

**Connecticut Institute of Water Resources
Annual Technical Report
FY 2017**

Introduction

The Connecticut Institute of Water Resources (CTIWR) is located at the University of Connecticut (UConn) and reports to the head of the Department of Natural Resources and the Environment (NRE), in the College of Agriculture, Health and Natural Resources (CAHNR). The Director, Dr. Glenn Warner, retired from the University on Feb 1, 2018 after serving 18 years as Director of the Institute. Following consultation with the Dean of CAHNR, the NRE Department Head recommended Dr. Michael Dietz to assume the role of CTIWR Director. Dr. Dietz received his Ph.D. from UConn in 2005 and has been with the University since 2010, currently as an Associate Extension Educator. Current Associate Director is Mr. James Hurd.

Although located at UConn, the Institute serves the water resource community throughout the state as it solicits proposals from all Connecticut universities and colleges. The Institute works with all of Connecticut's water resource professionals, managers and academics to identify and resolve state and regional water related problems and to provide a strong connection between water resource managers and the academic community.

The foundation for this connection is our Advisory Board, whose composition reflects the main water resource constituency groups in the state. At the end of this reporting period the Advisory Board was composed of nine members. This past year, we are saddened to say we lost one of our long time Board members, Milan Keser who passed away in December 2017. We are currently working to add new Board membership, particularly from the academic and non-profit sectors following recommendations from current Board members. In addition to working with Advisory Board members, the CTIWR Director and Associate Director participate on statewide water-related committees whenever possible, enabling the CTIWR to establish good working relationships with agencies, environmental groups, the water industry and academics.

The USGS 104B program is the financial core of the CTIWR. The Institute does not receive discretionary funding from the state or the university, although the CTIWR does receive funds to cover two thirds of the Associate Director's salary per year from the Dean of the College of Agriculture, Health and Natural Resources as match for our program administration and other activities.

Research Program Introduction

The majority of our 104B funds (over 70%) are given out as grants initiated in response to our annual RFP that is released in September of each year. The majority of these funds go to research projects. To solicit research proposals, the Institute sends an announcement to Connecticut institutions of higher learning requesting the submission of pre-proposals. Submitted pre-proposals are reviewed by the CTIWR Director and Associate Director. When selecting potential projects for funding, the Institute considers three main areas: 1. technical merit, 2. state needs and 3. CTIWR priorities (use of students, new faculty, seed money for innovative ideas). Investigators submitting pre-proposals meeting the initial requirements are invited to submit a full proposal. Each full proposal received is reviewed by two to four outside individuals with expertise in the field described in the proposal. Proposals and reviewer comments are presented to the CTIWR Advisory Board, composed of 10 individuals that reflect the main water resource constituency groups in the state, and a determination is made on which projects are to be funded. This past reporting year we funded three one-year research projects, and funded the second year of one two-year research project.

We also encourage submission of proposals to the 104G Competitive Grants Program by distributing the 104G RFP to various institutions and individuals and working with interested investigators to develop ideas. This reporting year we had two investigators submit proposals to the 104G Program from the University of Connecticut.

State of Water Resources in Connecticut from a Human Dimensions Perspective – Baseline Data

Basic Information

Title:	State of Water Resources in Connecticut from a Human Dimensions Perspective – Baseline Data
Project Number:	2016CT296B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CT-002
Research Category:	Social Sciences
Focus Categories:	Water Use, Management and Planning, Water Quality
Descriptors:	None
Principal Investigators:	Anita Morzillo

Publications

1. Barclay, J.R., Z.B. Smiarowski, L.S. Keener-Eck, and A.T. Morzillo. A Landscape-Level Human Dimensions Analysis of Water Scarcity in a “Water-Rich” State. in preparation.
2. Smiarowski, Z.B., Barclay, J.R., L.S. Keener-Eck, and A.T. Morzillo. 2017. Human dimensions of water availability in Connecticut. Connecticut Conference on Natural Resources, Storrs, CT.
3. Morzillo, A.T., Barclay, J.R., Z.B. Smiarowski, and L.S. Keener-Eck. 2017. A landscape-level human dimensions analysis of water scarcity in a “water-rich” state. US Regional Association of the International Association for Landscape Ecology annual meeting, Baltimore, MD

Introduction/Research Objective

An ongoing challenge is the sustainability of water resources among competing biological and human uses. Compared to biophysical aspects of water resources and management, the human dimensions (the study of interactions between humans and the environment, and characteristics of humans that influence those behaviors) of water resources and management is understudied. This is particularly true in regions perceived to be “water rich,” yet experiencing relative drought conditions that can result in conflicts among water users or restrictions on public and private consumption-- including Connecticut. It is expected that uncertainty related to timing, frequency, and location of precipitation at the local and regional scales (NOAA 2013) will exacerbate stresses related to water resources on human communities (MEA 2005). To this researcher’s knowledge, no studies have holistically evaluated linkages between human knowledge about water sources, regional water issues, household use behaviors, and concerns about future water resources and management-- particularly in regions that are perceived as “water rich.” The proposed work is a first step toward addressing this critical knowledge gap.

Connecticut provides an excellent and timely location for pursuing such research, particularly as the state develops its first comprehensive water plan. Although perceived nationally as “water rich” in a relative sense, public and private concerns about water supply are expressed. Use restrictions are activated within the state on a regular basis as a result of combined shortfalls in and timing of expected precipitation, and distribution of urban development. Together, uncertainty in precipitation events and urban development are adding pressure to existing water resources, resulting in speculation about how to meet future water use expectations across the state. For example, the town of Mansfield recently acquired alternative water sources for ongoing expansion of the University of Connecticut campus, yet socio-political and infrastructural constraints existed in terms of rerouting surface or ground water to the campus. It is likely that similar issues will emerge within Connecticut in the future, potentially resulting in a need to set water allocation priorities and to develop strategies for adaptation to such changes within the water resources and management infrastructure. Statewide, little is known about human dimensions of water resources and management in Connecticut, including perceptions of both public and private stakeholders about issues such as water availability, water conservation, and water quality concerns, and potential community response to water management strategies.

At this time, a compilation of the baseline data that are needed to develop a rigorous geographic-based sampling strategy for assessment of human dimensions of water resources and management does not exist for Connecticut. This research addresses that knowledge gap, and the research question: from a human dimensions perspective, what is the current state of information and knowledge about water resources and management across Connecticut? This study is developing the information base necessary for using social science as a tool for understanding social dynamics that influence state-level strategic planning for water resource management across Connecticut’s diverse variety of stakeholders.

The objectives of this study are to:

1. Compile a compendium of information needed for detailed study of human dimensions of water resources for Connecticut (“state of water resources in Connecticut from a human

dimensions perspective”). Some information is publicly available but scattered at the town, municipal, regional, and state levels. Other sources include town, regional, and state officials and other stakeholders involved with development of the water resources and management plan. Aggregation and synthesis of these data will allow for state-wide assessment of water resources information.

2. Through data synthesis, develop a framework for broader future statewide sampling and detailed data collection. Organizing and synthesizing aggregate water source, water user, and socio-demographic data into a geographic information systems (GIS) framework will allow for geographic assessment and visual interpretation of social science data. Such information will allow researchers to identify patterns in existing information and data needs, and will inform future strategic geographically based sampling and analysis.

UPDATE - APRIL 2018:

A no-cost extension was requested to clean up the dataset and continue work on the resulting manuscript. Remaining funding has been spent. No new presentations or project personnel have been added. One student who worked on this project (Lindsay Keener-Eck) graduated in December 2017. Researchers are working to complete the manuscript in preparation, and hopefully it will be ready for submission over the summer.

REPORT - MAY 2017:

Methods/Procedures/Progress

Data were collected at the town level ($n = 169$), which allowed for geopolitical consistency and the ability to assess data patterns across the state. Additional information about municipalities and regions is included, as appropriate. We hypothesized that water resource information vary by town and region. Three main categories of data were collected included in this analysis:

1. Water Sources and Distribution

There are three categories of public water systems in Connecticut: 1) community (residential consumers), 2) non-transient/non-community (consistent, non-residential consumers, e.g., schools and office buildings), and 3) transient/non-community systems (e.g., restaurants and parks) (CSS 2015). For this project, we focused on community and private systems (category #1 above), which we defined as all non-public systems, including individual residences with private wells. The term “parent company” refers to entities that control one or more community systems.

Three sources of water systems data were integrated: 1) Community Water Systems from the CT DPH (CT DPH 2014); 2) water system services areas (Eric McPhee, CT DPH, personal communication); and 3) municipality-level Water Quality Monitoring Schedules (CT DPH 2016a). Together these data provided spatial data on existing water systems, population served

by water systems, and ability to reconcile discrepancies among the data. Also included were water sources for each water system (CT DPH 2016b), aquifer protection areas (CT DEEP 2012) and drinking water watersheds (Eric McPhee, CT DPH, personal communication).

2. Estimating Community versus Private Water Supplies

Water company service maps and population served data were integrated with town maps (CT DEEP 2005) and town population estimates (CT DPH 2012) to estimate the proportion of residents dependent upon community versus private water supplies. Because of data inconsistencies, several assumptions had to be incorporated to enable comparisons across towns (details included in “manuscript in prep”). Assumptions were applied to estimate the population served by community and private water sources in each town. The population within each town served by water systems serving only that town (i.e., single-town systems) was first identified using information from data category #1 (above). Two methods were used to distribute among towns the population served by systems serving multiple towns (i.e., multi-town systems; details included in “manuscript in prep”). For each town, method used to estimate the population served was determined based on which approach of the two resulted in a larger calculated population size. Further adjustments were made to the town-level estimates of population served by each water company until the estimates were constrained by the total population of the town (no more than 5% exceedance), and by the population served by the water system (within 5% of the population served). Finally, the population served by private water systems (i.e., wells) was estimated as the difference between the town population and the population estimated to be served by community water systems (both single town and multi-town systems combined).

3. Media Communications about Water Availability

We used multiple sources to compile water-related public media communications from the past five years (January 2012- November 2016): Lexus Nexus and Proquest Newspapers database search engines, websites of 13 water companies, and websites of all 169 towns/municipalities. For each communication, we recorded communication type (e.g., restriction, outreach, restriction type (e.g., mandatory, voluntary), issuer, date, geographic scope, topic, keywords, and source.

Other Data Sources

Additional data gathered included Connecticut socioeconomic and geographic data obtained from the American Community Survey 5-year Estimate (2010-2014) and the 2010 US Census Bureau decadal census. Connecticut land cover data were obtained from the UConn Center for Land Use Education and Research.

Data Analysis

ArcGIS was used to create a linkage of town maps, water communication, water system, sociodemographic, and land cover data. Media communications were organized and sorted using Microsoft Access. Relationships among water and socioeconomic variables were evaluated using R-version 3.2.2.

Results/Significance

To the researcher's knowledge, this is the first attempt to integrate the data described here. Key findings are summarized as follows. Findings are considered preliminary until peer-review of results are completed (manuscript in preparation; see below).

Water Systems

Sixty-five towns acquire >95% of their water from ground water sources. Twenty-three acquire >95% of their water from surface water sources. Thirteen towns acquire approximately 50% of water from surface and ground water each. Eight towns purchase >50% of their water from other water systems.

The largest public community systems in Connecticut (by population served) are the Aquarion Water Company of Connecticut, Regional Water Authority, Metropolitan District Commission, and Connecticut Water Company. Collectively, these four largest water systems serve people in 73 towns. The proportion of each town population served by at least one of these companies ranges from 5-100%. Five towns are served by two of these companies. One town is served by three of these companies.

The large public water systems are not representative of all Connecticut water systems. There are 355 unique parent company public water systems in Connecticut that serve ≥ 25 people; most serve <200 people (*n.b.* schools and correctional institutions are included in these summary numbers but not included in analysis). The majority of water systems serving <200 people were apartment complex, mobile home communities, parks, or senior citizen communities. Most Connecticut water systems ($n = 301$) serve only one town, and typically between 1,000-100,000 people. Towns associated with a larger proportion of private water systems were often considered to be rural, many of which are in eastern Connecticut. There are 17 towns for which >95% of water systems are categorized as private water systems.

Water-Related Communications

A propensity of water-related communications took place in the western part of the state, as well as the New London area. The western part of state is largely served by Aquarion water company. Also prominent were the towns of Mansfield and Lebanon. Mansfield is in the process of installing a diversion pipeline from the Shenipsit Reservoir to meet the needs of the growing University of Connecticut campus. Lebanon is a concentrated agricultural area with several large livestock and poultry farms.

Statewide alerts were categorized as either: 1) concerns about issues relating to water quantity, and 2) restrictions related water usage issues by the town, water company, or statewide. The majority of alerts (87%) were issued by the water companies and relevant to the west side of the state. Fewer communications existed among towns in eastern and south-central Connecticut ($n = 24$). Towns with fewer water-related communications were generally those containing a larger area of open water, and a greater number of residents on private systems (*i.e.*, groundwater).

Implications of results in the manuscript in preparation include:

- Areas of the state with the fewest number of communications may be attributed to ruralness and prevalence of private versus public water systems;
- There appear to be inconsistencies in the data related to large urban areas that have an unexpectedly low number of residents on community water systems, and residents in smaller towns on public systems (these inconsistencies are being verified and corrected);
- The role of dominant water systems in water communications and statewide water resource resiliency.
- System size versus degree of protection for local-level water shortages.

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Microfluidic-based Biosensor Chip for Rapid and Calibration-free Detection of Viable E. coli and Total Coliforms for Water Quality Control

Basic Information

Title:	Microfluidic-based Biosensor Chip for Rapid and Calibration-free Detection of Viable E. coli and Total Coliforms for Water Quality Control
Project Number:	2016CT297B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	2nd district
Research Category:	Engineering
Focus Categories:	Water Quality, None, None
Descriptors:	None
Principal Investigators:	Yu Lei, TaiHsi Fan

Publications

1. Qiuchen Dong, Donghui Song, Yu Lei. Microfluidic-based sensor for E. coli detection with single cell sensitivity based on its specific β -D-glucuronidase activity. 2018. In preparation.
2. Qiuchen Dong, Donghui Song, Yu Lei. Detection of microorganisms with single cell sensitivity. In preparation (will be submitted for CMOC 2019).

Introduction/Research Objective

Waterborne microbiological contaminations remain one of the major threats to public health. The Centers for Disease Control and Prevention has reported that each year, 4 billion episodes of diarrhea result in an estimated 2 million deaths, mostly among children. Waterborne bacterial infections may account for as many as half of these episodes and deaths.

In the past decades, a variety of technologies have been developed to detect the total coliforms and *E. coli* in drinking water. However, they usually take 18-24 h to complete. From a public health standpoint, it is too time-consuming to announce a boil water notification if the sample is positive for total coliforms or *E. coli*. Therefore, an innovative, calibration-free, easy-operation, robust, and ultrasensitive method for fast-screening skeptical drinking water samples is highly demanded. Preferably, it can also discriminate the viability of total coliforms and *E. coli* as conventional EPA-approved methods.

The research objective of this multidisciplinary proposal aims to develop a novel, cost-effective and user-friendly microfluidic-based digital biosensor chip (in conjunction with a commercial available large-volume water sample concentrator, if necessary) for rapid, ultra-sensitive, and calibration-free detection of viable *E. coli* and total coliforms in drinking water, based on the activity of β -glucuronidase for *E. coli* and β -galactosidase for total coliforms, respectively. A number of novel features are introduced to the proposed system to make the MEMS biosensor faster and more sensitive toward the targets. This project will also positively impact education of graduate, undergraduate and high school students by integrating advanced water quality monitoring into their educational and laboratory training.

Methods/Procedures/Progress

1. *Completing the training required for the fabrication of the microfluidic devices at Center for Nanoscale Systems (CNF) in Harvard University*

The Ph.D. student Qiuchen Dong received extensive training for the total of 18 training sessions required for our device fabrication at Harvard CNF over 6 months, including safety training, Nexx PECVD, Suss MJB4 Mask Aligner, Cleanroom Headway Spinner Training, Technics Plasma Stripper/Cleaner, Anatech Barrel Plasma System, Tystar Bank2 Wet/Dry Oxidation, Tystar Bank2 TEOS Silicon Dioxide, Tystar Bank2 Metal Anneal, Tystar Bank1 Silicon Nitride, Tystar Bank1 Polysilicon, Tystar Bank1 Non-Metal Anneal, STS PECVD, Denton E-Beam Evaporator, South Bay RIE, Veeco Dektak Profilometer, Scanning Ellipsometer, and Nexx RIE.

2. *Fabrication of microfluidic device with one set of sensing electrodes*

Microchannels with the narrowest cross-section feature of 10 μm in width and 15-25 μm in height were fabricated in PDMS by using the standard soft-lithography technology, developed in our previous research. Figure 1 shows the as-prepared microfluidic device with patterned electrochemical sensing electrodes and microfluidic channel and fluidic connectors

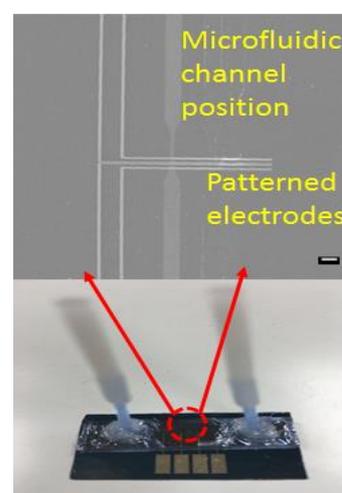


Figure 1. The as-prepared microfluidic device with patterned electrochemical sensing electrodes.

Scale bar = 100 μm .

developed in PI laboratory. In principle, arbitrary topology, depth, width, and feature size ranging from several microns to hundred microns can be fabricated. In brief, SU-8 2025 and 2015 negative resists (Microchem) were spin-coated on 4" silicon wafers. Exposure with the mask and development with propylene glycol methyl ether acetate (PGMEA) produced channels with the pre-designed feature size. Polydimethylsiloxane (PDMS, Sylgard 184, Dow Corning) was mixed at a 10:1 ratio and poured over the SU-8 mold which was then baked at 80 °C for 1.5 hr to create the final channel. On the other hand, the electrochemical sensing electrode patterns on the SiO₂-layered Si wafer are fabricated in photoresists with photolithography and then Pt/Ti metal layers were sequentially deposited on the SiO₂-layered silicon wafer using thermal evaporation technique. After lift-off process in the photoresist developer, the electrodes with pre-designed shapes and dimensions were formed on the substrate surface. To complete the device fabrication, the PDMS channel was plasma bonded to the SiO₂-layered Si substrate containing the pre-patterned electrodes and then assembled with appropriate connectors to form a microfluidic system. By regulating the perfusion rate of the carrying electrolyte, the targeted bacteria can be deployed to the channel for the proposed detection.

3. Fabrication of microfluidic device with two sets of sensing electrodes

In order to directly amperometric counting of both *E. coli* and total coliforms, microfluidic device with two patterned electrochemical sensors was also designed and fabricated following a similar photolithography aforementioned except that the maskless aligner was used. Figure 2 show the design of two patterned electrochemical sensors after photoresist development. Briefly, P-type Boron doped, <1 0 0> orientation silicon wafer are used. Silicon wafer was dry-oxidized through CVD-10 with an oxide layer of 106 nm in thickness (measured by ES-2 Scanning Ellipsometer). Positive photoresist Shipley 1805 was spun at 4500 rpm to create a 5 micron thickness of photoresist onto LOR3A which was first spun at 3500 rpm to create roughly 320 nm thickness of LOR3A on the wafer, followed by UV light exposure at wavelength of 405 nm for optimized intensity at 52 mJ/cm² with a focus at -2 plane (Defocus) by using Maskless Aligner MLA 150. The treated substrate was developed in CD-26 developer for 1 minute and dried by nitrogen gun. The detailed feature of electrodes pattern can be referred to Figure 2. After Pt/Ti metal deposition, followed by lift-off to generate the two sensors on the SiO₂-layered Si wafer, the prepared metal electrodes were extensively washed with acetone and isopropanol to remove any residual on the SiO₂-layered Si. To complete the microfluidic device fabrication, SU-8 patterns were utilized for the construction of microchannel by pouring mixture of polydimethylsiloxane (weight ratio 10:1), followed by baking at 80 °C for 1.5 hours. The solidified polydimethylsiloxane was cut in piece to separate each microchannel, and cleaned by nitrogen-blowing. Finally, the sensor chip and polydimethylsiloxane microfluidic channel were carefully transferred to a petri dish for oxygen plasma treatment to transform the hydrophobic surface to the hydrophilic one. The PDMS with microchannel was eventually aligned on the sensor chip and sit on two sets of sensing electrodes, thus allowing the counting under two detection scenarios. The first type of detection (c.f. to

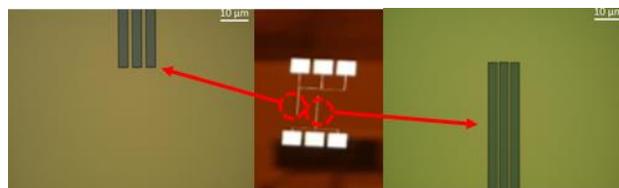


Figure 2. Featured pattern of pre-designed microelectrode devices (scale bar: 10 μm) after UV light exposure at 405 nm by Maskless aligner (MLA) 150.

Figure 4) can be realized by measuring the open circuit potential change between the two sets of sensing electrodes, while the 2nd type of detection (c.f. to Figure 5) can be realized based on the electrochemical oxidation of enzymatic reaction product 8-hydroxyquinoline (8-HQ) from the 8-hydroxyquinoline- β -D-glucuronide (8-HQG) by the enzyme β -D-glucuronidase (a specific marker for the major fecal coliform *E. coli*) on the sensing electrodes. As a proof-of-concept, β -glucuronidase activity will be tested in this project.

4. *E. coli* culturing

As *E. coli* possesses both activity of β -glucuronidase (unique for *E. coli*) and β -galactosidase (ubiquitous for total coliforms), *E. coli* will be used in this study to represent both *E. coli* and total coliform. First, a safe *E. coli* lab strain (DH5 α), obtained from the strain collection of our laboratory, was used as a model bacterium for the training purpose. *E. coli* was inoculated into Luria broth (LB) medium and incubated overnight on a gyratory incubator shaker at 37 °C and 200 rpm, which allowed the growing stationary phase to be reached. Then, bacterial cultures were serially diluted (10-fold steps), and 10 μ L aliquots of samples were applied to LB agar plates and incubated for 24 h at 37 °C, for enumeration of colonies. At the same time, the stationary-phase cultures were diluted to an appropriate concentration for the detection of *E. coli* in the microfluidic channels.

Results/Significance

1. Direct detection of *E. coli* in microfluidic-device based on amperometric signal

As the first test, the amperometric counting was conducted using the developed device in Figure 1. A constant voltage (+0.6 V) is supplied through the modified working electrode (deposition of Ag on the patterned electrodes to shrink the cross-section

area channel at the position of electrodes) and the current vs time response was recorded the flow of carrying buffer solution in the absence and presence of *E. coli*. The solution was driven by syringe pump to flow through the microfluidic device. Figure 3 shows the corresponding results. One can see that a lot of pulses are recorded in the presence of *E. coli*, while only background noise was observed for the buffer in the absence of *E. coli*. It is hypothesized that each pulse may be resulted from the pass of one *E. coli*. This result indicates that it is highly possible for direct counting of *E. coli* without using any calibration curve.

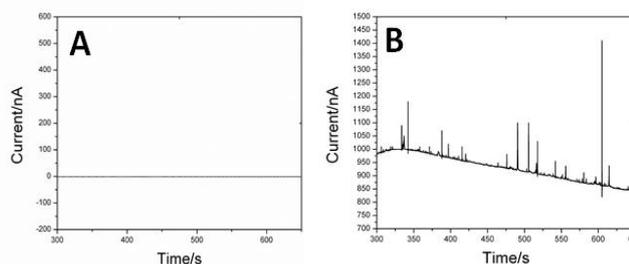


Figure 3. The study of amperometric detection for PBS buffer sample in the absence (A) and presence (B) of *E. coli*.

2. Direct detection of *E. coli* in microfluidic-device based on open-circuit potential signal

To validate the concept of open-circuit potential based direct counting, 10 mM PBS was loaded in syringe and pumped by a syringe pump at the flow rate of 5 $\mu\text{L}/\text{min}$. Figure 4A shows the schematic of the experimental set-up. More specifically, the CHI 601D electrochemical station was connected with one electrode pad in each sensor on the microfluidic device, thus forming a two-electrode system (Working electrode, WE, and Counter/Reference electrode, CE/RE, shown in Figure 4B). Afterwards, open circuit potential between the two electrodes were collected by a computer controlled CHI 601D electrochemical station while PBS buffer flew through the microfluidic channel. As shown in Figure 4C, there was no response for the case of 10 mM PBS buffer. However, when 10 mM PBS buffer containing certain number of *E. coli* flew through the microfluidic channel under the same condition, the open circuit potential displayed sporadic pulse response with each pulse corresponding to one *E. coli* passing the microfluidic channel between the two electrodes. This result indicates that direct counting of *E. coli* can be also achieved based on the measurement of the open-circuit potential in the microfluidic device.

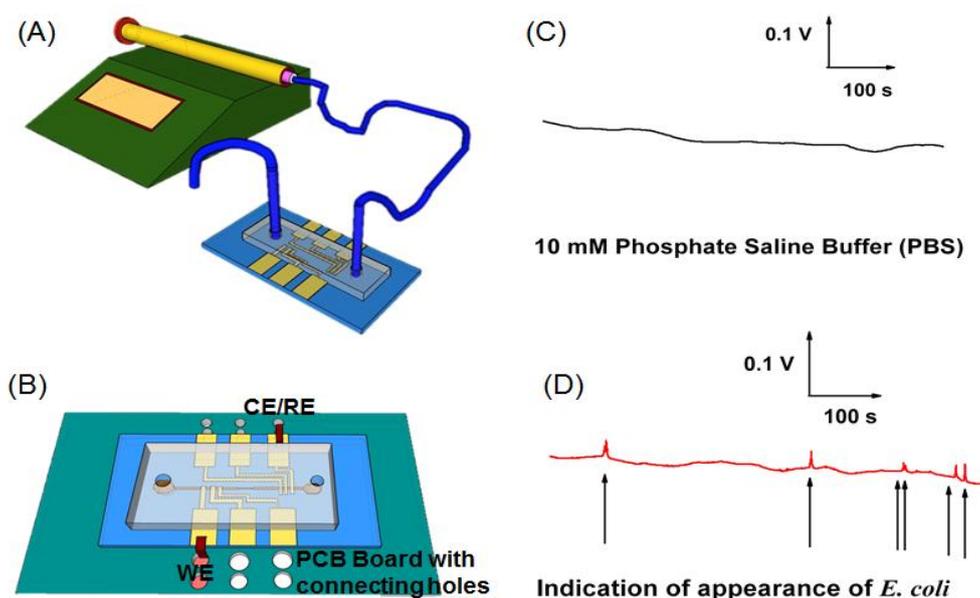


Figure 4. (A) Scheme of experimental set-up for open-circuit potential based digital counting of *E. coli* (not in scale). (B) The layout of microchannel and the patterned sensing electrodes (not in scale). (C) The representative time-dependent open-circuit potential when 10 mM PBS buffer flows through microfluidic channel. (D) The representative time-dependent open-circuit potential when 10 mM PBS buffer containing *E. coli* flows through microfluidic channel.

3. Direct detection of *E. coli* in microfluidic-device based on the activity of enzyme β -D-glucuronidase

E. coli specifically produces β -D-glucuronidase. Therefore, the activity of β -D-glucuronidase can also be employed to realize direct counting of *E. coli*, in conjunction with microfluidics. In the presence of *E. coli*, the substrate of 8-HQG can be enzymatically degraded by β -D-glucuronidase and then releases 8-HQ (surrounding the corresponding individual *E. coli*). 8-HQ is an electroactive compound and can be electrochemically oxidized to generate the current. Thus the number of its oxidation current pulses can be correlated to the number of *E. coli* (if the concentration of *E. coli* is low). In this detection scenario, each sensor patterned on the microfluidic device can be operated as an amperometric sensor. The corresponding schematic and the photo of the experimental set-up used in this study are presented in Figure 5A and Figure 5C, respectively. The detailed layout of the sensing electrodes and microfluidic channel is presented in Figure 5B. During the detection, 8-HQG was incubated with *E. coli* in the tube (length of 200 cm with ID of 0.031 inches) for 30 mins before pumping into microfluidic device for amperometric detection at an applied voltage of +0.6 V. At such applied potential, 8-HQ is electrochemically oxidized to generate current signal. The amperometric response of the control experiment (10 mM PBS buffer contacting 100 μ g/mL 8-HQG) was recorded at the applied potential of +0.6 V first and there is no pronounced current pulses existing due to the absence of *E. coli* or lack of β -D-glucuronidase (data not shown). However, the same solution (10 mM PBS buffer contacting 100 μ g/mL 8-HQG) was mixed with low concentration of *E. coli* (low enough to discretely distribute *E. coli* in 200 cm length of tubing) and incubated on bench for 30 minutes at room temperature. Then the solution in tubing was

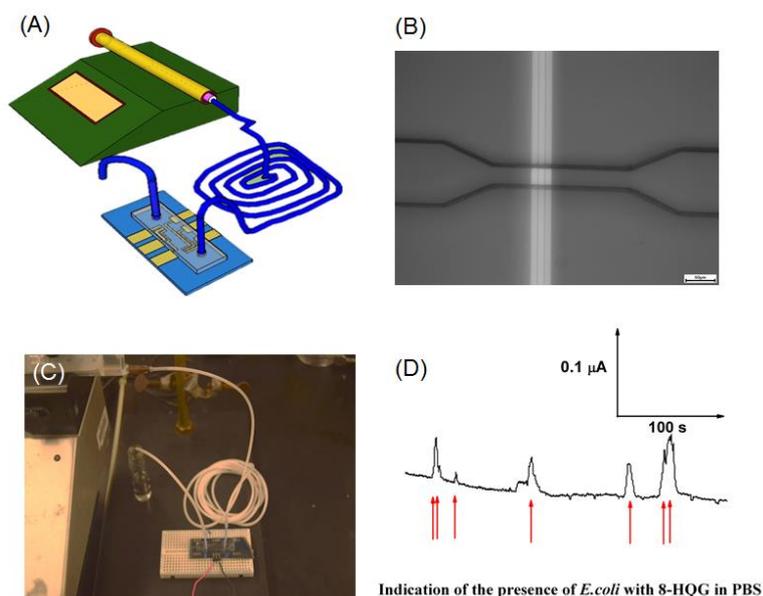


Figure 5. (A) Scheme of the experimental set-up for direct counting of *E. coli* based on its specific β -D-glucuronidase activity. (B) The microscopic image of the sensing electrodes and microfluidic channel on the device. (C). Photo of the experimental set-up. (D) The representative time-dependent amperometric response of 10 mM PBS buffer containing 8-HQG and *E. coli* after 30-min incubation at an applied potential of +0.6 V with a flow rate of 5 μ L/min.

pumped to flow through the microfluidic device with the patterned sensor for *E. coli* detection. Figure 6D shows the representative time-dependent amperometric current change. As the presence of *E. coli* (β -D-glucuronidase) converted 8-HQG to 8-HQ which surrounded the corresponding *E. coli*, when the mixture flowed through the patterned sensor in the microfluidic channel, the oxidation of 8-HQ (surrounding *E. coli*) resulted in the pulses which can be correlated to the presence/the number of *E. coli*. This result, for the first time, demonstrated the direct digital counting of *E. coli* based on its specific β -D-glucuronidase activity, which opens an avenue in direct counting of viable microorganisms.

Investigation of Bedrock Well Contamination by Uranium, Radium and Radon Resulting from Deicing Salt Exchange

Basic Information

Title:	Investigation of Bedrock Well Contamination by Uranium, Radium and Radon Resulting from Deicing Salt Exchange
Project Number:	2017CT304B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	2nd
Research Category:	Ground-water Flow and Transport
Focus Categories:	Groundwater, Radioactive Substances, Water Quality
Descriptors:	None
Principal Investigators:	Michael Dietz, Meredith Joy Metcalf, Gary A. a Robbins

Publications

There are no publications.

Introduction/Research Objective

Each year, an increasing amount of salt is being used in the U.S. as a deicing agent (Mullaney et al. 2009, Fay and Shi 2012). Researchers have observed a gradual salinization of both surface water (Kaushal et al. 2005; Kaushal 2016) and groundwater systems due to continued deicing practices (Kelly et al. 2008; Novotny et al. 2009; Perera et al. 2013; Trowbridge et al. 2010). In Connecticut, average chloride concentrations in groundwater have risen over 10 times average background levels in the last 100 years (Cassanelli and Robbins, 2013). In some areas of the state, chloride concentrations have exceeded 100 times the background levels. Individual wells have been found to have salinity levels greater than that of sea water.

Radium concentrations in groundwater have been highly correlated with sodium chloride levels in saline aquifers (Sturchio et al. 2001; Vinson et al. 2009). This phenomenon has been attributed to increased competition for adsorption sites due to the abundance of sodium ions (Krishnaswami et al. 1982; Sanders et al. 2013; Tamamura et al. 2014). Radium solubility can also be enhanced by the formation of RaCl^+ complexes in saline waters (Langmuir and Riese, 1985). Although there are many factors that influence the solubility of radon in aqueous solutions (e.g., temperature, pressure), the observed naturally occurring positive correlation between radium and salt in saline aquifers suggests that radium, and its progeny radon, could be mobilized by deicing salt contamination of groundwater. This represents a public health concern due to the carcinogenic nature of these elements: ingestion of radium can produce harmful health effects such as cataracts and osteosarcoma (CDC, 2015) and radon exposure has been identified as the second-leading cause of lung cancer in the US (Darby et al. 2001).

The metamorphic and igneous bedrock of Connecticut is known to contain significant levels of uranium and radium which can cause high fluxes of radon under natural conditions (Thomas and McHone 1997). These geologic conditions, along with our findings to date (see related research below), suggest that there is a significant potential for bedrock wells contaminated with high levels of deicing salt in Connecticut to also be contaminated with uranium, radium, and radon at concentrations of concern. In addition, a salinity increase in the shallow groundwater could result in a larger flux of radon to overlying buildings; this region is particularly susceptible due to the shallow nature of its groundwater (Krewski et al., 2005; Thomas and McHone 1997).

This project was a field experiment designed to evaluate whether salt contamination of fractured bedrock has caused elevated levels of uranium, radium and radon in wells. The broader goal of the project was to further the understanding of the risks associated with de-icing salt contamination in the state's supply of subsurface drinking water.

Procedures/Progress

The project began with a statewide search for wells impacted by salt contamination. First, the Connecticut Department of Public Health (DPH) was contacted for a list of wells with known salt contamination. This list contained sites impacted by de-icing salts, and possibly by saltwater intrusion in some coastal locations. Sites with concentrations of sodium (Na^+) and chloride (Cl^-) below 250 mg/L were excluded from the investigation as they were well below 1000 mg/L. This value is the salinity at which detectable radionuclide mobilization is expected to occur (McNaboe et al. 2017, Tamamura et al. 2014). A total of 26 potential sites were obtained from the DPH database, 9 of which were within a 1-mile radius in Brookfield, CT. These sites are enumerated in

table 1. As the database did not include coordinates, addresses, nor phone numbers, these sites needed to be reverse-georeferenced based on the water system name. Of these sites, all but one declined to participate in the study for reasons that include: there is no access to well, they already have undergone rigorous testing, or a presumed lack of interest due to a lack of correspondence.

Additional sites were identified by distributing a flyer seeking volunteers for well testing; the flyer is attached to this report. The flyer was sent to town sanitarians and municipalities, with the intent that they inform their citizens of the program. There were 2 responses to this flyer, which are also listed in table 1; one of these was amenable to sampling. The other respondent referred us to a neighborhood with saline groundwater, but the property owners were not interested in participating. The CT Department of Transportation (DOT) was also contacted to sample any saline wells they were aware of, as salt storage facilities are particularly susceptible to being sources of groundwater salt contamination (Dennis 1973). They informed of us at least two sites (table 1), but did not permit any sampling activities. The CT Department of Energy and Environmental Protection (DEEP) was contacted to sample any salt-impacted wells they were aware of; DEEP officials informed us that they weren't aware of any wells that met our investigation's criteria of Na^+ or Cl^- concentrations above 1000 mg/L.

We travelled to the locations to collect well samples by low flow sampling, according to the procedure attached in this document. For each site, we delivered 3 bottles to the CT DPH laboratory for radionuclide analysis (Rn, Ra, U), and delivered 1 bottle to UConn Center for Environmental Science and Engineering (CESE) laboratory for cation analysis (Na^+ , Mg^{2+} , Ca^{2+}). An additional bottle was delivered to the UConn Natural Resources (NRE) water quality laboratory for Cl^- analysis.

Due to the low response rate of our statewide inquiry, the scope of sampling was expanded to include shallow monitoring wells that penetrate only to the top of the water table. Five such wells were identified around the UConn campus in Storrs, CT (Figure 3); samples were collected from these wells by low-flow sampling during February 2018, as this period is historically the annual maximum for groundwater salinity in this area (Cassanelli 2011, McNaboe 2017).

Table 1: List of prospective sampling locations. Locations in bold were sampled during this study.

Map index	Location	Type	Wells	Recent Na^+ (mg/L)	Recent Cl^- (mg/L)	Bedrock	Surficial
0	Old Lyme, DEEP HQ	Municipal	1	568	1580	Granitic gneiss	Till
1	70 Merrow Road, Tolland CT	Commercial	1	110	601	Gneiss	Till
2	Greenwich, Fairview Country Club	Commercial	1	347	656	Gneiss	Till
3	Brookfield commons area	Comm, res, sch.	15	399	1005	Marble	Fines
4	East Hampton town hall	Municipal	2	168	651	Gneiss	Till
5	North Stonington Congregational Church	Church	1	316	--	Gneiss	Sand/Gravel
6	Franklin Elementary School	School (public)	1	280	--	Schist	Gravel
7	Dayville, Crystal Water Co.	Commercial	?	750	--	Granitic gneiss	Sand/Gravel
8	Brookfield, Down the Hatch Restaurant	Commercial	1	261	231	Granitic gneiss	Till
9	Knollbrook Rd. Bethany, CT	Residential	4	370	550	Gneiss	Till
10	Tony's Drilling, Montville CT	Industrial	1	--	3247	Quartzite	Till
11	Private well, South Windsor, CT	Residential	1	182	440	Arkose	Sand/Gravel
12	New Canaan CT, St. Luke's School	School (private)	1	312	908	Schist	Till
13	Colebrook school	School (public)	1	211	836	Gneiss/Schist	Till
14	Eastford; Whitcraft corp.	Industrial	2	58	626	Schist	Till
15	DOT Garage, New Milford, CT	Government	10	148	340	Marble	Alluvial/Fines
16	Storrs, CT**	School	5	--	1627	Gneiss	Till
17	DOT Garage, Ashford, CT	Government	1	--	--	Granofels	Till

*Cells with a hyphen (--) represent that no sample was analyzed for that respective constituent.

** Shallow, overburden wells were sampled at this location

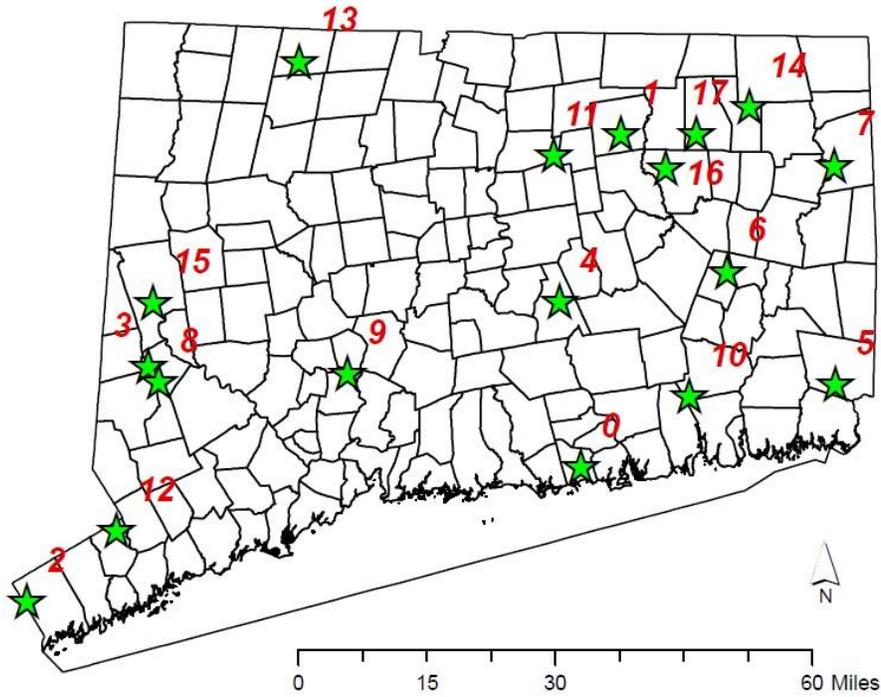


Figure 1: Prospective sites that were identified for groundwater sampling. Indices on this figure correspond to those on table 1.

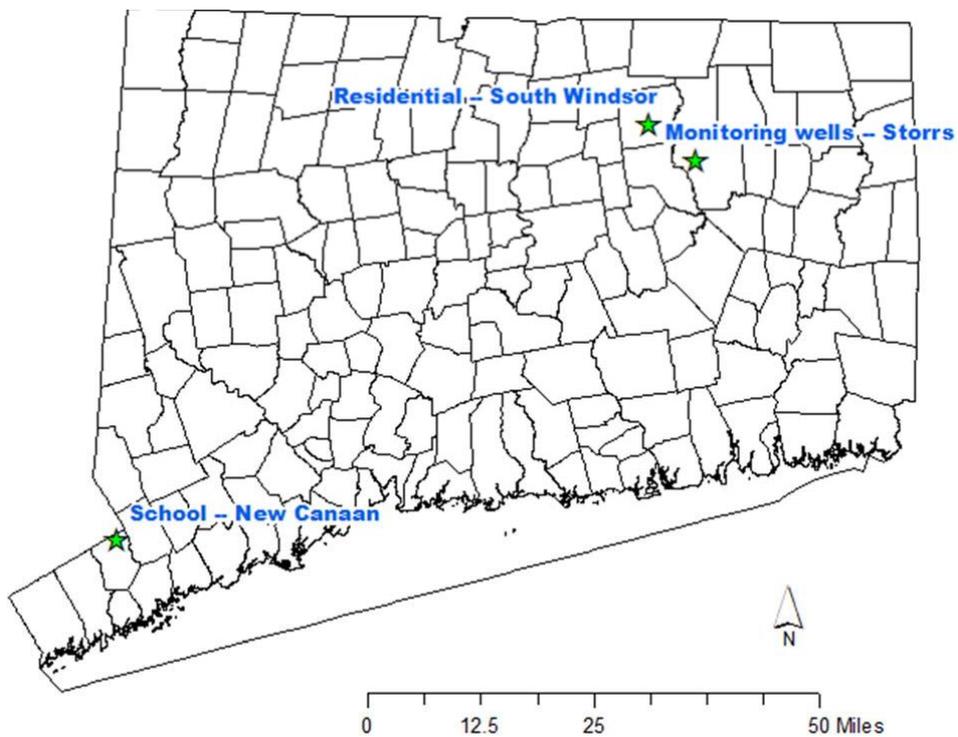


Figure 2: Sites that were sampled during this study.

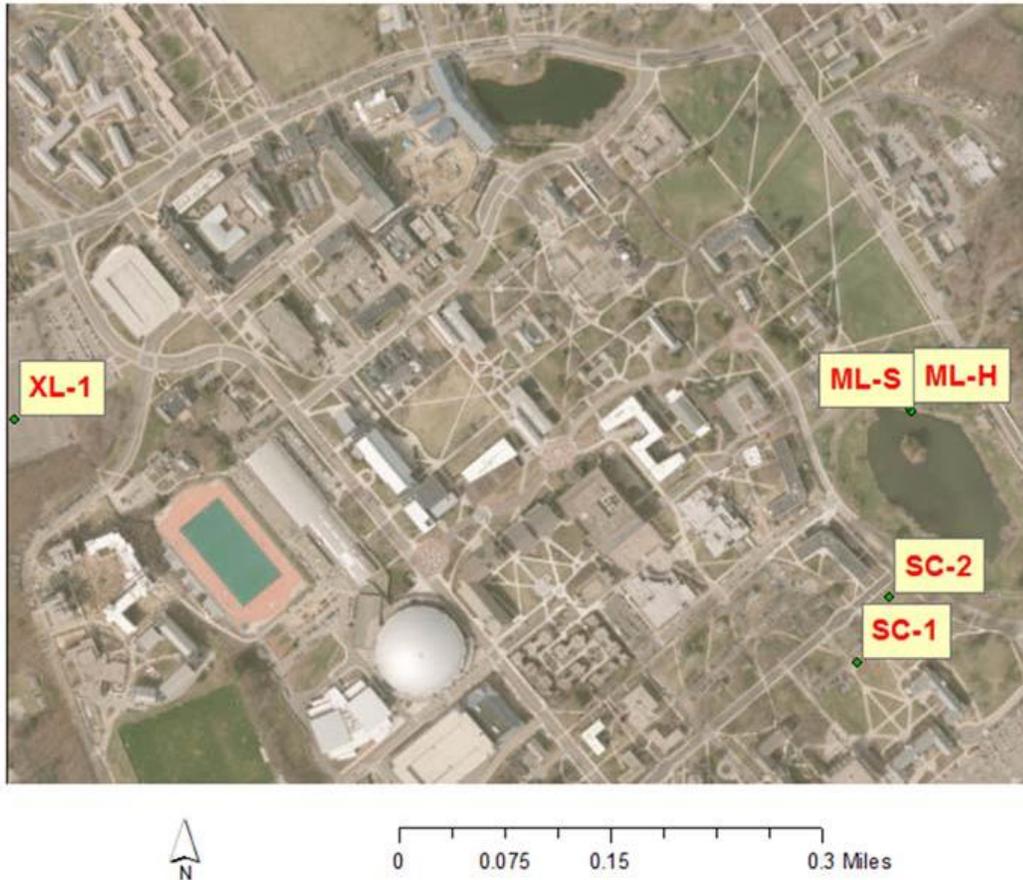


Figure 3: Monitoring well locations identified for sampling on the UConn campus at Storrs, CT. This location is identified as #16 in figure 1 and table 1.

Results/Significance

Table 2: Concentration of salts and radionuclides for samples taken in this study. Samples above the dashed line were collected from private wells; samples below the dashed line were collected from shallow, overburden monitoring wells.

Well location	Cl (mg/L)	Na (mg/L)	Mg (mg/L)	Ca (mg/L)	Rn (pCi/L)	Ra (pCi/L)	U (µg/L)
New Canaan	397	42.7	57.6	189.8	2070	ND	17
South Windsor	164	65.0	4.2	31.7			
STO -- SC-1	1520	720.6	18.0	115.8	628		
STO -- SC-2	52	17.9	6.4	38.0	390		
STO -- ML-S	767	238.3	20.6	129.1	1490		
STO -- ML-H	795	312.2	14.3	79.0	764		
STO -- XL-1	1630	983.5	11.1	28.7	486		

Upcoming work

Additional samples have been collected from two locations on the UConn campus, and two residential locations in Brookfield, CT. Water quality results will be available by the end of May 2018, and will be included in the final report.

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Evaluation of created thermal refugia in streams as a climate adaptation strategy for fish populations experiencing thermal stress

Basic Information

Title:	Evaluation of created thermal refugia in streams as a climate adaptation strategy for fish populations experiencing thermal stress
Project Number:	2017CT305B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CT 2nd
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Hydrology, Methods, Surface Water
Descriptors:	None
Principal Investigators:	Jason C Vokoun, Martin A Briggs

Publications

There are no publications.

Introduction/Research Objective

Connecticut's latitude, moderate uplift, and urbanizing development patterns combine to produce many streams that skirt the threshold between coldwater and warmwater habitat. Most local watersheds have characteristic upstream to downstream summer temperature gradients that see fish assemblages transition from coldwater-adapted to warmwater-adapted (Kanno and Vokoun 2008; Kanno et al. 2010; Beauchene et al. 2014). Current (and projected) climate change creates warm season physiological stresses for fishes adapted toward the coldwater end of the spectrum. The increases in ambient air temperature and frequency of short-duration droughts predicted for the region will produce hotter summers with reduced streamflow and natural groundwater baseflow in coming decades (Hayhoe et al. 2007; Huntington et al. 2009). Such events place cold- and coolwater-adapted fishes in jeopardy, as populations attempt to adapt to a rapidly changing environment. Behavioral thermoregulation (movement to more suitable thermal conditions) is a common adaptation strategy of fishes, which are adept at locating preferred temperatures and thermal refugia are heavily sought out by fishes when and where naturally available (Elliott 2000; Petty et al. 2012). In fact, some have argued to expend extra protections to streams with natural coldwater "climate refugia", predominately in higher elevations and the northern latitudes of ranges for species at risk (Isaak et al. 2015). This triage-based strategy may well be necessary given the limited resources for broad-scale conservation actions, but of course leaves behind many extant populations in watersheds that are 'geographically challenged'. Point-scale thermal refugia, that may allow fishes in borderline coldwater habitat to survive particularly warm periods (e.g. weeks), are often generated by focused groundwater seepage to surface water (Mathews and Berg, 1997; Kanno et al. 2014). However, to create viable refugia, seepage must be high in dissolved oxygen and stable throughout the summer drydown; enhanced drought threatens these favorable dynamics by reducing water table elevations and decreasing groundwater discharge to streams. Further, in large fast-flowing streams cold tributary inflows and groundwater discharge zones must be protected from immediate mixing with surface waters by the local streambed geomorphology or upstream obstruction; if not, patchy, unmixed thermal refugia are unlikely to form.

It has recently been proposed that natural tributary and seepage-based thermal refugia can be anthropogenically augmented or created (Kurylyk et al., 2014). Augmentation is accomplished by installing baffles to locally decrease mixing between cold groundwater or tributary discharge and warm surface water, yet this will only be effective in surface water systems that show natural thermal heterogeneity in summer. Kurylyk et al. (2014) further suggest that in uniformly warm rivers local groundwater may be actively pumped into surface water flow to create such heterogeneity through an engineered solution. We propose exploring the effectiveness of human-created thermal refugia as an important climate adaptation strategy for lower elevation Connecticut basins, which are unlikely to be included in large-scale 'climate shield' conservation actions due to the developed nature of the landscape and general lack of naturally resilient coldwater habitat. Pumping small volumes of shallow alluvial floodplain groundwater into stream channels in a controlled manner during periods of high water temperatures could create localized thermal refugia, supporting biodiversity conservation at relatively low cost (fiscal and environmental) by reducing the extremes of thermal stress (Lynch et al. 2014). Providing

populations of fishes localized relief from the most extreme thermal stressors can be thought of as ‘taking the edge off’ of climate change, potentially buying populations time to evolve adaptations to new climate regimes.

The primary goal of the proposed project is to evaluate the feasibility and effectiveness of varied methods to create localized thermal refugia in stream channels by pumping in relatively cold floodplain groundwater during warm periods. We propose to address this goal with the following two objectives;

- 1) Characterize effective created thermal refugia volume by exploring the relationships between ambient warm surface water flow and facilitated discharge by pumping in controlled volumes of shallow floodplain groundwater across a natural gradient of in-channel flow velocity and geomorphic conditions.
- 2) Experiment with several methods of introducing the floodplain groundwater to the stream channel, including different release configurations (e.g. focused vs distributed) and baffled flow separation to reduce local mixing.

Methods/Procedures/Progress

There is no progress to share at this time, as the delayed funding arrival associated with the federal budget did not allow us time to purchase and test equipment in time for a field season. Currently we are gearing up for the summer 2018 field data collection. Plans have not changed, just delayed one year.

Shallow floodplain groundwater will be pumped into surface water from one or two of the many monitoring wells already existing in and around the UConn wellfields on the Fenton River and Willimantic River on University property. Small volumes of water (e.g. 10’s of L/min) from these wells will be pumped using flexible tubing and a rate-controlled 12v battery powered pump. This project will not feature continuous pumping, but will rather only pump long enough to create and measure the extent of the thermal anomaly created at quasi steady-state. We will also experiment with different water introduction techniques including, but not limited to; simulated upwelling (burying the end of the tubing in the substrate), distributed release (exiting through a slotted pipe) and point release (exiting into the water column at a single point.)

The volumetric extent and temperature of created thermal refugia will be evaluated using heat tracing methodology. Heat-based hydrologic methods are particularly suited for this study, as temperature differentials are used to efficiently map the areal mixing of surface and groundwaters, and temperature is the critical parameter of interest in the context of fish survival. Shallow alluvial aquifer groundwater temperatures are expected to approximate the local air mean temperature (Constantz, 2008), which in central Connecticut is approximately 12 °C. This relatively stable end-member contrasts strongly with warm surface water flows that approach 20 °C in this area, yielding significant ΔT between surface and groundwater that can readily be tracked with heat-tracing methodology. Beyond point measurements of temperature in the water column and streambed, new methods of locating cool groundwater discharge points in summer include fiber-optic distributed temperature sensing and infrared imaging (Hare et al., 2015).

Infrared is the most efficient method to map refugia (e.g. Dugdale et al., 2015), as surface thermal regimes are evaluated in real-time across a field of view up to 100's of m² in areal extent (Figure 1). However, in summer cool groundwater is relatively dense and tends to plunge in warm surface water, and infrared does not penetrate the water column. PI Briggs has used sub-surface fiber-optic distributed temperature sensing paired with surface infrared imaging to map the areal distribution of thermal refugia in large rivers in the context of thermal refugia (e.g. Briggs et al., 2013), and that paired methodology will be applied in summer 2018.

Results/Significance of Research

There were no results in year one as delayed funding resulted in the inability to collect data in summer 2017. We are on track to collect our first data in July 2018.

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Integrating fine-scale field measurements with regional groundwater models to predict legacy nitrogen transport in Long Island Sound watersheds

Basic Information

Title:	Integrating fine-scale field measurements with regional groundwater models to predict legacy nitrogen transport in Long Island Sound watersheds
Project Number:	2017CT306B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CT-002
Research Category:	Ground-water Flow and Transport
Focus Categories:	Nitrate Contamination, Water Quality, Groundwater
Descriptors:	None
Principal Investigators:	Ashley M Helton, Jeffrey Starn, Martin A Briggs

Publications

1. Barclay, JR; Helton, AM; Briggs, MA; Starn, JJ; Hunt, A. Groundwater Discharge of Legacy Nitrogen to River Networks: Linking Regional Groundwater Models to Streambed Groundwater-Surface Water Exchange. In preparation.
2. Barclay, JR; Helton, AM; Briggs, MA; Starn, JJ; Hunt, A. Groundwater Discharge of Legacy Nitrogen to River Networks: Patterns of Nitrogen Loading and Denitrification. In preparation.
3. Barclay, JR; Helton, AM; Briggs, MA; Starn, JJ. Groundwater Discharge of Legacy Nitrogen to River Networks: Spatial patterns of vulnerability and management implications. In preparation.
4. Helton, AM, JR Barclay, MA Briggs, JJ Starn, A Hunt. 2018. River network-scale patterns of groundwater discharge and denitrification of legacy nitrogen at the streambed interface. Society for Freshwater Science Annual Meeting. Detroit, MI.
5. Barclay JR, AM Helton, MA Briggs, JJ Starn. 2018. What's old is new: Managing nitrogen legacies. Connecticut Conference on Natural Resources. Storrs, CT.
6. Barclay JR, AM Helton, MA Briggs, JJ Starn, A Hunt. 2018. Groundwater Discharge of Legacy Nitrogen to River Networks: Patterns of Subsurface Travel Time, Nitrogen Loading, and Denitrification. Geological Society of America, Northeastern Section Meeting. Burlington, VT.
7. Barclay JR, AM Helton, MA Briggs, JJ Starn, A Hunt. 2017. Poster: Groundwater Discharge of Legacy Nitrogen to River Networks: Linking Regional Groundwater Models to Streambed Groundwater-Surface Water Exchange and Nitrogen Processing. American Geophysical Union Fall Meeting. New Orleans, LA.
8. Barclay, JR, AM Helton, JJ Starn, MA Briggs. 2017. Quantifying legacy nitrogen transport in Connecticut watersheds. Connecticut Conference of Natural Resources. Storrs, CT.

Introduction/Research Objective

Human activities have increased N loading to land surfaces by at least five times compared to pre-industrial conditions (Houlton et al. 2013). Over the past 50 years, this elevated N loading to land surfaces has dramatically increased N in receiving waters, resulting in eutrophication of coastal areas worldwide (Diaz and Rosenberg 2008). Surface runoff and river transport of N have been studied extensively at the watershed-scale (Van Breemen et al. 2002; Seitzinger et al. 2010; e.g. Moore et al. 2011). However, N applications to land surfaces have also substantially increased N in recharging groundwater, creating a source of N that is later discharged back to surface waters (“legacy N”). Typical groundwater transport times can be months, decades, or even centuries longer than surface water transport times (Hamilton 2012), creating substantial temporal and spatial lags between infiltration and discharge. Although approximately 70% of surface water in the U.S. is derived from groundwater that discharges during baseflow (Wolock 2003), the role of groundwater transport in reactive nitrogen (N) loading to receiving surface waters has not been quantified at broad scales and is typically not considered in management strategies for N load reductions. Indeed, N accumulating in aquifers and discharging to streams may be a reason many impaired coastal systems show little improvement despite efforts to reduce N loads (Sprague et al. 2011; Sanford and Pope 2013; Chen et al. 2014).

Recent research has begun addressing the effects of groundwater lags on the timing of N loading to sensitive downstream systems (Sanford and Pope 2013; Chen et al. 2014; Van Meter and Basu 2015). Ignoring these lags could lead to overly ambitious load reduction goals or incorrect conclusions about the effectiveness of N reduction strategies (Albiac 2009; Sanford and Pope 2013). Yet, we commonly apply surface runoff watershed models that disregard groundwater transport to predict surface water N dynamics. Therefore, there is a critical need for watershed-scale approaches that quantify legacy N loading from groundwaters to surface waters. In the absence of such approaches, our capacity to effectively evaluate management strategies that seek to improve coastal water quality will be inadequate.

For this project, our objectives were to 1) estimate the spatial distribution of groundwater discharge using a traditional groundwater modeling approach; 2) compare spatial patterns of modeled groundwater discharge to observed groundwater seeps over 10's of km of river length; and 3) identify initial locations where stream interface sediments are potentially important filters or conduits of legacy N.

Methods/Procedures/Progress

Study site: This project focused on the Farmington River watershed (1571 km²) located in northwestern CT and southwestern MA (Figure 1). The Farmington discharges to the Connecticut River, which discharges to the LIS. Principal bedrock aquifers in the Farmington are the New England Crystalline-rock aquifer and the Mesozoic sandstone and basalt of the Newark Supergroup. The bedrock is overlain by glacial till across most of the watershed, with areas of valley fill stratified drift aquifers (Olcott 1995). The watershed has experienced substantial changes in land cover over the last several decades. Between 1973 and 2011 there was a 38% reduction in agricultural and a 19% gain in urban land cover (based on GIRAS 1973 and NLCD 2011, D. Civco unpublished).

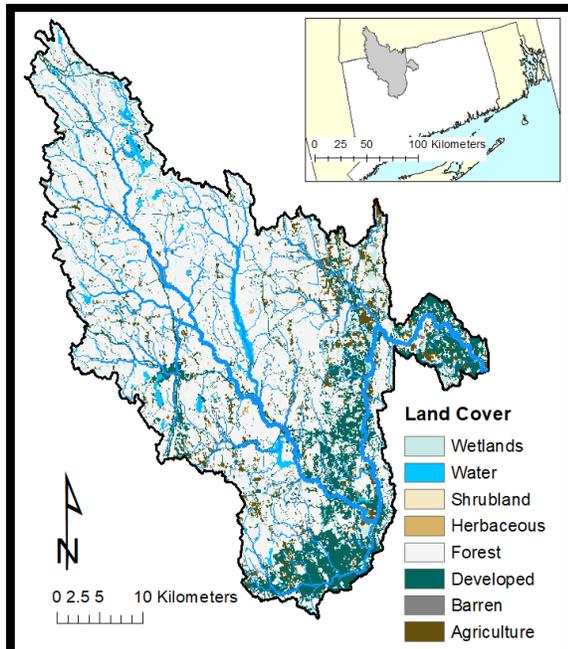


Figure 1. Farmington River watershed.

Thermal infrared (TIR) surveys & regional groundwater modeling: Heat can be an ideal tracer of groundwater flow in late summer as groundwater temperature is predictable, colder than surface water, and easily visualized with thermal infrared (TIR) cameras (Hare et al., 2015; Rosenberry et al., 2016). We surveyed 36.6 km of stream length, including 31 km of the 5th order main stem of the Farmington River by watercraft and 5.6 km of 1st to 3rd order tributaries in the Farmington River watershed by wading with handheld TIR cameras in summer and fall 2017 (Figure 2). Typically, focused groundwater discharge characterizations made with physical seepage meters and piezometers are done over reach lengths that do not exceed 100's of meters (Rosenberry et al. 2013). Thermal infrared surveys allowed us to efficiently map a comprehensive spatial distribution of groundwater seeps across 10's of kilometers.

We implemented and calibrated a steady-state groundwater flow model (MODFLOW-NWT; Niswonger et al. 2011) for the Farmington River watershed. The model has a daily time-step, a uniform horizontal grid of 300 m, four vertical layers of increasing thickness with depth, and five zones of surficial materials (Soller et al. 2012). Spatially varying recharge (Wolock 2003) drives subsurface flow. The model was calibrated with PEST++ (Welter et al. 2015) using 287 well head (USGS 2017) and 217 stream elevation measurements (US EPA & USGS 2012). We used MODPATH (Pollock 2012) with recharge scaled particle inputs to calculate median subsurface travel times.

We compared the occurrence of modeled groundwater discharge to discharge observed in the field during TIR surveys. Our field survey included 168 (out of 3743) model river cells. We will also evaluate predictions from a series of additional MODFLOW models. We expect hydraulic conductivity (K) of surficial materials, riverbed conductance, and the resolution of topography to drive disparities between spatial patterns of observed and modeled discharge. Thus, our initial model refinement will focus on these, with four specific models: 1) Base model (described above, 300 m grid) - K in unconsolidated sediments will vary smoothly across the study area using a single zone with uniform riverbed conductivity; 2) Heterogeneous surficial materials (300 m grid) - Five zones will correspond to surficial material (coarse, fine, till, wetlands, and open water) with uniform riverbed conductivity; 3) Variable riverbed conductivity (300 m grid): Five zones and riverbed conductivity will correspond to surficial material; 4) Higher resolution: (50 m grid) - We anticipate better model predictions in larger streams, where topographic drivers of discharge are more consistent with model resolution. To address the computational challenge of calibrating a finer resolution model, we will use pilot points from the best coarse model to create the K layer, rather than recalibrating. We acknowledge that further refinement may be needed in later models - such as observations of where organic-rich river fines "cap" sand and gravel deposits that intersect the river corridor or where flow patterns are dominated by bedrock fracture connectivity. Locations where model refinement does not

improve model fit are particularly important for understanding where and why current model and field techniques cannot be reconciled. *Progress: The base model scenario and field surveys are complete and other model scenarios are in progress for a manuscript in preparation (Barclay et al. In Prep. A).*

Groundwater sampling and analysis: At locations of apparent groundwater discharge identified during the field surveys we collected sediment water samples (n=50, depth = 23.5 cm unless local conditions require shallower) using a pore water sampler (Henry) perpendicular to groundwater flow. At each site we also collected surface water samples for comparison. We analyzed all water samples for N species (NO_3^- , N_2O , NH_4^+ and Total Dissolved N (TDN)), anions (Cl^- , SO_4^{2-} , Br^- , and PO_4^{3-}), dissolved gases (CO_2 and CH_4), dissolved organic carbon (DOC), and specific conductance. In addition, we analyzed sediment water samples for O_2 , N_2 , and Ar. We measured specific conductance in the field using a hand-held YSI 556 probe. Dissolved N_2O , CH_4 , and CO_2 were measured using headspace equilibration techniques (Helton et al., 2014; Hudson, 2004), and analyzed on a PerkinElmer Clarus 580 gas chromatograph. NO_3^- (and a suite of anion concentrations including Cl^- , SO_4^{2-} , Br^- , and PO_4^{3-}) were measured on a Thermo Fisher Ion Chromatography System (ICS-1100) and TDN (by persulfate digestion) and NH_4^+ was measured on a SmartChem 200 discrete analyzer. DOC was measured by combustion on a 1020A OI Analytical TOC Analyzer. Ambient N_2 , O_2 , and Ar were analyzed by Membrane Inlet Mass Spectrometry (MIMS). All laboratory analysis was completed at the University of Connecticut. *Progress: The laboratory analysis is complete and data analysis is in progress for a manuscript in preparation (Barclay et al. In Prep. B).*

Groundwater flux measurements: In 26 locations of apparent groundwater discharge, indicated by anomalously cold temperature, we installed discrete temperature loggers (e.g., iButtons®) in short vertical profilers designed to capture the unique shallow surface heat propagation of discharge zones (Briggs et al., 2014). We used the USGS GUI for VS2DH 1DTempPro (Koch et al., 2015) to analyze the temperature data and calculate variable groundwater discharge rates over time using proven methods. Recently, Rosenberry et al. (2016) showed that when thermal parameters are measured in-situ using passive diurnal signals, 1D temperature-based models return comparable data to seepage meter measurements over a large range of natural groundwater discharge (0-3 md^{-1}). However, unlike most seepage meters, the thermal models can be applied at sub-daily timestep over many months to elucidate spatiotemporal groundwater discharge patterns. *Progress: We are currently analyzing this dataset.*

Results/Significance of Research

Initial Results

Thermal infrared surveys: We observed extensive focused groundwater discharges (stars and crosses, Figure 2b) along the main stem of the Farmington that included both expansive stream bank seepage facie (Figure 2c) that spanned up to 10s of meters along stream banks and individual or clusters of individual seeps (Figure 2d).

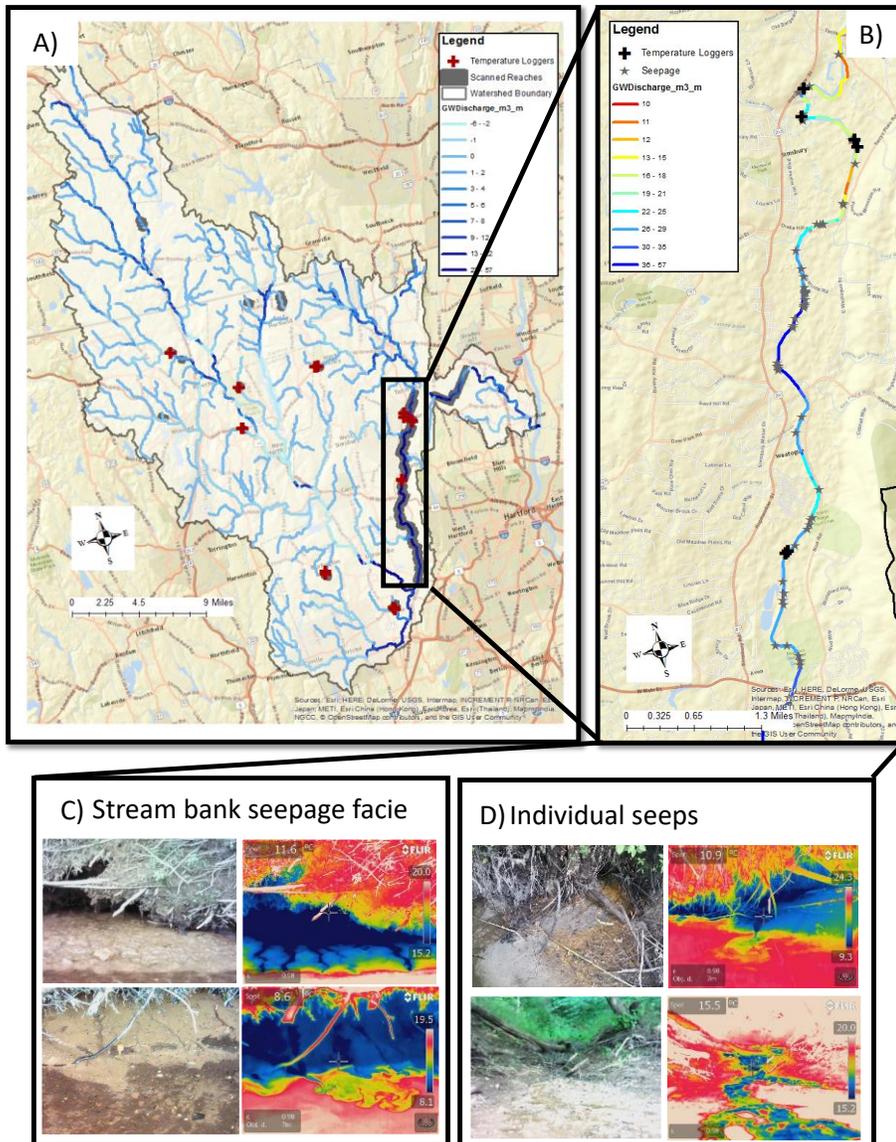


Figure 2. We implemented a groundwater model and surveyed >35 km stream length for focused groundwater discharges using thermal infrared (TIR) imagery surveys in the Farmington River watershed. A) Farmington River watershed. Grey shading indicates TIR survey extent and blue shading indicates simulated groundwater discharge rate (higher rates are darker blue). B) Survey length of the 5th order main stem of the Farmington River. Stars and crosses indicate groundwater discharge zones observed during TIR surveys. Blue shading indicates high rates of simulated groundwater discharge. Examples of focused groundwater discharge zones observed with handheld TIR cameras: C) Stream bank seepage facie and D) Individual groundwater seeps. Blue indicates colder water from regional groundwater flow paths.

Groundwater model: For the base model scenario, modeled well head and stream elevation measurements fit observed datasets well (Figure 3). We are currently analyzing model output and refining model scenarios.

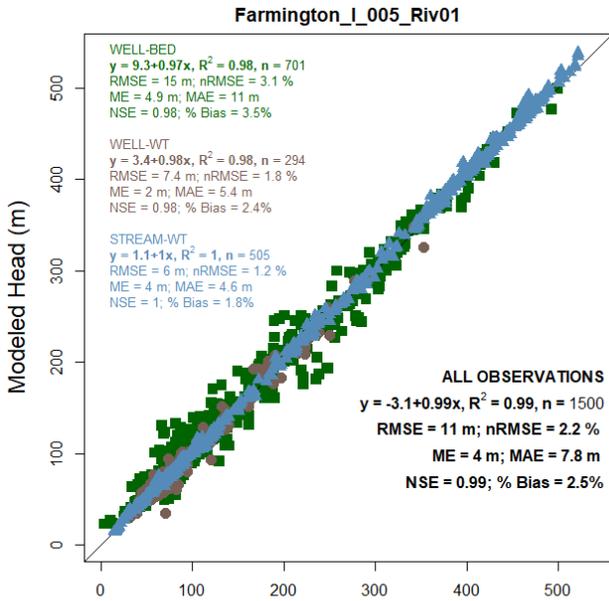


Figure 3. Modeled versus measured well head and stream elevation for MODFLOW base scenario.

Model comparison: We observed groundwater discharge with TIR imagery in the majority of model cells surveyed (>60% in the 5th order Farmington, i.e., paddling reaches, and >80% in small tributaries, i.e., wading reaches). We are currently evaluating model predictions against the observed spatial distribution of seeps.

Nitrogen dynamics: Legacy N loads, based on measured concentrations and modeled discharge rates, vary considerably from near detection to higher than 25 g N m⁻¹d⁻¹ (Figure 4a). Even in areas with high rates of groundwater discharge, a wide range of nitrate concentrations drives huge variability in N loads to the stream. Areas with high nitrate concentrations (darker red circles, Figure 4b), high groundwater discharge, and long

travel times are of particular interest from a legacy N perspective because they may contribute disproportionately large N loads for many years into the future. We are currently building statistical models to predict spatial patterns of legacy N loads and denitrification.

Significance of Research

We expect our proposed project to contribute widely to the field of hydrologic sciences, to have a significant positive impact on N management strategies, and to have immediate implications for the management of N and the evaluation of N reduction strategies for the Long Island Sound watershed. Upon completion of the proposed research, we expect to have established groundwater model downscaling techniques that integrate fine-scale empirical measurements of groundwater-surface water exchange with regional groundwater models to accurately predict spatiotemporal patterning of groundwater discharge. These patterns are not typically the focus of groundwater model calibration; however, it is essential that we represent the spatial and temporal patterns of groundwater discharge as

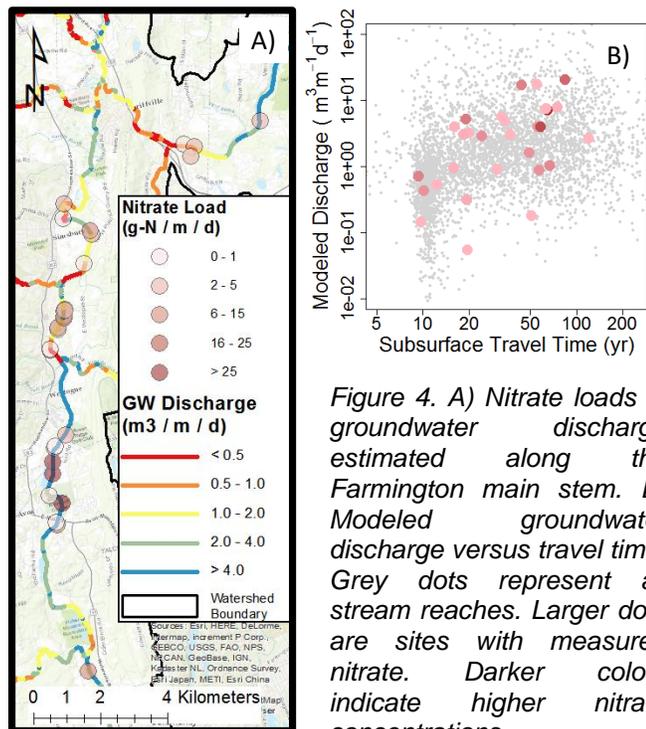


Figure 4. A) Nitrate loads in groundwater discharge estimated along the Farmington main stem. B) Modeled groundwater discharge versus travel time. Grey dots represent all stream reaches. Larger dots are sites with measured nitrate. Darker colors indicate higher nitrate concentrations.

accurately as possible because we are interested in the discharge of legacy N from groundwaters to surface waters.

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Information Transfer Program Introduction

The general purpose of the Connecticut Institute of Water Resources information transfer activities are to support a number of ongoing efforts, such as an invited speaker for a Fall seminar series, conferences, educational information and web site development and maintenance, serving on boards and committees, as well as special projects and publications implemented as the need arises. All of these activities are funded through the Institute's 104B project, "Information Transfer Program."

CTIWR Technology Transfer

Basic Information

Title:	CTIWR Technology Transfer
Project Number:	2017CT311B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	Glenn Warner, James D Hurd

Publications

There are no publications.

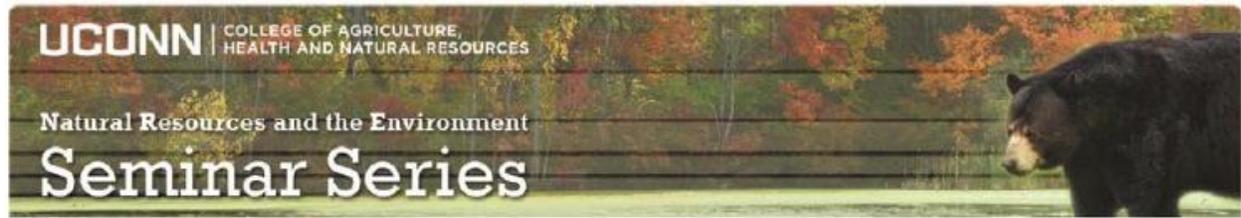
Connecticut Institute of Water Resources
INFORMATION TRANSFER PROGRAM

Seminar Series:

The CTIWR helps support a weekly seminar series held during the Fall semester by the Department of Natural Resources and the Environment. This series includes the CTIWR sponsored "William C. Kennard Water Resources Lecture" during which a respected water resources professional, normally from outside the state, is invited to speak on an issue of interest to researchers, students, and other interested individuals in our state. This past fall CTIWR hosted Dr. Richard Seager, Senior Research Scientist at the Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY. Dr. Seager provided an hour long presentation titled, "North American Drought: Past, Present and Future," to approximately 75 attendees. The presentation focused on the history of drought in North America, the causes and consequences, and the drivers of drought for the northeast region of the United States. In addition to the presentation, Dr. Seager met with Department Graduate Students for an informal discussion to share research ideas and experiences, and met with select Department faculty. See Seminar announcement on next page.

Conference Support:

The Institute is proud to be among several sponsors that support the annual Connecticut Conference on Natural Resources (CCNR) held each March during spring break recess at the University of Connecticut. The CCNR attracts over 300 individuals from throughout Connecticut who are conducting environmental research, involved in developing policy, or otherwise interested in the natural resources of Connecticut. This conference serves as a venue for networking and sharing ideas regarding the varied environmental resources in Connecticut. CTIWR contributes \$500 to support the conference. Additionally, this year the Institute had an informational table that allowed us to provide general information about the Institute to the attending public.



Please join us for a seminar by the Institute of Water Resources Invited Speaker on Friday, October 6th from 2:30-3:30 pm in WB Young Building Room 100

North American Drought: Past, Present and Future

Dr. Richard Seager

Senior Research Scientist
Lamont-Doherty Earth Observatory
Columbia University



Website:

Our Institute maintains the CTIWR web site (<http://ctiwr.uconn.edu>), which we continually update. It includes information about the WRRI program, our Institute and its Advisory Board members, a listing of the current year's seminars, a list of sponsored projects, reports and publications, and access to electronic copies of our "Special Reports" series. We also use the web to announce special events and release of our 104B Program RFP, in addition to secure access to grant proposals, technical reviews and information for the CTIWR Advisory Board's review. We continue to cooperate with the University of Connecticut's digital archives department, which maintains our electronic reports as a part of its "Digital Commons @ University of Connecticut" project. We continue to go through our digital and hardcopy archive of past reports and documents (dating from 1965 to current) and make appropriate content available for download and viewing on our website. These are being provided in a searchable PDF format. Additionally we have added links to federal sites that provide information regarding water resources for Connecticut. We continue to explore ways to provide useful information through our website.

Service and Liaison Work:

The previous Director, Dr. Glenn Warner, served on the following water related panels, committees or workgroups during the FY2017 time period:

- Participant, CT Water Planning Council Advisory Group (WPCAG).
- Member, CT WPCAG, Drought Plan Working Group.
- Member, Scientific and Technical Subcommittee of the Steering Committee, CT State Water Plan.



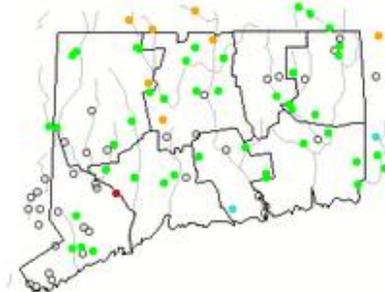
Connecticut Institute of Water Resources



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- REPORTS
- INFORMATION
- ABOUT

Current Streamflow Conditions

Friday, May 25, 2018 07:30ET

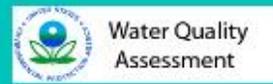


Explanation - Percentile classes						
Low	<10	10-24	25-75	76-90	>90	High
	Much below normal	Below normal	Normal	Above normal	Much above normal	

Information About Water Resources in Connecticut



<http://droughtmonitor.unl.edu/>



WELCOME

The Connecticut Institute of Water Resources is part of a national network of 54 state water institutes created by the Federal Water Resources Research Act of 1964. The general purpose of the institutes is to promote research related to water resources and provide information transfer within each respective state or territory. In Connecticut our goals are to arrange for research related to freshwater resources, cooperate with Connecticut higher education institutions to develop programs to identify, discuss and resolve state and regional water, watershed, and related upland issues, and share research results and information regarding water resources in Connecticut.



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Figure 1. Home page of the Connecticut Institute of Water Resources website.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	4	0	0	0	4
Masters	3	0	0	0	3
Ph.D.	5	0	0	0	5
Post-Doc.	0	0	0	0	0
Total	12	0	0	0	12

Notable Awards and Achievements

Publications from Prior Years

1. 2014CT287B ("Interactions between catchment land cover, storm events, and nitrogen export from Connecticut streams") - Dissertations - Sauer, Jason. 2016. Characterizing headwater stream hydrology and nitrogen export during storms across a gradient of watershed development. Master's Thesis, University of Connecticut.
2. 2012CT259B ("Influence of dynamic copper speciation on bioavailability in streams") - Articles in Refereed Scientific Journals - Luan, H., T.M. Vadas. 2015. Size characterization of dissolved metals and organic matter in source waters to streams in developed landscapes. *Environmental Pollution* 197:76-83.
3. 2012CT259B ("Influence of dynamic copper speciation on bioavailability in streams") - Conference Proceedings - Luan, H., T.M. Vadas. 2015. Characterization of effluent and stormwater metal sources and influence on bioavailability in developed streams. ACS National Meetings, Denver, CO. OP.
4. 2012CT259B ("Influence of dynamic copper speciation on bioavailability in streams") - Dissertations - Hongwei Luan, Impacts of effluent and stormwater runoff sources on metal lability and bioavailability in developed streams, Dissertation, PhD, 2016.
5. 2012CT256B ("Field Testing the Educational and Land Use Planning Value of a New Nitrogen Modeling Tool in the Niantic River Watershed") - Other Publications - Arnold, C.L., D.Q. Kellogg, K.F. Forshay, C. Damon, E.H. Wilson, A. Gold, E.A. Wentz and M.M. Shimizu. 2013. Tracking the Fate of Watershed Nitrogen: The "N-Sink" Web Tool and Two Case Studies. EPA Office of Research and Development National Risk Management Research Laboratory, Ada, OK, Publication 600/R-13/230. 54pp. (peer reviewed EPA Technical Report).