Tennessee Water Resources Research Center Annual Technical Report FY 2015

Introduction

Water Resources Issues in Tennessee:

The southeastern United States historically has been considered water-rich. However, the U.S. Global Change Research Program (USGCFP) in their 2014 National Climate Assessment Report (http://nca2014.globalchange.gov/report) has projected less frequent precipitation and more frequent days with higher temperature. As a result, we will see increased evapotranspiration and frequency of drying-and-wetting cycles. These changes will lead to deficits in both soil moisture and surface/ground water stores, and hence more droughts.

The increased drying-and-wetting of the soils will also weaken aggregates through repeated shrinking and swelling. Then higher intensity rains will cause extreme erosion events, washing away soil nutrients and contaminants. The subsequent degrading water quality will further limit water availability.

Beginning in 2006 and continuing on through the summer of 2008, Tennessee experienced a drought of record which severely strained the water supplies of many communities across the state. During this period over 35 water districts out of a total of 671 public systems in Tennessee experienced difficulty in supplying water to their customers. In recent years, many of the smaller municipal water suppliers and utility districts that rely on wells, springs, or minor tributaries for their water sources continue to face water shortage problems. All across the state many private, domestic, and commercial use wells have become strained, forcing users to seek alternative sources of water.

In addition to the effects of climate changes on water availability, there is an increased demand from a rising population and shifting land use distributions. These changes in demand are especially significant in adjoining urban and agricultural areas around Tennessee.

Withdrawals for municipal purposes are the fastest growing water-use category, rising 8% annually nationwide. Significant amounts of water are required to generate electricity through hydropower, as well as for cooling fossil fuel and nuclear power plants. These uses, which can be voluminous, can alter natural flows and influence the health of aquatic ecosystems. Along the same lines, higher food production will increase water demand for agriculture. Irrigation for agriculture is the largest water use and can diminish supplies for other uses. It also has the potential to degrade water and soil quality.

With more and more people migrating to cities, this demand may lead to a water crisis. As mentioned above, water shortages are occurring more often and may become problematic in the southeastern U.S., especially with groundwater resources dwindling. Shifting water demands may lead to complex natural and human interactions that have not been encountered before.

Tennessee is fortunate to have what many consider to be an abundance of good quality water. But, from the viewpoint of the state government, the legal, institutional, and administrative aspects of water management are becoming major concerns. Tennessee has moved to establish an integrated and coordinated policy and administrative system for managing water resources in the state. It is still a work in progress. For example, the Tennessee Water Resources Technical Advisory Committee (WRTAC) has recently joined the effort of other states throughout the country and requested the development and maintenance of a statewide hydrologic database to assess the impact of drought on public water supply systems in Tennessee.

Providing an adequate supply of quality water for agricultural, industrial, commercial, and domestic uses, while protecting our surface and groundwater resources are of major concern in all regions of the state and vital to the economic development and growth of the state. However, the level of knowledge necessary to understand the underlying hydrological, biogeochemical and social processes that control the availability of water in the state, as well as their interactions and feedbacks, is beyond the capacity of one group or agency to handle. This necessitates collaboration amongst academia, governmental agencies, and industry to collect and analyze information for water quality and quantity (WQ2) at any scale and at all times.

Tennessee has an active group of federal agencies, such as the Tennessee Valley Authority, Army Corps of Engineers, Natural Resource Conservation Service, and U.S. Geological Survey (USGS), who have historically contributed to the management and monitoring of water resources. In recent years, the state, through the Departments of Environment and Conservation, Wildlife Resources, Agriculture and others, have begun to develop a more active and aggressive role in the management and protection of these resources. Added to this group, are the cadre of hydrologic and hydraulic researchers at the state s academic institutions, who are working on more fundamental understanding of the hydrologic cycle in light of a changing climate and human development.

However, all these groups have been working independently and sometimes in competition, which has inhibited progress towards a unified front facing the water issues of the state. Tennessee is lacking a singular organization that has both the vision and the capability to bring these groups together. The Tennessee Water Resources Research Center (TN WRRC) has the right mixture of leadership, outreach, and interdisciplinary research that can unite the different groups and work towards a statewide adaptive governance plan to manage the state's water resources to the benefit of all.

Overview of Program Objectives and Goals:

The Tennessee Water Resources Research Center, located at the University of Tennessee - Knoxville, is a federally-designated state research institute. It is supported in part by the U.S. Geological Survey of the U.S. Department of Interior under the provisions of the Water Resources Research Act of 1984.

The TN WRRC and their university partners provide research expertise in identifying and addressing high-priority water problems and issues for each region. It is the primary resource to assist the state & the nation in the development and implementation of programs aimed at achieving sustainable quantities of quality water. It serves as a link between the academic community, federal/ and state government, water-related organizations, the private sector and local communities for purpose of mobilizing university. The Tennessee Water Resources Research is mandated to do the following by the Clean Water Act:

1. Plan, conduct, or otherwise arrange for competent research that fosters the entry of new research scientists into the water resources fields; the training and education of future water scientists, engineers and technicians; the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and the dissemination of research results of water managers and the public.

2. Cooperate closely with other colleges and universities in the state that have demonstrated capabilities for research, information dissemination, and graduate training, in order to develop a statewide program designed to resolve state and regional water and related land problems.

To carry out this mission, the TN WRRC has set these major goals:

1. To assist and support all the academic institutions of the state, public and private, in pursuing water resources research programs for addressing problem areas of concern to the state and region.

2. To provide information dissemination and technology transfer services to state and local governmental bodies, academic institutions, professional groups, businesses and industries, environmental organizations and others, including the general public, who have an interest in water resources issues.

3. To promote professional training and education in fields relating to water resources and to encourage the entry of promising students into careers in these fields.

4. To represent Tennessee in the Universities Council on Water Resources, the American Water Resources Association (including Tennessee Section), the Water Environment Federation, the American Water Works Association, the International Erosion Control Association, the Soil and Water Conservation Society, the Lower Clinch Watershed Council, the ORNL-TVA-UT Research Consortium and the National Institutes for Water Resources (NIWR).

Tennessee Water Resources Research Center Update:

During 2015, the TN WRRC has taken several steps forward to establish itself as a unifying body for the water resources researchers, managers, and educators in Tennessee. These steps are being driven by the new director, Thanos Papanicolaou and Assistant Director Tim Gangaware, who has been with the TN WRRC for several years. These steps include the development of an Advisory Board, enhancement of the 104B seed grant program, and initiation of other state/ national research efforts, as well as sustaining its already strong outreach efforts.

Advisory Board: As an initial step by the TN WRRC to bring together like-minded researchers & administrators across the state, Director Papanicolaou established an advisory board. The board consists of lead personnel from the U.S. Geological Survey, Oak Ridge National Lab, Tennessee Valley Authority, state agencies like the Departments of Agriculture and Environment & Conservation, and the private sector. Additional members are being considered from the Nature Conservancy and the West TN River Basin Authority.

With the Advisory Board, Director Papanicolaou hopes to garner input on the key water-related issue for the state. This information will be used to develop the priority areas for the 104B seed grants. After getting the state water resources organizations involved in the planning of the seed grant program, Director Papanicolaou is working to keep these groups engaged by encouraging them to help provide matching funds for new researchers, as well as places for the students to gain experience through internships. The first meeting of the Advisory Board was convened on March 2, 2016 in Knoxville. The second meeting is planned for mid-July in Nashville.

104B Seed Grants: The focus of the 2015 104B seed grants was on the impact of land management and nutrients on Tennessee s water resources and water/soil management decisions. Excess runoff and soil erosion, resulting from our land management choices affect soil health and landscape productivity, as well as water quality and quantity across the state. Public awareness of nutrient-related water quality issues is rising and this has put pressure on the state s governing bodies to address these issues through regulation. The regulatory and mission agencies welcome the focus on understanding better soil and water quality to improve mitigation strategies. The topics submitted in 2015 related to excess nutrients in surface and ground water, soil/sediment sourcing, sedimentation in dams, water quality monitoring, water availability, and land management. We had 5 projects funded in 2015 from researchers at the University of Tennessee and Tennessee State University, a Historically Black College/University (HBCU).

Research Program Introduction

The main push of the TN WRRC research program is through the 104B Annual Base Funding grant program. These base grants are provided to conduct applied research on water resource issues, education for helping train new scientists, and outreach activities to disseminate research results to water managers and the public. They are often used as seed funding for larger projects. Results for TN WRRC supported research efforts are expected to assist local, municipal, state, regional and federal agencies improve their decision-making in the management and stewardship of their water resources.

The 104B grants are solicited through an annual call-for-proposals to all the state's colleges and universities. Any full-time faculty member from a Tennessee institution of higher education are eligible to receive grants form TNWRRC. The call-for-proposals are centered on specific research priorities, but all water resources are considered.

The focus of the 2015 104B seed grants was on the impact of land management and nutrients on Tennessee s water resources and water/soil management decisions. However, to generate future research priority areas that are responsive to the water resource issues in Tennessee, Director Papanicolaou has probed the Advisory Board members for suggestions. A list of their suggestions that are being considered for next year are listed below in Table 2.

Table 2. Potential Topics for the 2016 Research Priorities of the 104B Seed Grants:

1. Water availability, water use forecasting, and water transfers;

2. Surface water quality monitoring and the need for better sensor technology to get background measures;

3. Groundwater remediation (natural attenuation);

4. Erosion control and preventive measures; monitoring BMP effectiveness and load reductions before & after studies;

5. The role of soil heath & cover crops on the hydrologic cycle;

6. Sediment sourcing;

7. Streambank protection; the using bioengineered structures needed;

8. Modeling efforts for sediment especially in west TN.;

9. Ecoflows/ minimum flows;

10. How to study ecological effects.

The following are the project summaries of the five studies conducted under the 2015 program and three on-going studies from pervious years. The PIs are from the University of Tennessee Knoxville and Tennessee State University.

Engineered Strategy to Remediate Trace Organic Contaminants using Recirculating Packed-Bed Media Biofilters at Decentralized Wastewater Treatment Systems: Determination of Trace Organic Sorption to Treatment Media

Basic Information

Title:	Engineered Strategy to Remediate Trace Organic Contaminants using Recirculating Packed-Bed Media Biofilters at Decentralized Wastewater Treatment Systems: Determination of Trace Organic Sorption to Treatment Media
Project Number:	2013TN99B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	2nd Tennessee
Research Category:	Water Quality
Focus Category:	Wastewater, Treatment, Water Quality
Descriptors:	None
Principal Investigators:	John R. Buchanan, Jennifer DeBruyn

Publications

1. Buchanan, J.R. 2013. Recirculating media filters providing wastewater treatment at rural schools with ammonia discharge limits. "in" Proceedings National Onsite Wastewater Recycling Association, 22nd Annual Technical & education Conference, Millennium Maxwell House Hotel, Nashville, TN. November 17-20.
2. Buchanan, J.R. 2014. Decentralized Wastewater Treatment: Volume Three, Remediation of Polluted Water, in the Series, "comprehensive Water Quality and Purification", Elsevrer, Oxford, United Kingdom.
3. Perez, Brittani, 2015.Removal of Trace Organic Compounds in Domestic Wastewater using Recirculating Packed-Bed Media Filters, "MS Dissertation" Department of Biosystems Engineering and Soil Science, College of Agriculture and Natural Resources, the University of Tennessee, Knoxville, TN. pp.137.
4. Buchanan,J.R., B.N.Perez, and J.M.DeBruyn. 2015. Engineered Strategy to Remediate Trace Organic Contaminants using Recirculating Packed-Bed Media Biofilters at Decentralized Wastewater Treatment Systems. WEFTEC, Chicago, IL, September 26-30.2015.

Introduction

Recirculating packed-bed media biofilters (RPBMB) are a low-cost and low-maintenance wastewater treatment process that is well suited for individual onsite and very small community applications. Approximately 25% of the domestic wastewater generated in the U.S. is processed by individual onsite or very small wastewater treatment systems.

Packed-bed media biofilters are a slow-rate, fixed-film (or attached-growth) unit process used for secondary and tertiary treatment. This process passes effluent through a porous, inert media (the packed-bed) where waste constituents diffuse out of the bulk water and into the biofilms that form on the media. Aeration is provided as the wet media is exposed to atmospheric oxygen. A recirculating packed-bed media biofilter (RPBMP) recirculates the effluent through the media several times for enhanced organic carbon removal and nitrification (oxidation of ammonia to nitrate). After trickling through the media, approximately 80% of the effluent is sent to the recirculation tank (for additional passes through the media) and the remainder goes to the final discharge (typically via a drip irrigation system). Because the influent from primary treatment is anaerobic, the recirculation tank is usually anaerobic and this reducing-environment allows for denitrification. Under reducing conditions, nitrate can be converted to nitrogen gas, thus reducing the nitrogen concentration in the effluent.

Previous trace organic wastewater contaminant (TOWC) research has focused on the disappearance of these compounds as wastewater passes through various treatment technologies and subsequent environmental monitoring in surface water. This project sought to determine the specific TOWC removal processes within this decentralized wastewater unit process. This knowledge will allow scientists and engineers to optimize these processes for TOWC remediation and to minimize or eliminate their release to natural environments mitigating potential ecological disturbance.

Nature, Scope and Objectives of Project

By design, the organic loading rate to RPBMBs is low (typically 2 to 5 kg BOD_5 100 m^{-2} d^{-1}). This loading rate minimizes the accumulation of biosolids within the media and starves the microorganisms for organic carbon rather than oxygen (endogenous respiration). It is possible that this operating mode may encourage the aerobic biodegradation of otherwise recalcitrant TOWC. Further, there is some evidence that changing from oxidizing to reducing conditions can enhance TOWC degradation. Lastly, the media provides tremendous trace organic contaminant adsorption/absorption potential. The specific objective of this project is to determine whether sorption to the media is the primary removal mechanism.

Four laboratory-scale RPBMB were constructed and were dosed with septic tank effluent that was augmented with 0.1 mg/L of either triclosan, ibuprofen, or naproxen for eight weeks. We monitored the treated effluent for the disappearance of the listed trace organics as part of a separate project. It is assumed that the major removal mechanisms are biodegradation and sorption. By measuring the sorption component, it is hoped to get a better understanding of the biodegradation aspect.

Methods, Procedures and Facilities

Four laboratory-scale recirculating media biofilters were assembled. These systems included a supply tank, a 56-cm tall column filled with media (3-5 mm fine gravel), and a recirculation tank. Primary-treated wastewater from a community-scale decentralized treatment system was used as the wastewater source. The supply tanks emulated the discharge from primary treatment (liquid/solid separation) and fed into the recirculation tank on a diurnal basis – representing higher wastewater flows that occur during mornings and evenings. Effluent in the recirculation tank was micro-dosed to the media column five times per hour. The discharge of the column flowed back into the recirculation tank. The recirculation rate was five volumes passed through the media column with respect to the daily volume of treated effluent, representing a 5 to 1 recirculation rate. A cycle consisted of five doses. During four doses, the column effluent returned back to the recirculation tank. Just before the fifth dose, a three-way valve on the bottom of the media filter switched and directed the effluent to the finished product container. All system components were manufactured from stainless steel, glass, or coated with polytetrafluoroethylene (PTFE) in order to minimize the partitioning of the trace organic compounds to the system surfaces.

Each of the four systems received primary treated wastewater for a minimum of 20 days to establish a biofilm within the media. COD analysis was used to confirm that the biofilm was established and metabolically active. After the initial maturation period, three of the four systems began receiving a 0.1 ppm spike of either triclosan (TRI), ibuprofen (IBU), or naproxen (NAP). The forth system served as a non-spiked control. The septic tank effluent sourced for this project contained measurable concentrations of each of the selected compounds. Thus each of the experimental units received concentrations of TOWC found in the septic tank effluent, with the TRI, IBU, and NAP units receiving an additional 0.1 ppm spike of their respected compounds.

The recirculating media biofilters received this dosage for 60 days. During each experiment, the concentration of the selected contaminants was measured in the spiked effluent and finished product.

Biofilm samples were collected to determine sorption of the target compounds. At the end of the eight week study period, the units were disassembled and media samples were taken from the top, middle, and bottom of each column. For the sorption study, a 25 mL aliquot of each media sample was placed in a glass centrifuge tube, along with 2.5 mL each of methanol and distilled water. Each tube was hand shaken, and then placed on an orbital shaker at 500 rpm for 1 day to dislodge the biofilm from the media. The media was removed from the tubes and the remaining mixture was centrifuged at 2400xg for 10 min. The supernatant was collected and evaporated under nitrogen gas until approximately 1 mL remained. The 1 mL was added to 300 mL of acidified distilled water and was loaded onto solid phase extraction cartridges.

Results and Findings

Media samples from each of the experimental units were collected from different depths (top, middle, and bottom layer) for analysis of the biofilm present. Initially, simple loss on ignition (LOI) tests were performed to determine the amount of total organics present between each of the layers. Two-way ANOVA analysis confirmed that there were statistical differences between the organics present within the layers ($P>0.01$, α=0.05) and no significant differences between experimental units ($P=0.68$, alpha=0.05). LOI measurements showed that the highest percentage of total organics were consistently present in the top layers (3.4% to 3.8%) of the columns, with minimal shown in the middle and bottom (0.45% to 0.83%). Results like these are expected from RMFs, because biofilm typically forms within the first 6” of media. Therefore, it can be stated that most of the biological treatment within the system was occurring within the uppermost layers of the column.

With regard to the mass of adsorbed TOWC, there were significant differences between layers ($P=0.04$) but no significant differences between experimental units ($P=0.26$). Most of the absorbed TOWC were shown to be within the top layer of the columns, which correlated to the LOI data presented earlier. However, there was an adequate amount of PPCPs detected within the middle layer as well. Totaling the concentrations of adsorbed PPCPs within each layer for each experimental unit, the control system was shown to have the highest amount (0.52±0.01%, 0.73± 0.01%, and 4.31±0.02% of IBU, NAP, and TRI), with the NAP column showing minimal sorption of IBU only (0.15±0.00%). TRI was shown to participate in sorption more than IBU and NAP, which corresponds to previous research, and had the highest sorption percentages were within the control and TRI column (4.31±0.03% and 5.13±0.03%). It was interesting to note that TRI only did so within those two columns; there was no sorption of TRI within the NAP columns, and minimal in the IBU column. IBU had half as much sorption occurring within the IBU column when compared to the control column (0.35±0.00%), with even less occurring within the NAP and TRI columns. NAP experienced low sorption in all columns except within the NAP column, where no sorption was detected.

Assessment of Watershed Land Use Stressors on the Biological Integrity of the Nolichucky River in Tennessee

Basic Information

Title:	Assessment of Watershed Land Use Stressors on the Biological Integrity of the Nolichucky River in Tennessee
Project Number:	2014TN103B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Second
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Toxic Substances, Water Quality
Descriptors:	None
Principal Investigators:	J Brain Alford

Publication

1. Alford, J.B. 2016. Assessing the effects of pesticides from agriculture runoff on the biological integrity of the Nolichucky River watershed. Tennessee Water Resources Research Center, the University of Tennessee, Knoxville, TN.,114 pp.

Introduction

The Nolichucky River watershed of east Tennessee (Fig. 1) is home to five fish and seven mussel species listed as endangered or threatened by the State of U.S. Fish and Wildlife Service. Thus, it is considered a "hot spot" for North American biodiversity. Land use change from undisturbed forest to agriculture and impervious surfaces are known to affect sensitive species due to increased non-point source pollution. The majority of the watershed includes Greene County, which is a top producer of cattle and fescue in TN. There is growing concern over how conversion of these fields to row crops and impervious surface will affect fish and aquatic invertebrates in the watershed.

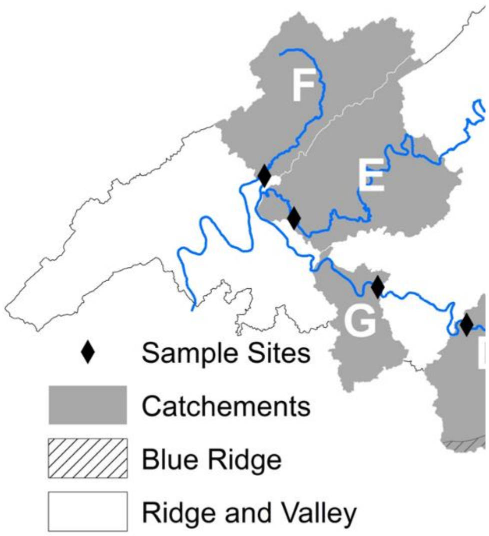
Figure 1. Nolichucky River watershed location in TN.

The objectives of this study are to **(i)** quantify changes in forested, impervious, and agricultural land use from 2000 to 2014 for selected HUC-12 sub-watersheds within the Nolichucky watershed, **(ii)** assess relationships between land use intensity and fish diversity, and **(iii)** use quantitative data to classify most impacted sites and guide land use management.

Study Design

Ten wadeable sites were surveyed for fishes during summer 2014 in the TN portionof the Nolichucky watershed (Fig. 2). Sites were located up- and downstream of observed ag-impacted areas (i.e., farms within 30 m riparian zone). Tennessee Valley Authority's (TVA) protocol for conducting Index of Biotic Integrity (IBI) assessments was used to assess fish assemblage health at riffle-run and pool habitats. A backpack electrofisher and seine were used to sample fish in run, riffle, and shoreline habitats. Seine hauls were used in pools. Fish species and number were recorded for each sample, as well as prevalence of diseases, external anomalies, lesions, and tumors (DELT) and evidence of hybridization. Twelve IBI metrics (Table 1) were calculated from fish species relative abundances (% of total number fish) and richness (no. of species in a taxa).

A supervised classification was done on Landsat 8 and Landsat 7 satellite images to quantify % areal land cover change in the watershed from 2000 to 2014. For each sample site, 12-digit hydrological unit code (HUC) catchments and EPA level-3 ecoregions were downloaded (Fig. 2) and evaluated for percent change of land cover fr0m 2000 to 2014. Generalized additive models (GAM) were conducted in CANOCO v. 4.5 software to test for associations between mean HUC IBI scores and land use metrics.



A - Big Lime Stone Creek
B - Clark Creek – Nolichucky River
C - Sinking Creek – Nolichucky River
D - Pigeon Creek – Nolichucky River
E - Lower Lick Creek
F - Bent Creek
G - Oven Creek – Nolichucky River

Figure 2. TN side of the Nolichucky watershed showing level-3 ecoregions and 12-digit HUC catchments.

Table 1. Definition of the 12 TVA fish IBI metric abbreviations.

Abbreviation	IBI Metric	Abbreviation	IBI Metric
%_DELT	% of fish with DELT	CPUE	Catch Rate
%_HYB	% of fish as Hybrids	N_INTOL	Number of pollution intolerant sp.
%_PISC	% of fish as Piscivores	N_SUCK	Number of Sucker sp.
%_OMNI	% of fish as Omnivores	N_SUNF	Number of Sunfish sp.
%_INSCT	% of fish as Insectivores	N_DART	Number of Darter sp.
%_TOL	% of fish Pollution tolerant	N_RICH	Total species Richness

Results

Overall, 199 electrofishing samples were taken and 43 species were identified at the 10 sites. Bent creek IBIs were not calculated due to cold weather. Impervious land cover increased the most (Fig. 3 and Fig. 4) from 2000 to 2014 with forested land increasing to a lesser extent than impervious surfaces, whereas agricultural land use decreased. IBI metrics (Figure 5) were high for insectivores at all sample sites, low % of tolerant species, and a high CPUE for Sinking Creek. % DELT and % Hybrids occurred only in catchments with the greatest agricultural land use (Big Limestone and Lower Lick). More developed and farmed land cover occurred in the Ridge and Valley level-3 ecoregion than in Blue Ridge ecoregion (Figure 7). Fish IBI scores showed no statistically significant association with 2014 land use coverages (Generalized Additive Models [GAM]; $F < 1.0$; $P > 0.05$). Impervious and Forested land use change difference in km^2 2000-2014) was positively associated with % DELT and % Hybrid, while these IBI metrics were negatively associated with change in agricultural land use (GAM; $P < 0.05$).

Discussion Current Results and Future Work

Supervised classifications show that there has been an increase in impervious surfaces in the total Nolichucky watershed as well HUC 12 catchments sampled for fish assemblages, but these are not showing any association with the variation in IBI scores. Therefore, the next step is to try and use remote sensing on a finer spatial scale (e.g., riparian buffers or plot-specific land use units) to discern associations between row-crop land use intensity and pasture intensity in the Nolichucky watershed, where tomato row crops occur, greater pesticide management is required to control insects, fungi, and weeds than on other types of crops (e.g., soy, corn) and pasture. If acute toxicity events, for example, fish kills caused by insecticides from storm-related agricultural runoff, are degrading fish community integrity, then it will likely be detected at smaller spatial extents than reported here. Future work will include a GIS-based assessment of riparian agricultural and urban disturbance as well as forested buffer width at 30-m and 240-m perpendicular distances from the stream channel at each site. The amount of disturbance and magnitude of forested buffer will then be modeled against fish assemblage and IBI metrics to determine if land use within the riparian zones has an effect on biotic integrity in the Nolichucky watershed.

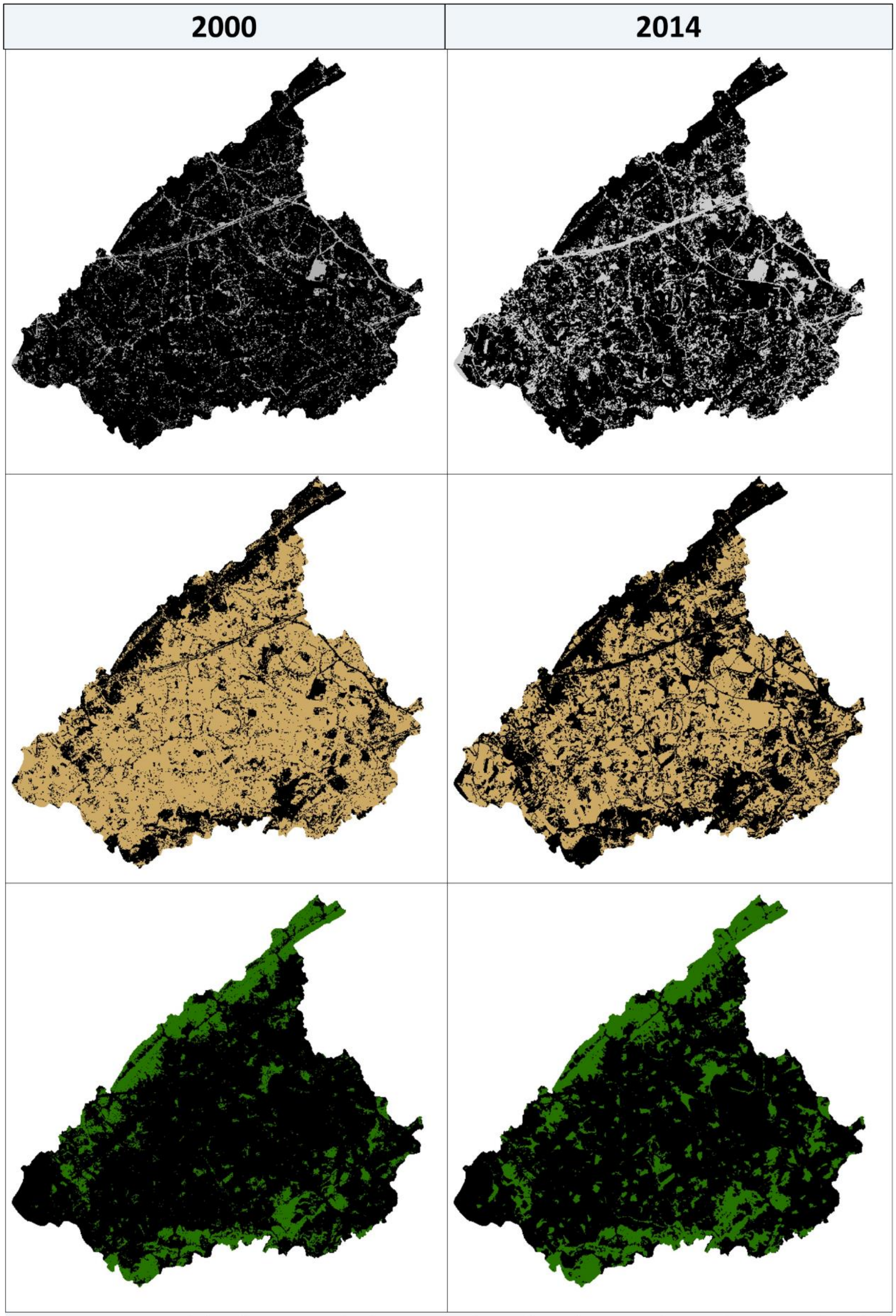


Figure 3. Supervised classification results for Lower Lick Creek 12-digit HUC showing how agricultural, impervious, and forested surfaces have changed. The Lower Lick Creek catchment had the most percent change in impervious surfaces.

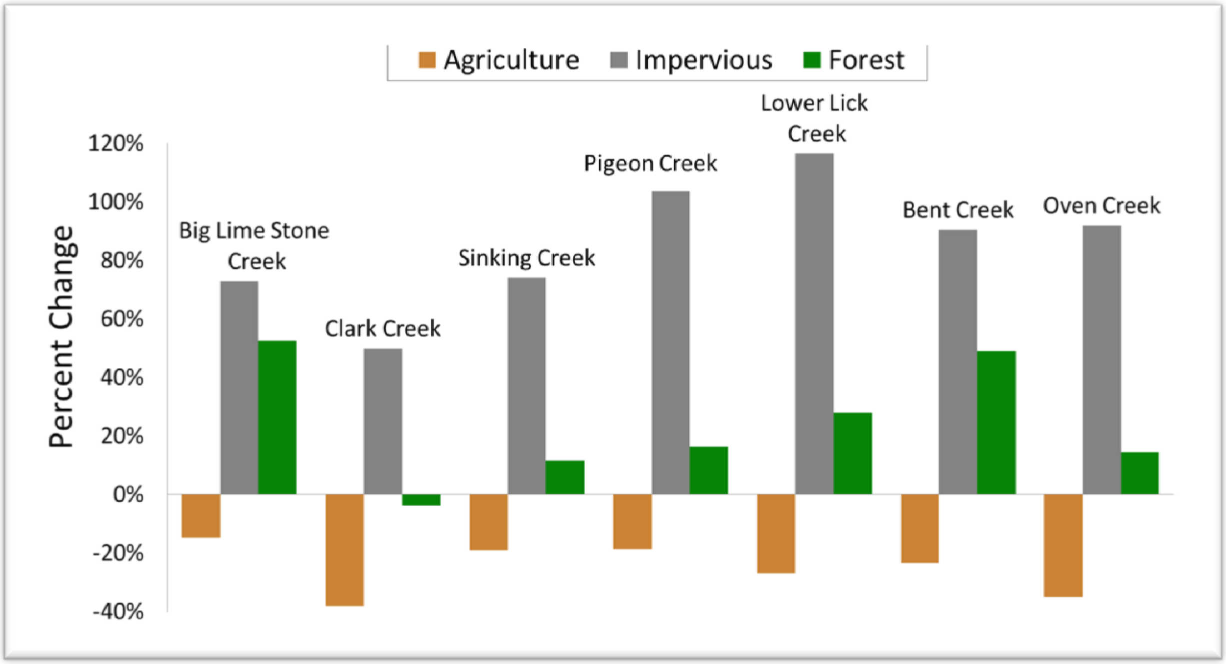
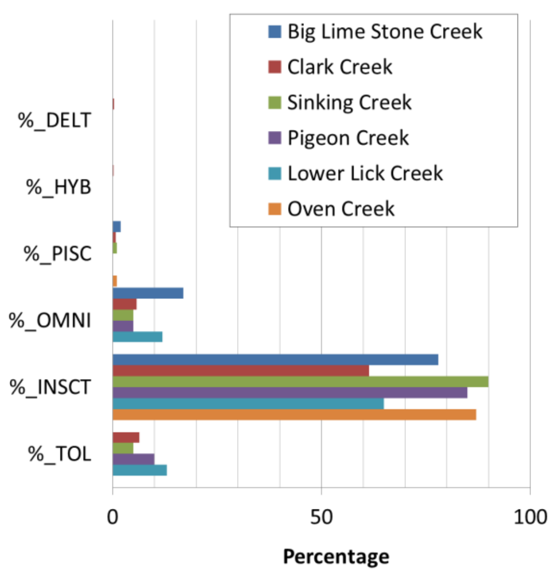


Figure 4. Percent change in area for impervious, forest, and agriculture land cover in the 12-digit HUC.



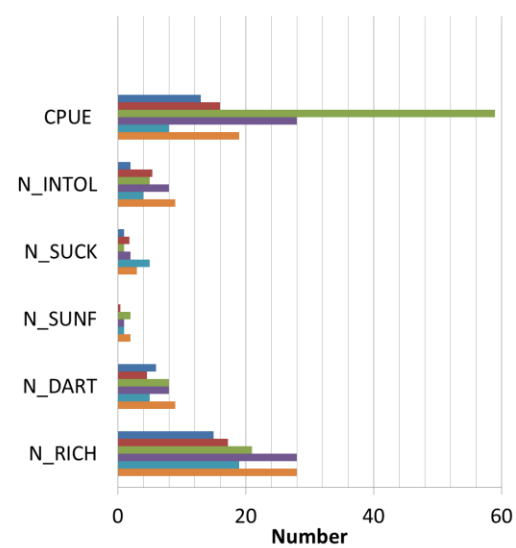


Figure 5. Calculated IBI metrics for each 12-digit HUC catchment.

Table 2. Calculated mean IBI scores for the 12-digit HUC and land use: stream km ratio (km^2 of land use/km of stream)

12-digit HUC	IBI Score	Ag : Stream	Imprv : Stream	For : Stream
Big Lime Stone Creek	36	0.27	0.07	0.05
Clark Creek	38.8	0.05	0.04	0.22
Sinking Creek	48	0.26	0.12	0.07
Pigeon Creek	46	0.22	0.07	0.10
Lower Lick Creek	38	0.20	0.10	0.10
Oven Creek	48	0.09	0.04	.19

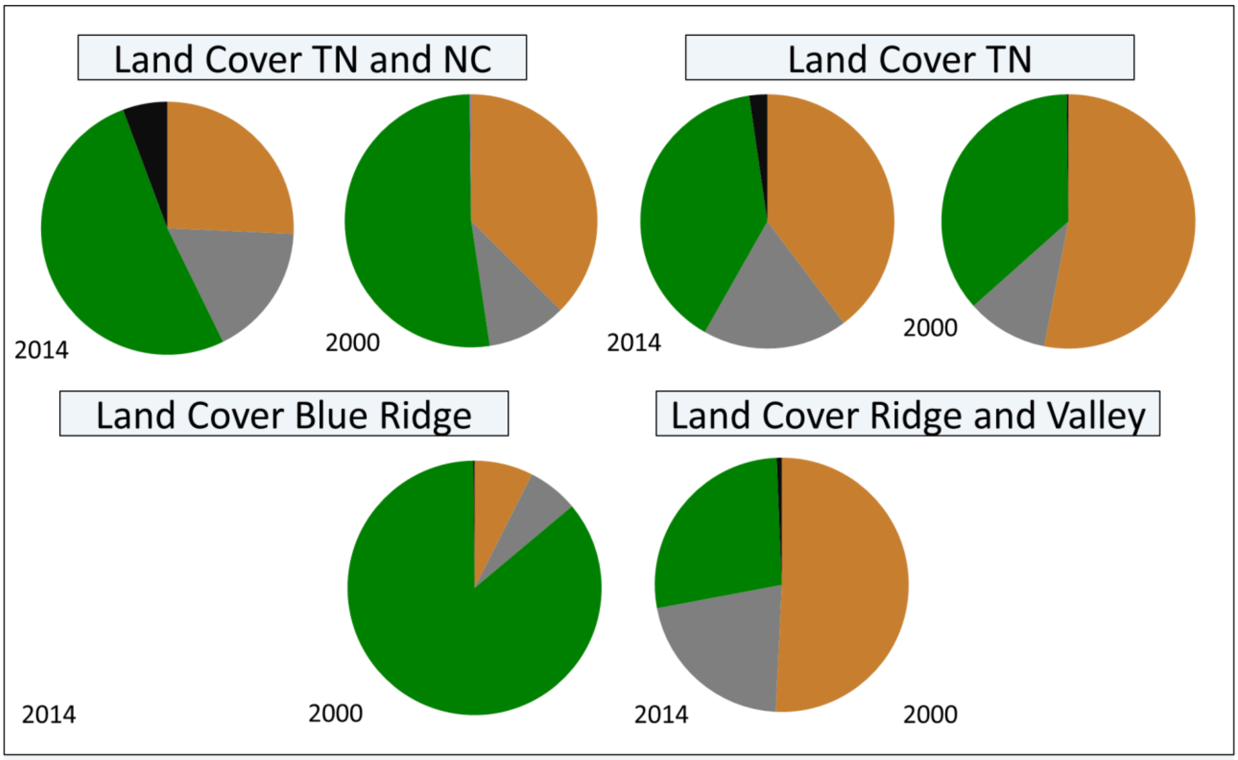


Figure 7. Pie charts showing how land use has changed in the TN side of the watershed compared to the whole watershed and how land use has changed in the two ecoregions in the watershed. Green is forest, tan is agriculture, gray is impervious, and black is masked cells containing no data.

High Resolution Monitoring of Urban Stormwater Quality: Phase 2

Basic Information

Title:	High Resolution Monitoring of Urban Stormwater Quality: Phase 2
Project Number:	2014TN104B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Surface Water
Descriptors:	None
Principal Investigators:	Jon M Hathaway, Kimberly Carter

Publications

1. Epps, T.H., J.M. Hathaway, 2015. Assessing Spatial Relationships of Distributed Urban Land Cover Compositions and In-stream, Flow Regime in Knoxville, TN., World Environmental and Water Resources Congress, Austin, TX. May18-20.
2. Epps, T.H., J.M. Hathaway, 2015. Assessing Spatial Relationships of Distributed Urban Land Cover Compositions and In-stream Flow Regime in Knoxville, TN. "in" Proceedings of the Twenty-fourth Annual Water Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN.. pp.B1-6.
3. Epps, T.H., J.M. Hathaway, 2016. Runoff Uncertainty Related to Fine-Scale Spatial Variability in Urban Watersheds, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, Tn. pp.1B-3.
4. Epps, T.H., J.M. Hathaway, 2016. Refining Urban Hydrologic Models: Incorporating the Spatial Variability of Rainfall, Vegetation, and Soil Infiltration. "in" Proceedings of the World Environment and Water Resources Congress. West Palm Beach, FL.
5. Christian, L.E., J.M. Hathaway, and T.H. Epps, 2016. Exploring the Influence of Urban Watershed Characteristics and Antecedent Climate on In-stream Pollutant Dynamics, "in" Proceedings of the 16th Annual Meeting of the American Ecological Engineering Society, Knoxville, TN. June 7-9, 2016.

Nature, Scope and Objectives

In the 2010 Tennessee Water Quality Assessment Report, urban runoff was identified as one of the primary causes of impairment in streams and rivers in the state. Similar results were found for the Southeast Region in states such as Georgia, Alabama, and Virginia. As such, watershed restoration efforts (such as developing TMDLs) require consideration of stormwater runoff. Stormwater had been shown to transport nutrients, sediments, metals, and indicator bacteria to local surface waters. Despite this fundamental understanding, further research is needed to understand the fate and transport of pollutants in stormwater.

Modeling is an integral part of watershed restoration efforts, as is an understanding of the pollutant of concern's fate and transport and what factors influence the pollutant's variability. Modeling provides valuable insight into the pollutant sources, sinks, and processes within a given watershed. This insight allows more targeted, efficient, and cost-effective pollution abatement efforts. High resolution data can aid in such efforts, offering a preliminary investigation of the variability of pollutants in stormwater and what factors influence this variability. In addition, pollutants such as *E. coli* and organic chemicals have not been extensively characterized in stormwater runoff, resulting in a lack of understanding as to the potential threat these pollutants pose to public and ecological health. The overall goal of this research is to better understand urban stormwater and provide sustainable ways to reduce its contribution to surface water degradation.

Objective

The specific objective of this project is to collect high resolution water quality data from urban streams in Knoxville, TN, to allow an understanding of factors explaining the variability of pollutants observed in these systems.

Methods, Procedures and Facilities

During FY2014, a gaging station was installed in Second Creek near its confluence with Lake Loudoun (Figure 1a). This station is powered by a permanent electric supply run from Estabrook Road on the campus of the University of Tennessee. The station consists of a refrigerated sampler connected to an ISCO Signature flow meter (Figure 2a). Flow was initially characterized using an area velocity probe fixed to the channel bed to collect depth and velocity readings for the stream. A survey of the stream cross section (Figure 2b) was performed by graduate and undergraduate students to allow development of a stage discharge relationship for the station. After this relationship was established, an ultrasonic depth sensor was installed underneath a foot bridge to allow measurements while avoiding in-stream hazards.

During Phase 2 of the project (the second year of funding), monitoring sites utilized by the City of Knoxville for Third Creek and Williams Creek were leveraged to add an additional two sites to the project (Figure 1b). This allows a better diversity of land use and watershed configuration within the project, resulting in more robust analyses. Automatic samplers with bubbler flow meters were installed at each stream at the same location as that of the longer term monitoring installations of the City of Knoxville. Historic data from the city was used to build stage discharge relationships for application to the monitoring regime herein.

Samples are flow paced, allowing evenly distributed sample collection throughout targeted storm events. Samples are retrieved after storm events, and transported to the water quality analysis lab in the SERF building at the University of Tennessee. Samples are analyzed by UT students for *E. coli*, TSS, nutrients, and metals. Additionally, a composite sample was created for a number of events at Second Creek and was sent to an outside laboratory for analysis of organic compounds.

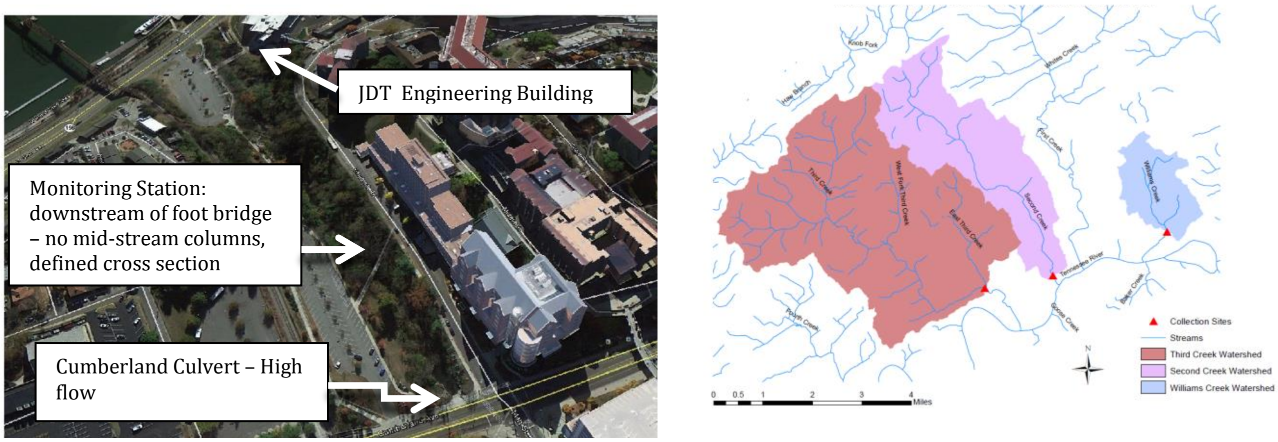


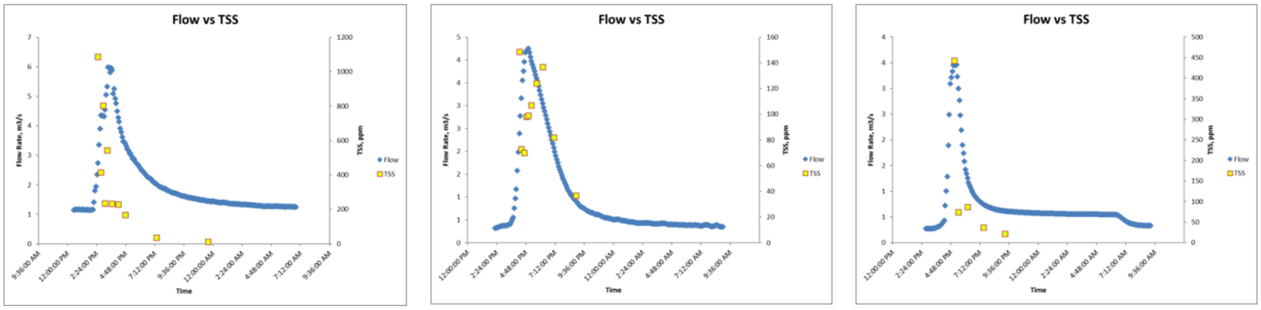
Figure 1: (a) Second Creek Monitoring Station Location Near Intersection of Cumberland Avenue and Estabrook Road

(a) **(b)**

Figure 2: (a) Second Creek Monitoring Installation, and (b) Undergraduate Student Surveying the Second Creek Cross Section

<u>Results and Findings:</u>

Since sampling began in September 2014, seventeen, eight, and eight storm events have been collected at Second, Third, and Williams Creeks, respectively. Well-defined pollutagraphs for the storm events were captured to better understand the variability in the inter and intra-event pollutant concentrations (Figure 3).



(a) (b) (c)

Figure 3: Example pollutagraphs from (a) Second Creek, (b) Third Creek, and (c) Williams Creek for TSS concentrations and flow from 11/2/2015 storm event

The data collected thus far confirm high concentrations of sediments, indicator bacteria, and some forms of nitrogen (nitrate) in the storm samples. For instance, *E. coli* concentrations reached as high as 19,700 MPN / 100 ml during the storm event on 11/2/2015 at Second Creek. This is over 150 times the average concentration desirable for primary contact in recreational waters. Initial analyses also suggest the variability in pollutant concentrations through the study, in particular for Second Creek, where inter-event TSS concentrations showed substantial fluctuations similar to fecal coliform, and even higher than those observed for *E. coli*. This is notable considering the high variability typically ascribed to bacteria data. However, the same trend was not observed in Third Creek, where TSS had much lower variability. This highlights that watershed specific attributes likely influence pollutant transport trends. Additional analyses will be performed to allow an investigation of the first flush tendencies of each pollutant, and how antecedent climate impacts pollutant concentrations.

Organics analysis failed to result in positive identification of organic pollutants in the storm flows sampled in the latter part of the 2014 as all concentrations were below the detection limits of the methods used. Further samples taken in the spring of 2015 also resulted in non-detected compounds. Stormwater samples taken for fluorinated organics and other organic contaminants samples also yielded no results.

Samples taken from June to October 2015 storm events showed phenol in five of the stormwater samples collected. Additionally, diethyl phthalate and Endosulfan I were detected in one of the samples. Table 1 displays the date, the organic compounds, the concentration, and the detection limit of the analysis that was used for these samples. Because these compounds were barely above the detection limit, it is suspected that the majority of the chemicals tested in these samples were below the detection limit of the methods used.

Table 1. Compounds detected in the stormwater samples taken during the course of the proposed project.

Date	Sample Type	Compound	Concentration (mg/L)	Detection Limit (mg/L)
6/29/15	Water	Phenol	45	10
7/1/15	Water	Phenol	30	10
7/15/15	Water	Phenol	11	10
8/23/15	Water	Phenol	17	10
8/23/15	Water	Diethyl phthalate	3.27	3
10/1/15	Water	Endosulfan I	0.063	0.05
10/6/15	Water	Phenol	12.4	10

Phenol is used for the production of herbicides, pharmaceuticals and plastics and is produced during the decomposition of plant material. The highest concentration of phenol was detected in June and decreased in July. The concentration then increased slightly in the August samples but then decreased in October. The increase (then fluctuation) of phenol could be due to the use of herbicides upstream of where the samples were taken or because of the vegetation surrounding the sampling area. Endosulfan I is a pesticide that is found in the environment at low levels and is a derivative of other components in the pesticides. Pesticides are commonly used during the sampling period in which this compound was detected. Diethyl phthalate is used in the production of certain plastics and trace amounts can be found in burned plastics.

In addition to insights into water quality made possible through this monitoring, the flow data collected from Second Creek are being paired with data from other streams in Knoxville by a doctoral student to investigate the patterns and connection of impervious areas in the city. Connected impervious areas have been found to most substantially impact the quality of receiving streams, thus, this is also a critical area of research need. Through this, more targeted approaches to watershed restoration may be possible.

Synergistic Activities

Additional funds were secured from the University of Tennessee Green Fee program to further add to the infrastructure at Second Creek and develop the Second Creek Observatory (Figure 4). This will allow Second Creek to function as a living laboratory for research and teaching while building public awareness as to the impact of stormwater runoff on surface waters.

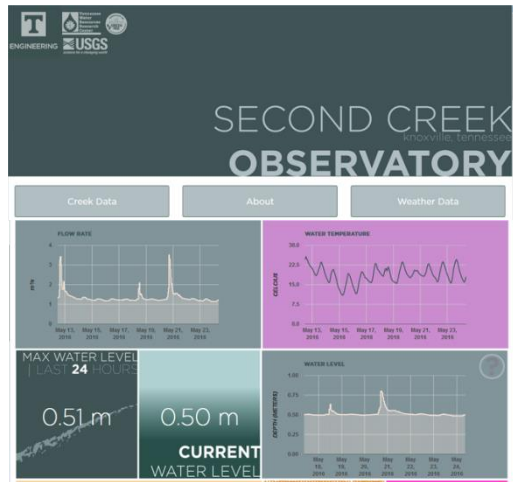


Figure 4: Website under development for the Second Creek Observatory

Underground Reactive Barrier to Attenuate Contaminants from Agricultural Drainage

Basic Information

Title:	Underground Reactive Barrier to Attenuate Contaminants from Agricultural Drainage
Project Number:	2014TN105B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Nutrients, Treatment
Descriptors:	None
Principal Investigators:	Jaehoon Lee, John R. Buchanan, Jennifer DeBruyn, Shawn Hawkins, Andrea Ludwig

Publications

1. Lee, J., A.C. Shefy, F.R. Walker, A.l. Ludwig, J.R. Buchanan and N.S. Eash, 2014. Evaluation of biochar as a medium for underground reactive barrier to attenuate chemicals from agriculture drainage. 2014 World Congress of Soil Science (invited).
2. Lee, J., A.C. Shefy, F.R. Walker, A.l. Ludwig, J.R. Buchanan and N.S. Eash, 2014. Evaluation of biochar as a medium for underground reactive barrier to attenuate chemicals from agriculture drainage. 2014 World Congress of Soil Science (invited).

(1) Statement of Critical Regional or State Water Problem(s): Typical concentrated animal feeding operations such as dairy facilities produce large quantities of manure which is stored in lagoons or holding ponds before being applied to nearby crop or pasture fields. Off-site movement of the manure as well as other fertilizers through storm water runoff or percolation to groundwater has been well recognized as a major source of contamination of water bodies. This is especially true in east Tennessee with high rainfall and substantial topographic relief. The author of this proposal has been actively involved in assessing the new UT Little River Animal and Environmental Unit for the potential stream and groundwater contamination. Our preliminary data show that the underlying soil and rock of the unit is highly permeable and will allow a rapid movement of chemicals and pathogens to groundwater and surrounding streams and rivers. In Tennessee, there are 303(d) list of impaired water bodies due to excess pathogens and nutrients. There is a great need for cost-effective and proven best management practices to mediate the excess nutrients. Our research findings will create science-based recommendations for the use of underground reactive barriers in challenging environmental conditions found in many areas of the Tennessee. This project will also be a demonstration at the UT Research and Education Center, and data will continue to be collected in the future.

(2) Research Objectives:

There are two specific aims and hypotheses in this proposed project.

Specific Aims

- Evaluation of biochar and charcoal as a medium for reactive barrier to capture P and other organic chemicals (e.g., veterinary antibiotics and pesticides).
- Evaluate the effects of water level and temperature on the rate of treatment.

Hypothesis

- Underground reactive barrier using combined sawdust and biochar/charcoal will increase the level of nitrate (NO_3^-) removal as well as P and other organic chemicals.
- Control of water level and residence time in the barrier in conjunction with seasonal variations of drainage will improve the removal rate.

(3) Methods, Procedures and Facilities

Barrier construction: We will install underground reactive barriers in the new UT Little River Animal and Environmental Unit located at 3217 Ellejoy Road, Walland, TN; about a 30 minute drive from UT Campus. The research and education center is bounded by streams on three sides and lies in the floodplain of a state-declared exceptional waterway. A charcoal-woodchip barrier will be installed right next to the already planned 100% woodchip traditional barrier. The new barrier will use a mixture of sawdust (80%) and biochar or charcoal (20% in volume). The barriers will be approximately 1.5 m deep, 7 m wide, and 15 m long, and will be designed to catch surface runoff as well as shallow ground water. The locations of the barriers are already determined by a consultation with Dr. Bobby Simpson (Director of the East TN Research & Education Center) and support staff, considering 5 years of previous runoff and groundwater monitoring data.

Barrier Control: Two water level control structures similar to the Agri Drain will be installed to control water levels in the barriers and tile-drained field. One structure will be installed right before (inlet) the barrier and the other will be installed at the end of the barrier. The two structures will allow us to control water level of the tile-installed filed as well as the barrier itself. The structures bypass excess drainage and runoff to nearby drainage field, if there is more water than the barrier can handle. The structures will also be used for routine water sampling. Temperature sensors will be installed in two locations at two depths (30 and 90 cm) to monitor barrier temperature. It is well documented that saturation provides the best environment for denitrifiers and thus works best for N reduction. However, there are limited literatures about charcoal amendment in the barrier, especially related to treatment of P, other organic chemicals, and pathogens and its relationship with water level. The barrier will be maintained for the highest possible water level to provide the best reduction of N. However, when there is not enough water, we will record the water level and/or saturation rate, and closely monitor the rate of reduction for N, P and other organic chemicals.

Water quality monitoring: At least two samplings each month will be done for analysis of N, P, selected chemicals (e.g., tylosin, chlortetracycline, sulfamethazine, and a few pesticides as well), and fecal bacteria/pathogen. The investigators have two full-time research associates (one engineer and the other for soil and water analysis), and nearly 1500 square feet of modern lab space combined. We have an analytical chemistry lab equipped with all the equipment and apparatus necessary for the water sample analysis (e.g., HPLC, GC, ICP, AA, GC/MS).
The BESS also has qualified faculty, scientists, and technicians with extensive experience in both laboratory and field research, as well as students interested in this research topic. Several types of vehicles (vans, trucks, trailers, and tractors), and a well-equipped fabrication shop with two full-time staff members are also available.

(4) Principal Findings to date:

Pilot Scale Test: We did small scale experiments to test the efficacy of biochar and charcoal as a reactive barrier medium. Various ratios (5, 10 and 20% v/v) of biochar and charcoal with sawdust were evaluated for their removal of N, P and other agricultural chemicals. The results showed that 10% of charcoal by volume provided the most economic rate of treatment. We also found out that addition of silage leachate to the reactive barrier significantly increased denitrification. The silage leachate contains high carbon content and degrades nearby water, however, if added to the barrier, the carbon can be immediately used for the denitrification process.

Field installation of barrier: Two locations in the Center has been identified and prepared for installation. All the materials, liners, woodchips, sand, charcoal, construction equipment, sampling access tubes, etc., are secured and installation will begin this summer.

Recalibrating the SAGT SPARROW to Accommodate Changes in Agricultural Inputs

Basic Information

Title:	Recalibrating the SAGT SPARROW to Accommodate Changes in Agricultural Inputs
Project Number:	2014TN106B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Water Quality
Focus Category:	Agriculture, Models, Water Quality
Descriptors:	None
Principal Investigators:	Dayton M Lambert, Christopher N Boyer, Christopher D Clark

Publications

There are no publications.

Introduction

By 2022, the United States (US) Renewable Fuels Standard (RFS) mandates that 36 billion gallons of ethanol be blended into gasoline, with 21 billion gallons of that coming in the form of advanced biofuels, including at least 16 billion gallons of cellulosic ethanol (USDOE, 2015). In examining increased cellulosic ethanol production, the Biomass Research and Development Board (BRDB, 2008) assumed conservatively 4 billion gallons of cellulosic ethanol would originate from woody material in support of meeting the RFS by 2022. Other research suggests that 10.5 billion of the 21 billion gallon annual production targets for advanced biofuels mandated by the RFS could originate in the Southeastern United States (USDA, 2010).

Nearly all of the biofuel currently produced in the US comes from first generation feedstock, primarily corn grain. Meeting the RFS requirements will require increased biofuel production from second-generation feedstock, such as switchgrass, miscanthus, canola, camelina, or woody biomass. The increased market demand for energy crops is expected to result in extensive conversion of previously uncultivated land, fallow agricultural land, pastureland, or Conservation Reserve Program (CRP) land, potentially resulting in a substantial increase in land in agricultural production (Robertson et al., 2010; Perlack and Stokes, 2011; Demissie, Yan, and Wu, 2012). Increased biofuel production from second generation feedstock offers the possibility of reducing the amount of tilled land and mitigating climate change by reducing the emission of greenhouse gases (GHG) associated with transportation fuels. However, converting enough land to feedstock production to meet the RFS could significantly affect nutrient emissions from agriculture and regional water quality balances. Changes in fertilizer use, tillage practices, and vegetal cover may generate unintended consequences that affect the ecosystem services provided by the region's streams and rivers. Agriculture is a major contributor to the region's economy and communities and predicting the nature of these consequences is difficult because of the extended growing season and diverse types of agricultural practices currently employed in the region. Seasonal and spatial variability in rainfall, temperature, soil types, and access to water support an intensive and diverse agricultural production region (Ingram et. al., 2013).

This research modifies the South Atlantic-Gulf-Tennessee basin (SAGT) system SPARROW (Spatially Referenced Regression on Watershed Attributes) model (SAGT-SPAROW), developed by Hoos et al. (2008) and calibrated and applied by Hoos and McMahon (2009), to examine potential impacts of land use change resulting from a mature cellulosic biofuel industry on water quality in the SAGT basin. The primary data-generating and modeling challenges addressed in this research are 1) generating agronomic and economic data sets to reflect the distribution of feedstock production potential, attendant production costs, and crop nutrient demand, and 2) integrating the agronomic and economic data sets with hydrological data sets provided by the US Geological Survey (USGS) at commensurable geospatial scales. Both procedures make extensive use of internal GIS capabilities and data management algorithms. A data harmonizing procedure is developed to benchmark data collected by NASS with fertilizer use data available in the SAGT-USGS data sets. After compiling downscaled and integrated data sets, we augment variables in the USGS-SAGT data set reflecting agriculture's contribution of N and P to aggregate N and P emissions. The revised set of variables is used to compare *ex ante* a baseline scenario (an agricultural landscape's impact on N and P emissions absent the RFS) to various target biofuel production levels for the SAGT region based on the RFS mandate. Canola (for biodiesel) and short rotation woody crops (SRWC) (for pyrolysis) are the feedstock considered in the analysis.

This report describes the: i) development of regional canola budgets; ii) estimation of canola and SRWC yields; and iii) impacts of land use change following the establishment of biodiesel refineries in the SAGT region on N and P emissions into the SAGT basin. Component (i) was crucial for developing an estimate of opportunity costs, which drive the conversion of conventional cropland to feedstock production and the distribution of biofuel refineries. First-pass runs for component (ii) suggest the N and P emission impacts of canola on the SAGT are statistically insignificant evaluated at an aggregate, regional level. Discussion focuses on the impacts of a biodiesel industry using canola as a primary feedstock because all modeling steps for this industry have been completed. Work on similar analyses for SRWC continues.

Methods and Procedures

Regional production costs and yields for canola

We begin by examining the feasibility of canola production in the Southeastern US on a profitably of production basis. To model the heterogeneity in production costs across the Southeastern US, we ideally would collect enterprise budgets for each state in the region to estimate per-acre costs of production. However, canola is not widely grown in the Southeastern US and we are not able to locate a budget for each state. So, we have to predict per-acre net returns in the counties where we do not have a budget. Therefore, using enterprise budgets from states in which canola is currently grown to provide cost of production data, we interpolate the per-acre net returns of canola production across counties in the Southeastern US. The budgets are aggregated on variable, fixed and total costs of production for each state. Each budget assumes a yield, typically based on historical averages for the region. In this study, we replace the assumed yield with a yield that is estimated by a plant growth model. Simulating yields with the plant growth model enables us to disaggregate yield estimates from the state- to the county-level. Utilizing the cost of production data and the estimated yields, net returns are calculated for the regions where we observe costs of production via the enterprise budgets. These observations are used to estimate a model which predicts per-acre net returns for the Southeastern US.

The canola budgets were collected from a variety of sources including Land Grant University Extension services. University Extension services provide enterprise budgets for crop production to aid in projecting costs and net returns as a guide in farm management. Although the focus of this project is on the Southeastern region, we collected budgets from as many states as possible, as future research may expand to areas outside the Southeastern US. Canola enterprise budgets (n = 29) representing 17 states (Georgia, South Carolina, North Carolina, Virginia, Tennessee, Kentucky, Texas, Oklahoma, Utah, Kansas, Missouri, Pennsylvania, North Dakota, Montana, Idaho, Washington and Oregon) were obtained. However, budgets from Utah, Kansas and Missouri were removed from the sample. The Utah and Kansas budgets did not report variable/operating costs or fixed/ownership costs and instead only listed total costs, while the Missouri budget did not report the year in which the budgets were generated, preventing the figures from being converted into current year prices and costs. After eliminating budgets from these three states, the remaining budgets represent 14 states, including seven of the nine states for which the US Department of Agriculture's National Agricultural Statistics Service (USDA NASS) reported commercial-scale canola production as of October 2014 (Idaho, Minnesota, Montana, North Dakota, Oklahoma, Oregon, Washington, Colorado and Kansas).

Multiple budgets were located for six of the states. For Idaho, we found three budgets, one for each of three different tillage methods (Conventional Tillage, Reduced Tillage and No Tillage). Two budgets for Montana were identified – one for irrigated and one for dryland production. Six budgets were found for North Dakota, one for each of six different multi-county regions. There are two budgets for Oregon, one for winter and one for spring canola varieties. Two budgets for Texas were found, with one budget assuming the planting of round-up ready seed and the other standard seed. Washington is represented by three budgets prepared for three different rainfall regions. One budget from each state was used to calculate net returns. With the exception of Texas and Washington, the budget selected was the one that reported higher per acre costs of production. In Texas, the budget with the higher per acre costs of production assumed the use of round-up ready seeds and, as a result, has a slightly higher assumed cost of production. The use of round-up ready seeds is an anomaly among the budgets, so the budget for standard canola seed and, thus, slightly lower production costs, was used. The budgets representing the state of Washington differ by rainfall region and the budget with the highest yield assumes production in the highest rainfall region, but not the highest cost of production. In this case the budget in the high rainfall region was selected.

Canola yields are estimated using the Environmental Policy Integrated Climate (EPIC) plant growth model (Figure 1). EPIC simulates the physical processes in hydrology, nutrient cycling and plant growth using readily available inputs (Larson et al 2005). EPIC has been extensively used throughout the US and in several foreign countries. The model provides erosion-productivity relationships for approximately 900 benchmark soils and 500,000 crop/tillage/conservation strategies throughout the US. Furthermore it is, computationally efficient and capable of computing the effects of management decisions (Williams et al 1989). Using yields estimated in EPIC and production costs projected in state enterprise budgets we calculate per-acre net returns.

Aggregating across the budgets poses a challenge due to inconsistencies in budget categories from one state to another. Production methods and the schedule of operations for canola vary by region, so it is natural to expect a varied projection of costs and returns. However, there is significant heterogeneity in the line item cost categories used in the budgets across the states and, thus, costs were aggregated into two categories; variable/operating costs and fixed/ownership costs. These two variables become the common variables to normalize on and the aggregated data set includes both variable and fixed costs for 13 of the 14 represented states, with Montana being the only state not to include both fixed and variable costs. To arrive at total cost, we sum the total variable costs and total fixed costs and then subtract costs for crop insurance and land rent where those cost categories were included in the budget. Crop insurance costs were excluded because crop insurance for canola is not available in all of the states for which budgets were obtained. Land rent was excluded because it is assumed to be invariant to land use. See Table 1.

Using aggregated versions of the budgets, per acre net returns for canola production in each county are calculated. It was found that break-even prices per bushel of canola approximate a normal distribution with a mean of $8.44, a minimum of $4.89 and a maximum of $13.71. Therefore, net returns are calculated using a range of $8 to $12 per bushel.

Focusing on the economic feasibility of canola production in the Southeastern US, we limit our sample to this region. To do so we exclude all states outside the Southeastern US from the interpolations. Therefore, predicted per-acre net returns for potential canola producing regions are interpolated using the calculated per-acre net returns in the sample of Southeastern states. Based on our cost of production data using the enterprise budgets, we have a statewide cost of production that is constant across counties within each state. Variation in net return across counties is due to the varying yields, which are estimated in the plant growth model EPIC. Therefore, based on our sample, net returns are calculated for each county in the states for which we have cost of production data. Using interpolation methods in ArcGIS, we then estimate our model and predict net returns for each county across the Southeastern US. Predicted net returns are estimated at three different prices - $8, $10 and $12 per bushel. There are several methods of interpolation to be considered. Using ArcGIS, the Inverse Distance Weighting (IDW) method and the Radial Basis Function (RBF) methods are used to estimate and predict net returns.

The IDW method implements the assumption that points closest in proximity to each other are more alike than those further away (ESRI 2014). Potential Canola producing regions with unobserved net returns are predicted using the calculated net returns surrounding the prediction region. Observed points nearest the prediction region are weighted more heavily in their influence. IDW assumes the level of influence observed points have on the prediction region diminishes with distance. Each observed point is assigned a weight, which is inversely proportional to the distance from the prediction region. The IDW formula is

$$\widehat{NR}_i = \frac{\frac{\sum_{i=1}^{n} NR_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}},$$

where $\widehat{NR}_i$ is the predicted net return for point (i), NR_i is the observed net return for point (i), d_i is the distance between NR_i and $\widehat{NR}_i$ and p is the weighting power. The rate at which the weight decreases with distance is determined by the weighting power, p. As a result, as the distance increases, the weight decreases rapidly (ESRI 2014). The weighting power is determined by the researcher, and in this case the default value of $p = 2$ is used for IDW interpolation. Implementing IDW methods also requires the researcher to choose the shape of the search neighborhood. Search neighborhoods are areas surrounding the prediction region to be used in the estimation. The shape of the search neighborhood influences the distance and the area to look for observed net return values to be used in the prediction. In this case, the default standard search neighborhood is chosen for interpolation.

Radial Basis Functions (RBFs) are a spline fitting interpolation method. Common splines include thin-plate spline, spline with tension, completely regularized spline, multiquadric function and inverse multiquadric function (ESRI 2014). The most general form of a RBF is $h(x) = \varphi[(x-c)'R^{-1}(x-c)]$, where $\varphi(z)$ is a function, such as the multiquadric. The term $(x-c)'R^{-1}(x-c)$ is the distance between the input x, the center c in the metric defined by R (Orr 1996). The ArcGIS default, completely regularized spline is used for net return interpolation. RBF methods, like IDW, are an exact fitting interpolation method; meaning, the surface must pass through each observed value (ESRI 2014). An advantage of spline fitting is that they can generate accurate surfaces from only a small number of sample points (Azpurua 2010).

Both IDW and RBF interpolations are estimated and the mean squared errors are compared (See Table 2). It is found that RBF models generate the lowest mean squared error, thus RBF becomes the model of choice in subsequent interpolation. Using the Geostatistical Analyst Wizard in ArcGIS, the completely regularized spline RBF is estimated, which generates a prediction map that can be exported to a raster layer. From this raster layer, raster value statistics are calculated for the prediction area. These raster value statistics contain the mean predicted net return within each county. Because the raster is a surface fitted to observed points, each county contains a range of predicted net returns. In the case of counties where the data contain an observed point, the range of predicted net returns is zero or very close to zero and the mean predicted net return is nearly identical to the observed value for the county. In the case of counties with unobserved data the RBF obviously will not find an exact point to fit and therefore will generate a range of predicted values across a county. For example in Lafayette County

Mississippi there are no observed net returns, these values are interpolated. The RBF interpolation predicts a range of net returns for Lafayette County with a minimum of -0.114, a maximum of 1.94 and a mean of 0.33.

Using the predicted net return for each county, ArcGIS was used to generate maps for the Southeastern region of the United States. These states include Alabama, Louisiana, Mississippi, Tennessee, Kentucky, Virginia, South Carolina, North Carolina, Georgia, Missouri and Arkansas. Three maps are generated, representing interpolated net returns assuming canola price is $8, $10, and $12 per bushel. When canola is assumed to be $8 per bushel, counties in the states of Georgia, Kentucky and South Carolina are predicted to have positive net returns to canola production. As the price increases to $10 per bushel, some counties within Alabama, North Carolina and Tennessee are predicted to have positive net returns. As the assumed price is increased to $12 per bushel, all counties within the states of Georgia, Kentucky, South Carolina, and Tennessee are predicted to have positive net returns, while only a portion of the counties in the remaining states are predicted to have positive net returns. See Figure 2.

SPARROW model, SAGT data, and variable rescaling

Next, we develop a procedure capable of generating *ex ante* forecasts of the impacts land use change resulting from a mature cellulosic biofuel will have on water quality in the Southeastern US by modifying the SAGT-SPARROW model. For the present study, we confine our analysis to the SAGT region, which is comprise of the states of Florida, Tennessee, Alabama, Mississippi, Kentucky, North Carolina, South Carolina, Georgia and Virginia. The SAGT region is 802,723 km^2. In this region, there are 321 USGS monitoring sites collecting information about water flow, nutrient loading, and sedimentation flux. Areal data from the corresponding watersheds such as land use patterns (e.g., urban, residential, agriculture, or forest), pollution point sources, nutrient runoff from agriculture and urban activities, and geophysical features are used as regressors to fit the flux data. Given an appropriately fitting model, nutrient loading predictions are generated using the stream network configuration of the basin. In effect, loading predictions are estimated for each n = 8,321 watershed comprising the basin. As a null hypothesis, the conversion of cropland/pastureland to canola production on a scale sufficient to reach biofuel production targets is hypothesized to have no effect on the water quality of the SAGT region. We further hypothesize that the share of total N and P attributable to the agriculture sector will not be significantly affected by this conversion.

The SPARROW model generates *ex-ante* forecasts of the impacts land use change have on water quality through changes in point and non-point source nutrient emission variables. SPARROW uses nonlinear least squares regression to explain nutrient mass balance in watershed networks as a function of anthropogenic, geographic, and climatic factors. The SPARROW model has been used extensively to forecast changes in nutrient emissions in North Carolina (Ator et al., 2011), New England and the Mid-Atlantic states (Moore et al., 2011), and the Tennessee River basins (Hoos and McMahon, 2009). SPARROW models have also been previously developed in the U.S. over spatial extents ranging from the conterminous U.S. (Smith *et al.*, 1997; Alexander *et al.*, 2000, 2008) to large regions such as the Chesapeake Bay watershed (Preston and Brakebill, 1999) and smaller watersheds such as those draining to the North Carolina coast (McMahon *et al.*, 2003). SPARROW models have been applied in many ways to improve the understanding of water-quality conditions and controlling factors, including: (1) identifying major sources of nutrients in streams of the conterminous U.S. (Smith *et al.*, 1997; Alexander *et al.*, 2008) and in individual watersheds in support of Total Maximum Daily Load (TMDL) assessments (McMahon *et al.*, 2003; Moore *et al.*, 2004), (2) understanding the role of stream processing in the delivery of nutrients to coastal waters, such as the Gulf of Mexico (Alexander *et al.*, 2000, 2008), (3) identifying the sources of salinity affecting water supply in the southwest (Anning *et al.*, 2007), and (4) understanding the environmental factors affecting sediment loading to the Chesapeake Bay (Brakebill *et al.*, 2010). SPARROW models have also been applied in New Zealand (Alexander *et al.*, 2002) and are now being developed for evaluating water-quality conditions in other parts of the world.

Schwarz et al. (2006), Smith et al. (1997), Quian et al. (2005), and Hoos and McMahon (2009) provide details on estimation and calibration of the SPARROW model. The general structure of SPARROW is:

(1) $$y_i = \begin{bmatrix} \sum_{j \in J(i)} y_j \cdot A\left(Z_i^S, Z_i^R; \theta_S, \theta_R\right) \\ + \sum_{m=1}^{M_S} \beta_m \cdot S_{m,i} \cdot D_m\left(Z_i^D; \theta_D\right) \cdot A\left(Z_i^S, Z_i^R; \theta_S, \theta_R\right) \end{bmatrix} + \varepsilon_i,$$

where:

y_i is the nutrient emissions in watershed *i* = 1,…8,321 of the SAGT basin (kg yr^{-1}) (observed data);

$S_{m,i}$ is nutrient source *m*, watershed *i* (observed data);

Z^D are physical landscape characteristics (observed data);

Z^S are physical stream characteristics (e.g., depth and velocity) (observed data);

Z^R are reservoir variables (e.g., reservoir hydraulic loading) (observed data);

J(*i*) indexes the upstream watersheds flowing into watershed *i*;

$D_m\left(Z_i^D; \theta_D\right)$ is a nutrient delivery function;

$A\left(Z_i^S, Z_i^R; \theta_S, \theta_R\right)$ are stream and reservoir attenuation functions;

(θ_D, θ_S, θ_R) are parameters governing the transport and movement of nutrients between watersheds (estimated); and

β_m are delivery ratio parameters characterizing the contribution of nutrient sources to stream emissions (estimated);

ε_i is an independent and identically distributed random disturbance with an expected value of zero and a constant variance.

Physical landscape characteristics include soil permeability (in natural logs), bedrock depth (in natural logs), mean annual precipitation (in natural logs), the percent of a watershed included in a hydrological landscape region (HLR) (five HLR regions cover the SAGT area), and the percent of a watershed included in an ecoregion (six ecoregions define the SAGT basin). Physical stream attributes are measured by (1) the segment travel time for small streams (mean flow < 2.8 $m^3\ sec^{-1}$), and (2) the segment travel time for larger streams (2.8 $m^3\ sec^{-1} \leq$ mean flow < 28 $m^3\ sec^{-1}$). Loss rate coefficients were estimated for small (< 2.8 $m^3 s^{-1}$) and intermediate (2.8-280 $m^3 s^{-1}$) streams, and are expected to be positive but lower in magnitude as stream sizes increase (Alexander et al., 2000). Land-to-water delivery factors ($D_m(Z_i^D; \theta_D)$) are modeled with an exponential kernel; $\exp(\theta'_D Z^D)$. Reach attenuation factors ($A(Z_i^S, Z_i^R; \theta_S, \theta_R)$) are modeled as an exponential decay; $\exp(-\theta'_S Z^S)$. The estimated reservoir loss coefficient summarizing the mean water column length from which N is removed annually is expected to be positive (Schwarz et al., 2006).

Fertilizer emission sources ($S_{m,i}$) include; (1) fertilizer mass permitted in wastewater discharge, (2) inorganic nutrient deposition, (3) impervious surface area, (4) commercial fertilizer applied to agricultural land, and (5) fertilizer mass from livestock manure (Hoos and McMahon, 2009). These variables are of interest to policymakers and analysts because they are anthropogenic sources of pollutants. In this application, changes in the contribution of fertilizer from applied agricultural fertilizer ($S_{FERT,i}$) are simulated, holding contributions from the other sources constant. The source variable for fertilizer applied to agricultural land used to calibrate the baseline SAGT-SPARROW model was calculated using 2002 county-level fertilizer expenditure data and 2001 USGS National Land Cover Database (NLCD) land cover classifications by Ruddy et al. (2006). This variable is an aggregate of fertilizer applied to all types of agricultural land, including dominant row crops, orchards, agroforestry, vegetables, hay and pasture, vineyards, row crops, small grains, and cereals. The changes in fertilizer applied in each watershed and the changes in fertilizer emissions due to changes in emissions from agriculture (i.e., fertilizer use) are approximated by adjusting $S_{FERT,i}$ to reflect the conversion of agricultural land to the production of canola. The statistical relationship between observed agricultural fertilizer applications, nutrient emissions, and nutrient concentrations in streams is estimated and then used to forecast nutrient emissions into each watershed.

Rewriting the non-linear model of equation 1 as a generalized function, the predicted values of the baseline regression are,

(2) $$\hat{y}_{0i} = g\left(S_{FERT,i} \cdot \hat{\beta}_{FERT}; S_{m-1,i}\hat{\beta}_{m-1}, Z_i\hat{\theta}\right),$$

where $\hat{y}_{0i}$ is the baseline predicted value for stream nutrient emission in watershed i = 1,…8,321; $g(\cdot)$ is the function of equation 1; $S_{FERT,i}$ is the applied fertilizer to agriculture in watershed i used in the calibration step of SPARROW; $\hat{\beta}_{FERT}$ is the estimated regression coefficient for fertilizer applied to agricultural land; $S_{m-1,}$ are all other source variables excluding applied fertilizer; $\hat{\beta}_{m-1}$ are the coefficients of all other nutrient sources; and Z_i are all other covariates with corresponding parameters $\hat{\theta}$.

To simulate the level of feedstock production needed to meet the RFS mandate for the SE of 10.5 BGY with biodiesel, BioFLAME was used to project the associated spatial distribution of barley, corn, cotton, hay/pastureland, oats, sorghum, soybeans, and wheat converted to the production of canola assuming differences in the extent to which the RFS mandate is achieved. Target levels of T = 22%, 31% and 50% production of 10.5 BGY of biodiesel were considered by the facility sitting model.

Using the land use changes generated by BioFLAME, published N and P application rates, and regional crop budgets from POLYSYS (Ray and de la Torre Ugarte, 1998), the watershed-level quantity of N and P applied under each production target was calculated in the SAGT Basin. Land use changes driven by industry demand for biomass feedstock enter the calibrated SPARROW model as changes in $S_{FERT,i}$ to simulate impacts on N and P emission sources. Aggregate fertilizer applied by the agricultural sector ($S_{FERT,i}$) is composed of fertilizer applied to the key field crops analyzed here ($S_{FERT,i}^{FldCrop}$), plus nitrogen applied by all other agricultural activities ($S_{FERT,i}^{OthAct}$):

(4) $$S_{FERT,i} = S_{FERT,i}^{OthAct} + S_{FERT,i}^{FldCrop}.$$

Changes in the baseline aggregate agricultural fertilizer source variable ($S_{FERT,i}$) are a function of the baseline field crop N and P demands and the new crop demand for N and P following policy implementation. Deviations from the baseline aggregate are simulated holding $S_{FERT,i}^{OthAct}$ constant and perturbing $S_{FERT,i}^{FldCrop}$. For example, define $S_{FERT,i}^{T}$ as the quantity of fertilizer applied in watershed i under target production level *T* (= 22%, 31%, 50%), noting that *T* = 0 indicates the baseline kilograms of nitrogen applied in the initial equilibrium. A relative change in aggregate fertilizer applied is:

(5) $$S_{FERT,i}^{T>0} = S_{FERT,i}^{OthAct} + (1 + \epsilon_i) \cdot S_{FERT,i}^{FldCrop},$$

where:

(6) $$\epsilon = \left[\frac{(F_i^{T>0} - F_i^{T=0})/N_i^{T=0}}{\left(NF_i^{T>0} - S_{FERT,i}^{FldCrop}\right)/S_{FERT,i}^{FldCrop}} \right],$$

and F_i^T is the total nitrogen applied in watershed *i* to the field crops estimated with the 2009 USDA cropland data layer used in BioFLAME (e.g., $F_i^T = \sum_{k=1}^{9} F_{i,k}^T$, with *k* indexing the eight conventional crops plus switchgrass). The components of the applied fertilizer variable ($S_{FERT,i}^{OthAct}$ and $S_{FERT,i}^{FldCrop}$) were unavailable in the SAGT data base. Therefore, NASS 2002 county level crop production data was used as a proxy such that $S_{FERT,i}^{FldCrop} = \sum_{k=1}^{8} F_{i,k}^{2002}$, where $F_{i,k}^{2002}$ are the applied nitrogen from the POLYSYS budgets containing region-specific fertilizer rates and the county level crop production data. In 22% percent of the watersheds, $S_{FERT,i} < S_{FERT,i}^{FldCrop}$. In these cases, we set $S_{FERT,i}^{OthAct} = 0$ and $S_{FERT,i} = S_{FERT,i}^{FldCrop}$. This provided a benchmark from which to compare changes in land use generated by the site locator model with the initial state documented by the 2002 USGS fertilizer use data. The denominator of ϵ adjusts for differences in the time periods the fertilizer data was compiled by Ruddy et al. (2006) for SPARROW and BioFLAME (2009 data). The factor is a decimal percent change when divided by 100. When *T* = 0, ϵ = 0, and $S_{FERT,i}^{T>0}$ = $S_{FERT,i}$ (the baseline applied nitrogen level). When $\epsilon > 0$ ($\epsilon < 0$), applied fertilizer increases (or decreases) following changes in the agricultural landscape due to feedstock demand by biorefineries during the simulation.

Incorporating the revised quantities of N and P applied under each production target into the SPARROW model, predictions for stream level N and P concentration and agricultural N and P source share were generated for each of the 8,321 sub- watersheds in the SAGT Basin. For the present study, N and P application rate for canola were taken to be 180 lbs/acre and 90 lbs/acre.

Results

Nitrogen Emissions and Canola/bio-diesel Production

Producing 2.31 BGY (or 22% of 10.5 BGY) of advanced biofuel in the Southeastern US, would result in the conversion of 1.97 million hectares of cropland in the SAGT region to canola production (Table 4). The primary source for the land needed to produce canola is land currently devoted to cotton, soybean and wheat production, accounting for around 94% of the converted land. Soybeans receive very little or no nitrogen and nitrogen application rates for cotton and wheat are less than for canola (Table 3). Phosphorous application rates for soybeans and wheat are less than for canola, while the rate for cotton is about the same as that for canola (Table 3). At this level of feedstock production, SPARROW predicts an increase in the mean level of N application in the region's watersheds of 14.25% (from 28,039.73 to 32,037.5 kg yr^{-1}) compared to the baseline and an increase in the agricultural source share of 12.79% (from 3.83% to 4.32%) from the baseline (Table 6). However, this increase is not enough to change the mean concentration in the SAGT region, which remains 1.09 mgL^{-1} (Table 6). This level of feedstock production results in an increase in the mean level of P application in the region's watersheds of 2.19% (from 16,562.6 to 16,926.61), an increase in the agricultural source share of 1.24% (from 15.28% to 15.47%), and an increase in the mean P concentration from 1.50 to 1.51 mgL^{-1} from the baseline (Table 7).

Producing 3.255 BGY (or 31% of 10.5 BGY) of advanced biofuel in the Southeastern US would require converting 2.37 million hectares of cropland in the SAGT region to canola production (Table 4). Land devoted to cotton, corn and soybean production remain the primary source of the land converted to canola production, accounting for around 94% of the converted hectares. At this level of production, SPARROW predicts an increase in the mean level of N application in the region's watersheds of 16.89% (from 28,039.73 to 32,775.69), and an increase in the agricultural source share of 10.18% (form 3.83% to 4.22%) from the baseline (Table 6). This increase is still not enough to alter the mean N concentration in the region (Table 6). At this level of production, there is an increase in the mean level of P application in the region's watersheds of 1.95% (from 16562.6 to 16886.97), the agricultural source share increases by 1.7% (from 15.28% to 15.54%), and the mean P concentration increases from 1.50 to 1.51 mgL^{-1} relative to the baseline (Table 7).

Producing 5.25 BGY (or 50% of 10.5 BGY) of advanced biofuel in the Southeastern US would require the conversion of 3.71 million hectares of land in the SAGT region to canola production (Table 3). Land devoted to either cotton, corn or soybean production comprises 94% of the land converted to canola production. At this production level, SPARROW predicts an increase in the mean level of N application in the region's watersheds of 26.71% (from 28039.73 to 35530.8) compared to baseline and an increase in the agricultural source share of 8.87% (form 3.83% to 4.17%) from the baseline (Table 6). This increase is still not enough to alter the mean N concentration in the SAGT region (Table 6). At this level of production, the agricultural source share of P applications increases by 3.59% (from 15.28% to 15.83%), and the mean P concentration increases from 1.50 to 1.51 mgL^{-1} relative to the baseline (Table 7). At this level of production, there is an increase in the mean level of P application in the region's watersheds of 3.67% (from 16562.6 to 17170.56) compared to baseline.

Conclusions and Further Research

The goals of this project were to 1) modify the USGS/SAGT database to include data that reflected land use change driven by the 2007 RFS mandate for the development of second-generation feedstock sources for biofuels, and 2) estimate the impacts land use change would have on nutrient loading into the SAGT basin with SPARROW. Two feedstock were considered – short rotation woody crops and canola. Each feedstock required the development of production costs, which were subsequently used to determine changes in applied nutrient levels, in particular, N and P. Findings suggest that, while agricultural land uses would clearly be impacted by the introduction of alternative feedstock sources such as canola or SRWC, the impact on water quality (in terms of nutrient loading into the SAGT system) in broad geographic terms would not differ from current nutrient levels.

Our research developed a procedure whereby crop production data generated by NASS could be used to proxy changes in applied fertilizer, given the displacement of conventional crops by dedicated energy crops. The research addressed two key challenges. The first was the dearth of information for canola and short rotation woody crop budgets. This information is critical for determining the opportunity costs of producing conventional crops (given economic impetus to develop feedstock), and therefore changes in land use. The second challenge was harmonizing the NASS cropland data layers (recorded in 2009) with the USGS/SAGT database (recorded in 2002). Addressing the second challenge required an imputation procedure that accommodated differences in spatial resolution and temporal scale.

There are caveats to this research. First, we did not model intensification of traditional crop production, assuming there would be no expansion of traditional crop production coincident to the conversion of agricultural land to feedstock production. Indirect land use changes resulting from intensified crop production could affect water quality in the SAGT basin and elsewhere. Second, nitrogen fixation by soybeans was not modeled, therefore underestimating changes in N loadings associated with conversion of soybean area to feedstock production. Third, livestock N sources were modeled, but no effort was made to determine the effects of hay and pasture land to feedstock production on livestock production. Fourth, we assumed pastureland and land cultivated in hay receive the same quantity of fertilizer N and P, and that 100% of their respective acres were treated. This assumption may be untenable. The 2009 USDA Census of Agriculture did not distinguish land in hay and pastureland, which therefore precluded calculating the quantity of N and P applied to each land use separately. The relative contributions of hay and pastureland to emissions therefore represent an upper-bound estimate since less N or P is usually applied on pastureland. Lastly, the counterfactual scenario depends on the assumption that fertilizer N and P expenditures were similar between 2002 and 2009. That high-resolution cropland data layers were unavailable until 2009 precluded generating a comparable data surface for 2002.

With these limitations in mind, our research extends the empirical methodology of integrating economic-driven land use change models with a mass-balance hydrologic model. The integration of these systems provides a gateway through which the interaction between economic variables affecting land use change and water quality can be analyzed. The combined system facilitates the examination of ceteris paribus effects of policy on water quality indicators at a macro-regional scale. Other water quality models, such as the Soil and Water Assessment Tool (SWAT), could possibly be modified to accommodate the simulation procedures outlined by this research.

Table 1. Per-acre production cost estimates for canola by state

State	Region	Total Variable Costs	Total Fixed Costs	Total Costs
Georgia*	Southern Seaboard	280.13	96.88	377.01
Idaho	Basin and Range	279.23	48.63	327.86
Kentucky*	Eastern Uplands	252.51	74.82	327.33
Montana	Northern Great Plains	327.98	-	327.98
North Carolina*	Southern Seaboard	436.34	112.10	548.45
North Dakota	Northern Great Plains	203.71	41.83	245.54
Oklahoma	Prairie Gateway	226.16	18.54	244.71
Oregon	Basin and Range	324.78	89.90	414.68
Pennsylvania	Northern Crescent	224.51	20.08	244.60
South Carolina*	Southern Seaboard	254.95	7.46	262.42
Tennessee*	Eastern Uplands	400.59	94.11	494.70
Texas	Prairie Gateway	168.75	12.86	181.61
Virginia*	Eastern Uplands	311.65	116.22	427.87
Washington	Basin and Range	156.17	25.36	181.53

* States used in the Southeastern Interpolation

Table 2. Mean Squared Error of Prediction

	Mean Squared Error	
	Radial Basis Function	Inverse Distance Weighting
Net Returns @ $8/bushel	29.79	32.92
Net Returns @ $10/bushel	32.46	37.93
Net Returns @ $12/bushel	38.28	45.00

Table 3. Mean level Nitrogen and Phosphorus applied in SAGT region

Crop	Mean Nitrogen applied (lbs/ac)	Mean Phosphorus applied (lbs/ac)
Canola	82.8	39.6
Barley	90.25 (10.68)	30.58 (7.46)
Corn	101.66 (13.57)	38.18 (8.21)
Cotton	60.19 (6.59)	40.44 (2.00)
Hay	14.99 (6.00)	35.99 (7.41)
Oats	35.37 (14.77)	17.23 (3.76)
Sorghum	45.61 (21.10)	26.10 (3.06)
Soybean	5.43 (5.92)	27.32 (13.17)
Wheat	59.81 (5.18)	32.25 (1.83)

Notes: N = 8,321 hydrologic units. Standard deviations of the means are in parentheses.

Table 4: Aggregate area and nitrogen applied under baseline and policy simulations

	Canola			
		Percent change from base		
Crop	Base (000's ha)	22%	31%	50%
Barley	2.15	0.00	-0.11	-7.35
Corn	2717.35	-2.88	-6.63	-14.68
Cotton	2767.43	-40.26	-54.58	-71.25
Oats	20.04	-34.87	-36.82	-41.37
Sorghum	89.77	-23.40	-27.38	-65.36
Soybean	2055.79	-31.61	-36.50	-65.62
Wheat	231.52	-44.40	-48.72	-63.58
Hay/Pasture	26693.34	0.00	0.00	0.00
Canola(ha)	0.00	1972.98	2585.84	3934.13
		Percent change from base		
Crop	Base (KgN '000)	22%	31%	50%
Barley	104.96	0.00	-0.12	-7.56
Corn	142889.75	-2.55	-6.01	-14.06
Cotton	80375.78	-39.63	-53.62	-70.40
Oats	300.94	-25.07	-26.80	-32.50
Sorghum	1750.01	-18.73	-23.01	-65.95
Soybean	2930.08	-45.05	-53.21	-77.65
Wheat	7126.13	-46.42	-50.84	-64.98
Hay/Pasture	0	0	0	0
Canola (kg N)	0	74099.13	97116.178	147753.6123
Total N applied (000's kg)				
Field Crops	282344.89	281598.84	281548.51	280816.25
All other Crops	402261.53	402261.53	402261.53	402261.53
All Agriculture	684606.42	683860.37	683810.04	683077.78

Table 5: Aggregate area and phosphorus applied under baseline and policy simulations

	Canola			
		Percent Change from the base		
Crop	Base(000's ha)	22%	31%	50%
Barley	2.15	0.00	-0.11	-7.35
Corn	2717.35	-2.88	-6.63	-14.68
Cotton	2767.43	-40.26	-54.58	-71.25
Oats	20.04	-34.87	-36.82	-41.37
Sorghum	89.77	-23.40	-27.38	-65.36
Soybean	2055.79	-31.61	-36.50	-65.62
Wheat	231.52	-44.40	-48.72	-63.58
Hay/Pasture	26693.34	0.00	0.00	0.00
Canola(ha)	0.00	1972.98	2585.84	3934.13
		Percent change from the base		
Crop	Base(KgP'000)	22%	31%	50%
Barley	39.22	0.00	-0.11	-7.32
Corn	53295.83	-2.53	-5.95	-13.79
Cotton	55597.00	-40.19	-54.43	-71.11
Oat	169.64	-30.24	-32.18	-38.50
Sorghum	1193.66	-21.87	-26.03	-65.33
Soybean	24926.22	-26.75	-32.32	-61.67
Wheat	3871.16	-43.97	-48.24	-63.22
HayPasture	0.00	0.00	0.00	0.00
Canola (kg P)	0.00	35434.72	46441.64	70656.81
Total P applied (000's kg)				
Field Crops	128070.85	127805.00	127765.98	127723.60
All other Crops	34933.36	34933.36	34933.36	34921.29
All Agriculture	163004.2183	162738.36	162699.34	162644.89

Table 6: Nitrogen loading yield and source shares means for the SAGT region; baseline and post-policy simulations

		Targets		
	Baseline	22%	31%	50%
N yield and loading concentration				
Upstream yield ($kg\ ha^{-1}yr^{-1}$)	4.23 (2.95)	4.24 (2.96)	4.24 (2.95)	4.23 (2.96)
Incremental yield ($kg\ ha^{-1}yr^{-1}$)	8.56 (216.53)	8.57 (216.57)	8.57 (216.62)	8.57 (216.52)
Flow concentration ($mg\ L^{-1}$)	1.09 (3.44)	1.09 (3.46)	1.09 (3.45)	1.09 (3.43)
Source Shares (%)				
Wastewater discharge	3.49 (13.25)	3.48 (13.24)	3.48 (13.24)	3.48 (13.24)
Atmospheric N	65.36 (21.65)	64.91 (21.70)	64.98 (21.70)	65.12 (21.64)
Impermeable surfaces	8.46 (12.41)	8.42 (12.39)	8.41 (12.38)	8.43 (12.40)
Commercial fertilizer	3.83 (6.64)	4.32 (7.29)	4.22 (7.18)	4.17 (6.94)
Manure	18.86 (16.53)	18.86 (16.54)	18.89 (16.56)	18.77 (16.48)

Notes: N = 8,321 hydrologic units. Standard deviations of the means are in parentheses.

Table 7: Phosphorus loading yield and source shares means for the SAGT region; baseline and post-policy simulations

	Baseline	Targets 22%	31%	50%
P yield and loading concentration				
Upstream yield ($kg\ ha^{-1}yr^{-1}$)	6.08 (6.93)	6.09 (6.91)	6.09 (6.91)	6.11 (6.92)
Incremental yield ($kg\ ha^{-1}yr^{-1}$)	7.09 (38.93)	7.10 (38.51)	7.10 (38.51)	7.12 (38.54)
Flow concentration ($mg\ L^{-1}$)	1.50 (4.24)	1.51 (4.30)	1.51 (4.30)	1.51 (4.30)
Source Shares (%)				
Wastewater discharge	1.82 (8.88)	1.80 (8.84)	1.80 (8.80)	1.80 (8.84)
Impermeable surfaces	35.89 (28.74)	35.76 (28.72)	35.76 (28.73)	35.74 (28.75)
Commercial fertilizer	15.28 (21.27)	15.47 (21.24)	15.54 (21.27)	15.83 (21.45)
Manure	47.00 (28.49)	46.95 (28.43)	46.88 (28.41)	46.61 (28.31)

Notes: N = 8,321 hydrologic units. Standard deviations of the means are in parentheses.

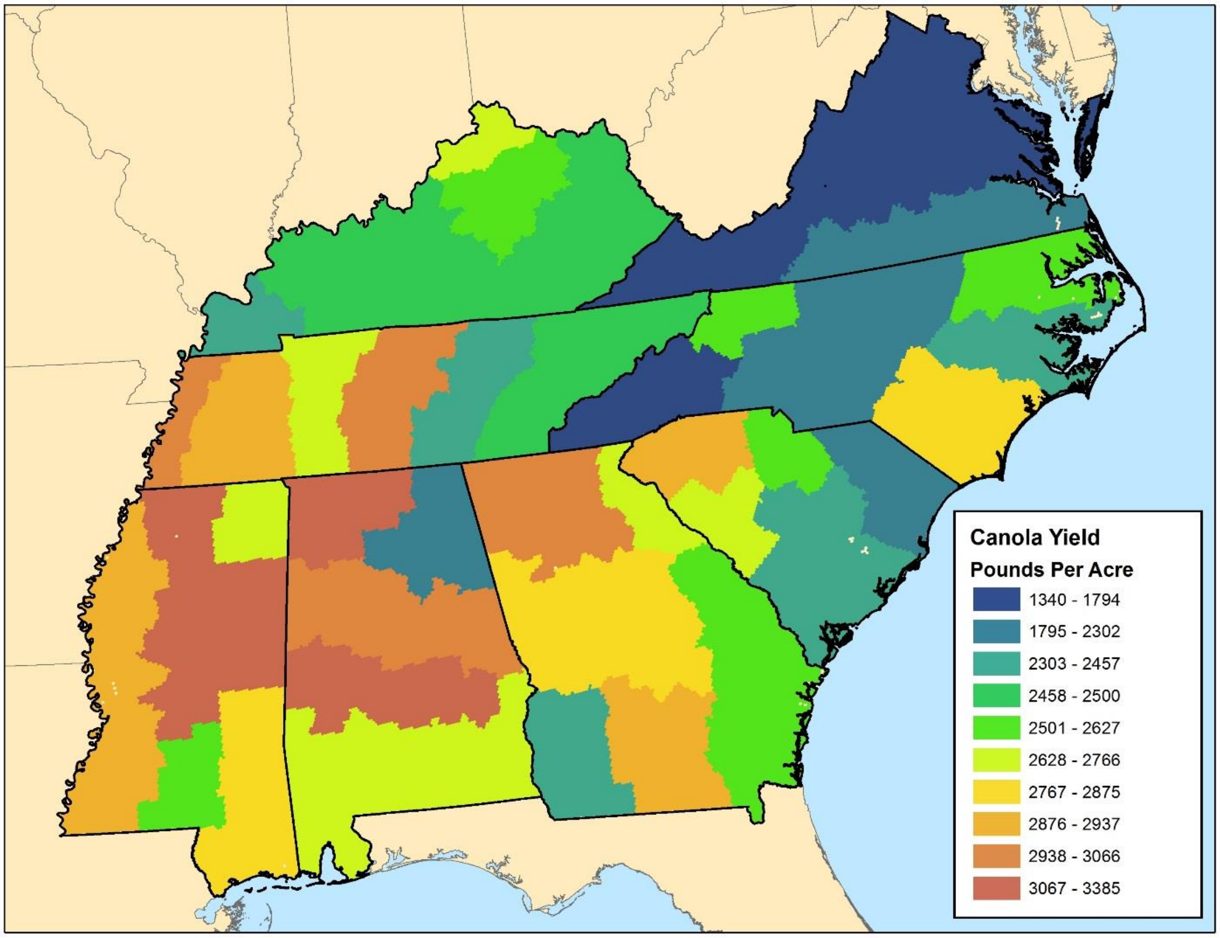


Figure 1. Canola yields generated by EPIC, aggregated t the Crop Reporting District level.

Figure 2: Predicted Net Returns when Canola is $8/bushel

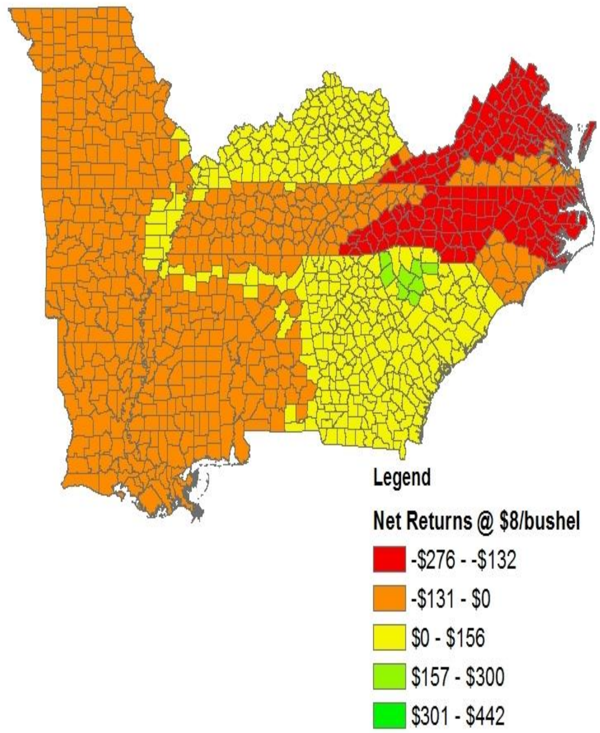


Figure 3: Predicted Net Returns when Canola is $10/bushel

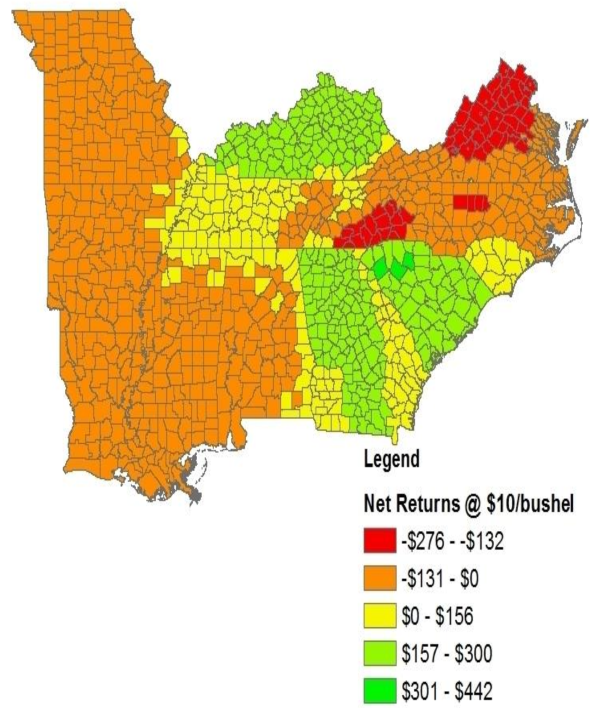
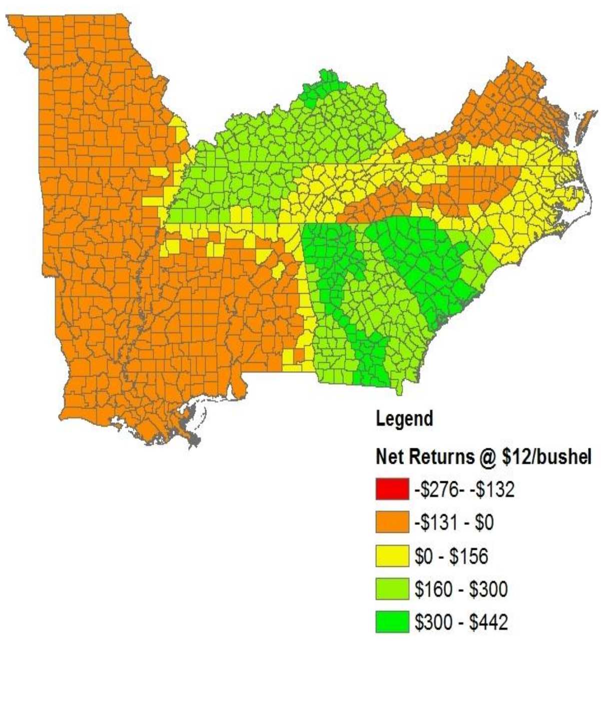


Figure 4: Predicted Net Returns when Canola is $12/bushel



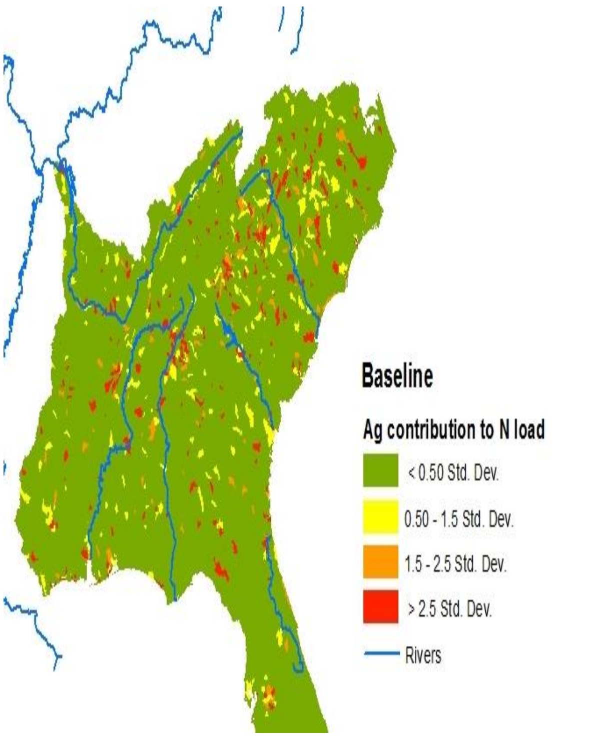


Figure 5: Agricultural N source share at baseline

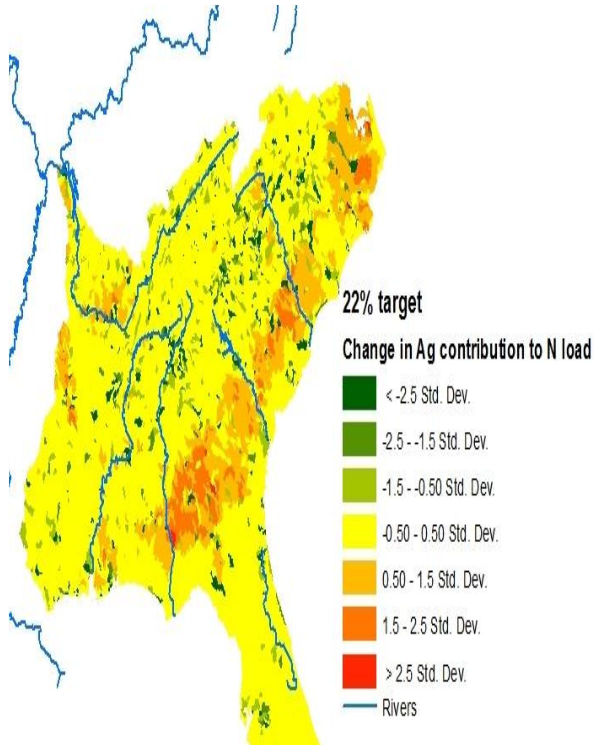


Figure 6: Agricultural N source share at 22% target

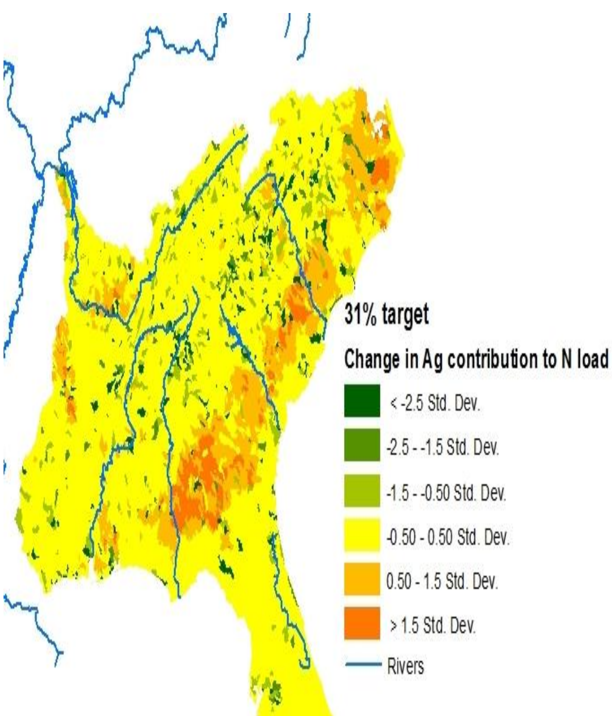


Figure 7: Agricultural N source share at 31% target

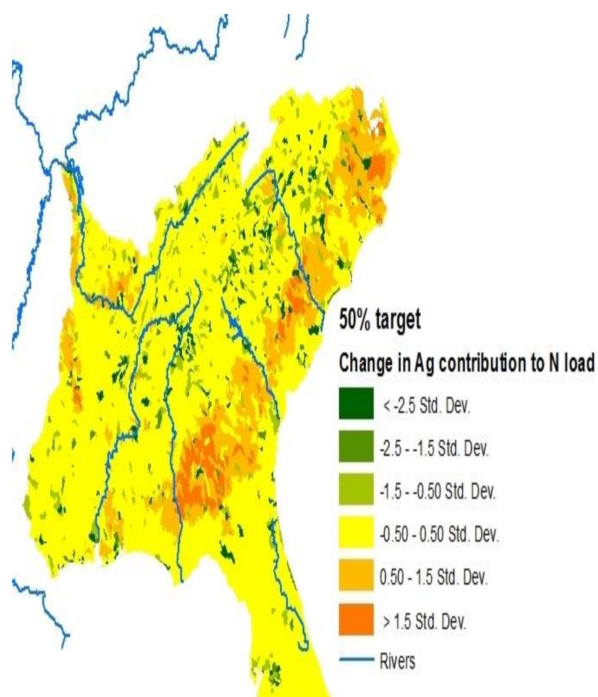
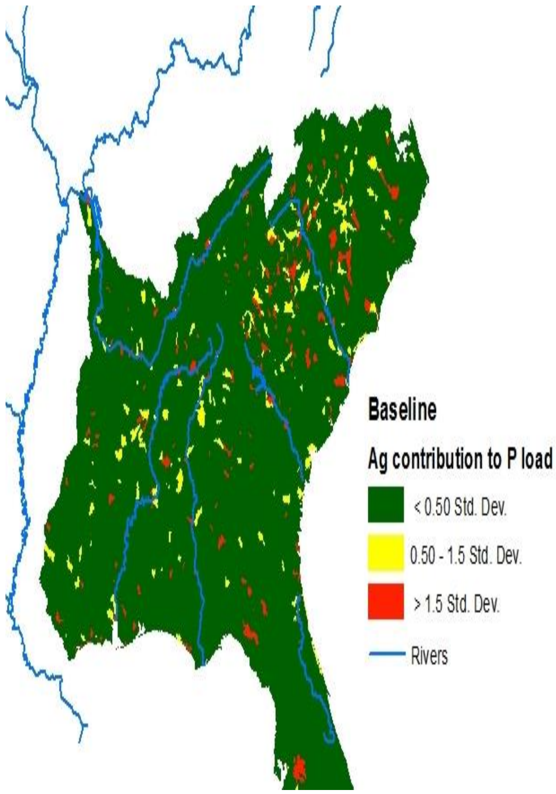


Figure 8: Agricultural N source share at 50% target



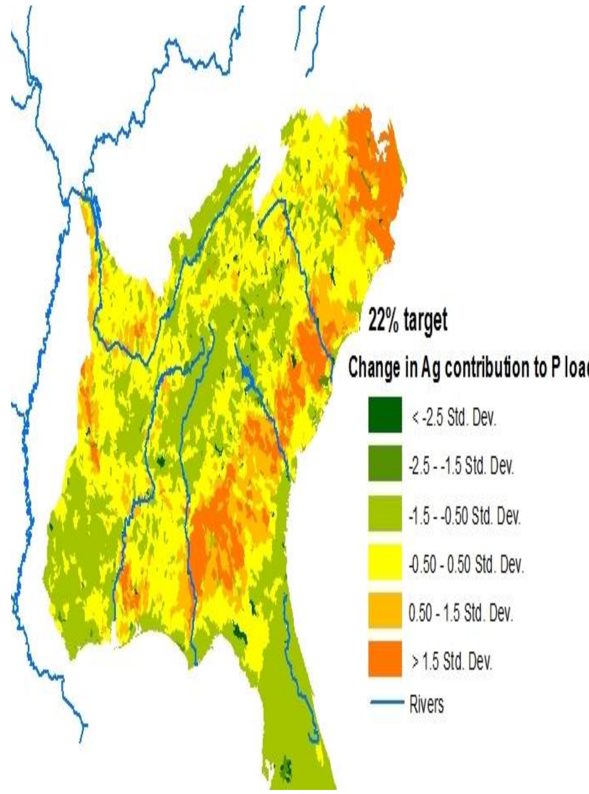
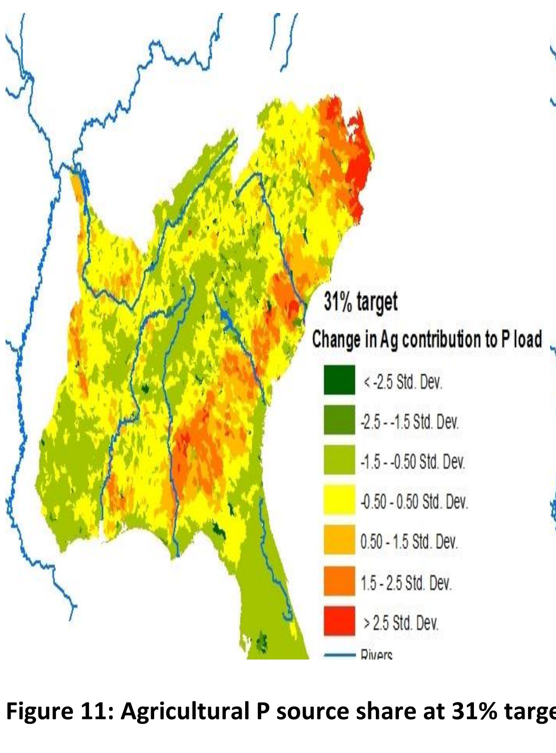


Figure 9: Agricultural P source share at base line

Figure 10: Agricultural P source share at 22% target



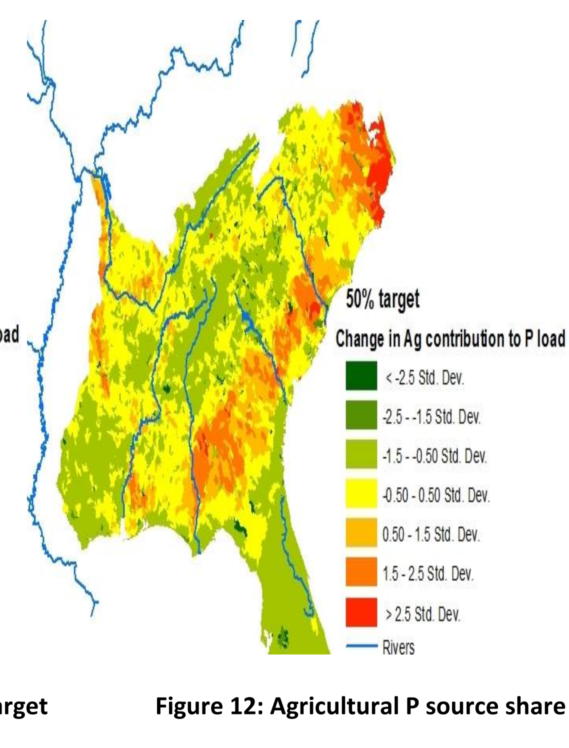


Figure 11: Agricultural P source share at 31% target

Figure 12: Agricultural P source share at 50% target

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Measuring evapotranspiration and soil moisture to close the hydrologic budget under different land-uses in Tennessee

Basic Information

Title:	Measuring evapotranspiration and soil moisture to close the hydrologic budget under different land-uses in Tennessee
Project Number:	2015TN110B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Tennessee-2nd
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Water Quantity, None
Descriptors:	None
Principal Investigators:	Thanos N Papanicolaou

Publications

1. Papanicolaou, A.N.,M. Elkhakeem, C.G. Wilson and B.K. Abban.2015. Evaluating the Impacts on Runoff of Landscape-Based Best Management Practices in Intensively Managed Watersheds "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN. pp.1C-7.
2. Papanicolaou,A.N., M. Elhakeem, and C.G. Wilson, 2015. Predictions of Saturated Hydraulic Conductivity Dynamics in Intensively Managed Watersheds, "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp. 2B-11.
3. Papanicolaou,A.N., K. Basnet, B. Abban, C. Giannopoulos, J. Schwartz, J. Hathaway, S. Hawkins, and C.G. Wilson 2016. Assessing Water Availability in the Hiwassee River Basin using a Hydrologic Budget, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the America Water Resources Association, Nashville, TN., pp. 2A-8.

Introduction:

Evapotranspiration (ET) is a major component of the land surface water cycle, as it directly affects the amount of water available for runoff and recharge, and hence human consumption. Despite the relative importance of ET to the hydrologic cycle, especially in the U.S. Southeast which has some of the highest mean annual ET in the country, it is one of the least systematically measured parameters.

Evapotranspiration in the United States varies significantly both spatially and temporally. The science community currently lacks ET data of adequate spatial density and temporal frequency to account for the level of heterogeneity seen within both natural and human-altered landscapes, thus preventing the identification and discrimination of the competing processes that control the observed patterns in the water quantity and quality of our local ecosystems. Furthermore, the stationarity of hydrologic data from the past 100 years is now in question because of major changes in land-use and climate. Hence, current models used for both research and management are based on insufficient data from all phases of the water cycle.

The most important factors that drive ET are net solar radiation, climate conditions (e.g., humidity, wind speed, temperature), soil moisture, and vegetative cover. However, most measurements use meteorological properties and reference crop corrections to determine potential ET, but neglect the role of soil moisture at the soil boundary surface (i.e., top 30 cm) on actual ET. As a result, our current ET monitoring and modeling capabilities lack of understanding about the role of soil moisture and pedology at different spatial and temporal resolutions sufficient to quantify ET, especially in regions exhibiting high heterogeneity in landscape characteristics

Water availability is a developing research theme as it is projected to become very important as the climate warms and our cities grow. Recently, the Tennessee Water Resources Technical Advisory Committee (WRTAC) has joined the effort of other states throughout the country and requested the development and maintenance of a statewide hydrologic database to assess the impact of drought on public water supply systems in Tennessee. This study can contribute significantly to this hydrologic database and it will significantly enhance our understanding of how changing land management, irrigation, and urbanization affect water quantity in mixed agricultural-urban watersheds of the Southeast under different climates to assist watershed planners in applying management strategies for mitigating drought impacts, as well as aid societal efforts to obtain sustainable water resources through integrated surface-subsurface water management.

Nature, Scope and Objectives of Project:

In this study, we are helping address a critical gap in our current ET monitoring and modeling capabilities, namely the lack of understanding about the effect of soil moisture on ET in regions exhibiting high landscape heterogeneity. Past research has used only meteorological properties and reference crop corrections to determine potential ET, but neglected the role of soil moisture at the soil surface on actual ET.

A mobile array of state-of-the-art sensors was developed that is capable of measuring not only the rate of ET under multiple land-uses throughout the region, but also the resulting change in soil moisture. The mobile array of state-of-the-art sensors measure ET, Leaf Area Index

(LAI), and soil moisture changes. It provides essential but missing data for a GIS Data Management System for water resources research in Tennessee, as well as ground-truthing data for satellite-based estimates of ET and soil moisture to develop regional scale water budgets for long-term water resources planning, management and risk analysis.

The nature of our study encompassed three main objectives centered on the development and use of the mobile ET/ LAI/ soil moisture monitoring array. The objectives included the development and testing of the mobile array; select data collection of ET, LAI, and changes in soil moisture; and a comparison of these data with remote sensing images from MODIS as a form of ground-truthing. These three objectives will be the initial stepping stones to closing the hydrologic budgets for the different ecosystems in Tennessee.

Methods, Procedures and Facilities:

This project is a seed instrumentation grant, with its whole purpose being to design/ acquire the appropriate equipment to conduct current and future research that is beyond the short term lifespan of the seed grant. In this case, the equipment consisted of monitoring stations for evapotranspiration (ET) corrected for soil moisture, a key parameter affecting ET magnitude in the state and region.

To monitor the resulting changes in soil moisture and its implications to ET, we use Water Content Reflectometers, which measure the volumetric water content of soils and porous media using time domain measurement methods sensitive to dielectric permittivity. Monitoring soil moisture is central as it constrains plant transpiration; however, the sparse availability of ground observations continues to be a limiting factor in understanding the connections between LULC, ET, and soil moisture.

Finally, we also purchased a LP-80 Ceptometer from Decagon Devices to measure Leaf Area Index. The role of vegetation in affecting ET has been previously established and LAI has been shown to be a critical variable when determining actual ET as it provides the total area of the transpiring surface. Essentially, ET will increase as LAI increases. The ceptometer is a portable sensor that will measure Photosynthetically Active Radiation (PAR) in real time. The PAR data can be coupled with the climate data to estimate total biomass production without destroying the crop and other canopy processes, such as precipitation interception and evapotranspiration.

Additionally, ET can be determined using remotely sensed vegetation indices (e.g., Normalized Difference Vegetation Index, NDVI) and micrometeorological data, although ground-truth results are needed. Our array will provide the meteorological/ temperature data and LAI data for the ground-truthing of the satellite-derived images

Results and Findings:

Initially, after we reviewed the literature pertinent to droughts in the Southeast, we completed the satellite analysis in advance to identify ranges of variability and bounds of uncertainty. ET was estimated using remotely sensed vegetation indices (e.g., Normalized Difference Vegetation Index, NDVI) and micrometeorological data.   We looked at the ability of

MODIS data to give us some spatial variability information for ET. It was through examining the MODIS data, and a modified Penman-Monteith equation that we found the variability was greater than 15-20%.

Once that was done, we felt confident that our initial design supplemented with soil moisture and heat fluxes measurements would work. We then began with the development of a monitoring protocol and selective testing of the ET array, LAI, and moisture sensors. After the LAI meter was obtained, we began testing it with the soil moisture probes that we had available. Through our discussions, this isolated testing process and exploring the available literature, we discovered a fourth sensor for monitoring soil heat flux, which was deemed important for Tennessee due to the expected increase in temperature and the need for a correction of potential ET due to losses.

This soil heat flux sensor was not part of the original design but came as an outcome of the evolution in the project. This heat flux sensor was needed to proceed with the potential ET correctly. Because our goal was to measure actual ET under different land covers, including cover crops, coupled with the fact that the Southeast has ubiquitous soil heat exchanges, it became apparent that we needed the additional corrections with LAI and soil moisture, as well as soil heat flux.

Therefore to determine the actual ET, the reference values from Eq.1 must be corrected using the crop coefficient for the specific crop/ vegetation (K_c). These coefficients have been determined experimentally and are documented in the literature.

However, as soil moisture decreases, it is less available for uptake by the plant. It will also be more difficult to uptake the water as it is more strongly bound by capillary and absorptive forces to the soil matrix. Hence, the ET will drop after the soil moisture content passes below a threshold value where the soil water can no longer be transported quickly enough to the roots to respond to the transpiration demand and the crop begins to experience a water stress. This value, p, is typically half-way between field capacity and the wilting point and detailed in the literature. Using this threshold value, the total available soil water in the root zone (W_t) from the DRI measurements, the measured change in soil moisture, $\Delta\theta$, we can determine the water stress coefficient (K_s) to correct our ET_0, which reflects the effects of soil moisture on ET.

$$K_s = \frac{W_t - \Delta\theta}{(1-p)W_t} \qquad (1)$$

The actual ET values over the monitoring can then be determined by correcting the ET_0 with both the crop coefficient (K_c) and the (K_s).

The acquisition of the soil heat flux ensured that we got (1) a system suited for Tennessee and droughts; and (2) that we were able to provide detailed measurements to support the seed grant needs and support larger efforts.

Evaluating Environmental and Biological Impacts of Acid Runoff from Pyrite-Bearing Rock Formations

Basic Information

Title:	Evaluating Environmental and Biological Impacts of Acid Runoff from Pyrite-Bearing Rock Formations
Project Number:	2015TN111B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Tennessee 5th
Research Category:	Water Quality
Focus Category:	Water Quality, Conservation, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	William Sutton, DeEtra Young

Publication

1. Hogan, B, C. Williams, T. Byl, D. Young, and W. Sutton, 2016, Streamside Salamanders as Indicators of Environmental Stress: Impacts of Acid Rock Drainage on Headwater Stream Integrity, "in" Proceedings of the 25th Tennessee Water Resources Symposium, TN. Section of the American Water Resources Association, Nashville, TN., pp.2B-8.

Introduction:

Pyrite and similar minerals containing sulfur and trace metals occur in several rock formations throughout Middle and East Tennessee. When the pyrite is exposed to oxygen and water, the minerals decompose and the sulfur can react to form sulfuric acid resulting in environmental problems and damage to the transportation infrastructure. In Middle and East Tennessee pyrite occurs in black shale in the Highland Rim and Valley and Ridge provinces, shale and coal formations along the Cumberland Plateau, and metamorphic rocks and shale in the Blue Ridge.

When the pyrite-bearing formations are exposed in a road cut, there is the potential for acidic runoff that can also contain elevated levels of iron and other metals (Equation 1).

Equation 1. $12\ FeS2 + 45\ O2 + 34\ H2O \longrightarrow 4\ [H3OFe(SO4)2.2Fe(OH)3] + 16\ H2SO4$

Groundwater and especially rainfall can transport dissolved oxygen into the formation. The oxidation of pyrite, which is enhanced by bacterial action, results in the formation of sulfuric acid and dissolution of other metal bearing material. Depending on the amount of acid drainage discharged from the formation, the acid drainage and dissolved metals can be transported to surface water or, under dry conditions, can form deposits of sulfur salts and entrained metals on the surface of road-cuts. The sulfur salts are soluble and the sulfur and metals are released and transported during wet seasons. The contaminated runoff can be treated similar to acid-mine- drainage. If left untreated, the acid and heavy metal runoff can have unintended and negative consequences on aquatic biodiversity and environmental conditions (Kucken et al. 1994; Schorr et al. 2013).

Strategies for the remediation of ARD can be categorized as either on-site or off-site treatment methods. Examples of treating acidic drainage off-site include use of constructed wetlands to treat AMD (Whitehead and Prior, 2005), diverting AMD to engineered anaerobic, sulfur-reducing-bacteria bioreactors (Sheoran, et al., 2010), or, neutralizing ARD by directing flow through reactive alkaline materials (Egiebor and Oni, 2007). On-site treatment includes modifying the hydrology, reducing the oxygen availability or altering the microbiology at the site. The site hydrology can be modified through physical alterations that cut off percolating rain water. Reducing water flow may also reduce the oxygen levels at the site of the ARD reaction.

Johnson and Hallberg (2005) described using caps and other sealing methods to prevent groundwater recharge at mine spoil piles. One concern about this approach is the longevity of a sealant. Caps and sealants are vulnerable to weathering, biological perturbations, or groundwater approaching the iron-sulfide from an unprotected side. Additional research is needed to determine if a similar strategy can be used to stimulate sulfur-reducing conditions at the source of ARD and deprive the chemolithotrophic bacteria of oxygen, thereby attenuating ARD problems. One of the challenges for any man-made anaerobic bioremediation system is the longevity of treatment since supplements can be consumed, carried away in rains, and oxygen replenished during recharge.

Given global-scale declines in amphibian biodiversity (primarily through anthropogenic means; Stuart et al. 2004), it is essential to evaluate the impacts of disturbances, such as ARD on potentially vulnerable taxa. These potential negative impacts echo the need to better understand the chemical, geologic, hydrologic, and bacterial factors that control the acid formation, transport mechanisms, and hazards to stream fauna. This information can be used to identify management practices to prevent the formation of acid rock drainage (ARD) from road projects in Tennessee. Aquatic acidification through anthropogenic means has been shown to negatively impact aquatic invertebrates (Niyogi et al. 2002) and vertebrates, including both fishes and amphibians (Huckabee et al. 1975; Kucken et al. 1994; Schorr et al. 2013). This adaptation requires moist environmental conditions for the diffusion of oxygen to occur, which increases the sensitivity of this species group to environmental stressors (Welsh and Droege 2001), such as stream acidification. Streamside salamanders in particular appear to be negatively associated with aquatic acidification. Grant et al. (2005) noted that streamside salamander abundance was negatively associated with stream acidification across multiple sites in the Shenandoah National Park. In terms of amphibian response to ARD, we are aware of only one study that has examined the impacts of ARD on streamside salamanders inhabiting a stream in the Anakeesta shale formation in the Great Smoky Mountains National Park (Kucken et al. 1994). Although the authors observed marked declines in relative abundance of Blue Ridge Two-lined Salamanders (*Eurycea wilderae*) and Blackbelly Salamanders (*Desmognathus quadramaculatus*) due to ARD, this study was limited to only one site. Our proposed research will take a larger perspective on the impacts of ARD on streamside salamander communities by examining the potential impacts of ARD at multiple sites throughout Tennessee associated with at least two geologic shale formations. The proposed study will also evaluate the impacts of ARD on both larval and adult salamander life stages, which will provide valuable input on whether ARD causes mortality to all life stages or potentially serves as a sub-lethal stressor to adult salamanders. Overall, this research will provide valuable information on the response of vulnerable aquatic vertebrates to ARD in Middle Tennessee and will help identify the range of impacts from this anthropogenic disturbance throughout the region.

ARD in Tennessee occurs along road cuts associated with the Chattanooga Shale and other black shale, the Fentress Formation and coal deposits, and sulfide-bearing igneous and metamorphic rocks (Figure 1). The Chattanooga Shale occurs along the Highland Rim escarpment in Middle Tennessee and along strike belts in East Tennessee. The Fentress Formation and equivalent formations and coal deposits occur along the escarpments of the Cumberland Plateau. Characterization of the hydrological, geochemical, and biochemical factors controlling acid production; fate and transport mechanisms; and biological consequences are needed to better understand the environmental impact of acid-rock drainage.

The objective of this study was to, 1) use stream salamanders as biological indicators to evaluate the impacts of ARD on stream integrity, and 2) attenuate ARD by manipulating the indigenous microbial community through different treatment injections, ultimately generating anaerobic sulfur-reducing conditions. The collective scope of the project was to evaluate the biological impacts of ARD and evaluate potential strategies to mitigate the impacts of ARD disturbance on stream ecosystems.

Materials and Methods:

Study Site:

Study sites were located in the Chattanooga and Fentress shale formations in middle Tennessee (Figure 1). Sites were selected to coincide with an on-going ARD project implemented by the USGS. While the USGS project has numerous ARD monitoring sites across Tennessee, we targeted 2 ARD sites in middle TN with direct drainage from the ARD disturbance into neighboring low-order streams. The first site included a road cut through the Ordovician geologic formation containing the Chattanooga Shale, located in south Williamson County, on US 840 and drains to the headwaters of Carter's Creek – which flows into the Mill Creek watershed. It is an example of a Central Basin – Highland Rim escarpment ARD site. The second site was located in Fentress County, TN, and feeds to a headwater stream in the Wolf Creek watershed.

Bioattenuation of ARD Discharge:

Source of Shale and Bacteria – The source of the pyrite-rich shale and the ARD bacteria inoculum was a road cut that was less than 5 years old in south Williamson County, Tennessee, (latitude 35.814339 and longitude -86.975004). The site had wet yellow-orange stains and other signs of ARD associated with the Chattanooga shale bedding plane and spoil piles (Figure 2). Water that had not been in contact with the Chattanooga Shale or spoil piles at the site had a pH range of 6.40 to 7.83, and a specific conductance range of 306 to 436 microSiemens per centimeter. Water draining from the spoil piles containing a mix of fragmented shale and limestone, as well as, water dripping from openings on the upper surface of the Chattanooga Shale had a pH ranging from 2.45 to 4.00. The specific conductance of these acidic waters ranged from 926 to 2266 microSiemens per centimeter, indicating they were rich in dissolved minerals. During dry, hot intervals in the summer of 2014, many of the ARD seeps dried up and produced secondary sulfur minerals along the desiccated flow path.

The USGS geologic laboratory (Reston, VA) confirmed the shale was rich in iron-sulfide minerals with 1.67 moles (93.1 grams) of iron and 3.19 moles (102 grams) of sulfide per kilogram of shale, respectively. This approximate 1:2 molar ratio of iron to sulfide is equivalent to that of pyrite (FeS_2). Approximately 30 kilograms of this pyrite-bearing fresh, unweathered shale was excavated from the site and placed in clean, 5-gallon plastic buckets, and transported to the lab to be processed. A small portion of the shale material was shipped to the USGS laboratory for analysis and the rest was readied for use in the microcosms. Also, one kilogram of gravel-sized, active ARD material from the spoil pile was collected in a separate plastic container to provide an inoculum of indigenous ARD bacteria. Sixty liters of background water was collected from neutral pH seeps above the shale formation for the dilute reservoir water.

Preparing the microcosms – The shale material was brittle and relatively easy to break with a hammer into 0.75-inch or smaller pieces. A series of sieves were used to separate the fragmented shale into discrete sizes: 0.5 to 0.75 inch, 0.25 to 0.5 inch, 0.125 to 0.25 inch, and less than 0.125 inches. The twelve microcosm containers consisted of clean, sterile 500-mL Erlenmeyer side-arm flasks. Each microcosm flask was filled with the following quantities of shale fragments: 1 gram of inoculum material from the spoil pile, 180 grams of 0.5-0.75 inch, 140 grams 0.25-0.5 inch, 80 grams 0.125-0.25 inch, and 100 grams of <0.125 inch fragments for a total of 501 grams of shale. The shale was placed in the flask with the largest pieces on the bottom and progressively smaller sized pieces stacked on top. A quarter-inch diameter polytetrafluoroethylene (PTFE) tube that touched the bottom of the Erlenmeyer flask was in place prior to adding the shale fragments to the flask. Once the shale fragments were in place, a rubber stopper was lowered down the PTFE tube and seated into the mouth of the flask. Silicone sealant was used to prevent gas and water leaks around the PTFE tubing and rubber stopper. The PTFE tubing was attached to a twelve channel peristaltic pump (model Watson-Marlow 205u).
Additional PTFE tubing was inserted into the side-arm for the discharge water and sealed with Parafilm™. A 16-liter carboy filled with purified water (16 Ohm resistivity), continuously stirred to aerate the water, served as the reservoir (Figure 3). The initial pump rate was 2 mL per minute to remove dust and colloidal particles. Air bubbles were removed from the microcosms as they slowly filled by gently tilting and tapping the flasks to allow the bubbles to escape via the side-arm discharge. Each microcosm required approximately 360 mL of water to fill. After running 5 volumes of water (1,800 mL) through each microcosm to remove dust and colloidal particles, the pump speed was lowered to 1 mL per minute. One liter of raw,

unfiltered, background water collected from neutral pH seeps at the site was blended into 15 liters of purified reservoir water. This blended reservoir water provided an inoculum with a mixed bacteria consortium indigenous to the site to improve ARD simulation. The inoculated microcosms were allowed to sit for 12 hours before pumping resumed at 1 mL/minute with the 1:15 blended water. The reservoir water was pumped through the microcosms 8 hours/day at 1 mL / minute for five days a week. Over the course of this project, the blended waters in the reservoir had a temperature of 25°C (+/-1.5), dissolved oxygen ranging from 6 to 10 mg/L, specific conductance ranging from 21 to 55 uS/cm, and pH ranging from 6.4 to 7.8.

Treatments –Different supplements have been used to stimulate sulfur reducing bacteria. Each supplement had success stimulating sulfur reducing bacteria under their respective environmental conditions, but none of the treatments were evaluated under active ARD conditions. Stimulating sulfur-reducing bacteria in situ at an ARD site must consider the low pH environment, the oxygen input, as well as, how to prolong the effect of the supplements in an environment that is subject to intermittent flow and stagnation. To address these concerns, different treatments were evaluated with 3 replicate microcosms per treatment. The study consisted of three experiments with four treatments per experiment. Treatment modifications built upon previous results. The treatments in the first experiment included: 1. Reference controls that consisted of reservoir water with no supplements or treatment injection, 2. Chemical shock treatment with bleach and sodium hydroxide to knock down the ARD microbial consortia, followed by non-sterile reservoir water, 3. Initially injecting 0.75 grams of sodium lactate followed by non-sterile reservoir water,
4. Initially injecting 0.75 grams sodium lactate and 1.5 grams soy-based infant formula followed by non-sterile reservoir water. The second and third experiments used information gathered from the previous study and modified the supplements to improve the outcome. The modifications to the four primary treatments and rationale are listed in Table 1. The supplements were pumped into the microcosms using the peristaltic pump at a rate of 2 mL/minute. The supplements were dissolved in purified water to a volume of 20 mL in twelve large test tubes with pump intake tubes inserted directly into the test tube containing the assigned treatment.

Using individual tubes to deliver the supplements provided an opportunity to confirm uniform pumping rates. As the supplement level declined in the test tubes, the tubes were refilled 2-times with reservoir water to rinse the treatment residue into the microcosms. After two rinses, the intake tubes were returned to the reservoir and the pump flow rate was adjusted to 1 mL/minute.

The duration of the experiments varied based on how effective the treatments appeared to be working as assessed by the geochemistry of discharge waters. Geochemical parameters that factored into the decision to terminate a particular experiment included pH, dissolved iron, and phosphate concentration in the discharge waters. The first experiment was terminated after 30 days, the second experiment was terminated after 40 days, and the third experiment was terminated after 231 days. The pump flow rate for experiments 1 and 2 was 1 mL/min for 8 hours a day, for 5 days a week for the entire study period. Experiment 3 started with the same flow rate as experiments 1 and 2 for the first 50 days, after which, the flow was reduced to two 8 hour days per week. The reduction in pumping time after 50 days was done because a greater residence time was needed to maintain ARD conditions in the reference control microcosms. The amount of water pushed through each microcosms (including pre-treatment injection water) for each experiment expressed in pore volumes was: 30 volumes in the first experiment, 45 volumes in second experiment, and 90 volumes in experiment 3.

Sampling procedure, geochemical and biological analysis – Prior to collecting the water samples for geochemical analysis, the pumps were run for 6 hours at 1 mL per minute, which is equivalent to 360 mL per microcosm or one pore volume. The discharge waters were collected in clean 40 mL sample vials. The vials were allowed to overflow for 20 minutes to minimize water interaction with the atmosphere. Water quality readings were taken in the following order using calibrated meters, dissolved oxygen (Orion meter, pH, and specific conductance. Sulfide concentration in the discharge water was also immediately measured after taking the meter readings. The vials were allowed to re-fill, capped without air bubbles, and stored in a fridge at 5^{o}C (+/-1) until the iron, phosphate and sulfate could be run within a few days. Geochemical analytical methods and lower detection limits are listed in Table 2. Microbial types were characterized using Biological Activity Reaction Tests™ (BART). The BART assays were run near the end of each study when the pH and iron concentrations appeared to be stable which suggested the microcosms had reached equilibria. The waters for the BART assays were pumped at 1 mL/minute directly into the tubes from the microcosms, incubated in the dark at 25^{o}C and monitored each day for 7 days (Culimore, 2007). The geochemical data were arranged in a computer spreadsheet for statistical analysis (Helsel and Hirsch, 2002). Plots of pH, specific conductance and dissolved iron concentrations through time were created to compare different treatments. The remaining geochemical data were summarized in tables providing the median distribution and the interquartile range to provide a measure of spread. The BART results were also plotted to show differences between treatments.

Salamander Sampling:

We conducted field surveys for streamside salamanders to evaluate biological impacts of ARD. We monitored abundance and richness of these organisms to serve as indicators of biological condition. We used a paired experimental design to evaluate the impacts of ARD on streamside salamanders. The paired design will included one stream segment that was impacted and a stream segment not impacted by ARD. This design permitted a direct and relative measure of ARD disturbance on stream salamander populations. We identified stream segments above and below ARD disturbances that contained

We used a combination of stream quadrat and transect surveys as described in Price et al. (2011) to evaluate the impacts of stream acidification on adult and larval streamside salamanders. We delineated one 15 m x 3 m linear transects and two 1 m x 1 m quadrats that spanned the terrestrial and aquatic portions of the stream environment. We surveyed for and captured adult and larval stream salamanders opportunistically by turning over cover objects, including rocks and logs within the transect and quadrat boundaries. Transects were surveyed using non-destructive methods (i.e., cover objects were briefly lifted and returned), whereas quadrats were surveyed using destructive methods (i.e., all cover objects were completely removed from the quadrat grid). We used these two survey methods to obtain a better estimate of both larval and adult salamander abundance. Each captured salamander was identified to species and measured (snout-vent length [mm]) and weighed (g).

We surveyed each stream site during September and October and surveyed each stream segment during the same week to reduce variabilities in salamander abundance patterns.

Data Analysis:

We determined total counts and species for richness separately for the ARD impacted and non-ARD impacted stream segments for larval, adult, and total salamanders encountered during surveys. We used a paired-samples t-test to evaluate if ARD impacted stream salamander richness and diversity patterns. We considered relationships statistically-significant if p-values were < 0.05. We used the R statistical package to complete all data analyses.

RESULTS

Bioattenuation of ARD Discharge:

Prior to starting the experiments, all the microcosms had to exhibit ARD conditions in the discharge water, including a pH of 3 or less, dissolved iron ranging from 75-100 mg/L, specific conductance ranging from 1,500 to 2,500 uS/cm. Additionally, dissolved sulfide was below detection (<0.01 mg/L) and sulfates were high (>500 mg/L) in the ARD discharge waters. These geochemical values were similar to field ARD conditions and provided evidence that the bacteria responsible for ARD were active in the microcosms. Once stable ARD conditions were observed for several days, the experimental treatments began and monitoring continued.

The first round of experiments consisted of four treatments, reference controls with no supplements, a chemical shock treatment combining bleach and sodium hydroxide, a single supplement of sodium lactate, and a mixed supplement of sodium lactate and soy formula. The reference control microcosms maintained a low pH of 3 to 3.4 the entire 30 days (Figure 4a). The pH of microcosms treated with bleach and sodium hydroxide initially climbed to pH 8.8, followed by a drop to pH 5 by day 30. The microcosms supplemented with lactate or lactate + soy formula initially experienced rising pH in the discharge waters indicating that non-ARD bacteria stimulation was occurring. However, after 20 days, the pH in both treatments stabilized for ten days at 4.37 for lactate and 5.36 for lactate + soy formula, respectively. The specific conductance, an indicator of dissolved solids, were indistinguishable for all treatments except for the microcosms treated with bleach and NaOH (Figure 4b). By day 30, all the treatments had similar specific conductance values. The dissolved iron in the discharge waters dropped for the reference control and the microcosms treated with bleach and NaOH, while remaining high in the microcosms treated with lactate and lactate + soy formula, 50 and 60 mg/L, respectively (Figure 4c).

Additional geochemical results are summarized in Table 3 as median concentrations in the discharge waters, and the interquartile range values, which provide a measure of the data spread. In the first experiment, only the microcosms treated with bleach and sodium hydroxide had any measurable alkalinity. The median dissolved oxygen was lowest in the microcosms treated with lactate and soy formula. The phosphate median was below 0.5 mg/L for all the experiment 1 treatments. Sulfide concentrations were greatest in the microcosms spiked with lactate and soy, while sulfate was greatest in the microcosms treated with bleach and NaOH.

Based on results of experiment 1, it was clear that microcosms treated with bleach and sodium hydroxide attenuated two ARD symptoms (lowered iron, raised the pH) as compared to the other treatments. However, treating an ARD site with sufficient bleach and sodium hydroxide to replicate the laboratory chemical shock is not a reasonable remediation treatment. For the second experiment, 10 mL of 1 molar potassium dibasic phosphate buffer, pH 9.1, was part of each treatment. It was conjectured that reactive phosphate would help remove dissolved iron through precipitation (Seida and Nakano, 2002) and that it would also act as a buffer to raise the pH slightly.

The results of adding phosphate buffer to the treatments helped to moderate the pH spike observed in Experiment 1 bleach and NaOH treatment (Figure 5a). The addition of phosphate buffer to the treatments enhanced the rise in pH for the other three treatments. The pH of waters from the microcosms treated with lactate and soy formula rose to pH 6 within 20 days (versus a maximum pH of 5.36 without the phosphate buffer). The specific conductance values were approximately 25% higher in the microcosms treated with phosphate than those without (Figure 5b). The iron concentrations dropped at a faster rate when phosphate was added to the microcosms (Figure 5c). Other geochemical indicators, such as lower dissolved oxygen levels and an increase in sulfide in the discharge water, support the premise that addition of pH- neutralizing phosphate buffer enhanced the environment for anaerobic bacteria and reduced the ARD symptoms (Table 3). Unfortunately, in addition to offsetting the ARD symptoms, there was a 100-fold increase in reactive phosphate in the discharge waters. Applying the use of phosphate buffers at an ARD field site would require scaling up the volume and would result in unacceptably high phosphate levels in the runoff.

Although the addition of phosphate buffer to the supplements resulted in nutrient complications, it did improve mitigation of several ARD traits. It was hypothesized that the neutralizing capacity provided by the phosphate buffer enhanced the colonization and growth of non-ARD bacteria, especially in the lactate and the lactate + soy formula treatments. The third experiment was designed to test that theory by slightly increasing the pH with a sequential injection of NaOH prior to injecting the food supplements. As a result of the NaOH injection, the water in the microcosms treated with lactate and soy formula rose to pH 6 in less than 10 days (Figure 6a). The concurrent rise in median alkalinity and sulfide, and drop in dissolved oxygen, implies that there was a significant rise in bacteria activity in the microcosms treated with NaOH followed by lactate and soy formula. This rise in pH was faster and higher than the rise triggered by a sequential injection of NaOH followed by bleach. The injection of NaOH caused a slight rise in specific conductance initially, but dropped to less than 500 uS/cm by day 25 (Figure 6b), with NaOH + lactate + soy formula treatment being the lowest. The dissolved iron dropped quickest in the NaOH + lactate + soy formula treatment (Figure 6c). This reduction in dissolved iron may have been due to elevated sulfides (Table 3) precipitating the iron. The median phosphate levels were less than 1 mg/L in all the treatments. The benefits of the sequential injection of NaOH, followed by lactate and soy formula, was still evident after 231 days.

The BART assays provide a population estimate of different bacteria types based on the time of color changes in the incubation tubes. The BART assays were conducted toward the end of each experiment to provide an evaluation of how the microbial community responded to the treatments after significant volumes of artificial recharge water have percolated through the microcosms. The microcosms dosed with phosphate as part of Experiment 2 had a distinct increase in iron related bacteria as compared to the other treatments (Figure 7a). The sulfur related bacteria appeared to respond positively to food supplements when there was an increase in pH brought about by phosphate buffer or NaOH (Figure 7b). The population of slime producing bacteria tended to stabilize at densities similar to the background water in the reservoir with the exception of a depressed population in the chemical shock treatment (experiments 1 and 2) and an increase due to pH adjustments and lactate and soy formula (experiments 2 and 3) (Figure 7c).

Salamander Sampling:

We captured 158 total stream salamanders representing 6 species during our stream surveys (Table 4). The Spotted Dusky Salamander (*Desmognathus conanti*) was the most-commonly captured adult salamander species (47 captures) and the Southern Two-lined Salamander (*Eurycea cirrigera*) was the most commonly-captured larval salamander species (85 captures; Table 1). The Black Mountain Salamander (*Desmognathus welteri*) and the Cave Salamander (*Eurycea lucifuga*) were both only captured once at the Fentress County site and the Williamson County site, respectively (Table 4). A total of 5 larval Spring Salamanders

(*Gyrinophilus porphyriticus*) were captured at the Fentress County site only (Table 4).

Salamander counts were similar for adult, larval, and total counts between ARD-impacted and non ARD-impacted stream segments. Although adult captures tended to be greater in ARD stream segments and larval counts tended to be greater in non-ARD stream segments, these results were not statistically significant (Figure 9). Similarly, salamander species richness for both adult and larval salamanders was similar between ARD and non-ARD impacted stream segments (Figure 10). Although species richness for larval and adult salamander combined tended to be greater in non-ARD impacted streams, these results were not statistically-significant (Figure 10).

When compared by stream disturbance type, the percent composition of Southern Two- lined Salamanders (*Eurycea cirrigera*) was greater in ARD impacted stream segments when compared to non-ARD impacted stream segments (Figure 11). In addition, the abundance of Spring Salamander (*Gyrinophilus porphyriticus*) larvae in ARD impacted streams was less than captures in non ARD-impacted stream segments (Figure 11).

<u>Discussion</u>:

Bioattenuation of ARD Discharge:

This study used geochemical and biological indicators to evaluate treatments with the goal of attenuating microbial-derived ARD. The treatment strategies included disrupting the microbial population through chemical shock or shifting the microbial population from iron-sulfide oxidizing bacteria to sulfur-reducing bacteria with supplements. In addition to evaluating effectiveness of the treatment, consideration was given to the longevity of the treatment. The optimum attenuation and longevity treatment was a sequential injection of NaOH, followed by sodium lactate and soy infant formula. This sequential treatment promoted the highest rise in pH, alkalinity, sulfide, slime-producing and sulfur-reducing bacteria in the discharge waters as compared to the other treatments and reference controls.

The initial injection of NaOH probably neutralized the pH within a niche long enough to allow heterotrophic, aerobic and anaerobic bacteria to colonize and feed on the lactate and soy formula. The dissolved soy formula is rich in nutrients, such as protein, carbohydrates, fats, and B vitamins. These nutrients stimulate heterotrophic aerobic bacteria, such as the slime-producing bacteria, responsible for rapidly consuming oxygen and establishing an anaerobic environment. Once the oxygen is consumed, the facultative anaerobic and obligate anaerobic bacteria begin to dominate the microbial community. Lactate was included in the supplement treatment since it is the preferred food of sulfur-reducing bacteria (Carr and Hughes, 1998) and has been used to stimulate their growth in groundwater systems (Bradley, 2003). The B-vitamins present in the soy formula are essential to anaerobic respiration enzymes and would normally take a long time to synthesize (Ellis, et al., 2000). Another benefit associated with the soy formula was that the milky liquid flowed effortlessly into the pore spaces while adhering to the shale surfaces. Even as the soy formula began to spoil and curdle, it continued to adhere to the surfaces, providing excellent conditions for biofilm development and generating anoxic conditions on the surfaces of the shale. Despite pumping 45 pore volumes of water with relatively high dissolved oxygen (6 to 10 mg/L) through the microcosms, the treatment continued to provide alleviation of ARD symptoms for the duration of the experiment (231 days). The success of the treatment was probably due in part to the biofilm development on the shale materials. Beyenal and Babauta, (2012) describe how environmental bacteria such as

Geobacter sulfurreducens develop biofilms on solid surfaces and establish extremely anaerobic, reducing (electron rich) conditions at the biofilm-solid interface. Such a biofilm would provide a physicochemical barrier to the oxygen and the chemolithotrophic bacteria involved in the oxidation of iron-sulfide minerals and production of acid rock drainage (conceptual model, Figure 8).

In addition to the beneficial results from the sequential injection of NaOH, soy formula and lactate, there were some other interesting results. Use of phosphate in experiment 2 provided favorable pH control, reduced iron and sulfate, and enhanced bacteria populations for both the lactate, and the lactate + soy formula. However, the treatments in experiment 2 also released water with high levels of phosphate, median values ranged 51-95 mg/L. Phosphate levels of this magnitude would not be acceptable due to eutrophication potential of receiving streams. Perhaps treatments using phosphate buffer would work in an engineered bioreactor where flow is more tightly controlled. Additional research is needed to determine if use of phosphate buffer would be feasible in a bioreactor. As noted earlier, the results of sequential treatment using NaOH, soy formula and lactate provided a promising treatment. There was one negative side effect of the treatment, a foul odor in the discharge waters associated with the initial curdling of the formula. The odor was most noticeable after 4 days and lingered for another 5 days. This odor might be an issue in a populated area, but not in a rural areas removed from the general public. In conclusion, the results of this study indicate there is good potential that ARD can be passively attenuated by using a sequential treatment of NaOH, followed by a mixture of lactate and soy formula.

Salamander Sampling:

Our project evaluated the biological impacts of ARD on stream salamander communities. Overall, we found little evidence to suggest that ARD is negatively impacting stream biota at the two sites that we examined in this study. Specifically, we found negligible differences in larval and adult salamander counts and richness between ARD-impacted vs. non-ARD-impacted stream segments. However, we did find that percent composition of *E. cirrigera* was greater in ARD-impacted stream segments when compared to non-ARD-impacted sites. Previous research suggests that *E. cirrigera* is somewhat tolerant of streamside disturbance and can assume a dominant position in moderately disturbed stream sites (Southerland et al. 2004). We observed this relationship of salamander diversity at the 840 site in Williamson County. Specifically, the upstream non-ARD site had a more diverse salamander assemblage composed of three species, including *D. conanti*, *E. cirrigera*, and *E. lucifuga*. The adjacent, ARD-disturbed stream section only contained one species, *E. cirrigera*, which we attribute to the disturbed nature of the downstream stream section. We did not observe the same relationship at the Fentress County site, but did find that the abundance of *G. porphyriticus* was comparatively less in the downstream ARD-disturbed stream section. The downstream ARD-disturbed stream section at the Fentress County site had a short streambed section that terminated underground abruptly approximately 30 m downstream from ARD runoff from the adjacent road construction. The ARD disturbance at the Fentress County site was not as extensive as the 840 site in Williamson County and likely explains the comparably high salamander abundance and richness of the downstream site compared to the upstream stream site at the Fentress County ARD site.

We explored the utility of steam salamanders as indicators of biological condition. Streamside salamanders in the family Plethodontidae are lungless and rely primarily on cutaneous respiration to acquire oxygen (Wells 2007). Previous research efforts have shown that degraded steam environments tend to have reduced abundance, richness, and total counts of stream salamanders (Wilson and Dorcas 2003; Southerland et al. 2004). Collectively, these species require well-oxygenated stream habitats with an abundance of cover objects and intact riparian buffers. Although salamanders are useful as indicators of biological integrity, these organisms can present difficulties as monitoring tools because they can be difficult to detect because they are primarily fossorial and activity patterns can vary greatly depending on weather patterns (Williams and Berkson 2004). Repeated sampling is often necessary account for environmental covariates that impact detection and to obtain accurate estimates of occupancy and abundance (Bailey et al. 2004; Dodd and Dorazio 2004).

Our results provide a preliminary examination of the impacts of ARD on stream salamander communities. Previous research in the Great Smoky Mountains National Park illustrated that ARD runoff from an Anakeesta shale formation resulted in decreased abundance and species richness of stream salamanders (Kucken et al. 1994). Our study only evaluated the impacts of ARD on salamanders at two sites in TN, which greatly limits the inference of ARD impacts on stream biota statewide. However, our preliminary data suggests that impacts of ARD on stream salamanders appears to be site-specific and related to the relative length of the stream impacted by the adjacent ARD disturbance. Future studies should include a much larger sample of sites across Tennessee and a variety of ecoregions and include streams that have a variety of impacts from ARD discharge.

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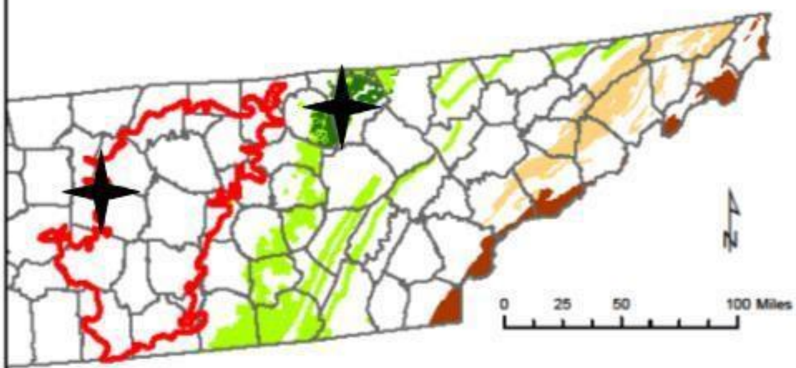

EXPLANTION

- Igneous and Metamorphic formations
- Fentress Formation
- Occurrence of the pyrite bearing Sevier Shale
- Outcrop of the Pennington Shale -- marks the lateral extent of the Pennsylvanian coal-bearing formation.
- General distribution of the Chattanooga Shale along the Highland Rim escarpment

Figure 1. -- Location of pyrite bearing formation in Middle and East Tennessee.

Figure 2. Road cut in Williamson County, Tennessee with signs of acid rock drainage.

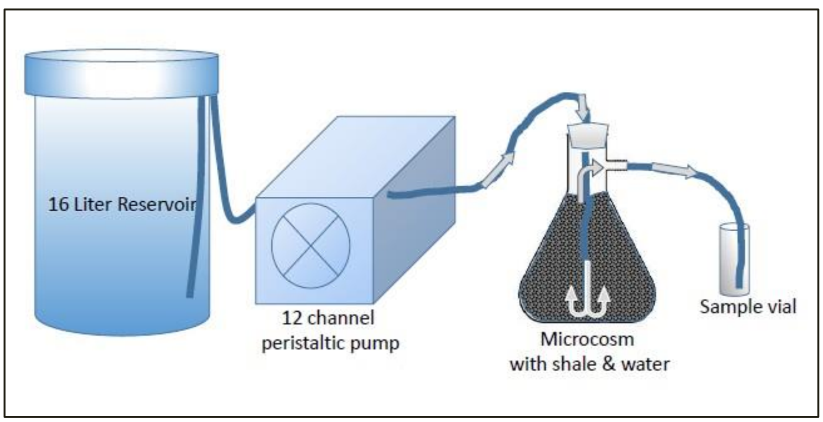

Figure 3. Reservoir, pump and microcosm schematic. Only one of twelve microcosms is depicted. Items are not to scale.

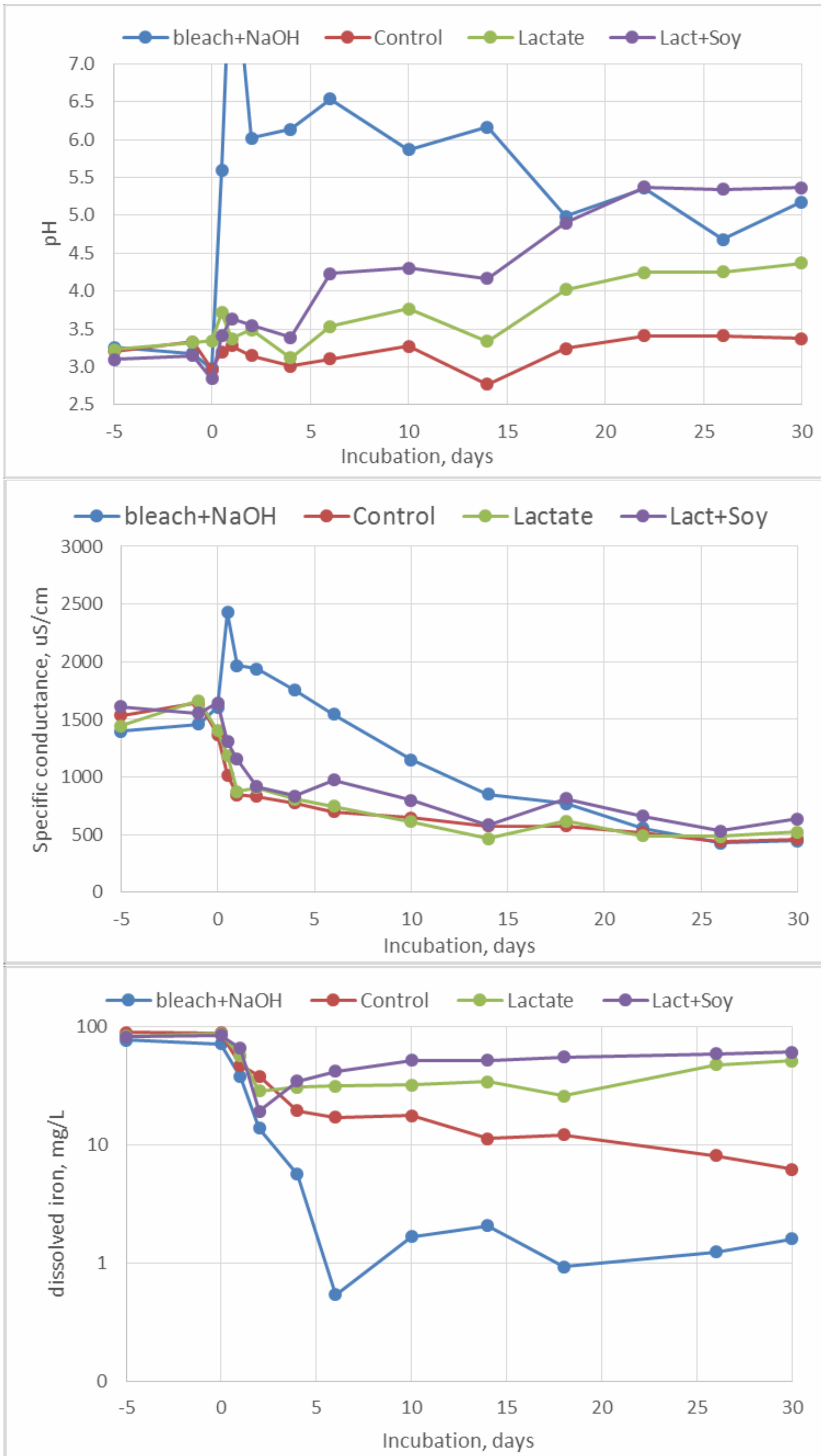

Figure 4. Experiment 1 (a) Average pH of discharge waters, (b) Average specific conductance of discharge waters, (c) Average dissolved iron concentration in discharge waters. Treatments included reference controls, addition of bleach and NaOH, addition of lactate, and addition of lactate and soy formula.

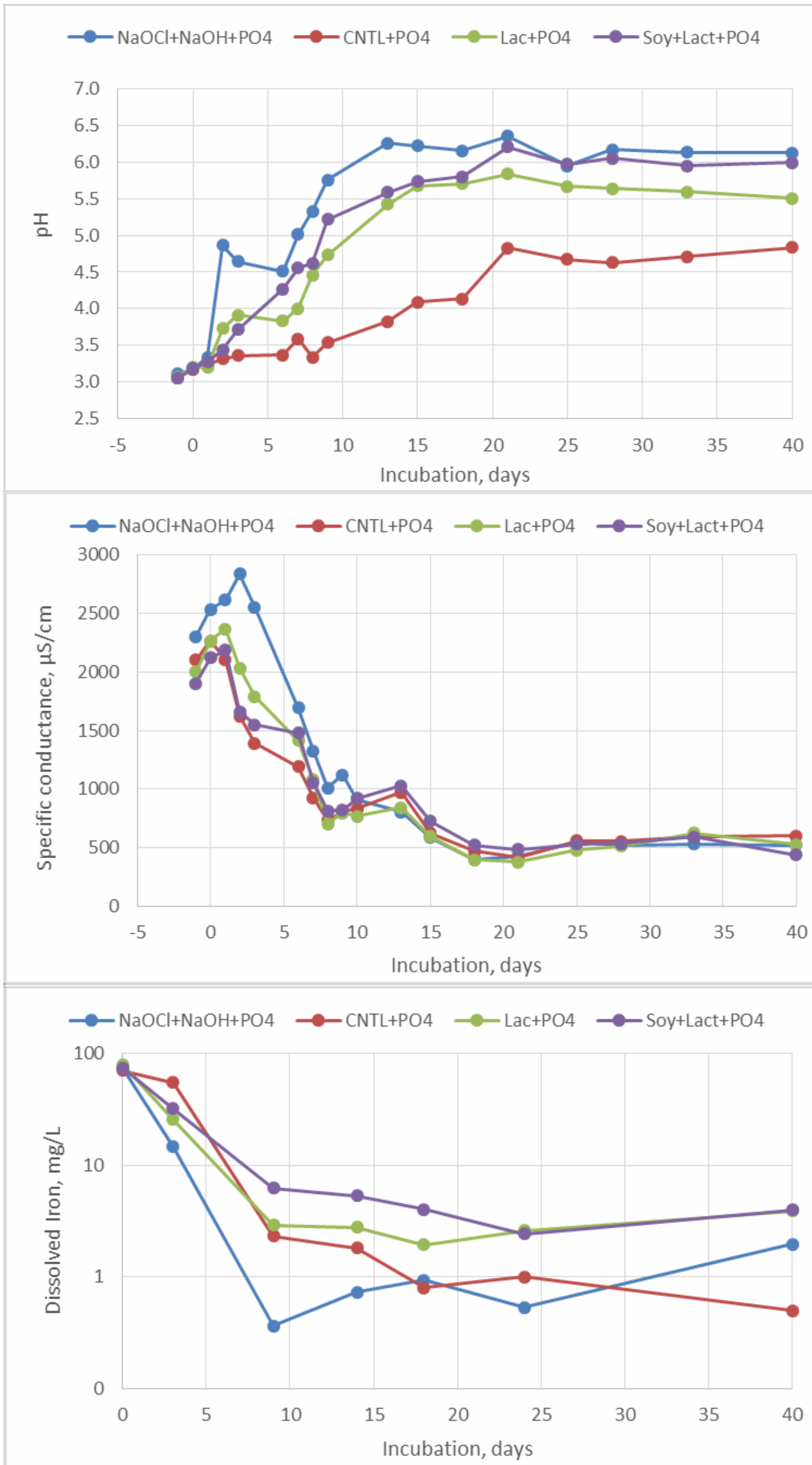

Figure 5. (a) Average pH of discharge waters, (b) Average specific conductance of discharge waters, (c) Average dissolved iron concentration in discharge waters. Treatments included reference controls with potassium phosphate (K_2PO_4), addition of bleach + NaOH + K_2PO_4, addition of lactate + K_2PO_4, and addition of lactate and soy formula + K_2PO_4.

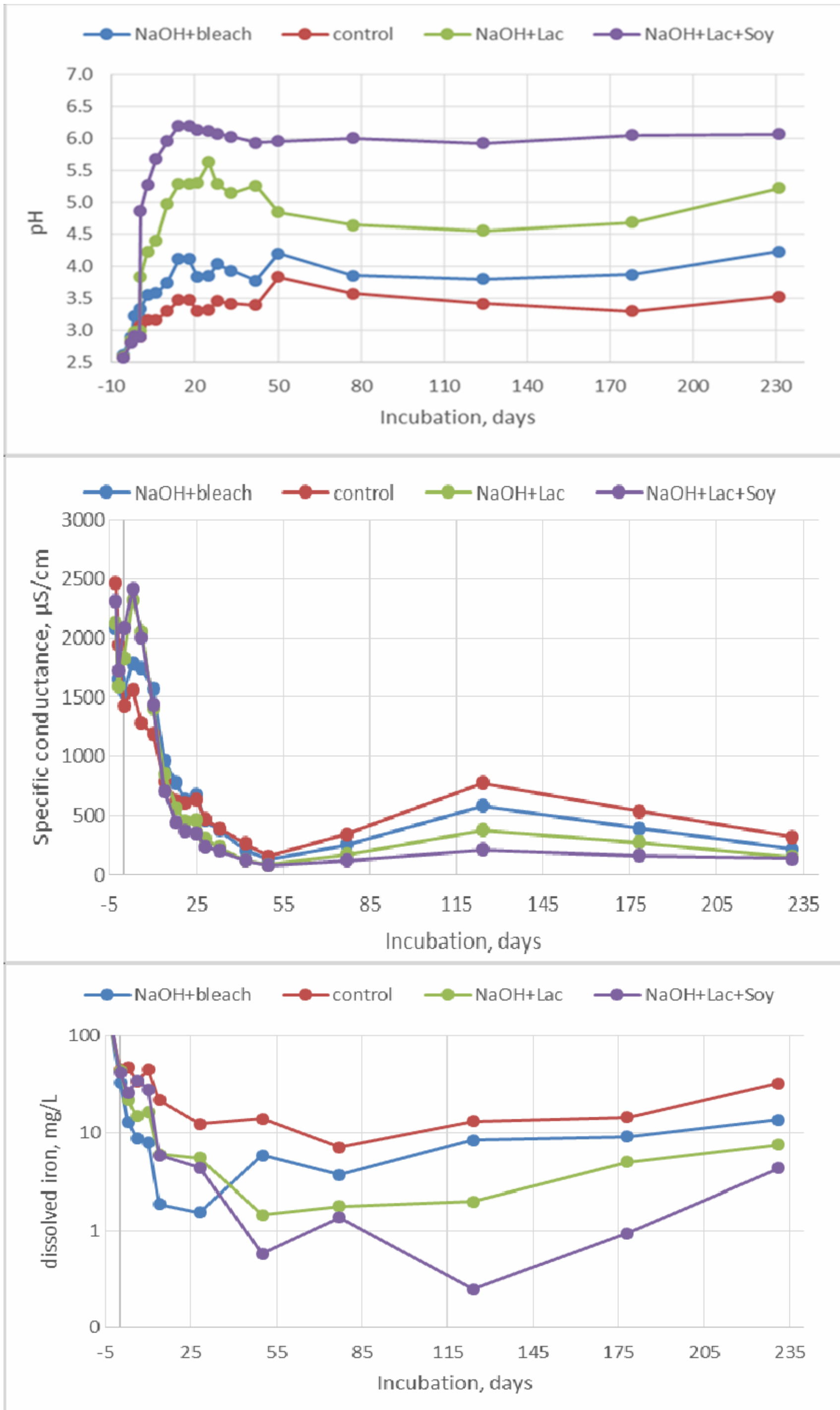

Figure 6. (a) Average pH of discharge waters, (b) Average specific conductance of discharge waters, (c) Average dissolved iron concentration in discharge waters. Treatments included reference controls with nothing added, sequential addition of NaOH followed by bleach, NaOH followed by lactate, and addition of NaOH followed by lactate and soy formula.

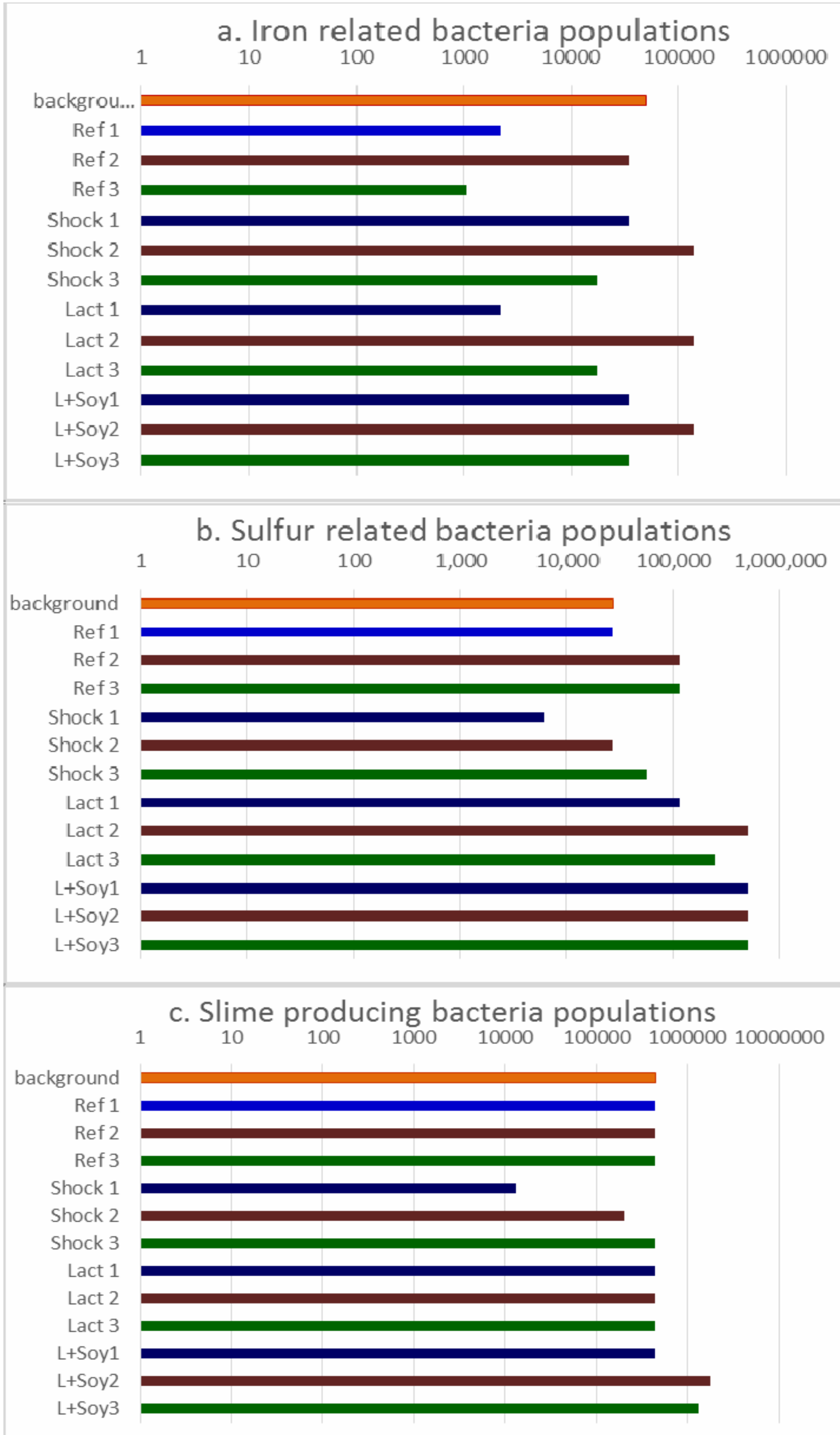

Figure 7. BART results - (a) Population estimates of iron related bacteria, (b) Population estimates of sulfur related bacteria, (c) Population estimates of slime producing bacteria. [background = neutral pH waters from site used in reservoir; Ref = reference control; Shock = NaOH and bleach shock treatment; Lact = Lactate treatment; L+Soy = Lactate and soy formula treatment; Experiment = 1, 2, 3]

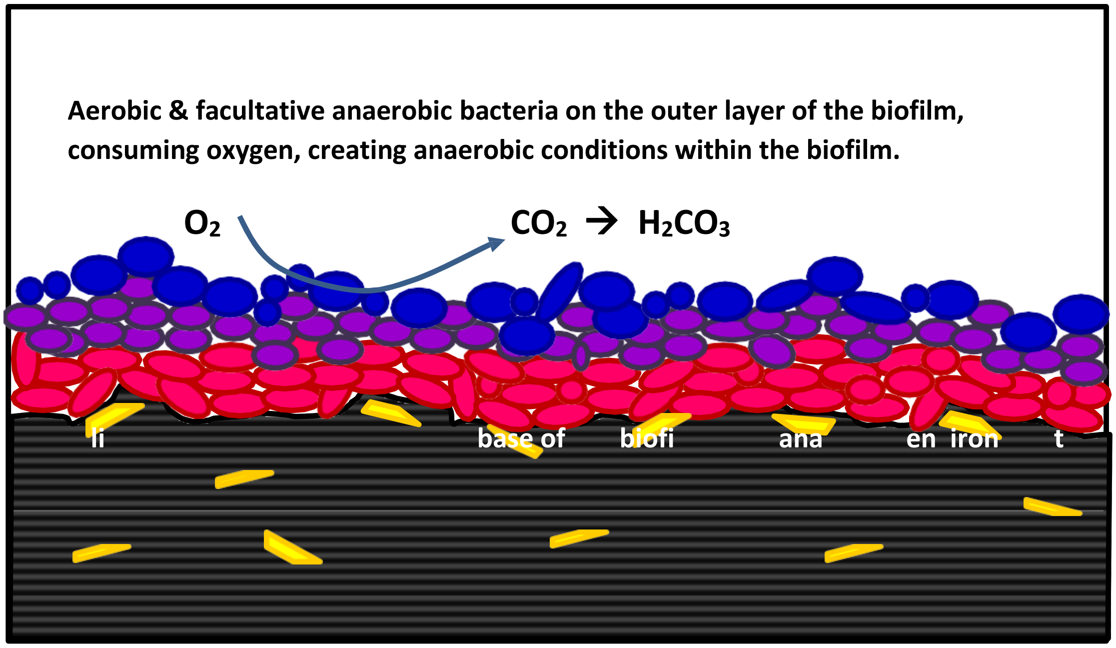

Figure 8. Conceptual model of biofilm augmented by the soy formula and lactate; setting up a oxidation-reduction gradient from the outside to the base of the biofilm.

Figure 9: Total salamander counts for adult, larval, and all life stages combined at ARD-impacted and non ARD-impacted streams in Tennessee.

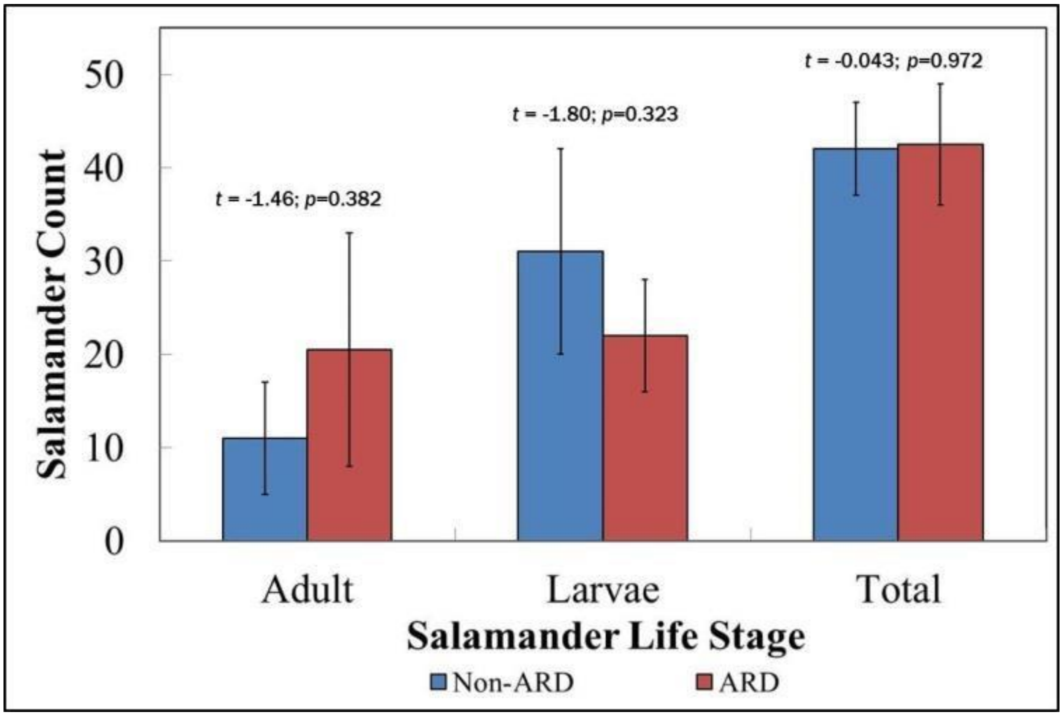

Figure 10: Total salamander richness for adult, larval, and all life stages combined at ARD-impacted and non ARD-impacted stream segments in Tennessee.

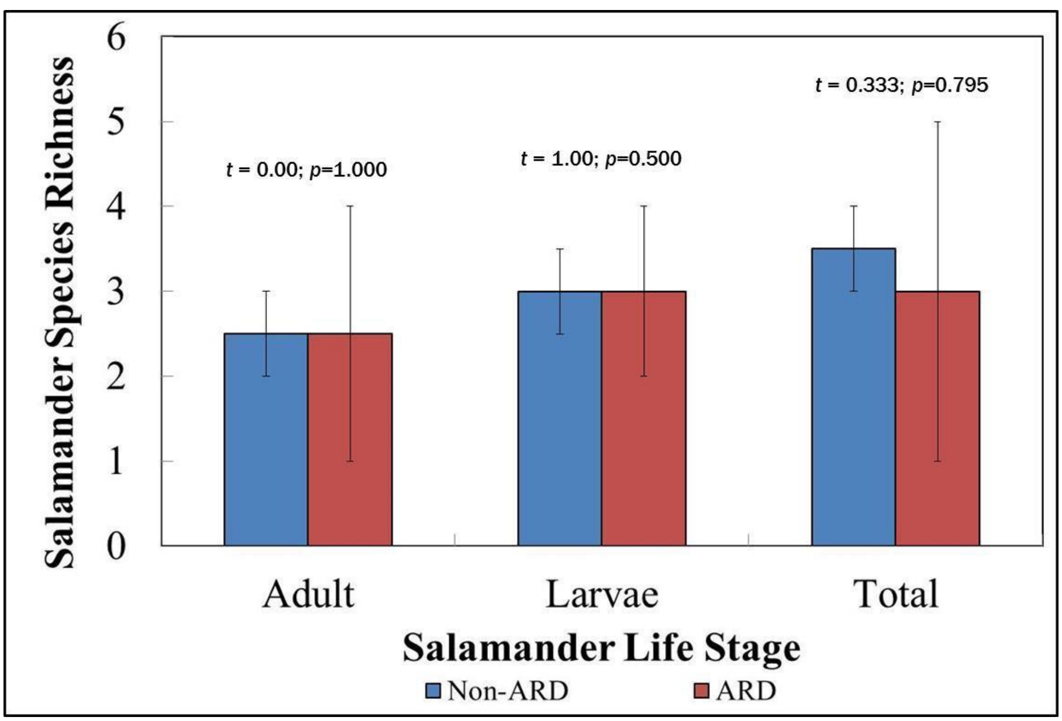

Figure 11: Species composition for larval and adult salamanders ARD-impacted and non-ARD impacted streams in Tennessee. Four-letter species codes correspond with species scientific names listed in Table 4.

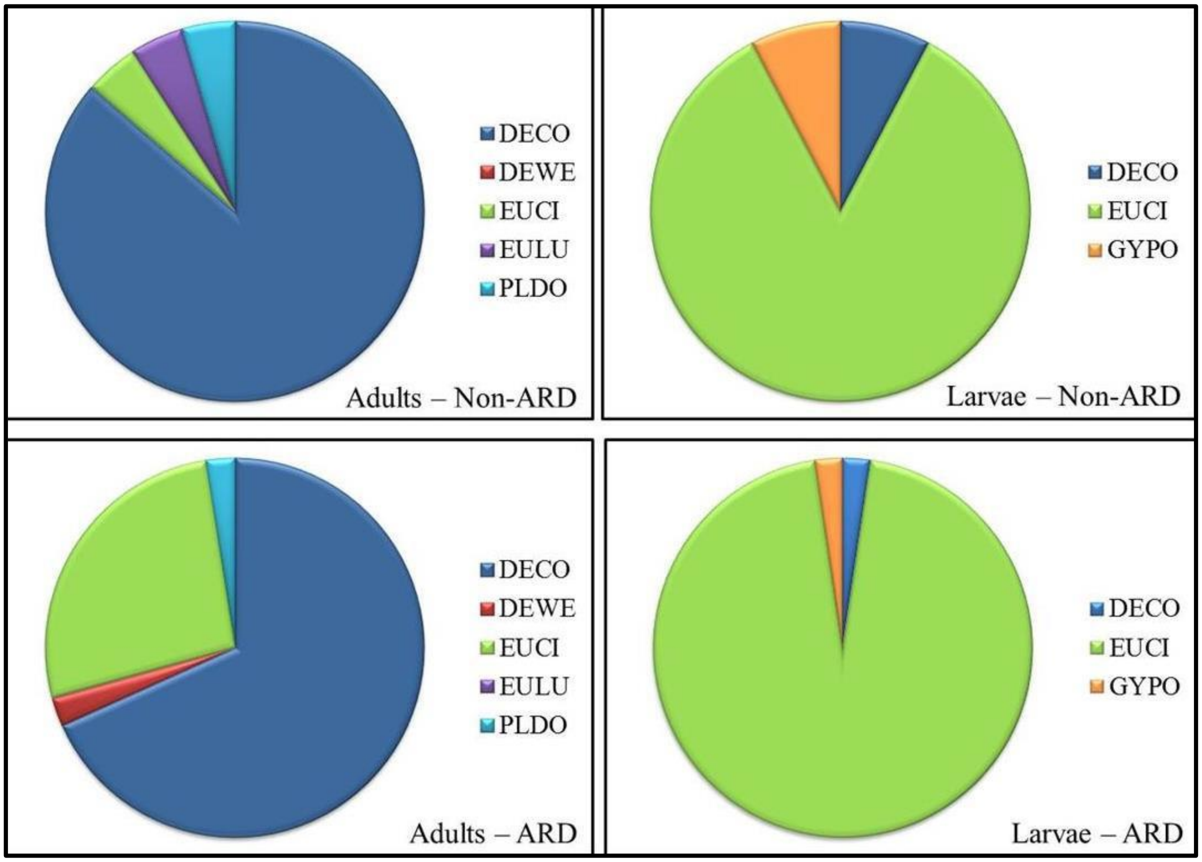

Table 1. Description of the three experiments, the duration of the experiment, the supplements injected and the rationale for the treatment. [3 replicate microcosms per treatment]

Experiment # (duration)	Supplements & amount	Rationale
Experiment 1 (30 days)		
Bleach ($NaClO$) + Sodium hydroxide ($NaOH$) together	1.5 mL of 6% bleach + 1.5 gr NaOH dissolved in 20 mL H_2O	Chemical shock would raise the pH and kill the bacteria, but water containing live bacteria would slowly re-inoculate the system
Nothing (reference control)	20 mL of reservoir water	No treatment, allowing ARD to progress in the system
Sodium lactate ($NaC_3H_5O_3$)	0.75 gr (1 mL) sodium lactate syrup in 20 mL H_2O	Lactate is a favorite food of sulfur reducing bacteria.
$NaC_3H_5O_3$ + Soy infant formula	0.75 gr sodium lactate + 1.5 gr soy infant formula (Kroger brand)	Lactate provide food, soy formula provides vitamins, especially B, and protein. Plus sticking endures due to coagulation on surfaces.
Experiment 2 (40 days)		
$NaClO$ + $NaOH$ + K_2HPO_4 together	1.5 mL of 6% bleach + 1.5 gr NaOH + 10 mL of 1 molar K_2HPO_4 buffer (pH 9.1)	Rationale above, with potassium phosphate buffer to help moderate pH and precipitate iron as $FePO_4$
just K_2HPO_4	Reservoir water + 10 mL of 1 molar K_2HPO_4 buffer (pH 9.1)	This treatment tested the ability of phosphate buffer to precipitate iron and maintain neutral pH of water
$NaC_3H_5O_3$ + K_2HPO_4	0.75 gr (1 mL) sodium lactate + 10 mL of 1 molar K_2HPO_4 buffer	Rationale above, plus the benefits of a buffer neutralizing pH and iron precipitation with phosphate.
$NaC_3H_5O_3$ + Soy infant formula + K_2HPO_4	0.75 gr sodium lactate + 1.5 gr soy infant formula + 10 mL of 1 molar K_2HPO_4 buffer	Rationale above, plus the benefits of a neutralizing buffer and iron precipitation with phosphate.
Experiment 3 (231 days)		
$NaOH$ + $NaClO$ sequential	1.5 gr NaOH dissolved in 10 mL H_2O added first, then 1.5 mL of 6% bleach added with 8.5 mL water	The NaOH was injected first to adjust the pH prior to injecting the treatment (bleach water) to facilitate reactions
Nothing – Reference control	20 mL of reservoir water	No treatment to facilitate comparison of treatment with normal ARD
$NaOH$ + $NaC_3H_5O_3$	1.5 gr NaOH dissolved in 10 mL H_2O followed by 0.75 gr of sodium lactate syrup in 10 mL H_2O	Pre-treating with NaOH would raise the pH in an area, allowing the pH sensitive SRB to establish a foothold
$NaOH$ + $NaC_3H_5O_3$ + Soy infant formula	1.5 gr NaOH dissolved in 10 mL H_2O followed by	Pre-treating with NaOH would raise the pH in an area, allowing the pH

	0.75 gr sodium lactate + 1.5 gr soy infant formula	sensitive SRB to establish

Table 2. Geochemical tests run on the discharge and reservoir waters. Not all the parameters were run on every sample.

Parameter	Method	EPA approved	Lower detection limit
Dissolved oxygen	Calibrated meter	yes	0.5 mg/L
pH	Calibrated meter	yes	0-14, 2 decimal places
Specific conductance	Calibrated meter	yes	0.1 uS/cm
Alkalinity, Total	Hach TNT 870	no	25 mg/L $CaCO_3$
Dissolved Iron	Hach TNT 858	yes	0.2 mg/L Fe
Reactive phosphorous	Hach TNT 843	yes	0.05 mg/L PO_4
Sulfate	Hach TNT 864	no	4.9 mg/L SO_4
Sulfide	Methlene Blue	yes	0.01 mg/L S^{2-}
Iron related bacteria	Biological Activity Reaction Test™	Not applicable	10 colony forming units
Slime producing bacteria	Biological Activity Reaction Test™	Not applicable	10 colony forming units
Sulfur related bacteria	Biological Activity Reaction Test™	Not applicable	10 colony forming units

Table 3. Geochemical data summarized as median and interquartile range (IQR) for alkalinity (Alk), dissolved oxygen (dO_2), reactive phosphate (PO_4), sulfide (S^{2-}), and sulfate (SO_4). All values are reported in milligrams per liter. [Blch+NaOH = bleach and sodium hydroxide; Ref Cntl = reference control; Lact = sodium lactate; Lac+Soy = sodium lactate and soy infant formula; NaOH = sodium hydroxide; NA = not available]

Treatment	median Alk	IQR Alk	median dO_2	IQR dO_2	median PO_4	IQR PO_4	median S^{2-}	IQR S^{2-}	median SO_4	IQR SO_4
Blch+NaOH	29	11	2.9	1.1	0.18	0.08	0.00	0.00	541	300
Ref Cntl	0	0	3.3	0.8	0.11	0.05	0.00	0.00	320	191
Lact	0	0	2.9	0.9	0.10	0.01	0.01	0.00	353	186
Lac+Soy	0	0	2.4	0.9	0.31	0.07	0.04	0.04	377	198
Blch+NaOH+PO_4	NA	NA	1.8	0.4	51	61	0.00	0.01	494	342
Ref Cntl+PO_4	NA	NA	2.4	0.6	67	72	0.00	0.01	413	244
Lact+PO_4	NA	NA	2.3	0.6	63	57	0.01	0.01	395	283
Lac+Soy+PO_4	NA	NA	1.6	0.7	95	61	0.03	0.10	357	309
NaOH	13	26	1.4	1.0	0.39	0.15	0.01	0.02	645	153
Ref Cntl	0	16	2.2	1.4	0.43	0.34	0.01	0.02	550	198
Lact+NaOH	25	24	1.8	0.6	0.56	0.64	0.02	0.06	620	220
Lac+Soy+NaOH	98	63	1.3	0.8	0.57	1.34	0.06	0.14	465	201

Table 4: Total counts and percent composition of adult and larval stream salamanders in streams monitored for biological impacts of ARD.

Species	**Species Count**	**% of Captures**
Adult		
Desmognathus conanti (Spotted Dusky Salamander)	47	74.6%
Desmognathus welteri (Black Mountain Salamander)	1	1.6%
Eurycea cirrigera (Southern Two-lined Salamander)	12	19.0%
Eurycea lucifuga (Cave Salamander)	1	1.6%
Plethodon dorsalis (Northern Zig-zag Salamander)	2	3.2%
Total Adults	**63**	**100%**
Larvae		
Desmognathus conanti (Spotted Dusky Salamander)	5	5.3%
Eurycea cirrigera (Southern Two-lined Salamander)	85	89.4%
Gyrinophilus porphyriticus (Spring Salamander)	5	5.3%
Total Larvae	**95**	**100%**

Characterizing Stream Sediment Source Potentials in Small Urbanizing Watershed

Basic Information

Title:	Characterizing Stream Sediment Source Potentials in Small Urbanizing Watershed
Project Number:	2015TN112B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Tennessee 2nd
Research Category:	Water Quality
Focus Category:	Geomorphological Processes, Sediments, Surface Water
Descriptors:	None
Principal Investigators:	John S. Schwartz

Publications

1. Woockman, R., J. Schwartz, 2015. Excess Stream Power Management in Small Urban Stream Systems in the Ridge and Valley Province in Tennessee, "in" Proceedings of the ASCE/EWRI Watershed Management Symposium, Reston Va.
2. Woockman, R., J. Schwartz, 2016. Reach Scale Sediment Source Potential in Small Urbanizing Stream Systems, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.1A-3.
3. Schwartz, J., R. Woockman,and C. Clark, 2016. Urban Stream Restoration Planning: Towards Cost-Effective Mitigation of the Effects of Hydromodification, "in" Proceedings of the World Environmental & Water Resources Congress, West Palm Beach, FL.
4. Woockman, R., and J. Schwartz, 2016. Channel Protection: Surplus Stream Power, Channel Erosive Resistance Elements, and Sediment Source Potential, "in" Proceedings of the 16th Annual Meeting of the American Ecological Engineering Society, Knoxville, TN.,June 7-9, 2016.
5. Schwartz, J., 2015,Urban Stream Restoration: A Monitoring and Assessment Framework, "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.4B-8.

Methods, Procedures, and Facilities:

Task 1 - Site Selection:

In order to accomplish the objectives listed above, fluvial audits will be performed at both reference condition and urban-impacted sites. Representative reaches within small stream systems will be selected from 2nd and 3rd order streams (Strahler 1957) in ER67. Reference conditions sites will be determined as those having similar environmental controls (Frissell, Liss et al. 1986) but either limited anthropogenic disturbance or have reached a new stable state following disturbance. Stable state can be broadly defined as those reaches which exhibit no apparent signs of incision and our lateral retreat. Reference sites will be validated through Rapid Geomorphic Assessments (RGA) (Simon and Downs 1995) and Channel Evolution Model (CEM) stage (Simon 1989). It is expected reference sites will provide benchmarks with respect to processes and form and discriminate potential thresholds and magnitudes of response. Reference states will be distinguished as CEM stage one and six. Reference sites will be compared to urban stream reaches destabilized by hydromodification and will be distinguished by CEM stages two thru five (Simon 1989; Simon and Downs 1995).

Initial site selection will be determined based on categorizing watershed scale variables, stream system, and stream segment variables through GIS analysis and identifying logical extremes of response. Initial site selection will then be screened based on site accessibility, GIS analysis of reservoir controls, potential legacy impacts not associated with hydrologic alteration, and availability of flow data with ultimate intent of conducting fluvial audits of roughly 15 streams. As well, site selection will favor those streams systems that offer multiple reaches meeting the criteria above. Geomorphological impacts are not independent, but are known to interact with both upstream and downstream systems from the point of disturbance through process-form feedback mechanisms relevant to the fluvial system (Thorne 1998).

Progress to Date:

The site selection process was started in October 2014 through desktop analysis of relevant GIS databases and conducted by Robert Woockman. After the potential candidate list was generated on-site visits were conducted to confirm there were no access issues or other potential issues that would affect the sites relevance in the study. Final site selection included an attempt to have a generally equal dispersion of stable (qausi-equilibrium) and unstable reaches distributed across the entire study domain (Ecoregion 67 bounded by the state of Tennessee). Further selection criteria were based on sites representing variations in watershed and reach characteristics. The site selection process was finalized in fall of 2015.

Task 2 - Fluvial Audits:

A host of variables representing critical components that may influence channel response to hydromodification will be considered for observation/analysis. Candidate variables will be selected based on their ability to directly or indirectly describe relevant environmental controls, processes, and form. The candidate variables will be utilized to potentially explain some portion of the variance in potential candidate response variables and identify elements of a stream system that describe a stream reaches erosive resistance. Variables under consideration will be selected at three hierarchical scales. These scales indirectly represent both spatial and time scales of response and ultimately predict the potential capacity of a reach in question (Frissell et al. 1986). The stream system spatial scale will be defined by the downstream point of the reach in question. The stream segment scale will be delineated by tributary junctions equal to or one order lower than the stream segment of interest and should have a uniform process domain (Montgomery 1999). The reach scale will be delineated as a channel section at a minimum of 5 to 7 channel unit widths, but could exceed this length if channel resistance properties remain consistent.

Progress to Date:

Fluvial audits were performed at both reference condition sites (stable) and sites that experienced land-use changes resulting in increased impervious surface cover. Topographical surveys were completed from December 2014 thru December 2015. Longitudinal profiles included a reach slope conducted from riffle crests above and below the reach itself and utilizing the water surface elevation as reference points. Additional fluvial features included head and toe of all riffle features and deepest point in all pools within the surveyed reach itself. In conjunction with the longitudinal profile, survey cross sectional data was sampled. The cross sections were sampled in the upper portion of riffles. Recorded points were intended to characterize cross-sectional area, bank height and angle, relevant terraces, and flood-plain connection for 1-D hydraulic modeling methods. Fluvial audits were performed in conjunction with the topographical surveys. Fluvial audits included vegetation audits, soil characterization, sample of bed material distribution, assessment of influencing grade control, and RGAs. Both audits and surveys were managed by Robert Woockman (graduate student) and conducted with the support of Jackson Mohler (graduate student) and Brandy Manka (undergraduate student).

Task 3 - Analysis:

In order to meet the formerly mentioned objectives statistical analysis will be performed on data provided through fluvial audits and desktop analysis. Statistical analysis will include exploratory analysis, correlation analysis, and probability analysis. Variable selection for the fluvial audits has been carefully selected to insure that controls, processes, and form are all thoroughly described. This allows for a detailed analysis of the drivers of susceptibility to hydromodification. Ultimately, the goal of data analysis will be to utilize the representative data set, provided by the fluvial audits as foundational evidence for classification of reach sediment source potential. It is expected that classification could ultimately be utilized to inform the degree of reach susceptibility to hydromodification and improve effectiveness of mitigation efforts. Improved clarity of response should provide better understanding of the appropriate hillslope and channel mitigation practices necessary to reduce external costs (Hardin 1968). A reduction in external costs would be expected through improved effectiveness of invested mitigation funds when compared to non-segregated uniform prescriptions.

Progress to Date:

Analysis of field collected data as well as desktop is currently being conducted by Robert Woockman. Work started in late May and continues. This work is currently on a timeline to be completed by late July if things continue to progress on schedule.

References:

Frissell, C. A., W. J. Liss, C. E. Warren and M. D. Hurley, 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental management* **10**:199-214.

Hardin, G., 1968. The tragedy of the commons. *New York*.

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Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union* **38**:913-920.

Thorne, C. R., 1998. *Stream reconnaissance handbook: geomorphological investigation and analysis of river channels*, John Wiley & Sons Ltd, ISBN 0471968560

Information Transfer Program Introduction

FY 2015 Information Transfer Program Progress and Achievements

The major emphasis of the information transfer program during the FY 2015 grant period focused on technical publication support, conference planning/development, and improvement in the information transfer network. The primary purpose of the program was to support the objectives of the technical research performed under the FY 2015 Water Resources Research Institute Program.

The primary objectives, as in previous years, of the Information Transfer Activities are:

To provide technical and structural support to water researchers performing research under the WRRIP.

To deliver timely water-resources related information to water researchers, agency administrators, government officials, students and the general public.

To coordinate with various federal, state, and local agencies and other academic institutions on program objectives and research opportunities.

To increase the general public's awareness and appreciation of the water resources problems in the state.

To promote and develop conferences, seminars and workshops for local and state officials and the general public which address a wide range of issues relating to the protection and management of the state's water resources.

During the FY 2015 grant period, a major focus of the information transfer activities was on the participation of the Center staff in the planning and implementation of several statewide conferences and training workshops.

As an on-going sponsor, the TNWRRC was involved in the planning and implementation of the 2015 Tennessee Water Resources Symposium, which was held on April 1-3, 2015 at Montgomery Bell State Park in Burns, Tennessee. The goals of the symposium are: (1) to provide a forum for practitioners, regulators, educators and researchers in water resources to exchange ideas and provide technology transfer activities, and (2) to encourage cooperation among the diverse range of water professionals in the state. As with previous symposia, the 2015 Symposium was very successful with over 360 attendees and approximately 73 papers and 29 student posters being presented in the two-day period. The event received a good deal of publicity across the state.

TNWRRC was a co-sponsor of the Annual Tennessee Stormwater Association Conference, Fall Into Green, held on October 20-22, 2015 at Fall Creek Falls State Park. Over 260 attendees including staff from MS4 communities, state agencies, and engineering consulting companies from across the State participated in the 3 day event which included over 40 presentations, 3 hands-on workshops and several social networking sessions.

TNWRRC was a co-sponsor of the 2015 East Tennessee Development Symposium held on Nov. 18-19, 2015 at the Knoxville Convention Center. This two day event provides a powerful platform for networking with hundreds of professionals and to share knowledge, lessons learned and best practices in the development field. Attendees include land developers, civil and environmental engineers, landscape architects, and consultants, professionals from the real estate and banking sectors, land use planners state and local government staff and policy makers from all level s of government. Last year over 375 persons attended the 2016 Symposium.

The Center also participated in several meetings and workshops across the state that were held to address water related problems and issues such as stormwater management, water quality monitoring, non-point source pollution, water supply planning, TMDL development, watershed management and restoration, multiobjective river basin management and lake management issues and environmental education in Tennessee. The following is a brief listing of formal meetings, seminars and workshops that the Center actively hosted, supported and participated in during FY 2015:

TNSA East Tennessee Regional Group meetings held on March 6, 2015; June 5, 2015; September 11, 2015; December 4, 2015 and February 19, 2016 at different locations in East Tennessee. TN Stormwater Association and TNWRRC sponsored a quarterly meeting of local government officials responsible of implementing local stormwater programs under the MS4 Phase II permit. These meeting are designed to provide local officials with information that will add them in development of their local stormwater management programs.

Tennessee Wetlands Technical Advisory Task Force meeting, May 4-5, 2015, Nashville, Tennessee. Meeting of government agency staff and technical experts to advise to the State on issues related to the Tennessee Wetlands Management Plan.

WaterFest, May 1, 2015, Knoxville, TN. An annual community-wide event sponsored by the Water Quality Forum that highlights the importance of our water resources and the activities of the WQF partners to protect and manage those resources. Over 930 elementary school age students from the Knox County school systems and schools from the surrounding region attended.

Fundamentals of Erosion Prevention and Sediment Control for Construction Sites - Level I Training and Certification course, sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. A one day course for developers, contractors, road builders and others involved with construction activities across the State. The course was offered on the following dates in FY 2015: February 17, 2015, Nashville; March 19, 2015, Knoxville; March 25, 2015, Memphis; April 21, 2015, Chattanooga; May 7, 2015, Nashville; May 15, 2015, Knoxville; June 16, 2015, Memphis; July 31, 2015, Nashville; September 2, 2015, Knoxville; September, 22, 2015, Nashville; October 8, 2015, Chattanooga; October 27, 2015, Clarksville; November 4, 2015, Memphis; November 12, 2015, Johnson City; December 7, 2015, Nashville; December 9, 2015, Knoxville; December 14m 2015 Chattanooga February 23, 2016, Nashville. For this time period over 2,167 persons obtained Level I certification.

Design Principles for Erosion Prevention and Sediment Controls for Construction Sites Level II Certification course sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. A two day training course for engineers, landscape architects, and other design professionals responsible for the development of Storm Water Pollution Prevention Plans for permitted construction sites. The course was offered on the following dates in FY 2015: February 4-5, 2015, Ft. Campbell; April 8-9, 2015, Nashville; May 20-21, 2015, Memphis; June 10-11, 2015, Knoxville; September 9-10, 2015, Cookeville; October 29-30, 2015, Nashville; November 17-18, 2015, Chattanooga, TN. For this time period over 342 persons obtained Level II certification.

Construction Site Inspection as Required by Tennessee's Construction Stormwater General Permit - Level I Recertification course sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. This is a half day course which focuses on inspection requirements under the current TNCGP. This course is required for all inspectors of construction sites that have coverage under the TNCGP and serves as a recertification course for those that have completed the Level I Fundamentals course. The course was offered on the following dates: May 12, 2015, Nashville; May 19, 2015, Memphis; June 3, 2015, Knoxville; September 18, 2015, Knoxville; October, 6, 2015, Jackson; October 7, 2015, Nashville; October 28, 2015, Chattanooga; November 3, 2015, Memphis; November 13, 2015, Johnson City; December 3, 2015, Nashville; December 15, 2015, Chattanooga; December 17, 2015, Knoxville and January 27, 2016 Nashville. For this time period over 2,837 persons obtained Level I Recertification.

Tennessee Hydrologic Determination Training (TN-HDT) program. This training program was developed and is being offered to meet the requirements of Tennessee Code Annotated, Section 69-3-105 which establish standard procedures for making stream and wet weather conveyance determinations in Tennessee. The three day course was developed by staff from the Tennessee Department of Environment and Conservation (TDEC) and faculty from the University of Tennessee and Tennessee Technological University. TNWRRC is responsible for administration of the TN-HDT program and works with TDEC and university faculty to deliver the course three to four times each year at select locations across the State. The course was offered twice in 2015 -; March 11-13, 2015 in Oak Ridge, TN.; and on August 10-12, 2015, at Montgomery Bell State Park in Burns, TN. Those that successfully complete the course and meet the other minimum qualifications at certified as Tennessee Qualified Hydrologic Professionals (TN-QHPs). The TN-QHP certification is good for three years. Every three years all TN-QHPs or TN-QHP In-Training must attended a one day Refresher course to maintain their certification. The TN-HDT Refresher courses were offered in 2015 on the following dates and locations: June 25, 2015, Knoxville; July16, 2015, Nashville; October 28, 2015, Nashville; November 20, 2015, Knoxville.

Low Impact Development Stormwater Manual and Training Courses The TNWRRC, including faculty and graduate students from the Department of Civil and Environmental Engi¬neering (CEE) and the Department of Biosystems Engi¬neering and Soil Science (BESS) have been working with staff from TDEC Division of Water Resources to develop the first edition of the Tennessee Permanent Stormwater Management and Design Guidance Manual. TDEC has established stormwater runoff reduction as the primary treatment objective for new development and redevelopment projects across Tennessee. This new manual will pro¬vide detailed design guidelines for permanent stormwa¬ter control measures that meet this treatment objective. The primary purpose of this manual is to serve as a technical design reference for designated and non-des¬ignated (unregulated) MS4 (municipal separate storm sewer system) communities in Tennessee. It is intended to provide the information necessary to properly meet the minimum permanent stormwater management re¬quirements as specified in MS4 permits. The UT team has also developed the Runoff Reduction Assessment Tool (RRAT) to be used in conjunction with the Manual. The RRAT will assist professional engineers and other design professionals to ensure that the stormwater management plans they have prepared meet the permanent stormwater performance standards for new or redevelopment sites. The first edition of the Manual was released in January 2015. The Manual and the RRAT model may be down loaded form the new Tennessee Stormwater Training Program website, http://tnstormwatertraining.org/index.asp

In addition, TNWRRC with support from faculty the Department of Civil and Environmental Engi¬neering (CEE) and the Department of Biosystems Engi¬neering and Soil Science (BESS) has developed and delivered new training courses that will inform local officials, administrators, design profes¬sionals and consultants, and private sector companies on the use of the manual to develop, implement, and maintain the permanent stormwater control measures and practices described in the manual. The Permanent Stormwater Management Design course is a one-day course designed for engineers, landscape architects; stormwater plans preparers and local government plan reviewers. The course describes how to create stormwater management systems using green infrastructure and evaluate performance with the Tennessee Runoff Reduction Assessment Tool (TNRRAT) so that stormwater management plans for new and redevelopment projects meet the requirements of the TN MS4 permit. The PSW Design course has been conducted on the following dates in 2015: March 30, 2015, Nashville; June 18, 2015, Knoxville; July 28, 2015, Memphis; July 30, 2015, Nashville; November, 10, 2015, Knoxville . Over 152 persons attended the course.

The two day Stormwater Control Measure Inspection and Maintenance training and certification course will be piloted in fall 2015 with reburial public offerings of the course to begin in early 2016. Course information and registration for both courses can be found on the Tennessee Stormwater Training program website. http://tnstormwatertraining.org/index.asp.

TNWRRC; the TN. Concrete Association; and Knox County Stormwater department sponsored a two day Pervious Concrete Installation and Maintenance workshop on May 7-8, 215. Local contractors, engineers, plan reviewers and Stormwater inspection personnel from across East Tennessee received hands on instructions on proper installation and maintenance practices for pervious concrete. The second day of the workshop was for those that want to obtain the TCA Pervious Concrete Technician Certification. Over 60 persons attended the first day and 23 obtain certification on the second day.

Adopt-A-Watershed teacher training workshop held on June 10-12 20154, Knoxville, TN. This four day workshop sponsored by TNWRRC and partners of the Water Quality Forum trains middle and high school science teachers on how to work with their students to conduct watershed investigations and develop watershed improvement service projects and part of their classroom curriculum. Eight new teachers completed the training course in 2015.

The Watershed Faculty at the University of Tennessee and TNWRRC hosted the 4th Annual Watershed Symposium on September 12, 2015, at Hollingsworth Auditorium on the UT Agriculture Campus. The primary purpose of the annual Symposium is to highlight the latest research in water-related fields and share insights from state and federal experts around this year s theme of Horizons of Environmental and Water Policy: Where we are and where we are going. The Keynote address was provided by Chris Thomas, Branch Chief of Sustainable Communities and Watersheds for the US Environmental Protection Agency Region 4. Other highlights from the technical agenda included presentations by Paul Davis, Water Resources Consultant; Damon Hearne of the Little Tennessee River Native Fish Conservation Area and Trout Unlimited Conservation Director; Robby Karesh, Stormwater Section Coordinator, Tennessee Department of Environment and Conservation; and experts from the many fields of science in watershed management. University of Tennessee students also provided presentations in technical and poster sessions. Over 350 faculty, students government and private water resources professional attended the 4th Annual Watershed Symposium.

Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2015 and January 2016. Meeting of government agencies and other organizations to share information and discuss water quality issues in the Tennessee River and it's tributaries in Knox County.

Other principal information transfer activities which were carried out during the FY 2015 grant period focused on the dissemination of technical reports and other water resources related reports published by the Center as well as other types of information concerning water resources issues and problems. A majority of the requests for reports and information have come from federal and state government agencies, university faculty and students, and private citizens within the state. The Center also responded to numerous requests from across the nation and around the world.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	14	0	0	0	14
Masters	6	0	0	0	6
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	23	0	0	0	23

Notable Awards and Achievements

Awards: TN WRRC researcher, Roy Arthur, received a commendation from the Tennessee Recreation and Parks Association for his work on the Harrell Road Stormwater Demonstration Park located in northwest Knox County. Harrell Road Park is a 19-acre passive nature park with three-quarter miles of soft trails. Roy helped design the project for public education that includes rain gardens, stormwater ponds, pervious pavement, stormwater diversions, native vegetation, and interpretive signage. The park is a collaborative effort between the Legacy Parks Foundation, Knox County Stormwater, Knox County Parks and Recreation, and the WRRC.

TN WRRC Research Associate, Ruth Anne Hanahan, and Tim Phelps, Forestry Communications & Outreach Unit Leader of TDA Division of Forestry, introduced the new Tennessee Urban Riparian Buffer Handbook, A Practical Guide to Establishing Healthy Streamside Buffers, at the Tennessee Stormwater Association Annual Conference at Fall Creek Falls State Park on October 20, 2015. Their presentation also included a discussion of the six-year, USDA Forest Service grant-funded Urban Riparian Buffer Program.

The Handbook provides practical step-by-step guidance to anyone wishing to organize volunteer-based riparian buffer tree planting projects. It includes a comprehensive recommended riparian buffer plant list organized by east, middle and west Tennessee, and examples of handout materials that can be used to engage the public as well as potential landowners in such projects. It is available on the Tennessee Division of Forestry website. There is an article on the Handbook in the TNSA Fall Newsletter and in the WEF Stormwater Report.

The Tennessee Water Resources Research Center was recently featured in Impact: a weekly newsletter from the Office of Community Engagement & Research. Read "Making a Difference: Tennessee Water Resources Research Center."

TN WRRC researcher, Dr. Bruce Tschantz was invited to Washington, D.C. by Homeland Security and FEMA to present a historical perspective on the development of the 1979 Federal Guidelines for Dam Safety to the Joint Meeting of the Interagency Committee on Dam Safety (ICODS) and the National Dam Safety Review Board (NDSRB) held January 21, 2015. Tschantz, who coordinated federal and nonfederal dam safety policy and program efforts for the Carter Administration from 1977-80 following the 1976 failure of Teton Dam, challenged the federal agencies to consider several contemporary dam safety issues, including hydrofracturing effects, cyber terrorism/hacking, public safety around dams, coal combustion residual (CCR) impoundments, and risk-informed decision making (RIDM), as the Joint Committee begins to update the Guidelines that President Carter, in October 1979, directed 22 federal agencies to adopt and implement.

Publications from Prior Years

1. 2011TN86S ("Development of Water Quality Model for Regional Loadings") - Articles in Refereed Scientific Journals - Liem Tran, Robert O'Neill, J. Burns, Elizabeth Smith, Carol Harden,2015, Linking land use/land cover with climatic and geomorphologic factor: regional mean annual streamflow models with spatial regression approach. Progress in Physical Geography. 39(2): 258-274.
2. 2011TN78B ("Evaluation of Bioretention Practices for Effective Stormwater Management and Treatment: A Laboratory to Field Study") - Conference Proceedings - Yoder, Daniel, Andrea Ludwig, and John Tyner. 2015. The Tennessee Runoff Reduction Assessment Tool(TNRRAT): A Tool for Permanent Stormwater Management System Design. "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp. 2B-19.
3. 2011TN78B ("Evaluation of Bioretention Practices for Effective Stormwater Management and Treatment: A Laboratory to Field Study") - Conference Proceedings - Ludwig, Andrea, John Buchanan, Tim Gangaware, John Tyner and Daniel Yoder, 2015, Tennessee Permanent Stormwater Management Design Training Program, "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.2B-25.
4. 2007TN58B.confused ("Strucruring of an Information Transfer and Outreach Strategy for TNWRRC Under a new Organizational FRamework") - Conference Proceedings - Logan, Joanne and Ruth Anne Hanahan, 2015, ArcGIS Online as a Tool to Teach Global, Regional, and Local Water Resources Issues to Middle and High School Teachers and Students, "in" Proceedings of the 2015 Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.2C-12.
5. 2013TN102B ("Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee") - Conference Proceedings - Larsen, Dan, John Buris, Brian Waldron, Scott Schoefernacker, and James Eason. 2016, Recharge Mechanisms to the Unconfined Memphis Aquifer, Fayette County, Western Tennessee, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., 1C-22.
6. 2007TN58B.confused ("Strucruring of an Information Transfer and Outreach Strategy for TNWRRC Under a new Organizational FRamework") - Other Publications - Hanahan, Ruthanne, Kelly Porter, Katie, Walberg, and Tim Gangaware, 2015. Tennessee Urban Riparian Buffer Handbook: A Practical Guide to Establishing Healthy Streamside Buffers, Tennessee Department of Agriculture, Division of Forestry, Nashville, TN., 108pp.