Tennessee Water Resources Research Center Annual Technical Report FY 2016

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 2016 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 2016 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 2016 from researchers at the University of Tennessee,Knoxville.

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.

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The focus of the 2016 104B seed grants was on the impact of land management and nutrients on Tennessee s water resources, water and energy, 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:

- Water availability, water use forecasting and water transfers;

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

- Groundwater remediation (natural attenuation);

- Erosion control and preventive measures, monitoring BMP effectiveness and local reductions before and after studies;

- The role of soil health and cover crop on the hydrologic cycle;

- Sediment scouring;

- Streambank protection using bioengineering techniques;

- Modeling efforts for sediment especially in west TN.;

- Ecoflows/minimum instream flows;

The following are the project summaries of the five studies conducted under the 2016 program and one on-going studie from the pervious year. The PIs are from the University of Tennessee Knoxville.

Using UV/Peroxyacetic Acid to Remove Pharmaceuticals from Reclaimed Wastewater

Basic Information

Title:	Using UV/Peroxyacetic Acid to Remove Pharmaceuticals from Reclaimed Wastewater
Project Number:	2016TN115B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	TN Second
Research Category:	Water Quality
Focus Categories:	Wastewater, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	John R. Buchanan

Publications

There are no publications.

(10) Methods, Procedures, and Facilities:
A near-collimated beam UV light device was built such that light can only strike the sample at a right angle to the water surface. This procedure allows for consistent and repeatable UV intensity and exposure. Additionally, this device prevents the laboratory staff from inadvertently looking at the UV lamp. The light source is a low-pressure mercury arc lamp that produces most of its light energy in the 254 nm wavelength. The intensity of exposure can be adjusted by moving the sample closer or further from the light source. UV dosage is the product of intensity multiplied by time of exposure. Intensity has units of mW cm^{-2}. If the exposure is measured in seconds, then the UV dosage becomes mW s cm^{-2} or mJ cm^{-2}.

Water samples containing various concentrations of pharmaceuticals and personal care products (PPCPs) are placed in a 10 mL beaker with a small stir bar. The beaker is placed on a stir plate that is positioned under the near-collimated beam device. The distance between the lamp and the sample water surface is held constant for a given UV intensity. To date, we have used two intensities – 0.060 mW cm^{-2} and 0.094 mW cm^{-2}. Ten minutes of exposure at the lower intensity is equivalent to 36 mW s cm^{-2}. The UV light industry typically reports dosage values in terms of µW s cm^{-2}, thus this dosage would be 36,000 µW s cm^{-2} as given in the above abstract.

For each PPCP, a 100 mg L^{-1} standard solution was assembled. 100 µL of this solution is put in a 10 mL glass beaker and diluted to a final concentration of 1 ppm of the selected PPCP. A small square of sheet metal (10 cm by 10 cm) is placed over the beaker (used as an aperture to block UV light) until the test begins. The PAA was sourced from SaniDate® 12 (BioSafe Systems, East Hartford, CT). This formulation is 12% peracetic acid (PAA), 18.5% hydrogen peroxide, 20% acetic acid and water. The PAA dosages are based on the peracetic acid content (e.g., 1 ppm PAA as peracetic acid). Using a 10 mL sample, 0.075 µL of Sanidate® 12 was added to achieve 1 ppm of PAA.

Each test was conducted in triplicate and the AOP process (PAA/UV) was conducted for 10, 20 and 30 minutes. At the end of each test, a two molar excess (as compared to PAA and H_2O_2 addition) of sodium thiosulfate was added to quench the oxidation reactions, and the beaker was re-covered to prevent additional UV exposure.

Analyses for PPCP removal was conducted with a HPLC using a C18 column (150 mm long by 4.6 mm dia.), an 80/20 methanol/water mobile phase operated at 1 ml min^{-1}.

Results and Findings
It was proposed to specifically evaluate the removal of 17α-ethinylestradiol, sulfamethoxazole, triclosan, and diclofenac. Two PAA concentrations and two UV dosages are being evaluated for removal effectiveness. At this time, we have evaluated triclosan (table 1).

Table 1. Preliminary results of removing 1 ppm of triclosan from water using PAA/UV. The values given are the percent reduction and are the average of three replicates.

Minutes of oxidation	1 ppm of PAA	5 ppm of PAA	Low UV Intensity	High UV Intensity	1 ppm PAA plus Low UV	1 ppm PAA plus High UV	5 ppm PAA plus High UV
10	33	26	3	26	14	31	54
20	40	36	28	40	17	38	68
30	25	38	42	40	23	38	69

The AOP process seems to increase the overall remove efficiency and the removal rates as compared to PAA alone and UV alone.

Precipitation Prediction in a Climate Model in the Obion River

Basic Information

Title:	Precipitation Prediction in a Climate Model in the Obion River
Project Number:	2016TN116B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	TN Second
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Climatological Processes, Floods, Models
Descriptors:	None
Principal Investigators:	Joshua S Fu, Xinyi Dong

Publications

There are no publications.

9. Introduction

Precipitation is the water released from the atmosphere to the Earth. It is an important component in the water cycle and provides the input to the hydrology. Long-term shortage of precipitation will lead to drought while extreme precipitation in a short period of time could cause the flooding issue, both of which are severe environmental concerns and bring tremendous loss to the water resource, agriculture and human life. Although the precipitation over the conterminous US (CONUS) is monitored and assessed by more than a thousand observation sites from NOAA's National Climatic Data Center (NCDC), they are not evenly distributed and there could exist lots of missing data for precipitation of a specific region. Therefore, model simulation is a good alternative to provide continuous information about the spatial distribution and magnitude of precipitation.

This research proposes to investigate the frequency and intensity of precipitation at the Obion region, a county in the Western Tennessee. We run the global climate model, the Community Earth System Model (CESM), to generate the necessary initial and boundary input for the regional weather model, the Weather Research and Forecasting (WRF) model. A 10-year simulation (2001 to 2010) is done to provide a long-term result of precipitation and reduce the interannual variability from the global climate model. We evaluate the model prediction ability by comparing the simulated precipitation with the observations from two sites at the Obion region. We evaluate both the bias of monthly mean precipitation and the probability distribution (PDF) of precipitation, which is a common way to examine how well the model can capture the extreme precipitation. If the model results agree well with the observational data, we can use it to provide the necessary input for the hydrologic model for a further study of hydrology.

10. Methodology

(1) Community Earth System Model (CESM)

To accomplish the objectives mentioned above, we first run the global climate model (CESM) for 10 years from 2001 to 2010. The horizontal resolution is 0.9° x 1.25° and the number of vertical layers is 26. We output the necessary results like temperature, wind speed and humidity at the frequency of 3 hours so that it can be used as the initial and boundary conditions to drive the regional weather model (WRF). For a detailed list of input parameters for WRF, please visit http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3/users_guide_chap3.htm. Those surface and three-dimensional variables at three-hour interval are extracted from the CESM output to be dynamically downscaled as the input for the WRF simulation.

(2) Weather Research and Forecasting Model (WRF)

Three nested domains are designed for WRF simulations, as is shown in Figure 1. The outer domain (D1) with a resolution of 36 km × 36 km is centered at 36°N, 85°W. The second domain (D2) is 12 km × 12 km and covers the whole Tennessee. The inner domain (D3) with a high resolution of 4 km × 4 km focuses specifically on the Obion region. The NASA Moderate Resolution Imaging Spectroradiometer (MODIS) satellite products, collected from 2001 to 2005, is used to represent the land-use type for the Obion region. It is better for our study period (2001 to 2010) than the United States Geological Survey (USGS) land-use data based on the Advanced Very High Resolution Radiometer (AVHRR) satellite products from 1992 to 1993. The WRF Preprocessing System (WPS) is used to interpolate CESM output into the WRF domains. In order to determine the appropriate combination of physics schemes, we have done several sensitivity studies of WRF simulations. It turns out that for the Obion region, the following choices yield the best performance of precipitation: (1) For microphysics, we use a sophisticated scheme that has ice, snow and graupel processes (mp_physics = 2); (2) For longwave and shortwave radiation, we use the Rapid Radiative Transfer Model for GCMs (RRTMG) scheme (ra_lw_physics = 4, ra_sw_physics = 4); (3) For land surface model, we use the Noah land surface model (sf_surface_physics = 2); (4) For surface layer, we use the Eta similarity (sf_sfclay_physics = 2); (5) For planetary boundary layer, we use the Mellor-Yamada-Janjic scheme (bl_pbl_physics = 2); (6) For cumulus parameterization, we use the Kain-Fritsch scheme (cu_physics = 1). For the option of four-dimensional data assimilation (FDDA), we find out that it is better to turn it on for winter, spring and fall seasons (grid_fdda = 1 for D1, D2 and D3) but off for summer (June-July-August, grid_fdda = 0 for D1, D2 and D3). The cumulus parameterization is also suggested to be turned off during summer for D3 (cu_physics = 0).

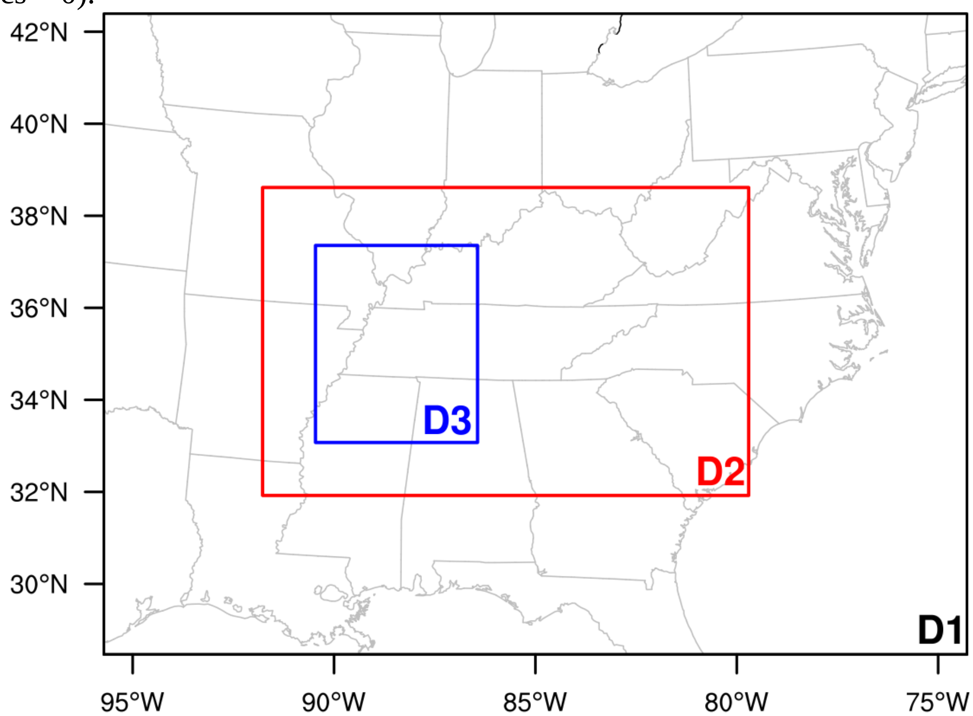


Figure 1. WRF simulation domain for the Obion region: D1 (36 km x 36 km), D2 (12 km x 12 km) and D3(4 km x 4 km).

11. <u>Results</u>

We compare the simulated 10-year precipitation with two observational sites from NCDC at the Obion region (site1: 36.3925°N, 89.0317°W; site2: 36.4527°N, 89.3027°W) and the results are briefly summarized in Table 1. It shows that CESM overpredicts the frequency of light rain (days with precipitation higher than 1mm) from 2001 to 2010 while WRF clearly reduces this bias. Considering the total amount of precipitation for the days with precipitation higher than 1mm, the WRF results are also close to the observation data, especially for site1. With respect to the frequency of extreme precipitation (e.g., days with precipitation higher than 30mm), strong underestimation is observed from CESM output while WRF again reduces the bias significantly. A similar improvement of the intensity of extreme precipitation (e.g., total amount of precipitation for the days with precipitation higher than 30mm) is also achieved by WRF simulation.

In addition, we also use the site2 as an example to visualize the probability distributions of daily precipitation (from 2001 to 2004 in order to match the simulation period in Gao et al. [2012]). It shows that when the daily precipitation is less than 10mm, CESM (blue) and WRF (red) predicts a higher probability than the observation (black). When the daily precipitation is higher than 30mm, CESM almost loses the whole information about the extreme precipitation while WRF generally captures the probability distribution of observation. We further compare the WRF results to our previous WRF results for the whole Eastern US (green, Gao et al., 2012). It turns out that the WRF results from Gao et al. [2012] yield certain improvement over the CESM results but don't perform as well as the WRF results from this study (Figure 2), which highlights the importance of doing sensitivity analysis of physics schemes for a particular region and using a newer land-use dataset.

We also show the scatter plots of 10-year averaged monthly total precipitation for all the observation sites (~200) inside the WRF D3 domain. It seems that for most sites, the WRF results agree well within ±50% of the observational data. There is certain underestimation of monthly total precipitation for WRF during the winter (December-January-February) but overestimation during the spring (March-April-May), which is probably related to the water evaporation from the soil.

Table 1. Model evaluation of precipitation at the Obion region.

Site1	**Days > 1mm**	**Amount > 1mm**	**Days > 30mm**	**Amount > 30mm**
OBS	952	13465	125	5946
WRF	1009	13330	112	5441
CESM	1545	11618	37	1489
Site2	**Days > 1mm**	**Amount > 1mm**	**Days > 30mm**	**Amount > 30mm**
OBS	785	11580	106	5118
WRF	982	11656	87	4227
CESM	1545	11618	37	1489

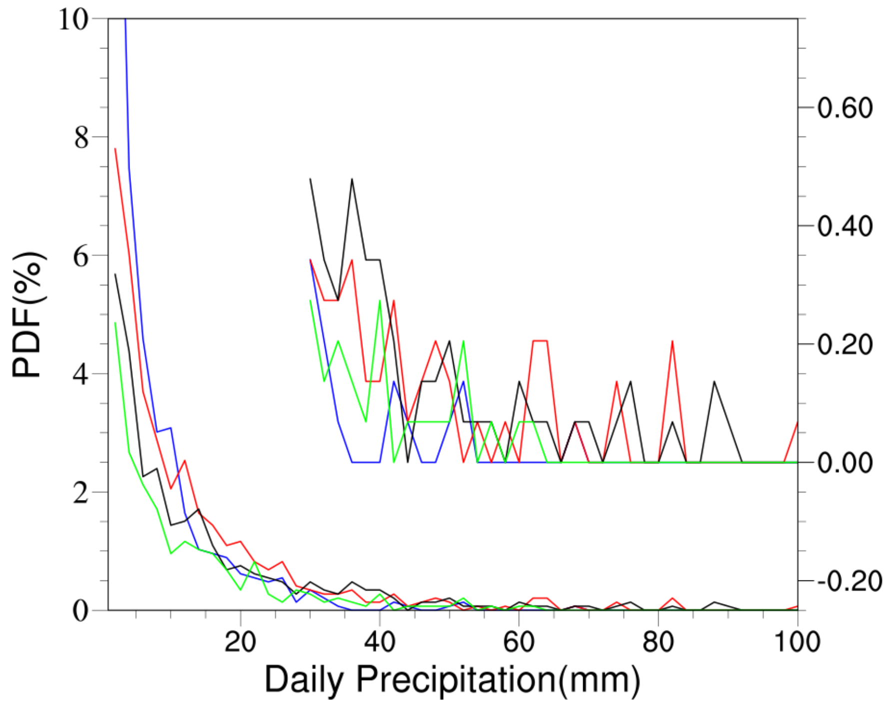
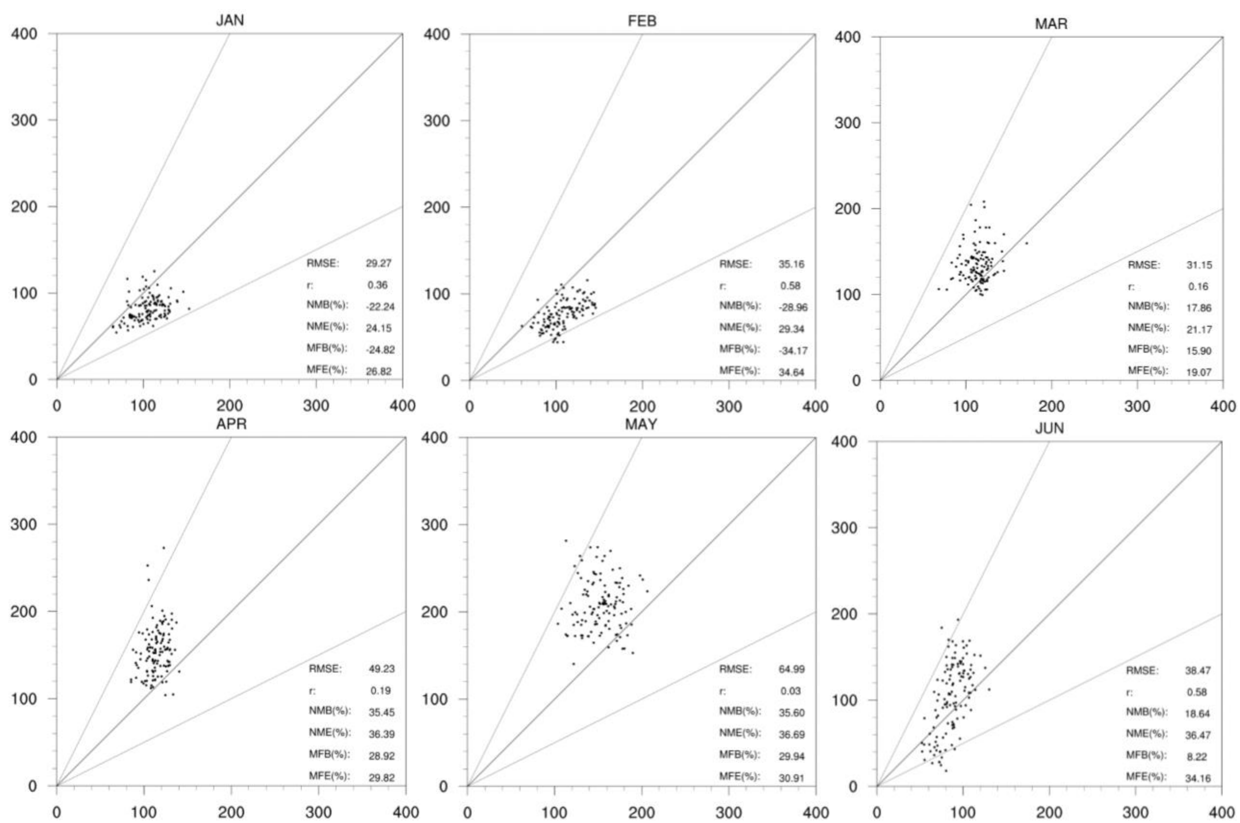


Figure 2. Probability distributions of daily precipitation at site2 for observation (black), CESM (blue), WRF from this study (red) and WRF from our previous study (Gao et al., 2012).



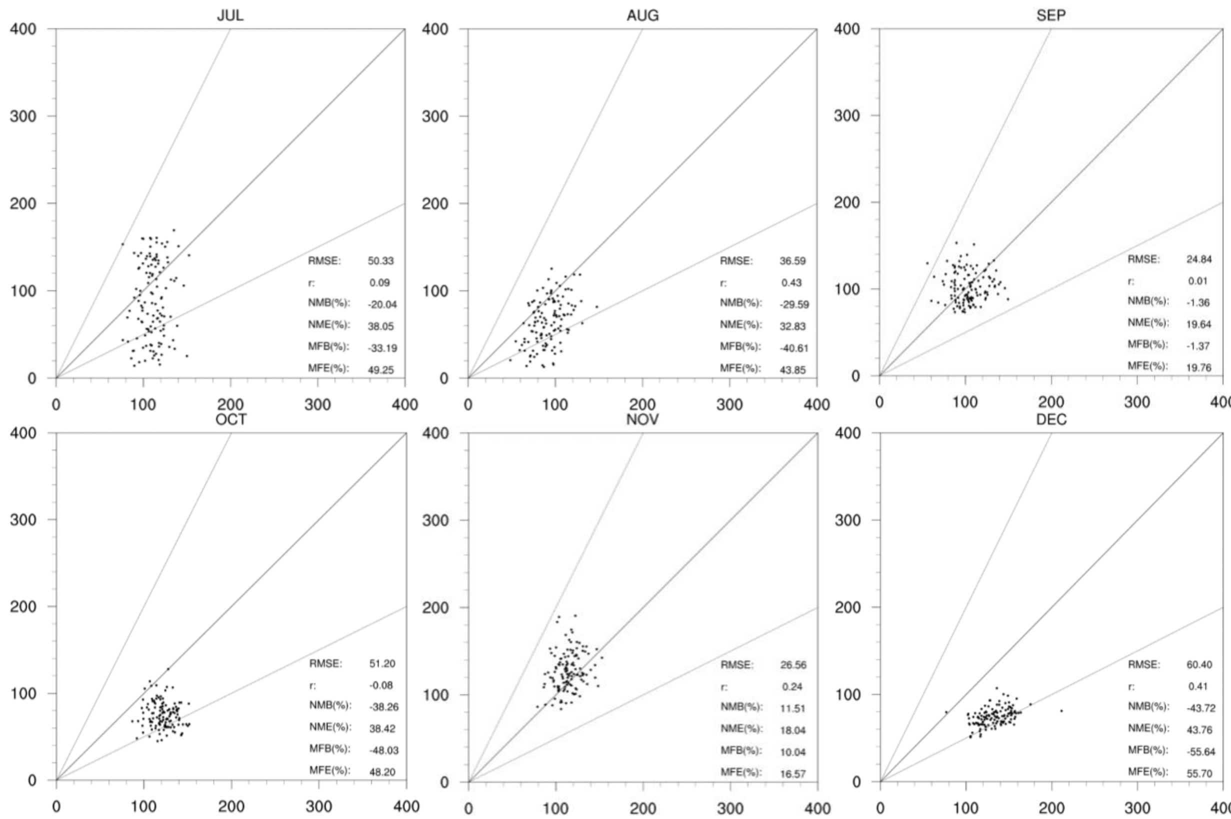


Figure 3. Scatter plots of 10-year averaged monthly total precipitation for all the observation sites (~200) inside the WRF D3 domain.

References:

Gao, Y., J. S. Fu, J. B. Drake, Y. Liu and J.-F. Lamarque (2012): Projected changes of extreme weather events in the eastern United States based on a high resolution climate modeling system, Environ. Res. Lett., 7(4), 044025, doi:10.1088/1748-9326/7/4/044025.

Measuring Water Table Flucations under Different Irrigation Regimes in Western Tennessee Agroecossystems

Basic Information

Title:	Measuring Water Table Flucations under Different Irrigation Regimes in Western Tennessee Agroecossystems
Project Number:	2016TN117B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	TN Second
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Hydrology, Irrigation, Water Use
Descriptors:	None
Principal Investigators:	Christopher Wilson, Jon M Hathaway, Shawn Hawkins

Publications

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2. Elhakeem, M.; A.N. Papanicolaou; C.G. Wilson; and Y.J. Chang, Understaing Saturated Hydraulic Conductivity Dynamics in Iowa due to Seasonal Changes in Climate and Land Use., Catena, "in preparation".
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4. Freudenberg, V.B.; A.N. Papanicolaou; B.K. Abban; C. Giannopoulos; C.G. Wilson; and M.S. Ghaneeizad, 2017, The Role of Cover Crops to Soil and Water Quality under a Variable Climate, "in" Proceedings of the Twenty-Sixth Annual Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN. pp.G3-8.

Research objectives:

In this study, we planned to address the above critical gap by establishing a nest of piezometers for measuring the movement and rate of change in the water table elevation under a field in western Tennessee supplied with different rates of irrigation. In addition to the piezometer nest, we planned to make simultaneous measurements of soil moisture, infiltration, and evapotranspiration (ET) to help close the water budget for the field. The instrumented farms at the Milan Research and Education Center (REC) run by the University of Tennessee Institute of Agriculture allow for pilot-scale studies to isolate the dominant hydropedologic factors affecting infiltration and percolation of irrigated water to help close the water budget of the field. These measurements would allow us to identify how ambient soil moisture conditions and soil characteristics, as well as vegetation coverage, affect the upward and downward movement of water in the soil column. This knowledge would provide improved predictive ability of water table fluctuations in response to changing weather conditions and irrigation rates by incorporating the “memory effects of soil”. The measurements also provide ground-truthing of satellite-derived estimates of field moisture levels. This provides the ability to scale up results using remotely sensed data and Geographical Information Systems (GIS) software using kriging interpolation techniques based on in-situ property cross correlation functions developed by the matrix of the proposed experiments. This effort can help decision-makers enact sound water resource policies that are science-based.

The nature of our proposed study encompassed three main objectives. Objective (1) included the development and testing of the sensors. Objective (2) involved data collection of water table fluctuations, as well as changes in soil moisture, infiltration, and ET in a field plot under a center pivot. Finally, Objective (3) involved the comparison of these data with soils data and remote sensing images from MODIS as a form of ground-truthing. These three objectives are initial stepping stones to closing the hydrologic budgets for the different ecosystems in Tennessee.

Methodology:

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. It also builds from existing USDA efforts that are looking at water availability issues in Tennessee and the U.S. Southeast. The findings of this study will help address the critical gap in our current monitoring and modeling capabilities, which is the lack of understanding about the interactions of soil moisture, infiltration, and pedology at different spatial and temporal resolutions and under different management practices.

Initially, after we reviewed the literature pertinent to in soil moisture, infiltration, and ET in the Southeast, we collected satellite imagery in advance to identify ranges of variability and bounds of uncertainty. Combinations of MODIS ET images and SMAP soil images were used to identify locations in western Tennessee where we see potential deficits in available water.

At these locations modeling simulations using VIC and WEPP were used to project potential water stresses under the different land-uses in the area. The simulations showed that the critical times of water stress occur in early spring and late summer, when ET exceeds precipitation. We targeted our monitoring these time periods

Once that was done, we began developing a monitoring protocol that included all the necessary instruments of the monitoring array and the different irrigation regimes to be tested.

The monitoring protocol included ET array, double ring infiltrometers, moisture sensors, and piezometers. The protocol also included a LP-80 Ceptometer to measure Photosynthetically Active Radiation (PAR) in real time and Leaf Area Index (LAI). The LAI data can estimate total biomass production without destroying the crop and other canopy processes, which can be used to convert ET0 to actual ET.

However, difficulties were met when planning the installation of the piezometer nest. The persistent presence of a clay fragipan in the region limited our ability to collect usable readings with the piezometers these measurements. Continued searching found a useable location however, we had missed to optimal window to measure water stress determined by the modeling exercises.

Principal findings:

A one-year, no cost extension was received for this project to finish additional field work. The plan was to measure water table fluctuations, soil moisture changes, infiltration, and ET under different irrigation rates. We were going to install a piezometer nest to understand the influence of irrigation on the water table but the persistent presence of a clay fragipan in the region limited our ability to collect usable readings with the piezometers these measurements. Once a suitable location was found, it was too late in the season to obtain measurements under the active irrigation period. With a suitable location now available, the measurements can be made during this upcoming season with a no-cost extension.

During the extension, the PIs will perform the tasks mentioned above. The additional field work is designed to provide more data for calibrating and validating the top-down, bottom-up modeling framework. Our plans include correlated measurements of infiltration, actual evapotranspiration, and soil moisture, as well as runoff and erosion. Understanding the complex connection between climate and management requires ample data. We are also examining the role of adaptive management, namely cover crops and the different effects of planting date and crop type.

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Urban Stream Restoration Planning: Towards Cost-Effective Mitigation of the Effects of Hydromodification

Basic Information

Title:	Urban Stream Restoration Planning: Towards Cost-Effective Mitigation of the Effects of Hydromodification
Project Number:	2016TN118B
Start Date:	3/1/2016
End Date:	2/28/2017
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Congressional District:	TN Second
Research Category:	Water Quality
Focus Categories:	Geomorphological Processes, Sediments, Water Quality
Descriptors:	None
Principal Investigators:	Robert R Woockman, John S. Schwartz

Publications

1. Woockman, R.; J. Schwartz, 2015, Excess Stream Power Management in Small Urban Stream Systems of the Ridge and Valley Province in Tennessee, 2015 ASCE/EWRI Watershed Management Symposium, Reston, VA.,August 5-7, 2015.
2. Woockman, R.; J. Schwartz, 2016, Reach Scale Sediment Sources Potential in Small Urbanizing Stream Systems, "in" Proceedings of the Twenty-Sixth Annual Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.1A3-7.
3. Schwartz, J.; R. Woockman; and C. Clark, 2016, Urban Stream Restoration Planning: Towards Cost-Effective Mitigation of the Effects of Hydromodification, 2016 World Environmental & Water Resources Congress, West Palm Beach, Florida, May 23-26, 2016.
4. Woockman, R.; 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.

9. Introduction

Urbanization causes widespread changes to watershed hydrology and channel geomorphic processes, where increased impervious surfaces cause hydromodification mostly observed as greater peak stormflows and longer durations. Hydromodification leads to channel bed and bank erosion increasing fine sediment loads to stream. These increases in fine sediment loads result in degradation of aquatic habitat and impairment of biotic integrity. Impacted streams are identified on federal/state 303(d) list requiring a total daily maximum loads (TMDLs) for suspended sediment to be produced, in addition to an implementation plan to achieve loading targets. In urban watersheds, the potential generation of fine sediment loads from geomorphic incision cannot be separated from uplands stormwater management practices. Although stormwater control measures improve water quality from local sites, a key question remains as to what levels of treated stormwater discharges are acceptable to maintain in-stream geomorphic stability, termed channel protection flows. However, the linkages between urbanization, stormwater management policy, and stream channel response are still poorly understood over the range of watershed settings. Therefore, a critical need exists for state and local agencies charged with the water quality protection of streams to have geomorphic field assessment tools that can prioritize streams reaches most vulnerable to in-channel bank/bed erosion.

This research proposes to clarify interrelationships between hydromodification from urbanization, fluvial geomorphological processes, and stormwater management and policy. It is proposed that classification of urban stream reaches by trajectory of response to hydromodification allows an approximation of impacts of land-use modifications, development of effective regulation to avoid or minimize externalities, and prioritization of mitigation efforts between stormwater control measures and stream rehabilitation. The classification scheme will be based on in improved geomorphic field assessment protocol for urban streams. Ultimately, this research is expected to support stream system rehabilitation in Ecoregion 67 through adaptation of mitigation practices relative to channel erosive resistance properties and adapted for use in channel protection efforts throughout the nation.

10. 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). This task was completed fall of 2015.

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 desktop and field collected data was completed by Robert Woockman, leading to a draft manuscript that was completed in fall of 2016. The manuscript has been revised and will be submitted for journal review during the summer of 2017.

Pending Publications:

It is intended that this work will be submitted for publication to *River Research and Applications*. Expectations are initial submission should be take place in summer of 2017.

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Development of a Robust Model for Cross-Scale Prediction of Flow and Sediment Transport

Basic Information

Title:	Development of a Robust Model for Cross-Scale Prediction of Flow and Sediment Transport
Project Number:	2016TN119B
Start Date:	3/1/2016
End Date:	2/28/2017
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Congressional District:	TN Second
Research Category:	Water Quality
Focus Categories:	Models, Sediments, Geomorphological Processes
Descriptors:	None
Principal Investigators:	Benjamin Abban, Thanos N Papanicolaou

Publications

1. Abban,B.; A.N. Papanicolaou; M.K. Cowles; C.G. Wilson; O. Abaci; K. Wacha; K. Schilling; and D. Schoebelen, 2016, An Enhanced Bayesian Fingerprinting Framework for Studying Sediment Source Dynamics in Intensively Managed Landscapes, Water Resources Research, DOI:10.1002/2015WR018030. (Impact factor=3.709).
2. Abban, B.; A.N. Papanicolaou; C.G. Wilson; O. Abaci; and K. Wacha, 2016, Towards a Holistic Model for Simulating Sediment Dynamics at Watershed Scales: Partitioning of Sediment Sources and Uncertainty Quantification, European Geosciences Union General Assembly, April 17-22, 2016 Austria.

Overview

Field work was performed in the summer of 2016 in headwaters of the Upper Sangamon River Basin (USRB), Illinois, USA (Figure 1). USRB is a U.S. National Science Foundation Intensively Managed Landscape Critical Zone Observatory (IML-CZO). The purpose was to determine the relative contribution of terrestrial and instream sediment sources for storm events over the growing season. In IMLs like the USRB, the terrestrial and instream sediment contributions have been observed to vary over the course of a season in response to changing hydrologic forcing and LULC [*Abaci and Papanicolaou*, 2009; *Wilson et al., 2012*]. The USRB is a low-relief hillslope characterized by mild gradients. The land use is predominantly row-crop agriculture with two-year corn-soybean rotations, and the dominant soil texture is silty clay loam [*Abaci and Papanicolaou*, 2009].

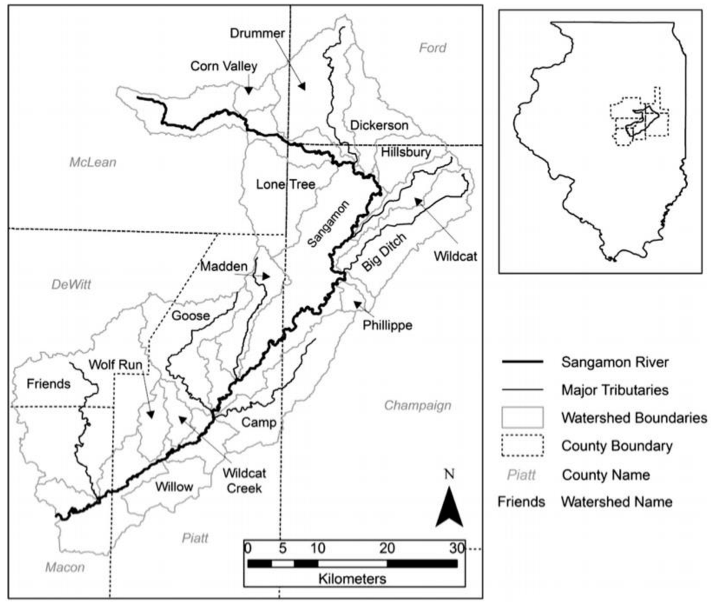

Figure 1: Upper Sangamon River Basin, IL

Methods and Procedures

Sampling of soils/sediments and transported eroded material was done during three consecutive time periods, each approximately one month long, from May to July, 2016. Land cover over the study period was obtained concurrently from Enhanced Thematic Mapper natural color satellite imagery for USRB, downloaded from the United States Geological Survey EarthExplorer repository. Rainfall data for the study period were obtained from a digital rain gauge situated within the sub-watershed. The purpose of all these data was for use in an un-mixing model, along with the signatures of the sampled soils/sediment for determining the sediment contributions from the various land use sources.

Several watershed sources and processes were identified during the field campaign based on the following considerations: 1) the total organic material collected at the outlet of USRB is a mixture of material from terrestrial and instream sources [*Wilson et al.*, 2012; *Delong and Thorp*, 2006]; and 2) source areas in the watershed that promote soil/sediment deposition and re-suspension affect sediment travel times with potential impacts on time-integrated source tracer signatures [*Olley*, 2002]. Terrestrial soil samples were collected from five fields distributed within the watershed that were considered to be representative of the land uses, soil types, and topography in USRB. In each field, surface soil samples (0-5 cm and 5-10 cm) were collected along 75- to 100-m long planar transects located along the downslope to capture planar and downslope heterogeneity from the summit to the backslope, toeslope, and floodplain (Figure 2). Figure 3 illustrates the transect locations for two of the fields with No Till Bean – Spring Till Corn (NTB-STC) and Fall Till Bean – Spring Till Corn (FTB-STC) rotations and their underlying soil series. In the first field, Transects 1, 2, and 3 were located on the summit, backslope and toeslope, respectively, whilst Transects 4 and 5 were located on the floodplain. Similarly, for the second field, Transects 10, 9, and 8 were located on the summit, backslope and toeslope, respectively, whilst Transects 6 and 7 were on the floodplain. As shown in Figure 3 with dots, there were approximately eight sampling locations per transect to capture the planar heterogeneity. At each dot location, samples were taken at two depths, since previous studies had shown that tracer signatures of the active layer (usually the top 10-20 cm depending on plowing depth) could vary with depth [*Fox*, 2005; *Fox and Papanicolaou*, 2008]. To characterize instream sediment sources, discrete samples were collected during non-flood flows using Sigma suspended sediment samplers following the *Olley* [2002] approach. Sampling of the total transported eroded material at the USRB outlet was done using stream tubes [*Phillips et al.*, 2000; *Fox and Papanicolaou*, 2007]. For each of the three sampling periods, two to four stream tubes were placed close to the bed of the stream outlet to continuously capture suspended sediments over the period. Stream conditions were such that the tubes primarily captured sediment contributions from the storms that occurred during the period.

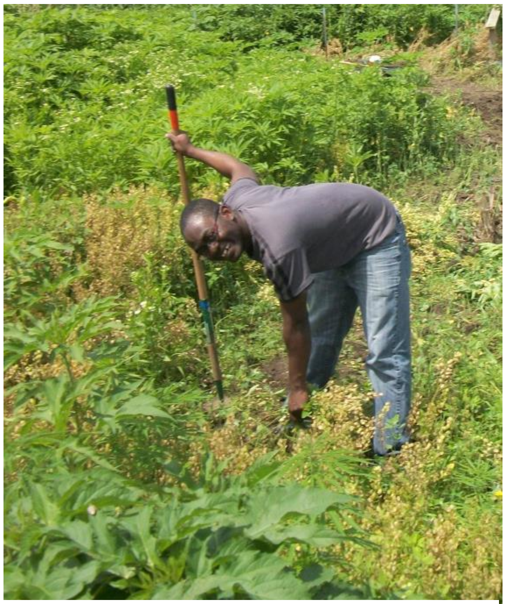

Figure 2: Terrestrial Soil Sampling

After the samples were collected, the $\delta^{13}C$ and $\delta^{15}N$ signatures of the fine grained portion (<53 μm) of each sample were quantified using mass spectrometry. The samples were initially dried at 60°C, then the coarse particulate organic matter (diameter >250 μm) was removed. Sub-samples between 15-30 g were disaggregated in 50 mL of 0.5 mol/L Na-hexametaphosphate and gently washed through a 53 μm sieve [*Cambardella and Elliott*, 1992]. Material passing through the 53 μm sieve was allowed to settle at 4°C, the overlying water was decanted, and then dried again at 60°C. The material was then ground on an orbital ball-mill for the mass spectrometry analysis to determine the $\delta^{13}C$ and $\delta^{15}N$ signatures. Hotelling's T^2 tests were performed on the signatures from different landuse sources to confirm that they were significantly different from each other ($p < 0.05$) and, thus, could be used to distinguish the sources. The differences in isotopic signatures between the 0-5 and 5-10 cm samples were found to be insignificant (p >

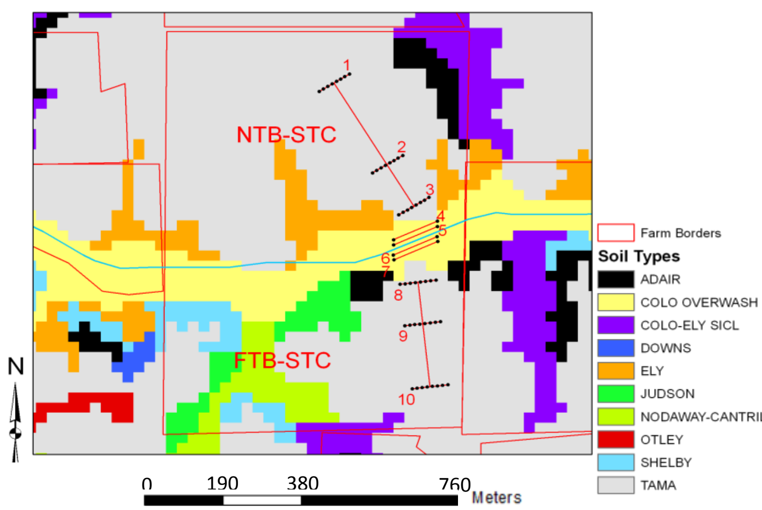

Figure 3: Sampling Locations, Transects and Soil Series

0.05) and so differentiation of contributions with depth was ignored in this study.

Key Findings

The tracer signatures were input into a Bayesian un-mixing model to determine the sediment contributions from the various sources. The analyses predicted mean terrestrial soil contributions to be larger than mean instream sediment contributions during both Periods 1(May) and 2 (June) – a trend consistent with observations from previous studies in the watershed by *Abaci and Papanicolaou* [2009]. This was attributed, for the most part, to less land cover and more bare soil. In addition, the mean instream sediment contribution in June was greater than the mean instream sediment contributions in May. This was due to greater amount of runoff generated resulting in more instream erosion [*Sutarto et al.*, 2014] and the slightly greater cover in the period resulting in relatively less terrestrial erosion. In Period 3 (August) the mean terrestrial soil contributions were less than mean instream sediment contributions. The smaller terrestrial contributions was attributed to the establishment of extensive surface cover, which has been shown to minimize rain drop impact and reduce erosion by both sheet and concentrated flow [*Dermisis et al.*, 2010]. The trends observed are in agreement with similar previous studies by *Abaci and Papanicolaou* [2009] and *Wilson et al*. [2012]. Scientific advances from the study include the accounting of sediment delivery and travel times in the sediment sourcing analysis, as well as the determination of the seasonal nature of source partitioning in intensively managed landscapes. The study thus accounts for critical processes such as material availability, exhaustion of material supply, flow power, and rainfall intensity.

On-going work

The predicted mean sediment source contributions from terrestrial and instream sources, predicted with the aforementioned sediment sourcing analyses, will be used to validate a state-of-the-art numerical model that simulates dynamic flow processes on landscapes exhibiting heterogeneity in land use/land cover. The numerical model has been designed to run on in parallel mode on GPU threads and will be implemented on a workstation with GPU capabilities. Although the study results thus far are useful for partitioning terrestrial and instream contributions over the growing season, they are not sufficient for further sub-partitioning the contributions the wide range of terrestrial land uses and sediment fluxes noted in the basin. Such sub-partitioning data which will be beneficial for validating the numerical model's ability to capture landscape heterogeneity. As such, the work is being extended in the summer of 2017 to collect more terrestrial samples iin the Upper Sangamon, and the analyses repeated in the Clear Creek Watershed, to validate under a wider range of conditions.

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Environmental Impacts of Coal Ash Spill on Nutrient Cycling and Surface Water Quality in Eastern Tennessee

Basic Information

Title:	Environmental Impacts of Coal Ash Spill on Nutrient Cycling and Surface Water Quality in Eastern Tennessee
Project Number:	2016TN120B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	TN Second
Research Category:	Water Quality
Focus Categories:	Water Quality, Surface Water, Geochemical Processes
Descriptors:	None
Principal Investigators:	Anna Szynkiewicz

Publications

There are no publications.

Introduction

Coal ash is a waste product of coal burning in power plants to produce electricity. It contains verity of toxic metals (Ag, Al, As, B, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, V, Zn) that may contaminate locally surface water and groundwater used for drinking. Currently, there are 8 contaminated sites with coal ash disposal and 1 coal ash spill into surface water in Tennessee. However, research about environmental impacts of coal ash spills on the aquatic environment is still limited. Few studies exist targeting this problem, and most are focused on general characterization of pollutants and their concentrations in surface water and sediments. Conversely, studies on disturbance of nutrient cycling and microbial biodegradation of coal ash spill pollutants in aquatic system are limited or nonexistent.

Using multiple chemical and isotopic tracers, this study has investigated impacts of the recent coal ash spill on three rivers: Emory, Clinch and Tennessee that took place in December 2008 in Kingston, Eastern Tennessee. Current contamination levels by toxic metals were determined in the light of new field and geochemical measurements.

The toxic remains of coal ash spills may cause cancer, developmental disorders and reproductive problems. Additionally, they can decrease water quality, kill fish and wildlife, and disturb cycling of sulfur (S) and carbon (C) during microbial decomposition of organic matter in freshwater sediments. The latter is crucial in releasing nutrients for aquatic life in riverine systems. Therefore, this project has the potential to provide new, inexpensive, and relatively simple environmental tracers (e.g., water chemistry, S-O-C isotopes) for state agencies and stakeholders in Tennessee and nationwide to evaluate the impacts of coal ash spills on surface water quality, nutrient cycling and metal bioremediation in contaminated sites.

Nature, Scope and Objectives of Project

Major objectives of this project were:

1) To determine if nutrient cycling via microbial sulfate reduction in the river bottom sediments can effectively immobilize toxic metals from coal ash spill due to formation of insoluble sulfides.
2) To determine changes of nutrient cycling (sulfur, carbon) in water column and sediments due to coal ash spill.
3) To evaluate water quality of Emory, Clinch and Tennessee rivers 8 years after the coal ash spill.

The study field area for this project is located in Kingston area of Eastern Tennessee (~65 km west from Knoxville). Water and sediment samples were collected from the portions of Emory River, Clinch River and Tennessee River that had been polluted by coal ash spill in December 2008. For comparison, water and sediment samples were also collected from upstream locations that did not show contamination by the spill. For collecting water and sediment samples, a pontoon boat was rented from a Caney Creek Marina located off of the Watts Bar Reservoir. In total, 10 different locations were sampled. All sediments and water samples were collected near the midpoint of the rivers in order to provide the most unbiased results.

Methods, Procedures and Facilities

Water sample collection took place on April 28, 2016. The water column (at 0, 4 and 6 m depth) was sampled using a Wilco sampler. In-situ measurements included: temperature, pH, and dissolved oxygen (DO) using a YSI ProDSS Multiparameter Meter. Additionally, alkalinity was determined using a Lamotte Titration Kit. Water samples for major ion, trace metal and isotope analyses were filtered using 0.45 μm nylon filters, stored in Nalgene bottles, and kept on ice until frozen at the end of the day. Water samples for S and O isotope analysis of dissolved sulfate (SO_4) were filtered using Whatman glass microfiber filters. The samples collected included the following: 1 L of water for S and O isotope analysis of dissolved SO_4, 60 mL of water for major anion and isotope composition of NO_3 analyses, 60 mL of water acidified with 2% HNO_3 for major cation and trace metal analyses, 1 mL of water injected into a GasBench vial, with He gas headspace and 100 μL phosphoric acid, for C isotope analysis of DIC and DOC.

The sediment sampling of riverbeds took place on June 15 and 16, 2016. The sediment samples consisted of 26-30 cm long cores, which accounted for ~16 cm sediment accumulation in the past 8 years. In order to obtain the cores, two scuba divers hammered a 30 cm PVC pipe into the riverbed sediment, capped off the cores, and brought them back to the surface. These cores were stored on ice until frozen at the end of each day.

Major chemical (cations, anions, DOC, DIC) and isotope analyses ($\delta^{34}S$, $\delta^{18}O$, $\delta^{13}C$) were performed in the PI's Stable Isotope Laboratory at the Department of Earth and Planetary Sciences (EPS) of University of Tennessee, Knoxville (UTK) using a Finnigan Delta Plus XL mass spectrometer and Dionex ion chromatography. Trace metal composition of water samples and sediments (e.g., Ag, Al, As, B, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, V, Zn) were analyzed via inductively coupled plasma optical emission spectrometry (ICP-OES) available on campus at UTK.

In order to determine the effects of metal immobilization by microbial sulfate reduction, a sulfur sequential extraction was performed on the riverine core sediments (4 cm intervals). This method allowed for separation of various sulfur species (acid-soluble SO_4, elemental sulfur, biogenic sulfides) for $\delta^{34}S$ analysis. The obtained results will be used for assessing the role of microbial sulfate reduction during decomposition of organic matter in freshwater settings (including riverine sediments) and remediation of toxic metals from coal ash spill. In addition, the sediment samples will be analyzed using x-ray diffraction (XRD) methods, and if necessary scanning electron microscope (SEM), to characterize mineralogical composition of biogenic sulfides formed during microbial sulfate reduction and bioremediation of river sediments.

Results and Findings

In the water column, the concentrations of trace metals such as Al, As, Cd, Cu, Cr, Be, Li, Ni, and Pb were below the detection limit of 0.002 mg/L. Only a few water samples showed slightly higher concentrations of B (0.02-0.04 mg/L), Se (0.03 mg/L) and Zn (0.03 mg/L). However, the measured concentrations were within a maximum contamination level determined by Environmental Protection Agency. In contrast, the elevated concentrations of As, B, Se, Cd, Cr, Pb and Zn were measured in the riverine sediments, particularly in close proximity to the Kingston power plant. This suggests that higher quantities of toxic metals are still present in the shallow riverine sediments. Among the studied metals, As appears to be of major concern. Using carbon-oxygen-sulfur-nitrogen-hydrogen isotope compositions of dissolved organic/inorganic carbon, sulfate, and nitrate in the water column and carbon-nitrogen-sulfur isotope compositions of the sediments, the conceptual model will be proposed to characterize major processes responsible for element cycling within the water column, sediment-water interface, and sediments. Consequently, this knowledge will be used to determine how the elevated metal toxicity in the sediments, resulted from the coal ash spill, might currently affect the water quality, people, and aquatic organisms in the studied area.

The negative bulk $\delta^{34}S$ values of -5.4 to -0.5 ‰ are indicative of active microbial sulfate reduction and the presence of biogenic metal sulfides in the studied riverine sediments. However, the content of metal sulfides appears to be low (<0.1 wt. %). Relatively low sulfate concentrations observed in the water column (2-17 mg/L) and sediments (<0.01 wt. %) might be limiting factor inhibiting microbial sulfate reduction and formation of biogenic sulfides. This, in turn, decreases the overall capability for microbial bioremediation of toxic metals introduced by the 2008 coal ash spill to the studied river systems. The results of sulfur sequential extractions and mineralogical analysis will be used to propose conceptual models of main processes leading to metal storage and potential releases in the studied river systems.

Information Transfer Program Introduction

The major emphasis of the information transfer program during the FY 2016 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 2016 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 2016 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 25th Tennessee Water Resources Symposium, which was held on April 13-16, 2016 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 25th Symposium was very successful with over 370 attendees and approximately 76 papers and 26 student posters being presented in the two-day period. TVA and TN-AWRA held a pre-symposium Water Science workshop that was attended by over 100 persons. This year there was a special session scheduled to highlight the USGS Water Resources Institute program. The session included presentations by Earl Greene, USGS Director of Water Resources Research Act Program; Dr. Thanos Papanicolaou, Director TNWRRC; and Robby Woockman, UT PhD student whose research has been supported by TNWRRC. The event received a good deal of publicity across the state.

TNWRRC, Department of Civil & Environmental Engineering and the Department of Biosystems Engineering & Soil Science at The University of Tennessee hosted the 16th Annual Meeting of the American Ecological Engineering Society on June 7-9, 2016 at Hilton Hotel in Knoxville. This year's theme, Rooftops to Rivers: Integrating Natural and Built Ecosystems, was highlighted by the two keynote speakers, Dr. Bill Hunt, NCSU and Laura Wildman, PrincetonHydro. The three day conference included over 100 professional presentations, 54 student posters, four technical field trips and a student design competition with teams from 8 universities and colleges participating. Over 250 attendees from twenty-three states and four countries made the 16th Annual AEES Meeting a huge success.

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 2016:

TNSA East Tennessee Regional Group meetings held on March 4, 2016; June 10, 2016; September 9, 2016; December 2, 2016 and February 17, 2017 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.

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WaterFest, May 5, 2016, 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 850 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 2016: February 23, 2016, Nashville; March 3, 2016, Knoxville; March 23, 2016, Chattanooga; April 5, 2016, Memphis; May 10, 2016, Nashville; June 2, 2016, Knoxville; June 15, 2016, Memphis; July 27, 2016, Nashville; September 20, 2016, Jackson; September, 28 2016, Nashville; October 4, 2016, Chattanooga; October 12, 2016, Knoxville; November 1, 2016, (Corps of Engineers) Memphis; November 9, 2016, Johnson City; November 15, 2016, Nashville; November 30, 2016, Memphis; February 23, 2017, Nashville.

For this time period over 2,034 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 2016: April 27-28, 2016, Knoxville; May 11-12, 2016, Nashville; June 15-16, 2016, Memphis; November 16-17, 2016, Nashville and December 7-8, 2016, Chattanooga, TN.

For this time period over 261 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: January 27, 2016, Nashville; May 4, 2016, Knoxville; May 19, 2016, Nashville; May 24, 2016, Chattanooga; September 15, 2016, Nashville; September 22, 2016, Knoxville; September 30, 2016, Chattanooga; October 25, 2016, Jackson; October 27, 2016, Clarksville; November 2, 2016 (Corps of Engineers), Memphis; November 3, 2016, Memphis; November 10, 2016, Johnson City; November 29, 2016, Chattanooga; November 29, 2016, Cookeville; December 6, 2016, Nashville; December 13, 2016, Knoxville and February 1, 2017, Nashville.

For this time period over 2,367 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 2016 -; March 7-9, 2016 in Oak Ridge, TN.; and on August 8-10, 2016, 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 2016 on the following dates and locations: July 21, 2016, Knoxville; August 3, 2016, Nashville; November 21, 2106, Knoxville; December 1, 2016, Nashville;

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.There were some changes made to section of the Manual to reflect changes in the MS4 Stormwater permit issued by TDEC in September 2016. The Manual and the RRAT model may be down loaded form the new Tennessee Stormwater Training Program website, http://tnstormwatertraining.org/index.asp.

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The Stormwater Control Measures Inspection and Maintenance Certification course is a 2 day foundation building course for individuals responsible for the inspection and maintenance of permanent stormwater management practices. The course is intended for design professionals, engineers and landscape architects; landscape and other green industry professionals; and inspection personnel from all levels of government. The SCM I&M course aims to build a solid working knowledge of proper operation and maintenance of permanent stormwater measures. Topics include the permanent stormwater management requirements in the MS4 general permit; the function, inspection and maintenance of key SCMs based on the new permanent stormwater manual; and annual inspection and reporting requirements by owners/operators of permanent SCMs. The SCM I&M course provides a Certification with 12 PDHs upon successful completion for a short certification exam The SCM I&M certification is valid for 3 years. Information about the course can be found on the training website, http://tnstormwatertraining.org/index.asp. The course was offered on the flowing dates in FY 2016: April 21-22, 2106, Nashville; September7-8, 2016, Nashville and December 5-6, 2016, Nashville.

Adopt-A-Watershed teacher training workshop held on June 20-22 2016, 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. Six new teachers completed the training course in 2016.

The Watershed Faculty at the University of Tennessee and TNWRRC hosted the 5th Annual Watershed Symposium on September 13, 2016, 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 and to expose undergraduate and graduate students to water related careers opportunities. This year the Watershed faulty decided to take a different approach from the past. The Symposium started off with a half day Careers in Water Expo with over eighteen government agencies, utilities and private consulting companies hosting booth to discuss job opportunities with UT students. The career expo was followed by the Keynote address by Andy Reese, PE, Vice President, Amec Foster Wheeler, Inc. Next faculty from the different colleges at UT offered career focused presentations followed by student zip talks. Finally, University of Tennessee students had a technical poster session. Over 120 students and 65 government and private water resources professional attended the 5th Annual Watershed Symposium.

Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2016 and January 2017. 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 2016 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	6	0	0	0	6
Masters	2	0	0	0	2
Ph.D.	4	0	0	0	4
Post-Doc.	1	0	0	0	1
Total	13	0	0	0	13

Notable Awards and Achievements

Thanos Papanicolaou, Director Tennessee Water Resources Research Center, was named a Fellow of the American Society of Civil Engineers, a honor that is bestowed on only 1.2% of ASCE members.

Bruce Tschantz, TNWRRC Senior Research Fellow was recently honored in Philadelphia at the national ASDSO dam safety conference with a National Merit Award for his life-long contributions to dam safety. Bruce has led efforts to improve US dam safety since the 1970's, following the failure of the Teton Dam when he was asked by President Carter to coordinate development of federal dam safety guidelines.

Jon Hathaway, TNWRRC Researcher was interviewed by the Christian Science Monitor (December 2016) on urban storm runoff for their article "Cities enlist nature to tame rising flood risks."

Publications from Prior Years

1. 2014TN104B ("High Resolution Monitoring of Urban Stormwater Quality") - Conference Proceedings - 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.
2. 2014TN104B ("High Resolution Monitoring of Urban Stormwater Quality") - Conference Proceedings - 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, Fla.
3. 2014TN104B ("High Resolution Monitoring of Urban Stormwater Quality") - Conference Proceedings - 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 D Society, Knoxville, TN. June 7-9, 2016.
4. 2013TN102B ("Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee") - Conference Proceedings - Larsen, D.; J. Bursi; B. Waldron; S. Schoefernacker; and J. 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., pp.1C-22.
5. 2013TN102B ("Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee") - Conference Proceedings - Ogletree, B.T. and S. Schoefernacker,2016, Historical Trends of the Water Table Aquifer in Shelby County, Tennessee, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.1C-25.
6. 2015TN111B ("Evaluating Environmental and Biological Impacts of Acid Runoff from Pyrite-Bearing Rock Formations") - Conference Proceedings - Hogan,B.; C. Williams; T. Byl; W. Sutton; and D. Young,2016, Streamside Salamander as Indicators of Environmental Stress: Impacts of Acid Rock Drainage on Headwater Stream Integrity, "in" Proceedings of the 25th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.2B-8.