



# **Nitrogen Sources and Transport Pathways: Science and Management Collaboration to Reduce Nitrogen Loads in the Great Bay Estuarine Ecosystem**

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National Estuarine Research Reserve System  
Science Collaborative  
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## 1. Abstract

New Hampshire's Great Bay Estuary is experiencing low dissolved oxygen levels, eelgrass loss and is impaired by elevated nitrogen. Reductions in both point and non-point sources of nitrogen throughout the watershed, which drains coastal New Hampshire and Maine, are needed. This collaborative science research project focused on identifying non-point nitrogen sources. We worked with a stakeholder advisory board to refine research objectives and identify products that would be useful for decision makers aiming to reduce nitrogen delivery to the estuary. We assessed the relationship between both dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON) concentrations among approximately 250 streams and rivers and the level of human impact (human population densities, land use and impervious surfaces) and natural features in the respective sub-watersheds. We also compared nitrogen concentrations among our stream and river sites to the total nitrogen inputs to the watershed from atmospheric deposition, human waste (distributed via septic systems), pet waste (dogs and cats), fertilizer use on lawns, recreational fields and agricultural areas and livestock waste. Concentrations of DIN were more responsive to the level of human impact than DON. We found that all types of human development (human population density, % impervious and % development) contribute DIN to streams, but agriculture was not a significant predictor of spatial variability in DIN. Wetlands were the main source of DON and agricultural lands were a minor source of DON. Increased nitrogen inputs, mainly from developed areas, resulted in increased DIN and total dissolved nitrogen (TDN) in streams. Agricultural inputs (fertilizer use on agricultural areas and livestock waste) were not a significant source of DIN, although there was a slight increase in DON with increased agricultural inputs. There was no relationship between total N inputs (or N inputs from developed areas) and DON in streams. Isotopic analysis of nitrate, mitochondrial DNA and canine detection were used to identify sources of nitrogen at select sites. In most samples taken for isotopic analysis, the nitrate signature does not reflect that of unprocessed wet deposition or of pavement drainage. Mitochondrial DNA analysis indicated dog waste was not common in most streams. Canine detection indicated that human waste was present in 6 of 7 urban streams and 2 of 3 suburban streams sampled. Based on these results our key findings for the Great Bay watershed are:

- All types of human development contribute DIN to streams.
- There is no silver bullet to reducing DIN.
- Wetlands are the main source of DON in streams and rivers.
- Improvements in land management may reduce stream water DIN, but are unlikely to significantly reduce DON.
- Currently agriculture is not a dominant land use in most sub-watersheds and thus agriculture is not a major source of nitrogen in most streams. It is a minor source of DON.
- Maintaining natural areas (forests, water and wetlands) will help reduce nitrogen.
- Leaky sewer lines and illicit connections may be an overlooked source of non-point nitrogen.

## 2. Management problem and context

The Great Bay is NH's largest estuary and its watershed drains 52 towns (42 in NH, 10 in ME) and is home to more than 22% of NH's population. Currently the watershed is mostly forested, but development pressures are large due to rapid population growth in this area (SPNHF 2010). In fact according to a national study conducted by the USDA Forest Service, the Great Bay watershed is in an area that is projected to experience the largest decline in water quality due to increased housing density on private forest lands (Stein et al. 2009). Management of the Great Bay watershed is complicated by the fact that the watershed drains multiple political divides (two states, 4 counties, 4 regional planning commissions and 52 towns) and often times land management decisions are made at the local town level without consideration of the impacts from a watershed perspective.

Environmental conditions in Great Bay are deteriorating and the long-term increase in DIN concentrations, the long-term decline in eelgrass and the fact that several of the tidal rivers draining to Great Bay do not meet state standards for dissolved oxygen for several weeks each summer is cause for concern (PREP 2013). Increases in nitrogen (N) concentrations and subsequent loading to the Great Bay estuary over the last 20 years is likely contributing to the observed habitat degradation. A priority issue for the Great Bay National Estuarine Research Reserve (GBNERR) is to understand the sources, fate and transport of the nitrogen that contaminates habitats and aquatic resources in the Great Bay watershed. The nutrient dynamics of Great Bay are complex, and gaps in our basic understanding of how high-N sources in the watershed are delivered to the Bay limit management options for reducing N loading to Great Bay. Fertilizers, human waste disposal with on-site septic systems, leakage of sewage from sewer lines, agricultural operations, and atmospheric deposition all have the potential to contribute non-point source (NPS) nitrogen directly to the Bay or to its tributary watersheds. On an annual basis, these non-point sources of N contribute 68% of the nitrogen load to Great Bay (PREP 2013). The goal of this study was to increase our understanding of the non-point sources of nitrogen that make their way to streams and rivers that feed Great Bay and to help inform science-based solutions for effectively reducing these non-point sources of nitrogen.

Identifying and reducing NPS nitrogen inputs to Great Bay will not be an easy task, and requires solid scientific investigation that is targeted to the needs of management agencies. Because most (60 to 80%) of the N inputs to major watersheds in the northeastern US are not exported to receiving estuaries such as Great Bay (Howarth et al. 1996), it is difficult to determine which of the many N sources are actually found in streams and rivers and delivered to downstream estuaries. Additionally, although there has been extensive work on total N concentrations in the Bay itself and at the mouths of its major tributaries, relatively little is known about the spatial variability of nitrogen concentrations throughout the entire Great Bay watershed. This project attempted to overcome these barriers to reducing non-point sources of nitrogen.

### **3. Outcomes, methods and data**

#### **The objectives of this study were to:**

1. Ensure results are relevant to local decisions and presented in an accessible format by working with a stakeholder advisory board of local leaders.
2. Identify nitrogen concentrations in surface waters at approximately 250 sites throughout the Great Bay watershed.
3. Assess how nitrogen concentrations respond to different land uses and different levels of nitrogen input to the watershed
4. Identify the non-point sources of nitrogen that reach surface waters at select sites

#### **Collaborative science methods, data and outcomes**

Our main mechanism for integrating intended users into the research project was the Nitrogen Sources Collaborative Advisory Board (NSCAB) and electronic distribution of the Nitrogen Newsbytes Newsletter. NSCAB members included civic leaders, community decision-makers, business owners, and others who have a stake in Great Bay nitrogen issues and want to help ensure that good science leads to sound community decision-making. Typically quarterly NSCAB meetings were held to discuss project objectives, progress towards objectives, next steps, and final products.

Members of the NSCAB represent a subset of stakeholders in the watershed who are deeply engaged and concerned about the nitrogen issue. The project team feels that the NSCAB members' knowledge of the science has reached a level to enable them to not only engage in informed dialogue, but to work with constituents in their own communities to address nitrogen-related issues. A good example of this is when a NSCAB member stood up and defended the science at a Southeast Watershed Alliance meeting.

The integration team worked with the scientists and local partners to issue seven Nitrogen Newsbytes newsletters since the start of this project. Newsletters included a project update, preliminary findings and other nitrogen relevant news items. The newsletter was a supplemental method for transferring information to stakeholders as well as collecting their input on questions that drove the activities of the project. The list of subscribers has grown to 150 people representing diverse interests, e.g. sewer districts, conservation and watershed organizations, taxpayers, businesses, national Senator staffers (Shaheen), etc.

A joint meeting with the NSCAB and local nitrogen experts was held on August 7, 2014. The goal of this meeting was to collectively determine what the results from the nitrogen sources research project can tell us about managing nitrogen in the Great Bay watershed and also to identify nitrogen management decisions the science can inform. It was clear from this meeting that an important product of this project would be for the team members to have time to interact with stakeholders so they could best utilize the project results and the team's broader knowledge on nitrogen issues. Based on the discussions at this meeting, the project team decided to peruse these final next steps:

- Develop a synthesis of research findings and land use dynamics (including limitations and remaining questions) for stakeholders – 2-4 pages
- Present project results at next Southeast Watershed Alliance (SWA) meeting
- Reach out to the Water Integration for the Squamscott-Exeter (WISE) and Green Infrastructure (GI) for Sustainable Coastal Communities NERSS Science Collaborative projects so they have the opportunity to incorporate results from this project in their work
- Reach out to Natural Resources Outreach Coalition (NROC) 2.0 so they have the opportunity to incorporate results from this project in their work

A draft 4 page research summary has been generated and this will be finalized after meeting with the SWA, WISE and GI groups to incorporate their feedback. We were able to schedule a meeting with the WISE and GI project teams on October 30, 2014, but due to scheduling conflicts we are unable to meet with SWA members until their January 2015 quarterly meeting. Steve Miller and Chris Keeley are active participants in NROC 2.0 and can highlight and transfer information from this project at NROC meetings. The meeting with the WISE and GI project teams on October 30, 2014 was very productive and collectively we identified specific information from this project that would be useful to the regional planning commissions (RPC, a graph of nitrogen concentrations vs. human population density that shows the degradation of streams even at the 2 acre zoning level) and the WISE and GI projects (e.g. tables of site metadata and concentration information). The project team was asked to share stream data directly with the WISE project team and to present to these results to the RPCs in January. There was also an interest from the Rockingham and Strafford RPC to tie the results into the Granite State Future and the Regional Master Plan over the next few months. The project team will follow up on all of these requests.

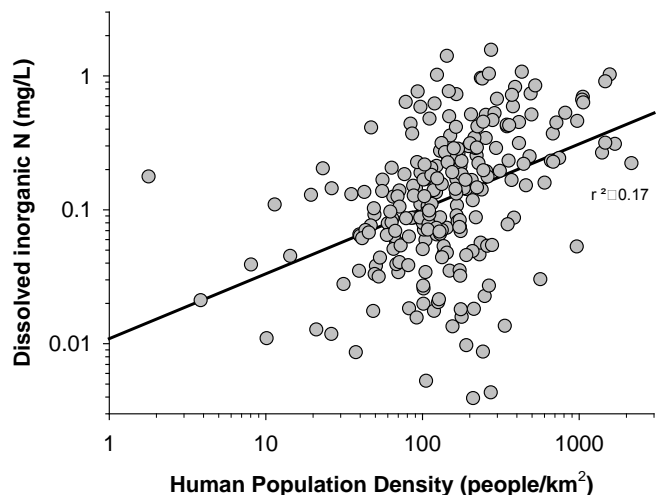
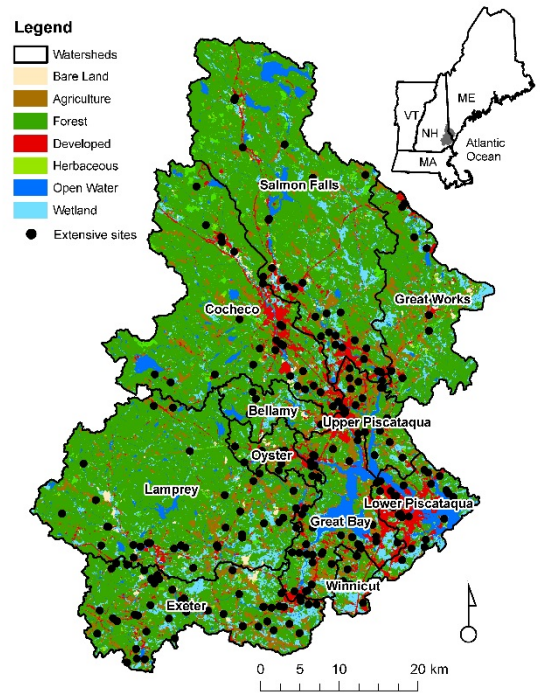
Over the life of the project, various stakeholders have been involved: the NSCAB, Sewer District representatives, state environmental services staff, Lamprey River Watershed Association, Lamprey River Advisory Committee, Oyster River Watershed Association, Oyster River Local Advisory Committee, Trout Unlimited, Southeast Watershed Association, Newmarket Town Council and Conservation Commission, Marine Docents, US Senator Shaheen's office (via newsletter), state representatives (Spang, Borden, etc.).

## Applied science methods, data and outcomes

### How do nitrogen concentrations in streams and rivers respond to different land uses in the watershed?

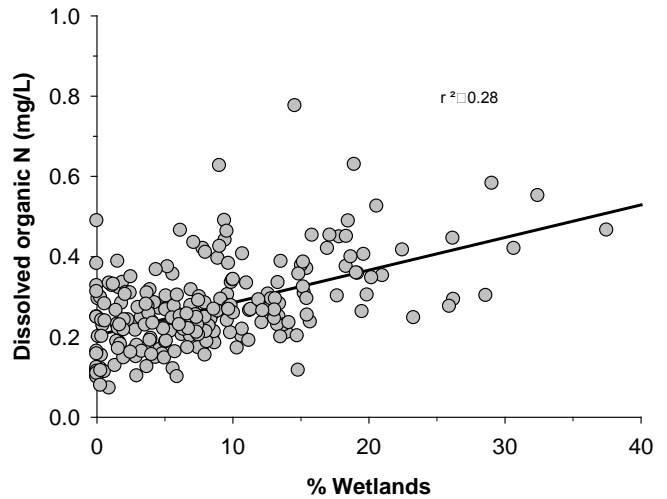
We sampled 236 sites 3-5 times from 2010-2012. Samples were analyzed for dissolved inorganic nitrogen (DIN) which is the sum of nitrate ( $\text{NO}_3$ ) and ammonium ( $\text{NH}_4$ ) and dissolved organic nitrogen (DON). The nitrogen associated with particles was not assessed as part of this study, but typically the majority of nitrogen in streams and rivers in the Great Bay watershed is dissolved and not attached to particles. Sites were chosen to represent the full range of land uses and land cover. We characterized each watershed by determining the following human impacts and natural features: human population density (including density on septic and sanitary sewers), % impervious, % developed (including high, medium and low intensity), % agriculture (cultivated crops and pasture or hay), % forests, % scrub shrub, % water and % wetlands. We used advanced statistical analysis to assess the relationship between median dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON) concentrations and all the various watershed characteristics.

- Measures of human impact explained 24%, natural features explained 5% and in total watershed characteristics explained 29% of the spatial variability in DIN concentrations.
- All types of human development (human population density, %



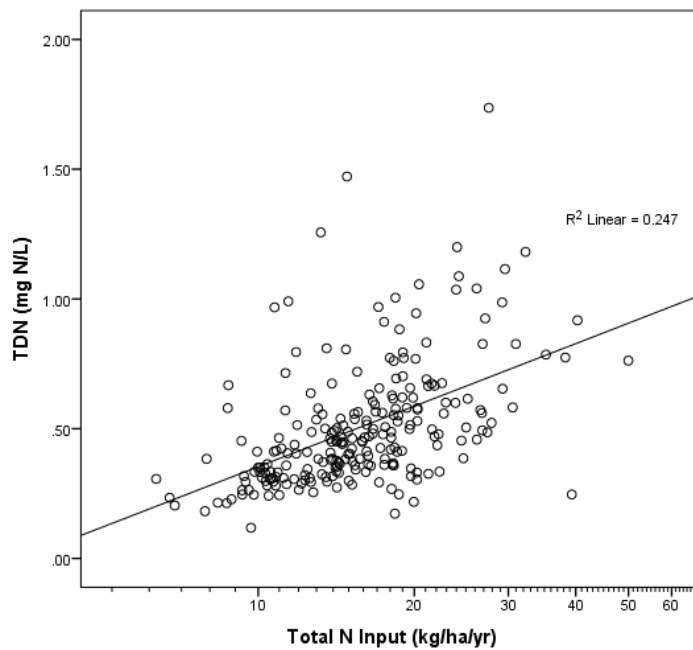
impervious and % development) contribute DIN to streams, but agriculture was not a significant predictor of DIN.

- Forests and wetlands significantly reduced DIN reaching streams.
- Total human population density had the strongest influence on increased DIN with wetlands having the strongest influence on reducing DIN.
- Together, wetlands, cultivated crops and pasture or hay could explain 35% of the spatial variability in DON. Wetlands were the main source of DON and agricultural lands were a minor source.



How do nitrogen concentrations respond to different levels of nitrogen input to the watershed?

We compared nitrogen concentrations among our stream and river sites to the total nitrogen inputs to the watershed from atmospheric deposition, human waste (distributed via septic systems), pet waste (dogs and cats), fertilizer use on lawns, recreational fields and agricultural areas and livestock waste. We used the same approach as the Great Bay Nitrogen Non-Point Source Study (Trowbridge et al. 2014) for calculating nitrogen inputs, but we did not determine the loss of nitrogen along the flow path or the predicted export of N to Great Bay.



- Increased nitrogen inputs resulted in increased DIN and total dissolved nitrogen (TDN) in streams. This was mainly from N inputs from developed areas which include human waste, fertilizers (lawns and recreational fields) and pet waste.
- Agricultural inputs (fertilizer use on agricultural areas and livestock waste) were not a significant source of DIN although there was a slight increase in DON with increased agricultural inputs.
- There was no relationship between total N inputs (or N inputs from developed areas) and DON in streams.

## What are the common sources?

- Isotopic analysis of the nitrate showed that stream water had the isotopic signature of pavement drainage in one sample at one site out of 25 stream sites sampled with a total of 155 samples collected (range of 2-23 samples per site). This suggests that nitrate reaching streams has undergone processing and is not typically unaltered atmospheric deposition.
- Mitochondrial (mt) DNA analysis of water samples indicated that dog waste was not common in streams, but was detected in 25% of the samples from urban sites and in 10% of the samples from suburban sites. There was a strong presence of human mt DNA in 58% of the samples from urban sites and 62% of the samples from suburban sites.
- Dogs trained to “sniff out” human waste detected human waste at 6 of 7 urban streams, 2 of 3 suburban streams and did not detect human waste at the reference site.



The results from this project will be posted on the project website at:  
<http://wrrc.unh.edu/great-bay-non-point-nitrogen-sources>

### **If additional resources and time were available, we would proceed with the following:**

- We have developed a readership of approximately 150 people for the Nitrogen Sources Newsbites, but are challenged with finding a way to keep this readership engaged and connected to the issue beyond the project.
- We would host workshops and present at regularly scheduled town meetings on the nitrogen issues.

### **4. Retrospective**

- What did you find challenging or unexpected about this project? This could include any aspect of the project—the integration of collaboration and applied science, physical, social, political, technical barriers, project management, communication, duration, resources, etc.
  - One challenge in this project was that we underestimated the amount of time we would need to allocate to stakeholder integration and to carry out the revised project objectives. We soon recognized that collaborative science slows the research process down, but using this approach allows stakeholders to become a part of the research process and thus project results are more useful in the end.
  - Although landscape characteristics were significant predictors of both DIN and DON, we expected that they would provide more explanatory power in predicting the spatial



variability in DIN and DON than they did. Because we were unable to explain more than half of the spatial variability in DIN (landscape models explained 29%) and DON (landscape models explained 35%) we felt that it was inappropriate to use these models to predict N concentrations for streams we did not sample. We also felt it was not appropriate to identify true “hot spots” of nitrogen.

- How did collaboration with intended users impact the applied science components of the project?
  - Collaboration with intended users significantly altered our applied science objectives. In the original proposal, we were only planning to sample our 250 extensive sites once and use the results to select sites for intensive tracer work. Since there is significant interest in understanding nitrogen concentrations and non-point N sources within the towns across the watershed, we decided to sample the ~250 extensive sites multiple times and develop spatial models that link nitrogen concentrations to watershed landscape characteristics. This resulted in less resource allocation to the intensive tracer work.
- Did you have all the skill sets on the team that you needed? If not, please identify the missing skill sets and how you adapted to the gap.
  - Yes.
- Did your budget include sufficient resources to execute the project? If not, what kinds of expenses would you include in a budget for this project if you were developing it today?
  - In hind sight, we should have budgeted more time for stakeholder integration and also for refreshments at NSCAB meetings. Because we expanded the sampling and analysis at our approximately 250 extensive sites, we had to limit the tracer work to identify specific N sources at our select intensive sites. If more resources were available we would have allocated funding towards repeated isotopic analysis of nitrate over time at multiple intensive sites.
- What do you know now that you wish you had known when you started?

## **5. Sharing your work with the Reserves and NOAA**

The results described in the outcomes, methods and data section above should be shared with others in the NERRS and NOAA.

### **Presentations at National Meetings**

Bucci, J. P., I. Sidor, A. Walant, M. Daley, J. Potter, W. McDowell. 2014. Detection of a Mitochondrial DNA Biomarker in Surface Water within Suburban Streams Impacted by Animal Fecal Waste: Does Flow Matter. American Society for Microbiology 2014 General Meeting. Boston, MA. May 2014.

- Daley, M.L., J.D. Potter, A. Kobylinski, C. French, S. Miller, C. Keely, J. Bucci, W.H. McDowell. 2014. Collaborative science to identify non-point nitrogen sources in a coastal New England watershed and reduce nitrogen delivery to an impaired estuary. Joint Aquatic Sciences Meeting. Portland, OR. May 2014.
- McDowell, W.H. 2011. Net manageable nitrogen: Definition and rationale for a new approach to nitrogen management in moderately impacted watersheds. NAFKI Sustainable Ecosystems meeting, Irvine, CA. November 2011.
- McDowell, W.H. and Daley, M.L. 2011. Net Manageable Nitrogen: Definition and Rationale for a New Approach to Nitrogen Management in Moderately Impacted Watersheds. American Geophysical Union Fall Conference, San Francisco, CA. December, 2011.
- McDowell, W.H. 2012. Consequences of climate and land use change for ecosystems and ecosystem services in New Hampshire. Invited symposium presentation, Ecosummit, Ecological Society of America, Columbus, OH, October, 2012.
- McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? European Geophysical Union Annual Meeting, Vienna, Austria April 2013 (invited keynote presentation).
- McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? University of Amsterdam, Amsterdam, Netherlands. April 2013.
- Price, A. J.; Wollheim, W. M.; Mulukutla, G.; and McDowell, W. H. 2013. Headwater catchment nitrogen flux and storm response among land use types through seasons. (Abstract ID: 8050). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013.
- Smith, Thor E., McDowell, William H., Wollheim, Wilfred M., Daley, Michelle, Mulukutla, Gopal, Baumann, Adam J., Snyder, Lisle, and Price, Allison. 2013. Sampling the Lamprey River watershed across space and time; New data collection efforts toward understanding nitrogen sources. The Geological Society of America Northeastern Section - 48th Annual Meeting. Omni–Mount Washington Hotel, Bretton Woods, New Hampshire. March 2013.

## **Related Research**

Members of the project team (Dr. William McDowell, Jody Potter and Michelle Daley) are actively involved in the NH EPSCoR project: “Interactions among climate, land use, ecosystem services, and society”. This NH EPSCoR (Experimental Program to Stimulate Competitive Research) project is funded by the National Science Foundation and contains three themes: terrestrial ecosystem services, aquatic ecosystem services and public and stakeholder understanding and perceptions. The aquatic ecosystem services theme focuses on how climate and land use have influenced water balances and nutrient dynamics in the state’s streams and

rivers historically, and how future changes are expected to alter these services. Aquatic sensors have been deployed to assess how land use, climate change, and climate variability affect water resources at multiple scales. A state wide LoVoTECS (derives from **L**otic **V**olunteer Network with the sensors recording temperature, electrical conductivity, and stage)) sensor network measures basic parameters while a river and headwater aquatic sensor network measures nitrate, dissolved organic matter, turbidity and DO. Both aquatic sensor networks measure stream water quality every 15 minutes. Data will be available on the Data Discovery Center (<http://www.epscor.unh.edu/data-discovery-center>) and there is significant focus on the Lamprey and Great Bay watershed. More information can be found at: <http://www.epscor.unh.edu/ecosystemsandsociety>.

## **6. Anything else?**

N/A

## **References**

PREP 2013. State of our Estuaries Report prepared by the Piscataqua Region Estuaries Partnership. 48 p.

SPNHF 2010. Population Growth and Land Use Change in the Granite State Prepared by the Society for the Protection of New Hampshire Forests.

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

Trowbridge, P., M. A. Wood, J. T. Underhill, and D. S. Healy. 2014. Great Bay Nitrogen Non-Point Source Study. R-WD-13-10. New Hampshire Department of Environmental Services.