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

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

## Basic Information

<b>Title:</b>	Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds
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## Publications

1. Buyofsky, L.A. 2006. Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed. M.S. Dissertation, Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH
2. Proto, Paul J. 2005, The Significance of High Flow Events in the Lamprey River Basin, New Hampshire, for Annual Elemental Export and Understanding Hydrologic Pathways. M.S. Dissertation, Department of Earth Sciences, College of Engineering and Physical Sciences, University of New Hampshire, Durham, NH, 176 pages.
3. Buyofsky, Lauren A. May 2006. Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, MS Dissertation, Department of Natural Resources, College of Life Sciences and Agriculture , University of New Hampshire, Durham, NH, .
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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 has experienced rapid growth in several counties. 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's population growth has slowed slightly and from 2000-2010 the state experienced a 6.5% population gain. This was still the largest gain among northeastern states and the fastest-growing areas in New England are concentrated in southern and central NH (Johnson 2012). 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 where several estuarine waters are 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.

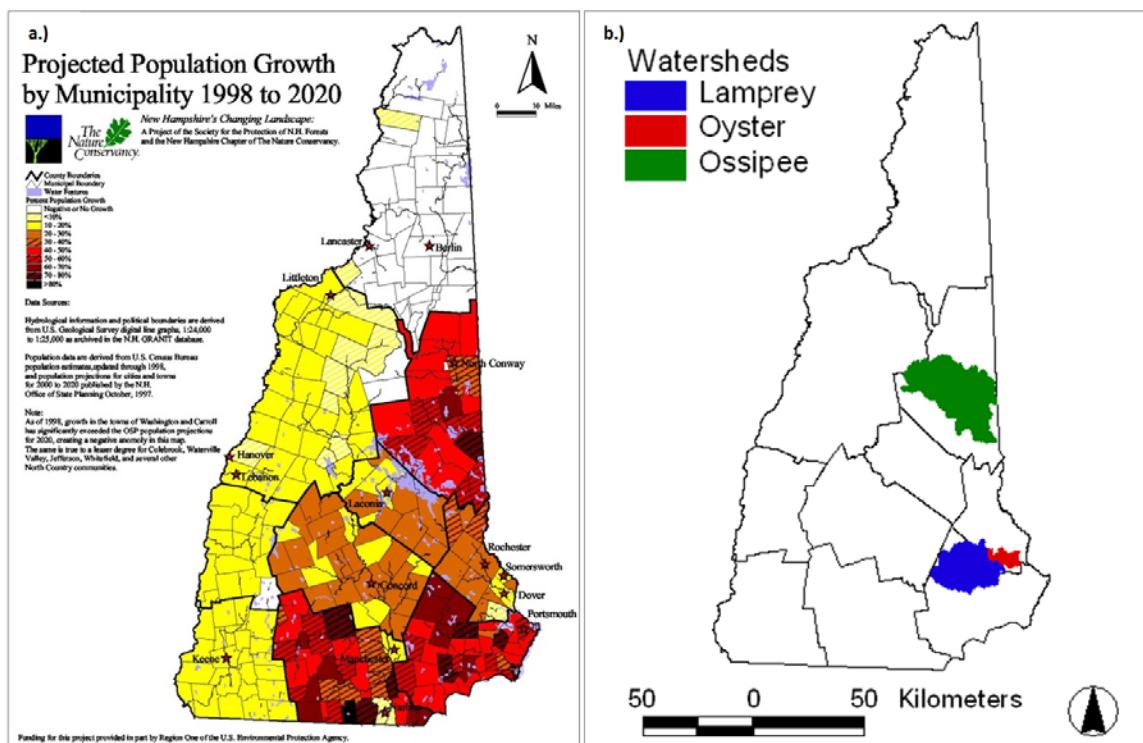


Figure 1. Projected population growth in New Hampshire (Figure from Sundquist and Stevens 1999; A) and study watersheds experiencing high population growth (B).

## Methods, Procedures and Facilities

### *Lamprey River Hydrologic Observatory*

The Lamprey River watershed (479 km<sup>2</sup>) 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<sup>2</sup>) 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<sup>2</sup>) 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). WRRRC 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  $\mu\text{m}$  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 ( $\text{NO}_3\text{-N}$ ), ammonium ( $\text{NH}_4\text{-N}$ ), dissolved organic nitrogen (DON), orthophosphate ( $\text{PO}_4\text{-P}$ ), chloride ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4\text{-S}$ ), sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{+2}$ ), calcium ( $\text{Ca}^{+2}$ ), and silica ( $\text{SiO}_2$ ). 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 ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{+2}$ ,  $\text{Ca}^{+2}$ ), discrete colorimetric analysis ( $\text{NH}_4$ ,  $\text{PO}_4$ ,  $\text{NO}_3/\text{NO}_2$ ), and High Temperature Oxidation (DOC, TDN). All methods are widely accepted techniques for analysis of each analyte.

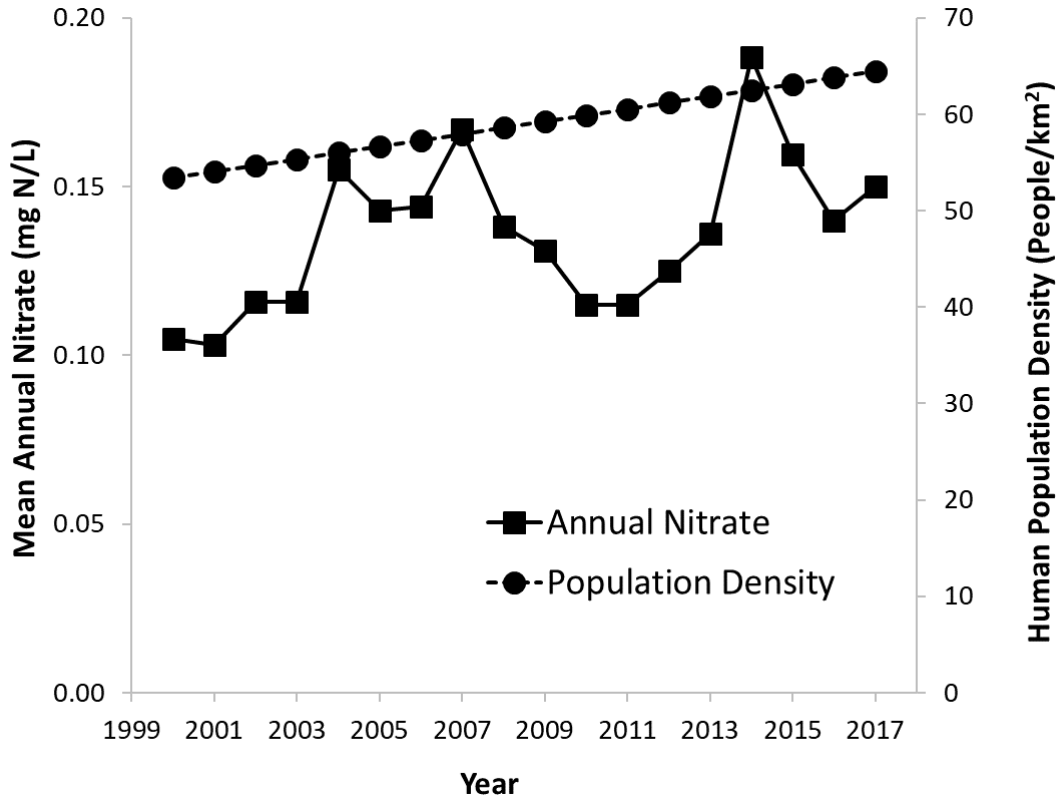
The WQAL was established by the Department of Natural Resources in 1996 to meet the needs of various research and teaching projects both on and off the UNH campus. It is currently administered by the NH Water Resources Research Center and housed in James Hall. Dr. William McDowell is the Laboratory Director and Mr. Jody Potter is the Laboratory Manager. Together, they have over 45 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 2017 from the LRHO is approximately 50% complete. Results of stream chemistry to date show a significant increase in annual nitrate concentrations at LMP73 (Figure 2) over the entire study period (2000-2016), but not at WHB01. 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 study period. The watershed population density increased from 53 to 60 people/ $\text{km}^2$  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

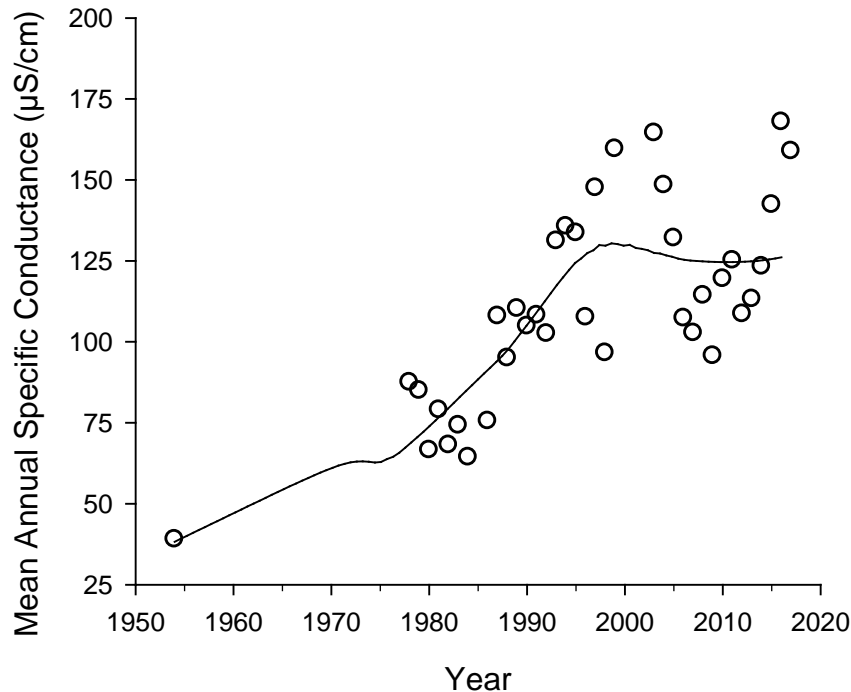
is impaired by elevated nitrogen and is currently in violation of the Federal Clean Water Act. Tidal tributaries to the bay are experiencing dangerously low dissolved oxygen levels and the bay is experiencing a significant loss of eelgrass which provides important habitat for aquatic life. The Lamprey 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 mean nitrate concentration and estimated annual human population density (2000 and 2010 Census) from 2000-2017 in the Lamprey River basin. Note that nitrate analysis for 2017 is approximately 50% complete.

When we combine our specific conductance data (2003 – 2017) with data collected by the USGS (1978 - 1999), we see a long-term increase in specific conductance in the Lamprey River (Figure 3). Sodium and chloride concentrations are directly related to specific conductance ( $r^2 = 0.95$ ,  $p < 0.01$  for  $\text{Na}^+$ ;  $r^2 = 0.93$ ,  $p < 0.01$  for  $\text{Cl}^-$ ) and we conclude that this increase in specific conductance indicates a corresponding increase in Lamprey River NaCl. Since  $\text{Na}^+$  and  $\text{Cl}^-$  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. Like nitrate, we are uncertain if NaCl levels in LMP73 will remain relatively constant, increase or decrease with changing climate, land use and management in the watershed.

Thus, continued monitoring is necessary to better understand how the interaction between human activities and climate variability affects water quality.

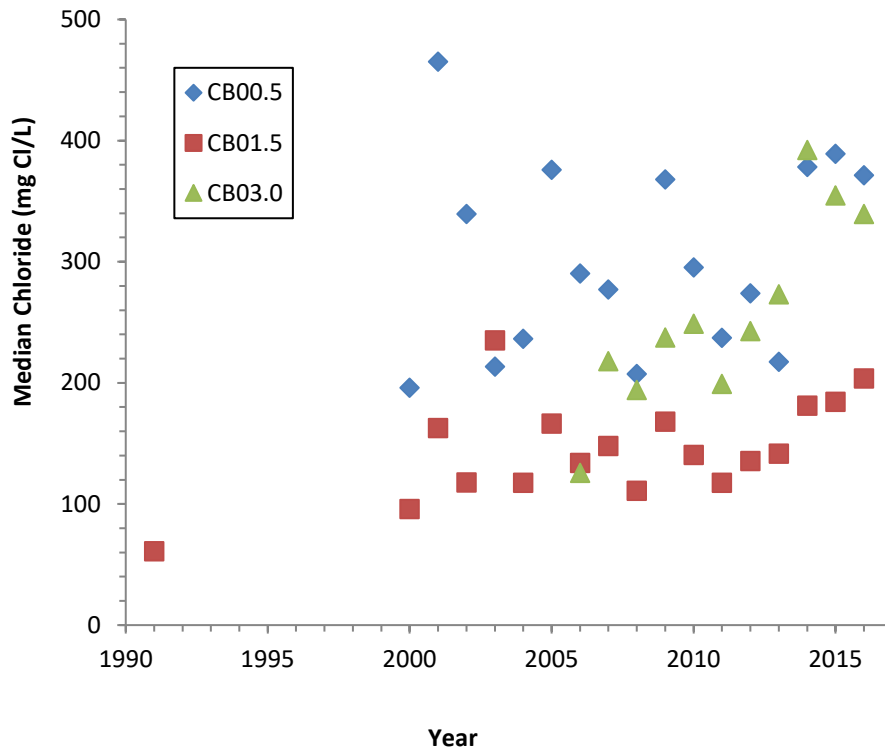


**Figure 3.** Mean annual specific conductance in the Lamprey River at LMP73 (co-located with the USGS gauging station in Durham, NH). (modified from Daley et al. 2009).

### *Oyster River watershed*

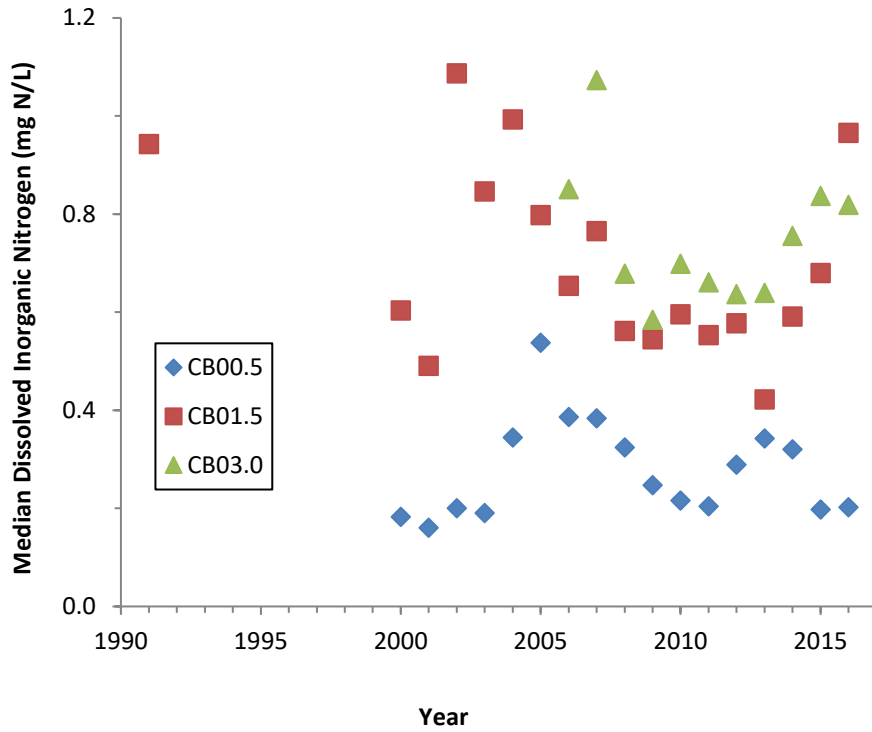
Laboratory analysis of the monthly CB and PB samples collected in 2017 is approximately 50% complete. Recent data show that DO is lowest at the CB upstream station (CB00.5) where it does drop below 5 mg/L (level that is necessary to support in-stream biota) during the summer months. The downstream stations 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 stream 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.

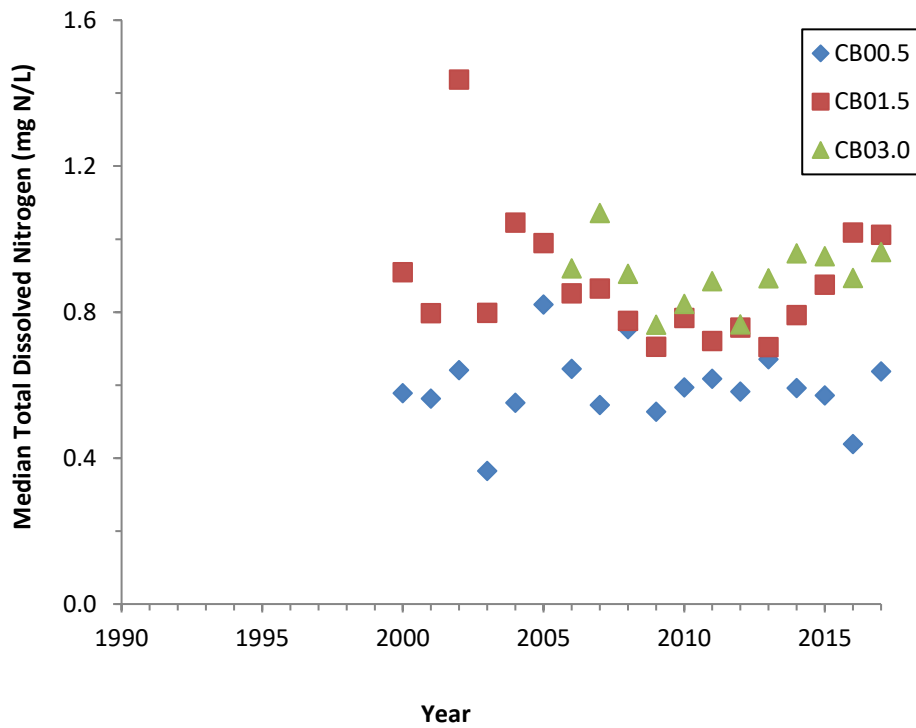


**Figure 4.** Median annual chloride in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

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 indicating that nitrification is occurring in the stream channel. However, an increase in dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (Figure 6) from the headwaters to the mouth indicates that there are additional sources of nitrogen entering the stream as it flows through 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, DIN or TDN concentrations from 2000 to 2017 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. 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.

### **Number of students supported**

Three PhD students (Lauren Koenig, Bianca Rodriguez, Rich Brereton), two MS students (Alison Herreid and Brian Saccardi) and 8 undergraduate hourly employees from the Department of Natural Resources & the Environment (John Ciaburri, Justin Sherman, Liam Waldron, Christina Lyons, Kyle Seawards, Light Mcharo, Danielle Chancey and Brooke Gauthier). Three post-doctoral students were also supported by this project (Adam Wymore, Ashley Coble and Qingtao Zhou).

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Stein, S.M., McRoberts, R.E., Mahal, L.G., Carr, M.A., Alig, R.J., Comas, S.J., Theobald, D.M. and Cundiff, A. 2009. Private forests, public benefits: increased housing density and other pressures on private forest contributions. Gen. Tech. Rep. PNW-GTR-795. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

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### **Notable awards and achievements**

McDowell, W.H. 2017. Received the 2017 Distinguished Professor Award. The purpose of this award is to identify and honor longstanding members of the faculty. This singular university-wide award will be given each year to the faculty member whose overall record of excellent teaching, caring about students, devotion to the university community and substantial record of scholarly achievement exemplifies what we would call a 'distinguished career'.

Rodriguez-Cardona, B. (PhD student) was awarded a 2017 Chateaubriand Fellowship. The Chateaubriand Fellowship is a grant offered by the Embassy of France in the United States. It supports outstanding Ph.D. students from American universities who wish to conduct research in France for a period ranging from 4 to 9 months. Chateaubriand fellows are selected through a merit-based competition, through a collaborative process involving expert evaluators in both countries. Bianca has travelled the globe, studying carbon and nitrogen coupling in streams across biomes. She traveled to Paris, France for this fellowship.



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

### **Publications**

- Bucci, J. P., M. D. Shattuck, S. A. Aytur, R. Carey and W. H. McDowell (2017). A case study characterizing animal fecal sources in surface water using a mitochondrial DNA marker. *Environmental Monitoring and Assessment* 189(8).
- Contosta, A. R., A. Adolph, D. Burchsted, E. Burakowski, M. Green, D. Guerra, M. Albert, J. Dibb, M. Martin, W. H. McDowell, M. Routhier, C. Wake, R. Whitaker and W. Wollheim (2017). A longer vernal window: the role of winter coldness and snowpack in driving spring transitions and lags. *Global Change Biology* 23(4): 1610-1625.
- Hunt, C. W., L. Snyder, J. E. Salisbury, D. Vandemark and W. H. McDowell (2017). SIPCO2: A simple, inexpensive surface water pCO<sub>2</sub> sensor. *Limnology and Oceanography-Methods* 15(3): 291-301.
- Koenig, L.E., Shattuck, M.D., Snyder, L.E., Potter, J.D. and McDowell, W.H. 2017. Deconstructing the effects of flow on DOC, nitrate, and major ion interactions using a high-frequency aquatic sensor network. *Water Resources Research*. 53: 10,655–10,673. DOI: 10.1002/2017WR020739.
- Snyder, L.E., Potter, J.D. and McDowell, W.H. 2018. An Evaluation of Nitrate, fDOM, and Turbidity Sensors in New Hampshire Streams. *Water Resources Research*. Special issue “Continuous nutrient sensing in research and management: applications and lessons learned across aquatic environments and watersheds”. DOI: 10.1002/2017WR020678
- Wymore, AS, J Potter, L Snyder, B Rodríguez-Cardona, and WH McDowell. 2018. Using in-situ optical sensors to understand the biogeochemistry of dissolved organic matter across a stream network. *Water Resources Research*. DOI: 10.1002/2017WR022168.

### **Conference Proceedings & Abstracts:**

- Contosta, A., Burchsted, D., Burakowski, E., Green, M., Guerra, D., Albert, M., Dibb, J., Martin, M., McDowell, W.H., Routhier, M., Wake, C., Whitaker, R. and Wollheim, W. 2017. A longer vernal window: How winter coldness and snowpack influence spring transitions and lags. *Northeast Ecosystem Research Cooperative Conference*. March 28-29, 2017, Saratoga Springs, New York, USA.

- Koenig, L.E., L.E. Snyder, A.P. Appling, C. Hunt, J.D. Potter, W.H. McDowell. 2017. Annual patterns in aquatic metabolism and CO<sub>2</sub> emissions from New Hampshire streams (Oral). June 4-9, 2017 Society for Freshwater Science meeting, Raleigh, NC.
- McDowell, W.H., J. Potter. 2017. Tradeoffs in Greenhouse Gas Fluxes from Aquatic Ecosystems Along a Rural to Urban Gradient are Driven by N Loading. 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec.
- Shattuck, M.D. and McDowell, W.H. 2017. U.S. Geological Survey - New England Water Science Center Science Symposium: Coastal Nitrogen Research. April, 18, 2017. Worcester, MA.
- Shattuck, M.D., Koenig, L. Potter, J.D., Snyder, L.E. and McDowell, W.H. 2017. Regional coherence in solute interactions during stormflow in a statewide aquatic sensor network. NH Water & Watershed Conference. March, 24, 2017. Plymouth, NH.
- Wymore, A., S. Kaushal, W.H. McDowell, P. Kortelainen, E. Bernhardt, P. Johnes, W. Dodds, S. Johnson, J. Brookshire, R. Spencer, B. Rodriguez-Cardona, A. Helton, R. Barnes, A. Algerich, S. Haq, P. Sullivan, C. Lopez-Lloreda, A. Coble, M.D. Shattuck. 2017. [Carbon and nitrogen stoichiometry across stream ecosystems](#). 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec.

### **Presentations/Information Transfer**

- Koenig, L. 2017. For the 5th consecutive year, Koenig served as the instructor for the STEM mini-course offered August 21st-25<sup>th</sup>, 2017 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 13 students in the class, but the broader CONNECT program served approximately 80 students in 2017.
- McDowell, W.H. 2017. Taking river biogeochemistry into the fourth dimension. Presentation to NSF EPSCoR program officers. 20 April, 2017.
- McDowell, W.H. 2017. The NH Agricultural Experiment Station at the University of New Hampshire welcomed Dr. Catalino Blanche, national program leader in the Division of Environmental Systems with the U.S. Department of Agriculture. Dr. Blanche provides national leadership for forestry and research programs related to the production, protection, and utilization of forest resources, including for the

McIntire-Stennis Cooperative Forestry Program. Dr. McDowell discussed with Dr. Blanche the nitrogen issues in Great Bay and the role of nitrogen cycling in suburbanizing forested watersheds that drain to the bay. Dr. McDowell also discussed the NH EPSCoR Ecosystems & Society project's investment in scientific instrumentation to build a sensor network and showed Dr. Blanche the aquatic sensors installed in the Lamprey River (the largest tributary to Great Bay) at Wiswall Dam in Durham, NH. April 26, 2017.

McDowell, W.H. and Shattuck, M. D. "Nonpoint Nitrogen Sources and Transport in New Hampshire's Great Bay Watershed". Presented 31 October 2017, at the workshop entitled "Nitrogen, Septic Systems, Great Bay and Why it Matters", Great Bay National Estuarine Research Reserve, Greenland, NH.

Shattuck, M.D. and McDowell, W.H. 2017 Nonpoint nitrogen sources and transport in the Great Bay watershed. Unitarian Universalist Church. April 30, 2017. Durham, NH.