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Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds 2010

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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. 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 (2010 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 systems, urban runoff, stormwater, 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. These datasets could be used to develop, test and refine predictive models, accurately assess the impacts of watershed management practices and serve as 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 also be essential to adaptive management strategies that strive to reduce non-point sources of pollution in New Hampshire.

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, and the Ossipee River watershed. Details of long-term datasets collected in each watershed are below.

College Brook watershed

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. Dissolved organic carbon (DOC), total dissolved nitrogen (TDN), nitrate (NO_3-N), ammonium (NH_4-N), dissolved organic nitrogen (DON), orthophosphate (PO_4-P), chloride (Cl^-), sulfate (SO_4-S), sodium (Na^+), potassium (K^+), magnesium (Mg^{+2}), calcium (Ca^{+2}), and silica (SiO_2), pH and conductivity are measured to assess water quality. Currently, samples from 3 sites are collected monthly throughout the year and sampling of College Brook began in 1991. Sample collection is done by UNH staff and/or students and samples are analyzed in the Water Quality Analysis (WQAL) Lab at UNH.

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 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 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.

The Lamprey River has been sampled weekly and during major runoff events since October 1999. Samples are analyzed for DOC, TDN, NO_3-N, NH_4-N, DON, and PO_4-P. Additionally, samples collected since October 2002 are also analyzed for total suspended sediment (TSS), particulate carbon (PC), particulate nitrogen (PN), dissolved inorganic carbon (DIC), Cl^-, SO_4-S, Na^+, K^+, Mg^{+2}, Ca^{+2}, SiO_2, pH, conductivity, dissolved oxygen (DO) and temperature. In January of 2004, we began routine sampling of additional Lamprey stream sites for dissolved organic matter (DOM) nitrogen, phosphorus and other parameters. During 2004 all stream sites were sampled on a weekly basis, in January 2005, the frequency of stream sampling was curtailed to monthly (instead of weekly) for most sites and three stream sites (the Lamprey River, the North River and Wednesday Hill Brook) remained at a weekly and major storm event sampling frequency. In the past year, 14 sites were included in the monthly sampling regime. All stream water samples are collected by UNH staff and/or students and analyzed by the WQAL at UNH.

From November 2003 to January 2005, bulk precipitation samples were collected on a weekly basis at numerous locations throughout the basin for analysis of nitrogen, phosphorus, DOM, major cations and anions and silica. Precipitation data from this time period indicated that rain chemistry within the Lamprey watershed does not vary spatially. Therefore since January 2005, we have collected wet-only precipitation samples from one collector in the watershed on an event to weekly basis. Several volunteers have been monitoring precipitation volume throughout the basin since October 2003 and will continue to do so as precipitation amount is spatially variable. All precipitation samples are collected by UNH staff and/or students and analyzed by the WQAL at UNH.

Quarterly ground water well samples have been collected from the James Farm and L1 well fields in Lee, New Hampshire. James Farm monthly samples were collected from January to September of 1995 and from July 2004 through December 2006. L1 monthly samples were collected from July 2004 through December 2006. Quarterly groundwater samples have been collected since January 2007 at both locations. All groundwater samples are collected by UNH staff and/or students and analyzed by the WQAL at UNH.

Ossipee Watershed

Volunteers of the Green Mountain Conservation Group sample streams within the Ossipee watershed of New Hampshire. Samples are collected every 2 weeks from May

to November, and monthly during the winter months. Water chemistry (DOC, TDN, NO_3-N, NH_4-N, DON, PO_4-P, Cl^-, SO_4-S, Na^+, K^+, Mg^{+2}, Ca^{+2}, SiO_2) is measured on a sub-set of the samples by the NH WRRC and WQAL. WRRC staff will assist in data interpretation.

Methods, Procedures and Facilities

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 Jody Potter is the Laboratory Manager. Together, they have over 40 years of experience in water quality analysis, and have numerous publications in the fields of water quality, biogeochemistry, and aquatic ecology.

Samples for this project are collected at intervals described above. Samples are filtered in the field using pre-combusted glass fiber filters (0.7 µm pore size), and frozen until analysis. All samples are analyzed in the WQAL of the WRRC on the campus of UNH, Durham, NH. Methods for analyses include ion chromatography (Cl^-, NO_3^-, SO_4^{-2} and Na^+, K^+, Mg^{+2}, Ca^{+2}), discrete colorimetric analysis (NH_4, PO_4, NO_3/NO_2), and High Temperature Oxidation (DOC, TDN). All methods are widely accepted techniques for analysis of each analyte.

Principal Findings and Significance

College Brook watershed

Monthly samples collected at 3 stations on College Brook and 1 station on Pettee Brook which also drains the UNH campus have been analyzed through 2010. We are now in the process of collecting and analyzing 2011 samples and updating our website: http://www.wrrc.unh.edu/current_research/collegebrook/collegebrookhome.htm.

Recent data show that DO is lowest at the upstream stations 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. It is highly unlikely that historical incinerator operations are impacting present day DO levels in this brook as they have in the past.

Data from 2000 until now indicate that the steam is strongly impacted by road salt application at its origin, which is essentially a road-side ditch along the state highway leading to a wetland area, and by road salt applied by UNH and the town of Durham which drains to the middle and lower reaches of the brook. 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.

College Brook has 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; the sum of ammonium and nitrate) and total nitrogen indicates that there are additional sources of nitrogen to the stream as it flows though UNH and Durham. 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 managers strive to reduce the nitrogen loading to Great Bay and Little Bay. Great Bay and Little Bay are "impaired" by elevated nitrogen and nitrogen (especially in the form of nitrate) exported from College Brook and into Little Bay is cause for concern.

Lamprey River Hydrologic Observatory

Analysis of weekly samples collected from the Lamprey River at the USGS gauging station in Durham, NH (referred to as "L73"), the North River at the former USGS gauging station in Epping, NH (N27) and a small tributary to the Lamprey River in Lee, NH (W01) and monthly samples collected at 13 other stations throughout the watershed through 2010 has been completed and we are in the process of updating the LRHO website (http://www.wrrc.unh.edu/lrho/index.htm). 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 W01 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 W01 where daily discharge can be estimated from meteorological measurements (such as precipitation and temperature) and this model is useful for estimating historic flows. Weekly precipitation samples at Thompson Farm (UNH property located in Durham, NH) were collected to document nitrogen inputs to the basin.

Results of stream chemistry to date show a significant increase in nitrate concentrations over time (Water Years (WY) 2000-2010) in the Lamprey River (Figure 1) and no change in nitrate concentrations in the North River or Wednesday Hill Brook over a shorter time period (2004-2010). 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. 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 W01 nitrate may be due to the limited population growth in this watershed, that this watershed has reached nitrogen saturation or that the relatively short period of data collection is not reflective of long-term trends. The long-term increase in nitrate in the Lamprey River has significant impacts for the downstream receiving water body, the Great Bay estuarine system. Great Bay is currently impaired by elevated nitrogen and is experiencing dangerously low dissolved oxygen levels and 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.

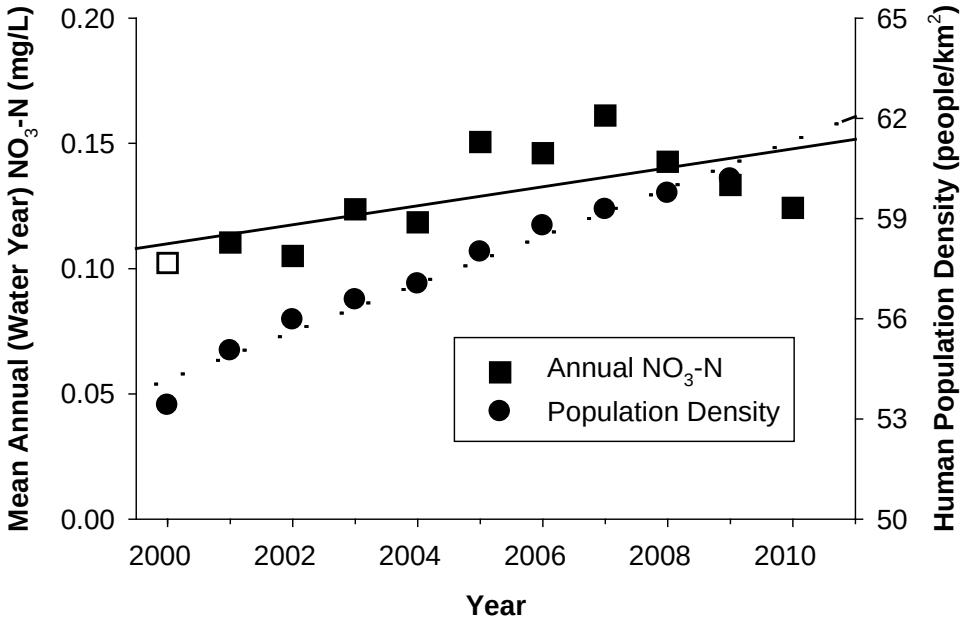

Figure 1. Annual (water year) nitrate concentration and estimated annual human population density over time in the Lamprey River basin. We have applied the Seasonal–Kendall Test (SKT; seasons set to 52) to weekly data from September 1999 through September 2009 and flow-adjusted nitrate concentrations have increased significantly over this time period (SKT $t = 0.28$, $p < 0.01$). The trend through mean annual concentrations and human population density is shown.

When we combine our specific conductance data (2002 – 2010) with data collected by the USGS (1978 - 1999), we see a long-term increase in specific conductance in the Lamprey River (Figure 2). Sodium and chloride concentrations are directly related to specific conductance ($r^2 = 0.95$, $p<0.01$ for Na^+; $r^2 = 0.93$, $p < 0.01$ for Cl^-) and we conclude that this increase in specific conductance indicates a corresponding increase in NaCl. Sine Na^+ and Cl^- are strongly correlated with impervious surfaces in southeast NH (Figure 3) and road pavement among southeastern and central NH basins. We conclude that the associated road salt application to these surfaces is responsible for these spatial and temporal changes in streamwater NaCl.

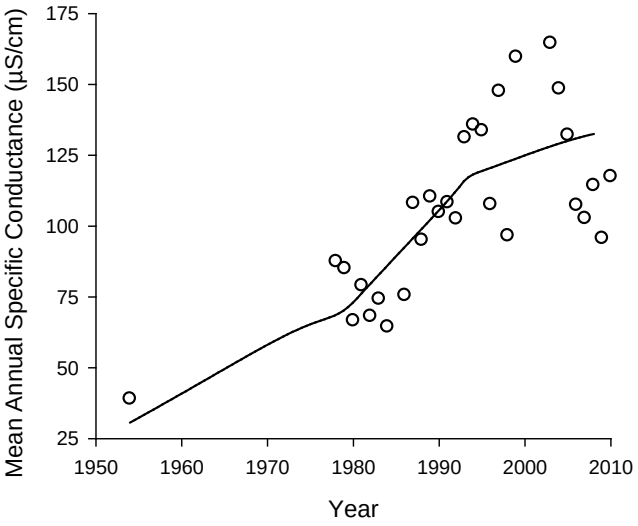

Figure 2. Mean annual specific conductance in the Lamprey River at the USGS gauging station in Durham, NH. (modified from Daley et al. 2009).

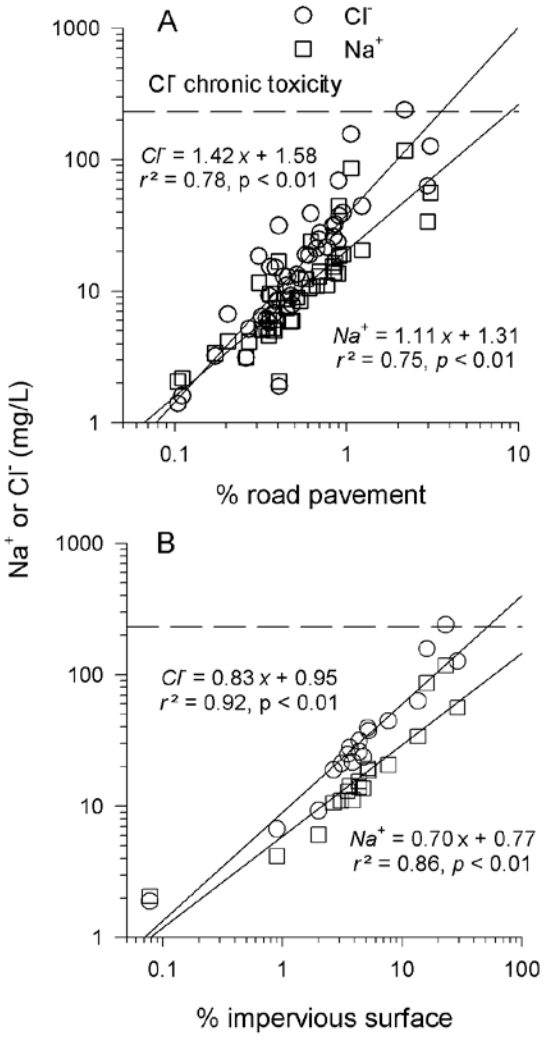

Figure 3. Relationship between both average concentrations of Na^+ (squares) and Cl^- (circles) and a.) % road pavement (College Brook, Lamprey and Ossipee sub-basins) and b.) % impervious surfaces (College Brook and Lamprey sub-basins only) (Daley et al. 2009).

Results of precipitation monitoring show that wet deposition and estimated dry deposition together account for more than half of the N input to the Lamprey watershed and that wet deposition 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.

James Farm ground water nitrate concentrations have shown conflicting patterns over the past ten years. There has been no change in nitrate concentrations among 4 wells, nitrate has increased in two wells and decreased in one well. L1 ground water nitrate concentrations have remained constant or decreased slightly with the exception of one well (L1A-21) where nitrate has ranged from <0.2 to 3.0 mg N/L. Decreased concentrations in recent years may reflect dilution by two 100 flood events in 2006 and 2007. James Farm and L1 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.

Results from long-term water quality monitoring in the LHRO have helped leverage funding for additional research on nitrogen cycling in NH's suburbanizing watersheds. Because of the significant interest in nitrogen loading to Great Bay, existing information on the spatial and temporal variability of nitrogen concentrations in the LRHO that are driven by population growth and land use change and the relationships that the NH WRRC has formed with various stakeholders in NH, the NH WRRC faculty and staff received a grant from NOAA and the National Estuarine Research Reserve System (NERRS). The grant is a collaborative science project to study nitrogen sources and transport pathways in watersheds of the Great Bay estuarine system. The project involves a significant amount of integration and collaboration with local stakeholders throughout the entire research process to ensure that the scientific results will be useful to local managers and decision makers.

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 GMCG staff at 7 sites. Over 100 samples were collected for analysis in the WQAL and additional field data was collected at a total of 45 sites throughout 6 towns using the help of many volunteers. Many presentations were made to planning boards, conservation commissions and other local government groups (see Information Transfer section below). Data have been used to heighten awareness of the impacts of excessive road salting and snow dumping in local streams. The impact of road salting in this central NH watershed is similar to what we see in coastal NH (Figure 3a). 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 rivers and streams within the watershed.

Number of students supported:

Five Master's students (Kate Dunlap, Michelle Galvin, Amanda Hope, Lucy Parham and Jason Bailio) and 3 undergraduate hourly employees (Althea Marks, Daniella Williams, Sarah Brown and Taylor Langkau) and one post-undergraduate/pre-graduate school volunteer (Jess Stevenson).

Publications:

Daley, M.L. and W.H. McDowell, *In Preparation*, Nitrogen saturation in highly retentive coastal urbanizing watersheds, Ecosystems.

Daley, M.L., J.D. Potter and W.H. McDowell, 2009, Salinization of urbanizing New Hampshire streams and groundwater: impacts of road salt and hydrologic variability, Journal of the North American Benthological Society, 28(4), 929–940.

Daley, M.L., J.D. Potter and W.H. McDowell, 2010, Nitrogen Assessment for the Lamprey River Watershed, Report prepared for the New Hampshire Department of Environmental Services. http://des.nh.gov/organization/divisions/water/wmb/coastal/documents/unh_nitrogenassessment.pdf

Dunlap, K, 2010, Seasonal Nitrate Dynamics in an Agriculturally Influenced NH Headwater Stream, M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 102 pages.

Galvin, M, 2010, Hydrologic and nutrient dynamics in an agriculturally influenced New England floodplain, M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 94 pages.

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

Conference Proceedings & Abstracts:

Daley, M.L. and W.H. McDowell, 2010, Landscape controls on dissolved nutrients, organic matter and major ions in a suburbanizing watershed, American Geophysical Union Fall Conference, San Francisco, CA, December, 2010.

Davis, J.M., W.H. McDowell, J.E. Campbell and A.N. Hristov, 2010, Hydrological and biogeochemical investigation of an agricultural watershed, southeast New Hampshire, USA, American Geophysical Union Fall Conference, San Francisco, CA, December, 2010.

Hope, A.J. 2010. Ecosystem Processes in a Piped Stream. Plum Island Ecosystems Long Term Ecological Research All Scientists Meeting, Woods Hole, MA. April 8, 2010.

Hope, A.J. and W.H. McDowell, 2010, Ecosystem Processes in a Piped Stream, Aquatic Sciences: Global Changes from Center to Edge, ASLO & NABS Joint Summer Meeting, Santa Fe, NM, June 2010.

Information Transfer:

Bucci, J., McDowell, W.H., Daley, M.L., Potter, J.D., Hobbie, E., French, C. and Miller, C. 2011. Detecting nitrogen sources and flow paths in the Great Bay watershed and engaging decision makers in the Science. Annual Lamprey River Science Symposium. Durham, NH. January 2011.

Daley, M.L. 2010. Current Water Quality Research in the Lamprey River Watershed: Nitrogen and Chloride. Lamprey River Advisory Committee. Durham, NH. January 2010.

Daley, M.L. 2010. Current Water Quality Research in the Lamprey River Watershed: Nitrogen and Chloride. Town of Newmarket, NH. January 2010.

Daley, M.L. 2010. Road Salt Impacts to New Hampshire Streams and Groundwater. "The Road Less Salted" Water Quality & Salt Reduction Seminar. Greenland, NH. May 2010.

Daley, M.L. 2010 Shared slides on nitrogen cycling from the Lamprey River watershed with Ted Diers for a presentation on nitrogen in the Great Bay watershed given by NH DES. May 2010.

Daley, M.L. 2010. Water Quality in the Suburbanizing Lamprey River Basin. University of New Hampshire Inventory and Monitoring of Ecological Communities class. Durham, NH. September 2010.

Daley, M.L. 2010. Suburbanizing NH watersheds and N Saturation. University of New Hampshire Watershed Water Quality Management class. Durham, NH. November 2010.

Daley, M.L. 2011. Testified in support of nominating the remaining segments of the Lamprey River and its major tributaries into the State Rivers Management Protection Program. NH House of Representatives Resources, Recreation & Development Committee Public Hearing. Concord, NH. January 2011.

Daley, M.L. and McDowell, W.H. 2011. Declining nitrogen retention with increasing nitrogen inputs in the Lamprey and Oyster River watersheds. Annual Lamprey River Science Symposium. Durham, NH. January 2011.

Hope, A.J. 2009. Proposed Research on Pettee Brook (a Piped Stream). ORWA Water Testing Committee. US Forest Service, Durham NH, September 2009.

Hope, A.J. 2010. Ecosystem Processes in Pettee Brook (a Piped Stream). Oyster River Watershed Association (ORWA) Water Testing Committee. US Forest Service, Durham NH, October 2010.

McDowell, W.H. 2010. Biogeochemistry of Suburban Basins – Putting People into the Landscape. Plymouth State University, April 2010.

McDowell, W.H. 2010. Biogeochemistry of Suburban Basins – Putting People into the Landscape. Duke University, April 2010.

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McDowell, W.H. 2010. Nitrogen Impairment in a Suburban Basin: Can We Engineer a Solution? University of New Hampshire, September 2010.

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McDowell, W.H. and Daley, M.L. 2011. Long-term water quality trends in the Lamprey River. Annual Lamprey River Science Symposium. Durham, NH. January 2010.

Press Releases

Daley, M.L. 2010. "Scientists say time to cut nitrogen in estuary is now" by Aaron Sanborn asanborn@seacoastonline.com in http://www.seacoastonline.com/ May 12, 2011.

Daley, M.L. and McDowell, W.H. 2011. Nitrogen research at the NH Water Resources Research Center as it relates to the nitrogen impairment of Great Bay. Lee, NH Town Crier. January 2011.

McDowell, W.H. 2010. "$600K grant helps study nitrogen in estuary, bay" By Dave Choate dchoate@seacoastonline.com in http://www.seacoastonline.com/ December 04, 2010.

McDowell, W.H. 2010. "Grant will seek pollution source in NH's Great Bay" by Associated Press in http://www.bostonherald.com December 6, 2010.

McDowell, W.H. 2010. "UNH's grant money may be a 'saving grace' for Great Bay" by Kristen Phelps in The New Hampshire (UNH newspaper) December 6, 2010.

McDowell, W.H. 2010. “New grant to address Great Bay's pollution 'hot spots'” on http://www.fosters.com/ December 6, 2010.

Presentations made by the Green Mountain Conservation Group staff March 2010 - February 2011.

March 12th Ossipee Aquifer Steering Committee Meeting
April 9th Ossipee Aquifer Steering Committee Meeting
April 10th WQM Volunteer Training
May 11th Ossipee Central School water testing program
May 12th Tamworth Brett School water testing program
May 13th Road Salt & Water Quality Regional Workshop
May 13th Pequawket Foundation WQM presentation
May 14th Ossipee Aquifer Steering Committee Meeting
May 14th Effingham Planning Board Presentation
May 15th VLAP Training
June 1st Ossipee Central School GET WET! & water quality presentation
June 1st, 2nd & 3rd Duncan Lake BMP Project
June 4th WQM Intern Lake Hosting Training
June 8th Mustang Academy Madison WQM RIVERS program
June 9th Camp Director Meeting & Presentation
June 11th Ossipee Aquifer Steering Committee Meeting – Work Session
June 16th Drive Time Radio Program WQM
June 18th MWV Chamber After Hours Program
June 25th NH Lakes Congress Conference
July 7, 8, 21, 22 Volunteer Lake Assessment Program & WQ Programs with Camps Cody, Huckins, Robin Hood, Marist & Danforth Bay
July 6, 20, Aug. 3 WQ Programs/Ossipee Lake & Tributary testing with Camp Calumet
July ?? Madison Library Kids Program on Macroinvertebrates
July 9th Ossipee Aquifer Steering Committee Meeting
August 7 Household Hazardous Waste Day WQ Table in Ossipee
August 10 VLAP & WQM Presentation with NH DES in Ossipee
August 13th Ossipee Aquifer Steering Committee Meeting
August 25 VBAP, Trout in the Classroom & WQM Volunteer Training
Sept. 16th Ossipee Aquifer Steering Committee Meeting
Sept 7-17 VBAP Programs & WQM daily with Ossipee Central School, Effingham Elementary, The Community School, Tamworth Learning Circles, Sandwich Elementary School & Tamworth Brett School
Oct. 22nd Ossipee Aquifer Steering Committee Meeting
October 29th Regional Road Salt Reduction Workshop with UNH T2 in Chocorua
November 12th Ossipee Aquifer Steering Committee Meeting
November 18th Student WQM Presentation in Tamworth of VBAP & WQ
December 7th Regional Groundwater Protection Workshop
January 14, 2011 Ossipee Aquifer Steering Committee Meeting
February 11, 2011 Ossipee Aquifer Steering Committee Meeting

January 8th 2010 Ossipee Aquifer Steering Committee Meeting
January 23rd 2011 Annual Meeting with WQ presentation in Freedom
February 8th 2011 Kingswood Fair for Youth Coalition for Clean Water
February 11th 2011 Ossipee Aquifer Steering Committee Meeting
February 15th Trout Unlimited & WQM Program Tamworth
February 16th Drive Time Radio Program
February 17th GET WET! & WQM Training Madison