlight contains ultra-violet rays that reduce the tensile properties of plastics with time. HDPE pipe installed in the ground is primarily in compression due to the annular profile design of the pipe. Additionally, once the pipe is backfilled it is protected from the effects of UV rays. The pipe's exposed ends are in areas of little or no stress and therefore a reduction in tensile strength due to UV does not affect the pipe's performance. AASHTO and ASTM specifications include requirements of coloration of HDPE pipes with carbon black to inhibit the effects of UV of the material.

J) Resistance to fire.

The HDPE pipe is extremely vulnerable to fire. However, since the pipe is placed at waterways and considering confinement effects for longer structure fire may not be major concern.

E) Cost of HDPE pipe.

One of the main reasons for evaluating alternative pipe materials for roadway drainage structures is to promote healthy competition among pipe manufacturers and suppliers.

However, the true cost of installed HDPE pipe will be impacted by potentially higher installation costs associated with the more rigorous compaction and backfill material requirements. Inspections during and after installation also affect the cost of the HDPE pipe. In addition to the installation costs the average life expectancy of 50 years for the HDPE pipe should be compared with other pipe materials.

B. TDOT HDPE Pipe Survey

We also decided to ask the following questions to other states DOT's to share their experiences with the HDPE pipe since TDOT is a member of the Research Advisory Committee.

- Does your state allow HDPE pipe and in what application?
- What size are they using?
- Backfill Compaction Density?
- Maximum fill height above the pipe?
- Bedding and backfill specifications?

See Appendix A for TDOT HDPE Pipe Survey Results

C. Evaluation of results for HDPE Pipes from the National Transportation Product Evaluation Program, AASHTO Test facilities, and other published studies

The following organizations reports are reviewed and tabulated below.

Universities	University of Massachusetts University of Minnesota Utah State University Ohio University
DOT's	Pennsylvania 15 yr. report Utah state 42" test report OHIO DOT Review OHIO DOT Survey

Kentucky DOT review

Federal National Cooperative Highway Research Program (NCHRP) Report # 429

ORGANIZATION	SUBJECT	CONDITIONS	CONCLUSIONS
National Cooperative Highway Research Program (**NCHRP**) Report #429	Recommended Material Specifications and Design Requirements	Total of 114 responses. 62 HDPE Pipe Cracked significantly. 11 out of 19 fail the SCR (Stress Crack Resistance) Test	**Controlled Back Fill requirements and Head Walls are required**
Kentucky DOT September 26, 2005	Evaluation of HDPE	61 HDPE Pipe installations in 7 Sites are studied.	26% Sag 10% Deflections 19% Radial Cracks
The American Pipe Association Jan 24,2004	Condition Investigations of HDPE Pipes in service in the US.	39 pipes studied between 28" to 60" diameter	27 pipes deflected more than 5% 24 pipes cracked, buckled 16 misaligned
Dept. of Civil & Env. Eng. **Univ. of Massachusetts** Transportation Research Record #1541	Field Test of Buried Pipe Installation Projects 36" & 60" in Various Back Fill and Compaction	No Live Load Applied	**Installation Methods Can Have a Significant Effect on pipe performance**
Pennsylvania **Deep Burial Study** 15 Year Summary Report Geotechnical Report No. AD588-351F April 1988 (With Supervision of Penn Dot)	Performance of 24" HDPE Under High Fill - 100'	For backfill grade 2A Material Placed and Compacted 100%. No Live Load applied	Pipe Performed Exceptionally Well. **We are adapting the Structural Backfill in the Trench instructions from this publication**
Utah State University study for ADS	Structural Performance of 42" HDPE Pipe.	75, 85, 95 % Standard Proctor density. Mechanically loaded, soil backfill only.	Pipe performed well under 18' of fill with min. deflection.
OHIO University Civil Engineering Department November 15, 2001	Three 42" diameter HDPE pipes under deep soil Cover	Two different back fill Three levels of relative compaction No live load	All pipes performed satisfactory under 20' and 40' of soil cover.

American Concrete Pipe Assoc. Follow-up of previous study, Ohio DOT January 1, 2006	Long-Term /Follow- up Performance Evaluation of HDPE Pipes Installed	11 HDPE Sites studied. 4 to 7 Times More Cracking is Observed Between 2001 & 2005 since last inspection. Deflection Increased	**No Specific Back Fill Requirements** **Large Deflections at Fill Slope Area** **In General, Deflections are Less than 5% Under Roadway Fill**
Civil Engineering Dept. **Ohio University w/ODOT** Transportation Research Board Paper #930514	Field Performance of a Corrugated HDPE Pipe	36" Pipe Back Filled w/Crushed Limestone to 128 lb/ft3 Standard Proctor Density. Pipe mechanically loaded	**Performed Well – Less Than 5% Deflection Under 40 psi**
OHIO DOT Survey	Use of High Density Polyethylene Pipe AASHTO M294 - limitations and backfill requirements	Does your state allow use up to 60" or do you have other diameter restrictions Do you allow under pavement or not? For a trench installation for HDPE pipe do you allow sand bedding and structural backfill up to 1 or 2 feet above the pipe or do you require a granular backfill like #8's or #57?	28 state DOT responded. Most allows HDPE pipe under pavement up to 48" and almost all requires granular backfill material.

D. Conclusion

During the review we found that the final performance of installed HDPE pipe is depending on the following parameters:

Trench width
Trench shape
Fill height
Soil type (in-stu)
Water table (Buoyancy – an erection/placement issue)
Back fill material type
Compaction (density)
Moisture content of backfill
Sections of pipe can be installed, backfilled, and compacted in a day
Weather conditions during installation (Frozen ground or Rainfall)
Deflection criteria (5% max.)
Longitudinal bending stresses
Headwall requirement
Inspection during the installation
Inspection 30 days after the installation
Following Installation procedures during installation

The HDPE pipe lacking significant intrinsic structural rigidity depends on an interaction with the backfill to establish the required structural integrity. Proper placement of backfill is then paramount for the HDPE to function as intended and close inspection is essential throughout the pipe installation process.

As a result TDOT proceeded with the following actions.

- The use of HDPE pipe has expanded to Arterials (without full access control) in the state highway system and the use of HDPE pipe with greater fill heights, up to 18 feet, has been allowed. CMP (10 gage) has been added as an alternative in the same categories as well.

- A new standard drawing has been prepared for HDPE pipe installation and submitted to FHWA for review and approval.

- The Pipe Selection Criteria Table showing the recommended uses for HDPE Pipe and CMP on TDOT projects has been revised and other effected sections of the Design Division Drainage Manual have been identified. The manual is under revision at this time.

APPENDIX A

Tennessee HDPE Survey													
State	APPLICATION	Size						DESIGN SERVICE LIFE	MINIMUM Fill	Maximum Fill	Bedding and/or Backfill	COMPACTION	COMMENTS
		12"	18"	24"	36"	48"	60"						
NEW YORK	Pipe, Culvert	X		X	X	X	X	70 YEARS	1'	3'	Layers not to exceed 6"	Minimun 95%	64.7% (OR 236,102') HDPE pipe No problems with any HDPE installations.
OHIO	All application including culvert	X		X	X	X	X	75 YEARS	N/A	20'	Type 2 bedding consists of structural backfill	Compact backfill	Negative; Large portion (1000') of plastic pipe may need to be removed due to excessive deflection,racking and other problems. Positive; Recently relined a metal culvert with 400' of HDPE
PROVINCE OF NOVA SCOTIA	Culvert (driveway only)	X	X	X	X			N/A	N/A		Gravel (3/4" minus)	Compacted gravel	Most part been very positive, The only problem we've experienced is distortion due to poor installation (inadequate bedding and/or cover)
MISSOURI	Storm sewers Sewer pipe (Paved portion of roadway <3500 ADT)	X	X	X	X	X	X	N/A	N/A	50'	Granular material max. 6 3/4" for up to 15" pipe, 1 1/2" above 15" diam.	Minimum 90%	THE first pipe was installed in 1999, after 26 months the maximum deflection was measured as 8.4%, not acceptable by our specs. No cracking has occurerred, pipe are corrugated with smooth unside.
MISSISSIPPI	Cross drains Side drains Storm drains Under drains	X	X	X	X			50 YEARS	1'	N/A	Granular material shall pass the 1.5 size	N/A	N/A

RHODE ISLAND	Edge Drainage			X				N/A	3'	N/A	Gravel borrow, limit on the maximum size	90%	Limited applications so far. Some edge drainage and some embankment locations
IOWA	Crossdrains	X	X	X	X	X		60	N/A	15'	Granular material	N/A	Not much experience to date. We started October 2005
BRITISH COLUMBIA	Side drains French drains Storm drains Cross culverts			X	X			50 YEARS	3'	N/A	Granular specified material	N/A	No problems have been encountered. We used this for new construction for access roads mainly. Across culverts or drainage under main line is discouraged in favor of steel.
ILLINOIS	Underdrains Pipe culverts Side Drains		X	X	X			50 YEARS	N/A	15'	4" Moist fine aggregate minimum in 8" lifts	85%	N/A
MAINE	All application	X	X	X	X	X		50 YEARS	N/A	8"	Fine readily compressible soild or granular material	Materical is rammed under haunches with power or pneumatic operated hand tampers	WE have been overall pleased with HDPE pipe. There are still pockets of resistance with some field personnel and designers.
ALBERTA	Culert drainage	X	X	X	X	X		100 YEARS	N/A	12"	Select soil material, free from frozen lumps and organic material shall be placed in layers not to exceeding 6" in depth	N/A	Each layer shall be thoroughly compacted at optimum moisture content by means of pneumatic or other mechanical tamping equipment.
ARKANSAS	Side drains							N/A	12"	Not defined	sand or gravel in layers not to exceed 6"	95%	Have no real experience with HDPE pipe since it is used only as an option for side drains. Usually the material of choice is C.M. pipe.

NEBRASKA	Cross drains Side drains Under drains Drive drains Drop drains Storm drains	X	X	X	X			N/A	N/A	40'	N/A	N/A	No problems. Limited use as cross drains. Extensive for underdrains.
MONTANA	Mainline Side drains		X		X	X		40	N/A	10"	2" LOOSELY	N/A	18" approch pipes. No problems but haven't had it in the ground for more than maybe 5+ years. We are doing an experimental project to get a better handle on the installation and constructability issues involved with this product. The construction report will be available on our website this fall.
SOUTH DAKOTA	Cross drains Side drains Drive drains Storm drains	X	X	X	X	X		50	N/A	20'	N/A	N/A	We have allowed HDPE pipe to be used in approches or any applicatication that does not cross our mainline pavement. However, other than testing and evaluation we have not had any HDPE pipe installed or bid to be used for approches or other applications.
UTAH	All application under any road interstate system	x	x	x	x	x	x	50 storm drains 40 cross-culverts	N/A	11' to 18'	Graded bedding and structural backfill free of organic material & frozen lumps particles 1.5"	N/A	HDPE pipes under interstate pavement since 1986 applications have been doing well. Research study of existing pipe installations in our system rate HDPE pipe conditions better than steel pipe.
LOUISIANA	Yard drains Side drains Cross drains	x	x	x	x	x		30 Side drains 50 Cross drains	1"	5"	Granular material (stone, recycled PCC, or flowable fill) compacted in layers not to exceeding 12" (granular) or 8" (stone recycled PCC flowable fill)	95%	N/A
WEST VIRGINIA	UNDER ROADS WITH ADT < 3000							N/A	SUPPLIER'S FILL TABLES	SUPPLIER'S FILL TABLES	ADT < 400 GRANULAR > 400 CONCRETE OR LEAN GROUT	N/A	EASY TO INSTALL INCORRECTLY BUT DIFFICULT TO INSTALL CORRECTLY

ENGINEERING DESIGN METHODS TO PREVENT STREAM BASE FLOW INTERCEPTION BY GRAVITY SEWER LINE CONSTRUCTION

William E. Griggs, P.E.[1], Richard D. Martin, P.G.[2], Heather J. Brown, Ph.D.[3]*

The Nashville Metropolitan Statistical Area (MSA) has experienced significant growth during the past decade. With a population growth rate roughly three times that exhibited statewide, the demand for new housing has forced expansion of sewer treatment plants and collection systems in the region.

Most sanitary sewers are gravity systems and follow regional topography, frequently flanking, and sometimes crossing, small tributary streams. Within the Karst dominated geologic setting of the MSA, conventional sewer line installation methods have sometimes resulted in the diminution or complete base flow interception of the impacted streams. Recognizing this problem, the Tennessee Division of Water Pollution Control tasked developers, as a component of the Aquatic Resource Alteration Permit program, to devise methods to prevent this phenomenon from occurring and perform pre- and post-construction stream base flow studies to confirm that the stream's hydrologic characteristics have not been altered by construction activities.

Griggs & Maloney, Inc. designed an innovative sewer line installation method whereby, in lieu of the classic anti-seep collars and aggregate stone bedding material, flowable fill encasement was utilized in conjunction with an anchoring system in settings where high risk of stream piracy exists. This sewer line construction method was applied in a project in Williamson County that encroached upon Dry Branch. A pre-construction flow study was performed in August 2005 at four locations in the stream and post-construction flow monitoring was performed in September 2006. These studies revealed that the alternative construction methods employed were successful in retaining the stream's base flow, with no sub-surface loss detected as compared to pre-project conditions.

1 Principal, Griggs & Maloney Consulting Engineers, P.O. Box 2968, Murfreesboro, TN 37133-2968, bgriggs@griggsandmaloney.com

2 Senior Project Manager, Griggs & Maloney Consulting Engineers, P.O. Box 2968, Murfreesboro, TN 37133-2968, rmartin@griggsandmaloney.com

3 Director and Associate Professor, Middle Tennessee State University, Concrete Industry Management Program, MTSU Box 19, Murfreesboro, TN 37132, hjbrown@mtsu.edu

INTRODUCTION

The Nashville Metropolitan Statistical Area (MSA) has experienced significant population growth during the past decade.[1] Associated with this expansion is the need for public utilities, most of which are constructed below ground.

Installation of buried utility lines provides numerous benefits. These include aesthetics, safety (line protection), security, and easement considerations, to name a few. Moreover, gravity sewer lines, in addition to the aforementioned, must maintain adequate slope throughout its course to provide velocities necessary to carry solids along with the liquid phase of sewerage. In order to achieve the necessary gradient, while minimizing the depth of excavation, gravity sewer lines often follow surface topography, frequently flanking, and sometimes crossing, streams that occupy the valley floors.

Traditional sewer line construction practices have sometimes proven disruptive to base stream flows in Middle Tennessee streams. Specifically, trench excavation in rock (frequently achieved by blasting) in the immediate proximity of a stream, coupled with unintentionally placing a subterranean preferential flow zone adjacent to or across the stream (in the form the sewer trench with stone aggregate bedding material) has, in some cases, effectively pirated surface base flow underground. Classic control methods such as sewer trench dams and concrete encasement have proven to be ineffective or impractical in controlling this phenomenon.[2]

The need for a cost-effective, alternative method to prevent stream piracy by sewer lines, provide accessibility to the line for future maintenance or additional customer connections, and comply with environmental regulations precipitated the engineering solution described herein.

DESCRIPTION OF TRADITIONAL SEWER LINE CONSTRUCTION METHODS

Traditional construction practices for gravity sewers involve placing the sewer pipe on a bed of granular material and then backfilling the pipe with similar material, either for the entire trench or to a depth of 12 inches over the top of the pipe. The remainder of the trench is then backfilled with select, native material-typically soil. Granular backfill and native backfill material both exhibit moderate to high rates of hydraulic conductivity. In an effort to reduce infiltration and inflow (I/I) from using sewer granular backfill as a conduit to a possible sewer main leak or manhole leak, TDEC has historically required that concrete sewer trench dams are constructed near all manholes to intercept and stop such flows.[3] Figures 1, 2, and 3 depict a schematic of the construction method previously described.

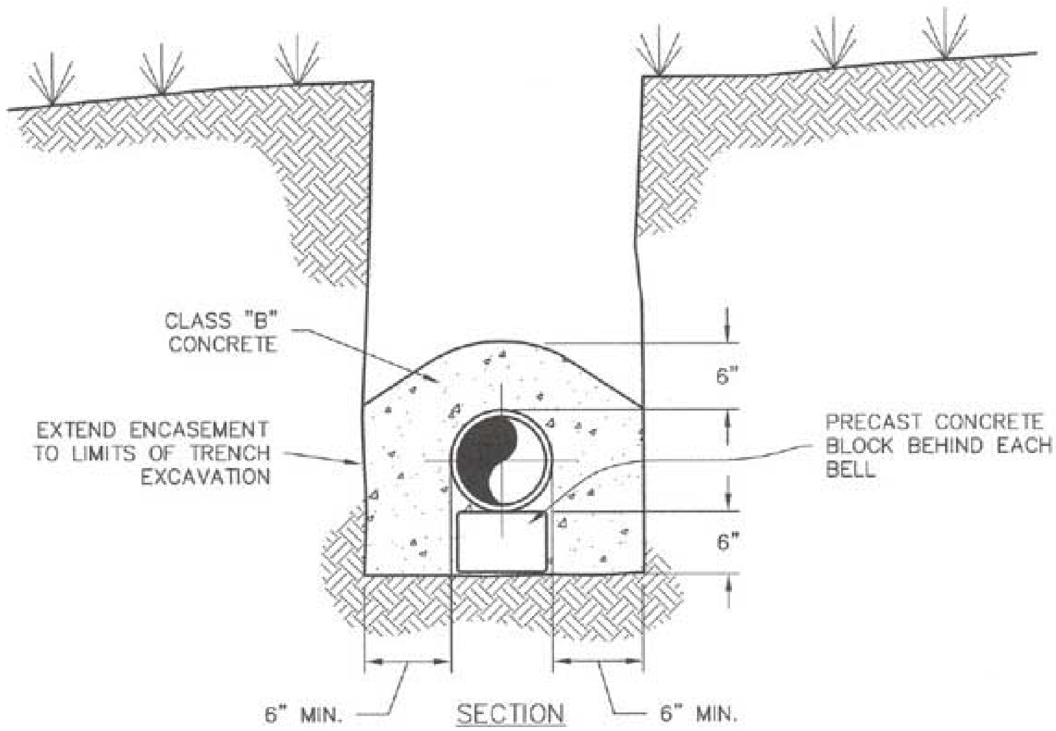


FIGURE 1

STANDARD CONCRETE ENCASEMENT AT CREEK CROSSING

N.T.S.

GRIGGS & MALONEY INCORPORATED
Engineering & Environmental Consulting
P.O. BOX 2968, MURFREESBORO, TN 37133-2968
(615) 895-8221 * FAX (615) 895-0632

FILE NAME: G: \Engineering\08\Bill\Fig 1 Concrete Encasement at Creek Crossing.dwg

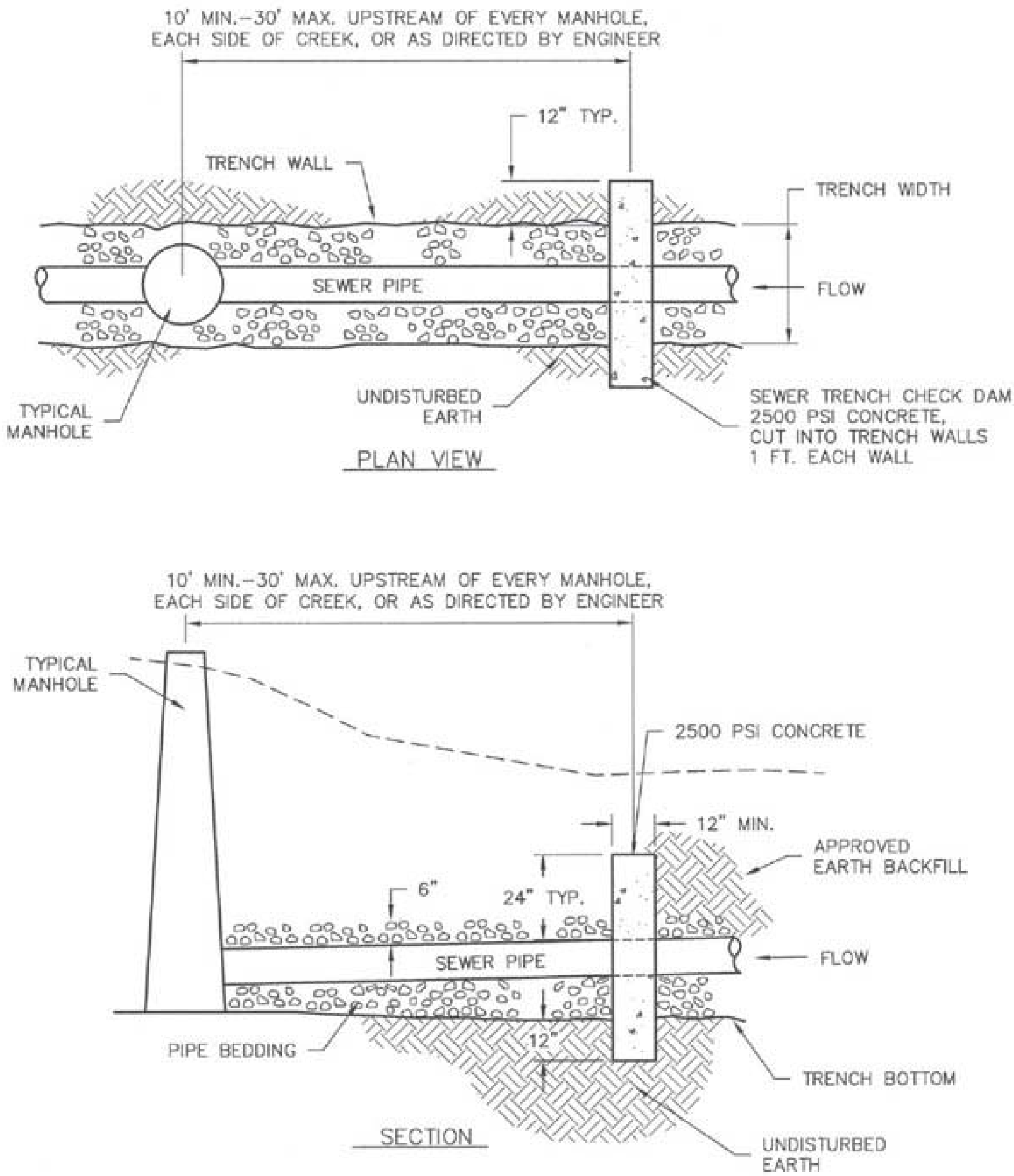


FIGURE 2
SEWER TRENCH CHECK DAM
N.T.S.

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Engineering & Environmental Consulting
P.O. BOX 2968, MURFREESBORO, TN 37133-2968
(615) 895-8221 * FAX (615) 895-0632
FILE NAME: G: \Engineering\08\88\Fig 2 Sewer Trench Check Dam.dwg

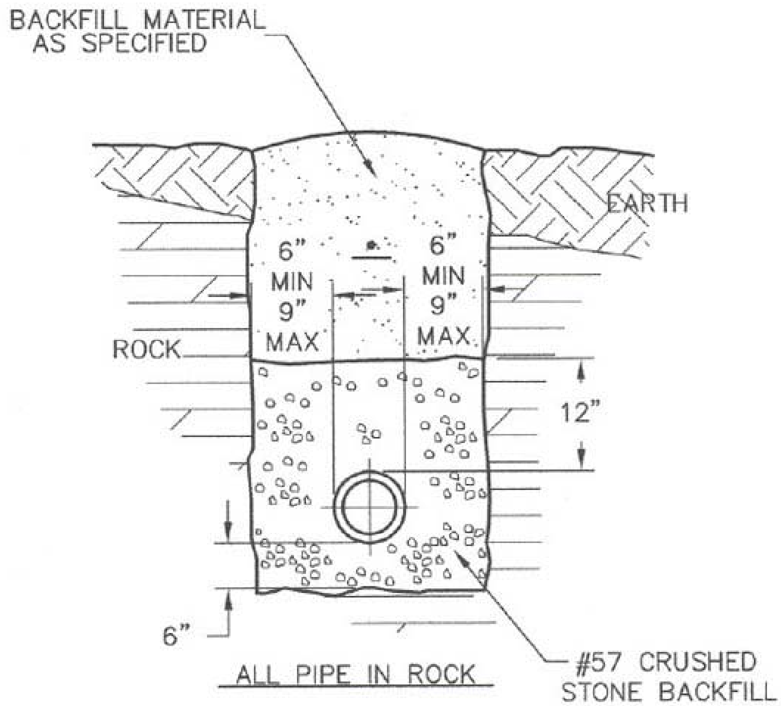


FIGURE 3
STANDARD GRAVITY SEWER BEDDING & BACKFILLING

N.T.S.

GRIGGS & MALONEY
INCORPORATED
Engineering & Environmental Consulting
P.O. BOX 2968, MURFREESBORO, TN 37133-2968
(615) 895-8221 * FAX (615) 895-0632

FILE NAME: G: \Engineering\08\Bill\Fig 3 Sewer Bedding & Backfilling.dwg

It is also common construction practice in Tennessee to use concrete encasement for utility stream crossings. The conventional encasement for stream crossings is generally designed to encase only the bottom and sides of pipe trenches at channel stream crossings. The concrete encasement can terminate a few inches above the pipe or it can extend to the top of the rock or to the top of the trench, depending on the construction plans and specifications.

REGULATORY REQUIREMENTS

The Tennessee Department of Environment and Conservation, Division of Water Pollution Control (TDEC) has developed an Aquatic Resource Alteration General Permit (ARAP) for utility line crossings. Similarly, the U.S. Army Corps of Engineers has developed CWA §404 Nationwide Permit 12 that authorizes utility line impact up to ½ acre. However, in instances where the risk for hydrologic disruption of a stream system poses an appreciable risk, the Division may elevate the utility line crossing project to an individual permit which carries additional levels of applicant demonstration, regulatory agency review, and pre- and post-construction monitoring.

PROJECT DESCRIPTION

SITE DESCRIPTION

TDEC has classified Dry Branch as not supporting fish and aquatic life in conjunction with its receiving stream, Spencer Creek. The full designated uses for Dry Branch are: fish and aquatic life, recreation, livestock watering and wildlife, and irrigation. Dry Branch at the proposed crossings has a substrate dominated by limestone bedrock and unconsolidated gravel. The width of the channel varies from 2 to 8 feet and the riparian vegetation varies from absent to good cover.

The stream is underlain by the Bigby-Cannon limestone, which in this area is known to weather unevenly with deep cutters and intervening rock pinnacles. As is typical in Karst geology, groundwater is present in solution openings that have developed along vertical fractures (joints) and bedding planes. The underlying rock unit exerts effect upon both channel formation patterns through bedrock structural influence and the associated geohydrology in the rock unit atop which and through surface streams flow.[4]

The stream is estimated to exhibit 7 day 10 year (7Q10) and 30 day 5 year (30Q5) recurrent low flows of 0 cfs. Mean annual flow is predicted to be 1.89 cfs and the mean summer flow of is predicted at 1.13 cfs.[5]

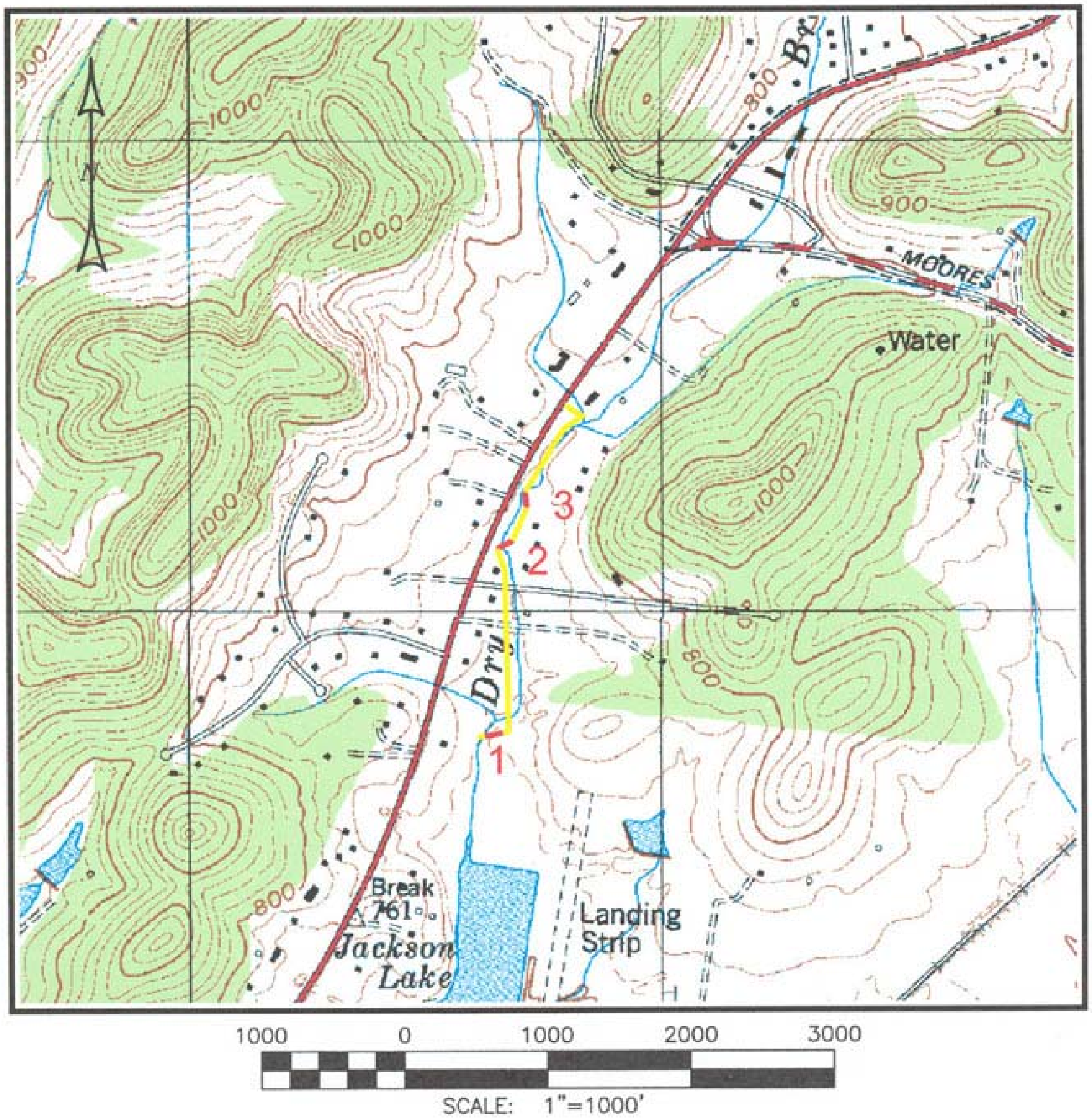
PROJECT HISTORY

In the summer of 2005, a Williamson County, Tennessee developer had a gravity sewer designed by others to transport wastewater from their proposed residential housing complex along Dry creek, a first order stream, to an existing municipal sewer. (See Figure 4)

TDEC reviewed the sewer line construction plans and specifications and expressed serious concern that the proposed methods to install the gravity sewer could severely interrupt the stream's surface and ground water hydrology. TDEC was also concerned about the possibility that the use of explosives to excavate the sewer trench might cause excessive bedrock fracturing that would further alter stream base flow. Correspondence from TDEC stated …."our concerns regarding the proposed gravity sewer line that included that capture of flow from the stream and the destruction of the stream bank that would result from the trench". The correspondence further stated that "Our streams are valuable resources and we have lost many due to stream flow capture and interception by gravity sewer lines. This is an on-going problem that presents itself time and again. Therefore, we want to be reasonably certain this will not happen in this case."[6] TDEC directed the developer to "provide a more detailed description of actions to restore the stream bank and we (TDEC) would decide if the proposed activity is permittable."

The construction plans and specifications required the sewer to be installed in a narrow corridor between an existing paved road and the stream. TDEC inquired about the possibility of installing the sewer further from the streambed. However, relocating the proposed sewer layout to the opposite side of the stream would add two creek crossings to the project and would also involve additional easement issues. Moreover, adding two creek crossings would increase the probability of channel impact and stream flow loss. Therefore, avoidance of the stream was discounted as an option and the focus directed toward implementing construction methods that would be minimally invasive to the stream.

The possibility of using a rock trencher instead of explosives was considered to lessen secondary fracturing; however, the use of a rock cutting trenchers, while likely creating less bedrock impact, would not eliminate the possibility of intercepting groundwater discharging into the stream if traditional sewer construction methods and backfill materials were used.



Taken from: U.S.G.S.
7.5 Minute Series (Topographic)
Franklin Quadrangle
1981

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INCORPORATED
Engineering & Environmental Consulting
P.O. BOX 2968, MURFREESBORO, TN 37133-2968
(615) 895-8221 • FAX (615) 895-0832
FILE NAME: G:\Eng\08\Bill\Fig 4 Sewer Alignment & Crossing Locations.dwg

Figure 4
Dry Creek Sewer Alignment
and Service Crossing Locations
Williamson County, Tennessee

SOLUTION

The developer then requested Griggs & Maloney, Inc. to participate in designing construction alternatives that would allow gravity sewer line installation at the desired locations, yet exert little, if any, impact upon the stream.

As previously stated, concrete encasement of stream utility line crossings is a traditional construction practice designed primarily to help prevent erosion of the buried pipe by stream flows. Contractors traditionally use a very dry (low slump) mix of concrete with a compressive strength of 2,500 psi or greater that is usually not vibrated to remove voids. (A dry mix is used to prevent concrete loss down the trench and increasing the amount [and cost] of concrete used.) A gravity sewer line is generally installed on a granular material bed to support the pipe and provide correct grade. Concrete rarely migrates under the pipe barrel that is set atop the bedding material; therefore, traditional concrete encasement is wholly incapable of preventing stream loss. Its general objective is to provide physical protection to the pipe.

Similarly, concrete encasement is not generally installed when underground utility lines are installed parallel and near streambeds, unless it is needed for physical protection or erosion prevention. Such installations near streams generally include select backfill material, either granular fill or native material.

During discussions between TDEC and Griggs & Maloney, Inc., it became apparent that an ARAP would not be issued for this project if traditional engineering design and construction methods were proposed.

An initial option considered was to backfill all areas with vibrated concrete from the bottom of the pipe trench to the top of the rock in the area that exhibited the greatest potential to intercept groundwater flow or divert stream flow. This would theoretically simulate the existing rock profile, and by vibrating the concrete, the material would be forced into the exposed rock atop and adjacent to which the pipe is to be installed.

This option was discounted for the following reasons:

Consolidation of concrete by vibration or by the use of plasticizers causes the concrete to approach a liquid phase. This creates a buoyant force on the pipe equal to the weight of the volume of concrete displaced by the pipe. (The density of concrete depends on the mix design but concrete has a density at least twice that of water.) Simply plugging the sewer pipe and filling it with water would not prevent flotation. In addition, the municipal sewer department objected to backfilling the sewer pipe with consolidated concrete due to the difficulty in excavating the pipe should future maintenance be required. (The sewer was to be deeded to the municipality after construction was complete.)

As an alternative, concrete flowable fill was considered. Flowable fill is usually less expensive than regular concrete and, as its name implies, possesses high flow and approaches a liquid state until set. It will fill voids under and around the sewer pipe and will readily flow into any rock crevices without vibration or the use of additives. Flowable fill has a lower unit weight than regular concrete, although it is still denser than water and preventing pipe flotation during backfill must still be considered. With a compressive strength of 80 to 120 PSI, flowable fill can also be excavated with a backhoe, thereby satisfying the municipality’s concern about future pipe access.

In an effort to determine if flowable fill would be a viable option that would satisfy the concerns of the developer, TDEC, and the municipality, the option of utilizing flowable fill was researched.

FLOWABLE FILL TECHNICAL CHARACTERISTICS

Flowable fill uses fly ash as one of the principal ingredients in the mix and is the key ingredient in producing a lower ultimate strength matrix applicable for this intended use. TDEC expressed an additional concern relative to the potential toxicity (metals mobility) exerted by the fly ash in an aquatic environment. (Some past research indicated a slight potential for metal-bearing leachates emanating from fly ash.) Toxicity testing sponsored by the U.S. Department of Energy indicated little potential for toxicity to exist from fly ash sources, particularly in an alkaline environment as is present in flowable fill [7,8].

Tennessee Technological University conducted prior research whereby multiple trenches were backfilled with flowable fill, the material allowed to fully set, and the material removed with conventional excavation equipment. This study was documented by both technical paper and video record.

The Tennessee Department of Transportation (TDOT) has used flowable fill for several years to backfill utilities in roadways and to fill abandoned excavations and water supply wells. Also, flowable fill has been included in TDOT's Standard Specifications for Road and Bridge Construction since at least 1995 [9]. Several ready mix concrete plants in Middle Tennessee were contacted and it was determined that flowable fill was readily available in the Middle Tennessee area.

Flowable fill can have different characteristics depending on the mix design. In general, flowable fill characteristics include: [10]

- Available in ready mix trucks
- Can be placed by chute, conveyor, pump, or bucket
- Self leveling
- 28 day compressive strength can vary from 1200 psi to 50 psi, depending on the mix
- Mixes with 28 day compressive strengths of 50 psi to 100 psi can be excavated with conventional excavation equipment
- Self consolidating
- Workers can place flowable fill without entering the trench
- Will displace standing water
- Contains 25 to 150 pounds type 1 cement per cubic yard
- Contains 0 to 600 pounds fly ash per cubic yard
- Contains 0 to 35% air
- Unit weight is 90 to 110 pounds per cubic foot

Griggs & Maloney, Inc. recommended using flowable fill to backfill under, around and over the proposed sewer pipe, including backfilling the trench up to the surface of the existing rock.

The developer and the design engineer proposed to TDEC to use this alternative backfill at the two stream crossings, backfill the entire trench where the sewer paralleled the stream in close proximity, add additional concrete check dams, restore the disturbed stream bank with bioengineering methods, and raise the sewer profile in certain locations.

The sewer pipe was placed on concrete blocks resting atop bedrock rather than the conventional stone aggregate bed to achieve the proper pipe slope and to allow the flowable fill to readily migrate under the pipe.

Since flowable fill would create a positive buoyant force on the pipe, it had to be secured to bedrock by metal or cables tied with adjustable turnbuckles to anchors installed into sound rock in the bottom or side of the trench. Figures 5, 6, and 7 depict the engineering details previously described.

The pipe material was required to be ductile iron rather than the originally specified PVC, since the flowable fill would exert a greater buoyant force upon PVC and the pipe had to possess the structural strength to bridge between the hold-down straps without bowing.

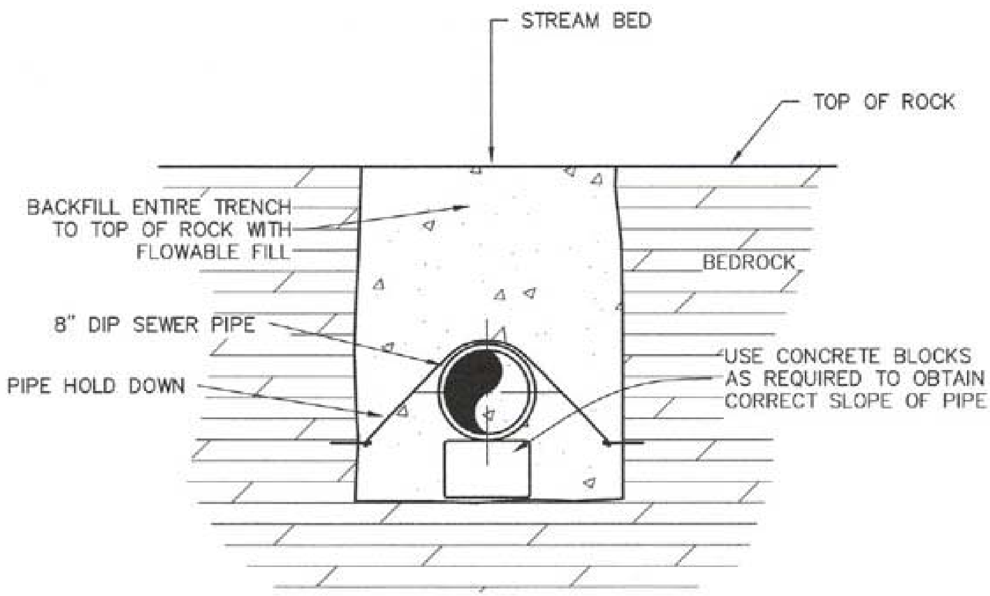
The advantages of flowable fill include:

- Its ability to fill existing and created voids in the excavated rock,
- Reestablishing the existing rock profile in the bank to prevent the diversion of groundwater flow,
- Reestablishing the existing rock profile in the streambed to prevent diverting stream flow,
- Is easily excavated by standard construction equipment,
- Does not require tamping or vibration for compaction,
- Provides trench backfill suitable for road crossings and paving.

The disadvantages of flowable fill revolve mainly around its increased cost as compared to using native material or quarried aggregate; however, savings can be realized through decreased labor in placing the material.

CONCLUSION

TDEC accepted the proposed technical addenda to the ARAP application and subsequently issued the permit authorizing this project. The project has now been installed and has been in service for several months.



NOTE:

1. DO NOT LAY PIPE ON CRUSHED STONE BEDDING. DO NOT BACKFILL PIPE WITH CRUSHED STONE IN ROCK EXCAVATION AREAS.

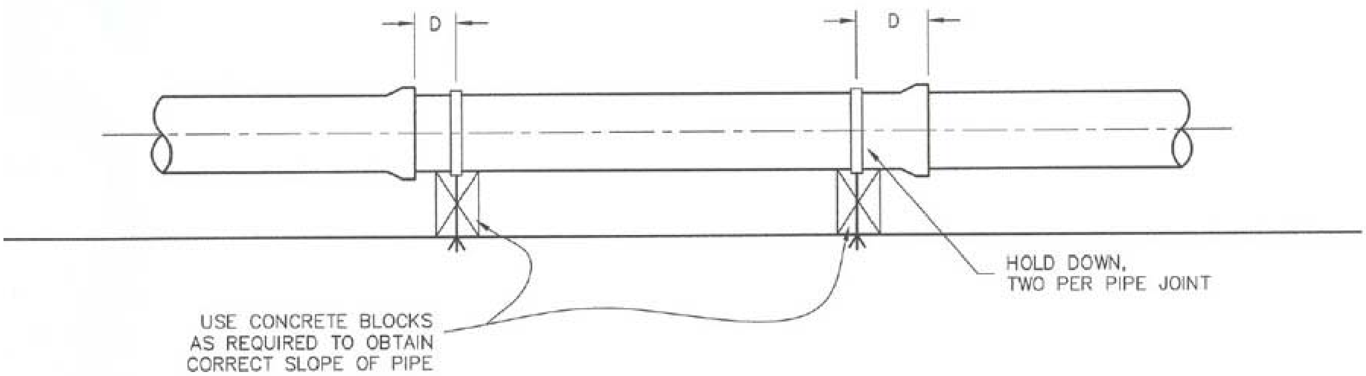
2. FLOWABLE FILL TO BE UNDER AND AROUND DIP SEWER PIPE FROM BOTTOM OF TRENCH IN ROCK EXCAVATION AREAS TO TOP OF ROCK EXCAVATION.

3. FLOWABLE FILL TO BE GENERAL USE FLOWABLE FILL CONFORMING TO TENNESSEE DEPARTMENT OF TRANSPORTATION (TDOT) STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION MARCH 1, 2006 SECTION 204.06 FOR CONTROLLED LOW-STRENGTH MATERIAL (CLSM) FOR GENERAL USE FLOWABLE FILL.

FIGURE 5

SANITARY SEWER LINE
CREEK CROSSING IN ROCK UTILIZING FLOWABLE FILL
END VIEW
N.T.S.

GRIGGS & MALONEY INCORPORATED
Engineering & Environmental Consulting
P.O. BOX 2968, MURFREESBORO, TN 37133-2968
(615) 895-8221 * FAX (615) 895-0632
FILE NAME: G: \Eng\08\Bill\Fig 5 & 6 Creek Crossing in Rock.dwg



NOTES:

1. DO NOT LAY PIPE ON CRUSHED STONE BEDDING. DO NOT BACKFILL PIPE WITH CRUSHED STONE IN ROCK EXCAVATION AREAS.

2. DIMENSION "D" TO BE NOT LESS THAN 12" FROM END OF PIPE AND NOT MORE THAN 48" FROM END OF PIPE.

3. DUCTILE IRON PIPE AND FLOWABLE FILL BACKFILL TO A POINT 10 FEET FROM TOP OF CREEK BANK, MINIMUM.

FIGURE 6

SANITARY SEWER LINE
CREEK CROSSING IN ROCK – SIDE VIEW

N.T.S.

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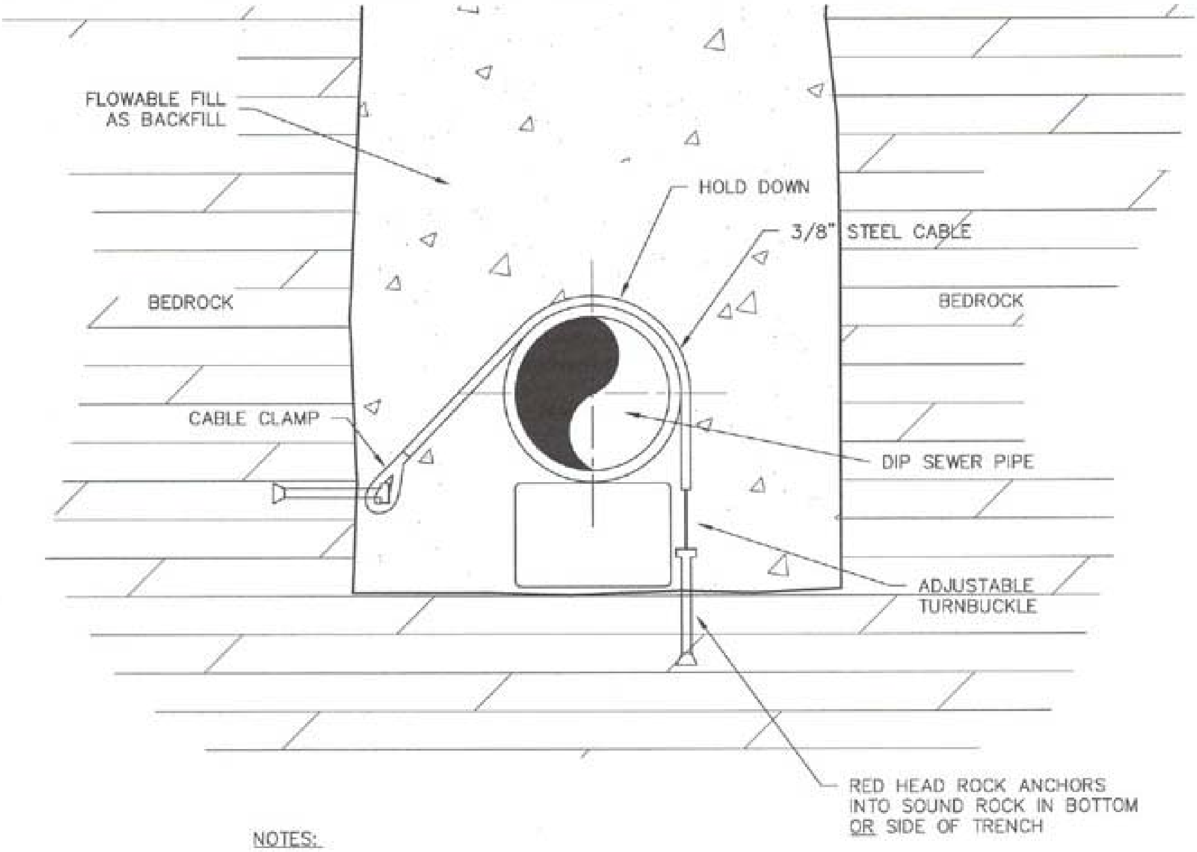
FILE NAME: G: \Eng\08\Bill\Fig 5 & 6 Creek Crossing in Rock.dwg



NOTES:

1. ROCK ANCHORS TO BE 3/8"ø X 5" LONG INTO SOUND ROCK. ANCHORS TO BE IN TRENCH BOTTOM OR INTO TRENCH WALL BELOW THE INVERT OF THE PIPE.

2. HOLD DOWN TO BE 3/8" STEEL CABLE.

3. CONNECT CABLE TO ROCK ANCHORS WITH 3/8" FLAT WASHERS AND CABLE CLAMPS.

4. TWO HOLD DOWNS PER LENGTH OF PIPE.

FIGURE 7

SANITARY SEWER LINE HOLD DOWN DETAIL

N.T.S.

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P.O. BOX 2968, MURFREESBORO, TN 37133-2968
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FILE NAME: G: \Eng\08\BW\Fig 7 Sewer Hold Down.dwg

Stream Flow Measurements Methods and Results

In compliance with monitoring provisions of the ARAP [11], stream flows were measured at four locations within the project area before and after construction at the locations shown on Figure 8. Specifically, pre-construction flows were measured on August 5, 2005 and post-construction stream flows were measured on September 27, 2006).
Stream flow was measured at each monitoring site by utilizing the dye dilution methods whereby Rhodamine WT® dye was injected upstream at a known concentration and at a constant delivery rate with a FMI® Model RP-BG75 12-volt dye metering pump at the aforementioned flow monitoring locations The dye was introduced into the stream at points of turbulent flow far enough upstream from the measurement sites that the dye had time to mix thoroughly, producing a uniform concentration across the three dimensional water column at each stream flow measurement point. The flow measurements were performed beginning at the lowermost monitoring point (Station 4), proceeding upstream to ensure that dye travel from upstream injection points did not interfere with the instream dye concentration readings at the location(s) of downstream measurement. The concentration of tracer dye injected was determined by diluting the feed stock 1000 to 1 and analyzing the concentration of the diluted sample (which was well within the range of measurement linearity of the fluorometer) before the study commenced. Background fluorescence of ambient stream water, while negligible, was also determined and the fluorometer adjusted accordingly to negate potential minor interference in dye measurement accuracy. All dye concentration readings were performed in the field with a Turner Designs® Model 10-000 fluorometer under constant ambient stream temperatures to ensure that thermal factors did not exert influence on the degree of dye fluorescence. Moreover, the dye injection pump's delivery accuracy was confirmed at each station before injection occurred by timing the pump's discharge into a 100 ml graduated cylinder. Under these conditions, instantaneous stream flow was calculated as follows:

$$Q_s = Q_t \times \frac{C_t}{C_s}$$

Where:
Q_s is the instantaneous stream discharge rate in liters per minute,
Q_t is the rate at which the dye was injected (liters/minute),
C_t is the concentration of the injected dye, and
C_s is the instream concentration of dye at the points of measurement.

Using the flow measurement method previously described the following flow values were observed at the monitoring stations during each stream flow monitoring event:

Table 1. Dry Creek Flow Study Pre-Construction Field Data and Stream Flow Calculations August 5, 2005

Station No.	Time	In-stream Dye Conc., ppm	Stream Flow, liters/min.	Stream Flow, cfs
1	1445	0.22	21	0.012
2	1426	0.07	67	0.039
3	1400	0.064	73	0.043
4	1310	0.056	90	0.053

Note: Qt = 0.05 l/min; Ct = 94 ppm

Table 2. Dry Creek Flow Study Post-Construction Field Data and Stream Flow Calculations September 27, 2006

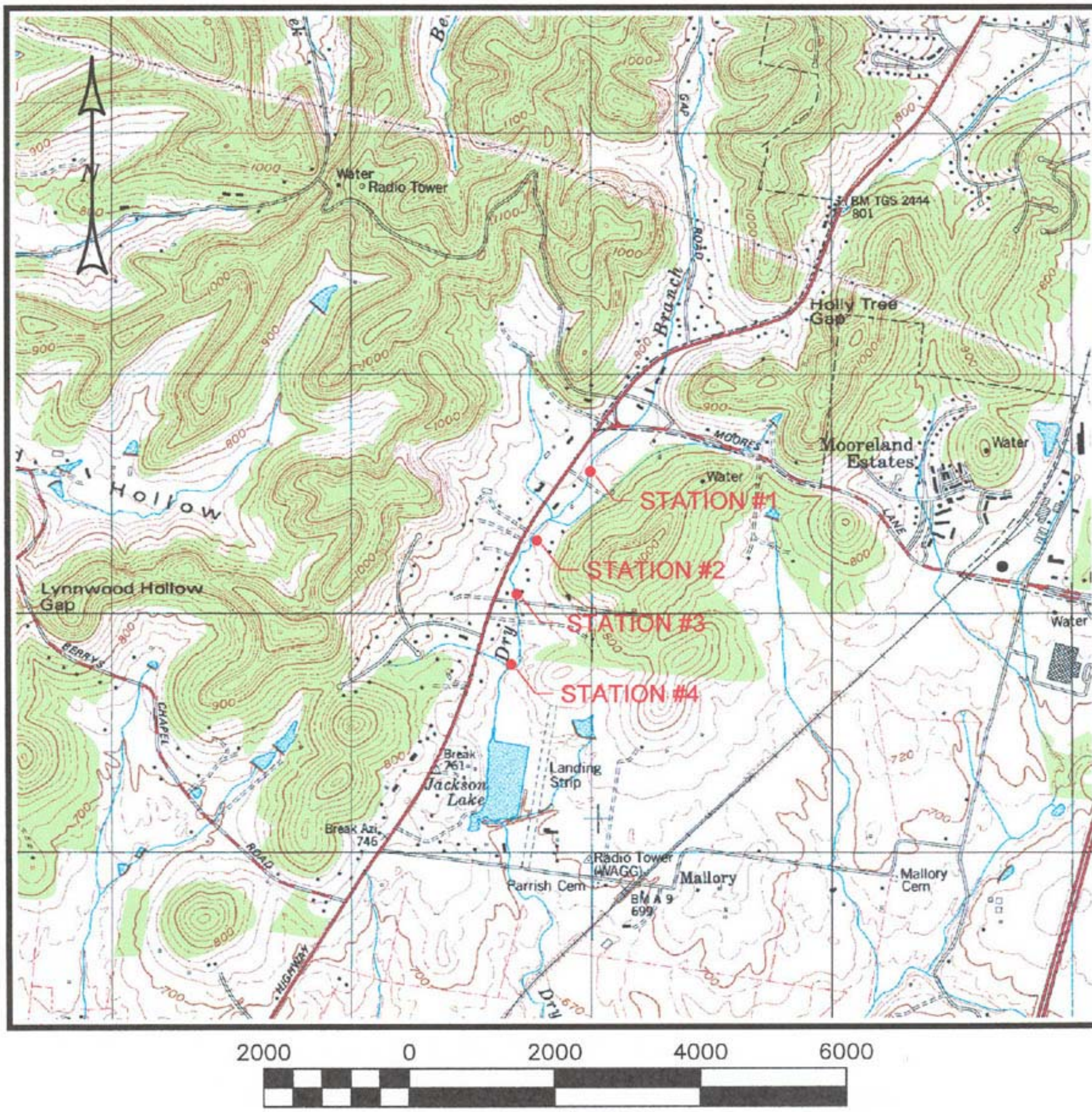
Station No.	Time	In-stream Dye Conc., ppm	Stream Flow, liters/min.	Stream Flow, cfs
1	1425	0.042	300	0.18
2	1357	0.032	394	0.24
3	1202	0.028	450	0.27
4	1115	0.016	788	0.47

Note: Qt = 0.063 l/min; Ct = 200 ppm

The flow studies revealed that Dry Creek exhibits similar hydrologic base flow characteristics both before and after the sewer line was installed. An additional flow study is planned for late summer 2007 to again evaluate Dry Creek's base flow behavior in the study area.

Moreover, visual observation during and after rain events, reveal that groundwater flow from the stream banks to the stream is not being intercepted or diverted by the utility line, but readily enter the stream at points where the flowable fill barriers have been installed.

The use of readily available materials in a non-traditional method allowed a needed utility to be provided to a development in a challenging setting without harming an important natural resource.



SCALE: 1"=2000'

Taken from: U.S.G.S.
7.5 Minute Series (Topographic)
Franklin Quadrangle
1981

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FILE NAME: G: \Eng\08\Bill\Fig 8 Flow Monitoring Stations.dwg

Figure 8
Dry Creek Flow Monitoring Stations

Williamson County, Tennessee

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INVESTIGATING SEDIMENT RETENTION IN PROPRIETARY STORMWATER TREATMENT DEVICES

John Dawson and Kwabena Osei[1]

In approving stormwater BMPs, regulators usually review sediment removal data as the basis for their decisions. One factor that is usually overlooked is the ability of a treatment device to retain captured material in the event of high flow rates. Lately, some agencies are requiring vendors to indicate washout prevention of their stormwater treatment systems. However, no standard protocol exists that measures how much of previously captured pollutant is resuspended and carried downstream of the treatment device during high flows. This paper discusses an effective test protocol for evaluating the sediment retention efficiency of proprietary stormwater treatment systems. The sump of a full-scale treatment device is filled with a known mass of sediment or sediment tracer. The unit is run at steady-state for a specified duration that exceeds several multiples of its effective detention time. Repeated tests are undertaken at different flowrates and the amount of material retained in the device for each flow rate is determined. The sediment retention efficiency is then calculated based on a comparison between mass of material retained in the sump after running flows through the unit and the original mass of material deposited in the sump. Test data using this protocol for different device configurations are discussed and this highlights the importance of chamber geometry and hydrodynamic regime on the sediment retention efficacy of stormwater treatment devices.

1 Research and Development Manager, Hydro International, 94 Hutchins Drive, Portland, ME 04102 kosei@hil-tech.com

CONTINUATION OF WADEABLE STREAMS ASSESSMENT PROJECT IN TENNESSEE

Gregory M. Denton [1]

In 2004, Tennessee participated in EPA's 2004 National Wadeable Streams Assessment (WSA). In this project, biological, physical, and chemical data from a random sub-sampling of wadeable streams were used to extrapolate to all similar streams in the nation. These data will provide a baseline to which future efforts can be compared, thus providing an opportunity for scientifically valid trend analysis.

For the 2004 project, EPA aggregated Level III ecroregions into larger regions, within which a minimum of 50 stations were established. In Tennessee, there were two of these large regions: east and middle Tennessee (interior plateau, southeastern appalchians, ridge and valley, and blue ridge ecoregions), plus west Tennessee (coastal plain and delta ecoregions). Twenty-six stations were established in Tennessee, three in west Tennessee and 23 in east Tennessee.

The results of the national study of wadeable streams was released in 2006.

Tennessee has applied for an EPA grant to continue the wadeable streams project. This project will build upon the work previously done and has the potential to answer questions about the condition of all wadeable streams within Tennessee.

The project will have the following major activities:

1. We will establish a minimum of 30 randomly-selected stations in each of three areas based on Level III ecoregions (or aggregated Level III ecoregions) in Tennessee. These three regions will be east Tennessee (Blue Ridge Mountains, Ridge and Valley, Southeastern Appalachians), middle Tennessee (Interior Plateau), and west Tennessee (Coastal Plain, Mississippi Delta).

2. Collect chemical, physical, bacteriological, and biological data over a period of one year at each station.

3. At each station, identify violations of water quality criteria. According to the magnitude, frequency, and duration of exceedences, establish the degree of use support at each stream. Combine data for stations within each region, plus the entire state, to extrapolate to the larger area.

Reconnaissance of potential stations will begin in the summer of 2007 with sampling to begin by August or September. It is expected that the final project report will be published in the latter part of 2008.

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1 Environmental Program Manager, Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Planning and Standards Section. Nashville, Tennessee. 615-532-0699. Gregory.denton@state.tn.us.

MERCURY LEVELS IN TENNESSEE FISH

Gregory M. Denton [1]

The Department of Environment and Conservation is identified by the Tennessee Water Quality Control Act as having the primary statutory responsibility to ensure that the quality of our lakes, streams, rivers, wetlands, and reservoirs support the public's reasonable uses of them. Particular attention is given in the act to the commissioner's responsibility to report and take action upon evidence of direct human health threats. Section 69-3-107 states that the commissioner should *"post or cause to be posted such signs as required to give notice to the public of the potential or actual dangers of specific uses of such waters or restrictions of uses of such waters."*

Mercury is a toxic metal with a well-documented link to environmental harm and human health impacts. Ingested mercury is readily carried throughout the body by the bloodstream and can migrate through the placenta to the developing fetus. According to EPA, recent studies of mercury exposures in children have noted effects at levels within the range of some U. S. population exposures.

Since the consumption of contaminated fish is considered to be the major pathway of exposure for most people, in 2001, EPA proposed a revised water criterion based on a fish tissue level of 0.3 ppm. In order to determine the locations where this level might be exceeded in Tennessee, the Department of Environment and Conservation has compiled and analyzed fish tissue data from multiple agencies. Agencies providing data include the department, EPA, Tennessee Valley Authority, Tennessee Wildlife Resources Agency, Oak Ridge National Laboratory, and the Corps of Engineers.

1 Environmental Program Manager, Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Planning and Standards Section. Nashville, Tennessee. 615-532-0699. Gregory.denton@state.tn.us.

PAVILION BRANCH STREAM RESTORATION PROJECT

Gary M. Myrncza, PE, PH[1]

The Tennessee Stream Mitigation Program (TSMP) contracted with KCI Technologies (KCI) to provide professional assessment, design and construction management services for the restoration of Pavilion Branch, two tributaries, and their associated riparian buffers on the Tennessee Preparatory School (TPS) property in Nashville, Davidson County, Tennessee.

The project site is located in an urban setting within the Interior Plateau. The local watershed is part of the Cheatham Reservoir 8-digit HUC (05130202). The area draining to the project reach is approximately 0.7-square mile and is dominated (69%) by urban or built up land use / land cover. KCI relied on a hybrid approach using analog and analytical techniques together to assess the site conditions and prepare a comprehensive design.

The Pavilion Branch main stem was channelized and armored and was therefore devoid of many of its natural morphologic characteristics. KCI developed a hydrology model to utilize as a design discharge prediction/validation tool. Ground-truthing was conducted to verify conditions and document how and where water was routed through the drainage. Surface water fluctuations were documenting using pressure transducers. These measurements were useful for calibrating the hydrology models. Once calibrated, the models predicted hydrographs for various precipitation events (of varying recurrence probabilities). These flows were used in conjunction with a hydraulic model to best approximate the design discharge for the restored channel.

Sediment transport characteristics of the existing stream were also evaluated. A theoretical model was used to predict the bedload capacity based on the sediment collected above the armor layer. Riffle enhancement structures were specifically designed based on the sediment analysis as part of the restored stream system.

The planning process for the Pavilion Branch project also included an evaluation of the habitat associations of the federally-endangered Nashville crayfish (Orconectes shoupi) that inhabit the Mill Creek watershed. KCI studied the associations and attempted to replicate the characteristics and features of the habitats through designed structures as part of the stream restoration project. Further, the project serves as an educational opportunity for students at the Nashville School of the Arts, which is also located on the TPS complex.

This presentation provides a case study of the Pavilion Branch Stream Restoration project from its inception through its implementation. It includes a brief synopsis of the hybrid design approach, a discussion of the important design considerations, and a sequential documentation of the project through each of its phases.

1 Senior Associate, KCI Technologies, Inc., 4601 Six Forks Road, Suite 220, Raleigh, NC 27609 gmryncza@kci.com

POND CREEK LEVEE SETBACK AND STREAM RESTORATION PROJECT

Michael F. Adams[1], Robert Bailey[2], Aaron J. Kopp[3]

When the West Tennessee River Basin Authority (WTRBA) initially identified the need to address flooding and flow maintenance issues along Pond Creek, the Tennessee Stream Mitigation Program (TSMP) was pleased to join the effort to find an opportunity to conduct a project that would contribute to the restoration of natural stream and floodplain dynamics. The result of this joint effort is the Pond Creek Stream Restoration Project in Crockett County which consists of two separate but dependent components: levee setback and stream restoration. FMSM served as the design consultant for the project.

Extensive channelization of the watershed was conducted in the mid 1900s to improve the drainage for agricultural land use. The primary goals of this stream restoration project were to improve water quality, enhance aquatic habitat and restore riparian habitat. These goals were accomplished by: restoring stable channel morphology supported by natural in-stream habitat and bank stabilization structures; reducing sedimentation; and enhancing the capacity of the site to mitigate flood flows by restoring a functional floodplain at bankfull elevation. This project addresses these goals by relocating 1,941 linear feet (LF) of Pond Creek and adding 617 feet to six unnamed tributaries by using natural channel design techniques. Final project stream length is approximately 2,853 LF. An average riparian buffer zone width of 100 LF, on each side, was planted with a mosaic of live stake, tree, and herbaceous species.

The design of Pond Creek was based on reversing the stream channelization and increasing flood storage capacity. The expansive wetlands that once dominated the West Tennessee coastal plains have been significantly impaired ecologically. Diverse and stable watersheds, such as the Hatchie and Wolf River, are rare since most of the coastal plain has been converted to cotton and soybean production. Stable streams in the Mississippi coastal plain tend to have slow flow velocities, flat slopes, low width to depth ratios, and expansive floodplains. Levees and ditches have lowered the water table and created unstable, eroding streambanks. Restoration on the Pond Creek project site integrated a sinuous, low width to depth ratio stream into the widest floodplain possible; hence the levee set back and riparian planting plan. Large woody debris will initially establish from streambank live stake plantings and later from maturing bare-root stock trees on the floodplain. In-stream root wad and log vane structures were constructed in the outer bends of pools for habitat, hydraulic, and bioengineering purposes. Natural channel design techniques were bolstered with channel evolution expectations, regional curve development, sediment capacity modeling, and Hec-Ras modeling.

1 Project Manager, Fuller, Mossbarger, Scott and May Engineers, Inc., 1901 Nelson Miller Pkwy, Louisville, KY, 40223, 502.212.5000.

2 Project Manager, Tennessee Stream Mitigation Program (TSMP), P.O. Box 336
Lobelville, TN 37097, 931.593.3237.

3 Project Engineer, Fuller, Mossbarger, Scott and May Engineers, Inc., 1901 Nelson Miller Pkwy, Louisville, KY, 40223, 502.212.5000.

RESTORATION OF WALLENS BEND AND CLINCH RIVERS TO REDUCE SEDIMENT NEAR THREATENED MUSSEL SHOALS

Nick Cammack[1], Greg Babbit[2], Michael F. Adams, Jr.[3]

The Clinch River in Northeastern Tennessee supports some of the most diverse, and threatened, mussel shoals in the world. Sediment produced by agriculture, mining, and other anthropogenic activities upstream has endangered the stability of this fragile ecosystem. The Tennessee Stream Mitigation Program, in conjunction with The Nature Conservancy and the Tennessee Wildlife Resource Agency, identified two sites along the Clinch River and a tributary where suitable restoration practices could significantly decrease the amount of erosion and sediment subsequently entering the Clinch River system. One site consisted of a 450 foot section of actively eroding bank on the Clinch River. The other site was a 2,400 linear foot tributary that had been channelized and was actively incising into the valley floor. This paper discusses the process of identifying potential restoration sites; conducting assessments to identify the existing condition of impacted streams; collecting and analyzing relevant geomorphic and sediment data; developing channel plan, dimension and profile geometry; selecting appropriate vegetation; acquiring agency buy-in for restoration in an environmentally sensitive watershed; and constructing the project according to plans. The project was designed utilizing a combination of empirical and theoretical methods. Dimensionless ratios derived from a reference condition provided the foundation on which the design was developed; however, before the design was finalized a series of analytical equations were utilized to assess the sediment transport characteristics of the stream. To minimize the intrusion of equipment into an environmentally sensitive area, the eroding bank along the Clinch River was reconstructed to correct geometrical deficiencies and was supplemented with in-stream structures designed to relieve shear stress along the banks. The tributary was relocated in the historic valley bottom and the sinuosity was greatly increased, adding approximately 2,000 linear feet to the channel. The net result of the project is a significant reduction in bank erosion at both sites and an increase in biodiversity in the channel bottom and riparian corridor.

1 Project Engineer, Fuller, Mossbarger, Scott & May Engineers Inc., 1901 Nelson Miller Parkway, Louisville, KY 40223, 502.212.5000, email: ncammack@fmsm.com.

2 Project Manager, Tennessee Stream Mitigation Program (TSMP), P.O. Box 336
Lobelville, TN 37097, 931.593.3237.

3 Project Manager, Fuller, Mossbarger, Scott & May Engineers, Inc., 1901 Nelson Miller Parkway, Louisville, KY 40223, 502.212.5000, email: madams@fmsm.com

STREAM RESTORATION IN WEST TENNESSEE – CROOKED CREEK

Aaron J. Kopp[1], Robert Bailey[2], Michael F. Adams[3]

The Crooked Creek stream mitigation project, located near Milledgeville, TN in Hardin County, was an opportunity for both aquatic and terrestrial habitat restoration of a tract of land where extensive channelization of the watershed was conducted to improve the drainage for agricultural land use. A joint partnership between the Tennessee Stream Mitigation Program and the Tennessee Wildlife Resource Agency was established to improve the quality of the wildlife management area.

Restoration of aquatic habitat was achieved with Rosgen natural channel design to reduce the erosion of the oversized and entrenched ditches within the refuge. Stream hydraulics were modified to mimic the natural streams of West Tennessee by building an undulating stream profile connected to the floodplain and increasing plan form sinuosity. In stream structures of log vanes, live stakes, and root wads were added for habitat and streambank stabilization. Terrestrial plantings will contribute more large woody debris upon forest maturation. The 72 acre project area was planted with a myriad of bottomland hardwood species, shrubs, and a native herbaceous seed mixture. Novel terrestrial improvements included stream shade structures of live willow and alder trees, random forest debris piles, ephemeral pools and snag tree placements for raptor perching.

This project addresses the restoration goals by relocating approximately 3,905 linear feet (LF) of Crooked Creek and four unnamed tributaries totaling approximately 2,825 LF using natural channel design techniques. Final project stream length is approximately 6,029 LF for Crooked Creek and 4,376 LF for the tributaries. A width to depth (w/d) ratio of 8 is typical for unaltered reference reach streams along the Mississippi coastal plain. Building such narrow streams is not practical on streambanks requiring vegetative cover for stabilization. Building a channel with a w/d of 12 with minimal profile grade control allows for the evolution of a lower width to depth ratio stream over time, while also giving the streambanks time to develop the root density necessary to withhold bankfull flow shear stresses. A limitation of the natural channel design process was that sediment competency calculations are not applicable in sand-sized sediments. Another methodology was needed to verify the appropriate design w/d ratio. Sediment capacity modeling using PowerSed/FlowSed tools in the RIVERMorph software package served this purpose.

1 Project Engineer, Fuller, Mossbarger, Scott and May Engineers, Inc., 1901 Nelson Miller Pkwy, Louisville, KY, 40223, 502.212.5000.

2 Project Manager, Tennessee Stream Mitigation Program (TSMP), P.O. Box 336
Lobelville, TN 37097, 931.593.3237.

3 Project Manager, Fuller, Mossbarger, Scott and May Engineers, Inc., 1901 Nelson Miller Pkwy, Louisville, KY, 40223, 502.212.5000.

MARBLE SPRINGS: STREAM RESTORATION ON GOVERNOR JOHN SEVIER'S HOMESTEAD

Ryan V. Smith, CPESC, PWS[1]

Marble Springs is the original home of "Nolichucky Jack," better known as John Sevier, the first governor of Tennessee. The Tennessee Stream Mitigation Program (TSMP), in a cooperative effort with the Tennessee Department of Environment and Conservation (TDEC), the Tennessee Historical Commission (THC) and the Governor John Sevier Memorial Association (GJSMA), funded and managed the restoration of two streams on the historical property. The two streams, Neubert Springs and an unnamed tributary to Neubert Springs (UT), were identified as degraded streams that met TSMP's criteria for restorable channels. Both streams had been historically channelized and regularly maintained. The vegetated riparian buffer was sparse to nonexistent in many areas, with an overabundance of invasive non-native plants, dominated by Chinese privet (Ligustrum sinense). Regular maintenance and channelization led to channel incision and mass wasting of the banks, which contributed to the degradation of water quality within and downstream of the site. Neubert Springs is a direct tributary to Stock Creek which is a 303(d) listed stream. The primary goal of the project was to restore a stable dimension, pattern, profile and vegetated riparian buffer to both Neubert Springs and the UT. The two channels were restored using Natural Channel Design and construction principals. A planting plan was prepared and implemented to aid in the establishment of a native vegetated riparian buffer.

PROJECT STARTUP

The TSMP's primary objective is to provide cost-effective, meaningful compensatory mitigation for unavoidable impacts to Tennessee's aquatic resources (Woodard, 2006). To achieve "meaningful compensatory mitigation" the TSMP must identify and obtain a conservation easement on stream sites which provide offsetting aquatic benefits for mitigated impacts so as to meet the goal of the Clean Water Act and the "no net loss" policy (Tennessee Wildlife Resources Foundation, 2002). Stream sites used for mitigation should give preference to the same Level III Ecoregion, 6 digit Hydrologic Unit Code (HUC), or 8 digit HUC as the impacts. The streams should be within one stream order of the impacted stream and their watershed should generally display the same characteristics for land use (i.e. urban or rural) as the impacted stream. Priority should be given to 303(d) listed streams. As a result, the streams on the Marble Springs site were identified as suitable to mitigate for impacts located within the Fort Loudon Tennessee River Watershed in the Ridge and Valley Ecoregion. Additionally, because both streams are tributaries to Stock Creek, which is a 303(d) listed stream, they were given increased priority over other potential stream restoration sites in the region.

EXISTING CONDITIONS

Both Neubert Springs and the UT are shown as first order perennial streams with drainage areas of 0.33 and 0.30 square miles, respectively, on the Knoxville and Shooks Gap USGS topographical quadrangle maps (USGS, 1978 and 1979). A survey of both Neubert Springs and the UT was conducted to determine the existing morphological condition and discharge of each stream. A cursory visual survey revealed that both streams had been relocated from their historic location in the low point of the valley to the toe of slope of each stream's valley. Physical

1 Designer, Ko & Associates, P.C., 1011 Schaub Drive, Raleigh, NC 27606, rsmith@koassociates.com, 919-851-6066

surveys, which included measurements through the profile, dimension, pattern, and substrate material, were conducted to determine the stability of each steam. Data compiled from both visual and physical surveys revealed that each stream was a G4/6 type channel, based on Rosgen's stream channel classification system (Rosgen, 1996). G type channels display conditions where the bankfull (channel forming) discharge is contained within the channel's banks, and does not readily access a floodplain. Additionally, the channel's width-to-depth ratio (channel width at the bankfull discharge compared with the average channel depth) is typically low (≤12). The descriptors of 4 and 6 indicate that each channel displays sections where the substrate is dominated by gravel (4) or clay (6).

The most important aspect of conducting existing conditions surveys is to determine the bankfull discharge for the channel that is to be restored. This is the discharge for which each channel will be designed. Bankfull indicators typically indicate where the insipient point of flooding onto a floodplain should occur. Typically, in G type channels, it is difficult to determine the bankfull discharge because suitable bankfull indicators are not always present, or accurate. However, both Neubert Springs and the UT contained short reaches that displayed good bankfull indicators. These indicators were used to determine the bankfull discharge for both Neubert Springs and the UT.

Another component that was studied for existing conditions was the vegetative makeup of each stream's riparian corridor. Generally, the site displayed three separate vegetative communities. These communities include areas of maintained grass, Chinese privet thickets, and wooded areas with a maintained understory.

REFERENCE CONDITIONS

Reference reaches are stable stream channels which are representative of the proposed stream type to be designed. Morphological data is collected on the reference reach and used in the design of the restored stream. Reference reaches can help to verify bankfull discharge if located in close proximity to the site. It is imperative to collect data on reference reaches that are the same stream type as the proposed design stream type. Following a review of existing conditions data and conducting a topographical survey on the site, it was determined that two stream types, an E/C4 and a B4 type channel, would be designed for the site. E/C type streams typically have a wide floodplain at the bankfull discharge elevation, and display a moderate width-to-depth ratio (in the range of 10 - 12). B type streams typically have a very narrow floodplain at the bankfull discharge elevation and display a moderate width to depth ratio (> 12). A stream which displayed reaches of both E/C and B type characteristics was located and surveyed approximately 2.5 miles west of the Marble Springs site. The reference stream displayed stable characteristics where the bankfull discharge elevation was at top of bank, the drainage area was similar to site streams, and the bankfull discharge was similar to site streams.

HISTORICAL RESOURCES

Both a Phase I and a limited Phase II Archaeological Survey were conducted at the site to determine the potential for cultural resources eligible for the National Register. The report revealed two sensitive areas, one along Neubert Springs and one along the UT. The sensitive area along the UT was reported to be the site of a historic domestic structure and required a limited Phase II survey. The Tennessee Historic Commission required that, to the fullest extent possible, impacts to these sensitive areas be minimized during construction. The following guidelines were implemented by the Tennessee Historical Commission for the construction phase of the project in order to meet requirements as listed under Section 106 of the National Historic Preservation Act:

- All ground disturbing activities within the sensitive areas must be monitored by an on-site qualified professional archaeologist.
- A representative sample of the material removed in the vicinity of the sensitive area will be screened for artifact recovery and analysis.
- If significant archaeological resources are encountered during construction, all work must stop and the proper agencies contacted. A monitoring and artifact analysis report must be submitted to the agencies for their review.

No significant cultural resources were unearthed during construction while following these guidelines.

DESIGN AND CONSTRUCTION

A permanent conservation easement was recorded on the property that generally encompassed an area 50 feet from the top of bank on each side of the proposed design channel. As noted earlier, a stable dimension, pattern, and profile was designed for Neubert Springs and the UT using Natural Channel Design principals. Morphological data obtained from the reference reaches and bankfull discharge rates collected from on-site were used to complete the design. Neubert Springs was divided into two reaches, one upstream of the convergence with the UT and one downstream of the convergence of the UT. Both reaches were designed as Priority I restorations which raised the proposed stream bed elevation (when compared to the existing stream bed) so that the bankfull discharge elevation (top of bank of the design stream) was at existing ground. The upstream reach of Neubert Springs was designed as a B type channel that dissipates most of its energy through bed form (pools). The B type channel was required because of a restricted valley. The downstream reach was designed as an E/C type channel that dissipates its energy through both plan form (meander bends) and bed form. An E/C type channel was designed because of a wider valley.

The UT was divided into three reaches (upstream, middle, and lower). All reaches on the UT were designed as a Priority I restoration. The upstream and lower reaches were designed as an E/C type stream because of a wide valley. The middle reach was designed as a B type channel because of a constricted valley. The constrictions were caused by a historically sensitive area off of the right bank and a road embankment off of the left bank.

Structures such as log and rock cross-vanes, log vanes, log sills and rootwads were used to help protect channel banks, enhance pool formation, and provide areas of shading and foraging for aquatic fauna. Construction began in late June of 2006 and ended in early October 2006. All Chinese privet was eradicated from within the conservation easement areas. A planting plan was completed which encompassed the easement area and reintroduced native trees and shrubs to the channel banks and floodplain. Planting of the riparian corridor began in December 2006 and was completed in February 2007.

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THIRD CREEK RESTORATION PROJECT
KNOXVILLE, TENNESSEE

Andrew Bick, PE[1]

The Tennessee Stream Mitigation Program, in partnership with the City of Knoxville and the Knoxville Utilities Board, has sponsored the restoration of 6,900 linear feet of Third Creek and 700 linear feet of an unnamed tributary in Knoxville, Tennessee. The purposes of the project are to improve habitat and water quality while providing stream mitigation credits within the Fort Loudon Tennessee River Reservoir watershed. Third Creek and the tributary have been impacted by watershed urbanization, utility construction and dredging. In addition to being unstable in terms of erosion and deposition, Third Creek is listed on the state's 303(d) list of impaired waters due to nutrients, siltation, habitat alteration, and pathogens.

The restoration project as designed by Baker Engineering includes the following elements:

- Constructing sections of new stream off-line of the original streams, with dimensions and slopes in balance with sediment movement and with features that promote habitat diversity.

- Restoring the floodplains by lowering the bank heights and allowing flood flows to spread out, reduce stress on the channel and help filter pollutants through planted vegetation.

- Removing invasive species (including bamboo and privet) and planting native riparian trees, shrubs and grasses to provide shade, improve bank and floodplain stability and enhance the terrestrial habitat.

- Establishing a Land Preservation Agreement to protect the restoration project in a permanent conservation easement.

Earthwork began in August 2006 and is expected to be completed by March 2007. Planting will follow during the early spring.

1 Office Manager, Baker Engineering, 797 Haywood Road, Suite 201, Asheville, NC 28804; abick@mbakercorp.com

SESSION 3A

HYDROLOGIC REQUIREMENTS OF AQUATIC ECOSYSTEMS I
8:30 a.m. – 10:00 a.m.

Past, Present, and Future of Instream Flow Assessment Methods
M. Sale (Paper not available)

Determination of Hydrologic Requirements of Aquatic Ecosystems in the Tennessee and Cumberland River Watersheds
Rodney R. Knight

Instream Flow Protection in TN: TWRA's New Program Test Methods for Establishing Flow Criteria
K. Elkin (Paper not available)

HYDROLOGIC REQUIREMENTS OF AQUATIC ECOSYSTEMS II
10:30 a.m. – 12:00 p.m.

Probabilistic Monitoring of Streams Below Small Impoundments in Tennessee
Rebecca James

Geomorphology and Vegetation of Alluvial Bars Along the Obed Wild and Scenic River
W.J. Wolfe

Dissolved Oxygen in the Harpeth River: Connecting Point Source, Non-point Sources, and Water Withdrawals
Dorene Bolze, John Michael Corn, and Michael R. Corn

DETERMINATION OF HYDROLOGIC REQUIREMENTS OF AQUATIC ECOSYSTEMS IN THE TENNESSEE AND CUMBERLAND RIVER WATERSHEDS

Rodney R. Knight[1]

As competing water demands increase, water managers are investigating new approaches which balance human and ecological needs. Adverse effects on the aquatic ecology of streams and rivers resulting from increased demands are an unintended consequence of growth, often going unnoticed until aquatic communities are stressed beyond recovery. In some cases, ecological flow requirements have been based on findings from expensive, reach-specific models for selected rivers and streams; however, it is commonplace that decisions regarding ecological flow requirements are made using a combination of modeling and hydrologic statistics. Water managers need scientifically based and cost-effective tools to assess ecosystem flow needs that are based on regional and landform characteristics.

In 2006, the U.S. Geological Survey began developing a regionalized statistical model to assess ecosystem flow requirements by combining estimates of streamflow and physical watershed characteristics with indicators of aquatic-ecosystem health. In the first phase of the study, a conceptual model of ecological function will be developed using multivariate statistical methods in conjunction with input from a technical advisory committee. The application of predictions from the regionalized model to decision making will be evaluated in the final phase of the project. Long-term objectives of this project are to improve understanding of how anthropogenic alteration of streamflow affects aquatic-ecosystem health and to improve the accuracy and scientific defensibility of predictions of the ecological sustainability resulting from changing water demands. The spatial scope of this study includes the Tennessee and Cumberland River watersheds which drain approximately 60,500 square miles. The study has the potential for broad application to the ecological function and issues of resource allocation affecting much of the Southeastern United States.

1 Hydrologist, U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211 rrknight@usgs.gov

PROBABILISTIC MONITORING OF STREAMS BELOW SMALL IMPOUNDMENTS IN TENNESSEE

Rebecca James*[1]

ABSTRACT

The Tennessee Department of Environment and Conservation, Division of Water Pollution Control receives requests to impound streams through the Aquatic Resources Alteration Permit Program (ARAP). The majority of these requests are to impound first to third order streams. Dams on these streams not only affect the impounded stream segment but also have the potential to alter the physical, chemical, and biological components of downstream reaches.

The Division of Water Pollution Control was awarded a 104(b)(3) grant to perform a probabilisitc monitoring study of 75 streams below small impoundments. Using a random number generator, 150 impoundments were selected for field reconnaissance and possible inclusion in the study. Over half of the sites chosen did not meet study requirements. An additional 50 sites were randomly selected and visited before 75 suitable sites were located. Figure 1 depicts the locations of the study sites.

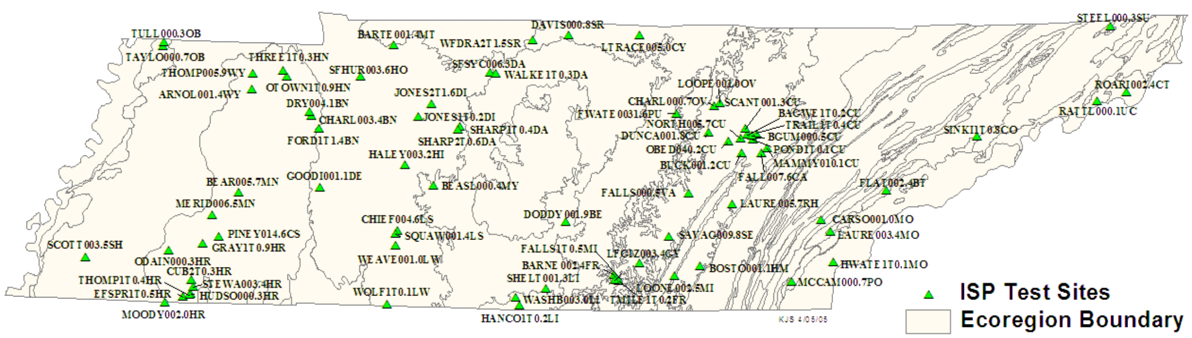

Figure 1. Location of the 75 test sites for the Tennessee impounded stream study.

The study measured the physical effects on flow, channel structure, substrate, and habitat in the downstream reaches. The most frequent problem was lack of flow below the impoundments. Thirteen of the 31 test sites located on first order streams were dry during at least one season. Eight of the 44 test sites located on streams larger than first order were dry during at least one season. The channel structure of the stream adjusts with the flow. Sites below impoundments that consistently had low flow developed small channels within the main channel to maintain some flow. Sites below impoundments that receive large releases of water during heavy rainfall often had unstable banks that were sloughing and caving in. The substrate size of the bed material was often found to be smaller than the expected size for the stream, indicating that impoundments trap sediment. The habitat of the study sites below impoundments was often

1 Tennessee Department of Environment and Conservation, Division of Water Pollution Control, 7th Floor, L & C Annex, 401 Church Street, Nashville, TN 37243, Rebecca.James@state.tn.us

found to be degraded. Habitat assessments were conducted seasonally. Over 75% of the streams failed habitat at least one season.

This study also measured the biological effects on aquatic life and periphyton below the dams. Macroinvertebrate communities were sampled at the test sites during the spring and fall seasons. Only four of the 75 test sites passed biological criteria guidelines or were comparable to first ordere reference conditions both seasons sampled. Periphyton was observed in most of the ecoregions included in this study. Microalgae were elevated at least one season at 22 sites while macroalgae were elevated at 14 sites. Seventy two percent of the samples that had elevated periphyton density in fall 2003 also failed to meet the target macroinvertebrate index score (TMI) of 32.

The chemical effects of impoundments on nutrients were measured. The most prominent effects were seen in total ammonia concentrations found below the impoundments. Ammonia levels were above the 90th percentile of reference data at 81% of the test sites. Total phosphorus levels were above the state guidelines at approximately 75% of the test sites. Total kjeldahl nitrogen (TKN) concentrations were above the 90th percentile of reference data at 65% of the test sites. Nitrate+nitrite levels exceeded state guidelines at 41% of the test sites.

The chemical effects of impoundments on dissolved oxygen, pH, iron, and managanese were also measured. Dissolved oxygen concentrations were below criteria at least one season in 21 of the 75 test sites. The pH criterion was met at the test sites except for four sites. These sites had a pH below 6.0. The EPA recommended and Tennessee proprosed iron criterion of 1000ug/L was exceeded at 61% of the impounded test sites. Even more test sites were found to have elevated manganese concentrations. More than 90% of the test had manganese levels above the 90th percentile of reference data.

Landuse, geology, population, drainage area, amount of precipitation, and amount of canopy cover were also considered when measuring the physical, chemical, and biological effects of the impoundments to these streams. The results of the study indicate that impoundments on small first order to third order streams have adverse affects on physical, chemical and biological components downstream. Lack of adequate flow and disruption of the stream and bank environment were major issues for habitat and aquatic life. The most frequently encountered chemical water quality problems below impoundments included elevated iron, manganese and nutrients as well as low dissolved oxygen.

The macroinvertebrate community of the test sites appeared to be highly affected by the impoundments. The most frequent change in the benthic community structure downstream of small impoundments was a loss of the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). Ninety-six percent of the samples failed to meet reference guidelines for the number of distinct EPT taxa. The abundance of EPT that were present was also reduced, with 86% of the samples failing to meet %EPT guidelines. Eighty-seven percent of the samples failed to meet taxa richness guidelines. There was also a shift in the dominant organisms in the streams below impoundments.

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GEOMORPHOLOGY AND VEGETATION OF ALLUVIAL BARS ALONG THE OBED WILD AND SCENIC RIVER

W.J. Wolfe[1]

Alluvial bars are among the most distinctive and ecologically important habitats of the Obed Wild and Scenic River (OWSR). The bars make up only a small part of the land surface of the OWSR but support a disproportionately large number of rare, threatened, or endangered (RTE) plants. An improved understanding of the geomorphic stability and flooding regimes of the alluvial bars is needed to help managers anticipate threats to the RTE plant habitats. In 2004, the U.S. Geological Survey (USGS) and the National Park Service (NPS) initiated a reconnaissance study to develop a preliminary understanding of the distribution, morphology, composition, stability, and vegetation structure of alluvial bars along the OWSR. The study approach included: (1) field reconnaissance by boat of selected reaches of the Obed River and Clear Creek with more detailed examination of 56 alluvial bars; (2) analysis of air photos, topographic and geologic maps, and other geographic data; (3) surveys of topography, surface particle size, vegetation structure, and ground cover on three selected alluvial bars; and (4) analysis of hydrologic records.

The alluvial bars that provide plant habitat in the OSWR are seasonally flooded, vegetated *boulder bars*—composed largely of rock particles at least 10.08 inches or 256 millimeters in diameter (boulders). Boulders comprise the structural framework of these bars and cover much of their surface area. Smaller cobbles (2.52-10.08 inches or 64-256 millimeters in diameter) are common on most of these bars. The spaces between the boulders and cobbles typically are filled with sandy alluvium. Surface deposits of sand and silt are common. Three boulder bars surveyed during this study ranged from 190 to 330 feet (58-100 meters) in length and from 105 to 150 feet (32-46 meters) in maximum width. The tops of the surveyed boulder bars were 3 to 5 feet higher than the summer base-flow water surface.

The boulder bars of the OSWR were formed by river flows with sufficient power to transport large boulders to surfaces several feet higher than the channel bottom. Hydraulic analysis and examination of hydrologic records suggest that transport of large boulders along the channel bottom is relatively frequent—probably at least once every 3 years. However the flows needed to form or destroy boulder bars appear to be infrequent extreme events. Comparison of a 1985 air photo to a topographic map published in 1967 shows that a May 27, 1973 flood, with a peak discharge of about 100,000 cubic feet per second and a calculated recurrence interval of about 500 years, had little or no apparent effect on the shape, size, or location of boulder bars along the Obed River near Nemo Bridge.

Sunny, glade-like clearings form the most visually striking feature of vegetation structure on the seasonally-flooded boulder bars. The clearings dominate the highest, driest areas of the bar tops and commonly include exposures of imbricated boulders. Ample sunlight, permeable substrate, and elevations 3-to-4 feet above summer base flow give the bar-top clearings a distinctly xeric character, reflected in a characteristic flora of drought-resistant grasses, herbs, and low shrubs. Most of the RTE plants found on boulder bars in the OWSR, including Cumberland sandreed (*Calamovilfa arcuata*), shortleaf sneezeweed (*Helenium brevifolium*), pineywoods dropseed (*Sporobolus junceus*), Eggert's sunflower (*Helianthus eggertii*) , and Cumberland rosemary (*Conradina verticillata*) grow mainly in the bar-top clearings.

Thickets of flood-resistant shrubs typically dominate areas of the boulder bars along the edge of water. These thickets typically include smooth alder (*Alnus serrulata*), common ninebark (*Physocarpus opulifolius*), Arrow wood species (*Viburnum, dentatum and nudum* var.

1 U.S. Geological Survey, USGS Tennessee Water Science Center, Email: wjwolfe@usgs.gov

cassinoides), and rhododendrons (*Rhododendron spp*.). One bar visited during this study had a large stand of Virginia spiraea (*Spiraea virginiana*), a federally listed RTE plant. The shrub thickets typically are rooted in alluvial silt deposits. Bars in contact with the valley wall typically have forest vegetation along their landward edge.

Non-native invasive plants were noted on at least 8 of 56 boulder bars visited in 2004. Five non-native invasive plant species were identified: Sericea lespedeza (*Lespedeza cuneata*), autumn olive (*Elaeagnus umbellate*), silktree mimosa (*Albizia julibrissin*), crown vetch (*Coronilla varia*), and multiflora rose (*Rosa multiflora*). Multiflora rose was common on at least one of the bars and represents a serious threat to shade-intolerant native plants.

The vegetation structure of the boulder bars of the Obed WSR reflects a balance between the forest on adjacent riverbanks, the riverside shrub thickets, and the bar-top clearings that is maintained largely by hydrologic processes. Seasonal inundation and flood scouring make the bar tops inhospitable for upland vegetation. A major shift in the balance between flood and drought could leave the bar-top clearings vulnerable to shading by encroaching trees or shrubs. Significant reduction of the frequency or severity of flooding would remove or reduce the periodic inundation and flood scouring that make the bar tops inhospitable to upland forest vegetation. Analysis of streamflow records indicates no such reduction in the Obed WSR. Conversely, increased summer base flow may have potential to reduce drought stress for flood-tolerant shrubs on the bar tops. Such an increase has been observed in streamflow records in the OWSR and reflects a combination of increased regional precipitation and releases of treated urban wastewater, which can approach 50 percent of late summer base flow in the Obed River upstream of Clear Creek.

PowerPoint File

DISSOLVED OXYGEN IN THE HARPETH RIVER: CONNECTING POINT SOURCE, NON-POINT SOURCES, AND WATER WITHDRAWALS

Dorene Bolze[1], John Michael Corn, P.E.[2], Michael R. Corn, P.E.[2*]

Dissolved Oxygen (DO) monitoring has been conducted in the Harpeth River over the last several years during low-flow high-temperature months. This monitoring continues to show that along most of the 125-mile long mainstem, the river during the low-flow, and high-temperature summer and fall months violates the state of Tennessee's DO water quality standard of 5 mg/L at any time. In fact, diurnal DO readings at several stations along the mainstem of the Harpeth River have been recorded at less than 1 mg/L dissolved oxygen for several days in the river. The locations where these extremely low readings have been recorded occur starting in downtown Franklin area after the water intake low-head dam at RM 87.7, at two locations below the Franklin POTW discharge at RM 854.4 and RM79.8, and even much further downstream after two other NPDES discharges and the input from significant subwatershed drainages, at RM 45. This phenomenon occurs from the headwaters near Eagleville to at least Kingston Springs, over approximately 80 river miles. The USEPA has also conducted a Total Maximum Daily Load (TMDL) analysis of the River and projected that the point source loadings would have to meet extremely low organic loadings of 1 mg/L or less of 5-day biochemical oxygen demand (BOD_5) to meet the stream DO standard of 5 mg/L. Although the Harpeth River was believed to be nutrient enriched, the USEPA data indicated that the River may in fact be nutrient limited during low-flow periods. There are numerous reasons and sources for the DO deficits in the River including the following:

1. Headwaters of the Harpeth near Eagleville are spring-dominated with low DO and habitat alteration;
2. Water withdrawals for water supply (at Franklin for a 2 MGD drinking water plant) and irrigation (upstream and downstream from Franklin) that reduce the flow of water available to assimilate introduced BOD;
3. NPDES Point Source loadings at the Franklin Publicly Owned Treatment Works (POTW)- 12 MGD , Lynwood Sewage Treatment Plant (STP)- 0.45 MGD, and Cartwright Creek STP- 0.25 MGD;
4. The low-head dam on the Harpeth at RM 89.2 for the water supply intake that stops the river's flow entirely during low-flow conditions;
5. Non-point and illicit point source discharges to the main stem and to the tributaries, especially the streams draining the older parts of Franklin that drain into the mainstem in the Franklin downtown (e.g., Liberty Creek);
6. Algal diurnal DO swings from night to day; and
7. Sediment oxygen demand (SOD) resultant from storm-event nonpoint-source runoff.

The DO data collected by the EPA, TDEC, and HRWA since 2000 and the 2006 DO data collected by TDEC and the Harpeth River Watershed Association will be presented. Each of the potential causes for the DO deficits in the Harpeth River will be discussed and data needs for determining how each of these affect the overall health of the Harpeth River will be discussed. The Harpeth is a case study for considering the management of the flow or water quantity in the

1 Dorie Bolze is the Executive Director for the Harpeth River Watershed Association located in Franklin, Tennessee; and

2 John Michael Corn, P.E. is a project manager and Michael R. Corn, P.E.* is the President of AquAeTer, Inc. located in Brentwood, Tennessee

river to meet water quality standards that are directly related to the need for the river to also assimilate point-source and non-point source inputs. This then has bearing on both the 5-year

renewal of the 3 NPDES permits for the sewage treatment plants that discharge on the mainstem in short succession and the water flow management related to the water withdrawal that occurs just a few river miles upstream for the city of Franklin's drinking water plant. The city of Franklin recently submitted an ARAP permit application with a proposed withdrawal scenario.

SESSION 3B

WETLANDS
8:30 a.m. – 10:00 a.m.

Simazine Removal Using Sphagnum Peat Moss in Mesocosms Simulating Subsurface Flow Constructed Wetlands
G. Kim Stearman, Plaxedes Makweche, and Dennis B. George

Sizing and Laying Out a Stormwater Wetland for the Sevenmile Creek Stream Enhancement Project
Louise Slate

Monitoring and Modeling the Hydrology of a Forested Sinkhole Wetland on the Tennessee Highland Rim
A. Jason Hill and Vincent Neary

STATUS REPORT OF WOLF CREEK AND CENTER HILL DAMS
10:30 a.m. – 12:00 p.m.

Session to be moderated by Bob Sneed, U.S. Army Corps of Engineers

Wolf Creek and Center Hill Dam Seepage Project Overview

Wolf Creek and Center Hill Dam Inundation Mapping

Wolf Creek and Center Hill Dam Projects: Lessons Learned About Public Education and Involvement

PowerPoint File

SIMAZINE REMOVAL USING SPHAGNUM PEAT MOSS IN MESOCOSMS SIMULATING SUBSURFACE FLOW CONSTRUCTED WETLANDS

G. Kim Stearman*, Plaxedes Makweche and Dennis George[1]

Removal of the herbicide simazine using peat moss and gravel in sterilized and nonsterilized mesocosms was tested at one and four day hydraulic retention times (HRTs) in an environmental growth chamber where temperature and humidity were maintained at 23 ºC and 35 %, respectively. In addition, simazine adsorption and mass balance were determined by a batch adsorption study and a simazine recovery study. A 0.6 ppm simazine solution was gravity fed to gravel and peat moss mesocosms for one and four day HRTs. The leachate samples collected daily were analyzed for simazine using gas chromatography. The significance of HRT, media and sterilization were tested using analysis of variance and mean separation tests at $\alpha = 0.05$. Significant difference was observed between peat and gravel media and between one and four day HRT. Peat moss removed 100 % simazine while gravel removed 42% simazine. Peat moss removed 100 % simazine whether sterilized or nonsterilized. Conversely, gravel showed significant difference under sterilized and nonsterilized conditions (39 % vs. 45 %, respectively) as well as under one and four day retention times (81 % vs. 3 %, respectively). Gravel unlike peat moss, apparently became overloaded with simazine during the 40- day duration of the mesocosm column study and was unable to remove significant simazine during the four day HRT. During the adsorption study, 1g peat moss adsorbed more simazine (Kd = 0.41 L/g) than 2 g peat moss (Kd = 0.31 L/g). In the peat moss recovery study, 90 % of simazine could not be accounted for because it could have been chemically or microbially broken down or remained as bound residue on the peat moss.
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1 Professor Soil Chemistry, Former graduate student in Biology and Director of Water Center, respectively, Water Center, Box 5033, Tennessee Technological University, Cookeville, TN 38505 gkstearman@tntech.edu

SIZING AND LAYING OUT A STORMWATER WETLAND FOR THE SEVENMILE CREEK STREAM ENHANCEMENT PROJECT

Louise Slate, PE[1]*

ABSTRACT

As part of the Sevenmile Stream Enhancement Project done for the Tennessee Stream Mitigation Program (TSMP), a half-acre stormwater treatment area was designed and built in the 100-year floodplain. This wetland treats stormwater runoff from a residential neighborhood and road drainage. Runoff primarily enters the site via four culverts under Edmonson Pike. Components of the wetland include diversion swales directing flow into the wetland, three separate depth zones to support a wide variety of plants and wildlife, a sinuous flow path for extended detention time, a water quality release hole, and emergency spillway. The design process will be explained in terms of sizing the wetland based on total drainage area, the components of the design, and layout of the wetland on site.

INTRODUCTION

Stormwater wetlands are designed and constructed to mitigate the impacts of stormwater quality and quantity that occur with urbanization. They mitigate these impacts by temporarily storing stormwater runoff in shallow pools that create growing conditions for shallow emergent and riparian plants. Microbes will break down and remove nutrients while plants will uptake nutrients to remove them from receiving waters. Ideally a stormwater wetland will be designed to act as a sediment trap, remove nutrients, attract and support wildlife, and aesthetically fit into the landscape (Scheuler, 1992). The example that follows addresses the major design components in sizing and locating a demonstration stormwater wetland at the Ellington Agricultural Center as part of the Sevenmile Creek Stream Enhancement Project in Nashville.

DESIGN PROCESS

The first item to consider is to get a general idea of where the proposed wetland will be located. If possible, it is important to avoid impacting natural wetlands; also bear in mind the location of utilities and easements. In this case, the proposed site is located in a hayfield that lies within the 100-year floodplain of Sevenmile Creek. There are no hydric soils on site according to the Davidson County soil survey; however, TDEC claimed jurisdiction for the existence of wetlands in this area based on a site visit in March of 2006. At that time the water level was nearly level with the ground elevation. Based on the topography and the location of two separate sanitary sewer lines, a preliminary location was selected. The selected site does overlap the jurisdictional wetland. While not ideal, in this case the overlap was deemed acceptable due to the fact that much of the existing wetland was covered in fescue despite the high groundwater level and its functionality as a natural wetland was limited. Figure 1 shows what the hayfield and wetland looked like prior to any construction.

1 LOCHNER, 2840 Plaza Place, Suite 202, Raleigh, NC 27612, lslate@hwlochner.com 919-571-7111 (p) 919-571-0454 (f)

Figure 1. **Hayfield looking down from Edmonson Pike toward the entrance to the Ellington Agricultural Center**

Once the rough location was determined, then we needed to know the watershed characteristics, drainage area, and the design storm to determine the volume of runoff to be treated and subsequent size of the wetland. Ellington Agricultural Center is located in the Central Basin on the edge of the Highland Rim on the south side of Nashville in Davidson County. Land use is predominantly residential and agricultural. Mapped soils are Lindell silt loam (hydrologic group C) and Arrington silt loam (hydrologic group B). The drainage area to the proposed wetland is 37 acres. Much of the stormwater enters the site via four culverts under Edmonson Pike. See Figures 2 and 3 for typical culverts.

Figures 2 and 3. **Culverts draining onto the site**

The runoff to be treated is that generated from a one inch rainfall.

The equations used to calculate the volume of runoff are from *Elements of Urban Stormwater Design* (Malcom, 1995). They are as follows:

$$S = (1000/CN)-10$$

$$Q^* = (P-0.2S)^2/(P+0.8S)$$

in which:

S = Soil storage (in)
CN = SCS curve number
P = Precipitation (in)
Q* = Runoff depth (in)

To find the volume to be treated, multiply Q* times the associated drainage areas.

$$\text{Vol (ac-in)} = \text{RO (in)} * \text{area (acres)}$$

In this case the volume to be treated is nearly one acre-inch. The surface area required to treat that is calculated by the height of water over the normal pool, usually between 6 and 18 inches, divided by the treatment volume. For this wetland, a storage height of 9 inches was selected. Runoff storage volume divided by the allowable height yielded the required surface area of the wetland. How that surface area is laid out will influence the effectiveness of the stormwater wetland. For example, if the wetland were laid out as a square, flow times through the wetland would be minimized. Therefore the length (L) to width (W) ratio for the flow path should be laid out so that L/W is greater than three. In this case L/W = 4.3.

Along this flow path, microtopography is created so that there are deep pools below both swales entering the wetland and a deep pool at the outlet. The pools are intended to be wet most of the time. Shallow land areas are also planned to force flow into a more sinuous pattern through the wetland. The shallow land is dry when the wetland is a normal pool. It is only submerged immediately following a significant rain event. Finally, the shallow water zone is located around the shallow land and connects the pools. A long view of the wetland which shows some shallow land areas is shown in Figure 4.

Figure 4. **Shallow land projections which force normal flows along a sinuous path**

The outlet is composed of a primary and emergency spillway. The primary spillway consists of a small riser with a one inch diameter hole drilled at normal pool elevation so as to draw down the stored runoff over a period of 2.5 days. The emergency spillway is a weir covered in rip rap that will pass the flow from a 50-year design storm.

Now that the size and general layout are known, there are two more significant design considerations. The first directly addresses the question, "Will this hold water?" Whether or not the wetland will hold water relates not only to the ground water elevation but also to the soil permeability. Soils that infiltrate at 0.20 to 0.6 in/hr (1.41 – 4.23 micrometer/sec) require minimal compaction. If soils infiltrate at a rate of 0.6 to 2.0 in/hr (4.23 to 14.11 micrometers/sec) then compaction is necessary. Finally, if water infiltrates through the soil at a rate greater than 2.0 in/hr (14.11 micrometers/sec), then clay importation is probably necessary (Hunt, 2000). In this case, minimal compaction was necessary. It is best to check soil permeability prior to construction to know whether there is enough clay on site to hold water and how much compaction will be required.

The last item to consider in locating the wetland is how it relates to utilities, easements, topography, and other site factors to facilitate construction and avoid intereference with activities such as maintenance of a sewer line. In this case study, there are two sanitary sewer lines that had to be avoided. There is also a natural dip in the landscape to cradle the proposed wetland that would minimize grading. Flow from the culverts under Edmonson Pike was directed to the wetland via swales. Swales were designed to accommodate the 10-year design storm. Side slopes were relatively flat (4:1 side slopes) so as to facilitate future mowing in the hayfield. A turf reinforcement mat was placed in the bottom of the swales to protect them from scour before grass was established. A plan view of the final stormwater wetland and diversion swales is shown in Figure 5.

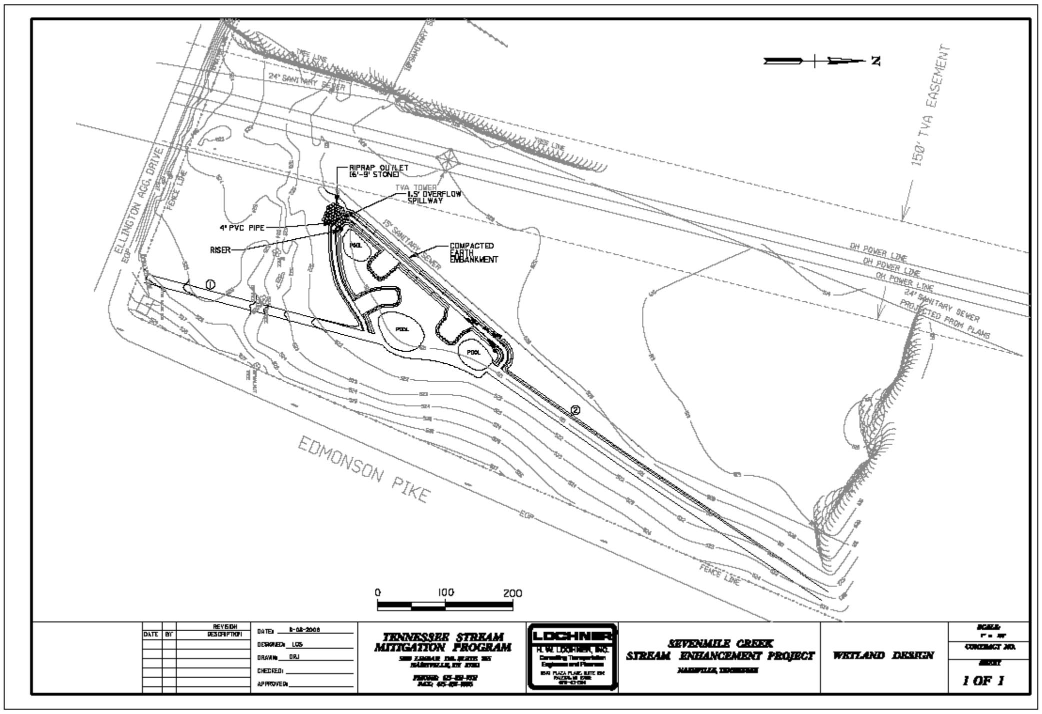

Figure 5. **Plan view of the stormwater wetland design**

The end result is that this stormwater wetland was permitted and constructed in late August and early September of 2006. Some photographs that document the before and after conditions follow in Figures 6 through 10.

Figures 6 and 7. **Before and after views from Edmonson Pike**

Figure 8. **Stripping the grass from the area that will become the stormwater wetland. Note the mowed area on the left side of the photograph. That is the location of a sanitary sewer easement.**

Figures 9 and 10. **After views of the stormwater wetland taken three weeks and three months following construction. Note how well the wetland blends into the natural landscape in the photograph on the left. Water levels are high in the photograph on the right following a recent rain event.**

Lastly, it is important to note that while this is a constructed wetland, it is functioning as a demonstration project for education purposes, it is creating wildlife refuge for waterfowl not previously noted in the hayfield, and it is treating stormwater to remove nutrient loads and pollutants before that runoff enters Sevenmile Creek. See Figure 11. Herbaceous cover was planted following construction. Woody plantings were done in December 2006.

Figure 11. **Ducks resting and dabbling three weeks after construction.**

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Scheuler, Thomas R. 1992. *Design of Stormwater Wetland Systems.* Anacostia Restoration Team, Dept. of Environmental Programs, MWCOG, Wash. DC

MONITORING AND MODELING THE HYDROLOGY OF A FORESTED SINKHOLE WETLAND ON THE TENNESSEE HIGHLAND RIM

A. Jason Hill[1] and Vincent Neary, Ph.D., P.E.[2]

Sinkhole wetlands are common features on the Tennessee Highland Rim. The formation of these wetlands is tied closely to the geology of the area. In general, these wetlands form when the underlying carbonate rock is subjected to surface drainage or groundwater that results in dissolution, weakening, and eventual collapse of the rock. In 2003, a monitoring program was initiated to improve the existing knowledge of hydrologic processes occurring in these wetlands. A 1.6 ha sinkhole wetland was selected for detailed study and instrumented with an extensive network of monitoring equipment, including monitoring wells, weather stations, water level sensors and a network of rain gauges. This paper provides an overview of the monitoring program and a comprehensive characterization of site hydrology including: (1) the relative importance of various transfer processes including precipitation, canopy interception, evapotranspiration, surface runoff, and groundwater, and (2) the results of modeling studies to study the effects of existing and future watershed developments on site hydrology.

1 Ph.D. Candidate, Tennessee Technological University, Assistant Professor, Tri-State University, Email: hillj@tristate.edu

2 Associate Professor, Tennessee Technological University, Email: vneary@tntech.edu

SESSION 3C

STORMWATER AND MORE
8:30 a.m. – 10:00 a.m.

Use of an Innovative Mobile Treatment System for Stormwater Runoff and Dewatering Programs
Mark B. Miller, Doyle Dobson, and Frank Sagona

Gas Chromatography Analysis of Polycyclic Aromatic Hydrocarbons in Sediment and Stormwater Runoff Samples Collected in Murfreesboro, TN
Perry A. Wilbon and John P. Divincenzo

An Erosion and Sediment Control Strategy for Success
Gary Moody

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

Waters and Civilizations: A Class to Teach College Students About the Local, Regional, and Global Aspects of Water
Joanne Logan

Chattanooga Creek and the Neighborhood Environmental College
M. Rogee, K. Davis, and L. McKay

The New Dynamic Stormwater Business
Don Green

PowerPoint File

USE OF AN INNOVATIVE MOBILE TREATMENT SYSTEM FOR STORMWATER RUNOFF AND DEWATERING PROGRAMS

Mark B. Miller[1]*, Doyle Dobson[2], Frank Sagona[3]

The reduction of pollution in urban waterways is a high priority in northwest Georgia and southeast Tennessee; and, is tied to several regional economic development programs. An innovative mobile water treatment system designed to improve water quality in two diverse waterways of the region is described. Home to 76 native species of fish, more than the Columbia and Colorado Rivers combined, the Conasauga River serves residential, agricultural and textile industry needs in Dalton, Georgia. Segments of the river are impaired with sediment, nutrients and fecal coliform. Chattanooga Creek, another impaired stream located in a former industrialized area near downtown Chattanooga, Tennessee, has long served as a dumping ground for hazardous materials. Sediment below and along the creek is impacted by coal tar, a by-product from processes once located in the area. The creek is now designated as a U.S. EPA Superfund cleanup site. Stream remediation includes a large-scale dewatering program designed to mitigate the potential spread of contamination downstream.

Minimizing the impact of pollutants to both waterways presented unique design and operational challenges to provide a single, cost-effective and technically proven treatment solution. An innovative mobile treatment system (MTS) was designed to provide treatment to waters of sites that do not require fixed installations. The trailer-mounted AquaShield™ MTS uses a patented "treatment train" approach utilizing Aqua-Filter™ technology that consists of two pre-treatment hydrodynamic swirl separators followed by a filtration chamber having either a gravity flow (down flow) or up flow treatment configuration to remove contaminants. Filtration media selection is dependent on site-specific pollutants.

An independent field performance demonstration of the AquaShield™ MTS began in 2005 to reduce total suspended solids (TSS) to the Conasauga River. The MTS was tested at the 30-acre Whitfield County public works maintenance and roadway materials storage facility that was known to be a significant sediment source. Influent and effluent samples collected at the MTS were analyzed for TSS and particle size distribution. The MTS unit achieved TSS removal efficiencies greater than 80 percent.

Dewatering is another application for the AquaShield™ MTS design. Given the favorable results of the field verification testing, two gravity flow MTS units were used at Chattanooga Creek beginning in 2005 in order to meet site-specific NPDES discharge requirements for dewatering activities. Stream remediation required sectional dewatering to allow for excavation of contaminated material below the creek bed and along its banks. The main stream channel was dammed and water was pumped to the MTS units. The treated water was safely released downstream from the dams without the need for further stream flow controls. The MTS units were easily transported across the site to reach the dewatering areas, and to minimize project downtime. Independent testing confirmed that the treated water consistently complied with EPA and NPDES effluent quality standards for TSS and petroleum hydrocarbons.

1 Technical Writer, AquaShieldTM, Inc. 2733 Kanasita Drive, Suite B, Chattanooga, Tennessee 37343, mmiller@aquashieldinc.com

2 Director, Whitfield County (Georgia) Public Works, 170 Gillespie Drive, Dalton, Georgia 30721

3 Watershed Services, 183 Greystone Drive, Ringgold, Georgia 30736

GAS CHROMATOGRAPHY ANALYSIS OF POLYCYCLIC AROMATIC HYDROCARBONS IN SEDIMENT AND STORMWATER RUNOFF SAMPLES COLLECTED IN MURFREESBORO, TENNESSEE

Perry A. Wilbon* and John P. Divincenzo[1]

Stormwater runoff is a major source of freshwater contamination in many urban environments. Some of the sources of stormwater runoff in Murfreesboro include parking lots, roadways, and agricultural activities. Stormwater runoff is a complex mixture of various organic compound contaminants. The non-polar Polycyclic Aromatic Hydrocarbons (PAH) are of great interest due to their toxicity and bioaccumulation effects. The two PAHs of interest for this project are pyrene and fluoranthene, which account for roughly one half of all PAHs in the environment. This project focused on the quantification of these two compounds in sediment and stormwater runoff samples by way of Soxhlet extraction and solid-phase extraction combined with GC/MS analysis. Runoff samples were collected from two urban environments within the city of Murfreesboro. The first site, Lytle Creek, had PAH concentrations that ranged between 31 – 80 μg/L, while the second site, Stones River, produced results that were below our detection limit. The sediment samples collected from the Lytle Creek site had PAH concentrations that ranged from 1.96 – 10.2 mg/kg. The concentration for the Stones River site ranged from 0.04 – 0.41 mg/kg. Sediment samples collected from a rural control site contained no detectable levels of either PAH. This suggests that urban stormwater runoff has a significant impact on the different types and concentrations of contaminants present within an aquatic environment.

1 Associate Professor, Department of Chemistry, Middle Tennessee State University, 1301 East Main Street, Murfreesboro, TN 37132 jdivince@mtsu.edu

AN EROSION AND SEDIMENT CONTROL STRATEGY FOR SUCCESS

Gary Moody

INTRODUCTION

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

PREFACE

Very little of what I'll say on April the 19th is new technology- although some is. I'm indebted to two people named, Lewis Bumpas and Dave Rosgen, for their friendship and demands, and numerous people here for their support, influence, and continued sharpening of my skills.

1. Part of a Vision:
   - COE…"doing things right vs doing the right thing" and "Can't do it alone"
   - Grassroots consciousness… Heartland people, or people with a Heart

2. Unrelated Activities:
   - Three separate & conflicting roles and goals…
   - Encourages generously given, and physically ineffective BMP's
   - Encourages a sub-culture of
   - Spray and Pray and/or
   - Show-up and Throw-up
   - Piece-milled vs Purpose Driven

3. Required vs Desired vs Needs
   - Not an ethical dilemma
   - Indifference (The Show Stopper)

4. Attitude vs Skills vs Insight
   - Engaged on your own
   - Purpose, outcome, and success driven
   - Logical and "Elementary" decisions
   - Objective vs components
   - Results must mimic environmental reality

Man-made vs Site opportunities
Exploit the site opportunities

5. Consultative Level of Erosion and Sediment Control

Anticipate but don't assume
Focused and Efficient
Intuitive based on
Past successes and failures
Communication and Explicity
Communicate the technology in such a way that it does what it says it will do, thereby extracting the value and meaning with reasonable accuracy ahead of what is being done that created it ...

WHEN NEEDS ARE MET
KYLES FORD & THE CLINCH

"CASE IN POINT"

1. Methodology

Open to advantages
Project size
Space & time
Pervasive vs accelerating vs induced
Productivity vs potential
Won't work if it's not productive
Won't work if it doesn't protect
Synergistic, symbiotic, & syntactical
Complex transformations require you to
Model it
Choosing your model
Design it
Implement it
Test it
Refine it

Final quote from the Corps' article;
"Our faithfulness to the pursuit will re-define success and be visible in the results"

REFERENCES

Chief of Engineers, *Adjust Corps' Vision*, Bernard Tate, Headquarters, U.S. Army Corps of Engineers, Huntsville Sept 2005

WATERS AND CIVILIZATIONS
A CLASS TO TEACH COLLEGE STUDENTS ABOUT THE LOCAL, REGIONAL, AND GLOBAL ASPECTS OF WATER

Joanne Logan[1]

The University of Tennessee implemented new general education requirements in 2004. Students must take two Cultures and Civilizations (CC) classes, designed to improve the ability of students to function effectively in the global community of the twenty-first century by developing an appreciation of linguistic, historical, and cultural diversity. A new course, “Waters and Civilizations” was submitted and approved as a CC class, since a natural resource such as fresh water is intricately linked to peoples, cultures and history. This class teaches students about the local, regional, and global aspects of fresh water. Case studies include Louisiana Wetlands, Water Wars in the U.S. West, Drought and the Mayans and Aztecs, Water Projects in the Roman Empire, Dams and Flood Control in India and China, The TVA and Rural Appalachia, Rainwater Harvesting in Africa and the Dominican Republic, From Ancient Aquifers to Modern Demands, Watershed Communities, and Ice Water and the Inuit.

1 Biosystems Engineering and Soil Science, University of Tennessee

CHATTANOOGA CREEK AND THE NEIGHBORHOOD ENVIRONMENTAL COLLEGE

Rogge, M.[1*], K. Davis[2] and L. McKay[3]

In 2005, the University of Tennessee began a partnership with the Alton Park Development Corporation in Chattanooga and the Southside/Dodson Avenue Community Health Centers to form the Alton Park/Piney Woods Environmental Health and Justice Collaborative (EHJC). This is a community-based participatory research initiative funded for four years by the National Institute for Environmental Health Sciences. In the summer of 2006, EHJC launched the Neighborhood Environmental College (NEC). The goal of the NEC is to facilitate and strengthen neighborhood empowerment and leadership, ongoing information exchange, health promotion, and policy improvements in regard to environmental health and justice, with a focus on industrial and commercial chemical contamination in the Alton Park community of Chattanooga. The pilot course entitled *Contamination and the Chattanooga Creek* started May 16, 2006 and ran through June 30, 2006. Other courses to be added in 2007 include *Environmental Health and Wellness* and *Leadership Development.*

1* (Speaker) College of Social Work, University of Tennessee, Knoxville, TN 37996 mrogge@utk.edu

2 Institute for a Secure and Sustainable Environment, University of Tennessee, Knoxville, TN 37996 kdavis17@utk.edu

3 Dept. of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 lmckay@utk.edu

THE NEW DYNAMIC STORMWATER BUSINESS

Don Green[1]

Stormwater has become a dynamic and iterative business. New stormwater requirements are being imposed almost as fast as new technology is being developed. There are relatively few places for the MS4 to go to get help to fund the additional requirements except for increasing the burden on the public with either more taxes or user fees. Relic landuse problems that, to a large extent, have not been addressed by anyone in the past are now becoming MS4 municipalities' concerns.

Stormwater is a relatively new endeavor here and much of what the municipalities are doing is 'experimenting'. The old tried and true BMPs can not fully address the problems of increased imperviousness and pollution levels and stream bank protection. 'New' Best Management Practices, BMPs, such a Low Impact Development, LID, techniques: infiltration/biofiltration, rain gardens and proprietary stormwater treatment units are just now being used and evaluated for effectiveness. This new approach to land development has also forced developers, consultants and engineering firms to adapt to how they design new development.

Other stormwater related issues include: BMP Terminology, Certification Training, education and public outreach opportunities, and Stream Buffers.

1 Stormwater Coordinator, City of Franklin, TN. 109 3rd Ave South, biogreen1@comcast,.net

PROFESSIONAL POSTER

Presenters will be available to answer questions from 5:30 to 6:00 p.m. on Wednesday, April 18.

Investigative Report of Carbon Disulfide Contamination in Powder Free Latex Exam Gloves
Clyde E. Worthington, John E. Sebastian, Donald F. Gilmore, and Robert C. Benfield

INVESTIGATIVE REPORT OF CARBON DISULFIDE CONTAMINATION IN POWDER FREE LATEX EXAM GLOVES

Clyde E. Worthington, R.G., John E. Sebastian, P.G., Donald F. Gilmore, P.G., and Robert C. Benfield, P.G.

CARBON DISULFIDE CONTAMINATION DISCOVERED IN POWDER FREE LATEX EXAM GLOVES USED FOR ENVIRONMENTAL GROUNDWATER SAMPLING:

Tennessee Department of Environment and Conservation (TDEC) Division of Department of Energy Oversight (DOE-O) is tasked with providing an oversight role in monitoring groundwater on the Oak Ridge Reservation (ORR).
As part of fulfilling this obligation the Division conducts independent sampling and analysis of groundwater in and around the ORR.

During summer and fall of 2005, TDEC/DOE-O personnel in Oak Ridge, Tennessee received analytical results from routine sampling showing carbon disulfide in groundwater samples. These detections were in areas that had not been known to exhibit carbon disulfide contamination in the past and appeared to be randomly distributed between sampling events and locations, further carbon disulfide had not been a known or suspected contaminant within the Division's sampling area, the ORR and its environs. TDEC DOE-O personnel began to investigate and question potential factors that would have resulted in the carbon disulfide detections.

The factors considered were legitimate detections of carbon disulfide, cross contamination at the analytical laboratory during analysis, cross contamination of the storage area for sampling equipment, cross contamination from environmental aspects during sampling and transport to the laboratory, and cross contamination by the powder free latex gloves worn by personnel during sampling. Tests for each factor were developed and completed. These testing methods included communication with the analytical laboratory, a sample blank for the equipment storage area, sample blank for the transport of the sample, a sample blank for field sources, and an experiment with the powder free latex gloves in which samples of the glove were soaked in de-ionized water and then sent for analysis. Positive carbon disulfide results from the glove experiment indicated that the carbon disulfide was a product of cross contamination from the powder free latex exam gloves.

STUDENT POSTERS

Presenters will be available to answer questions from 5:30 to 6:00 p.m. on Wednesday, April 18.

Consequence Management Strategies for Water Distribution Systems Utilizing Optimization
Terranna M. Baranowski and Eugene J. LeBoeuf

Advection Versus Dispersion as Determined by Single-Well Tracer Studies
Tarra M. Beach, Michael Bradley, Roger Painter, and Tom D. Byl

A Comparison of Empirical and Analytical Approaches to Stream Restoration: A Case Study on Abrams Creek in the Great Smoky Mountains National Park, Tennessee
Daniel L. Carter and John Schwartz

Effect of a Riverine Wetland on Parking Lot Runoff at Tennessee State University
Carlton Cobb, Jameka Johnson, and Tom Byl

Characterizing Episodic Stream Acidity During Stormflow in the Great Smoky Mountains National Park
Edwin Deyton, John Schwartz, and R. Bruce Robinson

Investigating the Effective Hydraulic Conductivity of Multifractal Hydraulic Conductivity Fields from Multiple Well Pumping Tests
Richard W. Donat, Edmund Perfect, Randy Gentry, and Larry McKay

Impact of Basin Characteristics on Water Quality
Amanda Dunnavant, John S. Schwartz, and Bruce Robinson

Sensitivity of the Oxydase-Enzyme Induced Chemiluminescent to Water Quality Parameters
Farida Forouzon, Lonnie Sharpe, and Tom Byl

Evaluating Peclet Values and the Role of Advection, Dispersion, and Diffusion in Tracer Studies
Jameka Johnson, Carlton Cobb, Lonnie Sharpe, and Tom Byl

Comparing In Situ and Laboratory Flume Methods to Collect Soil Erosional Properties for Bank Stability Models
Tara L. Mallison, John S. Schwartz, Andrew Simon, and Larry McKay

Chemical and Biological Analyses of Water from Sites Located in the Watauga Watershed in Northeastern Tennessee
Kelly Moore, Yongli Gao, Jessica Buckles, and Morgan Pate

A Modeling Tool for Determination of Process Importance Across the Groundwater/Surface Water Interface
Ravi Palakodeti, Eugene J. LeBoeuf, and James H. Clarke

Application of the RTD Model to Analyze the Fate and Transport of Ammonia in Laboratory Karst System
Kelly Ray, Roger Painter, and Tom Byl

Determining the Relative Permeability Functions of Various Porous Media by Transient Flow Centrifugation
Ching Tu, Edmund Perfect, and Engelmundus H. Van Den Berg

CONSEQUENCE MANAGEMENT STRATEGIES FOR WATER DISTRIBUTION SYSTEMS UTILIZING OPTIMIZATION

Terranna M. Baranowski[1*] and Eugene J. LeBoeuf[2]

Following the events of September 11, 2001, the nation's water supply and distribution utilities began to examine threats that had been previously considered low risk. Water utilities are now required to perform vulnerability assessments to aid in the identification of water utility components that require strengthening against possible attacks. Accompanying the vulnerability assessment is the emergency response protocol that explores possible consequences and corrective actions following a physical/chemical/biological attack. Once a contamination threat to a network is established, the U.S. Environmental Protection Agency's (EPA's) Response Protocol Toolbox provides recommendations for implementation of specific response actions to minimize the potential impact to the public. Optimal responses to remediate contaminated systems must then evaluate possible consequences and corrective actions. These consequence management strategies may include (i) isolation and containment of a contaminant through valve operations; (ii) public notification; (iii) demand locations and quantities to "flush" the system; and (iv) any combination of valving, notification, and flushing. The overarching goal of this research is the development of consequence management strategies utilizing optimization for water distribution networks in response to chemical/biological attacks. In this current effort, we employ a genetic algorithm to determine the optimal flushing and valving operations in order to minimize the total network contaminant concentration following sensor detection. Application of this technique to two relatively simple networks demonstrates the usefulness of this optimization method as a consequence management strategy to reduce contaminant concentration.

1 Graduate Student, Department of Civil and Environmental Engineering, Vanderbilt University, Box 1831 Station B, Nashville, TN 37235; email: terranna.m.baranowski@vanderbilt.edu

2 Corresponding author, Associate Professor, Department of Civil and Environmental Engineering, Vanderbilt University, Box 1831 Station B, Nashville, TN 37235; email: eugene.j.leboeuf@vanderbilt.edu

ADVECTION VERSUS DISPERSION AS DETERMINED BY SINGLE-WELL TRACER STUDIES

Tarra M. Beach[1], Michael Bradley[1,2], Roger Painter[1], and Tom D. Byl[1,2]

Approximately two-thirds of Tennessee and Kentucky are underlain by karst terrain. The groundwater aquifers in karst terrains are particularly susceptible to contamination; once a contaminant has entered a karst-bedrock aquifer it is difficult to determine its precise flow-path through the bedrock. The contaminant may reside for long periods in stagnant areas of the aquifer or it may be rapidly transported through tortuous conduits. All the while, the contaminants are susceptible to biodegradation processes in the aquifer. Traditional dye trace studies carried out in karst terrains required two or more points of assessment. A dye, such as rhodamine or sodium chloride, would be injected into a well, sinkhole, or stream; that dye's length of time to resurface at a spring would be measured – this could lead to extremely long-term projects which could provide no conclusive results. Therefore, the objective of this research was to develop a tracer injection procedure that would involve one well. A quantity of sodium chloride was injected and its dissipation over time was monitored. The data collected yielded a response curve for the specific conductance of the sodium chloride injections, and in turn, permitted an examination of the properties of advection and dispersion in the area around the well. These properties indicated whether a site was suitable for remediation. Monitoring and production wells in Dickson, Tennessee and Fort Campbell, Kentucky were utilized to determine these hydraulic conductivity properties.

1. Civil & Environmental Engineering, Tennessee State University, Nashville, TN
2. US Geological Survey, Nashville, TN

A COMPARISON OF EMPIRICAL AND ANALYTICAL APPROACHES TO STREAM RESTORATION; A CASE STUDY ON ABRAMS CREEK IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK, TENNESSEE.

Daniel L Carter[1] and John Schwartz[2]

Bankfull flow, sedimentation, "stable", reference reaches and the effects of hydraulics on the ecology in a stream are all subjective areas in stream restoration. Using a study site, located on Abrams Creek in the Great Smoky Mountains National Park, Tennessee, these subjective areas were compared using two general assessment approaches typically applied in current stream restoration efforts. The two approaches are empirical or reference reach approach and analytical or non-reference reach approach. An unstable study reach and a stable reference reach were identified along Abrams Creek in the Cades Cove area of the Great Smoky Mountains National Park, Tennessee. Current techniques used in stream restoration to determine effective flows, sedimentation, stream stability, and ecohydraulics were applied to both reaches for comparison of the empirical and analytical approaches. The analog "Natural Channel Design", hydraulic models (HEC-RAS, River 2D, CONCEPTS), dimensionless ratios developed by Richard Hey and ecological studies (fish and habitat surveys) by National Park service and The University of Tennessee were applied to both the study and reference reaches. The reference reach acted as both reference for the "Natural Channel Design" and a control for comparison of results in the study reach. With so many different factors, techniques and personal subjectivity, misinterpretation by a professional when carrying out stream restoration projects is likely. Improvement in these areas, by identifying commonalities and reducing the likelihood of misinterpretation between the two general approaches, empirical and analytical, is the goal of this comparison.

1 Graduate Research Assistant, University of Tennessee, Department of Civil and Environmental Engineering, 57A Perkins Hall, Knoxville, TN 37996 dcarter1@utk.edu

2 Assistant Professor, University of Tennessee, Department of Civil and Environmental Engineering, 63 Perkins Hall, Knoxville, TN 37996 jschwart@utk.edu

EFFECT OF A RIVERINE WETLAND ON PARKING LOT RUNOFF AT TENNESSEE STATE UNIVERSITY

Carlton Cobb[1], Jameka Johnson[2], Tom Byl[3,1]

A major contributor to non-point source pollution is parking lot runoff during rain storms. Wetlands have been shown to attenuate suspended sediments, bacteria and agricultural pollution. The objective of this project was to determine if a natural riverine wetland located down gradient of a TSU parking lot helped to mitigate the NPS for the runoff. The first phase of the project required walking through the wetlands and the parking lot during a rain storm to observe where the water would flow. This was done to establish sampling points. The second phase was to collect water at the sampling sites during a rainstorm that produced sufficient runoff after a minimum of 3 dry days. These samples were taken back to the lab for analysis. The samples were evaluated for turbidity, specific conductance, pH, and volatile organic compounds (VOC). The most dramatic change in water quality was associated with the VOCs. The water coming off the parking lot – driveway had 62 ug/L benzene, 132 ug/L toluene and 106 ug/L xylenes, as well as, 4 unidentified peaks. As the water moved through the wetland and into a stream, the VOC concentration became undetectable. Additional work is needed to determine if the VOC removal was due to sorption, dilution or biotransformation. However, these preliminary results prove that wetlands are valuable for purifying contaminated runoff from parking lots.

1. carlton_cobb@yahoo.com, Civil and Environmental Engineering, Tennessee State University, Nashville, TN 37209
2. Jameka Johnson, tsugyrl87@yahoo.com, Civil and Environmental Engineering, Tennessee State University, Nashville, TN 37209
3. tdbyl@usgs.gov, 640 Grassmere Park, Suite 100, Nashville, TN 37211

CHARACTERIZING EPISODIC STREAM ACIDITY DURING STORMFLOW IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Edwin Deyton[1], Dr. John Schwartz, Dr. R. Bruce Robinson

Episodic acidification in streams occurs as storm events temporarily reduce ANC and pH. Stream acidification is suspected to have damaging effects on the health of aquatic species. The objective of this research is to characterize the magnitude and duration of stormflow acidity and quantify proton mass loadings to better understand source contributions of acids and watershed response. Acid deposition, pyritic (Anakeesta) geology, and organic acids are all known sources of acidic inputs that potentially affect stream quality. The cation exchange capacity of the soil also plays a role in the watershed's ability to neutralize acids or acidic anions. Three forested, high elevation sites were selected in the Middle Prong of the Little Pigeon River Watershed in the Great Smoky Mountains National Park. Multi-parameter YSI data sondes were installed at each site to record continuous stream data. ISCO autosamplers were set up in connection with the sondes to collect samples during a storm event. Storm samples and precipitation samples were analyzed for pH, ANC, conductivity, and a broad spectrum of cations and anions that contribute to the ion balance. A mass balance approach will be utilized to examine acidic inputs versus outputs leaving the watershed. Based on previous research in Southeastern Highlands, acidic deposition is expected to be the dominant contributor to stream acidity in forested, high elevation sites; however more evidence is needed to understand this process.

1 Graduate Student, University of Tennessee, 223 Perkins Hall, Knoxville, TN 37996, edeyton@utk.edu

INVESTIGATING THE EFFECTIVE HYDRAULIC CONDUCTIVITY OF MULTIFRACTAL HYDRAULIC CONDUCTIVITY FIELDS FROM MULTIPLE WELL PUMPING TESTS

Richard W. Donat[1], Edmund Perfect, Randy Gentry, and Larry McKay.

Different techniques have been used in the past to generate and study the behavior of hydraulic conductivity and storativity in models of heterogeneous aquifers. According to recent analyses of field data, it has been suggested that saturated hydraulic conductivity distributions of rocks and soils are multifractal in nature. For this reason investigating the scaling and heterogeneity of known fractal models can result in an improved understanding of these phenomena in natural aquifers. This project plans to generate and examine multifractal Sierpinski carpets that represent different hydrologic properties, such as heterogeneity and homogeneity. The approach involves using transient state multiple well pumping tests. The two main goals of this project include studying the effects of effective hydraulic conductivity in multifractal Sierpinski carpets at different iteration and probability levels and determining the optimum number of wells needed in order to achieve a good estimation of effective hydraulic conductivity for the varying ranges of heterogeneity commonly seen in aquifers. From this information one will be able to determine the probability of effectively describing hydraulic conductivity using one well in different hydrologic settings.

1 Earth and Planetary Sciences, University of Tennessee Knoxville, rdonat@utk.edu

IMPACT OF BASIN CHARACTERISTICS ON WATER QUALITY

Amanda Dunnavant[1] John S. Schwartz[2] Bruce Robinson[3]

Park-wide data collected from 1993 to 2007 for 43 sites in the Great Smoky Mountains National Park (GRSM) were analyzed to determine the relationship between basin characteristics and water quality. Unlike previous studies, the relationship between basin soil type and water quality will be determined by performing zonal statistics within ArcMap to determine the percent of each soil type for each watershed. Once the percent of each soil type and other basin characteristics was known, multiple linear regression was performed to create a model that can be used to predict water quality in unsampled areas similar to the GRSM. Since over 75% of the 43 sites have median pH values which have adverse effects on aquatic organisms, establishing the causes of poor water quality is important to protect the 3,000 kilometers of mountain streams and 53 species of fish in the park.

1 Hydrologist, U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211 jakingsb@usgs.gov

2 Hydrologist, U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211 jakingsb@usgs.gov

3 Hydrologist, U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211 jakingsb@usgs.gov

SENSITIVITY OF THE OXYDASE-ENZYME INDUCED CHEMILUMINESCENT TO WATER QUALITY PARAMETERS

Farida Forouzon[1], Lonnie Sharpe[2], and Tom Byl[3]

Biomarkers or enzyme activity are often used to assess the quality of an environment. These indicators are useful because they represent a biological endpoint to toxicity. The objective of this research was to determine if the chemiluminescence from the catalase reaction could be used as a monitor of environmental quality. The primary task to achieve this objective was to evaluate the cause of the chemiluminescence when hydrogen peroxide is added. The second task was to determine whether microbial or plant sources of oxidase enzymes was better. And, the third task was to run assays to determine how water quality parameters affect the chemiluminescence response. Tis would include tests for optimum pH, optimum temperature, and dose-response tests for various environmental toxins. First a native organism of Tennessee, the glow warm named *Orfelia fultoni* was collected and the gut bacteria were isolated. It was determined that luciferase was not present in the isolated bacteria and that an oxidase reaction in the presence of hydrogen peroxide catalyzed a chemiluminescent response. Additional work is needed to determine which oxidase enzyme is responsible. Since we achieved a chemiluminescent response with the bacteria oxidase enzymes, we tested other sources of oxidase, such as potato, and determined they also gave a chemilumescent response. The experiment shifted to a more available source of catalase, a plant such as potato. A simple experiment using different metals (Pb^{2+}, Ag^{2+}, Ni^{2+}) found that the reaction was microbial and plant oxidase activity was sensitive to the metals at 500 mg/L concentrations. These preliminary tests indicate that plant and microbial sources of oxidase enzymes were capable of producing light. And, that these reactions were sensitive to dissolved metals. Additional work will be done to determine the optimum conditions for the reaction and to describe the dose-response to metals and some organic contaminants. It could be beneficial if this reaction is found to be suitable for monitoring environmental conditions such as water quality and air pollution.

1 Farida Forouzon, fforouzan@yahoo.com, Civil and Environmental Engineering, Tennessee State University, Nashville, TN 37209

2 Dr. Lonnie Sharpe, sharpe@coe.tsuniv.edu, Massie Chair of Excellence, Tennessee State University, 37209

3 tdbyl@usgs.gov, 640 Grassmere Park, Suite 100, Nashville, TN 37211

EVALUATING PECLET VALUES AND THE ROLE OF ADVECTION, DISPERSION AND DIFFUSION IN TRACER STUDIES

Jameka Johnson[1], Carlton Cobb[2], Lonnie Sharpe[3], and Tom Byl[4]

Karst aquifers have been recognized as one of the most challenging geological media in terms of groundwater modeling. Numerical models based on Darcy's Law often are unable to accurately characterize contaminant flow through the heterogeneous fractures and dissolution features. Lab and field data were used to study dispersion, matrix diffusion and advection. The Residence-time Distribution (RTD) formula was used to calculate Peclet values, which are indicative of advection and dispersion properties. Based on field tracer studies published in the literature, it appears that when a tracer study was conducted with an artificial head (i.e., the dye is pushed or flushed through the system), the system was dominated by advection processes. When a natural water gradient was used, the system was dominated by dispersion processes and a longer tail is produced. However, it was not clear if the dispersion was due to turbulence or matrix dispersion. Lab experiments were conducted to try and differentiate between the hydrodynamic dispersion, heterogenous advection and matrix diffusion. The lab system, consisting of a plexiglass box holding limestone rocks with permeable fractures, was used to measure tracer diffusion under different hydrologic conditions. Preliminary results from those studies back the field observations, that pushing the system tends to result in plug-like flow (advective flow) and less matrix diffusion. Additional tracer studies are scheduled for a wetland to evaluate the Peclet values, dispersion and advection values for the system under storm- and base-flow. These findings will have implications for the interpretation of tracer tests designed to measure advection, dispersion and diffusion of contaminants as they transport through complex hydrologic systems.

1 Jameka Johnson, tsugyrl87@yahoo.com, Civil and Environmental Engineering, Tennessee State University, Nashville, TN 37209

2 Carlton Cobb, carlton_cobb@yahoo.com, Civil and Environmental Engineering, Tennessee State University, Nashville, TN 37209

3 Dr. Lonnie Sharpe, sharpe@coe.tsuniv.edu, Massie Chair of Excellence, Tennessee State University, 37209

4 tdbyl@usgs.gov, 640 Grassmere Park, Suite 100, Nashville, TN 37211

COMPARING IN SITU AND LABORATORY FLUME METHODS TO COLLECT SOIL EROSIONAL PROPERTIES FOR BANK STABILITY MODELS

Tara L. Mallison[1]*, John S. Schwartz[2], Andrew Simon[3], and Larry McKay[4]

Considering the significant role of soil and sediments in water quality and management of river systems nationally, there exists an urgent need to improve sediment delivery and transport models. Because several studies have found 70 to 90% of the sediment in streams are from bank erosion sources, improving the bank stability components to these models are critical. For bank stability models, two input parameters are needed: critical erosion shear stress and erodibility rate. These two parameters are collected in the field by available testing methods, including the submerged jet tester, a sediment core sample subjected to an erosion test in a specially-design flume, and the cohesive strength meter. These three testing methods will be compared to each other, and compared to standard values for different soil types as developed by the National Sedimentation Lab. Two study sites will used for this investigation: Goodwin Creek, Mississippi, and Abrams Creek, Tennessee. Because all three of the methods exhibit strengths and weaknesses during the data collection, the procedure and outcome of each testing method will be weighed against one another and to the standard erodibility rate for both sites. The erosional properties produced from the three testing procedures and the standard value will be further evaluated by incorporating the bank soil critical shear stress and erodibility rates into the sediment transport model, Conservational Channel Evolution and Pollutant Transport System (CONCEPTS). CONCEPTS generates output that assesses the long-term changes in sediment transport and channel morphology by incorporating bank mass failures. A sensitivity analysis of model simulations utilizing different inputs from the testing methods for determining soil erosional properties will be evaluated. Hydraulic engineers and fluvial geomorphologists involved in river restoration projects will be able to utilize the results of this investigation to improve their use of bank stability models as part of design effort.

1 *Dept. Of Environmental Engineering GRA, University of Tennessee, 57A Perkins Hall, Knoxville, TN 37996-2010; tliyana@utk.edu

2 Dept. of Environmental Engineering Professor, University of Tennessee, 63 Perkins Hall, Knoxville, TN 37996-2010; jschwart@utk.edu

3 Geologist, National Sedimentation Lab, USDA ARS P.O. BOX 1157, Oxford, MS 38655; asimon@msa-oxford.ars.usda.gov

4 Dept. of Earth & Planetary Sciences Professor, University of Tennessee, 419 Earth & Planetary Sciences Building, Knoxville, TN 37996-1410; lmckay@utk.edu

CHEMICAL AND BIOLOGICAL ANALYSES OF WATER FROM SITES LOCATED IN THE WATAUGA WATERSHED IN NORTHEASTERN TENNESSEE

Kelly Moore*[1], Yongli Gao[2], Jessica Buckles[2], Morgan Pate[2]

The Watauga watershed is located in northeastern Tennessee. It is composed of many karst features such as sinkholes, springs, loosing streams, and caves. For this project two creeks, Dry and Buffalo, two caves located between them, Rock House Cave and Salt Peter Cave, and the cave spring that flows into Buffalo Creek were chosen as locations for water analysis. Water samples were taken over a two-year period in both the fall and spring seasons for chemical and biological analyses. The results from these analyses are important because in northeastern Tennessee most of the drinking water comes from karst aquifers and springs. These creeks and cave system are also areas of recreation for children and adults. For both these reasons, the EPA has set drinking water and recreational water standards for these water sources.

To evaluate the aquatic environment at each of these locations the following analyses were performed on the collected water samples: nitrate and phosphate concentrations, water hardness and alkalinity, major cations and anions, along with concentrations of total coliforms and E. coli. Since the composition of a stream varies regionally and within a watershed, evaluating such components of an aquatic system can provide valuable information about the system. Variations within the watershed occur seasonally through changes in precipitation, which can alter ground water contributions and the influence of the land-use around the system. Variations also occur within a specific stream or aquifer due to natural and anthropogenic exposures that occur as surface and groundwater flow through.

1 Department of Environmental Health, East Tennessee State University, Johnson City, TN 37614

2 Department of Physics, Astronomy, and Geology, Box 70652, East Tennessee State University, Johnson City, TN 37614

A MODELING TOOL FOR DETERMINATION OF PROCESS IMPORTANCE ACROSS THE GROUNDWATER/SURFACE WATER INTERFACE

Ravi Palakodeti[1]*, Eugene J. LeBoeuf[2], and James H. Clarke[3]

Prediction of distribution and concentrations of contaminants across the groundwater/surface water interface (GWSWI) is essential for evaluating human health and environmental risk as well as remedial alternatives at contaminated sites. The overall objective of this work is to provide a framework that assists in model development for the GWSWI to guide regulatory agencies and other interested parties in identifying existing modeling capabilities and in recognizing the need for development of new modeling tools where existing modeling techniques are inadequate to represent the interactions within the GWSWI. As a part of this effort, identifying dominant and rate-limiting physical and biogeochemical processes in the context of contaminant mass transfer and transformation is critically important for estimating contaminant fluxes and compositional changes across the GWSWI. A new, user-friendly, spreadsheet- and Visual Basic-based analytical tool that enables assessment of dominance of controlling processes across the GWSWI is presented. Application of the new modeling tool is demonstrated through evaluation of the biodegradation process for Chlorobenzene for a canal exhibiting gaining and losing characteristics.

1 Graduate Student, Department of Civil and Environmental Engineering, Vanderbilt University, VU Station B 351831, Nashville, TN 37235. email: ravi.c.palakodeti@vanderbilt.edu

2 Associate Professor, Department of Civil and Environmental Engineering, Vanderbilt University, VU Station B 351831, Nashville, TN 37235. email: eugene.j.leboeuf@vanderbilt.edu

3 Professor of the Practice, Department of Civil and Environmental Engineering, Department of Civil and Environmental Engineering, Vanderbilt University, VU Station B 351831, Nashville, TN 37235. email: james.h.clarke@vanderbilt.edu

APPLICATION OF THE RTD MODEL TO ANAYLZE THE FATE AND TRANSPORT OF AMMONIA IN LABORATORY KARST SYSTEM

Kelly Ray[1], Roger Painter[1], and Tom Byl[1,2]

Elevated ammonia concentrations in groundwater pose health and environmental problems. The impact of ground water contamination can be exacerbated in karst systems where water can enter directly through sinkholes or disappearing streams without any filtration. Karst aquifers are highly heterogeneous and cannot be adequately described by Darcian principles used to characterize flow in sandy aquifers. The objective of this research was to determine if a residence time distribution (RTD) based model in conjunction with the advection dispersion equation could adequately describe the fate and transport of ammonia in a karst aquifer. To accomplish this task, a laboratory karst system was constructed to simulate the non-ideal flow. Feeding ammonia solution to this simulated system in a controlled fashion allowed the model to be validated by comparing the actual concentration versus time data at the systems effluent to the model predicted values. Static batch reactors using indigenous karst bacteria established a first-order rate of NH_3-oxidation with a k value of 0.0209 per day. These results suggest that ammonia degradation does not occur at significant rate in karst under ambient conditions. In a follow-up experiment, supplements and surface area were investigated. A flow-through karst system with a 400% increase in surface area to volume (SA/V) ratio increased the k value 54%. The addition of 1 g of lactate/L increased the k value almost 10-fold.

1Tennessee State University, 3500 John Merritt Blvd, Nashville, TN 37209

2 U.S. Geological Survey, 640 Grassmere Park, Suite 100, Nashville, TN 37211

DETERMINING THE RELATIVE PERMEABILITY FUNCTIONS OF VARIOUS POROUS MEDIA BY TRANSIENT FLOW CENTRIFUGATION

Ching Tu[1], Edmund Perfect[1], and Engelmundus H. Van Den Berg[1]

The relative permeability function (k_r) is an important property for understanding fluid migration through porous media, particularly under unsaturated transient flow conditions. Knowing how k_r changes through different degrees of saturation is critical, because in the vadose zone water and air coexist in the same pores. In an air-water porous network, k_r indicates the ratio of the unsaturated hydraulic conductivity function, $K(\theta)$, to the saturated hydraulic conductivity, K_s. An example of k_r is as follows: when a porous medium is fully saturated with water, the k_r of water (k_{rw}) is unity. Then, as pressure is applied to this porous network, the water (wetting phase) is replaced by air (non-wetting phase). Consequently, k_{rw} is decreased and the relative permeability of the air (k_{ra}) is increased relatively to each other.

Traditionally, three different approaches have been adopted for obtaining data for k_{rw}; these are: indirect analytical models, steady-state centrifugation that involves either unsaturated flow apparatus (UFA) or internal flow control (IFC), and the transient flow method.

The main contribution of this study is that we are combining the centrifugal and transient flow methods to determine k_{rw}. Usually, the whole procedure of a transient flow draining experiment can be highly time-consuming under natural one-gravity situation. One advantage of using centrifugation, over other techniques, is that it can accelerate the process of extracting pore water from rock and soil samples for an array of analyses. Moreover, transient flow measurements can be conducted under multi-gravity centrifugal forces to accelerate the fluid velocity that can reduce time required and provide valuable k_{rw} data.

1The department of Earth and Planetary Sciences, The University of Tennessee, Knoxville, email: ctu@utk.edu

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Fax: (865) 974-1838
TNWRRC Contact: Tim Gangaware
E-mail: gangwrrc@utk.edu

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E-mail: bharring@hach.com
www.hachenvironmental.com

Hach Environmental designs, manufactures, and services Hydrolab and OTT instruments. Hydrolab multi-parameter water quality instruments incorporate multiple sensors into a single housing and are used for either unattended monitoring or sampling and profiling. OTT instruments include surface water and groundwater level monitors, precipitation gauges, and complete hydrological and meteorological stations.

In-Situ, Inc.
221 E. Lincoln Ave
Ft. Collins, CO 80524
Phone: (970) 498-1654 or 800-446-7488 x654
Contact: John Murray
E-mail: jmurray@in-situ.com
http://www.in-situ.com/

In-Situ® Inc. designs, manufactures, services and rents water level, water quality, water sampling and environmental monitoring equipment. Our goal is to provide rugged, reliable, and accurate instruments to monitor Level, Pressure, Depth, Temperature, Dissolved Oxygen, pH, Conductivity, TDS, Salinity, ORP, Barometric Pressure, Nitrate, Chloride, Ammonium, Turbidity, Total Dissolved Gas & more. In-Situ's products include Level TROLL®, TROLL® 9500, RuggedReader®, RDO® - Optical Dissolved Oxygen, Total Dissolved Gas sensors and more.

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145 Old Shackle Island Road
Hendersonville, TN 37077
Phone: (800) 452-4435
FAX: (615) 822-9460
Contact:
Email: info@jenhill.com
http://www.jenhill.com

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2840 Plaza Place, Suite 202
Raleigh, NC 27612
Phone: (919) 571-7111
FAX: (919) 571-0454
Contact: Sharon Hampton
E-mail: shampton@hwlochner.com
http://www.hwlochner.com

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P.O. Box 682526
Franklin, TN 37068
Phone: (615) 395-4102
FAX: (615) 395-4515
Contact: Mike Donovan
Email: miked@midtnerosion.com
http://www.midtnerosion.com/

Mid-TN Erosion and Sediment Control is a full service erosion and sediment control contractor offering installation, maintenance and inspections of all BMPS. Mid-TN also offers complete construction of stream restoration projects. Mid-TN has the knowledge and manpower to handle any project from small sites to the toughest of projects. Mid-TN believes in working with designers and engineers to solve many of the issues that arise during the construction process.

P.E. LaMoreaux & Associates, Inc. (PELA)
106 Administration Road, Suite 4
Oak Ridge, TN 37830
Phone: (865) 483-7483, ext. 101
Fax: (865) 483-7639
Contact: Barry F. Beck
E-mail: bbeck@pela-tenn.com
http://www.pela-tenn.com

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Revere Control Systems
2072 Remington Park Road
Old Hickory, TN 37138
Phone: (615) 847-2325
Contact: Dave Abel
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http://www.co-generation.com/

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6106 Corporate Park Drive
Browns Summit, NC 27214
Phone: (336) 375-1989
Fax: (336) 375-1801
Contact: John Peters, jpeters@shamrockenviro.com
http://www.shamrockenviro.com/

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5465 SW Western Ave. Ste. F
Beaverton, OR 97005
Phone: (800) 452-5272
Contact: Fred Holloway
Email: fholloway@stevenswater.com
http://www.stevenswater.com/

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65 Brown Road
Phenix, AL 36869
Phone: (334) 297-5193
Contact: Wade Loseman
Email: wloseman@sutron.com
http://www.sutron.com/

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Tennessee Instrumentation Company
Main Office
Ken Price
P.O. Box 627
Kingsport, TN 37662
Phone: 423-247-1148
Email: tic@chartertn.net

Branch Office
Bob Brykalski
Phone: 865-368-1488
Email: rebry@earthlink.net

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Tom Lawrence Storm Water Consultant
1663 Beard Place
Memphis, TN 38112
Contact: Tom Lawrence
Phone: (901) 274-2829
Email: bus@thecave.com

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U.S. Geological Survey
Tennessee Water Science Center
640 Grassmere Park, Suite 100
Nashville, TN 37211
Phone: (615) 837-4701
Fax: (615) 837-4799
Contact: Scott Gain, Director
E-mail: wsgain@usgs.gov
http://tn.water.usgs.gov/

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