Tennessee Water Resources Research Center
Annual Technical Report
FY 2017

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.

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:

In 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. There have been three additional meetings of the Advisory Board in 2016 and 2017.

104B Seed Grants: The focus of the 2017 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 2017 from researchers at the University of Tennessee, and Middle Tennessee State University.

Research Program Introduction

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 2017 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 future years funding 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 load reductions before & after studies;

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

- Sediment sourcing;

- Streambank protection; the using bioengineered structures needed;

- Modeling efforts for sediment especially in west TN;

- Ecoflows/ minimum flows How to study ecological effects

The following are the project summaries of the four studies conducted under the 2017 program and one on-going study from pervious years. The PIs are from the University of Tennessee Knoxville and Middle Tennessee State University.

Evaluation of Fecal Indicators and Pathogens at Recreational Beaches in Central Tennessee

Basic Information

Title:	Evaluation of Fecal Indicators and Pathogens at Recreational Beaches in Central Tennessee
Project Number:	2017TN129B
Start Date:	3/1/2017
End Date:	2/28/2019
Funding Source:	104B
Congressional District:	Fourth TN.
Research Category:	Water Quality
Focus Categories:	Water Quality, Sediments, Recreation
Descriptors:	None
Principal Investigators:	Frank Bailey, Megan Stallard

Publication

1. Bailey, F. and M.Stallard,2017,Presence of Fecal Indicator Bacteria in Sand by Distance and Depth at a Freshwater Recreational Beach, "in" Proceedings of the 26th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN.,pp.4C-12.

Statement of Critical Regional or State Water Problem(s):

Beach sand contact has been implicated as a potential health risk to beachgoers (Heaney et al., 2009) due to presence of fecal bacteria, viruses, and associated pathogens (Byappanahalli et al., 2006, Yamahara et al., 2012), but no federal criteria have been developed for fecal pathogens in sand. Most research on this topic has focused on investigating the presence of fecal indicators and pathogens in beach sand from coastal and Great Lakes locations (Zhang et al., 2015, Yamahara et al., 2012; Alm et al., 2003, 2006; Eichmiller et al., 2014; Staley and Sadowsky, 2016), while research at other inland recreational beaches are less represented in the literature (Wilson et al., 2016, Levin-Edens et al., 2012, Marion et al., 2010). To our knowledge, there is no regular monitoring of fecal pathogens at recreational beaches in Tennessee (TN), and there has been very little research on this topic in the state. This research project will benefit state and federal regulatory agencies by providing data on the presence, abundance and source(s) of fecal bacteria, viruses (coliphages), and other pathogens at inland freshwater recreational beaches in TN. The knowledge gained can potentially be applied to improve the understanding of fecal indicators found at inland beaches elsewhere the U.S. and inform regulators as they make decisions about formulation of regulatory criteria for fecal pathogens in beach sand.

Statement of results or benefits:.

This research will provide data on the presence of fecal bacteria, viruses (coliphages), and other pathogens at inland freshwater recreational beaches. Both traditional fecal indicator bacteria (*E. coli*) and alternative indicators (*Bacteroidales* and coliphages) will be assessed, thus assisting regulators in choosing the most appropriate and cost effective indicator for public health. Data from *Bacteroidales* qPCR assays will shed light on whether sources of fecal contamination originate from human waste and detection of coliphages may provide an estimate of the survival of enteric viruses (USEPA, 2016). This project will also provide data on *Staphylococcus aureus* and methicillin-resistant *Staphylococcus aureus* (MRSA) numbers, which are lacking from freshwater beaches (Fogarty et al., 2015). This will give important data on presence of non-fecal pathogens and antibiotic resistant organisms at freshwater beaches. The results from this project will have potential implications for both environmental and human health protection and will provide preliminary information in the likely event regulatory criteria are developed in the future for fecal indicators in sand at beaches. From a research standpoint, this will fill a knowledge gap in the literature regarding fecal contamination in sand and water from inland freshwater recreational beaches. Data will be disseminated through publication of peer-reviewed manuscripts and presentations at regional (e.g. TN section of American Water Resources Association) and national scientific meetings (e.g. University of North Carolina Water Microbiology Conference). This information will also be distributed to water quality stakeholders interested in recreational beach health (e.g. Tennessee Valley Authority, the US Army Corps of Engineers, and the Tennessee Department of Environment and Conservation).

Nature, Scope and Objectives of project, including a timeline of activities:

Based on a report conducted by the U.S. Census Bureau, approximately 59 million people visited a beach in 2010 (US Census Bureau, 2012). Beach water quality monitoring in coastal and Great Lakes states is mandated under the Clean Water Act (USEPA, 1986, 2012). In this monitoring, the potential presence of fecal pathogens and associated health risk is typically monitored by enumerating easily culturable surrogate (non-pathogen) fecal indicators in water samples (e.g. *Escherichia coli* or enterococci). However, even though sand contact has been implicated as a potential health risk to beachgoers (Heaney et al., 2009) due to presence of fecal bacteria, viruses, and associated pathogens (Byappanahalli et al., 2006, Yamahara et al., 2012), beach sand is typically not monitored and no federal regulatory criteria have been developed for fecal pathogens in sand. Most research on this topic has focused on investigating the presence of fecal indicators and pathogens in beach sand from coastal and Great Lakes locations (Zhang et al., 2015, Yamahara et al., 2012; Alm et al., 2003, 2006; Eichmiller et al., 2014; Staley and Sadowsky, 2016), while research at other inland recreational beaches are less represented in the literature (Wilson et al., 2016, Levin-Edens et al., 2012, Marion et al., 2010). To our knowledge, there is no regular monitoring of fecal pathogens at recreational beaches in Tennessee (TN), and there has been very little research on this topic in the state. Previous research in our laboratory in summer 2015 at one of the proposed sampling sites (see below) showed relatively high concentrations of *E. coli* in both wet and dry swash zone sand at Cedar Creek Recreational Area, a freshwater recreational beach at Old Hickory Lake in central Tennessee (see Table 1; unpublished data).

Table 1. *E. coli* (MPN/100g) detected in sand cores from Cedar Creek Recreational Area in TN.

	Min	Max	Average
Dry sand (foreshore)	8.3	14,440.8	1,982.3
Wet sand (intertidal)	8.3	1,258.3	218.7

In fact, these data demonstrate that the highest concentration of *E. coli* at this site are in the samples closest to shore (Figure 1B) and in the top 10cm of the sand (Figure 1A) where children and others often play and dig in the sand.

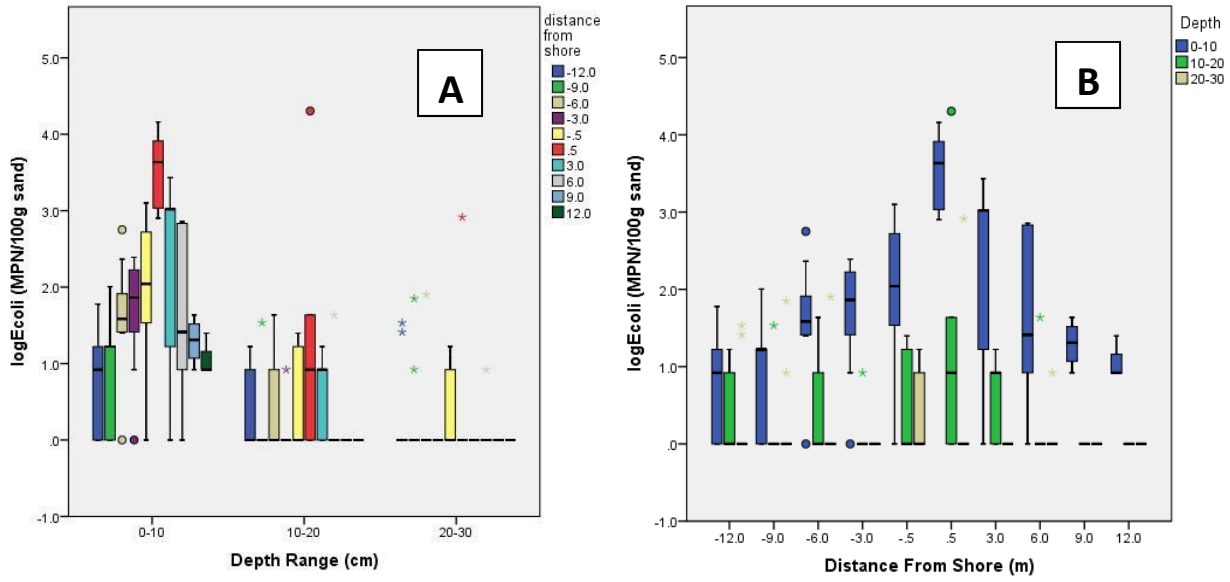

Figure 1. *Escherichia coli* concentrations in sand cores from Cedar Creek Recreational Area in TN.

Escherichia coli is the primary traditional fecal indicator bacteria (FIB) used by regulators to assign impairment to recreational waterbodies (freshwater). One drawback to use of *E. coli* as an FIB is its ability to multiply in the environment outside of the host gut (Desmarais et al., 2002; Ishii et al., 2006) and lack of source specificity (Wilson et al., 2016). Because of this, the USEPA has recognized other promising alternative indicators of fecal pathogen impairment with minimal replication outside of the gut, such as anaerobic fecal bacteria in the order *Bacteroidales* (Fiksdal et al., 1985; Kreader, 1995; USEPA, 2005) and viruses that infect fecal coliforms, known as coliphages (USEPA, 2015a, 2016).

Fecal bacteria in the order Bacteroidales are obligate anaerobes that are specific (Dick et al., 2005) or selective (Layton et al., 2006) with the digestive system of their host making them particularly useful to determine both the sources and amount of recent fecal contamination. Both general Bacteroidales 16S rRNA markers, and those specific for human or other animal hosts (Green et al., 2014; Dick et al., 2005; Layton et al., 2006), have been developed for use in quantitative polymerase chain reaction (qPCR) assays to rapidly determine sources of fecal bacteria or concentrations of Bacteroidales in general (Bernhard and Field 2000a, b; Seurinck et al., 2005; Layton et al., 2006; Okabe et al., 2007; Shanks et al., 2009). A quicker turnaround time to achieve results with these assays compared to *E. coli* culture methods minimizes the time needed for water quality regulators to make informed public health decisions for beachgoers.

Enteric viruses are suspected to be the cause of nearly 50% of waterborne gastrointestinal illnesses (Centers for Disease Control and Prevention, 1993). Among the leading culprits are human noroviruses, adenoviruses, rotaviruses, and hepatitis E viruses. Because of the differences in response to wastewater treatments, traditional FIB are not adequate indicators of viruses. Unfortunately, infectious viruses are difficult and expensive to culture and can take up to a week or more for results. The EPA recently performed a literature review to assess coliphages as primary indicators of fecal pathogen contamination and enteric viruses. Many authors recommended the use of somatic and F+ coliphages as indicators of infectious viruses for water quality (USEPA, 2015a). Coliphages, both somatic and F+, share similar morphology and responses to treatment as several types of infectious human viruses (King et al., 2011). Pricing and the difficulty level of culturing coliphages is competitive with the current primary FIB, *E. coli*, and coliphages have shown to have strong correlation with FIB and enteroviruses in water used for irrigation (Espinosa et al., 2009). According to U.S. EPA 2016 Coliphage Experts Workshop, coliphages can be used to evaluate wastewater treatment processes and disinfection efficacy and participants in the workshop agree that coliphages should be used as measured indicators in epidemiological studies (USEPA, 2016).

Staphylococcus aureus at beaches have been associated with community acquired GI illness as well as skin, ear and eye infections (Soge et al., 2009; Gabutti et al., 2000). While *S. aureus* is not typically a fecal pathogen, it is an opportunistic pathogen carried by 20-40% of people (Kuehnert et al., 2006). Therefore, it is not surprising that *Staphylococcus aureus* and methicillin-resistant *S. aureus* (MRSA) are shed by swimmers (Plano et al., 2011) and both are found in beach sand and water (Soge et al., 2009). It is also of note that the methicillin resistance gene from MRSA (mecA gene) can be transferred horizontally from MRSA to other live bacteria (Chambers, 2001) increasing levels of antibiotic resistant bacterial strains.

The proposed project will address the following research questions at two TN recreational beaches, with the goal of improving the understanding of fecal indicators found at these sites. The knowledge gained can potentially be applied to improve the understanding of

fecal indicators found at inland beaches elsewhere the U.S. and inform regulators as they make decisions about formulation of regulatory criteria for fecal pathogens in beach sand.

1. How abundant are fecal indicators and other pathogens in sand and water at two freshwater recreational beaches in TN?
2. Do human feces contribute to the fecal indicators found at these sites?

Specifically, the proposed research objectives are to

1) compare levels of fecal indicators in beach sand between two recreational beaches on different rivers - 1) Cedar Creek Recreational Area on Old Hickory Reservoir, and 2) Barton Springs Recreational Area on Normandy Reservoir;
2) measure *E. coli, Staphylococcus aureus*, and methicillin-resistant *S. aureus* (MRSA) concentrations in water and the first 10 cm of swash-zone beach sand;
3) screen for presence of human fecal pollution using qPCR (HF183 Bacteroides 16s rRNA genetic marker); and
4) measure coliphage (viruses that infect fecal coliforms) concentrations in water and the first 10 cm of swash-zone beach sand.

Figure 2. Timeline of project activities

Late May – early September 2017	September – December 2017	January – February 2018
• Water and sand sampling • Culture based assays for *E. coli*, coliphage, *S. aureus* and MRSA	• Processing PCR samples for HF183 (Bacteroides), *S. aureus*, and MRSA • Data analysis	• Report writing • Manuscript preparation for publication

Methods, Procedures and Facilities:

Prior to initiation of sampling, sanitary surveys (USEPA, 2015b) will be carried out at both Cedar Creek Recreational Area on Old Hickory Reservoir, and Barton Springs Recreational Area on Normandy Reservoir in central TN in order to determine the potential sources of fecal bacteria at each site. Sampling will occur six times per site during the 2017 recreational season (Late May to Early September), including the Memorial Day, Independence Day, and Labor Day holidays. On these holidays, water column sampling will occur in the morning prior to arrival of bathers and at ~1400hrs when many bathers are present in order to determine the impact of bathers on resuspension of fecal indicators.

Sand sample collection and processing: Beach sand cores (to ~10cm depth) will be collected in the morning before most bathers arrive from the swash zone at 5 locations at each site using sterile PVC pipe, both in the foreshore (dryer sand, ~0.5m inland from the shoreline) and in the intertidal (water-inundated) zone (~0.5m offshore). Sand cores will be transferred to sterile Whirl Pak® bags and placed on ice for transport to the laboratory. In the laboratory, 100g aliquots of sand from each core will be shaken for 2min in 1L of phosphate buffered saline (PBS) and then allowed to settle (Boehm et al., 2009; USEPA 2001). The supernatants will be collected and used for *E. coli,* coliphage, qPCR (*Bacteroidales*), and MRSA analysis. For qPCR, DNA will be extracted (DNeasy® PowerWater® Kit) and stored at -80°C until processing.

Water sample collection and processing: Water samples (3L) will be collected in sterile 1L plastic bottles at each of the 3 locations per site in ~0.5M deep water and transported on ice to the laboratory. Conductivity, pH, temperature, and DO will be measured in water during each sampling event (TDEC, 2012). Collected water will be used for *E. coli,* coliphage, qPCR (*Bacteroidales*), and MRSA analysis. For qPCR, DNA will be extracted (DNeasy® PowerWater® Kit) and stored at -80°C until processing.

Escherichia coli analysis: Concentrations for *E. coli* in the water column (100mL) and sand sample supernatants (100mL) will be measured by the EPA approved Colilert® method (TDEC, 2012). Water samples and sand samples will be reported as MPN/100mL and MPN/100g (dry weight sand) respectively. The method of Francy and Darner (1998) will be used to calculate numbers of *E. coli* per dry weight of sand.

Coliphage analysis: Coliphages in water samples (200mL) and supernatants from sand samples (200mL) will be filtered, plated and enumerated following Method 1602: Male-specific (F+) and somatic coliphage in water by single agar layer (SAL) procedure (EPA 2001). Coliphage numbers in water and sand samples will be reported as plaque forming units (PFU)/100 mL and PFU/100g respectively.

S. aureus and MRSA analysis: Staphylococcus aureus and Methicillin-resistant *S. aureus* (MRSA) will be determined by culture methods using selective agars and with confirmation by PCR (Levin-Edens et al., 2012). For culture methods, 100mL aliquots of water samples or sand sample supernatant will be filtered through 0.45µm filters and the filters placed on selective agar plates and incubated. For PCR confirmation, isolated colonies of putative *S. aureus* and MRSA will be chosen from the selective agar plates.

qPCR analysis: Human-specific fecal pollution will be determined as number of copies of the HF183 Bacteroides 16s rRNA genetic marker with a qPCR assay (Green et al. 2014). Values will be reported as copies/100mL for water samples and copies/100g for sand samples.

A flow diagram of the overall sampling and processing procedures can be seen in Figure 3.

Facilities: The Bailey (PI F. Bailey) laboratory is housed in the newly constructed $147M science building on the Middle Tennessee State University campus. All equipment necessary to carry out the proposed study are either in the Bailey laboratory or in shared facilities in the science building.

Related Research:

Sand contact has been implicated as a potential health risk to beachgoers (Heaney et al., 2009) due to presence of fecal bacteria, viruses, and associated pathogens (Byappanahalli et al., 2006, Yamahara et al., 2012), but no federal criteria have been developed for fecal bacteria in sand. Most research on fecal bacteria and pathogens in sand at beaches has focused on their presence at coastal and Great Lakes locations (e.g., Zhang et al., 2015, Yamahara et al., 2012; Alm et al., 2003, 2006; Eichmiller et al., 2014; Staley and Sadowsky, 2016), while research on other inland recreational beaches is less represented in the literature (e.g. Wilson et al., 2016, Levin-Edens et al., 2012, Marion et al., 2010). Traditional FIB were typically measured in the studies reviewed, while measurements of alternative FIB and pathogens were more sporadic and variable. The proposed study will not only be carried out at inland recreational beaches, but also

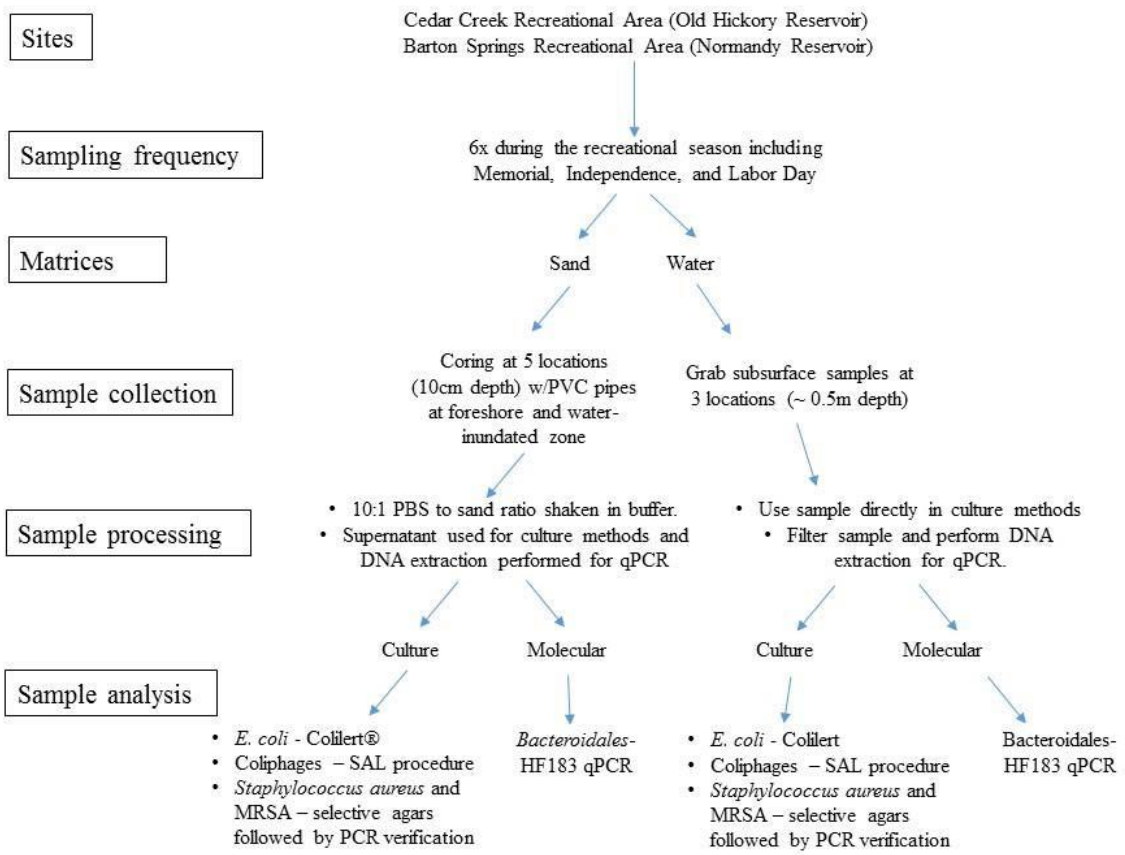

Figure 3. Workflow diagram for sampling and processing procedures.

will encompass measurement of traditional and alternative FIB (coliphages and qPCR of *Bacteroidales*) and pathogens (*S. aureus* and MRSA).

An extensive study by Yamahara et al. (2012) included all of the indicators and pathogens in the proposed study, with the addition of Salmonella and Campylobacter pathogens. However, only dry sand was sampled (Yamahara et al., 2012) and was not inclusive of the swash zone, where our laboratory has found the highest level of FIB. The only other study to our knowledge that has combined the use of sanitary surveys (USEPA, 2015b), enumeration of *E. coli*, and source tracking with *Bacteroidales* qPCR in freshwater beach sand in the swash zone is Wilson, et al. (2016) at Lake of the Ozarks State Park, Missouri.

In a Lake Erie study, numbers of *E. coli* were determined in sediment and water at public bathing beaches during the outdoor recreational season (Francy and Darner, 1998). However, unlike the proposed study, the Francy and Darner (1998) study did not additionally look at pathogens or coliphages, and also did not carry out microbial source tracking to determine if fecal pollution was due to human inputs.

At a Lake Huron beach, culturable *E. coli* (and enterococci) concentrations were appreciably higher (3-17 times) in sand samples compared to the ambient water samples (Alm et al., 2003). Although *E. coli* concentrations were measured in the Alm et al., (2003) study, the proposed study will use the Colilert® method instead of a filter membrane method and is more extensive due to measurement of alternative indicators, coliphages, and pathogens.

Pathogens, such as *S. aureus* and MRSA, have been found in beach sand and seawater in California (Goodwin and Pobuda, 2009; Goodwin et al., 2012; Yamahara et al., 2012), Washington (Soge et al., 2009), and Great Lakes Beaches (Fogarty et al., 2015). While the techniques used in the aforementioned studies are similar to those in the proposed study, traditional and alternative FIB will also be collected in the proposed study. In addition, the proposed study will take place in a geographic location that has been underrepresented.

Progress to Date

The first sampling event for the project occurred on 5/28/2018 at two freshwater recreational beaches in central TN. Sand samples were taken at 10 locations at each beach and water samples were taken at 3 locations at each beach. Initial sampling results show every beach sand and water sample to contain *E. coli*. The *E.* coli concentrations ranged from 20 MPN-1,989 MPN/100g for swash zone sand, but most sand samples contained less than 400 MPN/100g. Water *E. coli* concentrations ranged from 18.5 MPN/100mL to 90.8 MPN/100mL. MRSA was found in all sand samples with concentrations from approximately 120 CFU/100g to too numerous to count (TNTC) and in water from 56 CFU/100mL to TNTC. Ongoing qPCR will be used to verify the identity of MRSA on selective agars. These results show the presence of fecal bacteria and pathogens at these two freshwater sandy beaches and demonstrate a potential risk to beachgoers that will continue to be investigated throughout the summer.

Five more sampling events will take place during the summer, including one on Independence Day and one on Labor because these are known to be high traffic days at the beaches. Any qPCR analyses that are not completed during the summer will be completed September-November 2018 and report and manuscript preparation will take place December 2018-February 2019.

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Sediment Source Tracking in Urban Watersheds: An Applicationin the Second Creek Observatory

Basic Information

Title:	Sediment Source Tracking in Urban Watersheds: An Applicationin the Second Creek Observatory
Project Number:	2017TN130B
Start Date:	3/1/2017
End Date:	2/28/2019
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Water Quality
Focus Categories:	Sediments, Non Point Pollution, Surface Water
Descriptors:	None
Principal Investigators:	Jon M Hathaway, Thanos Nicholas Papanicolaou, Christopher Wilson

Publications

There are no publications.

Introduction:

As urbanization spreads throughout Tennessee, the effect of land use change becomes evident in the form of increased stormwater runoff, pollutant export, and stream degradation. Numerous studies have been performed to better understand these effects and develop methods for their amelioration, but gaps in knowledge still exist. Although the field of urban hydrology is relatively mature, the same cannot be said of urban water quality modeling. Recent studies have shown that current models of sediment export from urban watersheds do not perform well, necessitating new approaches to improve these models. These efforts are hampered by the high spatial variability of land uses in these watersheds, as well as the presence of stormwater conveyance infrastructure which greatly influences system connectivity and conveyance. All these variables lead to difficulty determining sediment source areas for individual storm events. However, sediment source tracking holds promise to aid in understanding these processes. Sediment tracking methods are an established tool for determining sediment source areas, but they have been rarely applied in urban systems. The objective of this research is twofold; (1) to better understand the sources of sediment in an urban watershed in Tennessee to inform management strategies and develop a methodology for similar studies elsewhere, and (2) to use this initial study as a way to develop new hypotheses for improving water quality modeling in urban watersheds.

Methods, Procedures, and Facilities:

This study will leverage infrastructure within the Second Creek (SC) Observatory which was made possible, in part, through past USGS 104B funding. The site's proximity to the John D. Tickle Engineering Building allows excellent access for sample collection and maintenance of the station. Due to the complexity of urban watersheds, this pilot study will identify one smaller catchment within the SC where the sources of sediment can be carefully identified, characterized, and tracked.

Three rainfall events will be targeted for analysis. A combination of naturally occurring radio-isotopes and artificially tagged particles with Rare Earth Elements will be applied to different land covers within the smaller catchment, including parking areas and surrounding open space. At the catchment outlet, high frequency collection of sediments (Figure 1) will capture the tagged material that is delivered to SC through the stormwater infrastructure. These samples will be transported to the University of Tennessee Hydraulics and Sedimentation Laboratory (HSL) where they will undergo isotope analysis. Using the isotope analysis from the source locations, a mixing algorithm will be applied to the event samples to better understand the source distribution present in the samples and how that distribution changes throughout the storm. That is, the most likely sources of sediment will be determined for each event.

Progress to Date:

A small urban catchment feeding to SC on the University of Tennessee campus has been selected for the project and initial field investigation of the stormwater infrastructure in the area has been performed (Figure 2a). Watershed analysis suggested the primary contributing areas to the point of discharge include a parking lot, concrete pathways, and turf / landscaped areas. Additionally, the methodology for the project has been refined to determine which tracers should be used and where they should be placed in the catchment. Figure 2b shows the primary tagging areas which feed directly to the underlying stormwater infrastructure. The stormwater runoff feeds to a single outlet (Figure 2c) where an autosampler will collect samples every 5

minutes. A time-lapse camera will be used to capture images of the outflow. Image analysis will be used to estimate the flow rate.

Conference Presentations Delivered: A presentation is planned for the 2019 Tennessee AWRA meeting.

Pending Publications: A publication is planned for this work, but a publication venue has not yet been selected.

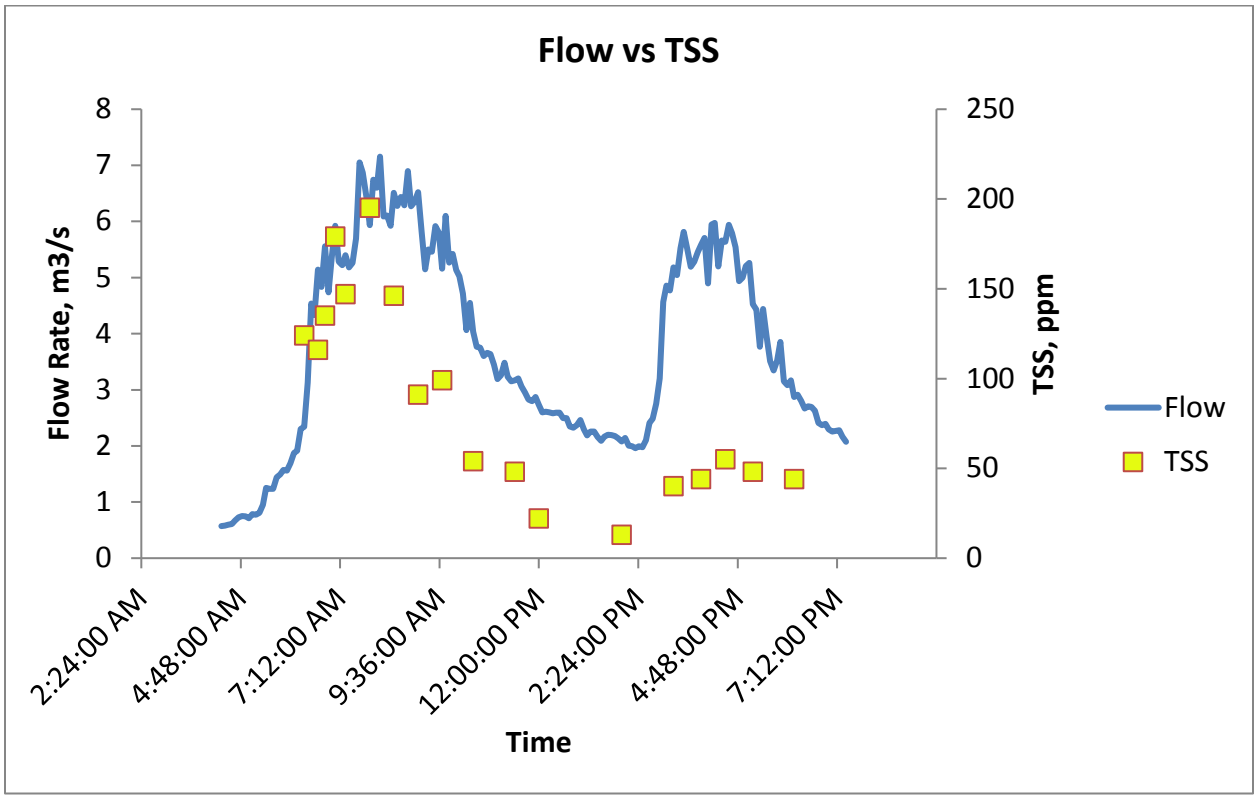

Figure 1: Example Pollutagraph for Second Creek Storm on 10/14/2014

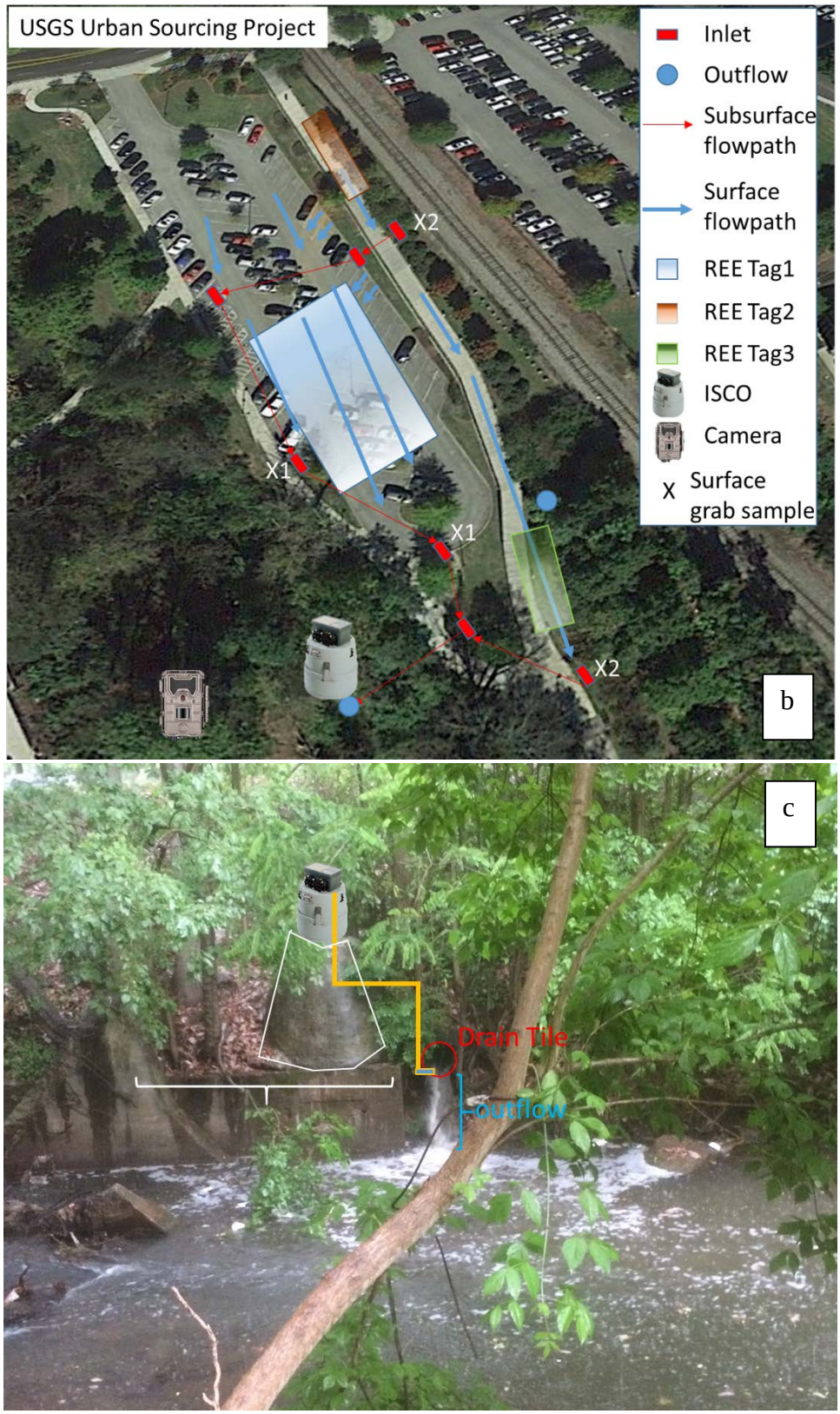

Figure 2: Catchment Selected for Study Near UTK Campus

Characteristics of Fine Sediment Embeddedness: Towards Understanding Drainage Network Transport Lags

Basic Information

Title:	Characteristics of Fine Sediment Embeddedness: Towards Understanding Drainage Network Transport Lags
Project Number:	2017TN131B
Start Date:	3/1/2017
End Date:	2/28/2019
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Water Quality
Focus Categories:	Sediments, Surface Water, Geomorphological Processes
Descriptors:	None
Principal Investigators:	John S. Schwartz

Publications

There are no publications.

Statement of Critical Regional or State Water Problem:

The State of Tennessee contains many waterbodies that have been identified on the 303(d) list as impaired or threatened, by which they do not meet designated beneficial uses including biological integrity [40 CFR Part 130; TCA §69-3-101 and TDEC Rules Chapter 1200-4]. A the majority of streams listed are impacted by excessive sedimentation in channels causing physical habitat degradation, which reduces biological integrity. The Tennessee Department of Environment and Conservation (TDEC) is required by statutes to produce total daily maximum loads (TMDLs) for 303(d) listed streams impacted by siltation and habitat alteration. Understanding the biophysical dynamics of fine sediment infusion into the streambed gravel is critical to enhancing management and restoration strategies for impaired streams. Tennessee is not the only state facing this environmental issue with the need to improve the biological integrity of impaired streams. Many states need better assessment techniques to effectively develop siltation and habitat alteration TMDLs that identify physical and ecologically limitations in human-dominated watersheds.

Statement of Results or Benefits:

The expected outcomes of the proposed research includes a statistically significant response that biofilms play a key role in embeddedness, embeddedness quantified by a McNeil sampler will be correlated to TMI scores and directly correlated with biological impairment, and development of a relationship of fine sediment influx into a gravel matrix, used towards predicting embeddedness in streams. Development of this relationship will include variables on stream flow and suspended sediment transport dynamics. Results can potentially be used in the CONCEPTS model. Overall, a better understanding of the biophysical characteristics of stream embeddedness will allow for improved assessment methodologies of fluvial conditions, which can be applied to watershed management strategies for ecological restoration.

This research will be conducted by an undergraduate (UG) researcher, promoting undergraduate education at the University of Tennessee. In addition, the collaborative interactions with the Czech Technical University (CTU) will promote the future international research with the aim to further our research under a National Science Foundation (NSF) Partnership for International Research and Education (PIRE) grant (*See Section 16 below*). We also plan to work with Dr. Eddy Langendoen at the USDA National Sedimentation Laboratory using CONCEPTS, but other models and modelers will benefit from the basic data we propose to collect. The main benefit of this proposed work is to begin field data collection that matches data collected by research colleagues at the CTU. Needed for a PIRE proposal is demonstrated collaboration between the international and American universities. Collaboration between UTK and CTU will also benefit the state of Tennessee by the technical transfer of modeling techniques and sediment monitoring.

The UG student researcher will draft one or two manuscripts for publication. He/she will receive a grade in CE409 for their effort on the project.

Nature, Scope and Objectives of Project:

The objectives of the research project are: 1) to improve our understanding of the biophysical processes associated with fine sediment embeddedness in the surficial (active) layer of stream channel alluvium; 2) explore how fractional transport mobility of fine sediment (silt-clay-organics) and associated embeddedness processes can be better incorporated into an existing sediment transport model, i.e., CONCEPTS, and 3) collaborate with Dr. Tomas Dostal at the CTU in order to build on our existing research with the goal to submit a NSF PIRE proposal in

2018-2019. The requested funds are essentially seed money to better position a UTK research team to win a NSF PIRE grant. Objectives 1 and 2 will be accomplished supporting an UG research student, where he/she will be enrolled in CE409, UG Research Projects. Because this proposed research is to initiate some research promoting collaboration with the CTU, and that it will be supporting the UTK ORE UG research initiative, its scope is not at a doctoral level. Though the goal will be for the UG researcher to produce a draft journal manuscript, or at a minimum generate data that can be used in a future publication. This proposed research for a USGS 104b grant aims to make progress on objectives 2 and 3 (tasks) above, collecting fine sediment data in a local catchment, and focusing on one aspect of this spatially and temporally complex problem with catchment sediment transport and in-channel retention processes.

Timeline for Activities: Collaboration between Dr. John Schwartz (UTK) and Dr. Tomas Dostal (CTU) will occur throughout the project period (April 15, 2017 through February 28, 2018). The undergraduate research will be conducted during the summer 2017 from May 15, 2017 through August 15, 2017.

Methods, Procedures and Facilities:

The first task by the UG researcher will be to conduct a thorough literature review on fine sediment embeddedness, including relevant articles on sediment transport modeling.

The second task for the UG student researcher will be to conduct two field studies. The first study will be to collect sediment samples at riffles where TDEC has benthic macroinvertebrate index (TMI) data. TMI data collected will be no older than 2-3 years. Sediment samples at riffles will be collected by use of a McNeil sediment core sampler, a unique sampler to collect fine sediment with the course size fractions. Particle size distributions (PSD) will be performed on the course and fine particle fractions. The fine particle fractions will be determined by the standard hydrometer method. In addition, the fine particle fraction will be dried, and using standard methods an inorganic/organic ratio will be determined. Gravel materials will be washed with laboratory DI water to obtain the organic content adhered to the course material. PSD and the inorganic/organic data will be statistically corrected with the TMI scores. The biofilm organic mass on the course material and within the fine sediment content will be estimated and normalized by weight to sampled streambed alluvium.

The second experimental design is to place "boxes" of clean river rock with known D_{50} and overall porosity, and bury it level with an existing riffle bar structure at a location on Fourth Creek (Knox County, TN). We will let the "box" be exposed to varying flood flow stages in which we collect fine sediment in transport and record the discharge hydrograph. Fine sediment transport over the hydrograph will be estimated with use of a turbidity probe and a multi-stage siphon sampler. The analysis will examine the temporal dynamics of fine sediment flux into the clean gravel interstitial and correlate the sediograph patterns (flux dynamics) with mass transfer into the gravel "box". The number of flood events sampled will be dependent of environmental conditions. The UG student researcher will contact Dr. Eddy Langendoen at the USDA National Sedimentation Laboratory and discuss how the silt-clay size fraction is modeled in the CONCEPTS model, and how the flux dynamics measured in the above described experiment can be incorporated into the model.

Related Research:

Embeddedness is defined differently between the physical and biological scientists (Diamond et al. 12002; Syite and Fischenich 2003; Sennatt et al. 2006; Paul et al. 2009; Chin et al. 2010; Mueller et al. 2010). Physical scientists have long known of this process, and it has been termed as armouring (Jackson and Beschta 1982). In the earlier work, it was observed that sand embedded between voids within the gravel matrix increased critical shear stress for incipient motion. Lee and Odgaard (1986) developed a simple model for the exchange of grain sizes between the surface and subsurface layers and associated simulation with the temporal variation observed with sediment transport rates. Curran and Wilcock (2005) developed a gravel-sand mixture bedload sediment transport relationship, which was incorporated in the BAGS model. Biological scientists have also long known about the impacts of fine sediment embedded into gravels, with the original work completed in the Pacific Northwest streams related to salmonid spawning redds (Kelley and Dettman 1980; Burns and Edwards 1986; Kramer 1989; MacDonald et al. 1991; Kaufmann et al. 1999). Schwartz et al. (2011) conducted an analysis of the impacts of episodic fine sediment transport on fish assemblages in the Great Plains Region of the US. In addition, Schwartz et al. (2008) developed a unique statistical procedure to characterize fine sediment transport and its potential impact on aquatic biota. More research is needed on the dynamics associated with fine sediment retention in streambed alluvium during episodic events; in addition to the influence of biofilms on those dynamic processes.

The research supports current research at the CTU where Dr. Josef Krava, Dr. Tomas Dostal and other faculty which modeled sediment yields from all sub-catchments within the Czech Republic. The project was an enormous effort on their part. They used the WATEM/ SEDEM model and calibrated it using 9,890 reservoirs from a database of 20,477 reservoirs (GIS spatial information taken from DIBAVOD). This watershed model utilizes a distributed approach, similar to USDA models SWAT and AnnAGNPS (Van Rompaey et al. 2001). Sediment trap efficiencies for the reservoirs were estimated utilizing the Brune curves method readjusted by Dendy and Champion (1978). Reservoirs with known construction dates and bathometry were measured for sediment deposition for verification. The initial national effort was to identify high yield sub-catchments for agricultural management. The WATEM/SEDEM model defined spatial patterns of erosion and deposition among the sub-catchments with the topography and land-use data being sufficient. However, estimating actual sediment transport flux were uncertain where CTU researchers recognized that their calibration procedure needed improvement incorporating stream channel erosion and sediment transport processes.

The CTU research team is interested in improving their national modeling results for sub-catchment sediment yields incorporating channel processes and sediment transport, erosion and deposition. They have submitted a proposal to their national research agency (Czech's NSF equivalent) for the Czech-American Scientific Cooperation Program, in which I am the American university collaborator on that proposal. UTK's role on the proposed CTU research is to: 1) contribute to modeling with a focus on sediment sources and transport processes associated with the stream channel utilizing the USDA National Sedimentation Laboratory's Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) model; 2) conduct statistical analysis of episodic sediment transport utilizing existing datasets from CTU and UTK; and 3) pursue collaborative research funding with preparation of US grant proposals to further advance the objectives of the proposed research.

Progress to date:

To date, nine streams have been selected to samples bed sediments using a McNeil sampler, in which the samples will be analyzed for particle size distributions and the percent organic matter. A student has been assigned to the project, his name is Nicholas Pettit. He will be completing the field work which will be completed during the 2018 summer period. Equipment has been organized for the field work. In addition, in-situ sediment collection chambers have been designed and the Civil Engineering Department shop is constructing them. Nicholas has also started his literature review on embeddedness studies to summarize the different methodologies others have applied to quantify embeddedness.

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Examining Sediment Rating Curve Hysteresis with State-of-the-Art Sensors

Basic Information

Title:	Examining Sediment Rating Curve Hysteresis with State-of-the-Art Sensors
Project Number:	2017TN132B
Start Date:	3/1/2017
End Date:	2/28/2019
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Sediments, Hydrology, None
Descriptors:	None
Principal Investigators:	Thanos Nicholas Papanicolaou, Jon M Hathaway, Christopher Wilson

Publications

There are no publications.

Introduction & Problem Statement:

Streams are the receptor, conveyor and transformer of terrestrial sediments. Geomorphologists quantify the sediment yield moving through the streams to examine the effects of sediment loading on the riverine channel responses and fluxes.

However, sediment moves through the channels in a series of steps. It can end up spending long periods sitting on the bed, bars, and floodplains. Additionally, the transported sediment is a combination of bed load, suspended material, and fine-grained wash load. The coarsest sediments are transported as bed load, rolling and bouncing close to the river bed. Finer sediment fractions are lifted off the river bottom by turbulence and become the suspended load. The wash load consists of sediments that are sufficiently fine-grained that the river is able to transport them at uniformly high concentrations and at nearly the same rates as the water flow itself. The ranges of sediment grain sizes that are transported instream in the three modes are governed by the stream-flow velocity and by the settling velocities of the grains.

These challenges can make it difficult to quantify sediment yields because they lead to a hysteresis that exists between water discharge and sediment transport fluxes. This hysteresis is more pronounced in reaches with hydraulic structures, which act as obstructions to the flow. Considerable strides have been made, though, in the last few decades that have resulted in several analytical and empirical formulations for developing rating curves to quantify sediment yield.

Methods, Procedures, and Facilities:

In this study we are monitoring sediment movement by tagging sediment particles with miniature Radio Frequency IDentification (RFID) sensors. We are combining this information on sediment transport flux timing with the flow discharge hydrographs to resolve phase-space relations between water and sediment for the rising and falling limbs of the hydrograph.

The RFID technology incorporates transponders that mimic the different sediment sizes and can communicate wirelessly with a base station. The transponders are sealed in carefully drilled particles with diameters and proportions matching the field sediment size distribution. Each transponder has a unique identification number and is being tested in the laboratory, for assessing their accuracy through video observations of the sediment particle movement. The laboratory tests are conducted in a 2-m x 3-m testing box filled with sediment material.

Following the laboratory testing, the RFID system will be installed at the Second Creek, a coarse-grained stream on the University of Tennessee, Knoxville campus. Subsequent periodic surveys conducted throughout the year will provide the transport characteristics of the tagged sediment for variable flow discharges.

Progress to Date:

To date, two types of spherical particles have been created to house the transponders, namely a glass particle and a concrete particle coated with tungsten Figure 1. The density of the encased particles matches the density of quartz. The glass particles were heated for 30 to 40 minutes at high temperatures (~ 600^{o}C) in order to be drilled without cracking. After being annealed, the glass particles were carefully drilled to house the transponder. When the transponder was placed inside the glass particle, it was sealed with silicon to keep the transponder in place.

For each type of material, the maximum detection distance was measured using a custom-made excitation antenna plane. The use of a custom-made excitation antenna allows the user to increase considerably the maximum antenna-transponder detection distance. However, there is an optimum in the increase of the excitation antenna's size after which the maximum antenna-transponder detection distance can dramatically deteriorate, since more ambient noise is picked up by the excitation antenna. Currently, the transponder spheres are being tested in the testing bed filled with sediment with the custom-made antennas. Overall, the proposed research will investigate the time lag, or hysteresis phenomenon, between the sediment flux and the flow discharge, which accounts for a considerable part of the variability in sediment rating curves.

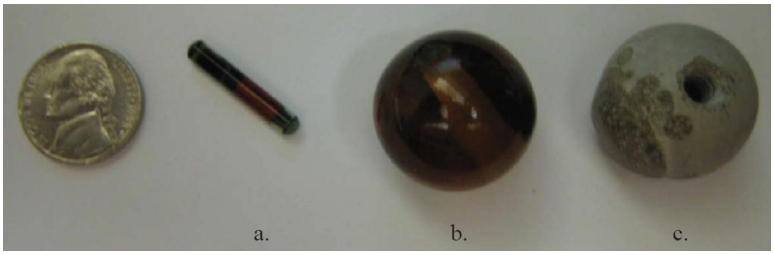

Figure 1: From left to right: (a) "naked" transponder, (b) glass particle and (c) concrete-tungsten particle.

Conference Presentations Delivered: A presentation is planned for the 2019 Tennessee AWRA meeting.

Pending Publications: A publication is planned for this work, but a publication venue has not yet been selected.

Combined Field Study of Turbulenceand Bed Morphology in Mountainous Boulder Arrayed Streams

Basic Information

Title:	Combined Field Study of Turbulenceand Bed Morphology in Mountainous Boulder Arrayed Streams
Project Number:	2017TN133B
Start Date:	3/1/2017
End Date:	2/28/2019
Funding Source:	104B
Congressional District:	Second, TN
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Hydrology, Geomorphological Processes, None
Descriptors:	None
Principal Investigators:	Micah A Wyssmann, Thanos Nicholas Papanicolaou

Publications

There are no publications.

Progress to date:

The overarching goal of my dissertation research is to develop of a mechanistic bedload transport prediction model that is applicable to gravel bed rivers where ubiquitous boulders affect sediment movement characteristics. As such, a primary objective of my research, and the primary objective of this study, is to connect bedload movement observations with the complex flow characteristics that occur in gravel bed rivers. By providing improved connections of sediment movement with the driving turbulent flow forces, we are aiming to develop and improve sediment transport prediction methods. This research has implications to water problems related to the prediction of transport distances for sediment (including contaminated sediment) through complex river networks, to predicting sediment inputs into critical water infrastructure such as dams, and to the design of river restoration practices for the dissipation of flow energy and the entrapment of sediment.

In this study, we planned to investigate the connections between flow and sediment movement in gravel bed rivers through the development of a field study. In the initial phases of this study, interaction with a collaborating research group in New Zealand led to a thorough review of existing literature and enabled us to pinpoint key data wherein the travel characteristics of bedload particles in gravel bed rivers was investigated. Following the findings from this effort, we decided to take a slight recourse for this project in order to develop a generic model for predicting the particle resting time of sediment atop the river bed and investigate the connections with the driving flow forces.

The methodology employed in the particle resting time model is based on the generic spectral characteristics of turbulent flow, which is used to predict the intermittent forcing on resting sediment particles. This model is thus able to account for the most important features of the flow field in order to predict the time that sediment rests atop the river bed. Calibration and validation of the model has been conducted by utilizing identified data (e.g., Knapp, 2002; Celik et al., 2010; Wu & Yang, 2004). Additional simulation scenarios designed to aid the development of generic particle resting time prediction tools are also a continuing effort in this project.

From this research, a conference paper was written based on the initial development and validation of the particle resting time model, which has been accepted to be presented at the IAHR River Flow 2018 conference in Lyon, France. Through presenting at the River Flow conference, we are seeking to gain further input from the research community on this topic and intend to meet there with collaborators from New Zealand in order to continue discussions about the next steps in this research. In addition, a manuscript detailing the generic resting time prediction tool for to gravel bed rivers is in preparation to be submitted to the *Journal of Hydraulic Research*.

Publications

Information in this study has been used in the following:

1. Wyssmann, M.A. and Papanicolaou, A.N. (2018). Lagrangian modeling of bedload movement via the impulse entrainment method. River Flow 2018.
2. Wyssmann, M.A. and Papanicolaou, A.N. A model for particle resting time in a turbulent open channel flow. *Journal of Hydraulic Research*. Forthcoming.

References:

Celik, A.O., Diplas, P., Dancey, C.L. and Valyrakis, M. (2010). Impulse and particle dislodgement under turbulent flow conditions. *Phys. Fluids* 22, 046601.

Knapp, D.D. (2002). Applications of particle velocity to bedload motion. MS Thesis, Washington State University

Niño, Y., and M. García (1998), Experiments on saltation of sand in water, *J. Hydraul. Eng.*, 124, 1014–1025.

Shih, W., P. Diplas, A. O. Celik, and C. Dancey (2017), Accounting for the role of turbulent flow on particle dislodgement via a coupled quadrant analysis of velocity and pressure sequences, *Advances in Water Resources*, 101(3), 37-48.

Sun, Z., and J. Donahue (2000), Statistically derived bedload formula for any fraction of nonuniform sediment, J. Hydraul. Eng., 126, 105– 111.

Wu, F.-C. & Yang, K.-H. (2004). A stochastic partial transport model for mixed-size sediment: Application to assessment of fractional mobility. *Water Resour. Res.*, 40, W04501.

Information Transfer Program Introduction

The major emphasis of the information transfer program during the FY 2017 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 2017 Water Resources Research Institute Program.

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

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

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

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

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

5. 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 2017 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 26th Tennessee Water Resources Symposium, which was held on April 5-7, 2017 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 26th Symposium was very successful with over 350 attendees and approximately 73 papers and 22 student posters being presented in the two-day period. EPA and TN-AWRA held two pre-symposium workshops on water quality modeling using EPA s WASP Model and an introduction to a stream qualification tool for ecological uplift. Over 80 persons attended the two workshops.

TNWRRC was a co-sponsor of the Tennessee Stormwaer Association Annual Conference, Streaming Together , held on October 16-19, 2017 at Fall Creek Falls State Park. Over 285 attendees including MS4 communities, state and federal government agencies and engineering consulting companies from across the State participated in the three-day event. The opening keynote speaker was Dr. Anna George, Director and Chief Research Scientist at the Tennessee Aquarium in Chattanooga, TN. The conference included over 38 presentations, a special Project WET workshop and several social networking sessions.

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 2017:

TNSA East Tennessee Regional Group meetings held on March 3, 2017; June 16, 2017; September 8, 2017; and December 1, 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.

Tennessee Wetlands Technical Advisory Task Force meeting, May 25-26, 2017, 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 9, 2017, 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 900 elementary school age students from the Knox County school systems and schools from the surrounding region attended.

The Fundamentals of Erosion Prevention and Sediment Control for Construction Sites - Level 1 Training and Certification course is sponsored by the Tennessee Department of Environment and Conservation, Tennessee Department of Transportation and the Tennessee Water Resources Research Center. Level 1 is a one-day course for developers, contractors, road builders. Local government inspectors and others involved with construction activities across the State.

The course was offered on the following dates in FY 2017: February 28, 2017, Nashville; March 17, 2017, Knoxville; April 4, 2017, Chattanooga; April 26, 2017, Memphis; May 11, 2017, Clarksville; May 19, 2017, Johnson City; June 14, 2017, Nashville; June 15, 2016, Memphis; September 6, 2017, Nashville; September 12, 2017, Memphis; September, 19 2017, Knoxville; October 6, 2017, Chattanooga; November 2, 2017, Clarksville; November 8, 2017, Johnson City; November 28, 2017, Knoxville; December 5, 2017, Nashville; February 15, 2018, Nashville

For this time period over 2,3174 persons obtained Level 1 certification.

The Design Principles for Erosion Prevention and Sediment Controls for Construction Sites Level 2 Training and Certification course sponsored by the Tennessee Department of Environment and Conservation, Tennessee Department of Transportation and the Tennessee Water Resources Research Center. Level 2 is 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 and for local government staff responsible for SWPPP review. The course was offered on the following dates in FY 2017: April 19-20, 2017, Nashville; May 31- June 1, 2017, Knoxville; October 30-31, 2017, Memphis; November 14-15, 2017, Nashville and December 12-13, 2017, Chattanooga, TN.

For this time period over 238 persons obtained Level 2 certification.

Construction Site Inspection as Required by Tennessee's Construction Stormwater General Permit - Level 1 Recertification course sponsored by the Tennessee Department of Environment and Conservation, Tennessee Department of Transportation 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 1 Fundamentals course.

The course was offered on the following dates: February 1, 2017, Nashville; May 2, 2017, Knoxville; May 24, 2017, Nashville; June 9, 2017, Cleveland; June 13, 2017, Memphis; September 15, 2016, Nashville; September 22, 2016, Knoxville; September 13, 2017, Memphis September 21, 2107, Nashville; September

22, 2107, Knoxville; October 12, 2017, Chattanooga; October 20, 2017, Cookeville; November 9, 2017, Johnson City; December 7, 2017, Memphis; December 14, 2014, Knoxville; December 14, 2017, Chattanooga; December 19, 2017, Nashville and February 7, 2018, Nashville.

For this time period over 2,160 persons obtained Level 1 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. Staff from the Tennessee Department of Environment and Conservation (TDEC) and faculty from the University of Tennessee and Tennessee Technological University developed the three-day course. 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 three times in 2017; March 27-29, 2017 in Oak Ridge, TN.; August 14-16, 2017, at Montgomery Bell State Park in Burns, TN and November 28-30, 2017 in Memphis, 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 perons that have completed the three day TN-HDT course must attended a one day Refresher course to maintain their certification. The HDT Refresher courses were offered in 2017 on the following dates and locations: May 23, 2017, Nashville; June 6, 2017, Knoxville; September 8, 2017, Nashville; and November 21, 2107, 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.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 two day foundation building course for individuals responsible for the inspection and maintenance of permanent stormwater management practices. The target audience for the course is 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 2017: April 18-19, 2107, Nashville; May 4-5, 2017, Chattanooga; and November 14-15, 2017, Nashville.

The Watershed Faculty at the University of Tennessee and TNWRRC hosted the 6th Annual Watershed Symposium- Putting Science to Work , on September 26, 2017, 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 of short hands on s kills building workshops for students. The workshops covered a variety of watershed-related activities including stream monitoring both water quality and biological sampling, watershed delineation and data representation using GIS and rain garden design and construction.. The workshops were followed by the Keynote address by Pippa Brashear, Director of Planning and Resilience, SCAPE Landscape Architecture, New York. Next The Landscape Architecture department's River Studio conducted a Community Design Charrette focused on the future of Knoxville's riverfront. Over 120 students, faculty and water resources professional attended the 6th Annual Watershed Symposium.

Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2017 and January 2018. 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.

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USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	7	0	0	0	7
Masters	3	0	0	0	3
Ph.D.	4	0	0	0	4
Post-Doc.	1	0	0	0	1
Total	15	0	0	0	15

Notable Awards and Achievements

TNWRRC Director, Dr. Thanos Papanicolaou was named a Fellow of the American Society of Civil Engineers, a honor that is bestowed on only 1% of ASCE members.

Dr. Thanos Papanicolaou and his research team were featured in EOS Earth & Space Science News on their research investigating how past, present and future human activities and climate affects the health of soil.

Publications from Prior Years

1. 2013TN102B ("Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee") - Conference Proceedings - Simco, W.; D. Larsen; and B. Waldron,2017,Implications of Water Balance for Recharge of the Memphis Aquifer, "in" Proceedings of the 26th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp. 5D-12-16.
2. 2014TN104B ("High Resolution Monitoring of Urban Stormwater Quality") - Conference Proceedings - Hathaway, J.H.;and T.H. Epps,2017,Exploring the Influence of Urban Watershed Characteristics and Antecedent Climate on In-Stream Pollutant Dynamics, "in" Proceedings of the 26th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.3C6-9.
3. 2015TN110B ("Measuring evapotranspiration and soil moisture to close the hydrologic budget under different land-uses in Tennessee") - Conference Proceedings - Abban, B.; T. Papanicolaou; and C. Wilson,2017,Investigating Hydrologic Non Stationarity within the Obion River, TN. Watershed, "in" Proceedings of the 26th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.8A-23-27.
4. 2016TN118B ("Urban Stream Restoration Planning: Towards Cost-Effective Mitigation of the Effects of Hydromodification") - Conference Proceedings - Schwartz, J.,2017,A Monitoring and Assessment Framework to Evaluate Stream Restoration Needs in Urbanizing Watersheds, "in" Proceedings of the 26th Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., pp.7B31-35.
5. 2016TN119B ("Development of a Robust Model for Cross-Scale Prediction of Flow and Sediment Transport") - Articles in Refereed Scientific Journals - Hernandes-Murcia,O.E., D.J. Schnoebelen, A.N. Papanicolaou,and B.K.B. Abban.2017. Coupling flow with nutrient dynamics via BioChemFOAM in the Mississippi River. Journal of Applied Water Engineering and Research. Feb. 21:1-23.