Water Resources Research Center
Annual Technical Report
FY 2007

Introduction

The New Hampshire Water Resources Research Center, located on the campus of the University of New Hampshire, is an institute which 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 Jeff Merriam, Michelle Daley and Jody Potter. The NH WRRC is a stand alone organization, in that it is not directly affiliated with any other administrative unit at UNH. The NH WRRC has no dedicated laboratory or research space on campus. The NH WRRC does have administrative space on campus, but no formal library holdings. To overcome these potential limitations, our website (www.wrrc.unh.edu) is used heavily, and serves as a focal point for information dissemination and includes all 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

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:	3/1/2006
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	NH01
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Nutrients
Descriptors:	
Principal Investigators:	William H. McDowell

Publication

1. Legere, K.A. September 2007. Nitrogen loading in coastal watersheds of New Hampshire: an application of the SPARROW model. Masters Thesis, University of New Hampshire, Durham, NH. 75 pages.
2. Traer, K. December 2007. Controls on denitrification in a northeastern coastal suburban riparian zone. Masters Thesis, University of New Hampshire, Durham, NH. 97 pages.

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. Many rivers and lakes also serve as local water supplies. New Hampshire currently leads all New England states in the rate of development and redevelopment (2000 Census). The long-term impacts of population growth and the associated changes in land use to New Hampshire's surface waters are uncertain. Of particular concern are the impacts of non-point source pollution to the state's surface waters (e.g. septic, urban run off, road salt application, deforestation and wetland conversion). Long-term datasets that include year-to-year variability in precipitation, weather patterns and other factors will allow adequate documentation of the cumulative effects of land use change and quantification of the effectiveness of watershed management programs.

Statement of Results or Benefits

The proposed project will provide detailed, high-quality, long-term datasets which will allow for a better understanding of the impacts of land use change and development on surface water quality. This could occur through the development, testing and refinement of predictive models, accurately assessing the impacts of watershed management practices, and potentially early warnings of dramatic changes to surface water quality in the region resulting from rapid development.

Objectives of the Project

This project allows for the continued collection of long-term water quality data in New Hampshire. It will use UNH staff, students and volunteers from local communities to collect samples from the College Brook watershed (Durham, NH), the Lamprey River Watershed (coastal NH), and the Ossipee River Watershed (central NH).

Water samples will be collected from the following sub-projects.

The **College Brook** watershed, which is dominated by the University of New Hampshire, receives a variety of non-point pollution from several different land uses. pH, conductivity, and nutrient concentrations (Cl^-, SO_4^{-2}, Na^+, K^+, Mg^{+2}, Ca^{+2}, NO_3, NH_4, PO_4, DOC, TDN, SiO_2) will be measured to assess water quality. Samples from 3 sites will be collected monthly throughout the year. Sampling of College Brook began in 1991. Sample collection will be done by UNH staff and/or students. The Water Quality Analysis Lab at UNH will analyze 2/3 of these samples as part of the non-federal match.

The **Lamprey River** has been sampled weekly and during rain events since October 1999. Samples are analyzed for total dissolved nitrogen (TDN), nitrate (NO_3-N), ammonium (NH_4-N), DON, DOC and orthophosphate (PO_4-P). Additionally, samples collected since October 2002 are also analyzed for dissolved inorganic carbon (DIC), pH, conductivity, dissolved oxygen (DO), temperature, total suspended sediment (TSS), particulate carbon (PC), particulate nitrogen (PN), silica and major anions (Cl^-, SO_4^{-2}) and cations (Na^+, K^+, Mg^{+2}, Ca^{+2}). In January of 2004, we began weekly sampling of additional stream sites throughout the Lamprey watershed for all above parameters except DIC, TSS, PC and PN. Stream data from 2004 showed that monthly sampling could be adequate to describe variation among sites throughout the watershed; therefore, the frequency of stream sampling was curtailed to monthly (instead of weekly) for 13 of our sampling sites. Three remaining stream sites (Lamprey River, North River and Wednesday Hill Brook - a small developed tributary) are still sampled weekly. These stream samples were analyzed by the Water Quality Analysis Lab at UNH.

In October of 2003, we initiated precipitation collection at numerous locations throughout the basin for analysis of nitrogen species, PO_4-P, DOM, major cations and anions and silica and also to monitor precipitation volume. Volunteers throughout the watershed were recruited to monitor precipitation volume at several stations in addition our stations used for both chemical analysis and volume recording. Precipitation data from 2004 indicated that chemistry does not vary significantly spatially, therefore we currently only sample from one collector in Durham, NH on an event basis. Homeowners have continued to monitor precipitation gages throughout the watershed as precipitation amount is spatially variable. These precipitation samples were analyzed by the Water Quality Analysis Lab at UNH.

Groundwater Chemistry and nutrient dynamics.

Monthly ground water well samples have been collected from the James Farm and Wednesday Hill Brook (WHB) well fields in Lee, New Hampshire within the Lamprey River watershed. James Farm monthly samples were collected from October 1995 through December 2006. Wednesday Hill Brook monthly samples were collected from July 2004 through 2007. James Farm and WHB ground water data demonstrates higher NO_3^- concentrations with low dissolved organic carbon (DOC) concentrations as well as low NO_3^- concentrations with high DOC concentrations, which suggests possible denitrification influencing ground water NO_3^- concentrations. In order to better understand groundwater nutrient dynamics, a graduate student used a push-pull method to estimate in-situ ground water denitrification rates by adding just NO_3^- and both NO_3^- and DOC (dextrose). We hypothesized that the dextrose additions will decrease NO_3^- concentrations at a faster rate than the NO_3^- only additions. A Master of Science student worked on the project and contributed her unpaid time as non-federal match.

SPARROW model estimates of Nitrogen in 5 coastal NH watersheds

This research is focused on nitrogen in coastal New Hampshire. Nitrogen in coastal areas is a growing problem because excess nitrogen can have damaging effects on coastal ecosystems including eutrhophication which can lead to harmful algal blooms. In the coastal areas of the United States nitrogen is the biggest threat to the health of estuaries. Currently coastal New Hampshire is not under eutrophic conditions but nitrogen inputs to the coast have increased in recent years so it is important measure and understand their sources.

In this research the SPARROW model was used to estimate the loading of nitrogen in five coastal New Hampshire watersheds. The SPARROW model, a spatially referenced regression model on watershed characteristics has been calibrated to New England and estimates nitrogen load based on features of the watershed. The SPARROW model estimates nitrogen using two main predictor variables; land surface characteristics, and channel characteristics. In the main SPARROW equation these two variables were re-worked using more detailed information to get a better estimate of nitrogen in coastal New Hampshire. Wetland area and stream channel density are the two areas where the most variability is expected to be found between SPARROW and actual watershed conditions.

The goal of this research is to get a better estimate of the nitrogen contribution in to coastal New Hampshire and to better understand the SPARROW model and its potential limitations in coastal areas. Also it may bring a new use for the SPARROW model where more detailed data can be input for more accurate results. The SPARROW model is often used to identify sensitive areas for nitrogen pollution and develop nutrient criteria so understanding its accuracy could be very important. Hopefully this research will lead to additional nitrogen research in coastal New Hampshire and the potential development of a model that can accurately estimate nitrogen loading in coastal areas. A Master of Science student will be working on the project and contributing her unpaid time as non-federal match.

Ossipee Watershed

Volunteers of the Green Mountain Conservation Group will sample streams within the Ossipee watershed of New Hampshire. Samples will be collected every 2 weeks from May to November, and monthly during the winter months. There will be approximately 340 samples collected. Water chemistry (Cl^-, SO_4^{-2}, Na^+, K^+, Mg^{+2}, Ca^{+2}, NO_3, NH_4, PO_4, DOC, TDN) will be measured on selected samples by the WQAL. WRRC staff will assist in data interpretation.

Methods, Procedures and Facilities

Samples will be collected at intervals described above. Samples for dissolved analyses will be filtered in the field using pre-combusted glass fiber filters (0.7 uM pore size), and frozen or refrigerated (depending on method requirement) until analysis. All samples will be analyzed in the Water Quality Analysis Lab of the WRRC on the campus of UNH, Durham, NH.

The Water Quality Analysis Laboratory (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 Jeffrey Merriam is the Laboratory Manager. Together, they have over 35 years of experience in water quality analysis, and have numerous publications in the fields of water quality, biogeochemistry, and aquatic ecology.

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, SiO_2), and High temperature Oxidation (DOC, TDN). All methods are widely accepted techniques for analysis of each analyte.

Principal Findings and Significance

College Brook

Previous work on College Brook in the early 1990's (McDowell unpublished) shows that the UNH campus had a severe impact on water quality and was negatively affecting stream biota and the integrity of downstream ecosystems. By any yardstick, campus operations could not be considered sustainable. There was clear evidence that the UNH incinerator was causing excessive organic matter loading, resulting in high biochemical oxygen demand (BOD) and low dissolved oxygen (DO) in stream water. Since the incinerator has been closed, BOD and DO are no longer at levels detrimental to in-stream biota. Our monthly sampling regime was scaled back beginning October 2006 to the 3 stations that have historically shown the greatest changes, and we eliminated the BOD and TSS measurements (both which change little over the reach since the incinerator was closed). The most downstream sampling location is now closer to where the stream empties into the Oyster River in an effort to better quantify inputs to the Great Bay estuary. We also added a 4th site that was previously sampled at Pettee Brook in May 2008. Analyses of samples collected through 2007 have been completed and we are in the process of updating our website http://www.wrrc.unh.edu/current_research/collegebrook/collegebrookhome.htm.

Dissolved Oxygen (DO) in the brook is lower at the upstream stations. This difference is presumably due to hydrologic properties of the upstream sampling location which resembles a wetland (i.e. slow flow, higher organic matter and organic carbon). DO increases downstream as flow becomes faster and re-aeration higher.

Data from 2000-2007 indicates that the steam is strongly impacted by road salt at its origin, which is essentially a road-side ditch leading to a wetland area. 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. Concentrations are highest at the upstream stations and tend to decline downstream as the stream flows through the athletic fields and then increase as the stream passes through the heart of campus and downtown Durham.

Another export to Great Bay that is a cause of concern is nitrogen and especially nitrate. As College Brook becomes more aerated as it moves downstream ammonium decreases and nitrate increases indicating that nitrification is occurring in the stream channel, however the mass of each and an increase in total nitrogen indicates that there is additional sources of nitrate to the stream. This is possibly from fertilization of the athletic fields and/or storm water runoff. There also appears to be a slight, but insignificant, increase in nitrate over time. This will need to be closely monitored as algal blooms and loss of Eelgrass have become a concern in Great Bay.

The Lamprey River Hydrologic Observatory

The Lamprey River watershed is a rural watershed located in southeastern NH and is under large development pressure as the greater area experiences rapid population growth. 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 therefore 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. We have continued to sample the Lamprey River at the USGS gauging station in Durham, NH (referred to as "LR 73.3"), the North River at the former USGS gauging station in Epping, NH (NR 26.9) and a small tributary to the Lamprey River in Lee, NH (WHB 1.03) on a weekly basis and 13 other stations throughout the watershed on a monthly basis.. The USGS discontinued the operation of the North River gauging station in October 2006 and since then we have been recording weekly stage height and calculating flow based on the USGS rating curve. We are able to record stream flow at WHB 1.03 using an electronic distance meter in combination with a rating curve that we have developed for this site. We have also developed a stream flow model for WHB 1.03 where daily discharge can be estimated from meteorological measurements (such as precipitation and temperature) and this model is useful for estimating historic flows. We continue to collect precipitation at Thompson Farm (UNH property located in Durham, NH) to document nitrogen inputs to the basin and work with NOAA/AIRMAP in an attempt to link to precipitation chemistry to airmass chemistry.

Results of stream chemistry to date show a significant increase in nitrate concentrations over time in the Lamprey River (Figure 1). Preliminary analysis of long-term sample collection (weekly since 2004, various intervals since 2000) shows that nitrate is also increasing over time in the North River, but not in Wednesday Hill Brook. 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 and North River watersheds, population growth is likely responsible for the increase in stream water nitrate. 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 WHB nitrate may be due to the limited population growth in this watershed.

Despite the rapid suburbanization that is occurring throughout southeast NH and the associated increase in road application, sodium and chloride concentrations have decreased recently in the Lamprey. However, we believe this is due to dilution from two 100 year floods occurring in May 2006 and April 2007. Annual exports (kg/ha/yr) of sodium and chloride have actually increased consistently since 2003. Variation of sodium and chloride concentrations among Lamprey and College Brook sub-basins are directly related to impervious surfaces and the associated road salt application (Figure 2).

Results of precipitation monitoring show that wet deposition is the largest input of N to the Lamprey watershed and precipitation chemistry can be linked to airmass chemistry.

DOC and TDN in precipitation are related to biogenic airmass sources, NH_4-N, NO_3-N and SO_4-S are related to urban/industrial airmasses and Na and Cl are weakly related to ocean aerosols.

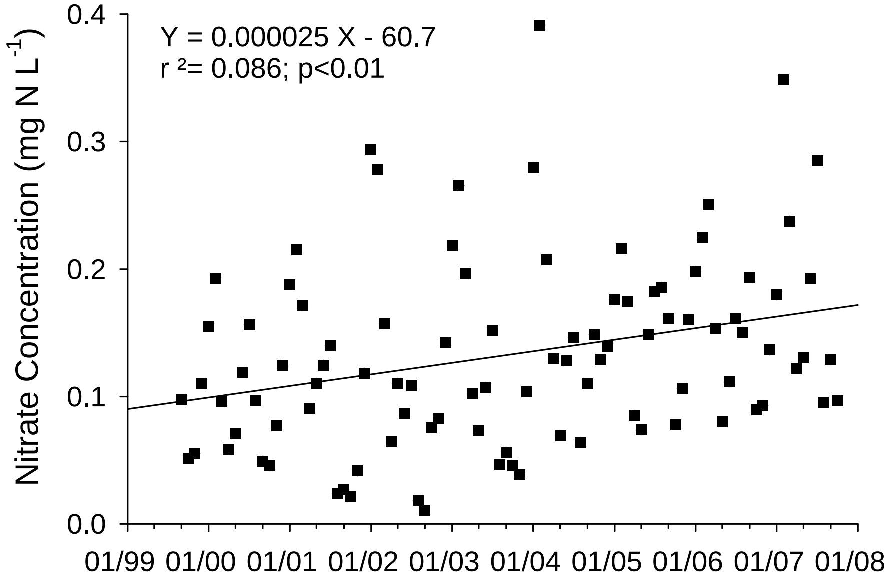


Figure 1. Average monthly nitrate concentrations over time in the Lamprey River at the USGS gauging station in Durham, NH.

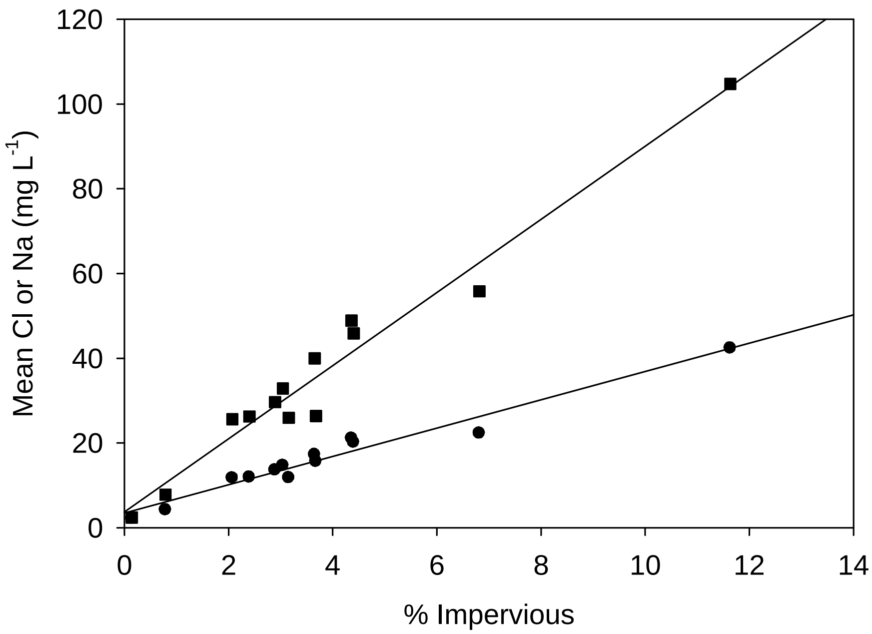


Figure 2. Average sodium and chloride concentrations versus impervious surfaces in Lamprey and College Brook sub-basins.

Groundwater Chemistry and nutrient dynamics.

Hydrogeologic characteristics and groundwater physical properties and chemical constituents were evaluated in the James Farm well field located in Lee, NH, USA from 1995 to 1996, and from James Farm and Wednesday Hill Brook (WHB) from 2004 to 2006. There were no clear seasonal NO_3^- patterns in the James Farm or WHB well field. In general, wells located in the north and southwest areas of the James Farm well field had higher mean NO_3^- and wells located in the center of the well field had lower mean NO_3^- concentrations. In the WHB well field, upslope groundwater had NO_3^- concentrations of 3.0 – 4.0 mg NO_3-N/L and downslope groundwater next to the stream had nitrate levels of less than 0.1 mg NO_3-N/L. In most James Farm wells, there was no significant change in groundwater nitrate between the 1995-1996 and 2004-2006 sampling periods. However, in well A4 nitrate increased from 0.4 to 1.0 mg NO_3-N/L and in well A7 nitrate increased from 1.0 to 2.0 mg NO_3-N/L between 1995-1996 and 2004-2006. There are no clear trends showing changes in nitrate concentrations over time in the WHB well field from 2004-2006. Based on this data, we currently recommend quarterly sampling of these well fields for 2008

The "push-pull" method estimated denitrification potential at James Farm by adding different quantities of nitrate and dissolved organic carbon to riparian groundwater. The constituents measured were nitrate, ammonium, total dissolved nitrogen, dissolved organic carbon, sulfate, bromide, chloride, sodium, magnesium, potassium, calcium, and silica. Patterns of nitrogen concentration in ambient riparian groundwater suggested that denitrification might be occurring as groundwater flowed through the center of the well field. Field experiments with the push-pull method, however, showed that substantial N loss did not occur even with large amounts of added nitrate and dissolved organic carbon. Short groundwater residence times may have been responsible for the lack of denitrification.

SPARROW model estimates of Nitrogen in 5 coastal NH watersheds

The New England SPARROW model was recalibrated to 31 sub-basins in Lamprey River watershed and 8 sub-basins in the Oyster River watershed for a total of 39 calibration sites in coastal NH. Most of the Nitrogen export data used for calibration purposes were collected and analyzed with WRRC funding and WRRC staff and student interpretation. Stream samples were all analyzed in the WQAL at UNH. Land use data input into the model was updated with NWI wetlands to better characterize these abundant features in the coastal landscape which are often misinterpreted by landsat imagery (used to develop land use GIS layers) as either forests or open water instead of forested wetlands and open wetlands. The final coastal NH model had parameter coefficients that were similar to the NE SPARROW, but the standard errors around these coeffiecients were reduced. The coastal NH model had a R^2 of 0.89 and a MSE of -0.14. Wetlands were not a significant source or loss term in the NE SPARROW, but were included as a source variable in the coastal NH model. This is likely due to the contribution of DON from wetlands. The newly calibrated coastal NH model was then applied to the Lamprey, Oyster, Exeter, Chocheco and Salmon Falls Rivers which comprise the major tributaries to Great Bay. The coastal NH model predicted lower N exports for Great Bay tributaries (average of

2.0 kg/ha/yr) compared to the NE SPARROW (average of 5.0 kg/ha/yr). Six samples were collected (in the spring and fall) from each of the major Great Bay tributaries and used to estimate annual flux from these watersheds. The coastal NH model was better at predicting N flux from the Great Bay tributaries than the NE SPARROW model (Figure 3). These results have large implications for establishing TMDL limits in coastal NH. The NE SPARROW over-estimates N flux in coastal NH and does not accurately identify all N source variables for this coastal region.

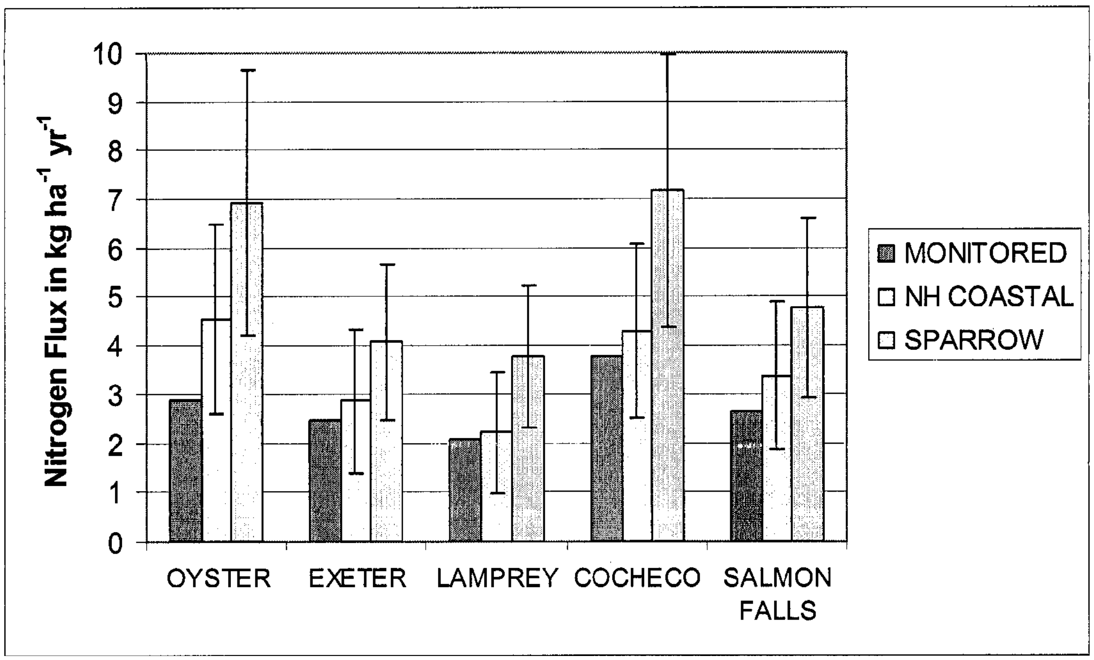


Figure 3. Flux estimates for each watershed based on WRRC monitored loads, coastal NH SPARROW predicted loads and NE SPARROW predicted loads.

<u>Ossipee Watershed</u>

Collaboration with the Green Mountain Conservation Group and their sampling of the Ossipee River watershed has continued to be beneficial. Volunteers sampled streams within the watershed every 2 weeks from April through October, and monthly winter sampling at 7 sites, with approximately 340 samples collected from 30 sampling locations. Many presentations were made to planning boards, conservation commissions and other local government groups (see Information Transfer section below). 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 has also been useful in promoting low impact development techniques and best management practices where new development has been proposed in proximity to rivers and streams within the watershed.

Material in Preparation:

McDowell, W.H., M.L. Daley, B. Sive, R. Talbot. Factors controlling atmospheric deposition at a coastal suburban site. *Journal of Geophysical Research (Atmospheres)*.

Conference Proceedings & Abstracts

McDowell, W.H. 2007. Biogeochemistry of a suburban basin. Marine Biological Laboratory, January 2007.

Daley, M.L., L.A. Buyofsky, W.H. McDowell. 2007. Linking Groundwater Quality to Landscape Characteristics in the Lamprey River Basin. The New Hampshire Water Conference, Concord, NH. April 2007.

McDowell, W.H. 2007. Biogeochemistry of a suburban basin. University of New Hampshire. November 2007.

McDowell, W.H. 2007. Water Quality in the Suburbanizing Lamprey River Basin. The New Hampshire Watershed Conference, Concord, NH. November 2007.

McDowell, W.H. 2007. Biogeochemistry of a suburban basin. New Hampshire Estuaries Project Meeting. December 2007.

McDowell, W.H., M.L. Daley, B. Sive, R. Talbot. 2007. Linking Atmospheric Deposition to Airmass Chemistry at a Coastal Rural Site. American Geophysical Union fall meeting, San Francisco, December 2007.

McDowell, W.H. 2008. Biogeochemistry of a suburban basin. Harvard Forest, Harvard University. March 2008.

McDowell, W.H. 2008. Biogeochemistry of a suburban basin. University of Connecticut, Storrs, CT. March 2008.

Dissertations and Theses:

Legere, K.A. September 2007. Nitrogen loading in coastal watersheds of New Hampshire: an application of the SPARROW model. *Masters Thesis*, University of New Hampshire, Durham, NH.

Traer, K. December 2007. Controls on denitrification in a northeastern coastal suburban riparian zone. *Masters Thesis*, University of New Hampshire, Durham, NH.

Information Transfer:

McDowell, W.H. and Daley, M.L. 2008. Current Research in the Lamprey River Watershed. Lamprey River Advisory Committee meeting. January 2008.

Symposia Organized and Funded:

First Annual NH Water Conference, April 2007, Concord NH (Organizing committee, provided partial funding, over 300 attendees)

Annual NH Watershed Conference, November 2007, Concord NH (Organizing committee, provided partial support, over 200 attendees)

First Annual Lamprey River Hydrologic Observatory Symposium, Durham, NH (totally funded and organized, over 50 attendees)

Presentations made by the Green Mountain Conservation Group staff.

3/10/2007 OWC Workshop w/ Board & Town Rep's (GIS, land use planning, watershed planning)
3/24/2007 Natural Resource Based Planning Workshop (regional meeting, Tamworth)
4/8/2007 Water Quality Monitoring Program & Training
4/14/2007 Water Monitoring Programs Training
4/28/2007 Drinking Water Protection Conference
5/3/2007 Watershed Ordinances, How to Write/Pass Ordinances, Groundwater Protection Workshop
5/29/2007 Camp Calumet Program (OLT & lake water testing with students)
6/1/2007 Camp Calumet Program (OLT & lake water testing with students)
6/7/2007 Water Quality Reporting/Summer Camp Director Meeting (OLT & VLAP)
6/13/2007 WQM program Sandwich school
6/14/2007 OWC Workshop Chocorua (land use planning, watershed planning)
7/3/2007 Camp Calumet Program (OLT)
7/3/2007 Camp Marist Program (macro/OLT)
7/13/207 NH Green Yards/BMP Open House w/ DES in Berlin
7/21/2007 Watershed Weekend (water quality, lake management/protection)
7/17/2007 Camp Calumet Program (OLT)
7/31/2007 Camp Calumet Program (OLT)
8/14/2007 Calumet Program (OLT)
8/15/2007 Drinking Water Protection workshop Concord
8/22/2007 Macro Training (expansion of WQM program)
9/5/2007 Tamworth Learning Circles School Program (RIVERS, macro)
9/10/2007 Sandwich Elementary School Program (RIVERS, macro)
9/15/2007 GIS/Drinking Water Protection Workshop w/ UNHCE Chocorua
10/1/2007 Effingham Planning Board/Conservation Commission Presentation (NR Guide)
10/7/2007 Madison Planning Board/Conservation Commission Presentation (NR Guide)
10/9/2007 Water Monitoring/Macro Sampling in Watershed/Mongolia Presentation Effingham
10/27/2007 Ossipee & Freedom Planning Board/Conservation Commission Presentation (NR Guide)
10/28/2007 Tamworth Planning Board/Conservation Commission Presentation (NR Guide)
12/6/2007 Sandwich Planning Board/Conservation Commission Presentation (NR Guide)
1/31/2008 OWC Workshop Chocorua (watershed planning, Guide follow up)

2/5/2008 Ossipee Planning Board Meeting (BMPs, Frenchman's Brook wqm data)
2/22/2008 BMPs, Drinking Water Protection NH DES Training for Town Officials

Number of students supported:

Two Master’s students and one undergraduate hourly employee

Water Quality Change−Effects of Development in Selected Watersheds

Basic Information

Title:	Water Quality Change−Effects of Development in Selected Watersheds
Project Number:	2006NH60B
Start Date:	3/1/2006
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	NH01
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Nutrients, Surface Water
Descriptors:	
Principal Investigators:	Jeffrey Schloss

Publication

1. Baumann, A.J. and J.S. Kahl. 2007. Chemical trends in Maine High Elevation Lakes. LakeLine 27:30−34.
2. 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.
3. Rosfjord, C., K. Webster, J.S. Kahl, S.A. Norton, I. Fernandez, and A. Herlihy, 2007. Anthropogenically−driven changes in chloride complicate interpretation of base cation trends in lakes recovering from acidic deposition. Environ Sci Technol, 41:7688 −7693.

Jeff Schloss-
Water Resources Research Center Project Update Report March 2007-February 2008:

Water Quality Change: Effects of Development on Nutrient Loading in Selected Watersheds

Problem:

The waters of New Hampshire represent a valuable resource contributing to the state's economic base through recreation, tourism, and real estate revenues. Some lakes and rivers serve as current or potential water supplies. For most residents (as indicated by boating and fishing registrations and shoreline re-development) our waters help to insure a high quality of life. As documented in the 2005 Census, New Hampshire currently leads all of the New England states in the rate of new development and redevelopment. The long-term consequences of the resulting pressure and demands on the state's precious water resources remain unknown. Of particular concern is the response of our waters to increasing non-point source pollutant loadings due to watershed development and land use activities.

Of all the in-depth watershed nutrient budget measurements and modeling efforts that have been attempted in NH none have primarily focused on change detection due to development as they were either base-line studies on relatively pristine lakes or focused on specific problems such as internal nutrient loading from past sewage outfalls, or septic systems in the water table of a seepage lake. In addition nitrogen species were only monitored for less than a handful of studies and the measurement technologies at the time were not sensitive enough to provide much usable data. The opportunity to add nitrogen monitoring and support GIS land change analysis to co-occurring externally funded phosphorus watershed nutrient budget studies on two lakes that had previous budgets done in the past provides a true cost-effective project that directly addresses Statewide concerns.

Alone, these watershed nutrient budgets represent only short-term examinations of non-point source pollution nutrient loadings to the lake. A longer-term monitoring program conducted through differing weather years at both shallow and deep sites is required to best estimate the lake response to the loadings due to development over time.

Objectives:

1- To complete phosphorus and nitrogen analysis of collected seepage water samples as a research add-on to an already funded project developing a water and total phosphorus budget for a small lake watershed that has experienced land cover change since a previous study was undertaken over a decade ago. (Mendums Pond, NH) and complete a water /phosphorus budget for a large multijurisdictional watershed that also had a previous study undertaken (Newfound Lake, NH) .

2- To further document the changing water quality in a variety of watersheds throughout the state in the face of land use changes and best management efforts.

3- The continued collection and analysis of long-term water quality data in selected watersheds through the NH Lakes Lay Monitoring Program (NH LLMP).

4- The dissemination of the results of the analysis to cooperating agencies, water managers, educators and the public on a local, statewide and regional basis.

5- To offer undergraduate and graduate students the opportunity to gain hands-on experience in water quality sampling, laboratory analysis, data management and interpretation.

6- To determine next steps for further analysis of long-term data sets and GIS spatial data on land cover.

Methods:

An EPA approved QAPP (Schloss 2006) for the watershed water/nutrient budget was followed that included volunteer sample collection and gage readings and student technicians sampling and conducting stream flow measurements using a Doppler water velocity meter (SonTek/YSI).

Lake and stream monitoring through the LLMP generally involved a minimum of monthly sampling starting at spring runoff through to lake stratification and weekly to bi-weekly sampling through to fall mixis. Water clarity, chlorophyll a, acid neutralizing capacity, dissolved organic color, dissolved oxygen and nutrients (total N, total P and nitrate) were the default suite of parameters measured for lakes while nutrients, turbidity, dissolved organic color and flow were the parameters of choice for the lake tributary work. On occasion, student field teams traveled to join the volunteer monitors to perform quality assurance checks and do more in-depth analysis and lake profiling.

The project utilized an extensive GIS database for the study subwatersheds created through previous WRRC funding to the PI. Updated and additional GIS data were made available through the UNH Complex Systems Research Center, which manages the NH GRANIT statewide GIS data depository. The extensive data directory contains statewide GIS data layers (usually at 1:24,000 scale) including hydrology, geology, soils, National Wetlands Inventory, land-use, land cover, and digital elevation models. Also available are Landsat Thematic Mapper, SPOT Panchromatic and digital orthophoto imagery.

As stated above the primary scope of this project was to maintain the long-term data collection effort but in addition, land cover changes to study subwatersheds were documented on our established GIS data base and any new management practices or conservation efforts were also documented. USGS WRRC support was used to enhance the two ongoing water nutrient budget studies, especially the Mendum’s Pond project, as the majority of the costs for these projects were underwritten by US EPA Nonpoint Source Project funds passed through by the NH Department of Environmental Services to the respective watershed associations.

Major findings and significance:

We expect completion of the Newfound Lake water nutrient budget in the early spring of 2008 and the Mendum’s Pond water nutrient budget in the summer of 2008. However, work on both lakes already documented the deleterious impacts of development projects with poorly managed erosion controls and a cease and desist order was written by NH DES to close down further work in the Mendum’s Pond case. Data from both studies was supplied to ENSR Incorporated who had been contracted by EPA New

England to develop Total Maximum Daily Loading models for nutrient impaired and blue green bacteria toxin impaired lakes in NH. Specific nutrient loading coefficients measured for the studies as well as from data analyzed in a previous NH WRRC funded project (Schloss 2001: Development of Statewide Nutrient Loading Coefficients Through Geographic Information System Aided Analysis) were employed in their model estimates. In addition, water flow and nutrient data from the two projects as well as other UNH Center for Freshwater Biology efforts were used to develop daily loading conversions from annualized loading from the model results.

The NH LLMP long-term data base analysis of the phosphorus to chlorophyll relationships in NH lakes indicates a more sensitive chlorophyll response to the nutrient then studies from other states and regions and that the slope of the relationship increases at a point somewhere near 10 ppb total phosphorus. These findings are informing current efforts underway by NH DES to set nutrient criteria and water quality standards for NH lakes.

Publications, presentations, awards:

Schloss, J. 2007. REALISTIC EXPECTATIONS AND OUTCOMES FROM THE SURVEY OF THE NATION'S LAKES. Invited presentation for: 20th Annual National Conference Enhancing the States' Lake Management Programs: *Interpreting Lake Quality Data for Diverse Audiences.* May 24-27, 2007. Chicago IL.

Craycraft, R. and J. Schloss 2007. NH LAKES LAY MONITORING PROGRAM: 2006 WATER QUALITY MONITORING REPORT SERIES. 31 lake/watershed specific reports for participants. UNH Center for Freshwater Biology, UNH Cooperative Extension.

Outreach or Information Transferred:

See above for information transfer to ENSR and NH DES; the nutrient data and phosphorus chlorophyll analyses are being used by the state’s Water Quality Standards Advisory Committee (WQSAC) as well as the WQSAC Nutrient Criteria Subcommittee. In addition, we uploaded our long-term database into the NH DES Data Exchange System which is the state’s warehouse of water quality data that is also shared with the US EPA Water Quality Data Exchange Network .

The reports listed above were supplied to our participants and their lake/watershed associations and their communities. Non-technical summaries provided were published in local papers and association newsletters. Over a dozen presentations were provided to lake associations across the state.

Number of students supported (and degree level, undergrad, Master, PhD):

Six undergraduate students and one PhD student were partially supported and the nitrogen analyses funded were a major component of a Masters graduate student’s study.

Grant No. 06HQGR0143 Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.

Basic Information

Title:	Grant No. 06HQGR0143 Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.
Project Number:	2006NH86S
Start Date:	3/6/2006
End Date:	3/5/2011
Funding Source:	Supplemental
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Steve Kahl, William H. McDowell

Publication

1. 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, in press.
2. Rosfjord, C., K. Webster, J.S. Kahl, S.A. Norton, I. Fernandez, and A. Herlihy, 2007. Anthropogenically−driven changes in chloride complicate interpretation of base cation trends in lakes recovering from acidic deposition. Environmental Science and Technology, in press.

Annual Report to

USGS WRD WRRI, Reston, VA and US EPA, Corvallis OR

May, 2008

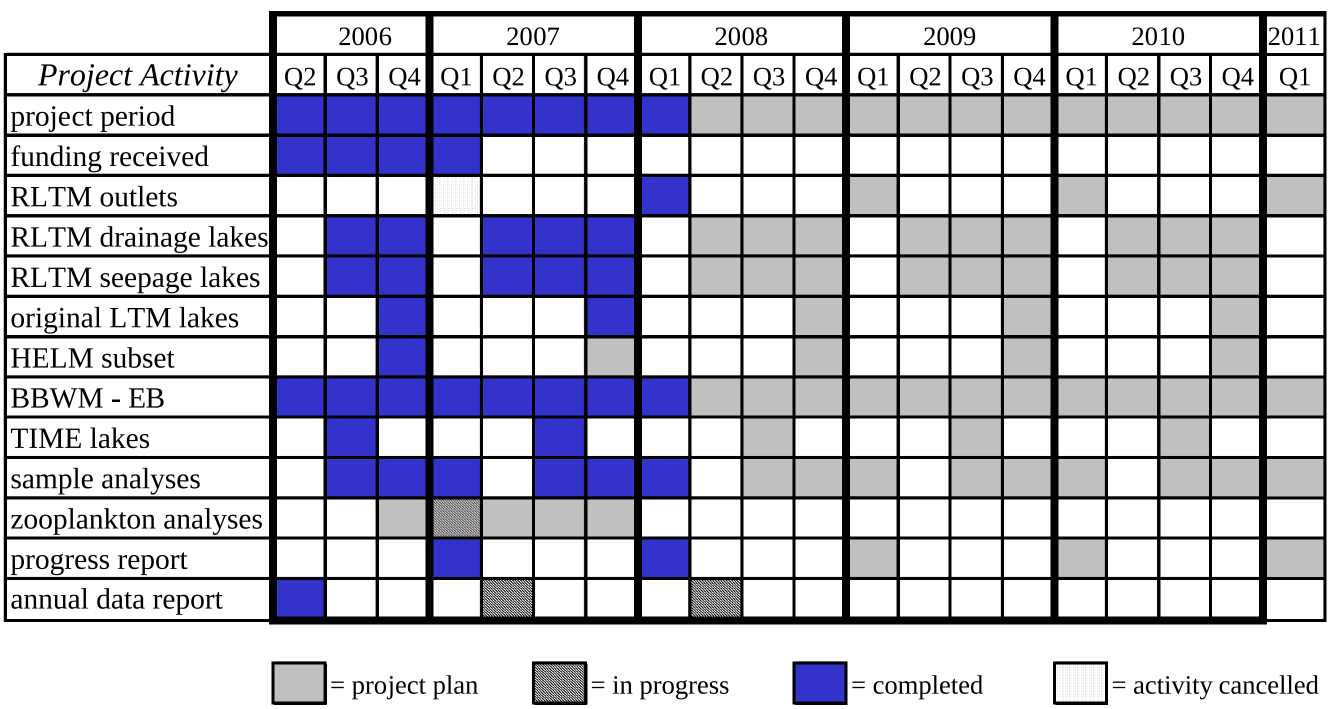
Determining the effectiveness of the Clean Air Act and Amendments on the recovery of surface waters in the northeastern US

IAG 06HQGR0143

Principal Investigators: *Steve Kahl*[1], *Katherine Webster*[2], *Bill McDowell*[3], *and Sarah Nelson*[2]
[1]Plymouth State University
[2]University of Maine
[3]University of New Hampshire

Overview of activities this period

A schematic summary of progress on the project plan is provided below and discussed on the following pages.



Project overview

<u>Objectives</u>. This proposed research is part of the EPA program to collect long-term data on the trends and patterns of response in surface waters sensitive to acidic deposition. The goals and methods are hierarchical from intensive site-specific to regional statistical populations. 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 linkages in changes in surface waters, if any, to changes in deposition that are related to regulatory goals;
3) characterize the effectiveness of the Clean Air Act Amendments in meeting goals of reducing acidification of surface waters and improving biologically-relevant chemistry in the northeastern US; and
4) provide information for assessment of the need for future reductions in atmospheric deposition based on the rate of recovery (or not) of the systems under study.

In 2008, we will also evaluate changes in biological condition using zooplankton collected in 2004 from 145 ELS-II lakes in the northeast, as part of our 20th anniversary re-analysis of the Eastern Lake Survey.

<u>Approach</u>. The schedule of tasks ranges from weekly to annual, continuing data records that now range from 12 to 22 years. We will evaluate chemistry on a weekly basis year-round at the small watershed-scale at BBWM, weekly during the spring melt period at LTM lake outlets, quarterly in LTM, and during an annual index period for the HELM and TIME lakes. These project components provide a *statistical framework* for inferring regional chemical patterns 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 provide a seasonal context for the annual surveys.

<u>Expected Results</u>. This information is fundamental for EPA to meet the Congressional mandate for reporting on the effectiveness of the Clean Air Act Amendments (CAAA). The highly effective combination of site-specific data within the regional context will provide for the recognition and understanding of declining SO_4, base cation depletion, and changes in N-saturation or DOC contributions to acid-base status. The results are also central to the decisions on additional emission reductions that may be needed to produce recovery.

Project Status

Field sampling. All project field objectives in the summer and fall of 2007 and early 2008 were accomplished as planned. Sample collection and analysis has continued despite delays in obtaining finding each year. Spring sampling of drainage lake outlets was prioritized for spring 2008 due to near-record snowpack in the region. However, lack of rainfall during snowmelt limited the excursions in magnitude of runoff. No evidence of major acidification events is expected in the data.

Analytical. Analyses are complete for all samples collected through the spring 2008, except for a few aluminum samples. The PSU laboratory now has an operational AAS HGA instrument for analysis of Al. Periodic inter-laboratory comparisons, and audit comparisons, continue between PSU, UNH, and UMaine.

Samples from East Bear Brook at BBWM, which are collected on a regular basis year around, are being analyzed in a contract laboratory at UMaine.

Zooplankton analyses. Zooplankton samples from 2004 have been counted (to genus level for cladocerans and groups for copepods) and images taken for body size spectra. Zooplankton samples collected in 1986 have been archived. We have taken images for body size spectra on about 1/3 of the lakes and plan to finish up the remaining samples in June. An Access database that includes all zooplankton samples, queries for body size and abundance metrics, and associated lake morphometry and water chemistry data has been built. The 2004 samples have been sent to Dr. Jim Haney's lab at UNH; the 1986 samples will be transferred shortly. Haney is replacing former collaborator Rich Stemberger, who passed away in late 2007. His lab will examine species composition of the cladoceran community in the two years during the summer of 2008. The EPA lab in Chelmsford has made arrangements for a permanent archiving of the zooplankton samples at Yale University.

Data reporting. All data collected through 2005 have been delivered to EPA. The next delivery of data to EPA is expected in June 2008, after evaluation of inter-laboratory comparisons and regular QA analyses by PSU and UMaine.

Presentation of findings. Several publications and presentations have resulted from this project since the final report for the previous LTM/TIME grant, listed at the end of this report. The next paper in preparation is a 20 year mass-balance analysis for the second book to be published from the Bear Brook Watershed in Maine. We published a paper on Maine high elevation lakes in Lakeline (Baumann and Kahl, 2007). These results will be incorporated in Baumann's MS thesis to be completed in late 2008. The regional scope of the thesis expands the analyses for this project to Maine and NH high elevation lakes.

Funding status: We have requested funding for field season 2008, and are in fiscal limbo until the funding arrives. Fortunately, the institutions allow us to continue operations despite not having new money, and technically not being able to spend existing money.

New developments: Co-PI Webster is leaving UMaine, and will continue her role as a science advisor and author as a Research Professor at Plymouth State University. Dr. Sarah Nelson of the Mitchell Center at UMaine has assumed the co-PI role in Maine. PI Kahl and Nelson will now oversee the field work.

Two Maine LTM ponds have recently been protected by conservation efforts. The New England Forestry Foundation acquired the entire watershed of Second Pond in Dedham. Kahl spoke at a 2007 fundraiser for the purchase. The Forest Society of Maine acquired the entire watershed of Partridge Pond in a 5,000 acre purchase. Kahl contributed to the funding proposal for the effort.

***Recent publications and presentations** using related project information*
(new listings since the last report are in **bold)**

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

Campbell, J, J. Hornbeck, M. Mitchell, M. Adams, M. Castro, C. Driscoll, J.S. Kahl, and others, 2004. Input-output budgets for inorganic nitrogen for 24 watersheds in the northeastern United States. Water Air Soil Pollut., 151:373-396.

Dupont, J., T. Clair, C. Gagnon, D. Jeffries, J.S. Kahl, S. Nelson, and J Peckenham, 2005. Estimation of critical loads of acidity in the northeastern US and eastern Canada. Environ. Monit. Assess. 109:275-291.

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.

Kahl, J.S., J. Stoddard, R. Haeuber, S. Paulsen, R. Birnbaum, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, K. Roy, W. Sharpe, S. Urquhart, R. Webb, and K. Webster, 2004. Response of surface water chemistry to changes in acidic deposition: implications for future amendments to Clean Air Act. Environmental Science and Technology, Feature Article 38:484A-490A.

Lawler, J., J. Rubin, B.J. Cosby, I. Fernandez, J.S. Kahl, S. Norton, 2005. Predicting recovery from acidic deposition: Applying a modified TAF (Tracking Analysis Framework) Model to Maine' High Elevation Lakes, Water Air Soil Pollut. 164:383-389.

Norton, S., I. Fernandez, J.S. Kahl, and R. Reinhardt, 2004. Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed, Maine, USA. Water, Air, Soil, Pollution Focus 4:289-310.

Rosfjord, C., K. Webster, J.S. Kahl, S.A. Norton, I. Fernandez, and A. Herlihy, 2007. Anthropogenically-driven changes in chloride complicate interpretation of base cation trends in lakes recovering from acidic deposition. Environ Sci Technol, 41:7688 -7693.

Rosfjord, C., J.S. Kahl, K. Webster, S. Nelson, I. Fernandez, L. Rustad, and R. Stemberger, 2006. Acidic deposition-relevant changes in lake chemistry in the EPA Eastern Lake Survey, 1984-2004. Final report to USDA NSRC, Durham, NH. 69 p.

Recent presentations using project information

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, 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

Grant No. 07HQGR0172 Watershed Assessment of New Boston Air Force Base

Basic Information

Title:	Grant No. 07HQGR0172 Watershed Assessment of New Boston Air Force Base
Project Number:	2007NH102S
Start Date:	8/23/2007
End Date:	8/22/2009
Funding Source:	Supplemental
Congressional District:	01
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quantity, Water Quality, Hydrology
Descriptors:	
Principal Investigators:	William H. McDowell

Publication

Project: Watershed Assessment of New Boston Air Force Base

Problem: New Boston Air Force Station (NBFAS) has a history of land use that may have contributed to contamination of the on-site water resources. In WWII, the land was purchased by the U.S. government and used as a target site for bomb training operations. Throughout the 1940s, thousands of bombs, both live and dummy ordnance, were dropped throughout the base, with the primary target being Joe English Pond. Extensive clean-up (identification and removal) of unexploded ordnance is on-going at the base. Contamination from ordnance, as well as from other point sources (i.e. an on-site landfill) has been detected in the groundwater and surface water on the base. An understanding of the hydrology on the NBFAS is needed to assess potential for off-site contamination.

Objectives:

1). Inventory the inputs (precipitation) and outputs (evapotranspiration and streamflow) for NBFAS (for one calendar year).

2). Evaluate surface water flow and develop a delineated watershed profile showing surface water movement.

3). Identify groundwater flow paths throughout the year.

Methods:

1). An understanding of the annual hydrologic cycle for the NBFAS is necessary in assessing the amount of water, potentially contaminated by past land use activities, that is leaving the base through the outlet at Joe English Brook. As the location of the base does not allow daily access by the Research Assistant, the BROOK90 hydrologic model is being employed to model the hydrologic cycle. This model was developed for use at the Hubbard Brook Experimental Forest, in the White Mountain National Forest in New Hampshire. Though many of the parameters are similar, localized parameters for NBAFS were obtained from existing reports (from Shaw Environmental, Inc.) and New Hampshire GRANIT.

This model requires inputs of precipitation, wind speed, and maximum and minimum temperatures at a daily time interval. A weather station was previously installed on NBFAS. The station was calibrated for the correct latitude, longitude, and elevation and a heating element was installed to allow for winter precipitation data to be collected. Monthly readings are obtained and checked against weather data from the nearby Manchester, NH airport. Weather data has been collected since 11/07. At least one full year of data is desired.

BROOK90 allows for input of measured streamflow and compares this to streamflow predicted by the model. As it was not possible to obtain daily streamflow, the modeled streamflow value will be used to approximate discharge leaving the base.

2). An understanding of the surface water flow paths is necessary to determine the direction of water movement on the base. Direction of surface water flow can be determined by delineating the NBFAS watershed (using GIS) and overlaying a topographic map. Surface water flow direction follows contour intervals.

3). Groundwater contamination has been detected on the base. It is necessary to identify the direction of groundwater flow to determine if this contaminated groundwater is leaving the base, or is contained within the watershed boundaries. Approximately 15 groundwater wells were installed throughout the NBFAS during past studies. The depth to water table is being measured monthly to allow a potentiometric map of groundwater flow paths to be drawn and to allow for seasonal fluctuations in flow direction to be identified. For these maps to be created, it is necessary to know the relative elevation of these wells. This information was provided by Shaw Environmental, Inc. Spot-checking of their values with surveying equipment has shown that they have a margin of error between five and ten feet. As this error is too large to allow for an accurate assessment of groundwater flow direction, the wells will be re-surveyed within the next two months.

Major findings and significance: An understanding of the hydrology of NBAFS is necessary to assess the contribution of the base to off-site water contamination. By estimating discharge from the watershed and by identifying groundwater and surface water flow paths, it is possible to identify "at risk" areas. As this study aims to provide a one-year hydrologic budget for NBFAS, there are currently no major findings of note.

Publications, presentations, awards: N/A

Publications from WRRC supported work completed in previous years and not reported previously (if applicable): N/A

Outreach or Information Transferred: N/A

Number of students supported (and degree level, undergrad, Master, PhD):
1 Master's Candidate

Physical , Biological, and biogeochemical response of a northestern river to a severe flood

Basic Information

Title:	Physical , Biological, and biogeochemical response of a northestern river to a severe flood
Project Number:	2007NH73B
Start Date:	3/1/2007
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	NH01
Research Category:	Water Quality
Focus Category:	Surface Water, Ecology, Sediments
Descriptors:	None
Principal Investigators:	William H. McDowell

Publication

Physical, Biological, and Biogeochemical Response of a Northeastern River to a Severe Flood

Problem

A highly unusual situation allows us to assess the effects of channel dewatering, channel creation, and increased sediment loads on the habitat, biota, and ecosystem processes of a large stream. The fourth-order Suncook River in southeastern New Hampshire drains a watershed of approximately 575 km^2 and has an average annual discharge of approximately 9 $m^3 s^{-1}$. The May 15, 2006 avulsion of the Suncook River naturally created a new stream reach of approximately 800 m (Figure 1). This new reach flows through a wetland and boggy area along the edge of an old railroad bed before converging on an access road, flowing into a sand pit, and rejoining the east branch of the Suncook River. Erosion of unstable sediments in the newly created Suncook River channel contribute to elevated sediment loads in and downstream of this new channel. Creation of the new stream reach resulted in nearly complete dewatering of the abandoned channel to the west (1.25 km long), which is now only fed from Mason Brook, a small tributary (Figure 1).

An examination of the effects of persistent dewatering on the biota and on ecosystem processes is particularly important in New England, which has only recently recognized the importance of instream flow issues. In New Hampshire, a pilot program was recently established for instream flow protection on the Lamprey and Souhegan Rivers, two of the state's fourteen designated rivers. Water quality is intrinsically tied to water quantity; dissolved nutrients and pollutants can be concentrated or diluted depending on instream flow. Stream temperature is regulated, in part, by instream flow, and water quantity determines the extent of instream habitat. The direct and indirect impacts of drought can greatly reduce population densities, species richness and alter life-history schedules, species composition, patterns of abundance, type and strength of biotic interactions (predation and competition), food resources, trophic structure and ecosystem processes (Lake, 2003). Recreational activities such as fishing and boating can also be impacted by significant reductions in stream flow.

Documentation of the effects of continuously elevated sediment loads is also increasingly important in New England and nationally, due to relentless increases in construction activities and the creation of impervious surfaces. Sedimentation of streams affects organisms in two major ways: through physical and chemical changes to the water, and through blanketing of the stream bottom. Specific effects of siltation on aquatic systems include screening out light, changing heat radiation, smothering the stream bottom, and retaining organic material and other substances, which create unfavorable conditions at the bottom (Ellis, 1936). By reducing the stream bottom's permeability to water movement, an increased amount of fine sediments in the streambed can affect the delivery and removal of gases, nutrients and metabolites, and potentially movement of animals (Allan, 1995).

Primary succession, involving site-specific, temporal change occurring after a disturbance that is so intense that no trace of the previous community remains (Fisher, 1990), has rarely been documented in streams at the spatial scale of whole river segments (Milner, 1994). With the proliferation of stream restoration activities that attempt to recreate natural channels (e.g. bypass channels and restored meanders), an understanding of the course and speed of the establishment of structure and function in a new stream would be timely. By advancing knowledge of the way that stream ecology and biogeochemistry respond to large-scale disturbances, this research has practical applications for stream conservation and restoration practices in New England.

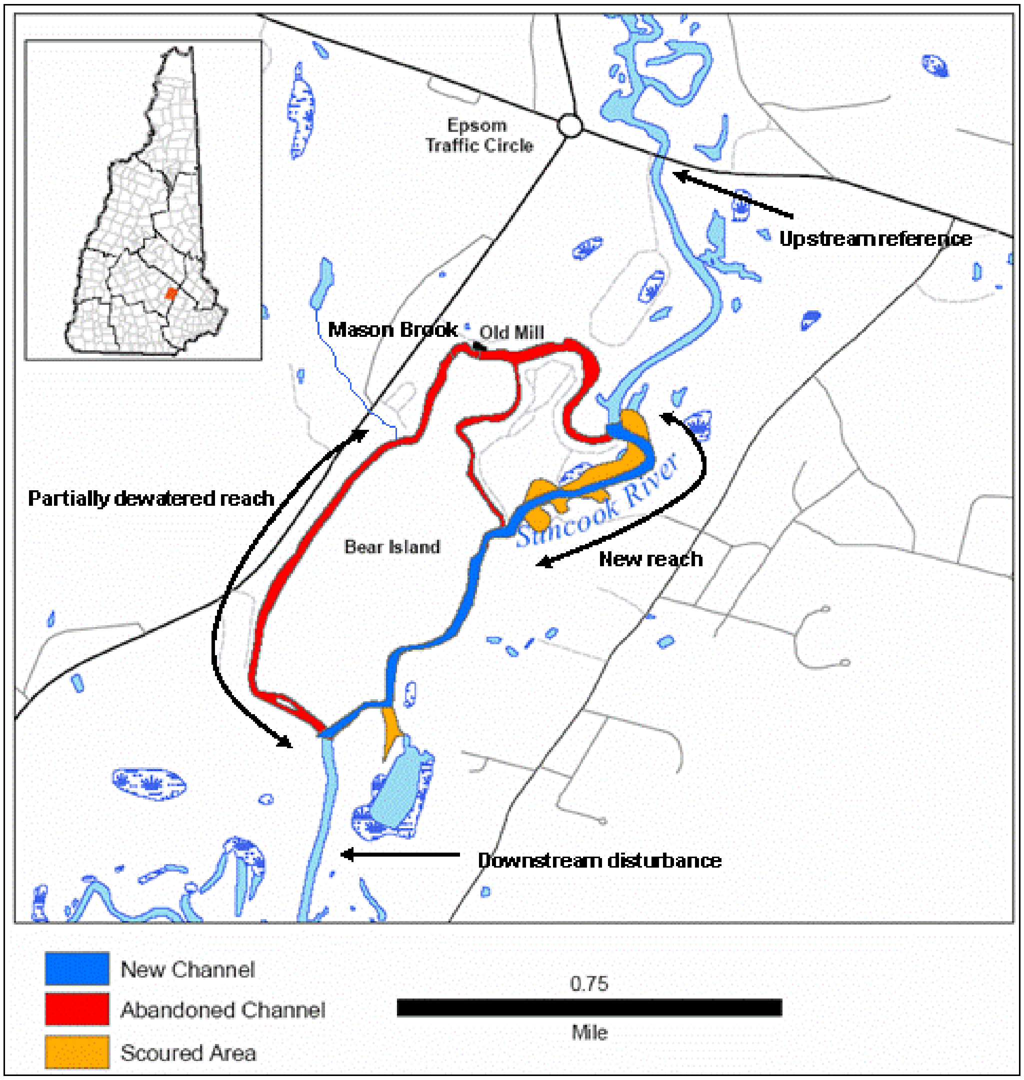


Figure 1. Changes to the Suncook River in Epsom, NH (Mapping by New Hampshire Geological Survey, NHDES)

Objectives

This research seeks to 1) determine the course of habitat transformation; 2) identify changes in biotic communities and; 3) investigate changes in biogeochemical processing in the radically altered Suncook River system. We collected data from three impacted reaches (new channel, dewatered channel, and sediment laden channel downstream of the avulsion) as well as an upstream reference site. We documented changes in: (1) streambed composition, (2) water physiochemistry (including temperature, pH, conductivity, dissolved oxygen, turbidity, suspended solids, DOC, NH_4^+, NO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}), (3) stream biota (benthic macroinvertebrates, and fish), and (4) ecosystem processes (stream metabolism) of the affected reaches and upstream reference sites. Work was carried out as shown in Table 1, below.

Table 1. Work plan

Activity	Frequency
Habitat	
Wolman pebble count	Annually (10/06, 8/07)
Water quality parameters (temperature, pH, conductivity, and dissolved oxygen)	Biweekly
Ecology	
Benthic macroinvertebrate collection	Quarterly (7/06, 9/06, 2/07, 5/07, 8/07)
Fish survey	Once (8/07)
Biogeochemical processing	
Water samples for nutrient, DOC and cation/anion analysis	Biweekly
Stream metabolism	Once (10/07)

Methods

Samples were collected at intervals described in Table 1 above. Stratified Wolman (1954) pebble counts (Kondolf, 1997) were carried out to characterize coarse surface substrate. Intermediate axes were measured using a ruler and hand-held gravel analyzer (Gravelometer, US SAH-97, Wildlife Supply Company, Buffalo, NY) for at least 100 particles. Benthic macroinvertebrates were collected using a kicknet sampler and by scrubbing all rocks and disturbing sediment within 1 ft of the kicknet frame. Specimens were preserved in 70% ethanol and subsampled according to EPA's Rapid Bioassessment Protocol for benthic macroinvertebrate collection. Specimens were identified to the family level. Fish were surveyed using electrofishing with backpack electroshockers in collaboration with the New Hampshire Department of Fish and Game. Whole-stream metabolism was measured using the diurnal upstream-downstream dissolved oxygen change technique (Marzolf et al., 1994).

Stream water samples were filtered in the field using pre-combusted glass fiber filters (0.7 µM pore size), and frozen until analysis. All samples were analyzed in the Water Quality Analysis Lab of the WRRC on the campus of UNH, Durham, NH.

The Water Quality Analysis Laboratory (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 Jeffrey Merriam is the Laboratory Manager. Together, they have over 35 years of experience in water quality analysis, and have numerous publications in the fields of water quality, biogeochemistry, and aquatic ecology.

Methods for analyses include ion chromatography (NO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{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.

Major findings and significance

Geomorphology

In the eastern branch of the Suncook River, substrate size now steadily decreases from cobbles upstream of the avulsion, to gravel in the new channel, to sand in heavily sedimented downstream portions of the river. Data collected more than one year after the avulsion suggests that this is a long-lasting trend; stream bed substrate within and downstream of the new channel remains small and unstable (Figure 2). This trend appears to have had a major impact on the stream biota and ecosystem processes, as will be described below.

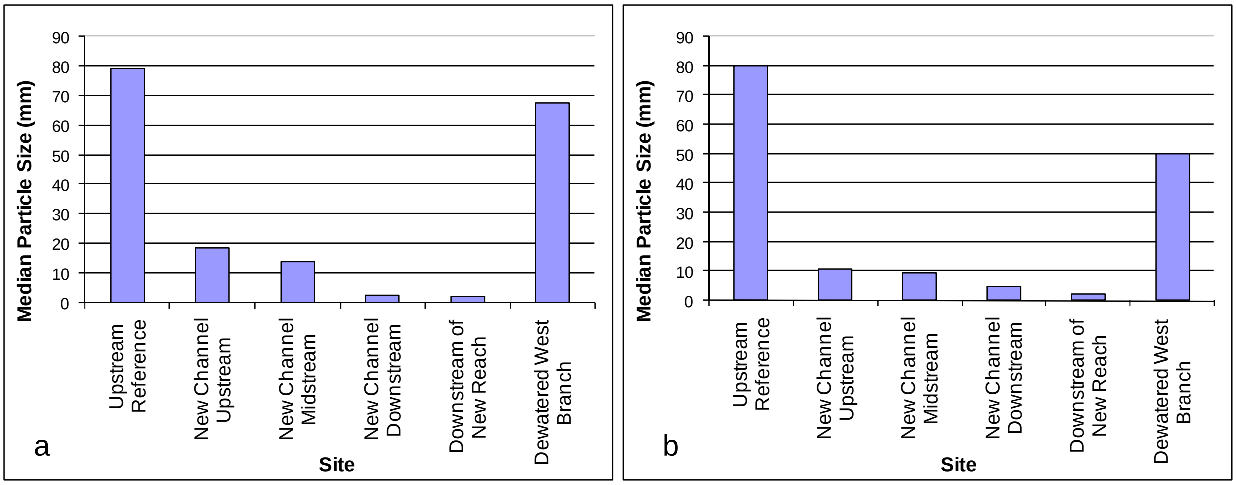


Figure 2. Substrate size in the Suncook River during (a) October, 2006; and (b) August, 2007.

Chemistry

The avulsion did not lead to noticeable changes in water chemistry in the main channel of the Suncook River. However, dewatering of the west branch of the Suncook River did lead to long-term increases in the concentration of major ions and nitrate in this reach. The concentration of nitrate and chloride over the monitoring period is shown in Figure 3 below; other major ions followed similar trends. The increase in concentration of major ions in the east branch of the Suncook River appears to be due to lesser dilution of high conductivity inputs from Mason Brook. Elevated nitrate concentrations in this reach are much higher than those in Mason Brook and are likely due to agricultural fertilizer inputs nearby in the watershed.

In the new and downstream reaches of the Suncook River where stream bottom substrate is small and unstable, there are also consistently higher concentrations of suspended solids in the water column. Extraordinarily high levels of suspended sediment in the new and downstream reaches of the Suncook River were measured immediately following the avulsion. Over the summer of 2006, these concentrations declined and approached baseline levels. However, notably higher concentrations of suspended solids continue to be found in these reaches during periods of storm flow (Figure 4).

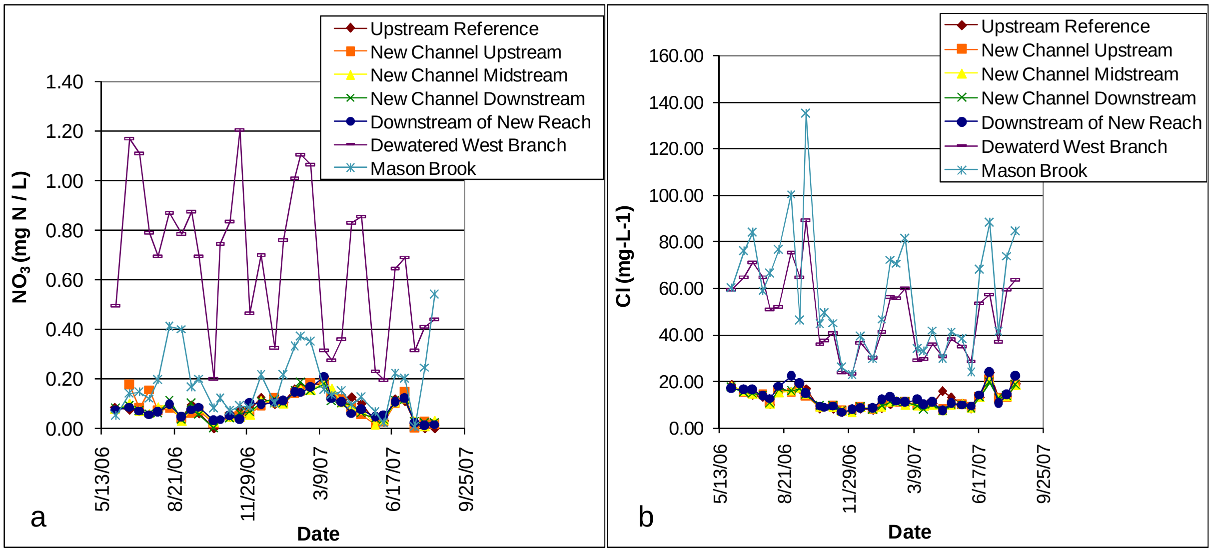


Figure 3. (a) Nitrate concentration; and (b) chloride concentration in the Suncook River.

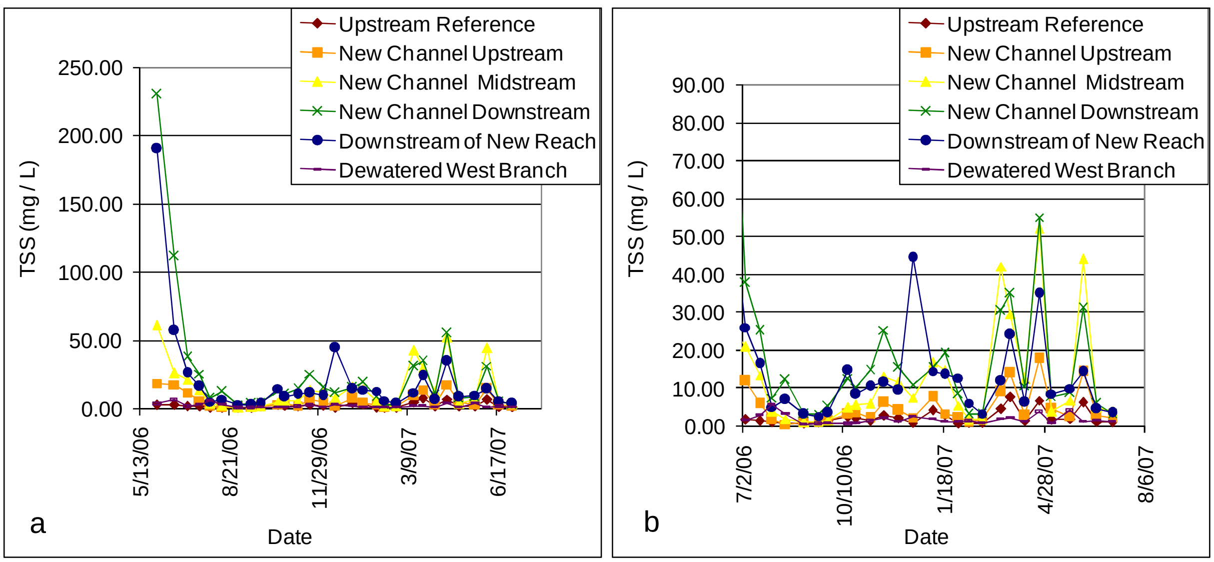


Figure 4. Suspended solids in the Suncook River (a) 5/06-7/07; and (b) 7/06-7/07 (note altered scale)

Biota

Along with decreasing substrate size and stability and increasing suspended solids as one travels downstream in the eastern branch of the Suncook River, benthic macroinvertebrate abundance declines (Figure 5). Fifteen months after the avulsion, macroinvertebrate density at the reference site is still two orders of magnitude greater than that found in reaches most impacted by sedimentation. Macroinvertebrate abundance in the dewatered channel remains comparable to that found within the reference site.

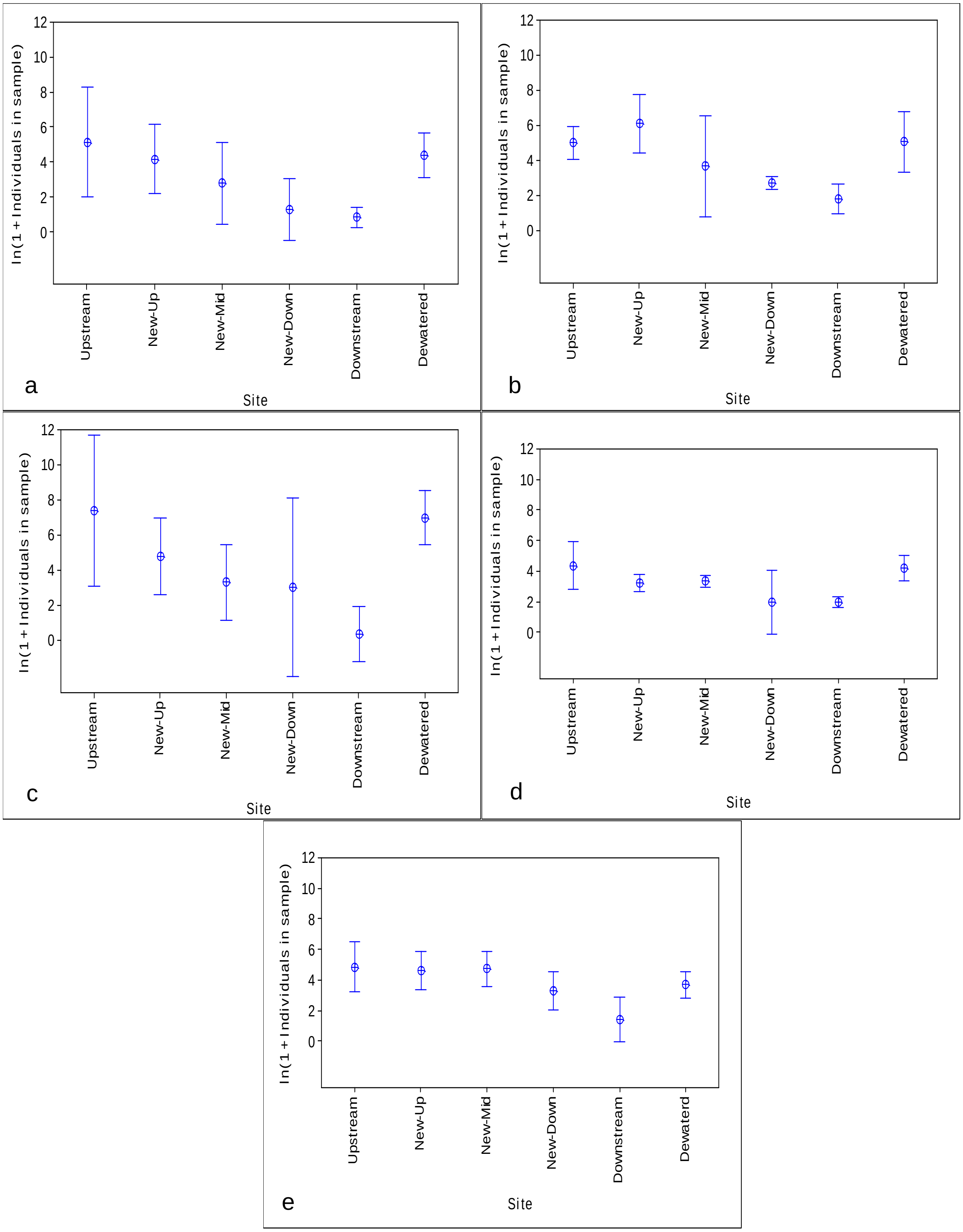


Figure 5. Macroinvertebrate abundance in the Suncook River (a) 7/06; (b) 9/06; (c) 2/07; (d) 5/07; and (e) 8/07; error bars show standard deviation.

Fish were surveyed fifteen months after the avulsion at four sites in the Suncook River system. While strong trends in fish community composition in the eastern branch of the Suncook

River were not apparent, the fish community within the dewatered western branch of the Suncook River was dominated by two species: Margined Madtom (*Noturus insignis*) and Fallfish (*Semotilus corporalis*) (Figure 6). Species richness was equal at the upstream reference site, within the new channel, and downstream of the avulsion, with eight different species found at each location. Compared with the reference site, catch per unit effort was slightly lesser in and downstream of the new channel, and much higher in the dewatered west branch (Figure 7).

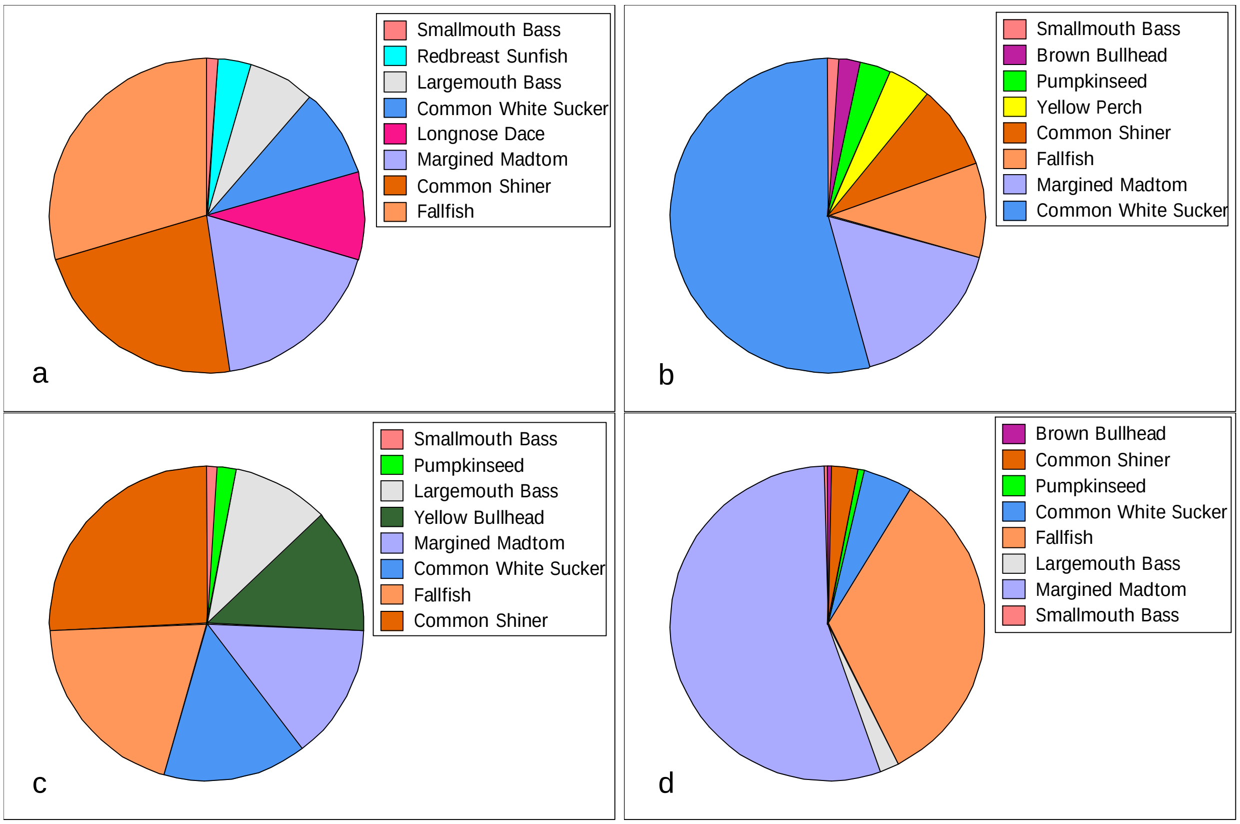


Figure 5. Fish communities in the Suncook River at (a) upstream reference; (b) new channel; (c) downstream of new channel; and (d) dewatered west branch.

Ecosystem Processes

Whole-stream metabolism in the Suncook River system was measured in October, 2007. At this time, seventeen months after the avulsion, gross primary production and community respiration were markedly depressed in and downstream of the new channel as compared with the reference site (Figures 7a and 7b). Whole stream metabolism in the dewatered west branch was also depressed relative to the reference site when assessed during a subsequent period in October, 2007 (Figures 7c and 7d).

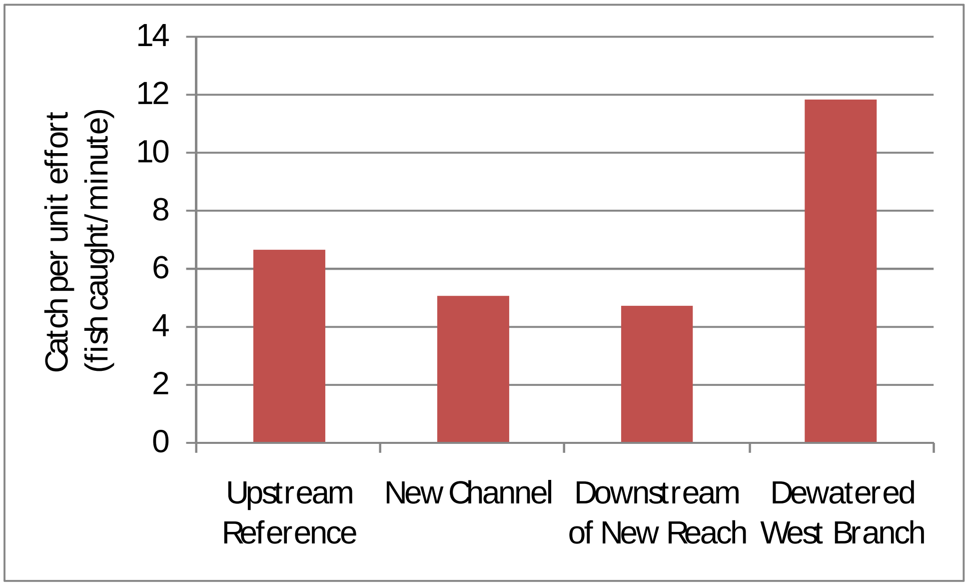


Figure 6. Fish abundance in the Suncook River fifteen months after the avulsion

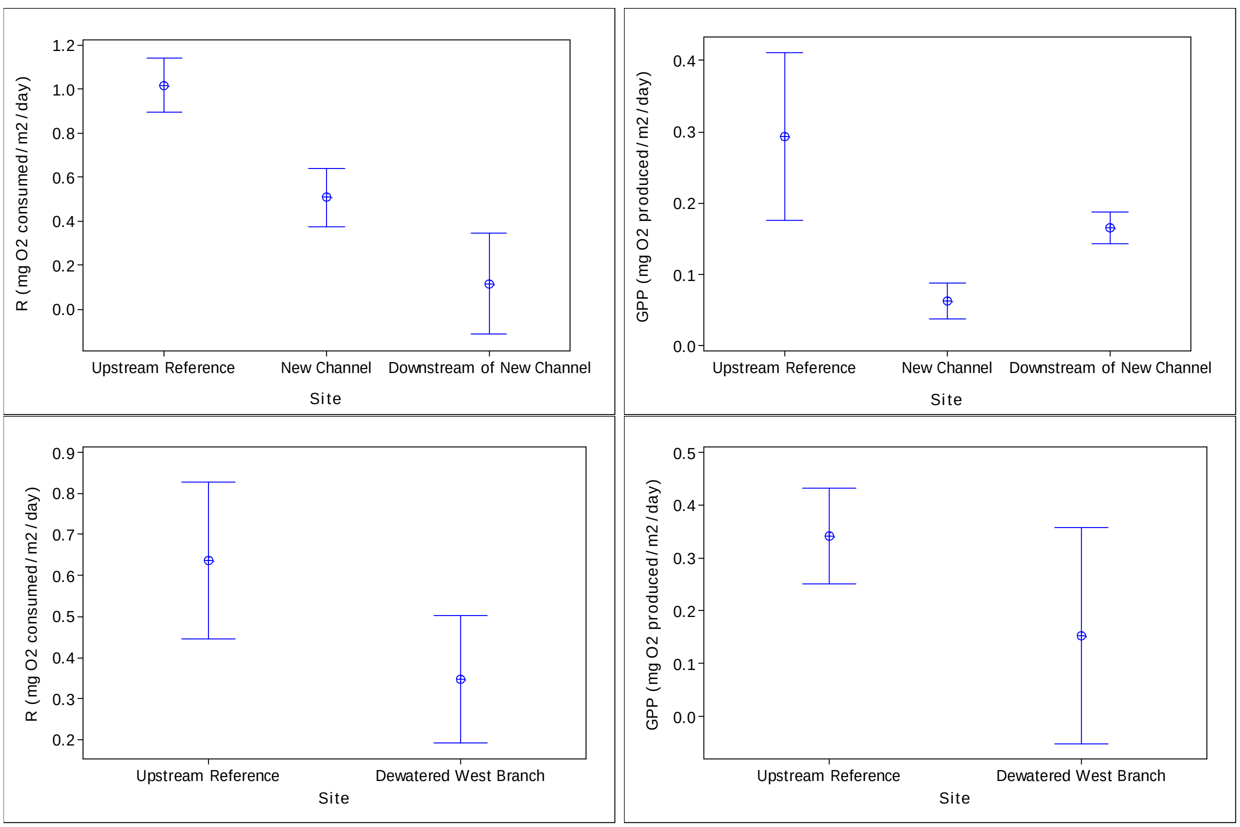


Figure 7. (a) Community respiration in the east branch of the Suncook River; (b) gross primary production in the east branch of the Suncook River; (c) Community respiration in the west branch of the Suncook River; and (d) gross primary production in the west branch of the Suncook River

Preliminary Conclusions

The May, 2006 avulsion has led to long-lasting changes in the Suncook River. In the eastern branch, reduced substrate size and stability and increased concentrations of suspended solids have led to dramatic reductions in macroinvertebrate abundance and whole-stream metabolism, while effects on fish communities have been less severe. In the western branch, where dewatering has altered water chemistry and reduced instream habitat area, whole-stream metabolism and fish species evenness have declined, while fish abundance has increased. There is a need for further research into the independent and combined roles of substrate size, substrate stability, suspended sediment, water chemistry, and instream habitat area in influencing lotic communities and ecosystem function.

Publications, presentations, awards

Traister, E.M. and W. McDowell. Physical, biological, and biogeochemical response of a northeastern river to a severe flood. (poster) Presented at the AGU 2006 Fall Meeting in San Francisco, CA.

Traister, E.M. and W. McDowell. Physical, biological, and biogeochemical response of a northeastern river to a severe flood. (poster) Presented at the UNH 2007 Graduate Student Research Conference in Durham, NH. (received poster award)

Traister, E.M. and W. McDowell. Physical, biological, and biogeochemical response of a northeastern river to a severe flood. (poster) Presented at the ESA 2007 Annual Meeting in San Jose, CA.

Daley, M.L., Traister, E.M. and W.H. McDowell. 2008. Physical, Biological, and Biogeochemical Response of the Suncook River to the May, 2006 Avulsion. Town of Epsom NH Public Meeting. March 2008.

Publications from WRRC supported work completed in previous years and not reported previously (if applicable)

Not applicable.

Outreach or Information Transferred

Water chemistry data was shared with the New Hampshire Department of Environmental Services.

A presentation was given to two fourth grade classes at Epsom Central School on 5/4/07 about the Suncook River avulsion.

Number of students supported (and degree level, undergrad, Master, PhD)

Equipment, sample analysis, and travel were provided for one PhD student, and support was provided for two laboratory technicians. Three undergraduate students were also supported for assisting with field and lab analyses.

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Information Transfer Program Introduction

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR−USGS Internship	Supplemental Awards	Total
Undergraduate	10	0	0	2	12
Masters	4	0	0	2	6
Ph.D.	2	0	0	0	2
Post−Doc.	0	0	0	0	0
Total	16	0	0	4	20

Notable Awards and Achievements

The first annual New Hampshire Water Conference was held on April 9, 2007 at the Grappone Conference Center in Concord. The conference drew over 200 people, including researchers, legislators, water system operators, land use planners, and government officials. Governor John Lynch spoke to the attendees about the importance of New Hampshire's water resources. Seven state legislators were in attendance. The conference theme was Sustainability of New Hampshire's Water Resources in a Developing Landscape. The current knowledge of the quality, quantity and use of water was examined through talks and sessions on the current conditions of New Hampshire's water resources, water demand trends, projected household costs for water, effects of climate change, and the sustainability and management of surface and ground water. The day closed with a panel discussion on the future outlook on the sustainability of our water resources.

The NH WRRC organized and totally funded the first annual “Lamprey River Hydrologic Observatory Symposium” in Durham, NH. Data from the WRRC project “Water Quality and the Landscape: Long−term monitoring of rapidly developing suburban watersheds” were presented along with various presentations made by UNH researchers from several different departments and one NH DES employee. Presentations focused on water quality, hydrology, nutrient cycling in coastal New Hampshire and also coastal Massachusetts. The symposium was quite a success and drew over 50 attendees including researchers, watershed organization members, legislatures, town officials and land use planners.

The annual NH Watershed Conference was held November 17, 2007 in Concord, NH and for the first time the NH WRRC was involved in supporting and organizing this conference. The conference drew approximately 200 people including researchers, legislators, water system operators, land use planners, and government officials. The conference contained 6 tracks including organizational development, effecting change, tech time, managing our watersheds, ecology and a newly added GIS track which was facilitated solely by the UNH cooperative extension and the NH WRRC.

Several high quality presentations have been made by the NH WRRC. Jeff Schloss was invited to give a presentation at the 20th Annual National Conference Enhancing the States' Lake Management Programs: Interpreting Lake Quality Data for Diverse Audiences in Chicago IL. Elena Traister presented a poster on the “Physical, biological, and biogeochemical response of a northeastern river to a severe flood”at the UNH 2007 Graduate Student Research Conference in Durham, NH and received a poster award.

Publications from Prior Years

1. 2002NH1B ("Linking Lakes with the Landscape: The Fate of Terrestrial Organic Matter in Planktonic Food Webs") − Articles in Refereed Scientific Journals − Lennon J.T. and K.L. Cottingham. 2008. Microbial productivity in variable resource environments. Ecology. 84(4): 1001−1014.
2. 2002NH1B ("Linking Lakes with the Landscape: The Fate of Terrestrial Organic Matter in Planktonic Food Webs") − Articles in Refereed Scientific Journals − Lennon J.T., A.M. Faiia, X. Feng, K.L. Cottingham. 2006. Relative importance of CO2 recycling and CH4 pathways in lake food webs along a terrestrial carbon gradient. Limnology and Oceanography. 51: 1602−1613.