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New Hampshire Water Resources Research Center Annual Technical Report FY 2015

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New Hampshire Water Resources Research Center
Annual Technical Report
FY 2015

Introduction

The New Hampshire Water Resources Research Center (NH WRRC), located on the campus of the University of New Hampshire (UNH), is an institute that serves as a focal point for research and information on water issues in the state. The NH WRRC actually predates the Federal program. In the late 1950s Professor Gordon Byers (now retired) began a Water Center at UNH. This Center was incorporated into the Federal program in 1965 as one of the original 14 state institutes established under the Water Resource Research Act of 1964. The NH WRRC is currently directed by Dr. William McDowell with administrative and technical assistance from Associate Director Ms. Michelle Shattuck and Mr. Jody Potter (Water Quality Analysis Lab (WQAL) Manager). The NH WRRC is a standalone organization, in that it is not directly affiliated with any other administrative unit at UNH, and it reports to the Dean of the College of Life Sciences and Agriculture (COLSA). The NH WRRC has no dedicated laboratory or research space, and instead relies on space allocated for the research activities of the WRRC director by COLSA. The NH WRRC does have administrative space on campus, which houses WRRC files and short-term visiting staff and graduate students. The WRRC website (www.wrrc.unh.edu) serves as a focal point for information dissemination and includes NH WRRC publications and results from past research, as well as links to other sites of interest to NH citizens and researchers.

Research Program Introduction

RESEARCH INTRODUCTION

The NH WRRC supported four research projects with its 2015 104b funding:

1. Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds

2. Contribution of fluvial wetlands to nitrogen retention in urbanizing coastal watersheds in New England across multiple scales

3. Natural dams and biogeochemistry at the river network scale: implications for water quality

4. Improved Ecosystem Indicator Tools for Water Quality Management – Genomic Analysis of Periphyton to Identify Stressors

The Water Quality Analysis Lab (WQAL) is affiliated with the NH WRRC and facilitates water resources research through technical assistance and sample analysis. The WQAL was established by the Department of Natural Resources in 1996 to meet the needs of various research and teaching projects both on and off the UNH campus. It is currently administered by the NH WRRC and housed in James Hall. The mission of the Water Quality Analysis Laboratory is to provide high-quality, reasonably priced analyses in support of research projects conducted by scientists and students from throughout the University, state, and nation. Past clients have included numerous research groups on the UNH campus, Federal agencies, scientists from other universities, and private firms. Many thousands of analyses are conducted each year.

Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds

Basic Information

Title:	Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds
Project Number:	2003NH21B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	NH01
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Nutrients
Descriptors:	
Principal Investigators:	William H. McDowell, Michelle Daley Shattuck

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Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds

Statement of Critical Regional or State Water Problem

New Hampshire's surface waters are a very valuable resource, contributing to the state's economic base through recreation (fishing, boating, and swimming), tourism and real estate values, and drinking water supplies. New Hampshire is experiencing rapid growth in several counties and from 1990 to 2004 the state grew twice as fast as the rest of New England, with a state-wide average population increase of 17.2% during that period (Society for Protection of NH Forests 2005). New Hampshire watersheds rank among the most highly threatened watersheds in the nation because of the high potential for conversion of private forests to residential development. In fact, three of the four most threatened watersheds in the US which could experience the largest change in water quality as a result of increased residential development in private forests occur at least partially in New Hampshire (Stein et al. 2009).

The long-term impacts of this rapid population growth and the associated changes in land use on New Hampshire's surface waters are uncertain. Of particular concern are the impacts of non-point sources of pollution such as septic systems, urban runoff, stormwater, application of road salt and fertilizers, deforestation, and wetland conversion. Long-term datasets that include seasonal and year-to-year variability in precipitation, weather patterns and other factors are needed to adequately document the cumulative effects of land use change and quantify the effectiveness of watershed management programs. No other agency or research program (e.g. NH Department of Environmental Services (NH DES), US Geological Survey (USGS) or Environmental Protection Agency (EPA)) has implemented such a long-term program.

Statement of Results or Benefits

This project provides detailed, high-quality, long-term datasets which allow for a better understanding of the impacts of land use change and development on surface water quality. These surface water datasets could support the development, testing and refinement of predictive models, accurately assess the impacts of watershed management practices on drinking water supplies, assess efforts to reduce surface water quality impairments, and be potential early warning signs of dramatic changes to surface water quality in the region resulting from rapid development. Long-term datasets from this project will be essential to adaptive management strategies that strive to reduce non-point sources of nitrogen pollution in New Hampshire's Great Bay watershed which is currently impaired by elevated nitrogen and in violation of the Federal Clean Water Act. A list of selected recent presentations, publications and press releases that utilize long-term datasets supported by NH WRRC funding for this project is included at the end of this report.

Objectives of the Project

This project allows for the continued collection of long-term water quality data in New Hampshire. It will use University of New Hampshire (UNH) staff, students and volunteers from local communities to collect samples from the Lamprey and Oyster River watersheds located in southeast NH and the Ossipee River watershed in central NH. All three watersheds are located in counties experiencing high population growth rates (Figure 1). Both the Lamprey and Ossipee watersheds are predicted to more than double in population from 1998 to 2020 (Sundquist and Stevens 1999). Surface water sites within each of the 3 watersheds and details on long-term datasets collected are described below. Together these 3 watersheds capture a broad range of urban, rural and agricultural land uses as well as a range of forests and wetland cover types.

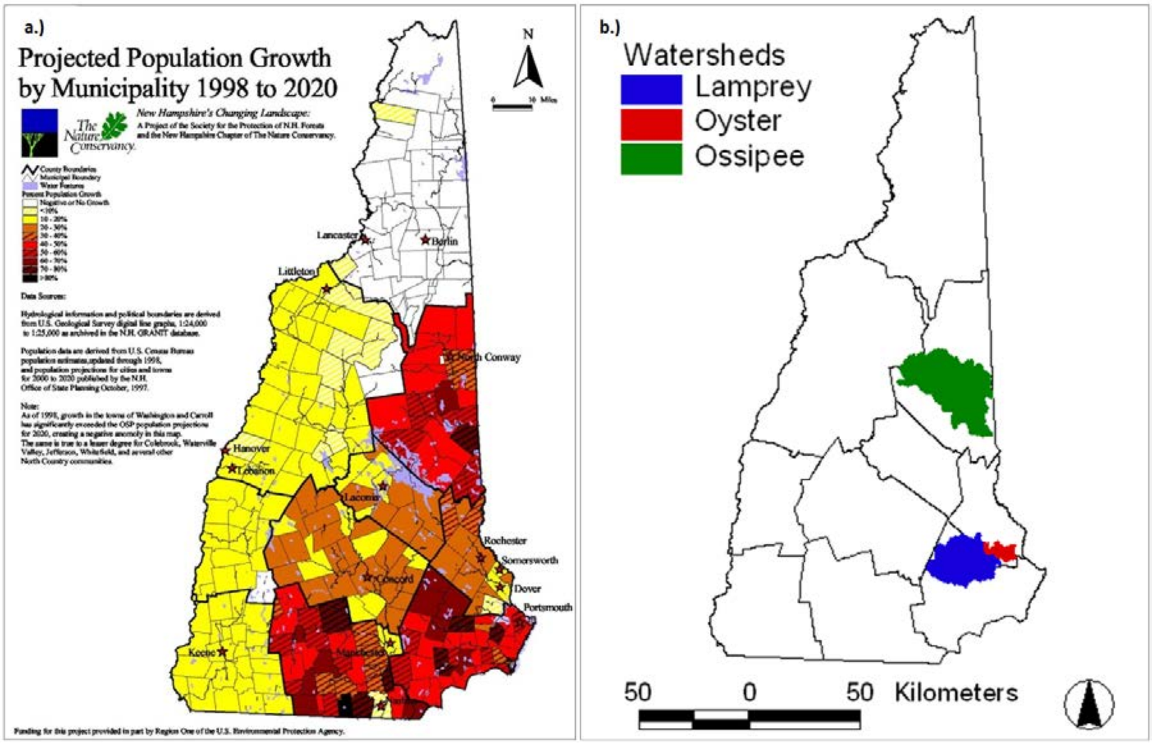

Figure 1. Projected population growth in New Hampshire (Figure from Sundquist and Stevens 1999; A) and study watersheds experiencing high population growth (B).

Methods, Procedures and Facilities

Lamprey River Hydrologic Observatory

The Lamprey River watershed (479 km^2) is a rural watershed located in southeastern NH and is under large development pressure as the greater area experiences the highest population growth in the state. The Lamprey River Hydrologic Observatory (LRHO) is a name given to the entire Lamprey River basin as it serves as a platform to study the hydrology and biogeochemistry of a suburban basin and is used by the UNH community as a focal point for student and faculty research, teaching and outreach. Our goal for the long-term Lamprey water quality monitoring program is to document changes in water quality as the Lamprey watershed becomes increasingly more developed and to understand the controls on N transformations and losses.

The Lamprey River has been sampled weekly and during major runoff events since September 1999 at site LMP73 which is co-located with the Lamprey River USGS gauging station (01073500) in Durham, NH. Two additional sites were added to the long-term Lamprey River monitoring program in January 2004. One site (NOR27) was located on the North River, the Lamprey River's largest tributary, less than 1 km downstream from the USGS gauging station (01073460) in Epping, NH. The other site (Wednesday Hill Brook; site WHB01) drains a small suburban area in Lee, NH where residents rely solely on private wells and private septic systems for water supply and waste disposal. A stream gauge at WHB01 is operated by UNH staff and/or students. Sites NOR27 and WHB01 were sampled on a weekly basis through 2010 and in January 2011, the North River sampling frequency (site NOR27) was reduced to monthly because accurate measures of river discharge were no longer possible. Site WHB01 along with LMP73 remain at a weekly and major storm event sampling frequency. Several other sites have been sampled for multiple years on a less frequent basis to assess the spatial variability of water quality in sub-basins with various land uses and development intensities. In the past year, 14 additional sites were sampled on a monthly basis. All LRHO stream water samples are collected by UNH staff and/or students.

Oyster River watershed

The Oyster River watershed (80 km^2) is a small watershed in southeast NH where land use ranges from rural to urban. Two urban sub-basins, College Brook (CB) and Pettee Brook (PB), were selected for long-term sampling in January 2004. Both sub-basins are dominated by the University of New Hampshire (UNH) and receive a variety of non-point pollution from several different land uses. Three sites (CB00.5, CB01.5 and CB03.0) are sampled along College brook which drains the center of campus and one site (PB02.0) is located on Pettee Brook which drains the northern section of campus. Both sub-basins drain areas with high amounts of impervious surface and College Brook also drains the UNH dairy farm and athletic fields. Historic water quality data for these two sites are available from 1991. UNH staff and/or students currently sample these sites on a monthly basis.

Ossipee River watershed

The entire Ossipee River watershed (952 km^2) is classified as rural due to its low but increasing population. Seven sites in the watershed were selected for long-term monitoring in May of 2004. These sites are monitored monthly by volunteers and staff of the Green Mountain Conservation Group (GMCG) and were chosen to capture the areas of concentrated growth and monitor the major inputs and outputs from Ossipee Lake. Additional sites are selected by GMCG for volunteer monitoring during non-winter months (May to November). WRRC staff assist GMCG in site selection and data interpretation. In 2006, the GMCG worked with the Department of Environmental Services to establish a Volunteer Biological Assessment Program (VBAP) for the Ossipee Watershed. Numerous volunteers, including students from five local schools, assist with invertebrate sampling at a total of eleven sites.

Water Quality Analysis

Field parameters (pH, conductivity, dissolved oxygen (DO) and temperature) are measured at all sites. Water samples are filtered in the field using pre-combusted glass fiber filters (0.7 µm pore size), and frozen until analysis of dissolved constituents. Samples collected at all LRHO, CB, PB and the 7 long-term GMCG sites are analyzed for dissolved organic carbon (DOC), total dissolved nitrogen (TDN), nitrate (NO_3-N), ammonium (NH_4-N), dissolved organic nitrogen (DON), orthophosphate (PO_4-P), chloride (Cl^-), sulfate (SO_4-S), sodium (Na^+), potassium (K^+), magnesium (Mg^{+2}), calcium (Ca^{+2}), and silica (SiO_2). Water chemistry is also analyzed on a sub-set of the GMCG seasonal sites and turbidity is measured in the field at all GMCG sites. Samples collected since October 2002 from LMP73 are also analyzed for total suspended sediment (TSS), particulate carbon (PC), particulate nitrogen (PN) and dissolved inorganic carbon (DIC). All samples are analyzed in the Water Quality Analysis Laboratory (WQAL) of the NH WRRC on the campus of UNH, Durham, NH. Methods for analyses include ion chromatography (Cl^-, NO_3^-, SO_4^{-2} and Na^+, K^+, Mg^{+2}, Ca^{+2}), discrete colorimetric analysis (NH_4, PO_4, NO_3/NO_2), and High Temperature Oxidation (DOC, TDN). All methods are widely accepted techniques for analysis of each analyte.

The WQAL was established by the Department of Natural Resources in 1996 to meet the needs of various research and teaching projects both on and off the UNH campus. It is currently administered by the NH Water Resources Research Center and housed in James Hall. Dr. William McDowell is the Laboratory Director and Mr. Jody Potter is the Laboratory Manager. Together, they have over 41 years of experience in water quality analysis, and have numerous publications in the fields of water quality, biogeochemistry, and aquatic ecology.

Principal Findings and Significance

Lamprey River Hydrologic Observatory

Analysis of samples collected in 2015 from the LRHO is 75% complete. Results of stream chemistry to date show a significant increase in weekly nitrate concentrations during the first 10 years (Water Years (WY) 2000-2009) of monitoring at LMP73 based on the Seasonal–Kendall Test (SKT; seasons set to 52) flow-adjusted nitrate concentrations (SKT $t = 0.28$, $p < 0.01$). However, there is no statistically significant change in nitrate concentrations at LMP73 (Figure 2) or WHB01 over the entire study period (2000-2015). We have shown previously that stream water nitrate is related to watershed population density (Daley 2002) and since suburbanization continues to occur throughout the greater Lamprey River watershed, population growth is likely responsible for the increase in stream water nitrate over the initial 10-year period. The watershed population density increased from 53 to 60 people/km^2 or by 12% from 2000 to 2010 (2000 and 2010 Census). The highest levels of nitrate at LMP73 occurred in 2014. We are uncertain if nitrate levels in LMP73 will remain relatively constant, increase or decrease with changing climate, land use and management in the watershed. Wednesday Hill Brook watershed is near its development capacity, unless the Town of Lee, NH changes its zoning regulations, and the lack of increase in WHB01 nitrate may be due to the limited population growth in this watershed, that this watershed has reached nitrogen saturation or that the current time period of data collection is not reflective of long-term trends. Changes in Lamprey River nitrogen, especially nitrate, can have significant impacts for the downstream receiving water body, the Great Bay estuarine system which is impaired by elevated nitrogen and is currently in violation of the Federal Clean Water Act. Tidal tributaries to the bay are experiencing dangerously low dissolved oxygen levels and the bay is experiencing a significant loss of eelgrass which provides important habitat for aquatic life. The Lamprey River is the largest tributary to Great Bay, and thus the long-term data provided by the NH WRRC from the LRHO are of considerable interest for watershed management.

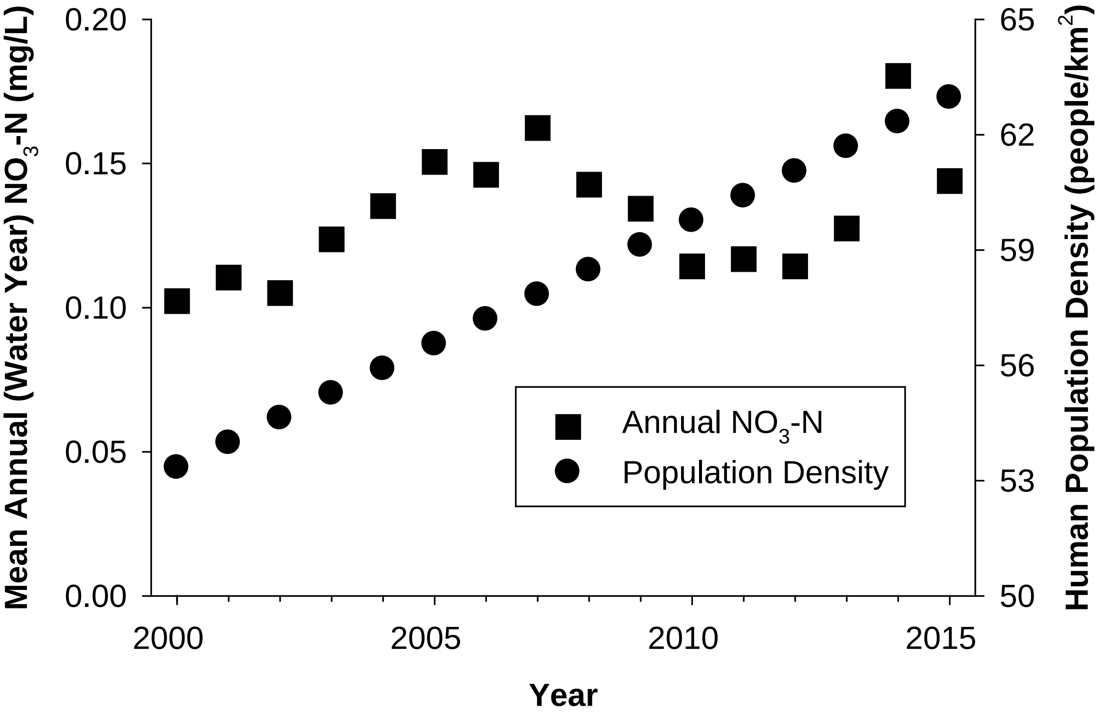

Figure 2. Annual (water year) mean nitrate concentration and estimated annual human population density from 2000-2015 (2000 and 2010 Census) in the Lamprey River basin. There is no statistically significant change in annual nitrate concentrations over the entire study period (2000-2015). Note that nitrate analysis for 2015 is 75% complete.

When we combine our specific conductance data (2003 – 2015) with data collected by the USGS (1978 - 1999), we see a long-term increase in specific conductance in the Lamprey River with a slight decline in recent years (Figure 3). Sodium and chloride concentrations are directly related to specific conductance (r^2 = 0.95, p<0.01 for Na^+; r^2 = 0.93, p < 0.01 for Cl^-) and we conclude that this increase in specific conductance indicates a corresponding increase in Lamprey River NaCl. Since Na^+ and Cl^- are strongly correlated with impervious surfaces in southeast NH (Daley et al. 2009) and road pavement among southeastern and central NH basins, we conclude that the associated road salt application to these surfaces is responsible for this long-term increase in stream water NaCl. The slight decline in recent years is likely due to the flushing effect of the 2006 and 2007 100-year flood events (Daley et al. 2009), but we are uncertain how long this slight decline will persist and thus continued monitoring is necessary to better understand how the interaction between human activities and climate variability affects water quality.

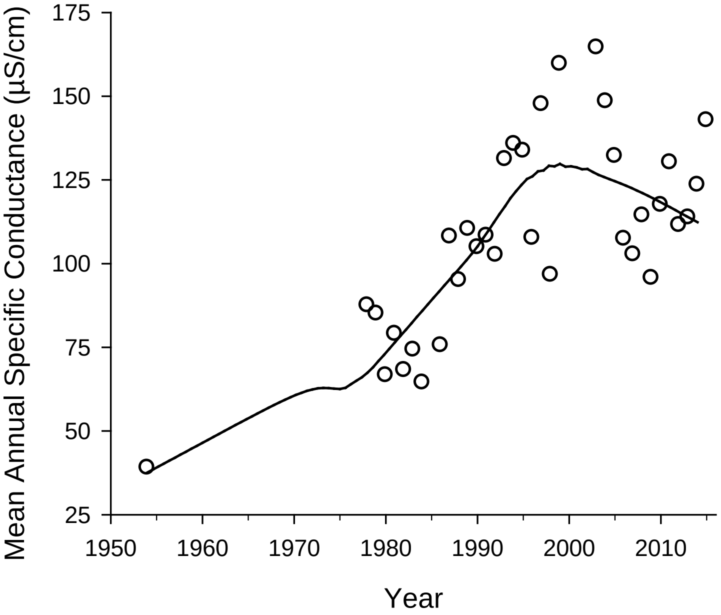

Figure 3. Mean annual specific conductance in the Lamprey River at LMP73 (co-located with the USGS gauging station in Durham, NH. (modified from Daley et al. 2009).

Oyster River watershed

Laboratory analysis of the monthly CB and PB samples collected in 2015 is approximately 90% complete. Recent data show that DO is lowest at the CB upstream station (CB00.5) where it does drop below 5 mg/L (level that is necessary to support in-stream biota) during the summer months. The downstream stations do not drop below 5 mg/L and this difference is due to the hydrologic and biogeochemical properties of the upstream sampling location which has slow stream flow, high dissolved organic matter content and resembles a wetland. DO increases downstream as flow becomes faster and the stream is re-aerated.

Data from 2000 until now indicate that the steam is strongly impacted by road salt application at its origin, which is essentially a road-side ditch along the state highway leading to a wetland area, and by road salt applied by UNH and the town of Durham which drains to the middle and lower reaches of the brook (Figure 4). Average sodium and chloride concentrations, as well as specific conductance, appear to have remained reasonably constant since 2001, but are much higher than in 1991 (Daley et al. 2009). Concentrations are highest at the upstream stations and tend to decline downstream as the stream flows through the campus athletic fields and then increase as the stream passes through the heart of campus and downtown Durham. Concentrations are also highest during years of low flow. Data from this project have been used to list College Brook as impaired for excess chloride.

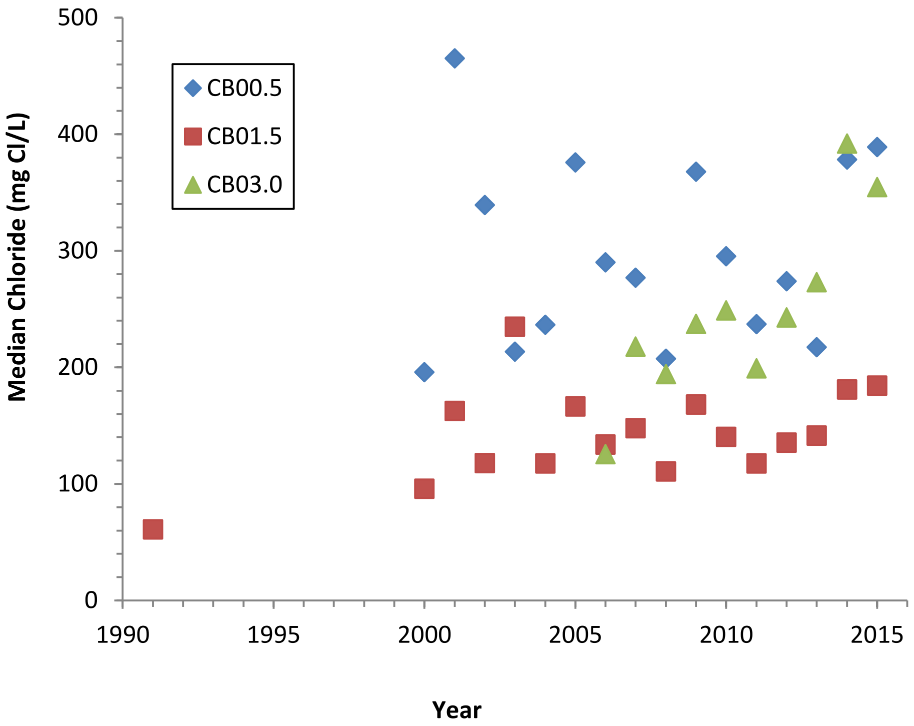

Figure 4. Median annual chloride in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

College Brook and Pettee Brook have noticeably higher nitrogen concentrations than many other local streams draining less developed or undeveloped watersheds. As College Brook flows from upstream to downstream where it becomes more aerated, ammonium decreases and nitrate increases (Figure 5) indicating that nitrification is occurring in the stream channel. However, an increase in total dissolved nitrogen (Figure 6) indicates that there are additional sources of nitrogen entering the stream as it flows downstream though UNH and Durham. This is possibly from fertilization of the athletic fields, storm water runoff or exfiltration from sewage lines. There is no statistically significant change in nitrate or TDN concentrations from 2000 to 2015 at the station with the longest record (CB01.5).

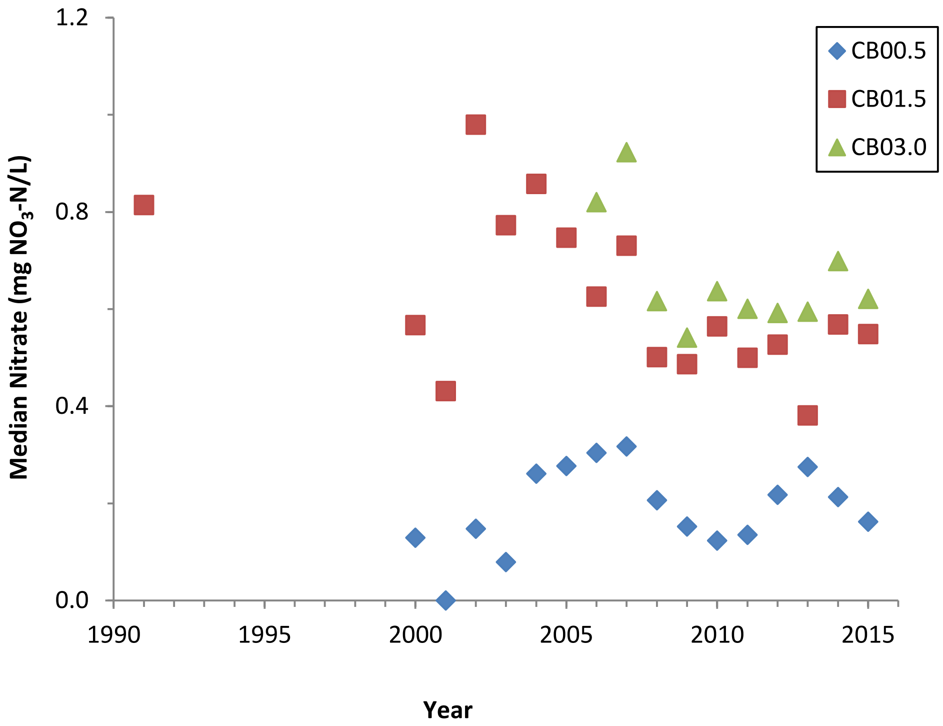

Figure 5. Median annual dissolved inorganic nitrogen (DIN) in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

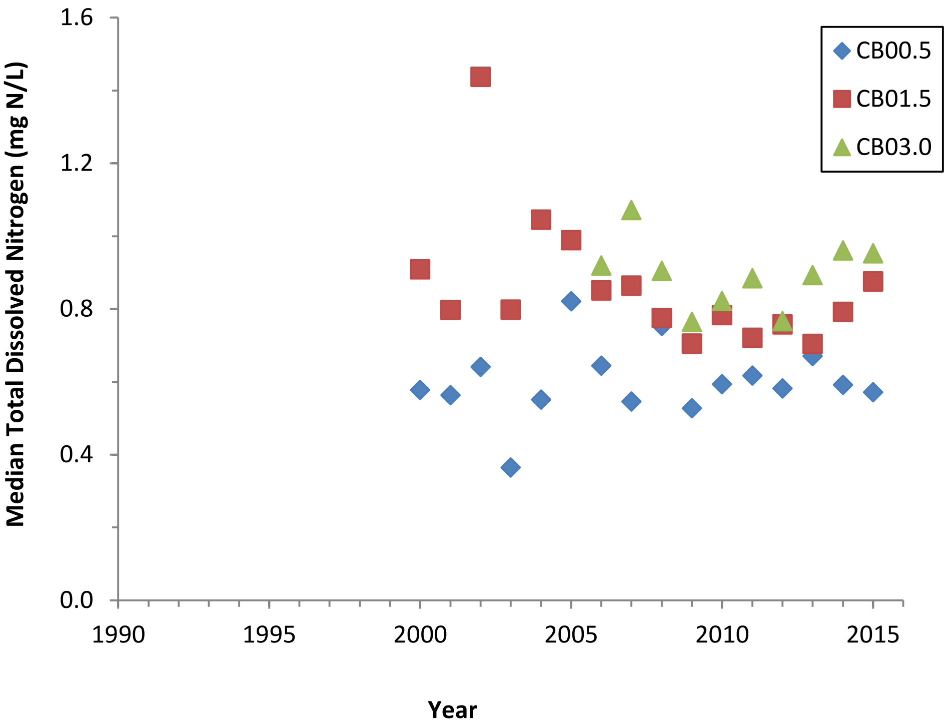

Figure 6. Median annual total dissolved nitrogen (TDN) in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

Ossipee Watershed

Collaboration with the Green Mountain Conservation Group (GMCG) and their sampling of the Ossipee River watershed provides much benefit to the NH WRRC and the long-term monitoring of rapidly developing suburban watersheds. Volunteers sampled streams within the watershed every 2 weeks from April through October, and monthly winter sampling was conducted by volunteers and GMCG staff at 9 sites. Over 100 samples were collected for analysis in the WQAL and additional field data were collected at over 40 sites throughout 6 towns using the help of many volunteers. Many presentations were made to planning boards, conservation commissions and other local government groups (see information transfer section below). The impact of road salting in this central NH watershed is similar to what we see in coastal NH (Daley et al. 2009). Data have been used to heighten awareness of the impacts of excessive road salting and snow dumping in local streams. Communication with local road agents has led to the remediation in one development where road salting was an issue. Samples collected and data generated from this funding have shown an improvement in water chemistry following reduced salting and snow dumping. Data have also been useful in promoting low impact development techniques and best management practices where new development has been proposed in proximity to lakes, rivers and streams within the watershed.

Notable awards and achievements

Currently NH has 49 watersheds listed as impaired due to elevated chloride levels resulting from salt use in winter road maintenance with the majority of those watershed located in the southern part of the state. College Brook is one of the impaired watersheds and the impairment listing was based on data produced from this project.

Two former undergraduate students at the University of New Hampshire supported previously be this NH WRRC grant are now pursuing a PhD. Chelsea Varrio is pursuing a PhD in Ecology & Evolutionary Biology Dartmouth College and Valerie Schoepfer is pursuing a PhD in Environmental Services at Southern Cross University in Lismore, New South Wales, Australia.

Number of students supported

One Master’s student (Bianca Rodriguez), two PhD students (Lauren Koenig and Bianca Rodriguez) 10 undergraduate hourly employees from the Department of Natural Resources & the Environment (Matthew Bosiak, Katie Swan, Shannen Miller, Colleen Dumphy, John Little, John Ciaburri, Casey McGrath, James Casey, Margaret Phillips, Christina Mroz) and 1 undergraduate hourly employee from the Engineering Department (Thomas Brigham). Three post-doctoral students were also supported by this project (Alison Appling, Adam Wymore and Ashley Coble).

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Information transfer activities that utilize long-term datasets supported by NH WRRC and matching funds

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Kaushal, S.S., McDowell, W.H., Wollheim, W.M., Newcomer Johnson, T.A., Mayer, P.M., Belt, K.T. and Pennino, M.J. 2015. Urban Evolution: The Role of Water. Water. 7:4063-4087. doi: 10.3390/w7084063.

McDowell, W.H. 2015. NEON and STREON: opportunities and challenges for the aquatic sciences. Freshwater Science. 34:386-391. DOI: 10.1086/679489.

Rodriguez-Cardona, B. 2015. Nitrate uptake kinetics in streams: Is carbon the driver? M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 67 pages.

Rodriguez-Cardona, B., Wymore, A.S. and McDowell, W.H. 2016. DOC:NO_3 ratios and NO_3 uptake in forested headwater streams. Journal of Geophysical Research: Biogeosciences. 121(1):205-217. doi:10.1002/2015JG003146.

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Conference Proceedings & Abstracts:

Appling, A., Leon, M. and McDowell, W.H. 2015. Optimizing watershed flux estimates: the R package 'loadflex'. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Contosta, A., A.C. Adolph, D. Burchsted, M. Green, W.H. McDowell, and the New Hampshire EPSCoR Ecosystems & Society Sensor Team. The Vernal Window Flow Path: a Cascade of Ecological Transitions Delineated at Scales from Points to Pixels. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

Koenig, L., L.E. Snyder, W.H. McDowell and C.W. Hunt. 2015. The contribution of aquatic metabolism to CO_2 emissions from New Hampshire streams. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

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McDowell, W.H., Potter, J, Snyder, L, Daley, M., Appling, A., Koenig, L, Rodriguez-Cardona, B., Wymore, A. and Brereton, R. 2015. Using a sensor network to understand drivers of nutrient and organic matter concentrations at multiple spatial and temporal scales. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Potter, J, McDowell, W.H. and Snyder, L. 2015. Patterns and drivers of specific conductance in New Hampshire rivers. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Rodriguez-Cardona, B. and McDowell, W.H. 2015. Influences of DOC on nitrate uptake in suburban streams. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

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Schade, J.D., J. Bailio, and W.H. McDowell. Nitrate loading and CH_4 and N_2O Flux from headwater streams. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

Shattuck, M.D. 2016. Non-Point Nitrogen Sources and Transport in the Great Bay Watershed. NH Water and Watershed Conference. Plymouth, NH. March 18, 2016.

Snyder, L. 2015. NH EPSCoR Intensive Aquatic Sensor Network. Joint NEAEB/NH Water & Watershed Conference: Partnerships for Environmental Progress. Bartlett, NH. March 19, 2015.

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Zeglin, L., Cooper, S, Utz, R., Ardon-Sayao, M., Bixby, R., Burdett, A., Dodds, W., Griffiths, N.A., Harms, T., Johnson, L., Johnson, S., Jones, J., Kominoski, J., McDowell, W.H., Rosemond, A.D., Trentman, M., Follstad Shah, J., Van Horn, D. and Ward, A. 2015. Synthesis of stream ecosystem responses to nutrient enrichment at multiple trophic levels. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Presentations/Information Transfer

Coble, A., Shattuck, M.D., Potter, J.D., McDowell, W.H. 2016. Concentration discharge relationships and long-term trends of solute fluxes vary among flood periods. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Koenig, L. 2015. Served as the instructor for the STEM mini-course offered August 24-28th through the CONNECT program at UNH (http://www.unh.edu/connect/). The objective of the course is to provide an opportunity for incoming freshmen that come from groups with historically low retention in STEM majors (e.g. low-income, multicultural, first-generation college students) to build community, discover college resources, and bolster skills that are needed to succeed in their academic programs (e.g. writing of lab/research reports, basic math and statistics for analyzing scientific data). There were 7 students in the class, but the broader CONNECT program serves approximately 100 students.

- Students learned about best management practices (BMPs) and discussed how these engineering solutions may help mitigate local nutrient pollution and eutrophication in Great Bay, NH. They measured nitrogen and phosphorus concentrations in stormwater collected at the inflow and outflow of two different stormwater management structures operated by the UNH Stormwater Center (http://www.unh.edu/unhsc/). The students found that the BMPs surrounding the UNH campus were effective in reducing nutrient concentrations in stormwater, and presented these results to the entire CONNECT program at the end of the week.

Koenig, L., L.E. Snyder, C.W. Hunt, and W.H. McDowell. 2016. The contribution of aquatic metabolism to CO_2 emissions from New Hampshire streams. Annual

Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Shattuck, M.D. 2015. Led field trip for undergraduate and graduate students to sites in the Lamprey River Hydrologic Observatory. September 22, 2015.

Shattuck, M.D. 2015. Water Quality Research in the Lamprey River Hydrologic Observatory. Presentation to University of New Hampshire undergraduate class: Studio Soils. October 28, 2015.

Shattuck, M.D. 2015. Urbanization and suburbanization in New Hampshire watersheds. Presentation to University of New Hampshire class: Watershed Water Quality Management. October 6, 2015.

Shattuck, M.D. 2015. Understanding Water Quality Impacts of Farm Practices in Groundwater and Stream Water. Research field day at the University of New Hampshire Organic Dairy Research Farm. Lee, NH. November 4, 2015.

Shattuck, M.D. 2015. Watershed management in practice: Great Bay. Presentation to University of New Hampshire class: Watershed Water Quality Management. December 1, 2015.

Shattuck, M.D., Potter, J., Snyder, L. and McDowell, W.H. 2016. Hydrologic controls on nitrate and specific conductivity in NH streams: New insights using sensor data. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Wymore, A., Rodriguez-Cardona, B. and McDowell, W.H. 2016. Direct response of dissolved organic nitrogen to nitrate (NO3-) availability in headwater streams. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Press Releases

Daley, M.L. 2015. Understanding Nitrogen Sources in the Great Bay Watershed. Great Bay Matters. Spring/Summer 2015. http://greatbay.org/documents/gbmspring2015.pdf

Green Mountain Conservation Group meetings, workshops and presentations supported by matching funds

2015

- Thursday, March 26, 6-8pm “What goes up must come down” a moderated forum to celebrate World Water Day, Runnells Hall, Chocorua.
- Saturday April 11 4-8 pm GMCG ANNUAL MEETING—”Raptor Encounter” Sunny Villa Restaurant, Route 16 Ossipee.
- Thursday May 12th 6 pm—Natural Resource Planning—Healthy Septic Systems, Runnells Hall, Chocorua.
- Saturday June 6—Community Kick-off meeting for the “Big Lake” phase of Ossipee Watershed Management Planning Process!
- Thursday June 18, 2-6pm “Bikers for Clean Water”, Windows to the Ossipees overlook Route 16, Ossipee.
- Saturday July 18, 3-6pm Heron House Conservation Center Groundbreaking Ceremony 196 Huntress Bridge Road, Effingham.
- Saturday August 15 4-7:30pm Annual Fundraiser Dinner and Auction, Province Lake Golf Club. Thursday August 20, 5 pm Volunteer Celebration 196 Huntress Bridge Road, Effingham.
- Saturday August 22, (rain date: Sunday August 23) Explore Green Mountain with Society for the Protection of New Hampshire Forests. Afternoon hike via High Watch Trail to summit of Green Mountain. Meet at High Watch Road. Please register to receive directions and details at 539-1859.
- Sunday September 20, 3-7pm Fall Music Festival “Loons, Tunes and Spoons”, Freedom.
- Thursday October 29, 6:30-8 pm BAT CHAT—What’s Up With Bats in New Hampshire?
- Thursday December 3 6-8 pm Youth Water Quality presentation, Ossipee Town Hall

2016

- Wednesday January 13, 4:00pm - Education Steering Committee meeting to help create Water Literacy Curriculum.
- Tuesday, January 19th 4:00pm Watershed Management Plan Phase 2– Ossipee Lake and the Lovell River Watershed Steering Committee Meeting at Indian Mound Golf Club in Ossipee
- Saturday February 6, 10:30am-1:00pm Family Winter Animal Tracking with naturalist Barb Bald!
- Saturday February 27 GMCG 18th ANNUAL MEETING with Project Coyote presenter Chris Schadler

Natural dams and biogeochemistry at the river network scale: implications for water quality

Basic Information

Title:	Natural dams and biogeochemistry at the river network scale: implications for water quality
Project Number:	2014NH183B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	NH-002
Research Category:	Water Quality
Focus Category:	Geomorphological Processes, Wetlands, Nitrate Contamination
Descriptors:	None
Principal Investigators:	Denise Burchsted, Christopher Brehme, Mark B. Green, Jennifer Jacobs, Wil Wollheim

Publications

There are no publications.

Problem Statement

In the absence of modern humans, river networks are patchy systems, where free-flowing reaches are interspersed with ponds and meadows generated by “natural” dams. In New England, most of these dams are beaver dams, which create ponds and meadows that can extend over more than half of the length of a headwater stream network. Additional natural dams that would have been common prior to the modern industrial age include bedrock knobs (which were blasted away for the sake of log drives), major log jams, and landslide dams. Despite this patchy nature of river systems, our conception of the pre-industrial river network is typically that of a system that is free-flowing and connected, and this assumption lies at the foundation of our infrastructure development and scientific models. As a result, when natural dams appear in a river network, both our infrastructure and scientific models tend to fail.

The impacts of natural dams on biogeochemical processing have dramatic implications for water quality. Intensive site studies show that the impoundments created by these dams tend to have higher temperatures, lower oxygen levels, higher concentrations of available nutrients, and larger pools of nutrients and organic matter. Although these characteristics are commonly viewed as undesirable for water quality, the opposite can often be the case. In particular, site studies show that, in enriched systems, these impoundments can remove significant amounts of nitrogen through denitrification. They also can provide sites of locally increased acid neutralizing capacity. However, nearly all of the knowledge of the impacts of natural dams is based on single site studies, with unknown implications for the river network scale. Given both the significant site-scale impact of single natural dams on biogeochemistry and the high frequency of natural dams in river networks without direct human intervention, we must understand the role of these dams on biogeochemical processes at the river network scale

Objectives

This research addresses the broad research question of: What is the difference in biogeochemical regime between free-flowing river reaches and river reaches associated with natural dams, and what is the extent of this difference at the river network scale? The three specific research questions addressed by this research are: (Q1) Can free-flowing river reaches and river reaches associated with natural dams be classified according to biogeochemical regime? (Q2) What is the nature of the transition in biogeochemical regime downstream of a natural dam? (Q3) Which landscape and demographic factors control their presence and frequency of natural dams? To address these questions, the research includes both of the following: measurement of site-scale biogeochemistry parameters along river networks that include free-flowing reaches and natural dams; and examination of the landscape-scale parameters that control the presence of natural dams.

Methods

The methods include field work and GIS, primarily in river networks in the Ashuelot and Contoocook basins of southwestern New Hampshire. The river networks in these basins range from entirely protected from modern human impact through highly managed urban streams.

Field research: Research questions 1 and 2 have been addressed with spatially and temporally extensive field data. The spatially extensive dataset was created using synoptic stream surveys along 138 river reaches in the summers of 2014 and 2015. The limits of the study reaches were defined by geomorphic features such as natural dams and the limits of the impoundments created by these dams. Field measurements in the study reaches include temperature, dissolved oxygen (DO), conductivity, pH, and oxidation-reduction potential (ORP) using an YSI Professional Plus multimeter. Channel cross-sectional shape and heights and widths of dams have also been surveyed with a laser distance meter and stadia rod.

Ten HOBO data logger arrays are collecting water level, temperature and conductivity at 15-minute (or shorter) intervals at three beaver ponds and one beaver meadow. The data logger arrays are upstream, downstream, and within each impoundment. An additional 27 temperature loggers are installed at an additional six ponds and meadows. These data are being used to both characterize biogeochemical state in the impoundments of natural dams versus free-flowing reaches and to assess the extent of downstream impact on biogeochemical state caused by these natural dam impoundments. Analysis of the hobo data has focused on temperatures as a proxy of ecosystem state.

GIS: Research question 3 has been examined for much of the Contoocook river network, in southwestern New Hampshire. For have been visually digitized and classified as one of the following patch types: (1) closed canopy; (2) beaver pond; (3) beaver meadow; (4) pond at a human-built dam; (5) meadow at a human-built dam; (6) human-managed floodplain (ditched); (7) unmanaged floodplain (many natural dams); and (8) renaturalizing human-created impoundment. The classifications were ground-truthed during the 2014 summer field season. These impoundments were overlaid onto a network for the study area extracted from the National Hydrography Dataset (NHD). A new river network of the study area was generated, where each segment of the extracted NHD network was assigned a patch type corresponding to the relevant digitized impoundment or, if there was no digitized impoundment that overlapped the network, the patch type was set as free-flowing.

We calculated a simple heterogeneity index (HI) for the new river network, where the HI at any given point is a simple count of the number of patch types along a reach that extends 500m upstream and 500m downstream of the each point. An alternative HI is the sum of the number of distinct patches, where a given patch type may be repeated. The HI was calculated every 25m along the digitized river network.

The landscape controls on patch type and HI are currently being assessed for the study network. The channel slope is calculated for each point on the digitized river network as the slope for the 250m reach extending upstream from the point. Elevations for slope calculations are extracted from the most recent DEM in the National Elevation Dataset. Relative stream power will be estimated as catchment area times channel gradient. The 2001 NH land cover assessment has been used to estimate percent forest, percent hardwood, and percent developed and agricultural land within a buffer for each reach. New Hampshire DOT GIS data have been used to estimate density of roads within a buffer along each reach, and the number of river crossings. When this dataset is complete, it will be used to determine the relationship between these physical parameters versus patch type and HI.

Findings

Field research – simple chemistry. The data from the synoptic sampling show a clear and distinct relationship between low oxygen and beaver meadows and ponds, with dissolved oxygen (DO) levels responding quickly as water flows into or out of a pond (Figure 1, next page). Examination of the high-temporal resolution data provides a more complex understanding (Figure 2, next page). Although these data generally support the simple message of lower oxygen levels in impoundments, they also show that the diurnal oxygen fluctuations are far greater within the impoundments, presumably due to increased photosynthesis and respiration generated by additional light. Further, the increased photosynthesis can even result in maximum oxygen levels in the impoundments that occasionally exceed the maximum in the free-flowing rivers. These fluctuations over space and time have obvious potential implications for biogeochemical cycling and water quality Continued research on a concurrent project involves lab analysis of collected water samples to assess the corresponding concentrations of common nitrogen species. Given the importance of oxygen in controlling biogeochemical reactions, particularly in the nitrogen cycle, these data strongly describe the importance of further understanding and assessing the network-scale role of beaver dams in water quality.

The pH data from the impoundments created by natural dams also show a similar trend of a clear, local impact, which is not necessarily transferred downstream (Figure 3, next page). These data show that the surveyed beaver ponds, as a population, have a lower pH than the free-flowing reaches; however, unlike the dissolved oxygen data, the longitudinal profiles show a more complex story at the local level (Figure 4, following page). There is a less clear trend in pH across the different patch types, with both increasing and decreasing trends found in meadows and free-flowing reaches. Log jams, on the other hand, show a much clearer trend of decreasing pH within the local impoundment (Figure 3). These log jam impoundments are usually less than 5m in length (in the direction of flow). When a given log jam impoundment is paired with its corresponding upstream and downstream reaches, the local pH is statistically lower, with an average decrease of 0.3. Unlike beaver dam impoundments, the changes in oxidative-reduction potential across the log jams are not statistically significant.

In combination, these data suggest that the small natural dams results in local changes in water chemistry—such as decreased pH, presumably due to increased organic acids—but not in larger changes in biogeochemical regime, which alterations of dissolved oxygen would generate. Further, these changes are only local in nature and the biogeochemical regime quickly returns downstream.

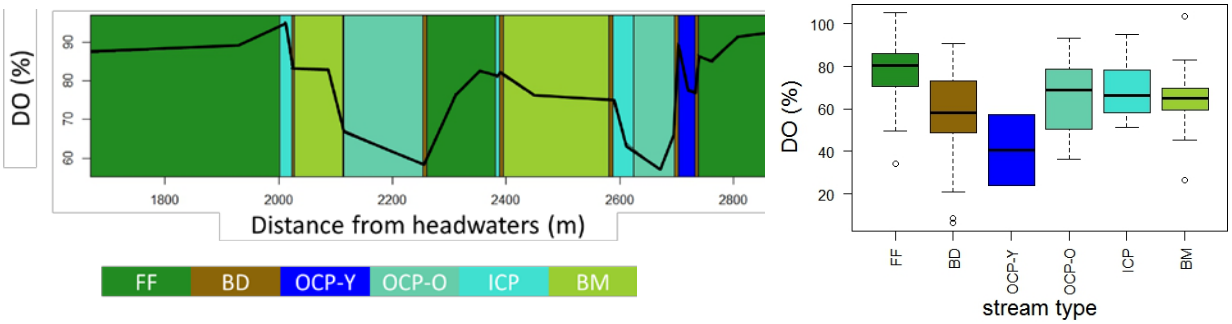

Figure 1. Left: example of dissolved oxygen profile along one study river (Hosley Brook, Hancock, NH). Right: comparison of DO across various feature types for all study reaches. Legend: FF—free-flowing; BD—beaver dam; OCP-Y—out of channel beaver pond, young; OCP-O—out of channel beaver pond, old; ICP—in-channel beaver pond; BM—beaver meadow.

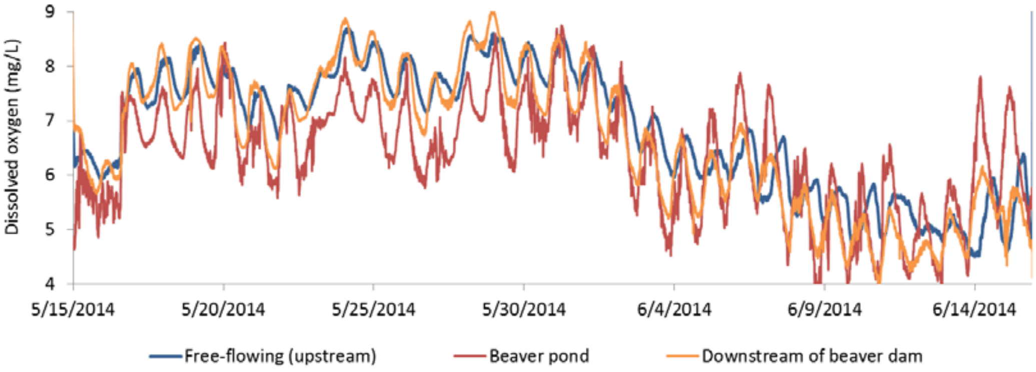

Figure 2. Dissolved oxygen concentrations over time (Hosley Brook, Hancock, NH).

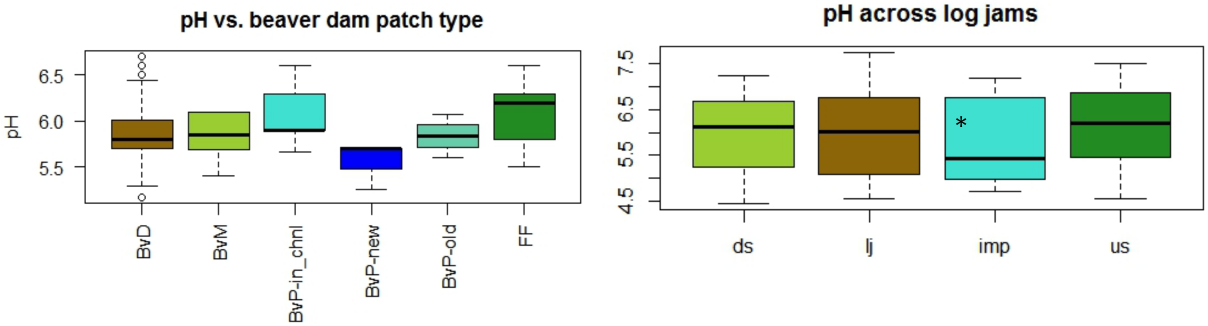

Figure 3. Left: Instream pH varies significantly across patch type associated with beaver dams (anova F=9.7, p<0.001).Legend: BvD—beaver dam; BvM—beaver meadow; BvP—beaver pond (can be young, old, or in-channel); FF—free-flowing. Right: Instream pH from downstream of log jams (ds), within log jams (lj), in the impounded water upstream of the log jam (imp), and in the free-flowing reach upstream of the log jam (us). pH was measured within each of these patches at each geomorphically significant log jam encountered.

* - significantly different from the upstream reach (paired t-test, p<0.05, mean difference = 0.36).

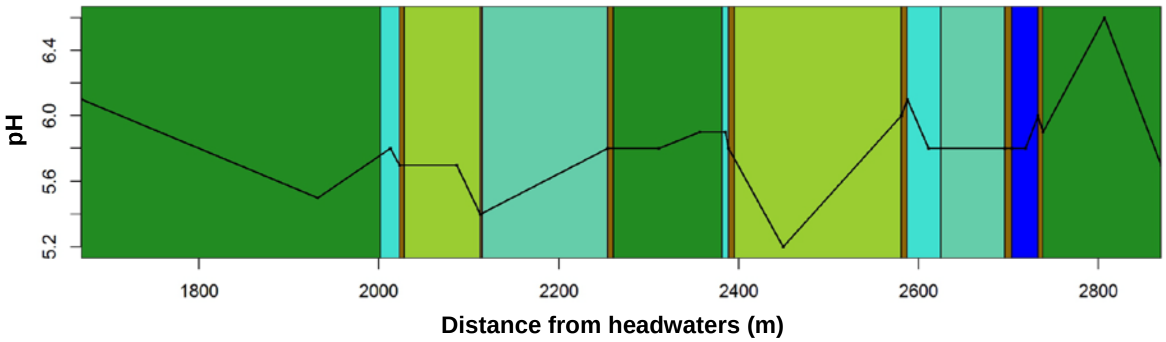

Figure 4. Example of a pH profile (Hosley Brook, Hancock, NH). FF—free-flowing; BD—beaver dam; OCP-Y—out of channel beaver pond, young; OCP-O—out of channel beaver pond, old; ICP—in-channel beaver pond; BM—beaver meadow.

In contrast to smaller log jams, the larger beaver dams create such significant changes—with accumulation of so much organic matter that decomposition drives the oxygen levels toward hypoxia or even anoxia—that the result is tremendous shifting in biogeochemical regimes, resulting in more complexity and less predictability with other measures such as pH. Further, although the impacts on dissolved oxygen are local and not transferred downstream, the resulting increased complexity of biogeochemistry is transferred downstream, as reflected in the fluctuations of pH.

Field research – temperature. The collected temperature data, which includes 15-minute data from 27 sensors, improve both the spatial and temporal extent of the data. Although temperature exerts less control on ecosystem state than a parameter such as oxygen, it is nonetheless a beneficial parameter because: heat is a useful tracer of water flow; incorporation of temperature allows for much greater spatial extent due to being much more affordable; it is a critical component of ecosystem state even if it is not the primary control.

The findings from the collected temperature data provide a more detailed description of the variability of ecosystem state in a river network that includes natural dams. This variability is most evident during the winter and summer, and less visible during the transitions of spring and fall (Figure 5, top, and Figure 6, top). In particular, during the winter, beaver ponds may be slightly warmer or colder than corresponding free-flowing reaches (Figure 5, top, and Figure 6, bottom left). In the summer, beaver ponds are generally warmer than free-flowing reaches; however, the beaver meadow group was somewhat cooler, and the one new beaver pond that was monitored was remarkably cooler (Figure 5, top, and Figure 6, bottom right). In addition to creating a wider range of variability across the river network, the beaver ponds and meadows also have a wider range of variability within each patch (Figure 5, bottom).

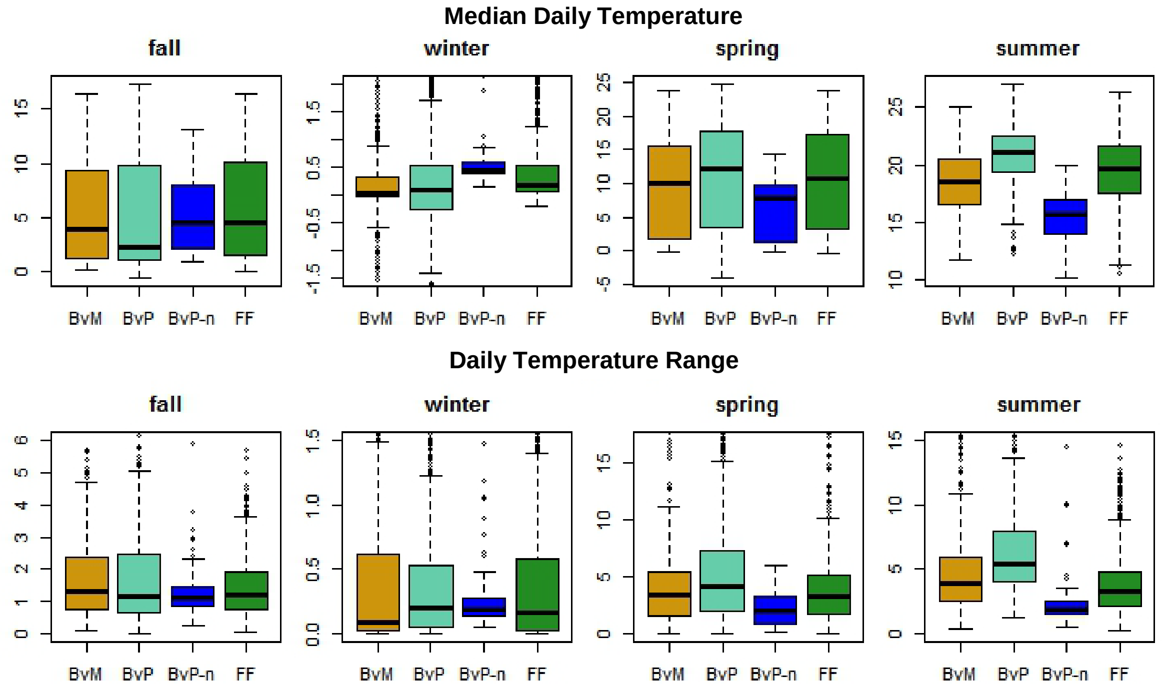

Figure 5. Maximum daily temperatures and daily temperature range (both in degrees C) across all patch types. See Figure 3 for abbreviations. Number of study sites (each with daily observations): BvM—6; BvP—8; BvP-n—1; FF—12.

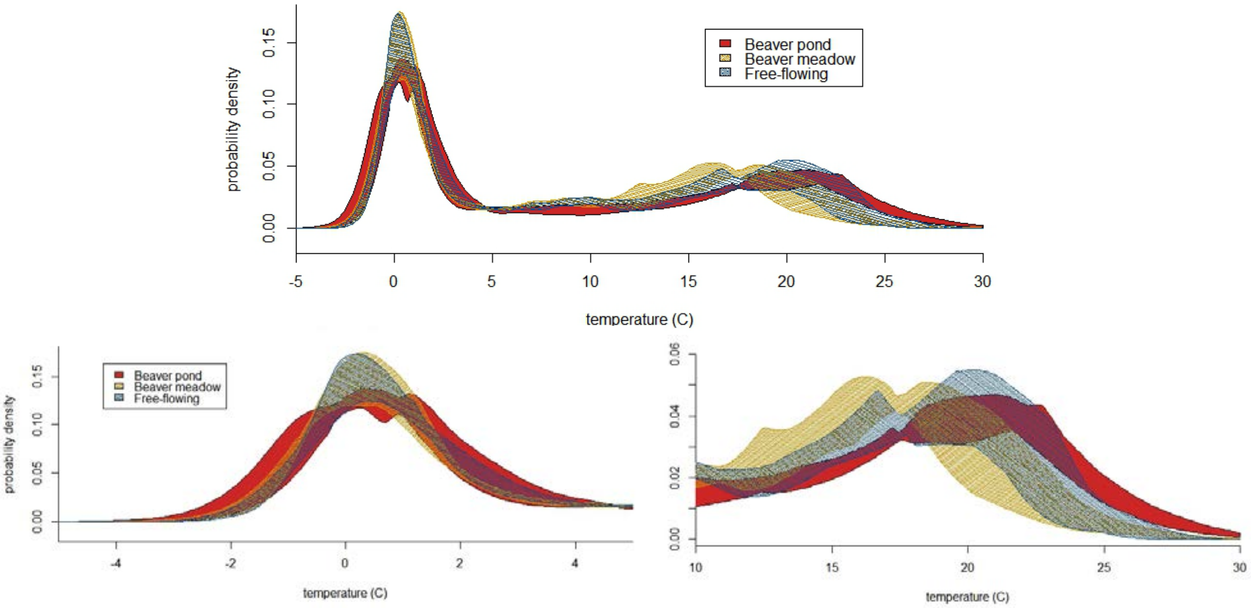

Figure 6. <u>Top</u>—probability distribution function (pdf) of temperature for each patch type. These were generated by first determining the pdf for the water year for each station. These were combined for each patch by determining the 25% and 75% exceedance of the probability density across the range of temperatures. <u>Bottom</u>—close-up views of the pdfs at low and high temperatures.

GIS: The GIS component of the research documented the extent of beaver ponds and meadows within the study landscape. A surprising finding as part of the GIS research is the occurrence of "naturalizing" river reaches that were once impounded by humans, where the impoundment has filled in with sediment and beavers have moved in to create small ponds within the human-created wet meadow. The GIS research has produced a complete data layer (see Figure 7) that has been created as a linearly referenced network.

The data layer shown in Figure 7 was used to calculate the relative representation of each patch type in the river network, as shown in Table 1. As Table 1 shows, up to 25% of the length of the river network is comprised of patches created by natural dams, which is particularly important in the headwaters. Human-created dams claim up to, and even more than half, of the river network length, and are particularly prevalent in the higher order watercourses. This analysis does not show the high frequency and extent of beaver ponds and meadows at the higher orders, because these features are embedded within the floodplains, which were mapped as larger "natural" features.

Table 1. Percentage of the study river network length comprised of patch types associated with natural dams and human-created dams.

Stream order	Beaver	Human	Other "natural"
1	11%	12%	77%
2	18%	17%	65%
3	26%	20%	54%
4	11%	44%	45%
5	12%	29%	60%
6	2%	49%	49%
7	0%	55%	45%

Note: "Beaver" = representation of beaver ponds and meadows along the river network; "Human" = representation of human-created ponds, meadows that have developed in human-created impoundments, and ditched floodplains; "Other natural" = free-flowing rivers, ponds with other natural genesis, and natural floodplains. Note that most natural floodplains also include extensive beaver activity and many small beaver ponds and meadows that were not captured by this study.

Analysis of the heterogeneity index versus the patch types shows a clear trend of increased heterogeneity at the beaver pond and meadow patch types versus the free-flowing reaches (Figure 8). There are two different heterogeneity indices: both describe the spatial heterogeneity around a given point. One index calculates the number of different distinct patches located 500ft upstream and downstream of an analysis point (Figure 8, left), and the second index calculates the number of patch types in the same distance (Figure 8, right). In both cases, the free-flowing patches in the river network are located in areas of less spatial heterogeneity, as are the impoundments associated with human-created dams. As the impoundments created by humans become more naturalized (see Figure 8 for the transitions from HmP to HmM to NHmP), they are also more likely to be set within increased spatial heterogeneity.

<u>*Summary:*</u> Natural dams are ubiquitous and their impoundments can occupy a significant percentage of the length of the study network. Without direct human intervention, these dams create a spatially heterogeneous network, with fluctuating patch types that exhibit distinct biogeochemical characteristics. Without human intervention, the river will shift from one state to the next as water moves downstream. In the case of the larger natural dams, the impact of the altered biogeochemical regime can extend downstream. Further, natural dams also increase the temporal heterogeneity within a given site. All of these alterations leads to a continued need to assess the impacts of these different states on water quality.

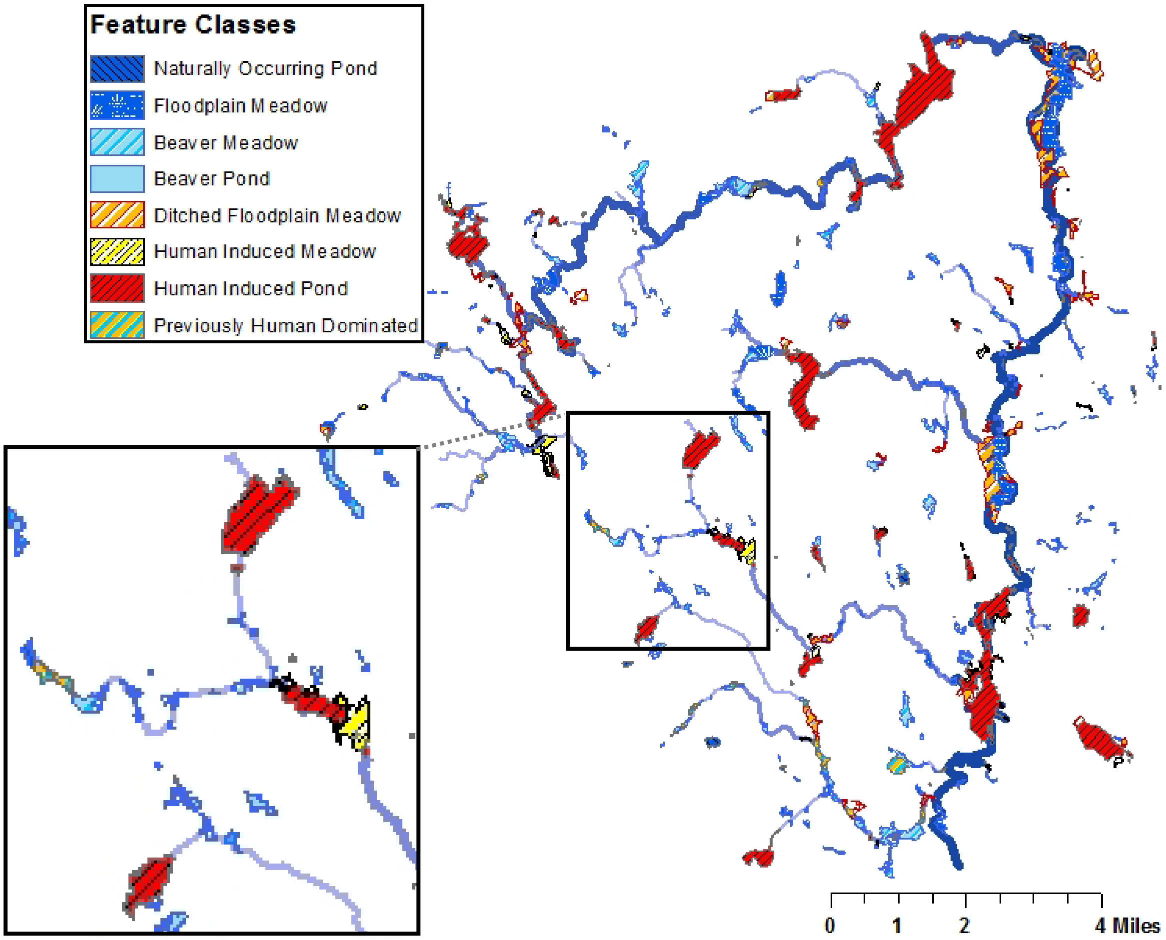

Figure 7. Impoundments along the river network for the Contoocook River, southwestern New Hampshire, digitized in Year 1 of this study. Inset shows typical detail. These digitized data will be used as the foundation for calculations of river network heterogeneity, of correlation between heterogeneity and land use, and for a predictive model of natural dam location.

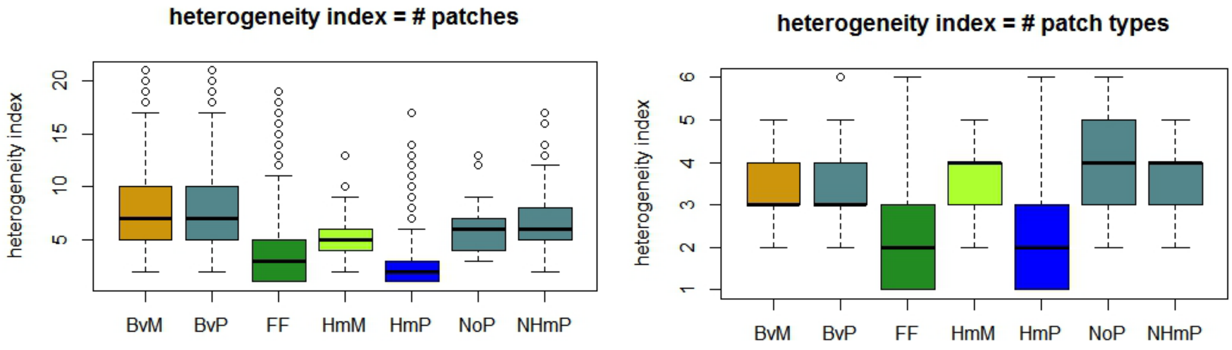

Figure 8. Spatial heterogeneity versus patch type. Left: heterogeneity is defined as the number of distinct patches within 1000' of a given point. Right: heterogeneity is the number of patch types within 1000'. Legend: BvM—beaver meadow; BvP—beaver pond; FF—free-flowing; HmM—meadow forming in human-created impoundment; HmP—human-created pond; NoP—naturally-occurring pond; NHmP—naturalizing area, previously HmP

Publications and presentations

Presentations at professional society meetings

Burchsted D. March 24, 2016. Stream temperature demonstrates that rivers are patchy systems. New England Association of Environmental Biologists. Rockport, ME.

Brehme, Christopher; Stoll, Charles*; Burchsted, Denise, 2014, *Using photo interpretation and linear referencing to quantify stream heterogeneity*, NESTVAL 2014: Water in a Changing World, New England-St. Lawrence Valley Geographical Society, Durham, NH.

Brehme, Christopher; Stoll, Charles*, 2014, *A classification and analysis of river channel conditions using aerial photos and network analysis*, American Association of Geographers Annual Meeting, Paper session 3567—Remote Sensing Applications for Characterizing Wetlands, Chicago, IL.

** - undergraduate student*

Presentations at local scientific meetings

Burchsted D. 2015. Heterogeneity of instream temperature. Hubbard Brook annual cooperator's meeting. Woodstock, NH.

Burchsted, Denise, 2015, *Natural dams and river network heterogeneity*. NH EPSCoR Ecosystems & Society All Hands Meeting, Durham, NH.

Burchsted, Denise. 2014. *Natural dams: Fluvial geomorphology and biogeochemistry,* Hubbard Brook Experimental Forest Cooperator's Meeting, Woodstock, NH.

Burchsted, Denise. 2014. *Patchy rivers: Implications for ecosystem function and services,* NH EPSCoR Ecosystems & Society All Hands Meeting, Concord, NH.

Stoll, Charles*; Brehme, Christopher; Burchsted, Denise, 2014, *Classifying riverine heterogeneity using photo interpretation*, NH EPSCoR Ecosystems & Society All Hands Meeting, Concord, NH.

Dallesander, Joshua*; Thorndike, Olivia*; St. Pierre, Lindsay; Burchsted, Denise. 2014. *Characterizing biogeochemical regime in river networks.* Council of Public Liberal Arts Colleges, Northeast Regional Undergraduate Research Conference.

** - undergraduate student*

Outreach or Information Transferred

Training sessions: Seminars

Burchsted, Denise, July 12, 2014, *Beaver dams as "natural dams" and the river dis-continuum*, Lake Nubanusit Watershed Association, Hancock, NH.

Burchsted, Denise, October 16, 2014, *Beavers: Nuisance species or ecosystem engineers?* Harris Center for Conservation Education Speaker Series, Hancock, NH.

Students

Joshua Dallesander, BS 2015, Environmental Studies, Keene State College

Michael McGuinness, BA 2015, Biology, Keene State College

Lindsay St. Pierre, PhD in progress, Environmental Science, Antioch University New England

Charles Stoll, BA 2015, Geography, Keene State College (first-generation student)

Olivia Thorndike, BS in progress, Environmental Studies, Keene State College

Faculty

Christopher Brehme, Associate Professor, Keene State College

Denise Burchsted, Assistant Professor, Keene State College

Special Story

Charles Stoll, one of the students supported through this research, is a first-generation student who worked for the first ten years of his adult life as a plumber. He is largely responsible for the GIS conducted as part of this research, and has presented his work at three meetings: locally (NH EPSCoR), regionally (NESTVAL), and nationally (AAG). Charles received his BA in May 2015 and is continuing to work on this research project this summer. We anticipate that, by the end of the summer of 2016, Charles will submit an undergraduate first-author manuscript for review for publication in *Northeastern Geographer*.

The attached Keene State news story provides some highlights regarding Charles' decision to restart his career as a student. The research mentioned in the news article is complementary summer research funded under a different grant. His work on the WRRC research was conducted primarily in the academic year.

From Plumber to Geography Major, Charles Stoll Finds Himself. Here.

October 1, 2014

Charles Stoll gathers data logger downloads for Prof. Burchsted's EPSCoR research project. (Photo by Mark Reynolds)

After spending 10 grueling years as a plumber and suffering three fairly significant injuries, **Charles Stoll** decided he needed a change of direction—something a little more rewarding and less physically taxing. So he enrolled at Keene State, thinking he'd pursue a career in engineering or business management.

But, even for a non-traditional student with his feet well planted beneath him, the opportunities and avenues for exploration that KSC laid before him let Stoll discover an even more engaging path. "After taking a few ISP courses throughout my first two semesters, I decided that I was more lent to the sciences and figured that was the direction I needed to follow," he explained. He found himself especially drawn to his Does the Earth Have a Fever? Integrative Quantitative Literacy (IQL) course, an entry-level earth systems science course, and Introduction to Geography.

It was in that geography course that Stoll found his predilection. "I was motivated to pursue a bachelors in geography because I feel as though I can relate to that spatial mindset," he recalled. "Geography is a spatial science, and given my previous occupation, I tend to think about things more analytically I think—processes and patterns, relationships and positioning. I also really enjoy history, and the cultural and/or sociopolitical aspects of geography help to satisfy those curiosities. It helps that I am also an anthropology minor, because learning about and developing an understanding of the human relationship with the environment is a story I have become more and more fascinated with."

Along with his geography major, Stoll is pursuing GIS certification. GIS (geographic information system) is a computer system designed to capture, store, manipulate, analyze, manage, and present spatial or geographical data. In the spring semester of 2014, he got an opportunity to put his science aptitude and geography skills to work when he began working with Assistant Professor of Environmental Studies **Denise Burchsted** on her EPSCoR research project on natural dams. "She enlisted me to analyze aerial photography of southwestern New Hampshire and to begin classifying watersheds for land cover, specifically for ponds and meadows caused by natural dams like those created by beavers, and for similar, though less natural, ponds and meadow systems created by humans," Stoll said.

That work led to a summer internship that saw Stoll in the field collecting data for the project. "I have to say it has been a truly awesome experience, and I feel very fortunate to have been involved with it. I have been learning about how river systems function, and what some of the influences on river characteristics are," he said.

Though Stoll hasn't decided exactly where he wants to go with his new career path, he's confident with the many options his education has opened for him. "I do feel as though the education that I have been receiving through KSC has more than fully prepared me for anywhere I choose," he said.

Contribution of fluvial wetlands to nitrogen retention in urbanizing coastal watersheds in New England across multiple scales

Basic Information

Title:	Contribution of fluvial wetlands to nitrogen retention in urbanizing coastal watersheds in New England across multiple scales
Project Number:	2014NH185B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	NH 1st
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Hydrology, Wetlands
Descriptors:	None
Principal Investigators:	Anne Lightbody, Linda Kalnejais, Wil Wollheim

Publications

1. Rosengarten, D. 2014. Spatial and temporal variability of nitrate cycling in a New England headwater wetland and stream. Department of Earth Sciences, College of Engineering and Physical Sciences, University of New Hampshire, Durham, NH, 184 pages.
2. Wilderotter, S. 2015. Parameterization of transient storage and nutrient retention in coastal New England wetlands. Department of Earth Sciences, College of Engineering and Physical Sciences, University of New Hampshire, Durham, NH, 235 pages.

NH WRRC Annual Report, 2016
Project title: Contribution of fluvial wetlands to nitrogen retention in urbanizing coastal watersheds in New England across multiple scales
PIs: Anne Lightbody, Linda Kalnejais, & Wil Wollheim

Problem

Surface water quality in rapidly urbanizing coastal watersheds in New England is at risk due to excess anthropogenic nutrient inputs, which threaten downstream water uses and could lead to fluvial and estuarine eutrophication (Bricker et al. 1999, Caraco and Cole 2003). Fluvial wetlands, which are biologically reactive and have long residence times (Vidon and Hill 2001), can remove excess nitrate, thus providing an important ecosystem service (Wollheim et al. 2005, Rabalais et al. 2009). Flow-through wetlands consist of an advective main channel, plus slow-flowing off-channel areas collectively termed “transient storage.” Wetlands with higher lateral connectivity between the main stream channel and transient storage are especially important because they may retain more nitrate than wetlands that receive little direct stream discharge (Racchetti et al. 2011). However, wetland connectivity and reactivity is still poorly understood, thus limiting our ability to predict the impact of future changes in land use and climate change on watershed retention of nitrogen inputs.

Project Objectives

1) Determine contribution of wetland-dominated stream reaches to surface transient storage as a function of inundation and season
2) Quantify nitrate uptake rates among different types of surface transient storage as a function of season.
3) Scale biogeochemical and hydrologic insights to wetland-dominated reaches throughout New England
4) Share results with local and regional policy makers

Methods

This project focused on eight wetland-dominated reaches (Figure 1) in four different watersheds in coastal New Hampshire and Massachusetts, with preference given to wetlands that

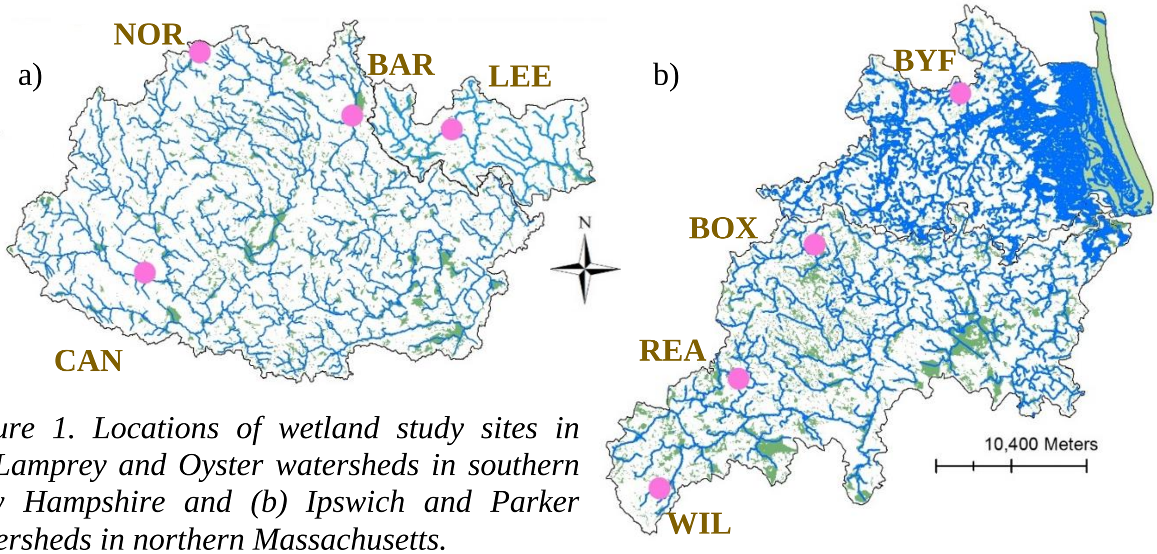

Figure 1. Locations of wetland study sites in (a) Lamprey and Oyster watersheds in southern New Hampshire and (b) Ipswich and Parker watersheds in northern Massachusetts.

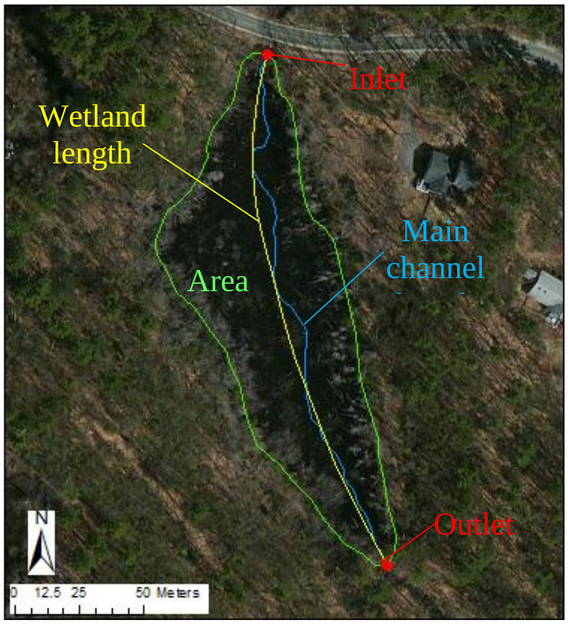

Figure 2. Aerial photograph of wetland site BOX in Boxford, MA, showing delineated geometrical parameters. Flow is from north to south; tracer was released at the wetland inlet and recorded exiting the wetland at the outlet.

have one channelized stream inlet and one channelized stream outlet. The eight wetlands used in this study are of varying sizes and shapes. Wetland geometrical characteristics were calculated from delineation of aerial photography (Figure 2) for all eight study wetlands plus a randomly chosen subset of 50 wetlands in the neighboring Charles, Concord, Merrimack, and Piscataqua-Salmon watersheds. Watershed area was delineated Light Detection and Ranging (LiDAR) digital elevation models. Wetland area and main wetland channel length were delineated from aerial photography based on vegetation differences. National Wetland Inventory (NWI) datasets were used to obtain another measurement of wetland area. Specifically, all NWI polygons that shared a boundary with the target wetland were combined to create one large polygon. Wetland length was obtained by smoothing the main channel length. Average wetland width was then calculated from the wetland area divided by the length of the main channel. Width-to-length ratio was calculated as the wetland width divided by wetland length. Finally, sinuosity was measured as the length of the main channel divided by the smoothed length of the wetland. All geographical analyses were performed using ArcMap 10.1 Spatial Analyst Toolbox.

Wetland connectivity was measured with the use of whole-reach slug releases of the nontoxic fluorescent tracer dye rhodamine WT (RWT). Tracer releases were performed during 2014 and 2015 during baseflow conditions. Three of the eight sites were studied multiple times to examine seasonal changes in baseflow connectivity, resulting in 19 studies in total. During each study, rhodamine was released into the stream feeding the wetland, then measured *in-situ* at the

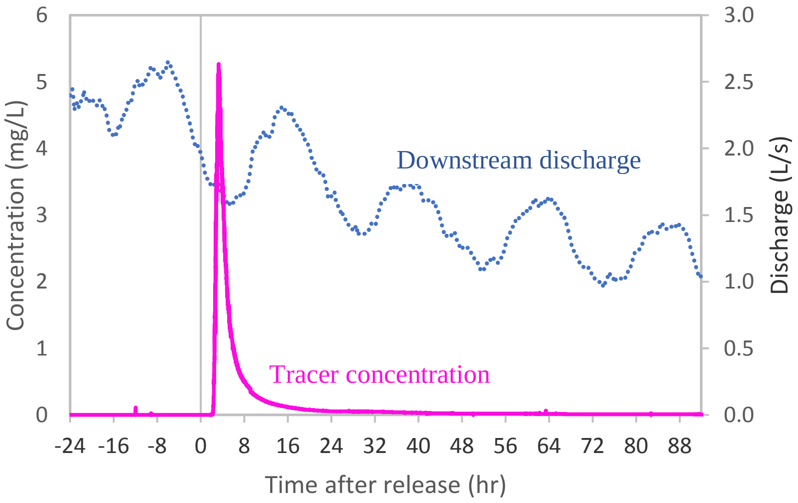

Figure 3. Continuous breakthrough curve of rhodamine WT (RWT) tracer concentration measured at the outlet of wetland study site BAR from June 18-23, 2014. The peak tracer concentration reached the outlet 3.5 hours after the release. Half of the dye exited by 9.7 hours. Discharge generally declined during the steady period.

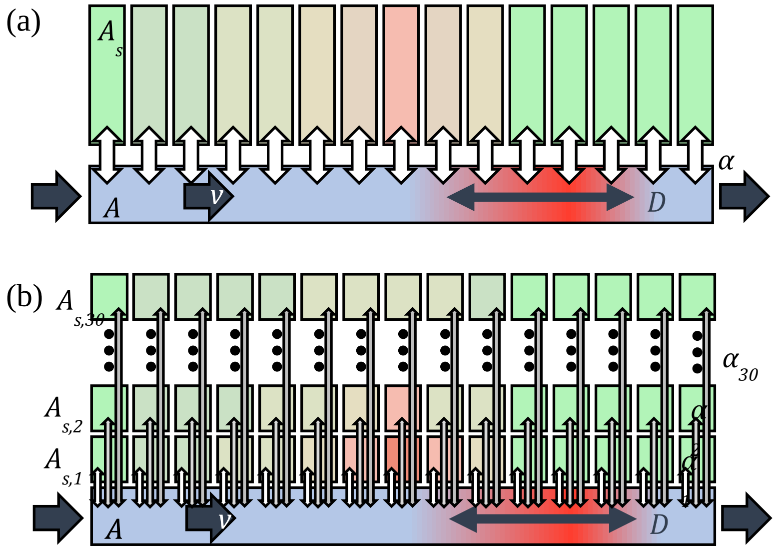

Figure 4. Conceptual model of the (a) single-zone and (b) multiple-zone model geometries used to parameterize transient storage connectivity α *and size* A_s*. Red color represents the conservative tracer added to the main channel, which advects and disperses in the main channel and is also transferred to and from the lateral transient storage zones.*

wetland11 outlet with a Turner C3 fluorometer set to record every 15, 30, or 60 seconds for at least 2 and typically 5 times the advective time scale of the wetland channel (Figure 3). Measured fluorescence at the wetland outlet was converted to excess rhodamine concentration using calibration curves and accounting for background fluorescence, instrument fouling, retardation, and photodegradation. Additionally, stage was measured at the inlet and outlet of each wetland at 12-15 minute intervals and converted to a continuous discharge record.

Tracer flux exiting the wetland was calculated by multiplying together tracer concentration and stream discharge (Figure 3). The mass of tracer recovered was calculated by integrating exit flux over time. The residence time distribution (RTD) of tracer in the wetland was calculated by dividing the exit flux by the mass recovered. The detention time (median travel time within the wetland) was calculated as the first moment of the RTD, and the variance was calculated as the second moment of the RTD. Because studies occurred during steady base-flow conditions, it was assumed that the movement of the introduced fluorescent tracer was representative of other dissolved substances (in particular, dissolved inorganic nitrogen) also moving through the wetland at the same time.

Transient storage characteristics at the reach scale were determined from inverse modeling of reach-scale tracer RTDs using the transient storage model STAMMT-L (Haggerty 2009). This approach conceptually divides the wetland into a main advective channel that exchanges water with stationary transient storage zones. The number of transient storage zones was specified in advance, and their size and connectivity were estimated by optimizing parameter values to obtain the best fit between the observed tracer RTD and a semi-analytical solution to the underlying partial differential transport equations. Different transient storage models were compared (Figure 4), including a single-zone model and multiple-zone models with 30 different zones (cf. Haggerty 2009); preliminary testing showed no difference in model parameter estimates for 30, 40, 50, or 60 zones.

Nitrate samples were collected at the inlet and the outlet of each wetland once during each tracer study. Samples were filtered in the field, placed on ice, then analyzed at the UNH Water Quality Analysis Laboratory using standard methods. Nitrate flux at the wetland inlet and outlet was calculated by multiplying concentration measurements by stream discharge. The change in nitrate flux from the inlet to the outlet provided an estimate of net reach-scale nitrate production or release.

Reach-scale nitrate uptake rate constants was estimated by combining the optimized transport parameters determined from the slug releases of rhodamine with the observed inlet and outlet fluxes of nitrate. Specifically, the models were re-implemented assuming steady discharge conditions and the measured inlet flux of nitrate. The nitrate uptake rate constant was increased until the steady modeled outlet concentration matched the measured outlet concentration. Two scenarios were considered to apportion uptake between the main channel and the storage zones. First, whole-wetland uptake rate constants were calculated assuming the same rate constant for both the channel and the storage. Second, maximum storage uptake rate constants were determined by assuming no uptake in the channel, which forced all the uptake to occur in the storage zones.

To determine the fate of nitrogen in different wetland compartments, *in-situ* nutrient addition experiments were undertaken at three study sites (BAR, BOX, and WIL) using benthic chambers that isolated a portion of the water column and substrate, including macrophytes. Chambers were deployed at each site in the wetland channel and two contrasting storage zones, with the goal of quantifying the magnitude and rate of nitrate uptake in different wetland riparian compartments. A disadvantage of chambers is that only a small portion of each environment is studied; to improve our spatial coverage, three chamber replicates were performed in each environment. Chamber experiments were performed during June and October 2015, to contrast net production/release of nutrients during growing and senescence periods (Stewart et al. 2011).

The chambers (Figure 5) were re-circulating, submerged, sealed from the atmosphere, open-bottom chambers, similar in design to those used by O’Brien et al. (2012). The chamber footprint was round with an area of 0.017 m^2; the depth of enclosed water in the chamber ranged from 10 to 25 cm. An innovation in chamber design was the use of 3-way valves on tubing that allowed remote sampling, preventing disturbance of the benthic sediment directly adjacent to the chamber. Following the method of O’Brien et al. (2012), the chamber experiments were run at midday for 3–5 hours. Oxygen, pH and temperature in the chamber were continuously monitored during the experiment to verify that conditions in the chamber remained stable (Figure 6a). Chambers were excluded from further analysis when measured dissolved oxygen concentration decreased below 1.3 mg/L.

During nutrient addition experiments, nitrate and bromide were injected into each chamber, and the concentration of both reactive nitrate and conservative bromide were monitored over time (Figure 6b). Bromide was used to allow the estimation of nitrate loss due to transport out of the chamber into the sediment. Samples were filtered in the field, placed on ice, then analyzed at the UNH Water Quality Analysis Laboratory using standard methods. Observed decreases in the ratio of the concentration of nitrate to the concentration of bromide were used to estimate zero-order consumption

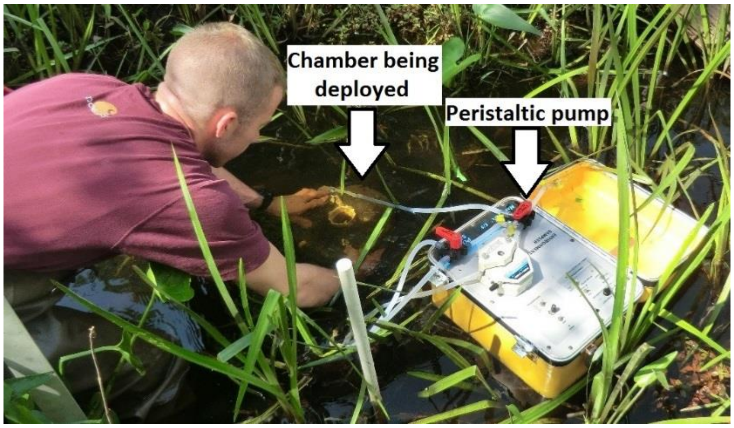

Figure 5. Chamber deployment in main channel at study site BOX on June 19, 2015, showing the 3-way valve system (on top of peristaltic pump) that allowed remote sampling.

(or production) rates, first-order uptake rate constants, and uptake velocities. Specifically, zero-order consumption rates were estimated using the negative slope of a straight line fit to the concentration ratio over time. First-order rate constants were estimated only for chambers exhibiting net consumption; rate constants were estimated using the slope of a straight line fit to the natural logarithm of the concentration ratio over time. The uptake velocity was calculated by multiplying the first-order rate constant by chamber depth.

Following each chamber deployment, sediment cores were obtained from the footprint of each chamber. The fraction of dry mass lost following ignition in a muffle furnace for 400°C for 24 hours was used to estimate organic carbon content.

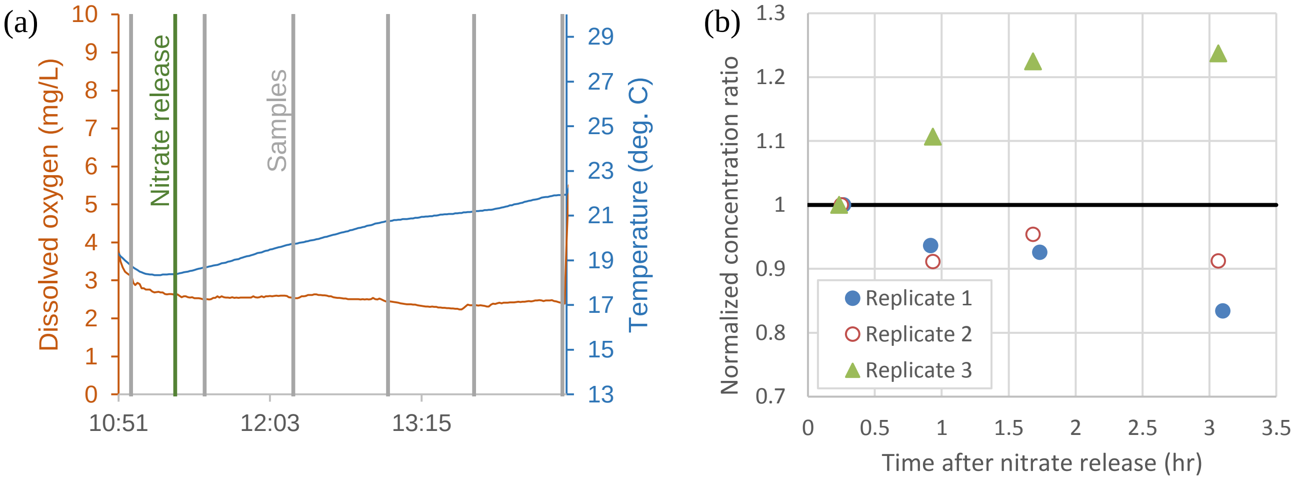

Figure 6. Chamber deployments on 6/30/2015 in transient storage near outlet at site WIL. (a) Time series of dissolved oxygen concentration and temperature within replicate #3 during the time the chamber was sealed. Vertical bars indicate the timing of the nitrate and bromide release and sampling. (b) Nitrate-to-bromide concentration ratio normalized by initial nitrate-to-bromide concentration ratio within each of the 3 chamber replicates.

Principal findings and significance

Objective 1: Determine contribution of wetland-dominated stream reaches to surface transient storage as a function of inundation and season.

The watershed area of the study wetlands ranged from 0.5 to 210 km^2. Wetland area ranged from 2,400 to 40,00 m^2, NWI area ranged from 1,200 to 52,000 m^2, wetland length ranged from 120 to 650 m, average width ranged from 18 to 50 m, width-to-length ratio ranged from 0.07 to 0.24, and wetland channel sinuosity ranged from 1.0 to 1.4. Only width was statistically different from (specifically, smaller than) a broad selection of other New England wetlands. Although study wetlands were on the small end of the range of wetlands chosen randomly from nearby watersheds in coastal New England, they were well within the observed variability, and thus believed to be geometrically representative of other wetlands in the area.

In general, velocity in the wetland channel ranged from 100 to 10,000 m/day and was quite similar to velocity upstream and downstream, which makes sense because the wetland channel was sized to pass the same flow that entered and exited the wetland. The exception was a few sites (BYF, LEE) which were affected by beaver, which reduced their velocities.

The detention time and variance of the RTDs of conservative tracer were compared to previous observations of 384 tracer releases in streams and rivers with discharge 10^{-3}–10^{3} m^3/s

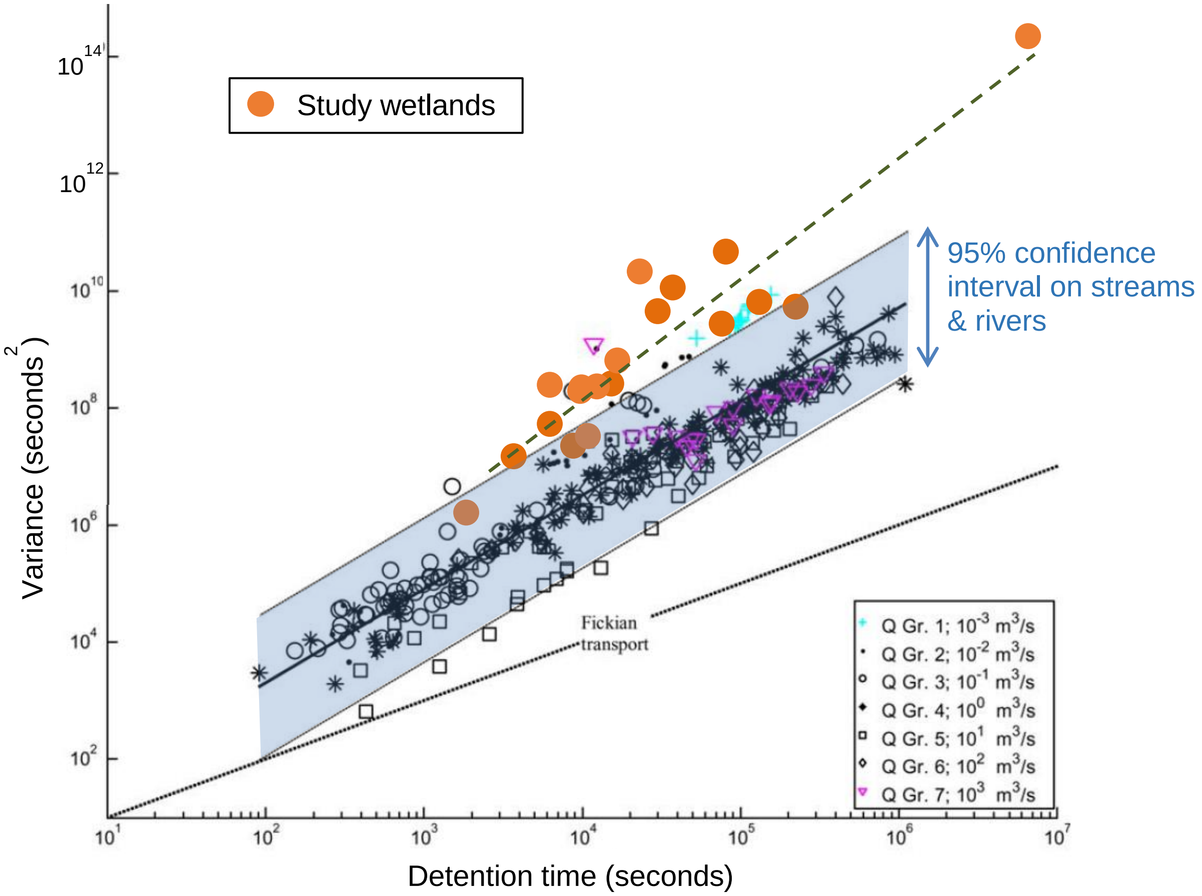

Figure 7. Comparison of residence time distribution statistics for study wetlands to previous observations of 384 breakthrough curves from tracer releases in streams and rivers, which are divided into seven discharge (Q) classifications. Adapted from González-Pinzón et al., 2013.

(Gonzalez-Pinzon et al., 2013; Figure 7). In streams and rivers, longitudinal spreading (characterized by variance) increases predictably with detention time, though this growth is faster than the linear increase expected with Fickian transport, suggesting that the effective dispersion coefficient increases with distance traveled and with discharge (Fischer et al., 1979; Gonzalez-Pinzon et al., 2013). Nearly all of the 19 observed RTDs in this study fall outside of a 95% confidence interval based on observations in streams and rivers, indicating that transport through wetland-dominated reaches is statistically different from solute transport through channelized streams (Figure 7). Thus, this study confirms that the large off-channel storage zones in wetlands increase the residence time of solutes, especially those that enter more slowly flowing areas.

Transient storage models were successfully fit to all measured tracer breakthrough curves. For nearly all studies, the multiple-zone models better matched experimental data, especially in matching tracer concentration in the tail of the breakthrough, representing flowpaths with long residence times (Figure 8). The tail of the tracer breakthrough curve at the wetland outlet exhibits the most sensitive response to different transport pathways including exchange with transient storage zones (Wang and Jawitz 2006, Gooseff et al. 2011); the better fit of the multiple-zone models confirmed that different types of transient storage characterized by different exchange rates were present in the study wetlands. The fraction of median travel time due to transient storage (Runkel 2002) ranged from 20–80%, indicating that most solutes moving through these reaches spent half or more of their time traveling through transient storage areas that may have exhibited high biogeochemical reactivity.

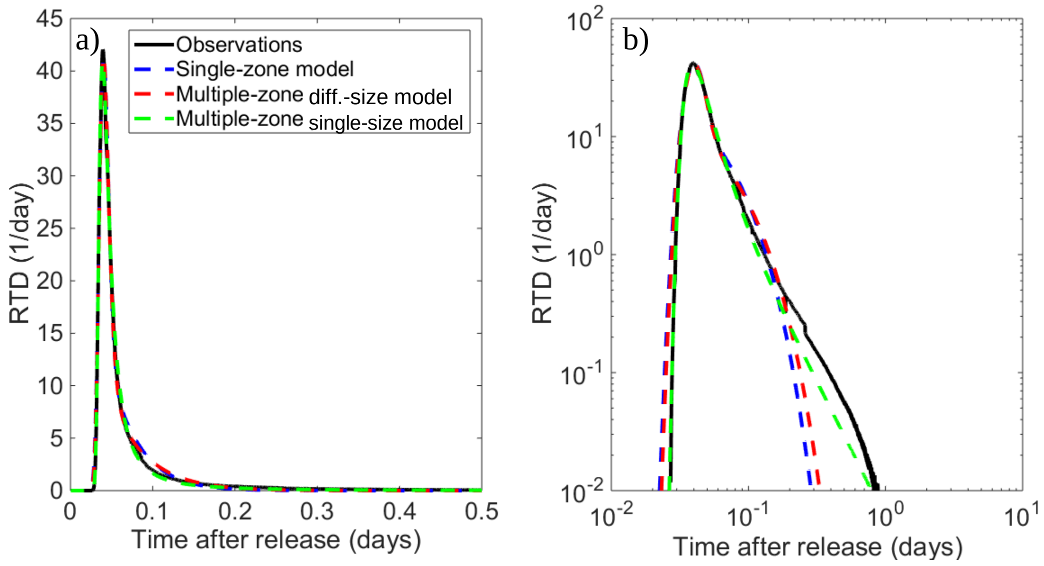

Figure 8. Measured and modeled residence time distribution (RTD) on (a) linear and (b) logarithmic axes for study REA2.

Objective 2: Quantify nitrate uptake rates among different types of surface transient storage as a function of season.

During 8 out of 11 studies, the outlet concentration of nitrate was less than the inlet concentration. In addition, in 7 out of 11 studies, nitrate fluxes (concentration × discharge) entering the wetlands were smaller than fluxes out of the wetlands. Thus, nitrate was retained within most of the study reaches during the period of observation.

Within chambers, net nitrate consumption, indicated by a decrease in bulk nitrate-to-bromide concentration over time, was observed in 14 out of 20 successful chamber deployments (Table 1). Five of these concentration decreases were statistically significant at the 90% confidence level. Nitrate-to-bromide concentration was observed to remain constant or increase (suggesting nitrate production) in the remaining 6 deployments. Net zero-order nitrate consumption rates were as high as 1.02 mg/L/hr, or 61 mg/L/hr/m^2. First-order nitrate uptake rates were as high as 9 day^{-1}, and uptake velocities were as high as 2.2 m/day, which is similar to observations in other wetlands in coastal New England (Wollheim et al. 2014). First-order uptake rate constants decreased as initial (ambient + added) nitrate concentrations increased (Figure 9), supporting patterns of efficiency loss in nitrate uptake (Wollheim et al. 2014). Uptake rates were not significantly different between channel and transient storage locations within the same wetland, and were not significantly different among wetlands.

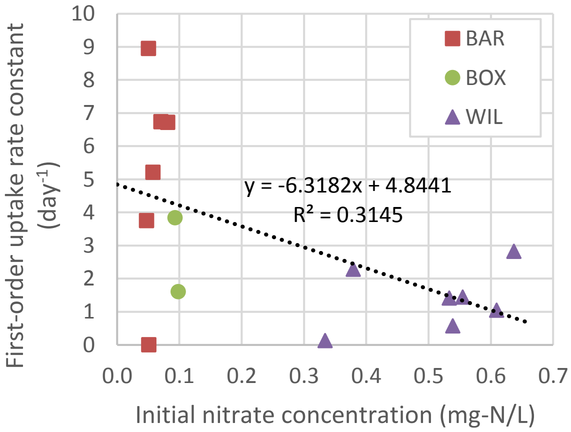

Figure 9. First-order nitrate uptake rate constants measured in chambers, compared to the initial nitrate concentration in the chamber, along with a best-fit straight line to this relationship across all sites.

Table 1. Summary of individual chamber deployments during June 2015. Ambient concentrations represent conditions prior to nitrate release; initial concentrations reflected the added nitrate. DO depletion rates and zero-order nitrate consumptions rates are negative when DO and nitrate decrease over time. Asterisks are used to indicate rates that are significant at the 90% confidence level.

				Depth (cm)	Temp. (ºC)	DO (mg/L)		DO depletion rate (mg/L/hr)	Organic carbon content	Ambient			Initial NO$_3$ (mg-N/L)	Zero-order consumption rate (mg-N/L/day)				First-order consumption rate constant (day^{-1})				Uptake velocity v_f (m/day)
Site	Location	Rep	Date			Start	End			NO$_3$ (mg-N/L)	NH4 (mg-N/L)	PO$_4$ (µg-P/L)		Z	SE	r^2	p	k	SE	r^2	p	
BAR	MC	1	6/8	25	16.45	5.81	4.01	0.47	64%	0.019	0.052	13.8	0.053	-0.05	0.18	0.02	0.81	-	3.43	0.04	0.76	-
BAR	MC	2	6/10	20	23.55	5.08	3.59	0.36	71%				0.058	0.30	0.11	0.77	0.12	5.21	1.58	0.84	0.08*	1.1
BAR	MC	3	6/10	19	24.19	5.26	5.02	0.05	65%				0.048	0.16	0.06	0.74	0.06*	3.75	1.04	0.81	0.04*	0.7
BAR	TS-up	1	6/5	14	19.4	6.33	5.83	0.12	43%				0.070	0.33	0.31	0.36	0.40	6.74	4.90	0.49	0.30	0.9
BAR	TS-up	2	6/5	19	18.54	5.50	3.20	0.54	28%				0.081	0.59	0.86	0.19	0.56	6.71	7.06	0.31	0.44	1.3
BAR	TS-up	3	6/10	20	22.89	3.67	3.37	0.08	38%				0.051	0.00	0.00	0.14	0.62	0.00	0.00	0.17	0.59	0.0
BAR	TS-down	1	6/4	20	18.26	8.27	6.63	0.47	50%				0.046	-0.04	0.09	0.16	0.74	-	2.06	0.18	0.72	-
BAR	TS-down	2	6/4	19	18.13	8.14	5.91	0.66	47%				0.051	-0.14	0.07	0.82	0.28	-	1.54	0.81	0.29	-
BAR	TS-down	3	6/8	25	15.6	4.20	3.63	0.15	43%				0.050	0.41	0.23	0.61	0.22	8.95	3.97	0.72	0.15	2.2
BOX	MC	1	6/19	17	22.61	1.46	1.38	0.02	35%	0.053	0.050	17.04	0.038	-0.03	0.09	0.06	0.76	-	1.86	0.08	0.71	-
BOX	MC	2	6/19	15	23.65	4.66	0	1.06	36%				0.101	-				-				-
BOX	MC	3	6/19	15	23.33	2.15	2.76	-0.15	38%				0.098	0.13	0.04	0.85	0.08*	1.60	0.47	0.86	0.07*	0.2
BOX	TS-up	1	6/22	15	22.75	4.86	6.08	-0.26	-	0.048	0.046		0.000	-				-				-
BOX	TS-up	2	6/24	10	23.87	2.56	6.10	-0.90	61%				0.093	0.21	0.06	0.85	0.08*	3.84	1.20	0.84	0.09	0.4
BOX	TS-up	3	6/24	14	25.63	2.15	2.98	-0.21	51%				0.058	-				-				-
BOX	TS-down	1	6/22	17	22.74	4.31	7.57	-0.69	-				0.071	-				-				-
BOX	TS-down	2	6/22	13	23.83	4.32	4.88	-0.13	-				0.092	-				-				-
BOX	TS-down	3	6/24	11	26.02	3.07	0.06	0.74	54%				0.042	-				-				-
WIL	MC	1	6/26	18	19.57	3.96	2.47	0.38	26%	0.470	0.165	8.151	0.380	0.85	0.15	0.94	0.03*	2.28	0.40	0.94	0.03*	0.4
WIL	MC	2	6/26	15	20	3.51	2.39	0.29	35%				0.534	0.58	0.30	0.65	0.19	1.41	0.71	0.66	0.18	0.2
WIL	MC	3	6/29	12	19.71	3.37	0	0.87	27%				0.666	-				-				-
WIL	TS-up	1	6/26	20	15.7	5.74	4.27	0.34	35%				0.637	1.02	0.93	0.37	0.39	2.83	3.04	0.30	0.45	0.6
WIL	TS-up	2	6/29	21	15.99	5.65	4.95	0.17	30%				0.609	0.64	0.26	0.75	0.14	1.05	0.43	0.75	0.14	0.2
WIL	TS-up	3	6/29	21	16.25	6.54	6.29	0.06	28%				0.334	0.07	0.06	0.43	0.34	0.13	0.11	0.43	0.34	0.0
WIL	TS-down	1	6/30	22	19.74	5.93	9.03	-0.88	24%	0.613	0.173		0.555	0.89	0.14	0.95	0.02*	1.44	0.22	0.95	0.02*	0.3
WIL	TS-down	2	6/30	21	20.23	3.19	3.57	-0.12	18%				0.539	0.36	0.29	0.43	0.35	0.57	0.47	0.43	0.35	0.1
WIL	TS-down	3	6/30	22	20.04	3.23	2.47	0.23	24%				0.405	-0.77	0.27	0.81	0.10	-	0.63	0.80	0.11	-

Previous research has suggested seasonal cycles in nutrient uptake and release in coastal New England (Claessens et al. 2009). Fall 2015 nutrient concentration measurements have not yet been received from the laboratory, so it is not yet possible to quantify seasonal variation in uptake rates.

Objective 3: Scale biogeochemical and hydrologic insights to wetland-dominated reaches throughout New England watersheds.

Reach-scale nitrate uptake rate constants calculated for study sites exhibiting retention were within the range of previous results from flow-through wetlands in Massachusetts (Wollheim et al. 2014) and Wisconsin (Powers et al. 2012) and, with the exception of study LEE, are higher than uptake rate constants for streams (Wollheim et al. 2014), confirming that small wetlands play a large role in providing the important ecosystem service of nitrate retention. In general, nitrate uptake rate constants were similar between sites. There were few significant relationships between nitrate uptake rate constants and wetland geometry, suggesting that all studied wetlands contributed similarly to nutrient retention and processing. All three instances of nitrate production occurred in fall, when uptake rates tended to be low as well.

When retention was assumed spatially constant throughout the wetland channel and storage zones, different storage zone models resulted in similar reach-scale nitrate uptake rate constants. However, when increased uptake in off-channel transient storage areas (cf. Wollheim et al. 2014) was considered, different storage zone connectivity resulted in different effective reach-scale uptake rates: a small or poorly connected storage zone with rapid uptake to result in the same observed reach-scale retention. Thus, both spatial variations in uptake and connectivity are both important in understanding reach-scale processing, and wetland-dominated stream reaches may serve as hot spots for nutrient retention because uptake rates are higher and/or residence times are longer. These reach-averaged removal rates will be suitable for direct incorporation into existing watershed models of the system (Wollheim et al. 2008; Stewart et al. 2011).

Objective 4: Share results with local and regional policy makers

We have shared results with local and regional policy makers to assist in on-going efforts to manage and mitigate nitrate loading in coastal New England rivers. Methods and results have been presented to members of the public, local policy makers, and scientists, at the Lamprey River Watershed Association at the Lamprey River Symposium, the Northeast Section Meeting of the Geological Society of America, the New England Association of Environmental Biologists annual meeting, the New Hampshire Waters and Watershed Conference, and the American Geophysical Union Fall Meeting. In addition, motivation for the project has been discussed with students and members of the public through school groups, the KEEPERS summer program, and UNH Ocean Discovery Day.

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Presentations

Woodward, J., A. Moskal, L. Kalnejais, and A. Lightbody. Sediment oxygen consumpion in New England wetlands. UNH Undergraduate Research Conference. April 23, 2016.

Lightbody, A., L. Kalnejais, W. Wollheim, and S. Wilderotter. Nitrogen transport & retention within wetland-dominated stream reaches in New England. New Hampshire Waters and Watershed Conference. March 18, 2016.

Dougherty, Michael P. Analysis of the photodegradation and sorption of Rhodamine WT in New Hampshire wetlands. UNH Undergraduate Research Conference. April 22, 2015.

May, Christian J. Using diurnal variations of stream discharge in small wetlands to determine water lost to evapotranspiration in New Hampshire and Massachusetts. UNH Undergraduate Research Conference. April 22, 2015.

Lightbody, A., Wilderotter, S., Wollheim, W. M., Kalnejais, L. Contribution of surface transient storage to nitrogen retention within wetland-dominated stream reaches in New England. Northeast Section Meeting of the Geological Society of America. March 23, 2015.

Wilderotter, S., Lightbody, A., Zuidema, S., Kalnejais, L. H., Wollheim, W. M. Predicting nitrate retention in wetland-dominated stream reaches using a conservative tracer. Conference on Partnerships for Environmental Progress, New England Association of Environmental Biologists. March 18, 2015.

Lightbody, A., Wilderotter, S., Rosengarten, D., Lawrence, K. Contribution of fluvial wetlands to nitrogen retention in urbanizing coastal watersheds. Lamprey River Research Symposium, NH Water Resources Research Center. January 9, 2015.

Wilderotter, S., Lightbody, A. F., Kalnejais, L. H., Wollheim, W. M., Zuidema, S. Transient Storage Parameterization of Wetland-dominated Stream Reaches. Lamprey River Research Symposium, NH Water Resources Research Center. January 9, 2015.

Wilderotter, S., Lightbody, A. F., Kalnejais, L. H., Wollheim, W. M., Zuidema, S. Transient Storage Parameterization of Wetland-dominated Stream Reaches. American Geophysical Union Fall Meeting. December 15, 2014.

Outreach

Presentation of watershed hydrology and water quality to 80 elementary school students as part of the UNH Leitzel Center, Kids Eager for Engineering Program with Elementary Research-based Science (KEEPERS) program, July 2014 and 2015. Unit featured on KEEPERS promotional materials: http://www.leitzelcenter.unh.edu/pdf/carmelina_cestrone.pdf

Hydrology and water quality presentations to over 300 elementary and middle students and the public through UNH Ocean Discovery Day, Oyster River Girls' STEM Club, Hampstead Middle School, Moharimet Elementary School Science Friday, etc.

Participation in the Lamprey River Advisory Committee, and discussion with volunteers/staff from the Ipswich River Watershed Association and Oyster River Watershed Association

Initiation of collaboration with Peter Steckler at the Nature Conservancy, who is currently updating the Land Use Plan for New Hampshire’s Coastal Watersheds to account for differences in wetland ability to retain nitrogen

Students supported

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Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.

Basic Information

Title:	Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.
Project Number:	2014NH192S
USGS Grant Number:	G14AP00132
Sponsoring Agency:	EPA
Start Date:	7/26/2014
End Date:	8/31/2017
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	

Publications

1. Brown, R., J. Saros S. Nelson. 2016. Using paleolimnological evidence to assess the consequences of increased dissolved organic carbon in recent decades in lakes of the Northeastern US. J Paleolimnol, in review.
2. Boeff, K.A., K.E. Strock, J.E. Saros. 2016. Evaluating planktonic diatom response to climate change across three lakes with differing morphometry. J Paleolimnol. DOI 10.1007/s10933-016-9889-z.
3. Strock, K.E., Saros, J.E., Nelson, S.J., S.D. Birkel, J.S. Kahl, W.H. McDowell. 2016. Extreme weather years drive episodic changes in lake chemistry: implications for recovery from sulfate deposition and long-term trends in dissolved organic carbon. Biogeochemistry, 127(2-3), 353-365.

Annual Report to

USGS WRD WRRI, Reston, VA
US EPA, CAMD, Washington DC
and US EPA, ORD, Corvallis OR
June, 2015

Determining the effectiveness of the Clean Air Act and Amendments on the recovery of surface waters in the northeastern US

IAG 06HQGR0143

Principal Investigators: *William H. McDowell*[1], *Sarah J. Nelson*[2], *J. Steve Kahl*[1], *J. Saros*[2]
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Overview of activities during 2015-2016. A schematic summary of progress on the project plan is provided below (Table 1) and discussed on the following pages. We have concluded the final year of five for the most current project agreement, which supports the continuing needs of EPA to assess the effectiveness of the Clean Air Act Amendments of 1990 (CAAA). Field work and data assessment continue on schedule. Project coordination as well as most analytical chemistry, and some field sampling are conducted by the University of New Hampshire. Additional field sampling, data quality assurance, and data reporting are conducted by the University of Maine. This year the project is partially funding a Postdoctoral Researcher who is evaluating biotic and abiotic changes in the LTM and TIME lakes. One graduate student at the University of Maine was partly funded through this project, or in research leveraged on this project. Publications by three graduate students who were supported last year by this funding or leveraged research were completed or are in review at present. One research faculty at the University of Maine was partly supported during this project year to coordinate sampling, develop R code for data QA and analysis, and begin to transition data management to a new secure server. Additionally, this project continues to fund a portion of the base program of stream chemistry monitoring at Bear Brook Watershed in Maine (BBWM), for the reference watershed, East Bear. BBWM is nearing completion of a three-year NSF DEB grant that is evaluating nitrogen dynamics in both watersheds using ^{15}N tracer studies. The base funding through this IAG project created continuity that was key in securing the NSF award.

Table 1. 2011-2015 Project plan progress to date.

	2011				2012				2013				2014				2015				2016
Project Activity	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
project period	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨
funding received	■				■				■						■		■		■		
RLTM drainage		■	■	■		■	■	■		■	■	■		■	■	■		■	■	■	
RLTM seepage		■	■	■		■	■	■		■	■	■		■	■	■		■	■	■	
original LTM				■				■				■				■				■	
HELM subset				■				■				■				■				■	
BBWM - EB	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨
TIME New England			■				■				■				■				■		
TIME Adirondacks			■				■				■				■				■		
sample analyses	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨
Data submission		■				■				■					■				■		▨
annual report		■				■				■				■				■			

▒ = project plan ▨ = in progress ■ = completed ⬚ = cancelled (weather)

Project background

Objectives. This research is part of EPA CAMD programs that are verifying the effectiveness of emission controls at reducing acidification of surface waters. Our approach is to collect long-term high-quality data that characterize the trends and patterns of response in low ionic-strength surface waters. We have specifically targeted waters that have been classified as being sensitive to acidic deposition and will represent lakes across the Northeast in varying landscape settings. The goals and methods are hierarchical, ranging from intensive site-specific investigations to regional assessment of sites that have been chosen to provide a statistically rigorous sample of regional surface waters. The objectives are to:

1) document the changes and patterns in aquatic chemistry for defined sub-populations and sites that are known to be susceptible to acidification or recovery;
2) evaluate the extent to which changes in surface waters, if any, can be linked to changes in deposition that are driven by regulatory actions;
3) characterize the effectiveness of the CAAA in meeting goals of reducing acidification of surface waters and improving biologically-relevant chemistry in the northeastern US;
4) provide information for assessment of the need for future reductions in atmospheric deposition based on the long-term trajectories of the systems under study; and
5) assess the extent to which increased variability in precipitation events will play a role in the long-term sustainability of CAAA success in these sensitive surface waters. This is leveraged through other funded research.

Approach. The schedule of tasks ranges from weekly to annual, continuing data records that now range from 22 to 33 years. We evaluate chemistry on a weekly basis year-round at the small watershed-scale at BBWM, quarterly in LTM, and annually during the historical index period for the TIME and HELM lakes. These project components provide a *statistical framework* for inferring regional patterns in chemistry using TIME and LTM (and ELS-II under separate funding). The *long-term records* of LTM, HELM and BBWM provide information on seasonal and annual variability, and thus provide a seasonal context for the annual surveys.

Expected Results. This information is needed for EPA to meet its Congressional mandate to assess the effectiveness of the CAAA. The combination of site-specific data within the regional context provides a rigorous assessment of the effects of declining pollutant emissions on SO_4 concentrations, base cation depletion, and changes in N-saturation or DOC contributions to acid-base status. The results are also central to assessing whether additional emission reductions may be needed to produce recovery.

Project Status: Water Chemistry

Field sampling. All project field objectives in 2015 were accomplished as planned. A summary of the annual field schedule for this project is provided below (Table 2).

Table 2. Annual project field schedule for lake sampling

Project	sub-project	n	Times Sampled	Field work	May	June	July	Aug.	Sept.	Oct.
RLTM-Maine										
	seepage	3	3	UMaine	X		X			X
	drainage	10	3	UMaine/UNH	X		X			X
	LTM lakes	3	1	UMaine						X
TIME										
	New England	31	1	UNH			X	X	X	
	Adirondacks	43	1	ALSC			X	X	X	
HELM		25-30	1	UNH						X

Analytical. Analyses are complete for all samples collected through 2015. All laboratory analyses for TIME, RLTM, and HELM are conducted at the University of New Hampshire Water Quality Analysis Laboratory (WQAL) except for aluminum. Total and organic aluminum samples are processed on an ICP at the USDA Forest Service Region 1 laboratory in Durham, NH. All analyses for TIME, RLTM, and HELM continue to be conducted by, or under the supervision of, Jody Potter as has been the case since 2012.

Samples from East Bear Brook at BBWM, which are collected on a regular basis year-round, continue to be analyzed at the University of Maine Sawyer Water Research Lab.

Data reporting. All data collected through 2014 have been delivered to EPA. The next delivery of data to EPA is expected before August 2016, after evaluation of inter-laboratory comparisons and regular QA analyses by UNH and UMaine.

Presentation of findings. Several publications and presentations continue to result from this project and are listed at the end of this report. Recent leveraged funding supported portions of two M.S. theses and a Ph.D. dissertation at UMaine under the supervision of co-PI Saros; results of those projects are now published (Strock et al. 2016; Boeff et al. 2016) or in review (Brown et al. 2016).

New developments: During the past four years we were able to make routine two new sets of analyses to continue to extract new and innovative information from these study sites. A subset of lakes were analyzed for DOC quality using SUVA and fluorescence (EEMS) analysis, as well as concentrations of the dissolved greenhouse gases (CH_4, CO_2, and N_2O) in surface waters. Moving forward, these data will provide valuable insight into changes in organic sources to acid-base status as well as the influence of precipitation event variability on long-term changes in surface water chemistry.

Publications using related project information ***(recent publications in bold):***

Brown, R., J. Saros S. Nelson. 2016. Using paleolimnological evidence to assess the consequences of increased dissolved organic carbon in recent decades in lakes of the Northeastern US. *J Paleolimnol,* in review.

Boeff, K.A., K.E. Strock, J.E. Saros. 2016. Evaluating planktonic diatom response to climate change across three lakes with differing morphometry. *J Paleolimnol*. DOI 10.1007/s10933-016-9889-z

Strock, K.E., Saros, J.E., Nelson, S.J., S.D. Birkel, J.S. Kahl, W.H. McDowell. 2016. Extreme weather years drive episodic changes in lake chemistry: implications for recovery from sulfate deposition and long-term trends in dissolved organic carbon. *Biogeochemistry, 127*(2-3), 353-365.

Strock, K., S. Nelson, J. Kahl, J. Saros, W. McDowell, 2014. Decadal trends reveal recent acceleration in the rate of recovery from acidification in the northeastern US. Environ. Sci. Technol. 48(9):4681-4689.

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Nelson, S.J., P. Vaux, M.J. James-Pirri, and G. Giese. 2012. Natural resource condition assessment: Cape Cod National Seashore, Massachusetts. Natural Resource Report NPS/NER/NRR—2012/605. National Park Service, Fort Collins, Colorado.

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Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J.L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley, H. Yao, 2011, The effects of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA, Biogeochemistry DOI 10.1007/s10533-011-9664-1.

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Baumann, A.J. and J.S. Kahl, 2007. Chemical trends in Maine High Elevation Lakes. LakeLine 27:30-34.

Hunt, K., J.S. Kahl, J. Rubin, and D. Mageean, 2007. Assessing the science-based needs of stakeholders; a case study on acid rain research and policy. Journal of Contemporary Water Research and Education, 136: 68-79.

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Dissertations/theses:

Strock, K.E. 2013. Deciphering Climate-Mediated Changes in Boreal Lake Ecosystems. Ph.D. Dissertation, University of Maine, Orono, Maine.

Boeff, K. 2014. Evaluating the effect of a changing climate on thermocline depth in Maine’s Great Ponds. Master’s thesis, University of Maine, Orono, Maine.

Brown, R. 2014. Assessing the ecological effects of increased dissolved organic carbon in Maine lakes over recent decades. Master’s thesis, University of Maine, Orono, Maine.

Presentations using related project information ***(recent presentations in bold)****:*

Nelson, S.J., C.Y. Chen, D.P. Krabbenhoft, J.S. Kahl. 2016. Beyond “Hotspots”: Dragonfly BioSentinels Describe Vulnerability (or not) of Northeastern Lakes and Their Foodwebs to Mercury Accumulation. 2016 Conference of the New England Association of Environmental Biologists (NEAEB), March 23-25, 2016, Rockport, ME.

W.H. McDowell, S.J. Nelson, J.D. Potter, 2015. DOC concentrations of New England (USA) lakes: is there a response to changing atmospheric deposition? Acid Rain 2015, Rochester, NY, Oct. 19–23, 2015.

Roy, K., H. Pembrook, S. Nelson, A. Riscassi, M. McHale, E. Boyer, G. Lampman, C. Funk, 2015. Long Term Monitoring of Acidification in Sensitive Areas of the Northern and Eastern United States: A New Generation of Research. Poster Presentation. Acid Rain 2015, Rochester, NY, Oct. 19–23, 2015.

McDowell, W.H. 2015. EPA TIME/LTM New England 2015. EPA Clean Air Act Cooperators meeting, Montpelier, VT. May 26 2015.

McDowell, W.G., K. Webster, S.J. Nelson, W.H. McDowell, J. Haney. Regulation and results: biotic and abiotic changes to northeastern lakes following tightening of air emission rules. Society for Freshwater Science, Milwaukee, WI, May 17- 21, 2015.

Appling, A.P., W.H. McDowell, J.D. Potter, S.J. Nelson, J.S. Kahl, 2014. From the frying pan into the fire? Lake greenhouse gas responses to acid rain recovery. Joint Aquatic Sciences Meeting. Portland, OR, May 18 – 23, 2014.

Brown, R.E., Saros, J.E. & S.J. Nelson. 2014. Algal community response to increases in dissolved organic carbon over recent decades. Poster presentation. Association for the Sciences of Limnology & Oceanography, Portland, OR, May, 2014.

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Strock, K.E., Saros, J.E., Nelson, S.J. & S. Birkel. 2014. Interactive effects of extreme weather and reduced sulfate deposition: accelerated recovery from acidification and increased brownification in lakes of the Northeast U.S. Association for the Sciences of Limnology & Oceanography, Portland, OR, May, 2014.

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S.J. Nelson, 2013. School of Forest Resources Faculty Blitz. Sept. 13, 2013.

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Brown, R.E., Saros, J.E. & S.J. Nelson. 2013. Algal community response to increases in dissolved organic carbon: Implications for drinking water utilities. Poster presentation. North American Diatom Symposium, Bar Harbor, ME, August, 2013.

Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, B. Zoellick, 2013. Validating landscape models for mercury in northeastern US lakes using dragonfly larvae as mercury bio-sentinels. Accepted for poster presentation at the ICMGP - International Conference on Mercury as a Global Pollutant, July 28- Aug. 3, 2013, Edinburgh, Scotland.

Boeff, K., J. Saros. 2013. Evaluating the Effect of Changing Wind Strength on Thermocline Depth in Maine's Great Ponds. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Brown, R.E., J.E. Saros, S.J. Nelson. Algal community response to increases in dissolved organic carbon in Maine lakes: implications for drinking water utilities. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Strock, K.E., J.E. Saros, S. Birkel, S.J. Nelson, 2013. Exploring the effects of extreme hydrologic events in the northeastern U.S.: Implications for brownification and episodic acidification in Maine Lakes. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, 2013. Dragonfly larvae as mercury bio-sentinels: a statistical survey of northeast lakes reveals landscape-driven patterns in water and biota mercury concentrations. NERC (Northeastern Ecosystems Research Cooperative) meeting, March 19 – 20, 2013, Saratoga Springs, NY.

Strock, K.E.D., J.E. Saros, S.J. Nelson. 2013. The effects of extreme climate events on lakewater chemistry: Implications for "brownification" in Maine lakes. Maine Water Conference. Augusta, Maine, March 19, 2013.

Strock, K.E.D., J.E. Saros, S.J. Nelson, S.D. Birkel. 2013. The effects of extreme climate events on lakewater chemistry: implications for dissolved organic carbon trends in the northeast U.S. American Society of Limnology and Oceanography Meeting. New Orleans, Louisiana, February 17-22, 2013.

Sanclements, M., G. Oelsner, D. McKnight, I.J. Fernandez, S.J. Nelson, M.B. Adams, M. Mineau, K. Simon, 2012. The effects of acidification and recovery on DOM quality and source in temperate forested watersheds. BIOGEOMON 2012, July 15-20, 2012, Northport, ME.

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Saros, J.E., K.E.D. Strock, S. Birkel & S.J. Nelson. 2012. Deciphering the effects of extreme hydrologic events on the response of northeastern lakes to reduced sulfur deposition. 20th annual Harold W. Borns Symposium, University of Maine.

Nelson, S.J., J.S. Kahl, A.J. Baumann, K.B. Johnson, 2012. "Rugged shores and clear waters": Interpreting biogeochemical response to environmental stressors using the lakes and ponds of Maine's Baxter State Park. Maine Water Conference, Augusta, ME, March 14, 2012.

Strock, K.E., J.E. Saros, S. Nelson. Why climate matters in recovery from acidification in northeastern US surface waters. Maine Water Conference, Augusta, ME, March 14, 2012.

Baumann, A.J., J.S. Kahl, T.R. Boucher, S.J. Nelson, and K.J. McGuire, 2012. "Changes in surface water chemistry in Maine high elevation lakes in response to the 1990 Clean Air Act Amendments. Maine Water Conference, Augusta, ME, March 14, 2012.

Mineau, M. M., K. S. Simon, D. T. Ely; R. L. Rancatti, I. J. Fernandez, S. A. Norton, and H. M. Valett. 2011. Effects of chronic nitrogen enrichment and acidification on coupled nitrogen and phosphorus cycling in streams: Insights from multiple spiraling techniques. Annual meeting, North American Benthological Society, Providence, RI.

Nelson, S.J., P. Vaux, M.J. James-Pirri. Data-driven assessments of National Park resources. (Invited). Acadian Internship in Regional Conservation and Stewardship, July 15, 2011.

Schneider, S.B., I.J. Fernandez, S.A. Norton, K.S. Simon. 2011. Soil base cation response to two decades of change at the Bear Brook Watershed in Maine. Gordon Conference on Catchment Science: Interactions of Hydrology, Biology and Chemistry. Bates College, Lewiston, Maine. July 10-15.

Nelson, S.J., C. Chen, H. Roebuck, B. Zoellick. Sensible sentinels: Preliminary mercury data for dragonfly nymphs (*Odonata: anisoptera*) across northern New England corroborate expected spatial pattern. The 10th International Conference on Mercury as a Global Pollutant (ICMGP), Halifax, NS, July 24-29, 2011; and presented at the Acadia Science Symposium, October 26, 2011.

Baumann, A.J., and J.S. Kahl, 2009. Assessing the effectiveness of federal acid rain policy using remote and high elevation lakes in northern New England. North American Lake Management Society International Symposium, Hartford, CT, October 29, 2009.

Kahl, J.S., 2009. Changes in base cations related to long-term changes in Cl distribution in northeastern lakes. Gordon Research Conference, Forested Catchments, July 12-17, 2009, Proctor Academy, NH.

Kahl, J.S., 2008 (invited). Twenty year changes in spatial patterns of Cl distribution in the northeastern US. NH Water Conference, April, 2008.

Kahl, J.S., 2007 (invited). Using societal-based incentives to address new threats to New England Lakes. Day-long short course in New England Lake Science Academy, Camp Kieve, Maine. July, 2007.

Kahl, S., K. Webster, D. Sassan, C. Rosfjord, S. Nelson, M. Greenawalt-Yelle, 2007. Increasing Cl in northeastern surface waters: an indicator of increasing development pressure. Maine Water Conference, Augusta, ME, March 21, 2007.

Kahl, J.S. 2006 (invited). Acid rain in New England: using high elevation lakes as sentinels of change. Maine Mountain Conference, October 21, 2006. Rangeley, Maine

Kahl, J.S., *et al.*, 2006 (invited). The design of a national mercury monitoring network: Learning from the EPA acid rain experience. The Eighth International Mercury Conference, Madison WI, August 8, 2006.

Kahl, J.S. *et al.*, 2006. Obfuscation of trends in base cations by regional salt contamination. Hubbard Brook Committee of Scientists annual meeting, July 12, 2006.

Kahl, J.S., 2006 (invited). 'Natural and human-derived sources of acidity in Maine Atlantic Salmon Rivers'. Atlantic Salmon Commission workshop on acidity, Bangor ME. April 10, 2006.

Kahl, J.S., 2005 (invited). The intersection of environmental science and environmental policy. NH Charitable Foundation Lakes Region annual meeting, Meredith, NH, September, 2005.

Kahl, J.S., 2005 (invited). Tracking response and recovery in surface waters in the northeastern US. Annual meeting of the Ecological Society of America, Montreal, August, 2005.

Kahl, J.S., and Catherine Rosfjord, 2005 (invited). Acid rain and the Clean Air Act in the northeastern US. Annual meeting of the NH-ME Androscoggin River Watershed Council, Bethel, June, 2005

Kahl, J.S., 2005 (invited). Developing a lake research agenda for NH. NSF workshop on lake research infrastructure in the northeast, Colby Sawyer College, April 2005.

Kahl, J.S., S. Nelson, and A. Grygo, 2004. Surface water chemistry data for the northeastern US for interpreting climate and acid rain trends. Northeast Ecosystems Research Consortium meeting, Durham, NH, October, 2004.

Kahl, J.S., K. Webster, M. Diehl, and C. Rosfjord, 2004. Successes of the Clean Air Act Amendments of 1990. Maine Water Conference invited plenary talk, Augusta, ME, 2004.

Kahl, J.S. and K. Johnson, 2004. Acid-Base Chemistry and Historical Trends in Downeast Salmon Rivers. Maine Water Conference, Augusta ME, April 2004.

Kahl, J.S., 2004 (invited). The Clean Air Act Amendments of 1990; testing a program designed to evaluate environmental policy. Lecture, Colby College. April, 2004

S.J. Nelson, J.S. Kahl, N.C. Kamman, D.P. Krabbenhoft, W.H. Halteman, 2009. (Poster) Predicting mercury concentrations in northeast lakes using hydrogeomorphic features, landscape setting and chemical co-variates. Gordon Research Conference, Forested Catchments, July 12-17, 2009, Proctor Academy, NH.

Nelson, S.J., I. Fernandez, S. Norton, B. Wiersma, L. Rustad, J.S. Kahl, 2008. The Bear Brook Watershed in Maine: Long-term research supporting climate change inquiry. Hydroclimatic effects on ecosystem response: participant workshop, Syracuse, NY, September 19, 2008.

Nelson, S.J., N. Kamman, D. Krabbenhoft, J.S. Kahl, K. Webster, 2008. Evaluating spatial patterns in mercury and methyl mercury in northeastern lakes: Landscape setting, chemical climate, and human influences. Northeastern Ecosystem Research Cooperative Conference, Durham, NH, November 12-13, 2008.

Nelson, S.J. 2008. Evaluating spatial patterns in mercury and methyl mercury in northeastern lakes: landscape setting, chemical climate, and human influences. Maine Water Conference, Augusta, ME, March 19, 2008.

Recent Bear Brook publications and presentations that include “base program” data (East Bear Brook stream chemistry partly funded through this grant):

Crossman, J., M.C. Eimers, N.J. Casson, D.A. Burns, J.L. Campbell, G.E. Likens, M.J. Mitchell, S.J. Nelson, J.B. Shanley, S.A. Watmough, K.L. Webster. 2016. Regional meteorological drivers and long term trends of winter-spring nitrate dynamics across watersheds in north-eastern North America. *Biogeochemistry*, in review.

Fatemi, F. R., Fernandez, I. J., Simon, K. S., & Dail, D. B. (2016). Nitrogen and phosphorus regulation of soil enzyme activities in acid forest soils. *Soil Biology and Biochemistry*, *98*, 171-179.

Phelan, J., Belyazid, S., Jones, P., Cajka, J., Buckley, J., & Clark, C. (2016). Assessing the Effects of Climate Change and Air Pollution on Soil Properties and Plant Diversity in Sugar Maple–Beech–Yellow Birch Hardwood Forests in the Northeastern United States: Model Simulations from 1900 to 2100. *Water, Air, & Soil Pollution*, *227*(3), 1-30.

Lawrence, G. B., Hazlett, P. W., Fernandez, I. J., Ouimet, R., Bailey, S. W., Shortle, W. C., ... & Antidormi, M. R. (2015). Declining Acidic Deposition Begins Reversal of Forest-Soil Acidification in the Northeastern US and Eastern Canada. *Environmental science & technology*, *49*(22), 13103-13111.

Eimers, C., J. Crossman, N. Casson, D. Burns, J. Campbell, G. Likens, M. Mitchell, S. Nelson, J. Shanley, S. Watmough, K. Webster, 2015. Nitrogen dynamics in the dormant season: an inter-watershed comparison. Poster presentation. Acid Rain 2015, Rochester, NY, Oct. 19–23, 2015.

Mineau M. M., F. R. Fatemi, I. J. Fernandez and K. S. Simon. 2014. Microbial enzyme activity at the watershed scale: Response to chronic nitrogen deposition and acute phosphorous enrichment. Biogeochemistry 117:131-142.

Mineau, Madeleine M., Chad M. Grigsby, Damon T. Ely, Ivan J. Fernandez, Stephen A. Norton, Tsutomu Ohno, H. Maurice Valett, and Kevin S. Simon. 2013. Chronic catchment nitrogen enrichment and stoichiometric constraints on the bioavailability of dissolved organic matter from leaf leachate. Freshwater Biology 58:248-260.

Gruselle, Marie-Cecile, Cayce Salvino, Ivan J. Fernandez, Kevin Simon and Corianne Tartariw. 2013. Does Chronic N Fertilization Increase P Limitation in Northeastern U.S. Forest Soils? (Paper 383-4). Presented at the ASA-CSSA-SSSA International Meetings. Tampa, Florida. November 3-6. ASA, CSSA, SSSA, Madison, WI.

Fatemi, Farrah, Michael D. SanClements, and Ivan J. Fernandez. 2013. Microbial Carbon Cycling Along a Drainage Sequence in a New England Forested Watershed. (Paper 252-2). Presented at the ASA-CSSA-SSSA International Meetings. Tampa, Florida. November 3-6. ASA, CSSA, SSSA, Madison, WI.

Morse, Jennifer L., Jorge Duran, Fred Beall, Irena Creed, Eric Enanga, Ivan Fernandez, and Peter M. Groffman. 2013. Soil denitrification fluxes and oxygen dynamics in three contrasting northeastern North American forests. Ecological Society of America. Minneapolis, Minnesota 8/4-8/9.

SanClements, Michael, Ivan Fernandez, Mary Beth Adams, and Jenny Erwin. 2013. Linking Stream DOM Quality and Source to Watershed Acidification and Recovery in Temperate Forests of the Northeastern United States. 12th North American Forest Soils Conference, Whitefish, Montana. p. 112.

Gruselle, Marie-Cecile, Ivan Fernandez, and Corianne Tatariw. 2013. Manganese Dynamics in the Third Decade of Forest Ecosystem Experimental Acidification and Nitrogen Enrichment. 12th North American Forest Soils Conference, Whitefish, Montana. p. 35

MacRae, J.D., C. Tatariw, D. Rothenheber, S. Nelson, I.J. Fernandez. The effects of nitrogen enrichment on forest soil microbial communities and their activities, 2013 AEESP 50th Anniversary Conference, July 14-16, Golden, CO.

Boca, Antra, Mercedes Roman Dobarco, Helga Van Miegroet, Marie-Cecile Gruselle, Beate Michalzik, and Ivan Fernandez. 2013. Linking Overstory, Soil and Climate Characteristics to Explain C Storage in Forest Soils. 12th North American Forest Soils Conference, Whitefish, Montana. p. 29.

Gruselle, M.-C., Fernandez, I., Simon, K., Norton S., 2013. The effects of long-term ecosystem N enrichment on 15N dynamics at the Bear Brook Watershed in Maine. NERC 2013 Conference, Saratoga Springs, NY.

Minocha, Rakesh, Swathi A. Turlapati, Stephanie Long, Mohammad M. Bataineh, Aaron Weiskittel, Ivan Fernandez, and Lindsey Rustad. 2013. Chronic N and S additions impact foliar physiology of forest trees at the Bear Brook Watershed in Maine, USA. Hubbard Brook Experimental Forest Annual Meeting, Thornton, NH.

Ohno, Tsutomu, Ivan J. Fernandez, Rachel L. Sleighter, and Patrick G. Hatcher. Influence of depth on soil organic matter characteristics: An ultrahigh resolution mass spectrometry study. Advanced Analytical Characterization of Natural Organic Matter, Goldscmidt 2013, Florence, Italy, August 25-30, 2013.

Fernandez, Ivan J. and Sarah J. Nelson. 2013. Bear Brook, Backpack Sprayers, and What's More Fun Than Gym Class? Invited seminar at the School of Forest Resources noon-time seminar series. University of Maine, Orono, Maine.

Mayewski, Paul, Ivan J. Fernandez, Stephen A. Norton and Sean Birkel. 2013. Presentation on Climate Change and Maine to the Allagash Wilderness Waterway Advisory Council. March 22. Augusta, Maine.

Fatemi, Farrah R., Ivan J. Fernandez, Stephen A. Norton and Lindsey E. Rustad. 2013. Soil solution response to two decades of experimental acidification at the Bear Brook Watershed in Maine. Water Air Soil Pollution. 223:6171–6186.

Mineau, Madeleine M., Chad M. Grigsby, Damon T. Ely, Ivan J. Fernandez, Stephen A. Norton, Tsutomu Ohno, H. Maurice Valett, and Kevin S. Simon. 2013. Chronic catchment nitrogen enrichment and stoichiometric constraints on the bioavailability of dissolved organic matter from leaf leachate. Freshwater Biology (in press).

Fernandez, Ivan J., Stephen A. Norton, and Tiffany Wilson (eds.). 2012. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. 261 pp.

Fernandez, Ivan J., Madeleine M. Mineau, Kevin S. Simon, and Stephen A. Norton. 2012. The influence of decadal-scale N enrichment on N dynamics and 15N discrimination in a New England Forested Watershed. (Paper 302-2). Presented at the ASA-CSSA-SSSA International Meetings. Cincinnati, Ohio. October 22-25. ASA, CSSA, SSSA, Madison, WI.

Mineau, M.M., K.S. Simon, I.J. Fernandez, S.A. Norton, and H.M. Valett. The effect of chronic watershed nitrogen deposition and acidification on the interaction among phosphorus, carbon, and nitrogen uptake in streams. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 167.

Norton, S.A., I.J. Fernandez, T. Navratil, K.S. Simon, and S. Jain. 2012. The Bear Brook Watershed in Maine (BBWM) at 25: manipulation, monitoring, mechanisms, and modeling. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 177.

Rancatti, R., K. Simon, M. Mineau, D. Anderson, I.J. Fernandez, S.A. Norton, and M.B. Adams. 2012. Effects of watershed acidification on abiotic and biotic phosphorus uptake in streams draining two whole-watershed experimental forests. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 204.

Improved Ecosystem Indicator Tools for Water Quality Management – Genomic Analysis of Periphyton to Identify Stressors

Basic Information

Title:	Improved Ecosystem Indicator Tools for Water Quality Management – Genomic Analysis of Periphyton to Identify Stressors
Project Number:	2015NH191B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	NH-1
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Nutrients
Descriptors:	None
Principal Investigators:	Alison Watts, WKelley Thomas

Publication

1. Allison Wood, 2016. Attached Algae as an Indicator of Water Quality: A Study of the Viability of Genomic Taxonomic Methods. A Senior Honors Thesis Presented to the University Honors Program, University of New Hampshire, In Partial Fulfillment of the Requirements for: Honors in Environmental Engineering. College of Engineering and Physical Sciences, Department of Civil and Environmental Engineering, University of New Hampshire. May 2016, Durham New Hampshire.

NH WRRC Annual Report

Improved Ecosystem Indicator Tools for Water Quality Management – Genomic Analysis of Periphyton to Identify Stressors
Project Number 2015NH191B

May 13, 2016

This report is based on a senior honors thesis prepared by Allison Wood, and presented to the University Honors Program University of New Hampshire as partially fulfillment of her undergraduate degree in Honors Environmental Engineering

Introduction and Problem Statement

Great Bay Estuary is a unique and valuable inland water body located just west of Portsmouth, NH. Water from the Gulf of Maine is driven into the estuary by some of the strongest tidal forces in north america, meeting the discharge of seven freshwater rivers that drain nearly 1000 square miles of watershed area in NH and Maine. Due to the area's geography, Great Bay is one of the most recessed estuaries in the nation, and its tidally-driven ecosystem is a unique environment encompassing a variety of aquatic habitats. The Estuary is home to hundreds of types of birds and fish, including 23 threatened or endangered species (GBNERR, 2011). Since the 1995 establishment of the New Hampshire Estuaries Project, Great Bay has been studied extensively by local and state agencies, as well as EPA. In 2005 the program was centralized at the University of New Hampshire, and re-named PREP: the Piscataqua Region Estuaries Partnership, to include monitoring the parts of the estuary located in Maine. Based on this comprehensive monitoring effort, in 2009 NH Dept of Environmental Services designated the Great Bay as impaired based on its failure to meet various water quality standards for aquatic life, including dissolved oxygen and total nitrogen levels (EPA, 2012). Moving forward, PREP, NH DES and EPA will be looking for economic ways to gather water quality data to prevent further degradation of this unique ecosystem.

Unfortunately, cause–effect relationships of different stressors on an ecosystem are not straightforward, as freshwater and coastal ecosystems respond to nutrient loading in various ways (McQuatters-Gollop, 2009). Therefore, it is useful for scientists to identify a biologic ecosystem component that is reactive to various ecosystem impairments to serve as an indicator of changing ecosystem health. In this study, algae were selected because they are comparable across geographic locations, have been studied extensively, are abundant in aquatic environments, are easy to collect, and their growth is stimulated distinctly by different nutrient conditions. Algae are a particularly useful ecosystem indicator of ecological conditions due to their ability to reflect water quality conditions in a certain aquatic location, based on species type and abundance (Smucker et al, 2013).

In 2009 USGS published a database of algal species which serve as indicators for various water quality conditions, including nutrient enrichment, conductivity, dissolved oxygen, pH, and others (Porter, 2008). This information, in combination with recent success of an attached algae water quality monitoring program by Maine DES, prompted this study to examine attached algae as a potential indicator of water quality in Great Bay.

Objectives

The project had three main objectives. First, determining whether or not algae would work as an indicator of water quality in the great bay ecosystem, an environment where tidal currents are strong and water composition is mixed. This question was explored using multiple riverine inputs from different locations in the estuary. This was accomplished using the USGS list of algal indicator species, using traditional microscopic taxonomic methods. The second goal of the project was to compare traditional microscopic methods of taxonomy with emerging genomic methods, increasing the economic viability of attached algae monitoring. The third project goal, which is still underway, was to generate and use massive amounts of genomic data from the Great Bay ecosystem to see if other organisms might serve as viable indicators of environmental conditions in the bay.

Background / Literature Review

Algae as an Indicator of Water Quality

In 1947 Dr. Ruth Patrick launched a groundbreaking study identifying algae as a potential indicator of water quality in streams (Patrick, 1948). Finding that they are strong indicators of environmental change, she became a proponent of the use of biology to assess the ecological health of streams and rivers in North America. Through her work, the idea that biology could serve as a critical source of information for environmental health was presented and proven, changing the way environmental scientists approach research (Peck, 2014). Today algae, fish, and macroinvertebrates are the most common taxa used as biologic indicators in stream monitoring, however algae have been shown to respond to water quality stressors most distinctly (Magadze et al., 2016).

Algae are an abundant yet diverse group of photosynthetic organisms found in all aquatic habitats. In recent years our knowledge of these organisms has greatly advanced, mainly thanks to new types of data from advancements in electron microscopy and DNA sequencing technologies (Cavalier-Smith, 2007). They are easy to collect, and can be readily identified down to the species level. The species-specific sensitivity of algae to environmental conditions and their high diversity in habitats provide the potential for precise and accurate assessments of physical, chemical, and biological conditions that may be causing problems (Stevenson & Smol, 2003). In addition, algae have short life cycles, meaning they react to any changes in aquatic environments quickly and dramatically, which can be observed via species presence and/or percent abundance, indicating the type and severity of a certain condition (CITATION).

Specifically, attached or benthic algae is a useful indicator of ecological conditions due to its ability to reflect water quality conditions in a certain aquatic location. Attached algae includes diatoms and non-diatoms which attach to surfaces such as rocks and plants. Diatoms are single-celled photosynthetic algae, and are a major type phytoplankton, abundant in fresh and saline waters. Diatoms are effective biological indicators because they respond to various conditions including salinity and various nutrients, including Nitrogen and Phosphorus (Smucker et al., 2013). Other types of attached algae, such as non-diatom “soft” algae species, are also valuable indicators (Porter, 2008).

Overall, algal bioassessments improve water-quality programs because algae are reliable indicators of water quality (Danielson et al., 2011). Attached algae analysis is a powerful tool for assessment of water quality in streams, and has the potential for application in routine monitoring programs (Mangadze et al., 2016). To date, real applications of such data has been limited due to the lack of available autecological databases from which algal-indicator metrics can be calculated (Porter, 2008). The goal of this research was to explore the use of genomics as a viable alternative method of analysis, to improve monitoring capabilities and lower the cost of biological water quality assessment. Prior to this effort, the use of attached algae for water quality monitoring purposes in the Great Bay Estuary had to be validated using field data, as there is evidence that diatom metrics or indices developed in one geographic area are less successful when applied in other areas (Potapova & Charles, 2007).

Current Applications

USGS

In 2008, USGS published Algal Attributes, a data file containing metrics indicating physiological optima or tolerance to nutrients and other water-quality constituents. The file, created to enhance analysis, interpretation, and understanding of trophic condition in U.S. streams and rivers, includes 37 algal attributes and 101 metric codes which apply to 5,939 algal taxa. Prior to this work, a comprehensive summary of algal autecological attributes for North American streams and rivers did not exist. Use of the database requires taxonomic identification of algal species, currently performed using microscopic techniques to identify algae down to the species level.

Taxa counts converted into % abundance measurements may be matched with taxa in the USGS Algal Attributes file for conversion to algal attributes, which may be manually selected and include salinity, pH, conductivity, and nutrients. Certain attributes contain sub-categories, such as soft algae and diatoms, and regional indicators for nutrient conditions. Each taxa linked to an attribute is given metric codes, which indicate what characteristics of each attribute the taxa represents. For example, taxa that contain the metric label EHTN_1 indicate high TN within the eastern highlands region, and taxa with the metric label DCOND_HI are diatoms with a high specific conductance optimum. Each taxa in the file is listed alphabetically, and metric labels are indicated for each attribute in columns to the right using numeric metric codes (Porter, 2008).

Maine Department of Environmental Protection

Work by Maine DEP has specifically explored the use benthic algae to assess the quality of Maine's wadeable freshwater streams as it relates to impervious cover. Maine DEP collected samples from 193 sites across the state, encompassing a range of streams from entirely forested watersheds to streams in urban watersheds. Sampling involved using a stiff brush to scrape benthic algae from cobbles or small boulders in riffles or runs of wadeable streams, where water levels were most constant. Algae were counted using traditional microscopy techniques; diatoms were typically identified down to the species level, and some non-diatoms were identified to the genus level. During analysis, enumeration data was converted to % abundance values to reduce the influence of numerically abundant species, similarly to Porter et al, 2008.

Maine DEP developed an empirical method of assigning tolerance values based on local data, rather than using professional judgment or tolerance values from other regions. Algal taxa were categorized as sensitive, intermediate, or tolerant according to Maine stream tolerance values, based upon stressors specific to Maine: Phosphorus, Nitrogen, Conductivity, % Developed watershed, and % Impervious Cover. It was found that metrics based on local tolerance values outperformed metrics that used tolerance values from other parts of the world; it was also found that many metrics used in other algal bioassessments were not useful indicators in Maine, presumably because of regional differences in climate, geology, and predominant anthropogenic stressors. At the end of analysis a novel set of metrics were created; both for algal families associated with streams in disturbed watersheds in Maine and genera associated with minimally disturbed sites in Maine.

In 2012 Maine DEP published a statistical model for analysis of Maine's wadeable streams with the best-performing metrics to evaluate algal community condition relative to the national Biological Condition Gradient (Danielson et al, 2012). The Biological Condition Gradient was published in 2006 in a collaboration between Maine DEP and the Environmental Protection

Agency, and describes how 10 ecological attributes change in response to increasing levels of stressors. The goal of the model is to provide a means to make more consistent, ecologically relevant interpretations and communicate those results to the public (Davies & Jackson, 2006).

From their work to date, Maine DEP has found that sensitivity of bioassessment programs may be enhanced by incorporating stressor-specific metrics when evaluating water-quality. Such metrics serve a critical role in diagnosing sources of impairment. Multimetric indices provide an assessment of overall condition, whereas those implementing water-quality programs can use stressor-specific metrics and autecological indices to prioritize & target actions to restore water quality and monitor improvements of resource condition (Danielson et al, 2011).

Next-Generation Genomic Sequencing

Recent technological developments have caused a major shift in DNA sequencing techniques. Modern methods involve sequencing high numbers of short DNA strands, and have been generally termed "next-generation sequencing", or NGS (Stillman & Armstrong, 2015). These technologies were first introduced to the market in 2005, and have already revolutionized the way scientists process environmental data (Morozova & Marra, 2008). Each organism/bacteria has a unique Ribosomal RNA sequence, which can be identified using a specific primer set for eukaryotes, bacteria, etc. (Smucker et al., 2013). Most NGS studies relating to biodiversity involved sequences that specify only to the family or genus, however diatom assessment typically requires species-level information (Zimmermann et al., 2015).

Data analysis is one of the main challenges of NGS (Smucker et al., 2013). Gathering outputs at the species level of specificity and matching those results to known databases is one of the main challenges in this field currently, and one of the focuses of this study.

Methods

Sampling Methods

Attached algae were chosen for this study because they grow in estuarine & freshwater, and are relatively easy to collect. Previous studies, including work by Maine DEP, have used algae attached to natural substrate such as rocks. This was considered, however it was determined that for the first study in Great Bay a periphytometer would be more appropriate (Figure 1).

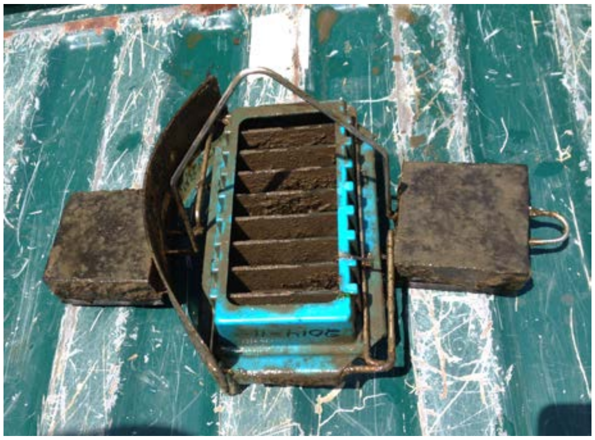


Figure 1: Periphytometer

Controlling for substrate, time, light, flow, depth at each sampling location helped eliminate variability across freshwater, tidal, and estuarine locations. Glass slides were submerged for 2-week intervals, then collected, scraped, and sent to a third party lab for taxa identification.

Sixteen sample sites within the estuary captured the Exeter, Lamprey, and Oyster rivers as well as the bay (Table 1). Approximately six sites were located at inland freshwater portions of the rivers, six sites captured the tidal sections of the rivers, and one site was located in the bay itself (Figures 2 and 3).

Table 1: Site Details

Site	Location	Water Body	Freshwater / Estuarine
001	Haigh Road Brentwood	Exeter River	FW
002	Pickpocket Dam	Exeter River	FW
003	Shaw Hill Road / Rt. 150	Great Brook	FW
004	Chadwick Ln / Gilman St	Little River	FW
005	Gilman St. / Gilman Ln	Exeter River	FW
006	High St. / Rt. 108	Exeter River	FW
007	0.75km below String Bridge	Exeter River	E

008	Exeter Country Club below Parkman Creek Confluence	Wheelwright Creek	FW/E
009	River Road	Squamscott River	E
010	Railroad Bridge, Stratham	Squamscott River Estuary	E
011	Above Wiswall Dam	Lamprey River	FW
012	Packers Falls, upstream of bridge	Lamprey River	FW
013	Downtown Newmarket, below falls	Lamprey River Estuary	E
014	Jackson Landing, Durham	Oyster River Estuary	E
015	Mid Great Bay, buoy	Great Bay	E

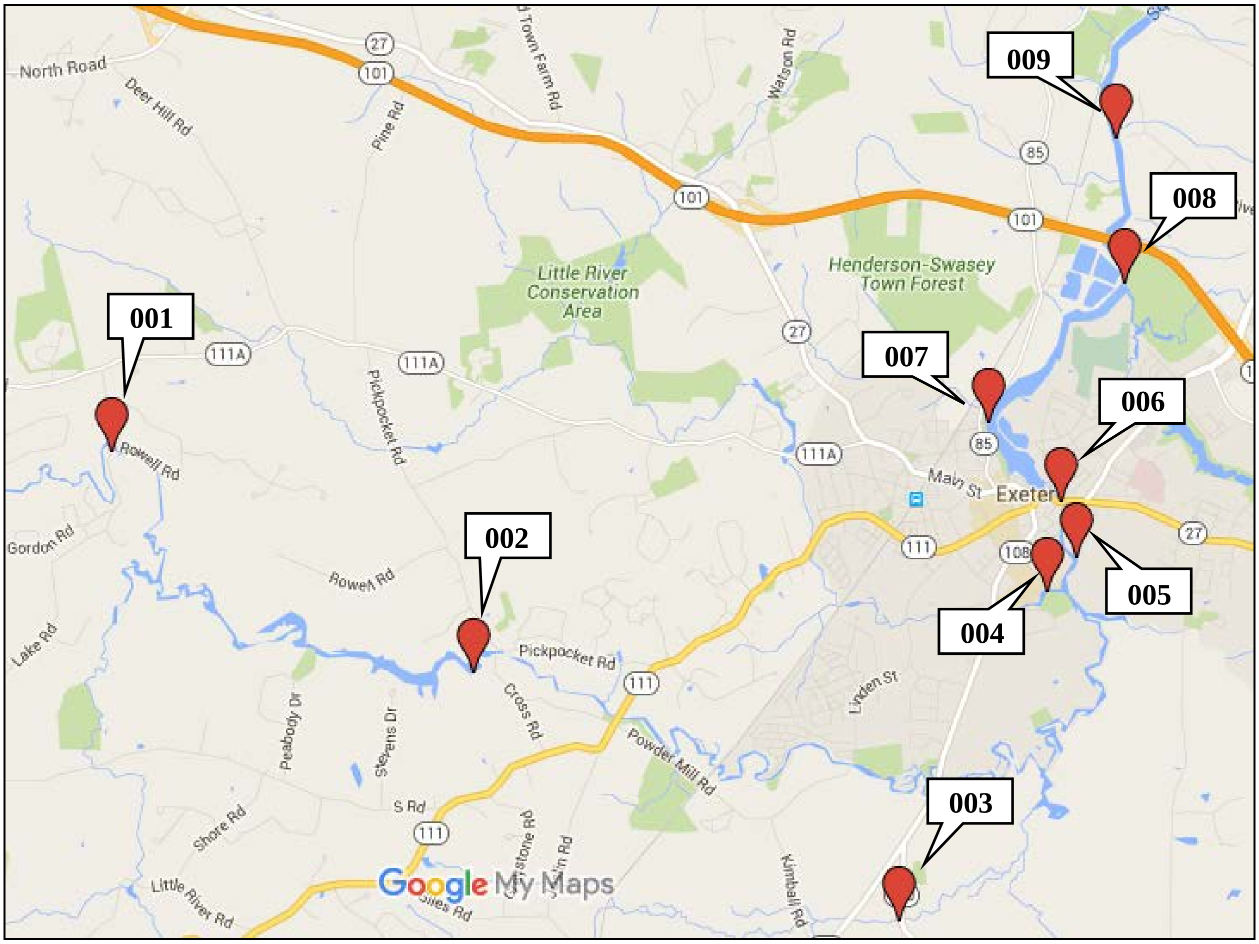


Figure 2: Upriver Site Locations

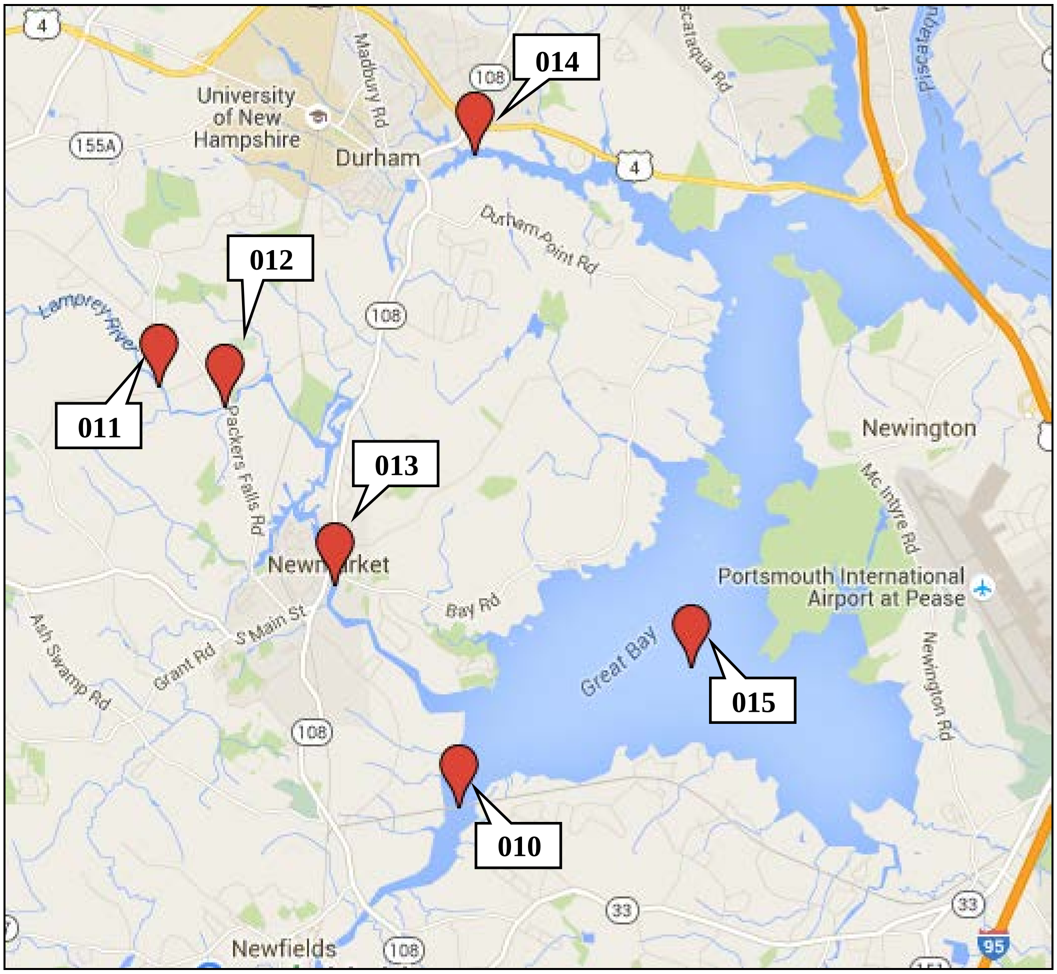


Figure 3: Downriver and Great Bay Site Locations

Traditional Microscopic Analysis Methods

Taxa counts were converted into % abundance for each site, and manually matched with taxa in the USGS Algal Attributes file for association with certain attributes; Salinity, pH, conductivity, and nutrients. Certain attributes contained sub-categories, such as pH indicator taxa for soft algae and diatoms, and regional indicators for nutrient conditions. Each taxa was linked to an attribute and given a metric code, which indicated what characteristics of each attribute the taxa represented. For example, taxa that contained the metric label EHTN_1 indicated high TN within the eastern highlands region, and taxa with the metric label DCOND_HI were diatoms with a high specific conductance optimum. Taxa in the file are listed alphabetically, and metric labels are indicated for each attribute in columns to the right using numeric metric codes. This analysis was performed manually and yielded basic water quality results from the USGS method, which was then compared to field data using two methods. First data was compared in excel, then data was analyzed in JMP using a principal components analysis. This analysis did not yield any statistically significant results due to the limited size of the data set, however early TP and salinity results yielded unexpectedly distinct patterns, encouraging further study and expansion of the data set.

Genomic Analysis Methods

In partnership with the UNH Genome Center, Illumina sequencing was used to analyze algae and water samples from each sample site. This type of sequencing is the most successful NGS technique to date, and is used worldwide. Illumina machinery can handle complex environmental samples and have an increased input ability compared to previous sequencing technologies. In the Illumina process, a combination of chemical reactions and detection methods are used to sequence large amounts of DNA or RNA strands. Prior to analysis, short pieces of DNA/RNA are washed across a flow cell with selected primers. Those that stick are amplified repeatedly using the polymerase chain reaction, forming clusters. Once colonies have formed, nucleotides tagged with fluorescent indicators are added one at a time, with a unique color identifying each base. As each indicator is added, it is hit with a laser which activates the colors, which are read with a camera. This sequencing produces millions of highly accurate reads, which may then be matched to known sequences in a database to identify what organisms are present in the sample (Illumina, 2016).

Results and Discussion

Chemical Water Quality Data

Water quality data was obtained at each site for Total Dissolved Nitrogen (TDS), Nitrate Nitrogen (NO3-N), Total Suspended Solids (TSS), Ammonia Nitrogen (NH4-N), Phosphate (PO4), Total Nitrogen (TN), and Total Phosphorus (TP). Each site was sampled three times; Trial 1 during June 2014, Trial 2 in September of 2014, and Trial 3 in June of 2015. For each trial, water quality was tested when the periphytometer was deployed and retrieved. This data is displayed in Table 2, where Sample codes reflect the trial number, deployment or retrieval, site number, and whether the site was freshwater or estuarine.

Table 2: Water quality field measurements

SAMPLE:	TDN (mg/L)	NO3-N (mgL)	TSS (mg/L)	NH4-N (µg/L)	PO4 (µg/L)	TN (mg/L)	TP (µg/L)
T1-D-001-fw	0.434	0.202	27.816	22.518	13.236		
T1-R-001-fw	0.407	0.205	5.135	17.665	9.010		
T2-D-001-fw	0.366	0.116	3.400	9.170	16.209		
T2-R-001-fw	0.398	0.137	0.600	22.831	2.615		
T3-D-001-fw	0.356	0.142	3.200	21.623	5.966	0.644	18.002
T3-R-001-fw	0.412	0.143	1.600	19.748	7.111	0.625	51.480
T1-D-002-fw	0.410	0.179	21.130	28.844	12.431		
T1-R-002-fw	0.368	0.107	2.821	18.996	15.249		
T2-D-002-fw	0.326	0.047	2.000	10.174	15.177		
T2-R-002-fw	0.328	0.033	1.600	19.331	2.615		
T3-D-002-fw	0.339	0.088	3.913	31.112	3.501	0.567	13.377
T3-R-002-fw	0.460	0.166	1.667	25.182	7.680	0.543	21.857
T1-D-003-fw	0.528	0.033	33.890	49.428	48.457		
T1-R-003-fw	0.382	0.003	20.667	40.940	35.777		
T2-D-003-fw	0.461	0.016	1.200	21.663	34.006		
T2-R-003-fw	0.348	0.000	49.167	31.331	32.340		
T3-D-003-fw	0.466	0.040	5.455	33.360	51.425	0.687	169.174
T3-R-003-fw	0.611	0.021	7.500	19.980	77.408	0.731	128.698
T1-R-004-fw	0.311	0.038	3.636	6.814	11.224		
T2-D-004-fw	0.581	0.075	4.412	25.973	20.207		
T2-R-004-fw	0.501	0.112	6.667	35.463	18.554		
T2-R-004-fw-duplicate	0.519	0.074	4.615	35.565	13.600		
T3-D-004-fw	0.540	0.129	3.784	51.589	9.491	0.691	53.258

T3-D-004-fw-duplicate	0.357	0.068	7.826	29.614	9.087	0.552	45.142
T3-R-004-fw	0.492	0.108	5.652	25.299	11.264	0.666	65.346
T1-D-005-fw	0.411	0.154	37.639	28.265	14.645		
T1-R-005-fw	0.482	0.143	6.000	18.084	16.255		
T2-D-005-fw	0.468	0.070	2.833	10.569	15.435		
T2-R-005-fw	0.348	0.009	3.030	8.084	3.907		
T3-D-005-fw	0.383	0.084	11.154	27.366	5.853	0.671	55.345
T3-R-005-fw	0.483	0.126	2.979	96.048	11.538	0.549	27.685
T1-D-006-fw	0.461	0.140	33.478	8.667	45.820		
T1-R-006-fw	0.301	0.007	3.333	8.911	11.022		
T1-R-006-fw-duplicate	0.331	0.010	3.143	10.594	14.846		
T2-D-006-fw	0.361	0.024	0.769	2.747	16.854		
T2-D-006-fw-duplicate	0.338	0.065	3.636	9.540	21.109		
T2-R-006-fw	0.367	0.004	2.286	7.675	5.415		
T3-D-006-fw	0.426	0.095	24.118	21.124	7.154	0.661	44.070
T3-R-006-fw	0.494	0.122	2.581	30.105	11.467	0.513	21.006
T3-R-006-fw-duplicate	0.483	0.128	4.000	24.669	11.676	0.770	40.635
T1-D-011-fw	0.465	0.257	18.754	31.437	17.664		
T1-R-011-fw	0.400	0.161	2.000	18.454	11.022		
T1-D-012-fw	0.476	0.265	9.858	21.692	13.639		
T1-R-012-fw	0.348	0.156	1.961	25.571	29.244		
T1-D-007-e	0.474	0.167	105.325	11.671	15.047		
T1-R-007-e	0.509	0.128	18.667	103.047	9.815		
T2-D-007-e	0.567	0.166	18.571	71.274	26.655		
T2-R-007-e	0.619	0.193	8.286	63.674	14.246		
T3-D-007-e	0.354	0.090	15.455	22.769	12.982	0.866	114.016
T3-R-007-e	0.509	0.195	18.261	14.445	19.955	0.826	105.881
T1-D-009-e	0.287	0.049	127.988	2.380	9.211		

T1-R-009-e	0.496	0.018	58.571	16.132	32.154		
T2-D-009-e	0.974	0.411	45.833	275.746	55.027		
T2-R-009-e	1.077	0.439	70.909	276.843	35.140		
T3-D-009-e	0.447	0.101	147.500	52.838	19.791	1.666	319.659
T3-R-009-e	0.611	0.292	30.588	49.801	39.363	0.990	98.064
T1-D-010-e	0.466	0.112	58.462	159.116	33.966		
T1-D-010-e-duplicate	0.414	0.100	57.500	155.550	33.765		
T1-R-010-e	0.303	0.030	54.286	61.331	30.142		
T2-D-010-e	0.272	0.039	17.027	4.597	33.232		
T2-D-010-e-duplicate	0.258	0.045	12.658	4.411	33.490		
T2-R-010-e	0.212	0.022	25.333	1.271	42.895		
T2-R-010-e-duplicate	0.238	0.020	20.909	6.764	38.156		
T3-D-010-e	0.269	0.050	38.500	31.861	16.528	0.460	76.828
T3-R-010-e	0.391	0.046	26.190	60.935	26.973	0.473	76.151
T1-D-013-e	0.523	0.258	5.909	52.242	17.060		
T1-R-013-e	0.303	0.127	1.333	24.000	14.645		
T2-D-013-e	0.355	0.074	10.476	3.302	31.427		
T2-R-013-e	0.448	0.132	2.857	41.870	17.047		
T3-D-013-e	0.368	0.120	7.000	36.356	7.669	0.654	40.143
T3-R-013-e	0.493	0.145	3.000	35.011	8.063	0.588	18.573
T1-D-014-e	0.413	0.156	3.846	69.151	34.972		
T1-R-014-e	0.336	0.103	10.000	50.276	27.868		
T2-D-014-e	0.397	0.119	0.571	12.185	16.725		
T2-R-014-e	0.325	0.059	38.095	78.612	101.268		
T3-D-014-e	0.437	0.077	13.548	61.578	19.219	0.496	38.006
T3-R-014-e	0.474	0.090	35.625	85.790	36.943	0.540	75.519
T1-D-015-e	0.260	0.054	6.000	56.829	21.287		
T1-R-015-e	0.079	0.007	12.667	10.451	12.230		

T1-R-015-e-duplicate	0.157	0.001	20.625	6.032	13.840		
T2-D-015-e	0.208	0.042	19.815	18.611	29.105		
T2-R-015-e	0.202	0.039	28.000	16.182	36.433		
T3-D-015-e	0.295	0.034	22.800	1.146	6.927	0.307	30.658
T3-R-015-e	0.269	0.042	30.952	45.335	19.049	0.285	26.778
T3-D-016-e	0.233	0.053	32.800	12.633	11.490	0.239	29.834
T3-R-016-e	0.285	0.034	33.333	21.383	21.005	0.376	32.806

Traditional Microscope Data

Taxa identification and counts were obtained from the Academy of Natural Sciences of Drexel University. This data is summarized in Table 3.

Table 3: Microscopic taxa identification results

Taxon ID	Taxon Name	Total Present
1010	Achnanthidium minutissimum (Kützing) Czarnecki	2522
1024	Achnanthidium exiguum (Grunow) Czarnecki	3
1036	Achnanthidium rivulare Potapova et Ponader	78
2122	Achnanthes brevipes Agardh	1
2990	Achnanthes sp. 1 ?	7
6001	Amphipleura pellucida (Kützing) Kützing	9
7010	Amphora inariensis Krammer	1
7043	Amphora pediculus (Kützing) Grunow	1
7073	Amphora subholsatica Krammer	1
7075	Amphora copulata (Kützing) Schoeman et Archibald	3
7161	Amphora sp.	43
10008	Aulacoseira ambigua (Grunow) Simonsen	5
10019	Aulacoseira italica (Ehrenberg) Simonsen	15
16003	Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	139
16004	Cocconeis placentula Ehrenberg	334

16010	Cocconeis fluviatilis Wallace	1
16011	Cocconeis pediculus Ehrenberg	1
16013	Cocconeis scutellum Ehrenberg	197
16035	Cocconeis sp.	1
20001	Cyclotella atomus Hustedt	572
20007	Cyclotella meneghiniana Kützing	109
20011	Cyclotella striata (Kützing) Grunow	3
23048	Cymbella aspera (Ehrenberg) Cleve	1
23068	Cymbella tumida (Brébisson ex Kützing) Van Heurck	111
25004	Denticula subtilis Grunow	1
30004	Diploneis oblongella (Nägeli ex Kützing) Ross	1
30006	Diploneis subovalis Cleve	1
31001	Entomoneis paludosa (Smith) Reimer	1
31003	Entomoneis alata (Ehrenberg) Ehrenberg	1
32003	Epithemia adnata (Kützing) Brébisson	2
33019	Eunotia flexuosa (Brébisson ex Kutzing) Kützing	2
33021	Eunotia formica Ehrenberg	3
33026	Eunotia incisa Smith ex Gregory	25
33036	Eunotia naegelii Migula	1
33059	Eunotia sudetica Müller	12
33066	Eunotia intermedia (Krasske ex Hustedt) Nörpel et Lange-Bertalot	8
33083	Eunotia paludosa Grunow	1
33168	Eunotia implicata Nörpel, Alles et Lange-Bertalot	36
33172	Eunotia faba (Ehrenberg) Grunow	2
33183	Eunotia minor (Kützing) Grunow	139
33185	Eunotia bilunaris (Ehrenberg) Souza	31
33362	Eunotia sp.	5
33395	Eunotia juettnerae Lange-Bertalot	2
33990	Eunotia sp. 1 ?	4
34006	Fragilaria capucina Desmazières	226
34017	Fragilaria crotonensis Kitton	518
34030	Fragilaria vaucheriae (Kützing) Petersen	11

34098	Fragilaria capucina var. gracilis (Østrup) Hustedt	28
34212	Fragilaria sepes Ehrenberg	31
34237	Fragilaria mesolepta Rabenhorst	172
35011	Frustulia vulgaris (Thwaites) De Toni	1
37001	Gomphonema acuminatum Ehrenberg	43
37003	Gomphonema angustatum (Kützing) Rabenhorst	9
37007	Gomphonema gracile Ehrenberg	184
37010	Gomphonema parvulum (Kützing) Kützing	2490
37022	Gomphonema truncatum Ehrenberg	75
37029	Gomphonema subclavatum (Grunow) Grunow	53
37057	Gomphonema turris Ehrenberg	25
37065	Gomphonema olivaceum (Lyngbye) Kützing	1
37071	Gomphonema augur Ehrenberg	39
37080	Gomphonema rhombicum Fricke	25
37084	Gomphonema brebissonii Kützing	5
37118	Gomphonema minusculum Krasske	4
37152	Gomphonema sarcophagus Gregory	2
37168	Gomphonema micropus Kützing	7
37178	Gomphonema minutum (Agardh) Agardh	243
37193	Gomphonema patricki Kociolek et Stoermer	8
37197	Gomphonema kobayasii Kociolek et Kingston	6
37302	Gomphonema drutelingense Reichardt	6
37308	Gomphonema pala Reichardt	6
37310	Gomphonema exilissimum (Grunow) Lange-Bertalot et Reichardt	269
37311	Gomphonema parvulius (Lange-Bertalot et Reichardt) Lange-Bertalot et Reichardt	2
37398	Gomphonema coronatum Ehrenberg	5
37990	Gomphonema sp. 1 ?	250
38004	Gyrosigma spencerii (Smith) Griffith et Henfrey	1
38017	Gyrosigma macrum (Smith) Griffith et Henfrey	3
38030	Gyrosigma sp.	2
44068	Melosira nummuloides (Dillwyn) Agardh	57
44073	Melosira varians Agardh	142

45001	Meridion circulare (Greville) Agardh	3
45002	Meridion circulare var. constrictum (Ralfs) Van Heurck	20
46003	Navicula arvensis Hustedt	2
46014	Navicula cryptocephala Kützing	57
46023	Navicula gregaria Donkin	35
46056	Navicula radiosa Kützing	7
46078	Navicula submuralis Hustedt	1
46104	Navicula tripunctata (Müller) Bory	1
46154	Navicula rhynchocephala Kützing	3
46289	Navicula peregrina (Ehrenberg) Kützing	2
46317	Navicula canalis Patrick	4
46324	Navicula cincta (Ehrenberg) Ralfs	1
46389	Navicula salinarum Grunow	7
46390	Navicula salinicola Hustedt	82
46504	Navicula veneta Kützing	1
46527	Navicula cryptotenella Lange-Bertalot	75
46538	Navicula perminuta Grunow	139
46616	Navicula germainii Wallace	10
46646	Navicula caterva Hohn et Hellerman	2
46648	Navicula erifuga Lange-Bertalot	4
46649	Navicula recens (Lange-Bertalot) Lange-Bertalot	967
46651	Navicula phyllepta Kützing	49
46859	Navicula lanceolata (Agardh) Kützing	3
46896	Navicula rostellata Kützing	1
46990	Navicula sp. 1 ?	50
46991	Navicula sp. 2 ?	685
46992	Navicula sp. 3 ?	17
48004	Nitzschia amphibia Grunow	15
48006	Nitzschia capitellata Hustedt	1
48008	Nitzschia dissipata (Kützing) Grunow	10
48013	Nitzschia frustulum (Kützing) Grunow	15
48015	Nitzschia gracilis Hantzsch	10

48023	Nitzschia linearis (Agardh) Smith	7
48024	Nitzschia microcephala Grunow	2
48025	Nitzschia palea (Kützing) Smith	318
48032	Nitzschia sublinearis Hustedt	6
48122	Nitzschia inconspicua Grunow	222
48123	Nitzschia pusilla Grunow	4
48126	Nitzschia perminuta (Grunow) Peragallo	11
48145	Nitzschia filiformis (Smith) Van Heurck	2
48157	Nitzschia linearis var. tenuis (Smith) Grunow	14
48165	Nitzschia paleacea Grunow	1
48174	Nitzschia reversa Smith	34
48197	Nitzschia brevissima Grunow ex Van Heurck	1
48225	Nitzschia sociabilis Hustedt	3
48229	Nitzschia angustatula Lange-Bertalot	1
48349	Nitzschia tubicola Grunow	3
48351	Nitzschia pellucida Grunow	5
48377	Nitzschia lacuum Lange-Bertalot	28
48381	Nitzschia filiformis var. conferta (Richter) Lange-Bertalot	1
48392	Nitzschia thermaloides Hustedt	3
48417	Nitzschia archibaldii Lange-Bertalot	25
48638	Nitzschia sp.	4
50990	Opephora sp. 1 ?	1
52013	Pinnularia borealis Ehrenberg	1
52045	Pinnularia microstauron (Ehrenberg) Cleve	1
52059	Pinnularia subcapitata Gregory	2
52148	Pinnularia acrosphaeria (Brébisson) Smith	1
52159	Pinnularia gibba (Ehrenberg) Ehrenberg	3
52194	Pinnularia interrupta Smith	1
53012	Surirella sp.	1
54004	Pleurosigma delicatulum Smith	1
57002	Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	5
58001	Rhopalodia gibba (Ehrenberg) Müller	1

62007	Stauroneis smithii Grunow	1
62008	Stauroneis kriegeri Patrick	2
62015	Stauroneis phoenicenteron (Nitzsch) Ehrenberg	1
65064	Surirella brebissonii var. kuetzingii Krammer et Lange-Bertalot	1
65068	Surirella brebissonii Krammer et Lange-Bertalot	5
67004	Tabellaria flocculosa (Roth) Kützing	31
69001	Thalassionema nitzschioides (Grunow) Van Heurck	5
70009	Thalassiosira bramaputrae (Ehrenberg) Håkansson et Locker	1
70029	Thalassiosira proschkinae Makarova	519
70034	Thalassiosira sp.	12
73001	Pseudostaurosira brevistriata (Grunow) Williams et Round	14
73010	Pseudostaurosira parasitica (Smith) Morales	3
76001	Bacillaria paradoxa Gmelin	24
87003	Licmophora sp.	1
89889	Undetermined Pennate	1
89895	Undetermined Centric sp. 1 ?	190
93021	Navicula duerrenbergiana Hustedt	154
93383	Navicula sp.	2
94071	Achnanthes sp.	15
98004	Psammodictyon panduriforme var. continua (Grunow) Snoeijs	4
110004	Encyonema minutum (Hilse) Mann	1
110005	Encyonema silesiacum (Bleisch) Mann	113
110009	Encyonema lunatum (Smith) Van Heurck	1
110063	Encyonema sp.	21
115001	Fallacia pygmaea (Kützing) Stickle et Mann	5
115003	Fallacia cryptolyra (Brockmann) Stickle et Mann	5
115990	Fallacia sp. 1?	6
115016	Fallacia lenzii (Hustedt) Lange-Bertalot	10
115037	Fallacia litoricola (Hustedt) Mann	1
125001	Karayevia clevei (Grunow) Bukhtiyarova	7
125002	Karayevia laterostrata (Hustedt) Bukhtiyarova	2
125011	Karayevia oblongella (Østrup) Aboal	1

130002	Luticola mutica (Kützing) Mann	1
150003	Odontella aurita (Lyngbye) Agardh	1
155003	Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	16
155005	Planothidium peragalli (Brun et Héribaud) Round et Bukhtiyarova	3
155009	Planothidium delicatulum (Kützing) Round et Bukhtiyarova	4
155017	Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	174
155018	Planothidium rostratum (Østrup) Lange-Bertalot	15
155026	Planothidium oestrupii (Cleve-Euler) Edlund	1
170006	Sellaphora pupula (Kützing) Meresckowsky	13
170014	Sellaphora seminulum (Grunow) Mann	43
170033	Sellaphora hustedtii (Krasske) Lange-Bertalot et Werum	3
172001	Staurosira construens Ehrenberg	6
172005	Staurosira construens var. binodis (Ehrenberg) Hamilton	1
172006	Staurosira construens var. venter (Ehrenberg) Hamilton	77
175005	Staurosirella pinnata (Ehrenberg) Williams et Round	18
185006	Tryblionella balatonis (Grunow) Mann	1
185021	Tryblionella calida (Grunow) Mann	2
185023	Tryblionella apiculata Gregory	5
185024	Tryblionella hungarica (Grunow) Frenguelli	2
185025	Tryblionella littoralis (Grunow) Mann	2
185039	Tryblionella compressa (Bailey) Poulin	4
186007	Psammothidium rossii (Hustedt) Bukhtiyarova et Round	1
186008	Psammothidium subatomoides (Hustedt) Bukhtiyarova et Round	1
187002	Eucocconeis laevis (Østrup) Lange-Bertalot	2
188001	Lemnicola hungarica (Grunow) Round et Basson	40
189004	Rossithidium anastasiae (Kaczmarska) Potapova	20
190005	Cymbopleura naviculiformis (Auerswald) Krammer	1
192001	Fragilariforma bicapitata (Mayer) Williams et Round	1
192003	Fragilariforma constricta fo. stricta (Cleve-Euler) Poulin	1
193001	Stauroforma exiguiformis (Lange-Bertalot) Flower, Jones et Round	18
194009	Placoneis placentula (Ehrenberg) Mereschkowsky	1
195003	Cavinula pseudoscutiformis (Hustedt) Mann et Stickle	1

197001	Diadesmis confervacea Kützing	31
197002	Diadesmis contenta (Grunow ex Van Heurck) Mann	1
200002	Tabularia fasciculata (Agardh) Williams et Round	35
201001	Ctenophora pulchella (Ralfs ex Kützing) Williams et Round	60
210003	Geissleria decussis (Østrup) Lange-Bertalot et Metzeltin	1
211010	Mayamaea permitis (Hustedt) Bruder et Medlin	1
213001	Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski	17
213002	Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin et Witkowski	22
213003	Hippodonta lueneburgensis (Grunow) Lange-Bertalot, Metzeltin et Witkowski	8
218002	Fistulifera saprophila (Lange-Bertalot et Bonik) Lange-Bertalot	5
225002	Berkeleya rutilans (Trentepohl ex Roth) Grunow	43
225990	Berkeleya sp. 1 ?	13
245001	Ulnaria ulna (Nitzsch) Compère	154
245005	Ulnaria acus (Kützing) Aboal	53
2506003	Discostella stelligera (Cleve et Grunow) Houk et Klee	1
2508001	Platessa conspicua (Mayer) Lange-Bertalot	4
8942001	Eolimna minima (Grunow) Lange-Bertalot	25
9049003	Seminavis pusilla (Grunow) Cox et Reid	1
9055990	Gomphonemopsis sp. 1 ?	2
9098003	Halamphora coffeaeformis (Agardh) Levkov	244
9098013	Halamphora veneta (Kützing) Levkov	1
9112001	Grammatophora marina (Lyngbye) Kützing	7

Following the taxa identification, data were processed using Microsoft Excel according to the 2008 USGS Method published by Porter et al. Taxa were quantified in terms of percent abundance at each site (averaged over four trials- June 2014, September 2014, June 2015, September 2015), then taxa were grouped by water quality attributes from the USGS Method. The proportion of diatoms present which indicated the given water quality parameter for each study site is summarized in Table 4.

Table 4: Percent Abundance of various water quality indicators by site ID using USGS method

SITE ID		J-001	J-002	J-003	J-004	J-005	J-006	J-007	J-009	J-011	J-012	J-013	J-014	J-015	S-001	S-002	S-003	S-004	S-005	S-006	S-007	S-010	S-013	S-014	S-015
NF	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
TROPHIC	1	0.007	0.005	0.018	0.007	0.007	0.010	0.002	0.000	0.088	0.126	0.002	0.000	0.000	0.072	0.068	0.047	0.066	0.036	0.005	0.000	0.000	0.000	0.000	0.000
	2	0.045	0.003	0.000	0.020	0.020	0.017	0.008	0.000	0.006	0.000	0.014	0.000	0.000	0.000	0.000	0.013	0.005	0.022	0.005	0.000	0.000	0.000	0.000	0.000
	3	0.156	0.038	0.089	0.159	0.100	0.089	0.022	0.005	0.016	0.008	0.129	0.011	0.012	0.036	0.020	0.108	0.202	0.254	0.610	0.000	0.000	0.022	0.004	0.000
	4	0.087	0.000	0.009	0.007	0.025	0.012	0.036	0.008	0.003	0.002	0.012	0.006	0.008	0.152	0.022	0.029	0.012	0.138	0.052	0.020	0.012	0.005	0.031	0.009
	5	0.243	0.316	0.413	0.139	0.396	0.378	0.891	0.907	0.317	0.616	0.709	0.129	0.033	0.231	0.513	0.399	0.404	0.452	0.270	0.761	0.157	0.859	0.308	0.099
	6	0.002	0.000	0.025	0.000	0.000	0.000	0.012	0.070	0.000	0.000	0.072	0.022	0.025	0.003	0.000	0.049	0.003	0.000	0.005	0.154	0.086	0.090	0.132	0.016
	7	0.375	0.616	0.250	0.663	0.446	0.481	0.012	0.000	0.549	0.210	0.026	0.031	0.000	0.403	0.367	0.284	0.287	0.075	0.036	0.006	0.032	0.002	0.015	0.020
EUTROPHIC	1	0.332	0.316	0.447	0.146	0.421	0.390	0.939	0.985	0.320	0.617	0.792	0.157	0.066	0.386	0.534	0.477	0.420	0.590	0.327	0.934	0.256	0.955	0.471	0.124
DIATASTN	1	0.132	0.285	0.401	0.131	0.390	0.366	0.788	0.278	0.292	0.470	0.691	0.073	0.041	0.179	0.481	0.531	0.245	0.260	0.145	0.880	0.128	0.734	0.253	0.049
	2	0.438	0.626	0.074	0.668	0.449	0.482	0.014	0.005	0.567	0.248	0.024	0.017	0.000	0.517	0.376	0.031	0.282	0.069	0.027	0.003	0.005	0.005	0.007	0.004
DIATASTP	1	0.123	0.285	0.204	0.131	0.390	0.366	0.799	0.980	0.291	0.470	0.719	0.126	0.041	0.178	0.481	0.340	0.283	0.256	0.175	0.920	0.150	0.765	0.434	0.067
	2	0.408	0.623	0.044	0.793	0.503	0.536	0.014	0.002	0.552	0.221	0.021	0.017	0.000	0.397	0.372	0.020	0.358	0.231	0.533	0.003	0.005	0.005	0.002	0.002
GNTP	1	0.002	0.000	0.009	0.007	0.005	0.007	0.161	0.205	0.000	0.000	0.515	0.014	0.000	0.000	0.000	0.031	0.050	0.006	0.036	0.692	0.000	0.593	0.035	0.002
	2	0.465	0.621	0.046	0.663	0.447	0.481	0.016	0.000	0.550	0.223	0.014	0.017	0.000	0.483	0.369	0.020	0.264	0.079	0.075	0.003	0.005	0.005	0.002	0.002
GNTN	1	0.021	0.002	0.014	0.007	0.005	0.007	0.175	0.902	0.002	0.000	0.595	0.078	0.000	0.000	0.000	0.031	0.019	0.002	0.002	0.707	0.027	0.797	0.240	0.038
	2	0.347	0.624	0.048	0.677	0.467	0.497	0.014	0.000	0.547	0.223	0.010	0.017	0.000	0.391	0.372	0.052	0.275	0.162	0.086	0.003	0.005	0.005	0.002	0.002
EHTP	1	0.134	0.028	0.199	0.007	0.005	0.005	0.289	0.065	0.024	0.148	0.112	0.048	0.021	0.067	0.028	0.183	0.036	0.026	0.029	0.162	0.140	0.058	0.086	0.038
	2	0.365	0.623	0.046	0.793	0.501	0.536	0.014	0.002	0.550	0.221	0.017	0.017	0.000	0.397	0.372	0.018	0.358	0.205	0.481	0.003	0.005	0.005	0.002	0.002
EHTN	1	0.252	0.313	0.408	0.136	0.415	0.378	0.540	0.012	0.315	0.617	0.072	0.042	0.004	0.245	0.521	0.475	0.257	0.347	0.184	0.057	0.140	0.007	0.031	0.031
	2	0.326	0.608	0.043	0.662	0.446	0.479	0.014	0.005	0.529	0.196	0.010	0.017	0.000	0.362	0.352	0.016	0.271	0.077	0.070	0.003	0.005	0.005	0.002	0.002
SAPROBIC	1	0.163	0.035	0.222	0.035	0.046	0.039	0.030	0.000	0.094	0.128	0.035	0.011	0.012	0.188	0.083	0.160	0.095	0.091	0.050	0.000	0.000	0.000	0.000	0.000
	2	0.589	0.659	0.284	0.828	0.551	0.577	0.154	0.017	0.576	0.334	0.155	0.062	0.012	0.478	0.407	0.228	0.563	0.582	0.714	0.048	0.157	0.031	0.070	0.054
	3	0.054	0.005	0.071	0.005	0.004	0.003	0.329	0.854	0.019	0.029	0.675	0.104	0.029	0.069	0.017	0.155	0.081	0.014	0.059	0.550	0.044	0.854	0.282	0.079
	4	0.125	0.285	0.379	0.129	0.390	0.364	0.457	0.053	0.291	0.470	0.031	0.000	0.000	0.174	0.481	0.408	0.226	0.258	0.138	0.188	0.000	0.002	0.007	0.000
	5	0.002	0.002	0.004	0.000	0.002	0.007	0.012	0.070	0.000	0.002	0.087	0.022	0.025	0.003	0.002	0.013	0.016	0.036	0.029	0.154	0.086	0.092	0.132	0.011
ORG_N	1	0.148	0.035	0.059	0.066	0.093	0.067	0.031	0.000	0.096	0.128	0.035	0.011	0.012	0.174	0.097	0.169	0.111	0.245	0.134	0.000	0.000	0.000	0.000	0.000
	2	0.519	0.646	0.477	0.794	0.506	0.543	0.158	0.713	0.580	0.356	0.089	0.126	0.025	0.533	0.411	0.302	0.420	0.258	0.535	0.068	0.172	0.045	0.280	0.094
	3	0.125	0.287	0.193	0.131	0.392	0.373	0.635	0.053	0.291	0.471	0.182	0.022	0.017	0.174	0.482	0.299	0.280	0.288	0.200	0.185	0.000	0.244	0.055	0.007
	4	0.002	0.000	0.004	0.000	0.000	0.000	0.012	0.070	0.000	0.000	0.068	0.022	0.025	0.003	0.000	0.013	0.000	0.004	0.000	0.154	0.088	0.092	0.143	0.025
POLL_CLASS	1	0.122	0.285	0.195	0.126	0.390	0.364	0.454	0.070	0.291	0.470	0.096	0.042	0.768	0.178	0.481	0.302	0.219	0.247	0.136	0.185	0.091	0.090	0.159	0.103
	2	0.158	0.040	0.323	0.055	0.070	0.057	0.392	0.917	0.023	0.008	0.801	0.179	0.017	0.016	0.008	0.385	0.126	0.178	0.118	0.769	0.093	0.888	0.385	0.076
	3	0.589	0.636	0.245	0.804	0.524	0.548	0.145	0.010	0.570	0.357	0.061	0.042	0.025	0.653	0.431	0.162	0.528	0.477	0.633	0.028	0.125	0.009	0.040	0.025
POLL_TOL	1	0.122	0.285	0.195	0.126	0.390	0.364	0.452	0.070	0.291	0.470	0.096	0.022	0.025	0.178	0.481	0.302	0.219	0.247	0.136	0.182	0.086	0.090	0.132	0.011
	2	0.010	0.000	0.016	0.002	0.000	0.002	0.006	0.014	0.006	0.000	0.054	0.050	0.000	0.000	0.002	0.016	0.017	0.008	0.005	0.011	0.000	0.206	0.093	0.000
	3	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.005	0.000	0.000	0.005	0.003	0.000	0.000	0.000	0.016	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000
	4	0.411	0.616	0.181	0.658	0.439	0.476	0.087	0.000	0.541	0.300	0.012	0.020	0.000	0.338	0.366	0.023	0.273	0.067	0.034	0.003	0.017	0.004	0.018	0.018
	5	0.203	0.012	0.051	0.012	0.032	0.015	0.006	0.003	0.015	0.005	0.084	0.000	0.000	0.102	0.022	0.036	0.043	0.150	0.057	0.000	0.002	0.025	0.011	0.002
OXYTOL	1	0.476	0.633	0.073	0.711	0.510	0.530	0.044	0.003	0.623	0.310	0.073	0.034	0.021	0.557	0.436	0.151	0.368	0.223	0.141	0.020	0.005	0.002	0.026	0.011
	2	0.030	0.015	0.032	0.144	0.082	0.076	0.016	0.710	0.011	0.002	0.063	0.076	0.000	0.031	0.027	0.052	0.105	0.260	0.488	0.034	0.025	0.016	0.216	0.029
	3	0.163	0.035	0.410	0.007	0.009	0.013	0.307	0.005	0.039	0.174	0.166	0.034	0.033	0.121	0.047	0.230	0.098	0.065	0.098	0.011	0.130	0.255	0.070	0.063
	4	0.123	0.285	0.218	0.126	0.390	0.364	0.454	0.076	0.292	0.470	0.099	0.042	0.025	0.178	0.481	0.345	0.238	0.247	0.143	0.185	0.101	0.107	0.163	0.022
	5	0.002	0.000	0.000	0.003	0.000	0.000	0.017	0.053	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.157	0.000	0.002	0.007	0.000
pH	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	0.012	0.012	0.225	0.005	0.009	0.008	0.002	0.000	0.006	0.018	0.000	0.000	0.000	0.024	0.000	0.052	0.003	0.024	0.063	0.000	0.000	0.004	0.000	0.000
	3	0.340	0.328	0.277	0.179	0.453	0.410	0.470	0.081	0.406	0.624	0.229	0.039	0.025	0.326	0.569	0.509	0.487	0.517	0.290	0.205	0.086	0.110	0.137	0.011
	4	0.267	0.036	0.470	0.154	0.096	0.094	0.501	0.907	0.041	0.151	0.749	0.171	0.212	0.253	0.068	0.396	0.181	0.373	0.580	0.752	0.403	0.864	0.368	0.330
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.000	0.000	0.002	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.318	0.611	0.021	0.658	0.440	0.479	0.012	0.000	0.531	0.181	0.010	0.022	0.000	0.314	0.352	0.016	0.309	0.067	0.057	0.003	0.020	0.004	0.004	0.009
SALINITY	1	0.016	0.012	0.225	0.007	0.009	0.008	0.002	0.003	0.093	0.139	0.012	0.000	0.000	0.091	0.068	0.094	0.067	0.053	0.063	0.000	0.000	0.004	0.004	0.000
	2	0.920	0.975	0.768	0.987	0.989	0.983	0.637	0.083	0.891	0.836	0.360	0.095	0.050	0.826	0.922	0.862	0.867	0.921	0.896	0.236	0.241	0.313	0.189	0.056
	3	0.002	0.000	0.000	0.003	0.000	0.000	0.342	0.907	0.000	0.000	0.607	0.098	0.017	0.000	0.000	0.014	0.033	0.004	0.029	0.704	0.015	0.655	0.295	0.049
	4	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.007	0.042	0.050	0.000	0.000	0.004	0.014	0.002	0.002	0.014	0.037	0.011	0.009	0.076
DIATCOND	1	0.000	0.000	0.000	0.000	0.000	0.000	0.159	0.146	0.000	0.000	0.513	0.011	0.332	0.000	0.000	0.005	0.002	0.002	0.000	0.561	0.052	0.604	0.009	0.043
	2	0.184	0.056	0.293	0.033	0.039	0.039	0.005	0.000	0.058	0.076	0.105	0.429	0.021	0.179	0.023	0.113	0.086	0.103	0.118	0.000	0.396	0.025	0.396	0.530
DIAT_CL	1	0.000	0.000	0.000	0.000	0.000	0.000	0.139	0.146	0.000	0.000	0.501	0.000	0.320	0.000	0.000	0.005	0.000	0.002	0.000	0.533	0.017	0.586	0.009	0.043
	2	0.863	0.995	0.752	0.856	0.916	0.914	0.573	0.022	0.904	0.872	0.244	0.521	0.025	0.845	0.902	0.687	0.608	0.464	0.306	0.066	0.548	0.224	0.493	0.566
DIAT_CA	1	0.097	0.015	0.165	0.000	0.002	0.000	0.231	0.151	0.016	0.121	0.510	0.017	0.012	0.024	0.013	0.014	0.012	0.022	0.018	0.561	0.034	0.595	0.000	0.004
	2	0.012	0.021	0.220	0.007	0.012	0.010	0.002	0.000	0.013	0.018	0.000	0.429	0.021	0.022	0.000	0.052	0.014	0.041	0.070	0.000	0.396	0.004	0.396	0.530

Following this analysis, results were run through a principal components analysis using JMP software to observe relationships between the USGS indicator taxa and real field conditions. The first analysis involved the use of TN field data, Land use TN load estimates from a previous study (Geosyntec, 2015) and DIATASTN percent abundance counts. The results, seen in Figure 4, reflect three mildly distinct groups of sites by Nitrogen levels. Green dots represent data from sites 003 and 004, which both had a low anticipated nitrogen load. Blue represent sites 1 and 2, for which a medium nitrogen load was predicted, and pink represents sites 5, 6 and 7 which had a high anticipated load based on land use. Land use nitrogen load estimates were not calculated for sites further downriver.

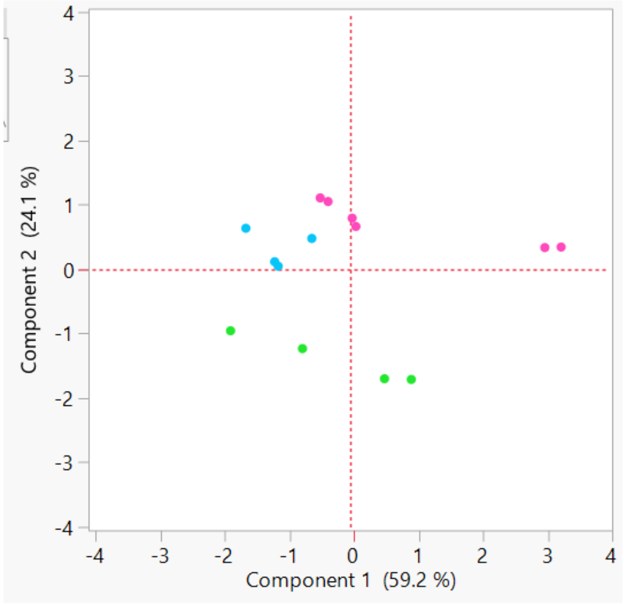


Figure 4: Nitrogen Principal Components Analysis

The next principal components analysis compared TP field measurements with two Phosphorus indicators; Diatom phosphorus, and Eastern Highland Taxa affected by Phosphorus (Figure 5). Orange dots indicate TP conditions below 40ug/L at sites 1,2,6,13, and 15. Blue dots indicate medium TP levels, between 40-75 ug/L and encompassing sites 4,5,14, and 10. Pink dots represent High TP conditions, above 75 ug/L and describe sites 3,7, and 9.

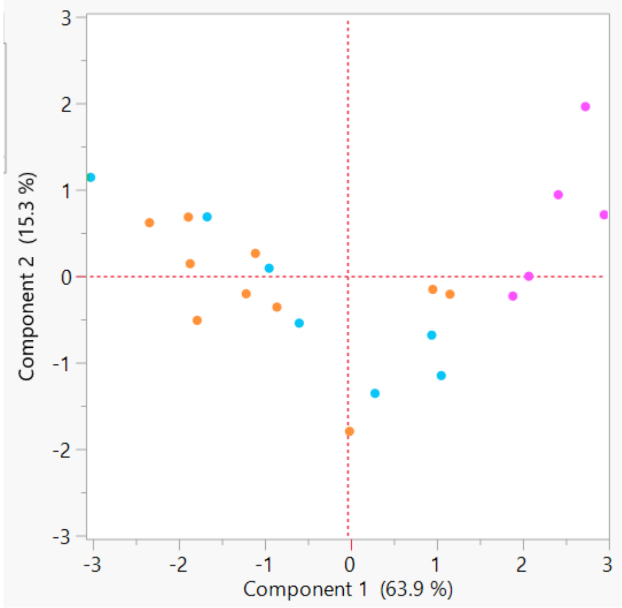


Figure 5: Phosphorus Principal Components Analysis

Diatom phosphorus indicator taxa and eastern highland indicator taxa densities were summed to create total percent abundance measurements for low and high phosphorus conditions. These values were then plotted in excel against TP field data to compare taxa presence to real water quality conditions. Sites 001, 002, 004, 005, 006 and 007 showed promising results (Figure 6). Using the USGS method and taxa database, these sites contained high amounts of taxa which corresponded with water quality field data.

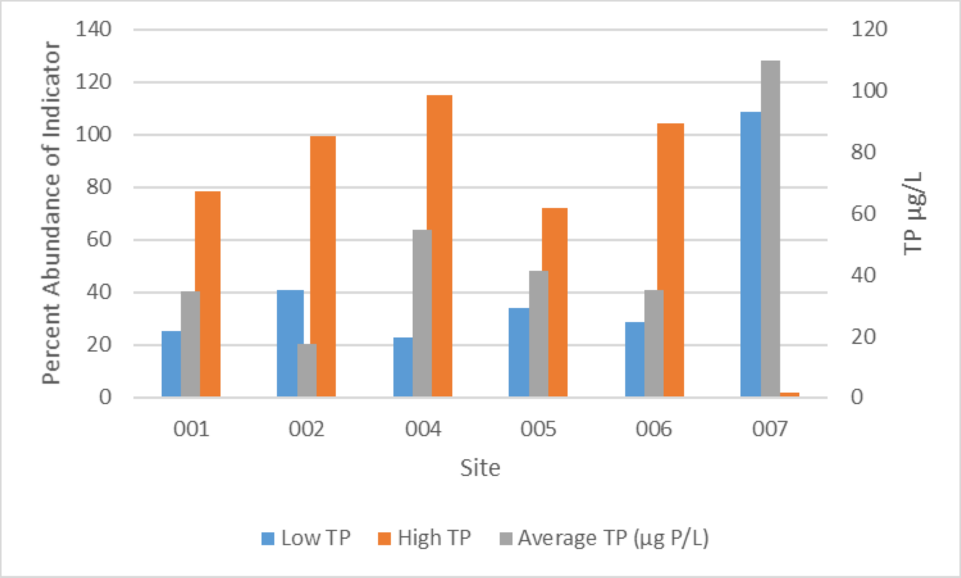


Figure 6: TP Field Data contrasted with Algal Indicator Results

In addition to Nitrogen and Phosphorus, salinity taxa were analyzed as a way of further evaluating the validity of the USGS method for Great Bay. As shown in Figures 2 and 3, site numbers increase as locations move from upriver freshwater rivers downstream into the estuary itself. Looking at Figure 7, sites 1-6 (all freshwater sites) contain primarily taxa indicating low chloride levels, below 500mg/L. Starting at site 7, which is located downstream in the tidal portion of the Exeter River, taxa indicative of chloride levels above 500 start to make up a more substantial portion of the total taxa. Sites 7 and 10, both located in estuarine ecosystems, have barely any taxa indicating Chloride levels below 100 mg/L. Moving further downstream to site 15, located in Great Bay, the largest proportion of taxa indicating Chloride levels above 1000mg/L can be observed.

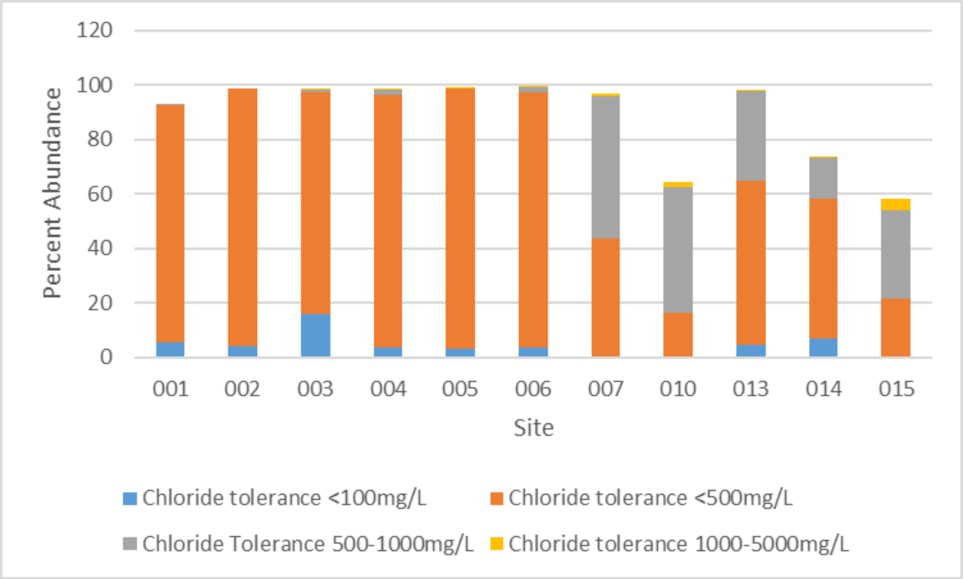
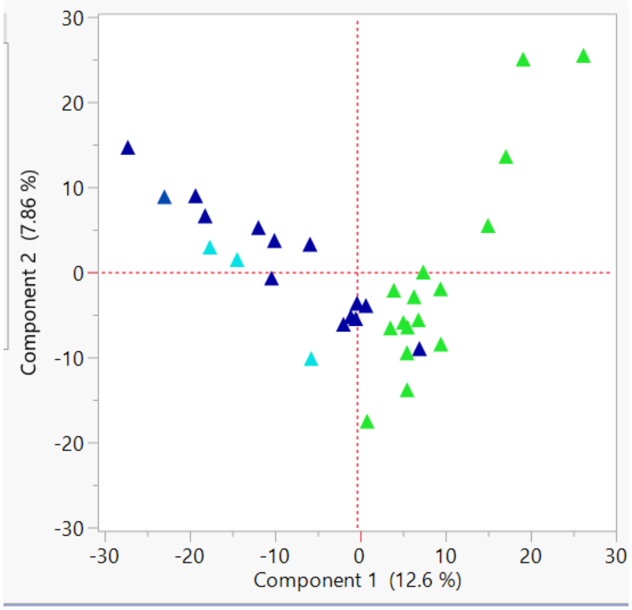


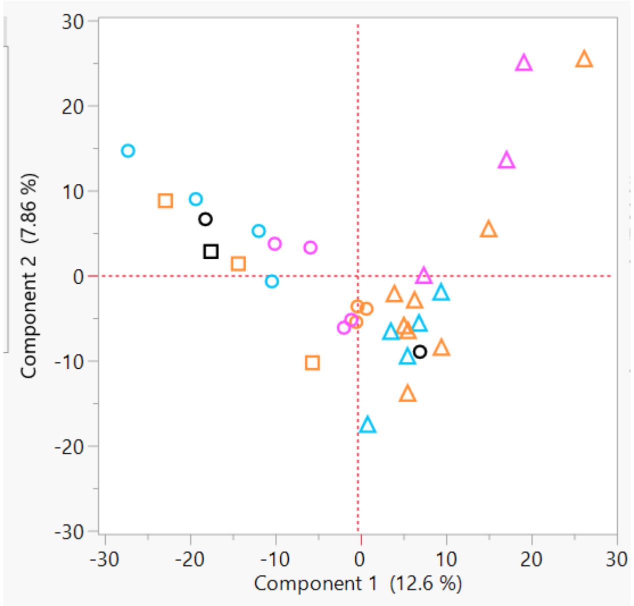
Figure 7: Algal Indicator Results for Salinity

Genomic Data

1. Algae only, bacteria genome data: Light green = upriver, Dark blue = tidal river (7 and beyond), Light blue = Great Bay



2. Algae only, bacteria genome data: Triangle = 1-6, Circle = 7-14, Square = 15-16; Orange = Low TP <40ug/L = 1,2,6,13,15; Blue = Med TP, 40-75 ug/L = 4,5,14,10; Pink = High TP >75 ug/L = 3,7,9



Conclusions

Microscope Results & Great Bay

Analysis of taxonomic results from the traditional microscope taxa identification was limited due to the size of the data set. This in combination with limited field measurements did not yield any statistically viable results, however several patterns were observed which support further investigation regarding the use of attached algae method in the Great Bay region. Specifically, Total Phosphorus and salinity results indicated species of algae (indicators) we would expect to see in certain areas of the estuary based upon field data. Sites known to be high in phosphorus did in fact overall contain more algae species that are high phosphorus indicators, and sites that were closer to the bay contained more species that were indicators of high salinity conditions.

These patterns, based upon the indicator series from USGS, indicate that attached algae may prove to be a viable method for water quality analysis in the unique great bay ecosystem environment.

Barriers to Genomic Analysis

Extraction techniques can have an impact on results, therefore it is important to process samples appropriately. It is unclear whether or not the hard shells of diatoms might affect the success of RNA extraction, and further research is necessary to determine if this is the case. It may be possible that current extraction techniques are not able to obtain a long enough sequence of RNA for the desired level of taxa identification, therefore further exploration of extraction techniques is necessary. Currently, available databases for species identification of algal RNA are limited, therefore further investigation of existing databases must also be included.

Next Steps

Future work will require gathering a larger, more geographically diverse data set to further evaluate algae species which may serve as good indicators for the great bay region. Additional work with genomic analysis will be necessary to determine if algal databases specific enough are available, and to refine current techniques to try to achieve species-level identification. Once this has been accomplished, more work will be possible relating to the identification of new indicators from existing and future genomic data. The University of New Hampshire should continue to work closely with NH-DES and others to identify applicability of any results to state water quality monitoring programs.

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Information Transfer Program Introduction

The NH WRRC supported one information transfer project with its 2015 104b funding:

1. New Hampshire WRRC Information Transfer

New Hampshire WRRC Information Transfer

Basic Information

Title:	New Hampshire WRRC Information Transfer
Project Number:	2008NH97B
Start Date:	3/1/2014
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	01
Research Category:	Not Applicable
Focus Category:	Management and Planning, Education, Non Point Pollution
Descriptors:	None
Principal Investigators:	William H. McDowell, Michelle Daley Shattuck

Publications

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2. Daley, M.L. and W.H. McDowell, In Preparation, Human impacts on stream nitrogen chemistry and watershed N retention across a wide range of rural to urban catchments, Ecological Applications.
3. Hope, A.J., W.H. McDowell, W.M. Wollheim, Submitted, Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream, Biogeochemistry.
4. Liptzin, D., M.L. Daley, and W.H. McDowell. Accepted. A comparison of wet deposition collectors at a coastal rural site. Submitted to Water, Air, & Soil Pollution. April 2013.
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Information Transfer

Unbridled development and population growth can have detrimental impacts to water resources and ecosystem services. Rapid population growth is occurring in New Hampshire and state regulations, planning board decisions and zoning classifications all attempt to minimize the environmental impact of this rapid population growth. Most land use planning decisions are made at the local level on a town by town basis, often by volunteers who serve on various boards, commissions and committees. Decisions by these various resource managers are often made without a full understanding of the consequences that their decisions will have on water resources or ecosystem services.

This project provided salary for the Center's Director and Associate Director to meet with state representatives, local town officials, watershed groups, school groups, the general public and scientists to discuss WRRC findings that relate to population growth, land use change and climate variability. Over the past year, the NH WRRC meet with the following groups to discuss water resource issues: NH Fish and Game, Natural Resources Conservation Service (NRCS), Trout Unlimited (TU), Southeast Watershed Alliance, The Nature Conservancy, Piscataqua Region Estuaries Partnership, NH Department of Environmental Services and the NH Geological Survey. The NH WRRC website (http://www.wrrc.unh.edu/) is also used to disseminate information on water resources, and is updated and maintained by salary provided by this project. The Director and Associate Director dedicate time discussing current and future research in the Lamprey River Hydrologic Observatory, which is partially funded by the longstanding 104B project "Water Quality and the Landscape: Long-term monitoring of a rapidly developing suburban watershed". On January 8, 2016 the NH WRRC funded and organized the **Ninth Annual Lamprey River Symposium** (see also below). Presentations focused on nutrients and other solutes, bacteria, sediment, hydrology, groundwater, climate and land use change, water quality indicators and monitoring programs in coastal New Hampshire. The symposium attracted approximately 90 attendees, including scientists, regional leaders, town officials, members of state agencies, and federal agencies. The agenda can be found on the NH WRRC Lamprey River Hydrologic Observatory Symposium website. This annual symposium and other discussions in which the Center's Director and Associate Director participate further the research and information transfer goals of the NH WRRC.

2016 Information Transfer Activities Supported by Section 104b Funding and Matching Funds

Data sharing with Lamprey River watershed local advisory committee

The Lamprey River Advisory Committee (LRAC) is undergoing a long-term analysis of Lamprey River water quality data collected by both the Lamprey River Watershed Association's (LRWA) volunteer monitoring program and the NH WRRC 104B project "Water Quality and the Landscape: Long-term monitoring of a rapidly developing suburban watershed". The NH WRRC associate director serves on the LRAC and is a member of the water quality sub-committee which is advising a LRAC funded intern who is conducting the long-term water quality analysis. Temporal and spatial trends in dissolved oxygen, pH and nitrate have been examined thus far and further analysis is underway.

Nitrogen Data in New Hampshire's Great Bay watershed

Over the last seven years, there has been significant focus on nitrogen loading to New Hampshire's largest estuary, the Great Bay estuary, and the impairment to aquatic life it has caused. In August 2009, Great Bay, Little Bay and the tidal rivers were added to the New Hampshire 2008 303d list of impaired waters rendering them in violation of the federal Clean Water Act. Based on the most recent "State of Our Estuaries Report" prepared by the Piscataqua Region Estuaries Partnership (PREP 2013), 32% of the nitrogen entering Great Bay and Little Bay is from point sources; the majority (68%) enters via non-point sources of pollution. The Lamprey River is the largest tributary to Great Bay, and thus the long-term data provided by the NH WRRC from the LRHO are of considerable value for watershed management. The NH WRRC provides the best dataset in NH for assessing the spatial and temporal variability in N concentrations and export in response to suburbanization and changes in land use. These 15+ years of data will be instrumental in assessing the success of current and future efforts to reduce non-point sources of nitrogen pollution reaching Great Bay. There is much interest in LRHO datasets from NH Department of Environmental Services (DES), PREP, the Environmental Protection Agency (EPA) and other municipal, regional, state and federal agents. Many of the presentations and meetings listed below focused on transferring information on nutrient cycling to stakeholders throughout NH's coastal watershed and beyond. The NH WRRC has received several phone calls and meeting requests to discuss the Great Bay nitrogen issue. The NH WRRC has also been asked by PREP to help update the nutrient loading indicator for the 2017 State of Our Estuaries report.

Water quality monitoring advice for wood restoration projects in NH streams

The Natural Resources Conservation Service and TU have selected 23 Wetlands Reserve Program (WRP) properties in NH for wood loading restoration work. The project involves adding wood into small segments of 1st and 2nd order stream channels (averaging about 1,000 feet) with a primary goal of recreating and increasing fish spawning and rearing habitat as well as preventing bank erosion and improving stream geomorphology. A supplemental goal of this work is to study the changes in water quality and nutrient uptake which may be enhanced by adding carbon (in the form of wood) to streams. The NH WRRC Director, Associate Director and the WQAL manager have been advising the NRCS and TU on how to best understand changes in water quality and nutrient dynamics with existing financial resources. With collaboration between the NRCS, TU and the NH WRRC, baseline water quality monitoring began in 2014. Wood installations began in the summer of 2015 and 10 properties have been identified for restoration in 2016.

Drinking water quality in New Hampshire

The recent Perfluorooctanoic Acid (PFOA) contamination of southern NH drinking water has prompted several inquiries to the NH WRRC and the Water Quality Analysis Laboratory (WQAL) from residents and local media concerned with drinking water quality in the state.

Symposia, Conferences and Seminars Organized and Funded

The NH WRRC funded and organized the "**Ninth Annual Lamprey River Symposium**" held January 8, 2016 in Durham, NH. The symposium is dedicated to exchanging the results of recent research on the water quality, hydrology, water resources issues, and management of the Lamprey River basin. The Symposium is a vehicle for researchers to share data and insights with other researchers, as well as those in the management and policy arena who would benefit from exposure to the latest research on the watershed. The symposium drew approximately 90 attendees, including researchers, legislators, water system operators, town officials, regional leaders and government officials. The symposium contained 13 presentations split up over three sessions. There was a poster session during and after lunch where 10 posters and displays were exhibited. The day ended with an open discussion on research priorities in the Lamprey watershed and southeast NH. This event was funded and organized by the NH WRRC. NH EPSCoR assisted with registration and printing. Survey results indicate that most of the attendees found the topics covered to be either helpful or very helpful.

The NH WRRC sponsored the "**NH Water and Watershed Conference**" which was held in combination with the 39th annual New England Association of Environmental Biologists (NEAB) meeting on March 18-20, 2015 in Bartlett, NH. The NEAEB conference serves as a platform for water resource experts, state and federal regulators, watershed organizations and other parties invested in environmental biology to share their first-hand experiences and knowledge as well as to discuss important issues affecting the world's waters. The NEAEB conference comes to New Hampshire only once every seven years thus this was a unique opportunity to combine these complementary events. The NH WRRC co-sponsored this conference along with Plymouth State University and the Center for the Environment, United States Environmental Protection Agency, New England Water Pollution Control Commission, and New Hampshire Department of Environmental Services. Two days of the conference were dedicated to concurrent sessions and workshops. One day was devoted to several relevant plenary presentations intermixed with a poster session and roundtable discussions. The Center's Associate Director also serves on the planning committee for the annual NH Water and Watershed Conference.

Publications

Appling, A.P., Leon, M.C. and McDowell, W.H. 2015. Reducing bias and quantifying uncertainty in watershed flux estimates: The R package loadflex. Ecosphere. 6(12): Article 269. DOI: 10.1890/ES14-00517.1.

Kaushal, S.S., McDowell, W.H., Wollheim, W.M., Newcomer Johnson, T.A., Mayer, P.M., Belt, K.T. and Pennino, M.J. 2015. Urban Evolution: The Role of Water. Water. 7:4063-4087. doi: 10.3390/w7084063.

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Rodriguez-Cardona, B. 2015. Nitrate uptake kinetics in streams: Is carbon the driver? M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 67 pages.

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Wymore A.S., Rodriguez-Cardona B. and McDowell, W.H. 2015. Direct response of dissolved organic nitrogen to nitrate availability in headwater streams. Biogeochemistry. 126:1-10. DOI 10.1007/s10533-015-0153-9.

Conference Proceedings & Abstracts:

Appling, A., Leon, M. and McDowell, W.H. 2015. Optimizing watershed flux estimates: the R package 'loadflex'. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Contosta, A., A.C. Adolph, D. Burchsted, M. Green, W.H. McDowell, and the New Hampshire EPSCoR Ecosystems & Society Sensor Team. The Vernal Window Flow Path: a Cascade of Ecological Transitions Delineated at Scales from Points to Pixels. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

Dodds, W.K., J. Rüegg, K. Sheehan, C. Song, F. Ballantyne, C. Baker, W.B. Bowden, K. Farrell, M.B. Flinn, E. Garcia, T. Harms, J. Jones, L. Koenig, J.S. Kominoski, W.H. McDowell, D. McMaster, S. Parker, M.T. Trentman, M. Whiles, W.M. Wollheim, A. Argerich and B. Penaluna. 2015. Biome Context and Lotic Ecosystem Rates. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

Koenig, L., L.E. Snyder, W.H. McDowell and C.W. Hunt. 2015. The contribution of aquatic metabolism to CO_2 emissions from New Hampshire streams. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

McDowell, W.G., Webster, K, Nelson, S, McDowell, W.H. and Haney, J. 2015. Regulation and results: biotic and abiotic changes to northeastern lakes following tightening of air emissions rules. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

McDowell, W.H. 2015. Aquatic sensor networks: Is there regional coherence in the response of stream chemistry to seasonal and hydrologic drivers? (abstract #90) HydroEco 2015, 5th International Conference on Hydrology and Ecology. Vienna, Austria, 13-16 April 2015.

McDowell, W.H. 2015. International Critical Zone Science: Opportunities to Build a Global Understanding of Land-Water Linkages. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

McDowell, W.H., Potter, J, Snyder, L, Daley, M., Appling, A., Koenig, L, Rodriguez-Cardona, B., Wymore, A. and Brereton, R. 2015. Using a sensor network to understand drivers of nutrient and organic matter concentrations at multiple spatial and temporal scales. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

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Potter, J, McDowell, W.H. and Snyder, L. 2015. Patterns and drivers of specific conductance in New Hampshire rivers. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

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Rodriguez-Cardona, B., A. Wymore, L. Koenig, A.A. Coble and W.H. McDowell. 2015. Response of non-added solutes during nutrient addition experiments in streams. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

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Schade, J.D., J. Bailio, and W.H. McDowell. Nitrate loading and CH_4 and N_2O Flux from headwater streams. American Geophysical Union Fall Meeting. San Francisco, CA. December 2015.

Snyder, L. 2015. NH EPSCoR Intensive Aquatic Sensor Network. Joint NEAEB/NH Water & Watershed Conference: Partnerships for Environmental Progress. Bartlett, NH. March 19, 2015.

Wymore, A., Rodriguez-Cardona, B. and McDowell, W.H. 2015. Patterns of dissolved organic nitrogen (DON) production and consumption with the addition of nitrate (NO_3): Insights into the controls on DON cycling. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Zeglin, L., Cooper, S, Utz, R., Ardon-Sayao, M., Bixby, R., Burdett, A., Dodds, W., Griffiths, N.A., Harms, T., Johnson, L., Johnson, S., Jones, J., Kominoski, J., McDowell, W.H., Rosemond, A.D., Trentman, M., Follstad Shah, J., Van Horn, D. and Ward, A. 2015. Synthesis of stream ecosystem responses to nutrient enrichment at multiple trophic levels. Society for Freshwater Science Annual Meeting. Milwaukee, WI. May 17-21, 2015.

Presentations/Information Transfer

Coble, A., Shattuck, M.D., Potter, J.D., McDowell, W.H. 2016. Concentration discharge relationships and long-term trends of solute fluxes vary among flood periods. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Koenig, L. 2015. Served as the instructor for the STEM mini-course offered August 24-28th through the CONNECT program at UNH (http://www.unh.edu/connect/). The objective of the course is to provide an opportunity for incoming freshmen that come from groups with historically low retention in STEM majors (e.g. low-income, multicultural, first-generation college students) to build community, discover college resources, and bolster skills that are needed to succeed in their academic programs (e.g. writing of lab/research reports, basic math and statistics for analyzing scientific data). There were 7 students in the class, but the broader CONNECT program serves approximately 100 students.

- Students learned about best management practices (BMPs) and discussed how these engineering solutions may help mitigate local nutrient pollution and eutrophication in Great Bay, NH. They measured nitrogen and phosphorus concentrations in stormwater collected at the inflow and outflow of two different stormwater management structures operated by the UNH Stormwater Center (http://www.unh.edu/unhsc/). The students found that the BMPs surrounding the UNH campus were effective in reducing nutrient concentrations in stormwater, and presented these results to the entire CONNECT program at the end of the week.

Koenig, L., L.E. Snyder, C.W. Hunt, and W.H. McDowell. 2016. The contribution of aquatic metabolism to CO_2 emissions from New Hampshire streams. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

McDowell, W.H. 2015. EPA TIME/LTM New England 2015. EPA Clean Air Act Cooperators meeting, Montpelier, VT. May 26 2015.

Shattuck, M.D. 2015. Led field trip for undergraduate and graduate students to sites in the Lamprey River Hydrologic Observatory. September 22, 2015.

Shattuck, M.D. 2015. Water Quality Research in the Lamprey River Hydrologic Observatory. Presentation to University of New Hampshire undergraduate class: Studio Soils. October 28, 2015.

Shattuck, M.D. 2015. Urbanization and suburbanization in New Hampshire watersheds. Presentation to University of New Hampshire class: Watershed Water Quality Management. October 6, 2015.

Shattuck, M.D. 2015. Understanding Water Quality Impacts of Farm Practices in Groundwater and Stream Water. Research field day at the University of New Hampshire Organic Dairy Research Farm. Lee, NH. November 4, 2015.

Shattuck, M.D. 2015. Watershed management in practice: Great Bay. Presentation to University of New Hampshire class: Watershed Water Quality Management. December 1, 2015.

Shattuck, M.D., Potter, J., Snyder, L. and McDowell, W.H. 2016. Hydrologic controls on nitrate and specific conductivity in NH streams: New insights using sensor data. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Wymore, A., Rodriguez-Cardona, B. and McDowell, W.H. 2016. Direct response of dissolved organic nitrogen to nitrate (NO3-) availability in headwater streams. Annual Lamprey River Science Symposium. University of New Hampshire, Durham, NH. January 8, 2016.

Press Releases

Daley, M.L. 2015. Understanding Nitrogen Sources in the Great Bay Watershed. Great Bay Matters. Spring/Summer 2015. http://greatbay.org/documents/gbmspring2015.pdf

McDowell, W.H. 2015. On the Suncook River, a slow, rolling disaster response. Concord Monitor. August 2, 2015.

- Interviewed by Nick Reid, a reporter from the Concord Monitor, on the Suncook River avulsion in Epsom, NH which resulted from the Mother's Day 100 year flood in 2006. Interviewed on July 20, 2015. http://www.concordmonitor.com/home/17941607-95/on-the-suncook-river-a-slow-rolling-disaster-response

Meetings attended

Daley, M.L. 2015. Met with NH Fish and Game, NRCS and Trout Unlimited to discuss water quality monitoring of adding wood to streams for stream restoration. Durham, NH. April 23, 2015.

Daley, M.L. 2015. Attended PREP monitoring meeting to discuss future eelgrass monitoring and PREP monitoring in general. Portsmouth, NH. May 7, 2015.

Daley, M.L. 2015. Attended Great Bay, Water and Science Meeting, Great Bay Discovery Center, Greenland, NH. May 5, 2015.

McDowell, W.H. 2016. Met with Kelsey Keegan, Legislative Assistant, Office of Senator Kelly Ayotte (R-NH), to discuss water resources issues in New Hampshire. Washington, D.C. February 9, 2016.

McDowell, W.H. 2016. Met with Travis Krogman, Legislative Assistant, Office of Representative Ann Kuster (D-NH-2), to discuss water resources issues in New Hampshire. Washington, D.C. February 9, 2016.

McDowell, W.H. 2016. Met with Michelle Jelnicky, Legislative Director, Office of Representative Frank Guinta (R-NH-1), to discuss water resources issues in New Hampshire. Washington, D.C. February 10, 2016.

McDowell, W.H. 2016. Met with Marissa Serafino, Legislative Correspondent, Office of Senator Jeanne Shaheen (D-NH), to discuss water resources issues in New Hampshire. Washington, D.C. February 10, 2016.

Shattuck, M.D. 2015. Attended a meeting to discuss the findings of the review of the two-year implementation of the Souhegan and Lamprey Instream Flow Pilot Program. Lee, NH. July 29, 2015.

Shattuck, M.D. 2015. Met with NRCS and Trout Unlimited to discuss water quality monitoring of adding wood to streams for stream restoration. Durham, NH. August 25, 2015.

Shattuck, M.D. 2015. Met with NH Fish and Game, NRCS and Trout Unlimited to discuss water quality monitoring of adding wood to streams for stream restoration. Durham, NH. October 10, 2015.

Shattuck, M.D. 2015. Met with NRCS and Trout Unlimited to discuss water quality monitoring of adding wood to streams for stream restoration. Durham, NH. March 22, 2016.

Shattuck, M.D. 2016. Attended The Nature Conservancy Coastal Plan Update for Water Resource Protection meeting – Identifying Spatial Priorities. Greenland, NH. March 31, 2016.

USGS Summer Intern Program

Basic Information

Start Date:	6/1/2015
End Date:	5/31/2016
Sponsor:	U.S. Geological Survey
Mentors:	Robin Stewart
Students:	Ursula Jongebloed

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Very Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Very Good
Learning Experience	Very Good
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A+

Additional Remarks

This internship has been an incredibly enjoyable and educational experience for me. Working at USGS has taught me more about how scientists collect, analyze, and present data in the past year than I have learned in years of school education. I learned safe and effective lab techniques, the functionality of numerous machines, and techniques for the organization, analysis, and presentation of data. I have also learned how bureaucratic, legal, and technical problems can roadblock science, which, although frustrating at times, has been nonetheless valuable. I loved going out into the field to collect samples and carrying those samples through the process of analysis. It has been fulfilling to understand the importance of my project and learn about other scientists' projects and their cumulative conclusions.Other scientists were more than happy to teach me about their problems and findings. Robin has been an incredible mentor for me -- she is a superb scientist and a wonderful person.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	19	0	1	5	25
Masters	2	0	0	4	6
Ph.D.	3	0	0	0	3
Post-Doc.	3	0	0	1	4
Total	27	0	1	10	38

Notable Awards and Achievements

Charles Stoll, one of the students supported through research project 2014NH183B, is a first-generation student who worked for the first ten years of his adult life as a plumber. He is largely responsible for the GIS conducted as part of the 2014NH183B project, and has presented his work at three meetings: locally (NH EPSCoR), regionally (NESTVAL), and nationally (AAG). Charles received his BA in May 2015 and is continuing to work on this research project this summer. We anticipate that, by the end of the summer of 2016, Charles will submit an undergraduate first-author manuscript for review for publication in Northeastern Geographer.

Research project 2015NH191B was the subject of an honors thesis by an undergraduate student at the University of New Hampshire, Department of Environmental Engineering. Allison Wood did much of the sample preparation, literature review, data analysis and report development. Ms Wood presented the results of her work at a state wide conference (the NH Water and Watershed Conference), and submitted an honors thesis to the University. Ms Wood will spend the year following graduation as an ORISE (Oak Ridge Institute for Science and Education) intern in the EPA Region 1 Office and will be partnering with scientists at Harvard to explore the policy barriers to developing new water technologies.

Ursula Jongebloed served as an USGS intern on the project “Investigations into the bioavailability and bioaccumulation of selenium (Se) and mercury (Hg) in the San Francisco Bay Estuary”. Ursula began the internship at the USGS National Research Program office in Menlo Park, California in June 2015 after completing her sophomore year at Dartmouth College (located in Hanover, New Hampshire). The internship experience was very rewarding for both Ursula and her USGS mentor Robin Stewart. The internship experience was so successful that Ursula is preparing a manuscript along with co-authors Robin Stewart and Amy Kleckner on the trends in dissolved and particulate selenium concentrations with respect to bivalve Se concentrations and water year in the San Francisco Estuary. This manuscript is in preparation for a special issue “Undergraduate Research in Water – Training the Next Generation of Water Scientists” in the Journal of Contemporary Water Research and Education which is scheduled for publication in April 2017.

Currently NH has 49 watersheds listed as impaired due to elevated chloride levels resulting from salt use in winter road maintenance with the majority of those watershed located in the southern part of the state. College Brook is one of the impaired watersheds and the impairment listing was based on data produced from the 2003NH21B project.

Two former undergraduate students at the University of New Hampshire supported previously be the 2003NH21B project are now pursuing a PhD. Chelsea Varrio is pursuing a PhD in Ecology & Evolutionary Biology Dartmouth College and Valerie Schoepfer is pursuing a PhD in Environmental Services at Southern Cross University in Lismore, New South Wales, Australia.