Restoring Water Quality in the Lake Memphremagog Basin:
2014 Memphremagog Water Quality Report

Prepared for the

Orleans County Natural Resources Conservation District and
Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

10 March 2015

Memphremagog Watershed Association

The Memphremagog Watershed Association, founded in 2007, is a nonprofit organization dedicated to the preservation of the environment and natural beauty of the Lake Memphremagog Basin. The Memphremagog Watershed Association achieves this mission by 1) promoting the ecological awareness of people who live in, work in, and visit the Lake Memphremagog watershed; 2) informing and educating the public and promote participation in efforts to preserve the environment and natural beauty of the watershed; 3) working with area lake associations; local, state, and federal governments; and businesses to develop guidelines and policies that protect and improve the quality of life in and around the watershed; and 4) participating in efforts to monitor water quality in the lake and its tributaries, clean-up and re-naturalize shorelines, and protect area plants and wildlife.

Beck Pond LLC

Beck Pond LLC, a limited liability company founded in 2009, partners with public and private organizations to conduct scientific research that not only increases our understanding of the natural environment but also informs and guides on-the-ground conservation efforts. Among other projects, Beck Pond LLC has conducted scientific studies and participated in conservation projects that assess the impacts of historical land uses on forest plant communities; assess the impacts of invasive plants on grasslands and forests; identify, assess, and propose solutions to water quality problems in the Lake Memphremagog and White River basins; protect and restore floodplain forests and wetlands along the Connecticut River; and identify and protect critical wildlife habitats across northern New England and eastern Canada.

Cover. *The high flows associated with rain events, such as this one sampled along the Junkyard tributary on 28 July 2014, allowed us to identify and assess nutrient and sediment sources that were not apparent at lower flows (e.g. runoff from River Road is evident flowing into the tributary in the background).*

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Beck Pond LLC
394 Beck Pond Road
Newark, VT 05871
beckpond@gmail.com

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Dedication

This report is dedicated to Susan Warren, who recently retired from the Vermont Department of Environmental Conservation. Susan was instrumental in initiating these water quality studies and efforts to identify and undertake projects to reduce phosphorus exports along the Vermont tributaries of Lake Memphremagog. Her insight, support, and friendship are all greatly appreciated.

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Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially the high phosphorus and turbidity levels and more frequent and widespread algal and cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, considerable effort has been undertaken to identify and remediate nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. In 2014, we undertook a two-part project to continue these efforts by further pinpointing, identifying, and assessing possible sources of water quality problems and identifying and developing projects to correct those problems.

2. In the first part of this project, we undertook targeted water quality sampling to further pinpoint and assess possible nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. To accomplish this goal, we collected and analyzed water samples for total phosphorus, total nitrogen, and turbidity at 22 sites on eight dates during April-October 2014.

3. With these data, we were able to further pinpoint and assess the sources of the high phosphorus and/or nitrogen levels measured previously in five tributaries: Brighton Brook and the Airport, Hamel Marsh, Junkyard, and Sunset Acres North tributaries. In addition, we assessed nutrient and sediment levels in two small tributaries that had not been sampled previously, including one tributary of the Black River (the River of Life tributary) and a tributary of Stearns Brook, which flows north into the Tomifobia River (rather than into Lake Memphremagog). Finally, we were able to determine that water quality conditions generally remained improved along Crystal Brook, where a phosphorus-reduction project was implemented previously, although extremely high nutrient and sediment levels were observed during one rain event.

4. In the second part of this project, we continued to map and identify possible sources of water quality problems and potential projects and practices to correct those problems in 28 priority subwatersheds that had exhibited the highest total phosphorus concentrations along the Vermont tributaries of Lake Memphremagog during 2005-2012. Within these priority subwatersheds, we identified agricultural production areas (i.e. barns, barnyards, manure pits, silage storage areas, and composting areas) and areas of corn, other row crops, hay, pasture, lawns, and residential, industrial, and urban areas lying within 25 m (82 ft) of mapped rivers and streams as possible phosphorus sources for further review. In 2014, we conducted field assessments in 18 of the 28 priority subwatersheds to verify and correct the maps of land uses and land cover types, to identify and assess possible sources of water quality problems, and to identify and prioritize potential phosphorus-reduction projects and practices that might address these water quality problems.

5. In 2014, we continued to share the results of these water quality data and analyses with key project partners in order to discuss likely phosphorus sources, any past or current efforts to improve land-use and land management practices, and possible approaches for engaging land owners and land managers in efforts to implement projects that will protect and improve water quality. These discussions led to several site visits, and several agricultural improvement projects are being discussed and reviewed for possible implementation of best management practices and structural improvements.

6. Collectively, these data and analyses greatly increased our understanding of water quality problems in the Lake Memphremagog Basin. With these data, we were able to identify and assess possible nutrient and sediment sources and to identify and develop projects and practices that protect and improve water quality in the Vermont portion of the Lake Memphremagog Basin. In 2015, we will continue these efforts to refine our knowledge about nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog and to identify and implement on-the-ground protection and restoration projects that will most effectively reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin.

Introduction

Lake Memphremagog straddles the United States/Canada border between the Northeast Kingdom of Vermont and the Eastern Townships (Cantons de l'Est) of Quebec. Lake Memphremagog and its tributaries are highly-valued resources that provide important ecological, economic, and aesthetic benefits to the residents of and visitors to Vermont and Quebec. Over the past decade, there has been increasing interest in protecting and improving water quality in Lake Memphremagog and its tributaries. This interest has been spurred by concerns that water quality in Lake Memphremagog has been declining and is now threatened by high nutrient and sediment levels, more frequent and widespread algal blooms, and accelerated eutrophication (Figure 1). This concern has been further exacerbated by the increasing occurrence of cyanobacterial (blue-green algal) blooms, especially during the past several years (Figure 2).

Figure 1. *Turbid water and algae near the mouth of the Johns River in 2006. Excessive nutrients and sediment increase plant and algal growth and decrease water quality.*

Figure 2. *Cyanobacterial bloom along the north shore of Derby Bay on 23 September 2008 (photo courtesy of Karen Lippens). Cyanobacterial blooms are exacerbated by high nutrient and sediment levels and suggest that water quality is declining in Lake Memphremagog.*

Lake Memphremagog and its tributaries support a wide array of recreational activities, economic benefits, and ecological functions. Water bodies in the basin are used extensively for boating, swimming, fishing, hunting, nature-viewing, and other recreational activities. Lake Memphremagog and the Clyde River (one of the four principal Vermont tributaries of Lake Memphremagog) are important links in the Northern Forest Canoe Trail, which extends 1,191 km (740 mi) from Old Forge, New York through Vermont, Quebec, and New Hampshire to Fort Kent, Maine. Lake Memphremagog and other water bodies in the basin also serve as public water supplies, provide hydroelectric power and disposal of treated wastewater, and support agricultural and industrial production. The floodplains and the many wetlands around the lake and in the tributary watersheds serve important flood control and water filtration functions. In addition, the surface waters and associated habitats support a number of rare plant and animal species and significant natural communities, which contribute greatly to regional biodiversity.

Lake Memphremagog and its tributaries currently face a number of threats, including high sediment and nutrient levels, elevated mercury levels, excessive algal growth, eutrophication, and exotic species invasions (State of Vermont 2014a, 2014b, Quebec/Vermont Steering Committee 2008). The Southern Basin, which lies primarily in Vermont and is the shallowest section of Lake Memphremagog, is listed by the State of Vermont as an impaired water needing a Total Maximum Daily Load (TMDL) due to elevated phosphorus levels, nutrient enrichment, and excessive algal growth (Part A, State of Vermont 2014a). Lake Salem, which is situated in the Clyde River watershed, is already part of an approved TMDL addressing elevated mercury levels in walleye (*Stizostedion vitrium*)(Part D, State of Vermont 2014a). Several lakes and ponds in the basin have been altered by locally abundant Eurasian watermilfoil (*Myriophyllum spicatum*) growth: Lake Derby, Lake Elligo, and Brownington and Great Hosmer Ponds (Part E, State of Vermont 2014a). Two water bodies have been altered by flow regulation: An unnamed tributary of the Clyde River, due to possible lack of minimum flows below a water supply intake, and Shadow Lake, where seasonal water level fluctuations may be altering aquatic habitats and aesthetics (Part F, State of Vermont 2014a). Finally, a number of water bodies have been listed as stressed waters: 1) Johns River due to elevated nitrogen and turbidity levels; 2) Lake Memphremagog, South Bay, and Clyde Pond due to elevated mercury levels in walleye; 3) Lake Salem due to elevated *Escherichia coli* levels in the inlet streams and lake; and 4) the Barton River in Orleans due to the presence of toxins (State of Vermont 2014b).

Water Quality Monitoring and Assessment

Efforts to assess the various threats and to protect and improve water quality in the Lake Memphremagog Basin are coordinated by the Quebec/Vermont Steering Committee on Lake Memphremagog, an international partnership of governmental and non-governmental stakeholders from Quebec and Vermont. Since 2004, the Steering Committee has coordinated water quality monitoring efforts on both sides of the Quebec/Vermont border. The overall goal of these efforts has been to identify, prioritize, and implement projects that protect and improve water quality in the Lake Memphremagog Basin. To that end, monitoring efforts have focused on documenting water quality conditions throughout the basin, assessing compliance with applicable water quality standards, calculating phosphorus loads in order to develop a comprehensive pollution control plan for the Vermont waters, and identifying possible sources of water quality problems and on-the-ground projects and practices that will protect and improve water quality in the basin.

Past monitoring and assessment efforts have been undertaken by a number of governmental and non-governmental organizations (Quebec/Vermont Steering Committee 2008). The Quebec Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC) and Memphrémagog Conservation Inc. (MCI) have monitored water quality in the open waters of Lake Memphremagog in Quebec since 1996. The Vermont Department of Environmental Conservation (DEC) has monitored water quality in the open waters of the lake in Vermont and at the outlets of the Barton, Black, Clyde, and Johns Rivers since 2005. Since 1999, the Municipalités régionales de comté (MRC) de

Memphrémagog has monitored water quality in the Quebec tributaries of Lake Memphremagog. Since 2005, the NorthWoods Stewardship Center, Memphremagog Watershed Association, and Beck Pond LLC have partnered with the Vermont DEC to monitor water quality in the Vermont tributaries of Lake Memphremagog. During 2004-2005, MCI and the Regroupement des Associations pour la Protection de l'Environnement des Lacs (RAPPEL) completed comprehensive habitat assessments along the littoral zones of Lake Memphremagog in both Quebec and Vermont (Rivard-Sirois 2005, Rivard-Sirois and Pouet 2006). Finally, in partnership with the Vermont DEC, the NorthWoods Stewardship Center has completed stream geomorphic assessments along all four principal Vermont tributaries of Lake Memphremagog.

Although 73% of Lake Memphremagog is located in Quebec, 71% of the basin lies in Vermont. Thus, monitoring efforts have focused on assessing water quality conditions and identifying nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. Sampling efforts in 2005 and 2006 initially identified a number of water quality issues in the watersheds of all four principal Vermont tributaries (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008). Specifically, these efforts indicated that water quality conditions were poorest in the Johns River watershed, which suffered from extremely high phosphorus and nitrogen levels. The Black River watershed, where agricultural land uses were most extensive, exhibited high phosphorus and sediment levels at numerous sites, especially during high-flow conditions. The Barton River watershed, which also had extensive areas of agriculture, occasionally exhibited high phosphorus and sediment levels, especially at the downstream-most sites. Finally, the Clyde River, especially the upper watershed with its extensive forests and many lakes and ponds, exhibited relatively low nutrient and sediment levels.

Based on these overall assessments, we then focused our efforts on further pinpointing and assessing the sources of these nutrient and sediment problems. In 2008-2009, we focused our efforts along the Johns River as well as seven small tributaries that flow directly into Lake Memphremagog (Gerhardt 2009, 2010). Through these efforts, we were able to determine that 1) replacing a failed manure lagoon and capturing leachate from a silage storage area dramatically improved water quality in Crystal Brook and, to a lesser degree, further downstream along the Johns River, 2) the high nitrogen levels in the Johns River and several adjacent tributaries were originating from groundwater springs and seeps, and 3) that high levels of phosphorus and sediment were emanating from five of the seven small tributaries that flow directly into Lake Memphremagog. In 2010-2011, we refocused our efforts towards pinpointing and assessing the high phosphorus and sediment levels measured in the Black River watershed previously (Gerhardt 2011, 2012a). Through this sampling, we identified a number of areas that were possible nutrient and sediment sources, including areas along the main stem of the Black River between the villages of Craftsbury and Albany and again downstream of the village of Irasburg and along four tributaries of the Black River (Shalney Branch, Lords Creek, and Brighton and Stony Brooks). Most recently, in 2012 and 2013, we continued our efforts to pinpoint and assess possible phosphorus and sediment sources along several tributaries of the Black River, but we also extended our sampling to the main stem and numerous tributaries of the Barton River, which had not been sampled since 2006 (Gerhardt 2013, 2014).

Priority Phosphorus-Reduction Areas

In addition to allowing us to assess overall water quality conditions and to pinpoint specific nutrient and sediment sources, the monitoring and assessment data have also allowed us to identify and prioritize subwatersheds where protection and restoration projects will most effectively reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin. Identifying and prioritizing such priority subwatersheds has been accomplished through both modeling and analyses of empirical data.

In 2009, SMi Aménatech was contracted by the MRC Memphrémagog to develop a spatially-explicit model of phosphorus exports from both the Quebec and Vermont portions of the Lake Memphremagog Basin (SMi 2009). This model used land-use and soils data; retention equations for lakes, ponds, and wetlands; and phosphorus-export coefficients to estimate phosphorus exports from 322 subwatersheds in both the Quebec and Vermont portions of the Lake Memphremagog Basin. Subsequently, staff from the Vermont DEC revised and updated this model by incorporating more accurate land-use data, phosphorus-export coefficients, and retention equations. In general, these models indicated that phosphorus exports were greatest in urban and suburban areas (e.g. especially around the City of Newport and the villages of Derby, Barton, and Irasburg), intermediate in the Johns River watershed and more agricultural areas in the downstream sections of the Barton River and Black River watersheds, and least in the more forested upstream areas of the Barton River and Clyde River watersheds.

Another approach for targeting priority subwatersheds in which to implement phosphorus-reduction projects is the identification of Critical Source Areas. Critical Source Areas are defined as geographic areas where phosphorus sources and transport pathways intersect to cause disproportionately high levels of phosphorus exports. In general, Critical Source Areas occur in those areas where high soil phosphorus levels or highly erodible soils are located in close proximity to rivers, streams, and other surface waters. Previous studies have shown that implementing phosphorus-reduction projects and practices in Critical Source Areas can significantly reduce nutrient and sediment exports (International Missisquoi Bay Study Board 2012). One approach for identifying Critical Source Areas uses a Soil and Water Assessment Tool (SWAT) model incorporating climate, topographic, land-use, soils, soil phosphorus, and agronomic data. Such an approach was undertaken in the Vermont portion of the Missisquoi Bay sector of the Lake Champlain Basin in order to better target projects to reduce phosphorus loads emanating from that sector (Stone Environmental 2011). Although ideal, modeling Critical Source Areas is a large and complex undertaking that requires considerably more financial and other resources than have been made available for the Lake Memphremagog Basin.

An alternative, less complex approach for identifying and prioritizing areas in which to focus phosphorus-reduction projects utilizes existing water quality monitoring and assessment data. In such an approach, spatial and statistical analyses incorporate existing water quality data to identify and prioritize subwatersheds that likely export the largest amounts of phosphorus. At the watershed scale, staff from the Vermont DEC have used a flux model incorporating phosphorus concentration and daily flow data to calculate the average annual phosphorus loadings from the four principal Vermont tributaries of Lake Memphremagog during 2005-2013: Black River (23,777 kg/year) > Barton River (18,805 kg/year) >> Clyde River (7,110 kg/year) >>> Johns River (1,275 kg/year). However, identifying areas where phosphorus-reduction projects should be targeted within these watersheds requires a more fine-scale, subwatershed approach.

Using the large amount of water quality data that has been collected along the Vermont tributaries of Lake Memphremagog, we developed a spatially-explicit approach for identifying and prioritizing subwatersheds in which phosphorus-reduction projects will most effectively reduce phosphorus exports into the Lake Memphremagog Basin (Gerhardt 2013, 2014). To accomplish this goal, we used the water quality data collected at 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012 to calculate the arithmetic mean total phosphorus concentrations at low and at moderate and high flows. We then calculated the mean rank of each site by averaging the rankings of each site at low and at moderate and high flows. For each sample site, we then delineated the subwatershed drained by that site, and we assigned the mean values and ranking calculated for that site to the associated subwatershed. In general, the subwatersheds exhibiting the highest phosphorus levels across all three approaches were concentrated in several areas of the Black River watershed, in the downstream halves of the Barton River and Johns River watersheds, and along several small tributaries that flow directly into Lake Memphremagog. Thus, in 2014, we focused our efforts on identifying and evaluating possible sources of water quality problems and developing and implementing projects and practices to reduce nutrient and sediment exports in these priority subwatersheds.

Study Goals

In 2014, the Orleans County Natural Resources Conservation District (NRCD), Vermont DEC, Memphremagog Watershed Association, and Beck Pond LLC again partnered to undertake a two-part program to protect and improve water quality in the Lake Memphremagog Basin. First, we undertook targeted water quality sampling to further pinpoint and assess nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. In 2014, this sampling focused on three categories of sites: 1) two tributaries where nutrient and sediment data were lacking because they had not been sampled previously, 2) five tributaries where high phosphorus levels had been measured previously but where they remained poorly understood, and 3) one tributary where phosphorus-reduction projects had been undertaken previously. In addition, we also sampled six sites along a tributary of Stearns Brook that is impaired due to nutrients from agricultural runoff (Part A, State of Vermont 2014a). Second, we continued to map and evaluate possible sources of water quality problems and to identify and develop potential phosphorus-reduction projects and practices in 28 priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin. As in previous years, we continued to share this information with key agency and organizational partners, who are able to further evaluate the need for and implement projects and practices to reduce nutrient and sediment pollution in the Lake Memphremagog Basin. Collectively, these two efforts greatly increased our understanding of water quality problems and allowed us to continue the process of developing and implementing protection and restoration projects where they will most effectively reduce nutrient and sediment inputs into the Vermont tributaries of Lake Memphremagog.

Study Area

The Lake Memphremagog Basin is located in the Northeast Kingdom of Vermont and the Eastern Townships (Cantons de l'Est) of Quebec and is a tributary watershed of the St. Francis River, which ultimately flows into the St. Lawrence River. This study focused on the Vermont portion of the Lake Memphremagog Basin, which includes approximately 1,266 km^2 (489 mi^2) in Orleans, Essex, Caledonia, and Lamoille Counties in northeastern Vermont (Figure 3). As noted previously, the Southern Basin of Lake Memphremagog is fed by three major tributaries that lie entirely within the state of Vermont (the Black, Barton, and Clyde Rivers) and one medium-sized tributary that straddles the Quebec/Vermont border (the Johns River). In addition, numerous small tributaries flow from the eastern and western shores directly into Lake Memphremagog.

The Barton River (Waterbody ID VT17-07/08) drains an area of 445 km^2 (172 mi^2) extending from its headwaters in the towns of Barton, Glover, and Westmore downstream to the south end of South Bay in Coventry. This watershed includes one large tributary (the Willoughby River) and several large lakes, including Lake Willoughby [657 ha (1,623 acres)] and Crystal Lake [274 ha (677 acres)] among others. The Barton River in Orleans is listed as stressed due to the presence of toxins (State of Vermont 2014b). Brownington Pond has been altered by invasive aquatic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2014a), and rapidly expanding populations of several other invasive species [purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and Japanese knotweed (*Polygonum cuspidatum*)] occur throughout the watershed. Finally, Shadow Lake has been altered by seasonal water level fluctuations that may be harming aquatic habitats and aesthetics (Part F, State of Vermont 2014a).

The Black River (Waterbody ID VT17-09/10) drains an area of 349 km^2 (135 mi^2) extending from its headwaters in the towns of Craftsbury and Greensboro downstream to the western shore of South Bay in Newport City. The watershed includes one large tributary (Lords Creek) and several small lakes and ponds. Lake Elligo and Great Hosmer Pond have been altered by aquatic invasive species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2014a). In addition, rapidly expanding populations of several other invasive species (purple loosestrife, common reed, and Japanese knotweed) occur throughout the watershed.

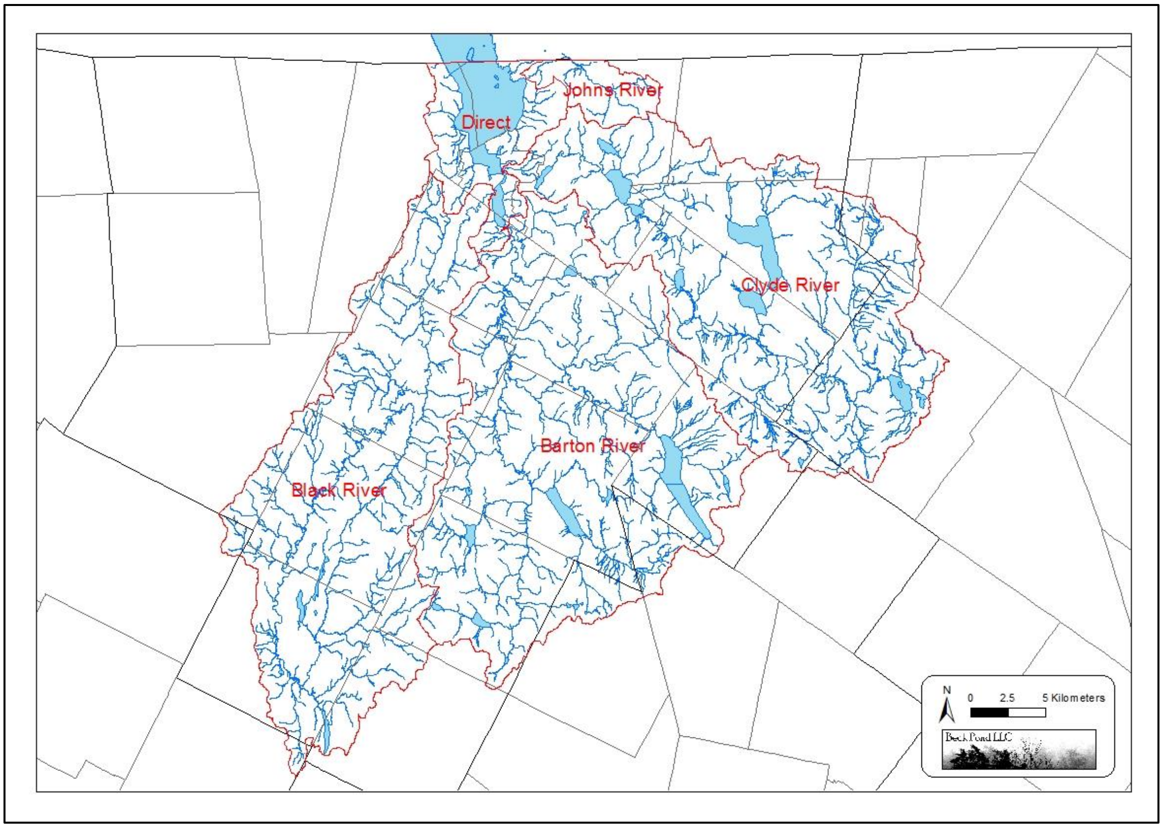

Figure 3. *The Vermont portion of the Lake Memphremagog Basin, including the watersheds of the four principal tributaries (Barton, Black, Clyde, and Johns Rivers).*

The Clyde River (Waterbody ID VT17-04) drains an area of 373 km^2 (144 mi^2) extending from its headwaters in the towns of Brighton and Morgan downstream to its mouth in Newport City. The watershed includes two large tributaries (the Pherrins River and the outlet of Seymour and Echo Lakes) and numerous large lakes, including Seymour Lake [667 ha (1,648 acres)], Lake Salem [232 ha (573 acres)], and Island Pond [221 ha (546 acres)] among others. Lake Salem, which is situated in the Clyde River watershed, is already part of an approved TMDL addressing elevated mercury levels in walleye (Part D, State of Vermont 2014a). Lake Derby has been altered by aquatic invasive species due to locally abundant Eurasian watermilfoil growth (Part E, State of Vermont 2014a). Small but rapidly expanding populations of purple loosestrife, common reed, and Japanese knotweed occur throughout the watershed but are most abundant in downstream sections. Two ponds in the watershed have been listed as stressed: Clyde Pond due to elevated mercury levels in walleye and Lake Salem due to elevated *Escherichia coli* levels in the inlet streams and lake (State of Vermont 2014b). Finally, an unnamed tributary in Brighton has been altered by flow regulation due to the possible lack of minimum flows below a water supply withdrawal point (Part F, State of Vermont 2014a). In addition, flows have been altered by the presence and operation of several hydroelectric and water storage dams along the Clyde River and its tributaries.

The Johns River (Waterbody ID VT17-01) drains an area of approximately 29 km^2 (11 mi^2) in the towns of Derby, Vermont and Stanstead, Quebec. The Johns River is fed by Crystal Brook and several smaller tributaries and flows into Lake Memphremagog at Derby Bay, just south of the Quebec/Vermont border. There are no large lakes or ponds in the watershed. The Johns River has been listed as stressed due to elevated nitrogen and turbidity levels (State of Vermont 2014b). However, Crystal Brook in Derby, which is one of three main tributaries of the Johns River, was recently removed from the list of impaired surface waters needing a TMDL due to excessive sediments and nutrients from agricultural runoff.

In addition to these four principal tributaries, the Southern Basin of Lake Memphremagog is fed by numerous small tributaries that flow directly into the eastern and western shores of the lake. Although small, any nutrients or sediments carried by these tributaries are delivered directly into and impact the health of the lake. None of these tributaries are listed as impaired or stressed (State of Vermont 2014a, 2014b), although high nutrient and sediment levels have been measured in several of these tributaries (Gerhardt 2009, 2010).

In addition, we assessed water quality in a small tributary of Stearns Brook, which is a tributary of the Tomifobia River (Waterbody ID VT17-02). The tributary of Stearns Brook drains an area of approximately 2.7 km^2 (1.1 mi^2) in the town of Holland and is impaired and in need of a TMDL due to elevated nutrients from agricultural runoff (Part A, State of Vermont 2014a). Stearns Brook itself is also listed as stressed due to sediment eroding from streambanks, poor logging practices, and poor road maintenance (State of Vermont 2014b).

Water Quality Sampling

Methods

In 2014, we sampled and analyzed water quality at 22 sites distributed throughout the Vermont portion of the Lake Memphremagog Basin to better pinpoint and assess possible nutrient and sediment sources (Figure 4; see Appendix A for descriptions of all sites). These 22 sites included eight sites along tributaries of the Black River, five sites along tributaries of the Barton River, two sites along the Johns River and one of its tributaries, two sites along a small tributary that flows directly into Lake Memphremagog, and five sites along the tributary of Stearns Brook. Thirteen of these sites were established to further pinpoint and assess the source(s) of the high phosphorus and sediment levels measured previously: two tributaries of the Black River (Brighton Brook and the Airport tributary), two tributaries of the Barton River (the Hamel Marsh and Junkyard tributaries), and one small tributary that flows directly into Lake Memphremagog (the Sunset Acres North tributary). Seven sites were established to sample tributaries that had not been sampled previously: one small tributary of the Black River (the

River of Life tributary) and the tributary of Stearns Brook. Finally, we sampled two sites to assess the success of a phosphorus-reduction project that had been implemented previously on Crystal Brook, a tributary of the Johns River. In addition, we sampled water quality during rain events at nine sites along tributaries where we had previously measured high nutrient or sediment levels or where we observed issues of concern. In a separate study, the Vermont DEC continued to sample water quality at four sites near the mouths of the four principal Vermont tributaries of Lake Memphremagog (Barton, Black, Clyde, and Johns Rivers), which have been sampled every year since 2005.

To accomplish the goals of this study, we sampled water quality at these 22 sites on eight dates during 21 April-23 October 2014 (the four DEC-maintained sites were sampled separately and on a different schedule, and those data are not reported here). These sample dates included two moderately high-flow events (21 April and 19 May) and two moderate-flow events (28 July and 23 October). However, the latter two sample rounds (28 July and 23 October) were ideally timed during rain events to allow us to pinpoint and assess phosphorus and sediment sources. The nine additional sample sites were sampled during one or both of these two rain events. Finally, due to low flows, two sites (Lower Nelson Farm and Upper Brighton Brook North) were not sampled on two dates (11 August and 8 September).

On each sample date, we collected water samples from each site to be analyzed for total phosphorus, total nitrogen, and turbidity. Samples were collected in pre-labeled, sterilized bottles according to protocols established in conjunction with the Vermont DEC and the LaRosa Analytical Laboratory (State of Vermont 2006, 2009). At all sites, we collected grab samples with a dip sampler. Before collecting the samples, we rinsed the total nitrogen and turbidity bottles and the dip sampler with sample water three times. All samples were collected on a single day, stored in coolers, and delivered to the LaRosa Analytical Laboratory the next day or the following morning. This schedule ensured that the laboratory was able to process the samples in a timely manner.

To relate these data to stream flows, we relied on two sources of stream flow data. The U.S. Geologic Survey maintained gage stations that measured water depths and stream flows on the Barton, Black, and Clyde Rivers; and the Vermont DEC maintained a seasonal gage station that measured water depths on the Johns River. For the latter, daily stream flows for the entire sampling season were estimated based on a rating curve developed from the water depths recorded by a YSI 600 LS vented sonde (YSI, Yellow Springs, Ohio) and stream flows measured with a SonTek Acoustic Doppler Flowtracker (SonTek, San Diego, California). In this study, we used the daily stream flows measured on the Johns River by the Vermont DEC as a proxy for stream flows for all sites, because all of the sites were located on streams that were more similar in size and gradient to the Johns River than to the Black River. Because the Johns River gage was not working on the last sample date (23 October 2014), we used the relationship between the flows at the Black River and Johns River gages to estimate the flow at the Johns River on that date.

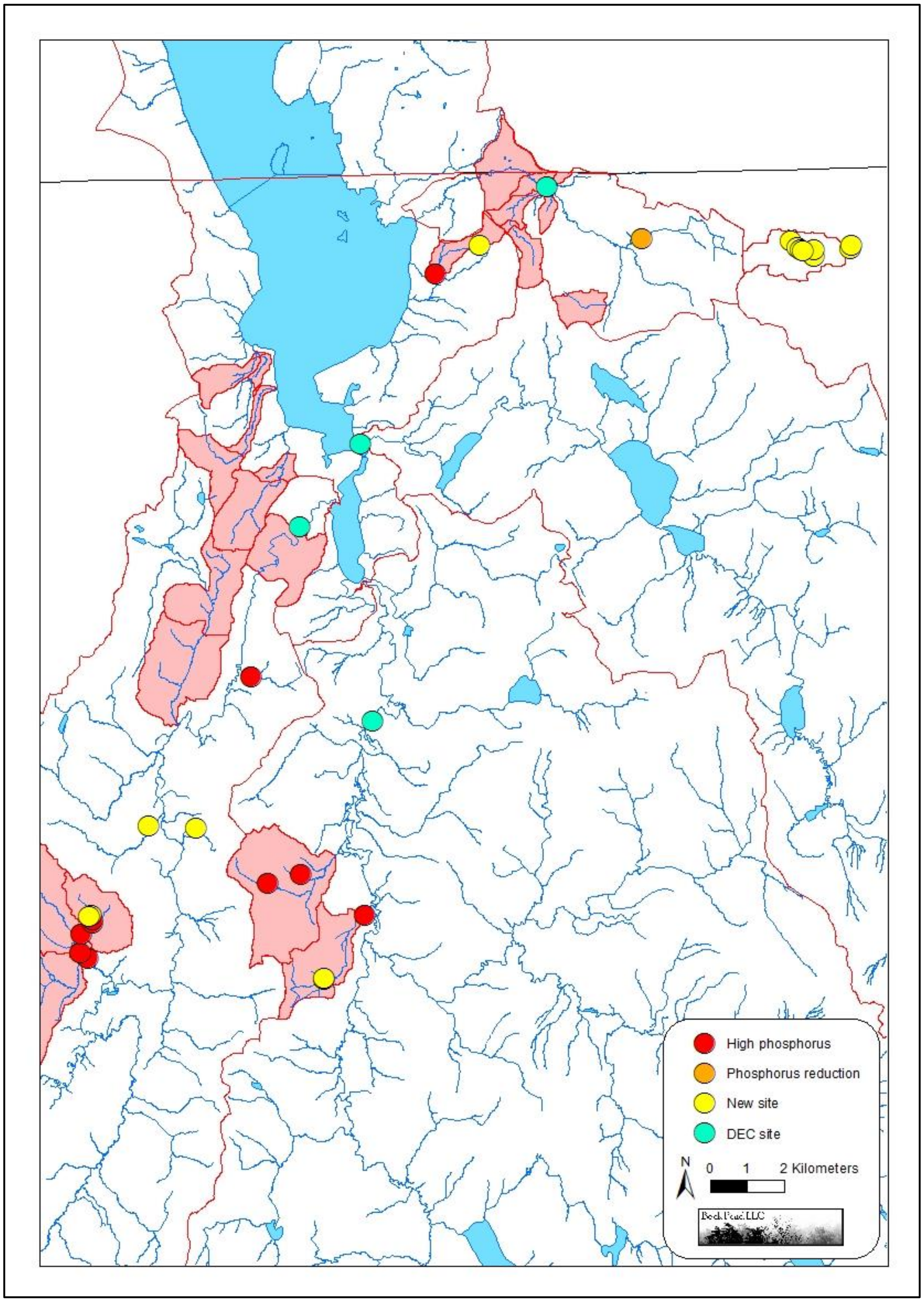

Figure 4. *Locations of the 21 sites (plus four Vermont DEC sites) where water quality was sampled along the Vermont tributaries of Lake Memphremagog during April-October 2014. The red shading outlines the 28 subwatersheds that exhibited the highest phosphorus concentrations during 2005-2012.*

Prior to sampling, we prepared a Quality Assurance Project Plan in conjunction with the Vermont DEC and U.S. Environmental Protection Agency. Based on this Quality Assurance Project Plan, we collected three field blanks and three field duplicates on each sample date. Blank sample containers were rinsed and filled only with de-ionized water and, if done properly, should result in values below the detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.2 NTU for turbidity). Field duplicates required collecting a second sample at the same time and place as the original sample. When done properly, the mean relative percent difference among all pairs of duplicate samples should be less than 30% for total phosphorus, 20% for total nitrogen, and 15% for turbidity. For total phosphorus, we also collected matrix spikes at three sites on each sample date, so that the LaRosa Analytical Laboratory could perform in-house quality assurance analyses.

Both field and laboratory data were entered into Microsoft Excel spreadsheets. All data sheets and analyses were archived by the author of this report, and the electronic data were uploaded to the Vermont DEC for inclusion in their online water quality databases.

Results and Discussion

The data for all parameters, sites, and sample dates are presented in Appendix B.

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with the Vermont DEC. Unfortunately, our 2014 sampling did not meet all of the quality assurance standards on several sample dates for two of the three parameters (quality assurance data are presented in Appendix C). The field blanks, which indicate possible contamination during the sampling process, exceeded the detection limits for two of the three parameters. All 23 field blanks for total nitrogen measured below the detection limit (0.1 mg/l). In contrast, six of the 23 field blanks for total phosphorus exceeded the detection limit (5 µg/l), although the excess values were relatively minor (5.04-7.56 µg/l). These six blanks were collected on three different dates: 21 April (two blanks), 16 June (all three blanks), and 11 August (one blank). As in past years, the field blanks for turbidity continued to be problematic: Three of the 22 field blanks exceeded the detection limit (0.2 NTU), although again the excess values were relatively minor (0.24-0.62 NTU). The reason(s) for the continued problems with the turbidity field blanks remain unknown but may relate to the possible sources of the problems with the phosphorus blanks, which are discussed later in this section.

On the other hand, the mean relative percent differences between duplicate samples were well below the prescribed differences for two of the three parameters [total phosphorus = 5% (prescribed difference <30%) and total nitrogen = 2% (prescribed difference <20%)]. In addition, no pairs of the 24 duplicate samples exceeded the prescribed difference for either total phosphorus or total nitrogen. Likewise, the mean relative percent difference between the duplicate turbidity samples also did not exceed the prescribed difference [turbidity = 7% (prescribed difference <15%)], but three of the 22 pairs of turbidity samples did differ by >15% (range = 16-23%). Thus, although the field duplicates indicated that the water samples were generally being collected in a repeatable manner, the field blanks for total phosphorus and turbidity indicated that we encountered some difficulties in collecting uncontaminated blank samples for these two parameters for some as-yet-unidentified reason(s).

Although none of the field blanks greatly exceeded the detection limit, the large number of failed blanks does raise concerns, and we have tried to identify and evaluate possible causes for these problems, especially for total phosphorus, as that is a new problem that has not occurred previously. A cursory review of other monitoring programs suggested that this problem was not widespread, as it did not occur in the major tributary sampling nor in the other volunteer monitoring programs that were reviewed. Possible causes of these failed blanks include:

1) Contaminated distilled water - Although we had problems with contaminated distilled water in 2013 (that is, we observed grit in one of our bottles of distilled water and the two blank samples filled from that bottle did exceed the detection limits), we did not observe this problem in 2014. In addition, if this was widespread problem, it would seem likely that the field blanks collected by other groups and as part of the major tributary sampling would have had similar problems.

2) Laboratory problems - The data for two of our phosphorus blanks that exceeded the detection limit and one of our regular phosphorus samples was annotated with a note stating "Reported value is associated with a blank contamination". Thus, there may be problems with contamination that was occurring in the laboratory during sample analyses; however, if this problem was widespread, it would seem likely that the field blanks collected by other groups and as part of the major tributary sampling would have had similar problems.

3) Contaminated dip samplers - The extremely high levels of phosphorus measured in some of the samples that we collected in 2014 may have left residual phosphorus adhering to our dip samplers. On the other hand, none of the failed blanks were collected at the sites with the highest total phosphorus concentrations, although they were collected at sites with high phosphorus concentrations. In addition, the water samples that measured the highest total phosphorus concentrations were not collected with the dip sampler but were collected directly in the sample bottles. Since we typically collected the blank samples after we collected the regular and duplicate samples, it seems probable that these failed blanks would have been collected at the sites with the highest phosphorus levels. However, it is possible that phosphorus has adhered to the inner walls of our dip samplers over time and that the distilled water, which is a slightly acidic universal solvent, might be dissolving this phosphorus back into solution during collection of the blank samples. We have been using the same dip samplers with the same bottles since 2008, although we did replace the bottles on both of the dip sampler prior to the last round of sampling in 2014.

Alternatively, we have been concerned for some time now that we have not been collecting true field blanks as part of our sampling. That is, we do not replicate the exact procedures followed when we collect field samples. Due to the limited amounts of distilled water available, we do not rinse the dip sampler as thoroughly as we do when we collect our field samples. Thus, there may be residual water in or on the dip samplers when we pour the distilled water into the blank sample bottles. In order to collect a true field blank, we would need to rinse our dip sampler in profuse amounts of clean distilled water (for the field samples, we rinse the dip sampler three times in the stream downstream of our sample site). Thus, the high phosphorus levels in these field blanks may not indicate a problem with our field sampling procedures but rather with our procedures for collecting field blanks. Unfortunately, collecting true field blanks would require large amounts of distilled water (e.g. approximately 15 l per site) in order to rinse the dip sampler as thoroughly as we do when collecting the field samples.

In the future, we recommend incorporating the following safeguards into our sampling protocols in order to reduce the likelihood of contamination and to ensure that the field blanks most closely approximate the procedures being used to collect field samples:

1) Replace the bottles on the dip samplers every year,

2) Reserve a “special” dip sampler for sampling sites that have extremely high levels of phosphorus or other pollutants,

3) At the end of each sample day, thoroughly rinse the dip samplers with tap water to prevent residue from accumulating over time,

4) Identify a way to obtain more distilled water, so that we can rinse the dip samplers more thoroughly when we are collecting the field blanks,

5) Continuously review quality assurance data as they become available, so that we can detect and correct any problems with our sampling.

We will continue to investigate this problem in order to better understand why so many of our field blanks exceeded their detection limits and to ensure that our sampling protocols are as good as possible. Despite the large number of failed field blanks, we believe that the water quality results presented in this report are nevertheless reliable and accurate, especially given the high total phosphorus levels reported from many of our field samples and the relatively low total phosphorus levels measured in the failed field blanks.

Stream Flow

Stream flow measures the volume of water passing a specific location per unit of time and is calculated by multiplying the cross-sectional area of the stream by water velocity. Stream flow affects both water quality and the quality and characteristics of aquatic and riparian habitats. For example, fast-moving streams are more turbulent and better aerated than slow-moving streams. High flows also dilute dissolved and suspended pollutants but, at the same time, typically carry more surface runoff and stormwater and the associated sediment and nutrients. Stream flow is extremely dynamic and changes frequently in response to changes in temperature, precipitation, and season.

To approximate stream flows at our sample sites, we relied on stream flow measurements from the gage maintained seasonally by the Vermont DEC on the Johns River. The 2014 sampling season was characterized by peak spring flows followed by generally decreasing flows through the first half of summer and relatively low flows through the remainder of the sampling season (Figure 5). Peak flows following spring snowmelt occurred during the first half of April. Higher flows were also recorded on numerous dates during May, June, July, and August following heavy rains. Otherwise, flows were generally low to moderate throughout the sampling season, and the lowest flows were recorded during September and early October, which is somewhat later than is typical in these watersheds.

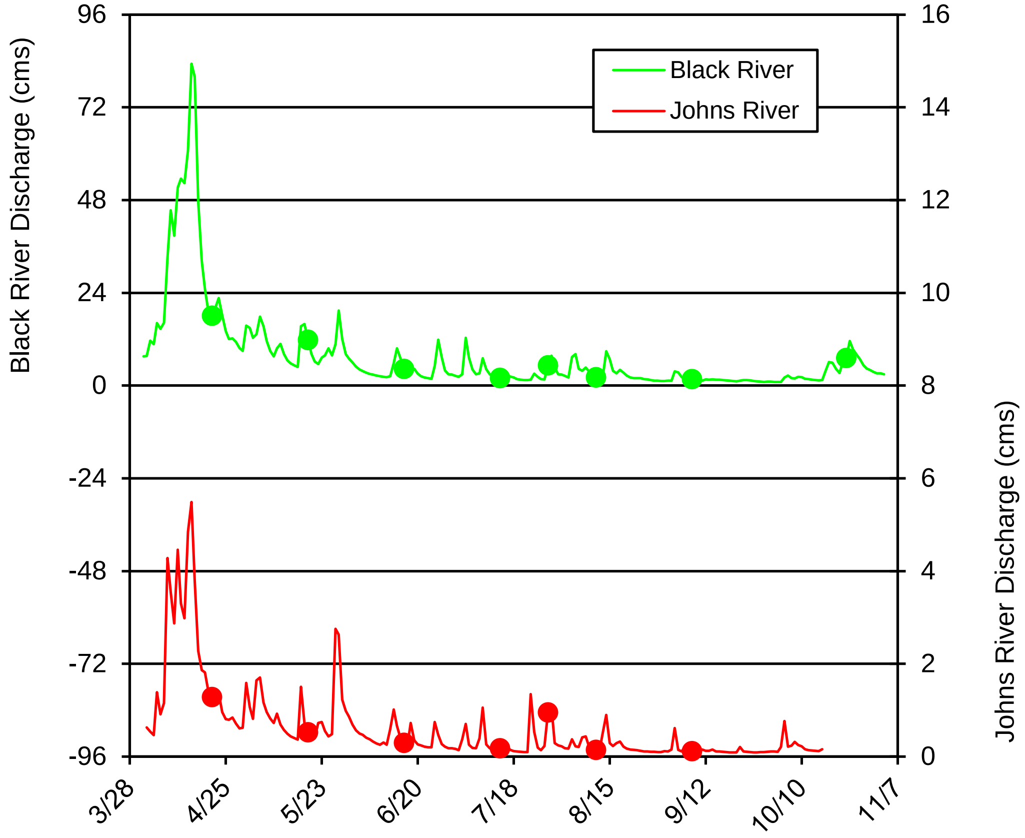

Figure 5. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2014. The eight dates on which water samples were collected are indicated by the circles (except the 2 October sample date for the Johns River). Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, Vermont)]; stream flows for the Johns River were measured by the Vermont DEC.*

Our sample dates largely reflected the variation in stream flows recorded in 2014 (Figure 5). We were able to collect water samples during the high flows following spring snowmelt (23 April) and following heavy rains that fell two days earlier (19 May). We were also able to sample moderate flows during and following moderate to heavy rain showers on 28 July and 23 October. The remaining water samples, especially those collected in mid- and late summer, were collected during low flows. Collecting water samples across this broad range of stream flows enhanced our ability to identify and assess water quality problems, especially those affected by stream flows. The low flows were most informative for identifying and assessing nutrient and sediment inputs originating from point and groundwater sources. In contrast, the moderate and high flows were more informative for identifying and assessing nutrient and sediment inputs originating from nonpoint sources, which typically generate the majority of the sediment and nutrient loads exported from these watersheds.

Total Phosphorus

Total phosphorus measures the concentration of all forms of phosphorus in the water column, including dissolved phosphorus, phosphorus attached to suspended sediments, and phosphorus incorporated into organic matter. Phosphorus is typically the limiting nutrient and regulates the amount of aquatic life in northern freshwater ecosystems. Consequently, excessively high phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to oxygen depletion and increased mortality of aquatic life. In Vermont, most phosphorus originates from soil erosion, wastewater, manure, and synthetic fertilizers applied to lawns and agricultural fields.

In 2014, total phosphorus concentrations at the 22 sites ranged between 8.22-9,150 μg/l. As in previous years, total phosphorus concentrations showed no marked seasonal pattern (Figure 6). Median total phosphorus concentrations were highest on the two sample dates with moderate flows (18 July and 23 October), when surface runoff following heavy rain showers likely carried large amounts of sediment and nutrients into the rivers and streams. Despite higher flows on the first two sample date (21 April and 19 May), total phosphorus levels were markedly lower on those two dates, possibly because the water samples on those two dates were collected during the falling limb of the high flows (that is, when flows were decreasing).

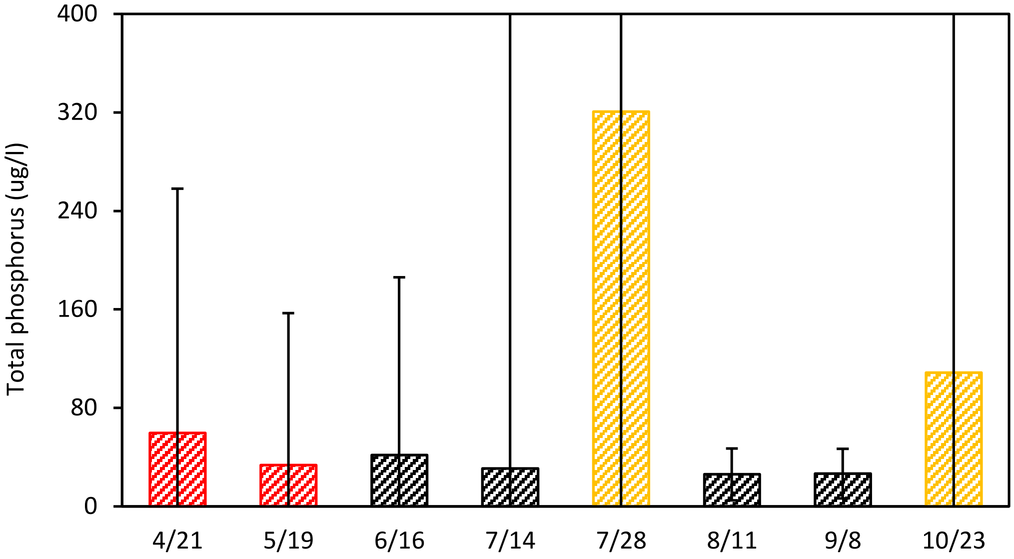

Figure 6. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Red hatching indicates the two high-flow events; orange hatching indicates the two moderate-flow events.*

Since our sampling was focused on assessing streams with high phosphorus levels, total phosphorus concentrations were generally high (median values >20 µg/l) at most of the sites (Figure 7-8). Total phosphorus concentrations were markedly high (median values >35 µg/l) along several tributaries of the Black and Barton Rivers (Brighton Brook and the Airport, Junkyard, and Hamel Marsh tributaries) and the tributary of Stearns Brook. All of these tributaries drained areas of diverse land uses but included large areas of agricultural land and associated production areas (e.g. barns, barnyards, and manure and silage storage). In contrast, total phosphorus concentrations were generally low (median values <20 µg/l) along one tributary of the Black River (the River of Life tributary) and at the Johns River site. These tributaries generally drained areas with more limited amounts of agricultural land uses, although the Johns River site did drain a large number of residential areas. Finally, total phosphorus concentrations were intermediate (median values = 20-35 µg/l) at Crystal Brook and along the Sunset Acres North tributary, which flows directly into Lake Memphremagog.

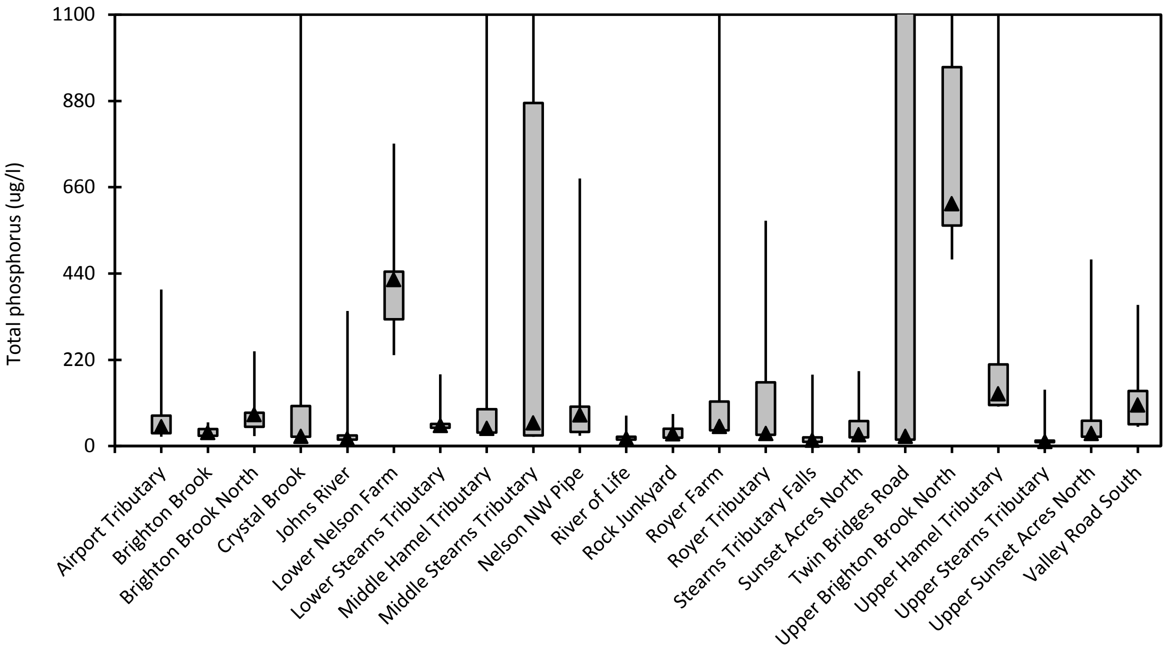

Figure 7. *Total phosphorus concentrations at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

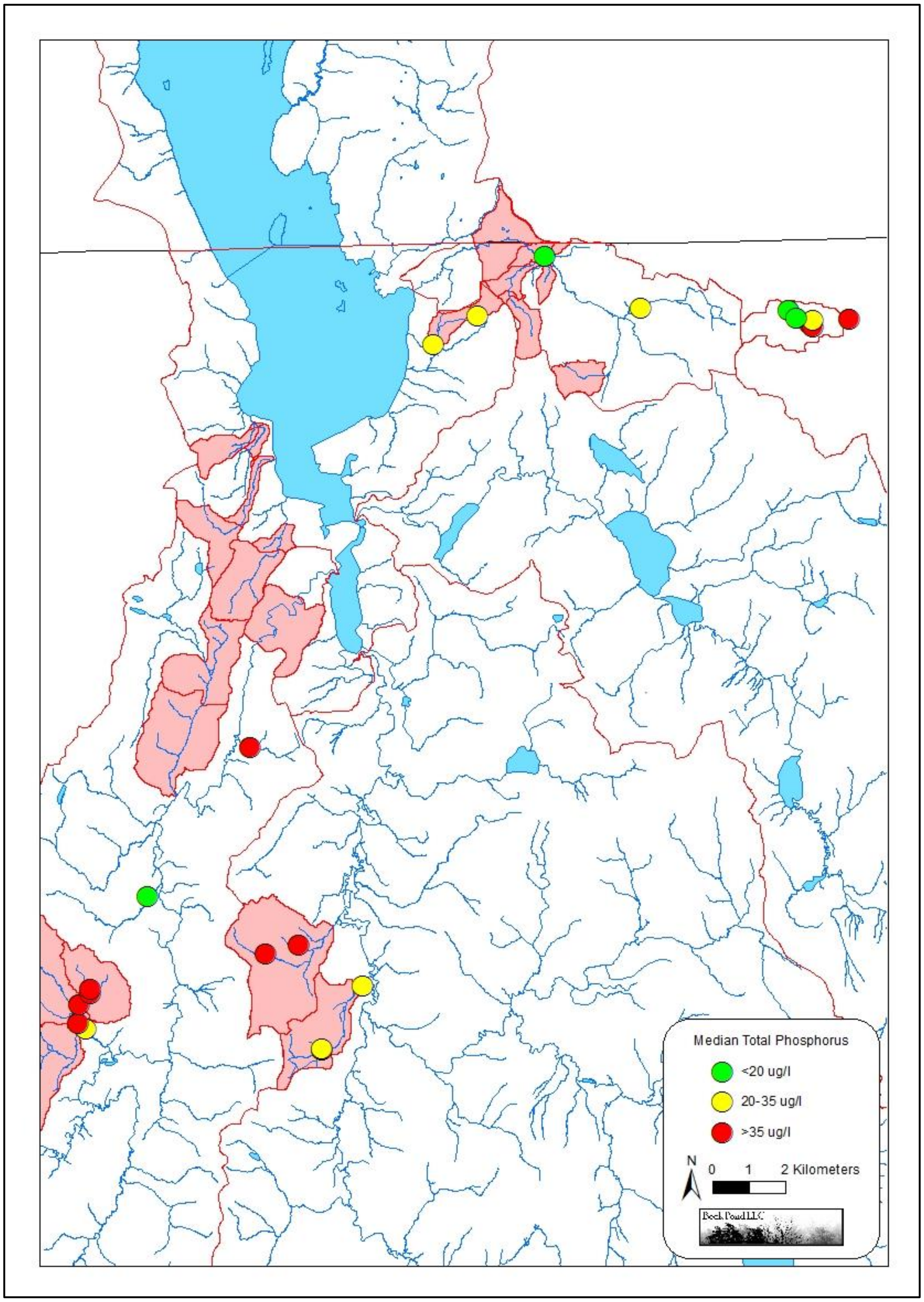

Figure 8. *Median total phosphorus concentrations at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. The red shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

Total Nitrogen

Although typically not the limiting nutrient in northern freshwater ecosystems, high levels of nitrogen can impact both in-lake and in-stream water quality and can exacerbate algal blooms and eutrophication and lead to more frequent and more toxic cyanobacterial blooms. Nitrogen is an essential plant nutrient and occurs in many forms in the environment, including nitrogen gas (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), ammonium (NH_4), and particulate nitrogen (N). Total nitrogen measures the concentration of all forms of nitrogen in the water column. In Vermont, most nitrogen in surface waters originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

In 2014, total nitrogen concentrations at the 22 sites ranged between 0.31-49.8 mg/l. As in previous years, total nitrogen concentrations showed no marked seasonal trend (Figure 9). Like total phosphorus, total nitrogen concentrations were highest on the two sample dates with moderate flows (18 July and 23 October), when surface runoff following heavy rain showers likely carried large amounts of both dissolved and particulate nitrogen into rivers and streams. Despite higher flows on the first two sample date (21 April and 19 May), total nitrogen levels were markedly lower on those two dates, possibly because the water samples on those two dates were collected during the falling limb of the high flows (that is, when flows were decreasing).

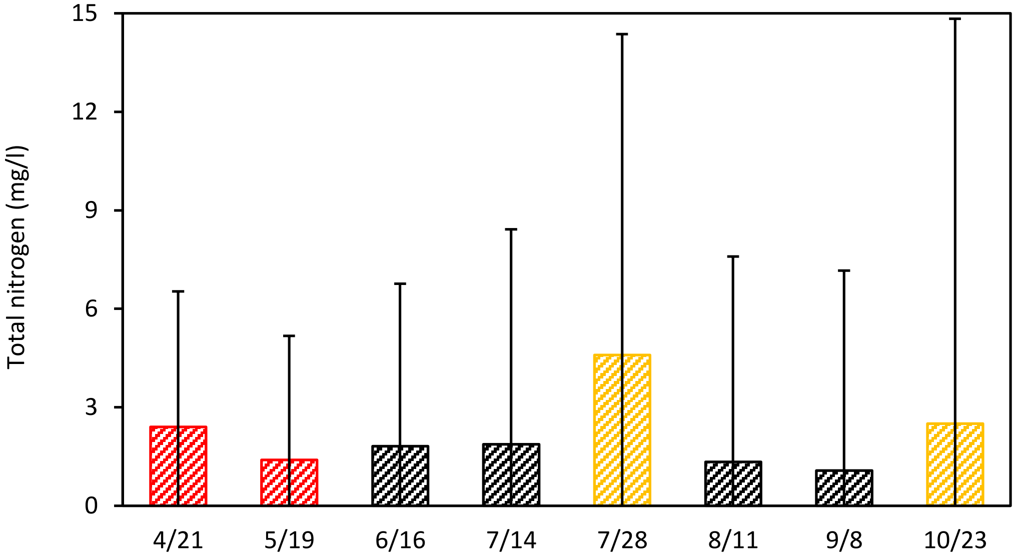

Figure 9. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Red hatching indicates the two high-flow events; orange hatching indicates the two moderate-flow events.*

Total nitrogen concentrations were relatively high (median values >1 mg/l) at many of the same sites that exhibited higher total phosphorus concentrations (Figure 10-11). Total nitrogen concentrations were markedly high (median values >2 mg/l) along two tributaries of the Black and Barton Rivers (Brighton Brook and the Hamel Marsh tributary), the Johns River, and the tributary of Stearns Brook. All of these tributaries drained areas of diverse land uses and included large areas of agricultural lands and associated production areas (e.g. barns, barnyards, and manure and silage storage). In contrast, total nitrogen concentrations were generally low (median values <1 mg/l) along two tributaries of the Black River (the Airport and River of Life tributaries). These tributaries generally drained more forested areas with more limited areas of agricultural and other land uses. Finally, total nitrogen concentrations were intermediate (median values = 1-2 mg/l) along one tributary of the Barton River (the Junkyard tributary), Crystal Brook, and the Sunset Acres North tributary, which flows directly into Lake Memphremagog.

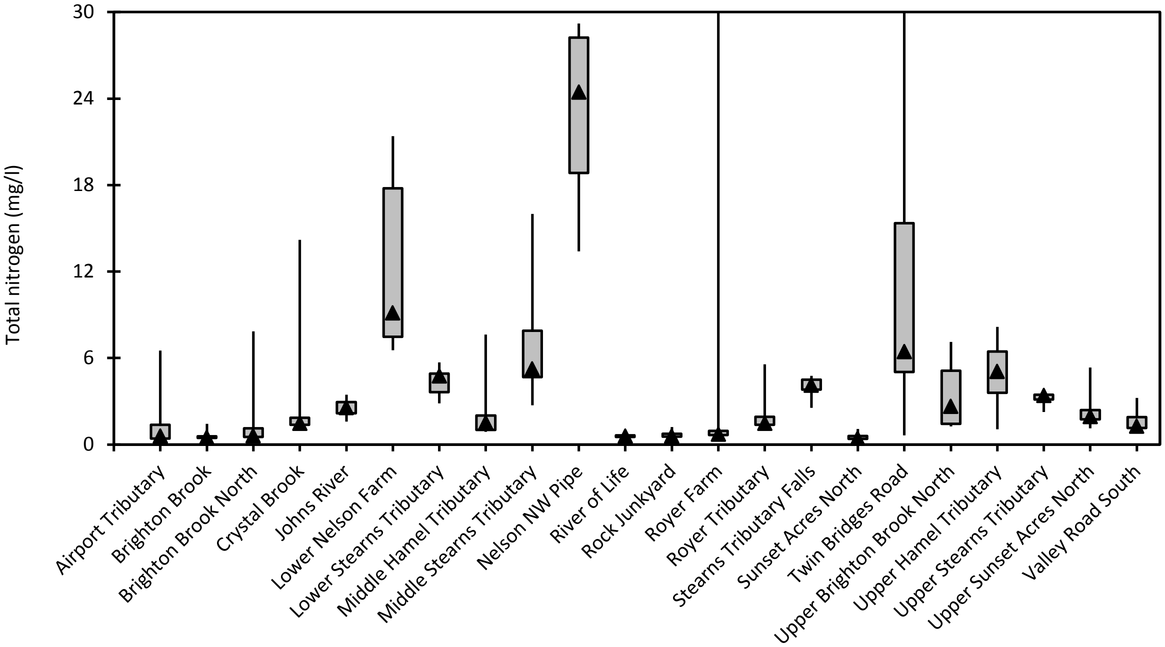

Figure 10. *Total nitrogen concentrations at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

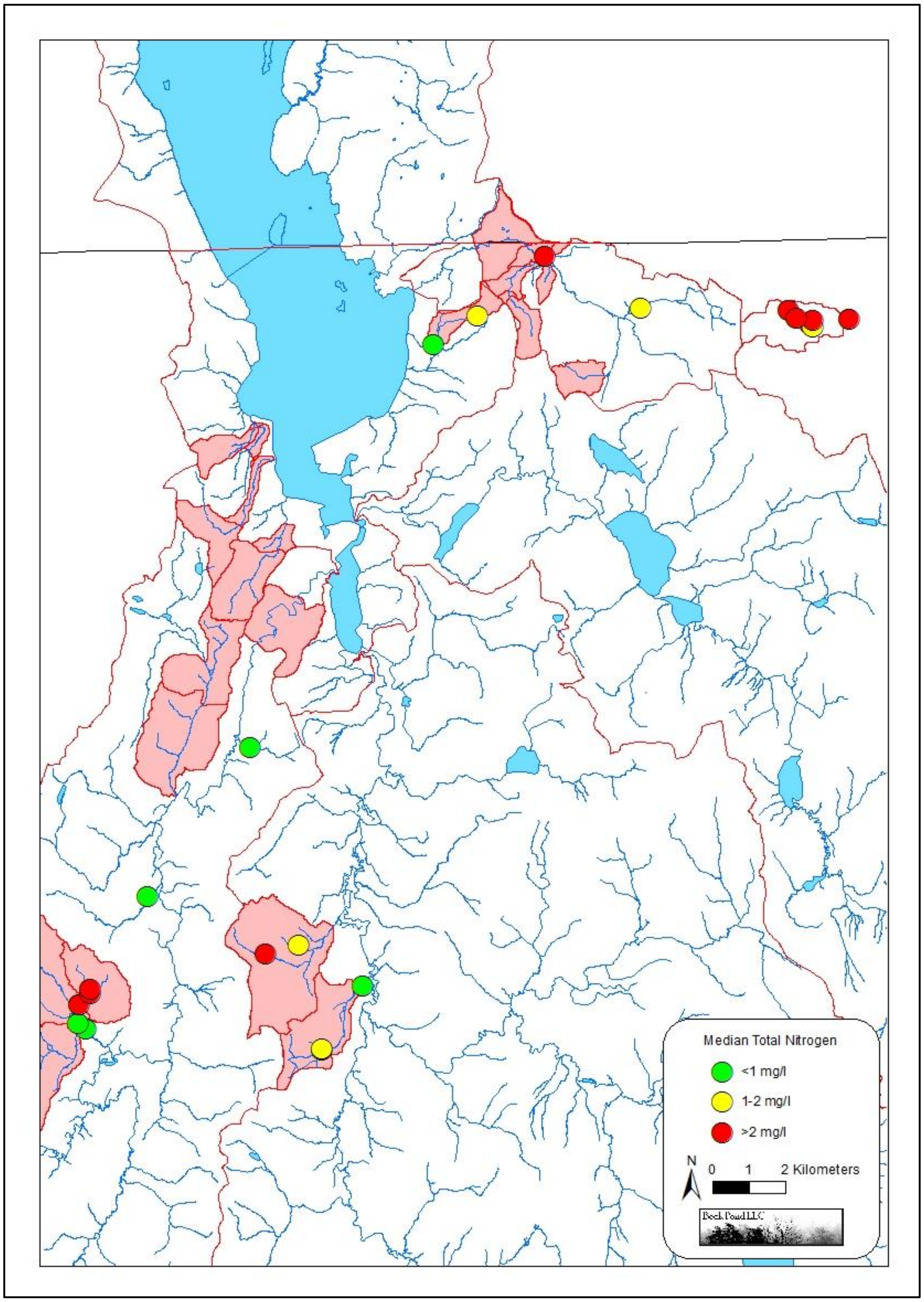

Figure 11. *Median total nitrogen concentrations at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. The red shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

Turbidity

Turbidity measures the light-scattering properties of all of the dissolved and suspended materials in the water column. Turbidity greatly affects the health of aquatic ecosystems, as more turbid waters allow less light to penetrate into the water column and transport more pollutants, nutrients, and sediments. In addition, the sediment and other suspended materials can settle out of the water column and smother aquatic biota and their habitats. Much of the dissolved and suspended material in the water column originates from erosion associated with agriculture, forestry, urban and suburban development, and stream channel adjustment processes. However, turbidity is also affected by natural biological and chemical processes and by the presence of chemical pollutants. Turbidity is measured in Nephelometric Turbidity Units (NTU).

In 2014, turbidity levels at the 22 sites ranged between 0.24-8,390 NTU. Like total phosphorus and total nitrogen, turbidity levels showed no marked seasonal pattern (Figure 12). The highest turbidity levels were measured on the two sample dates with moderate flows (18 July and 23 October), when surface runoff following heavy rain showers likely carried large amounts of debris and sediment into rivers and streams. Despite higher flows on the first two sample dates (21 April and 19 May), turbidity levels were markedly lower on those two dates, possibly because the water samples on those two dates were collected during the falling limb of the high flows (that is, when flows were decreasing).

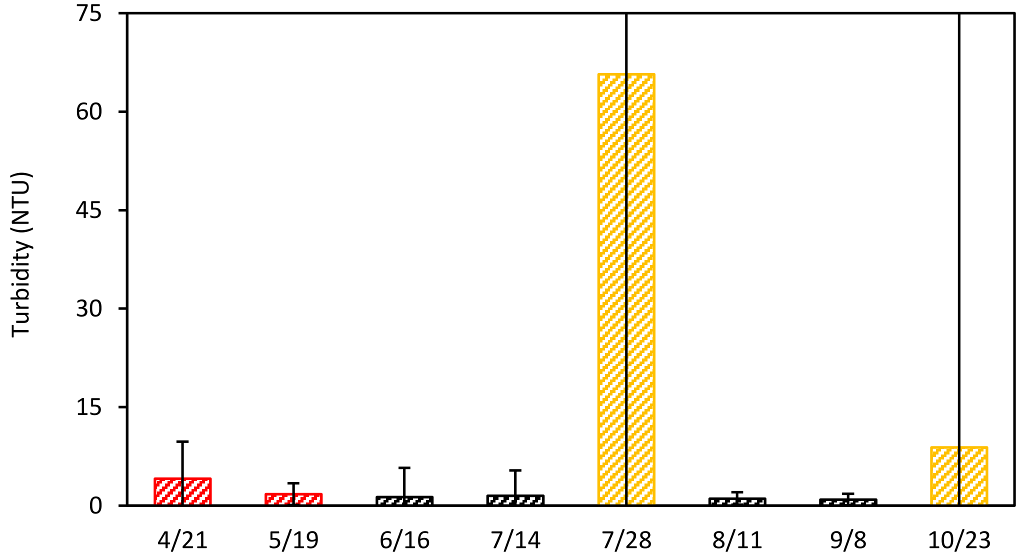

Figure 12. *Median turbidity levels (±1 SD) measured on each sample date at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Red hatching indicates the two high-flow events; orange hatching indicates the two moderate-flow events.*

Unlike total phosphorus and total nitrogen, turbidity levels were generally low at most sample sites along most tributaries (Figure 13-14). Turbidity levels were high (median levels >5 NTU) at only two sites, both of which were located along the northern tributary of Brighton Brook. This tributary drained a watershed characterized by large areas of agricultural lands and associated production areas (e.g. barns, barnyards, and manure and silage storage). In contrast, turbidity levels were generally low (median values <5 NTU) at the remainder of the sites and indicated that, at least on most sample dates, there were not large amounts of dissolved and suspended materials caused by biological or chemical processes, chemical pollution, or sediment or organic debris entering these streams.

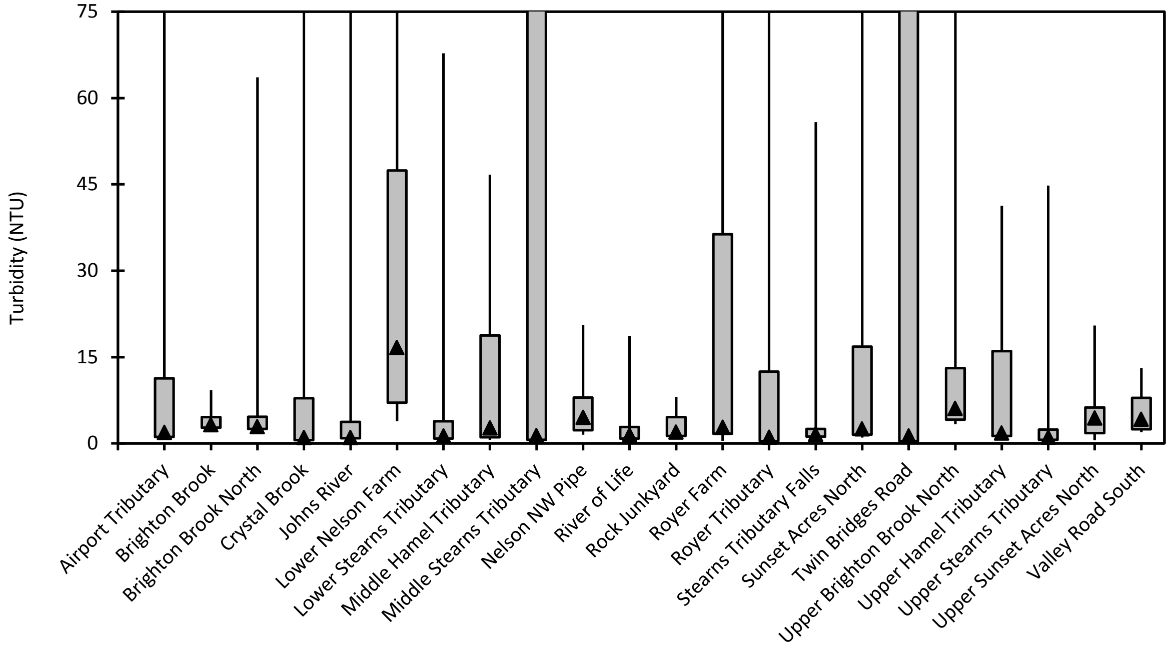

Figure 13. *Turbidity levels at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

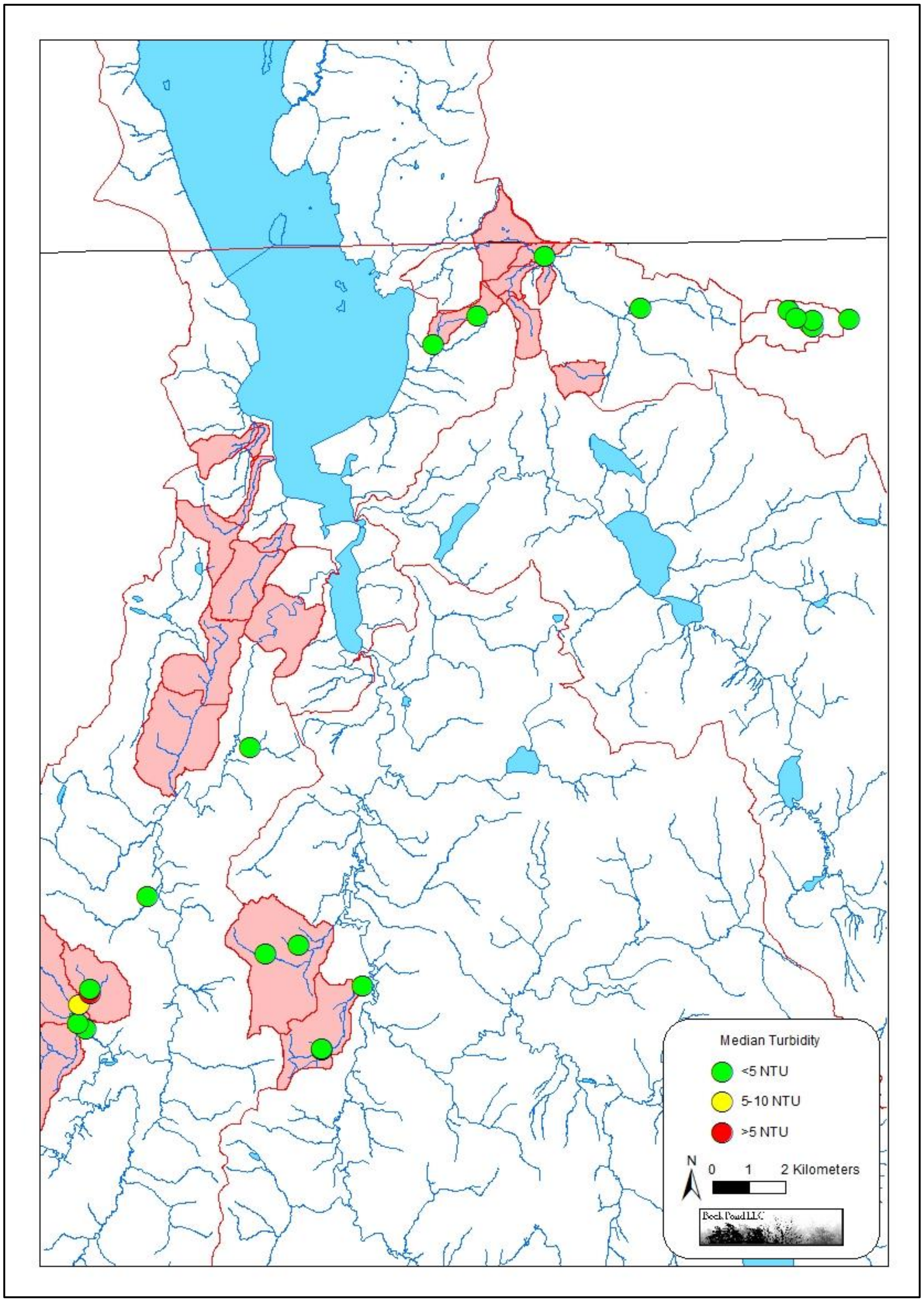

Figure 14. *Median turbidity levels at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. The red shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

Individual Tributaries

Airport Tributary

In 2014, we resampled one site on a small tributary of the Black River that had exhibited high total phosphorus concentrations previously. As in 2013, total phosphorus concentrations were high at the Airport Tributary site (median = 48.7 µg/l, range = 24.1-399 µg/l). In addition, total nitrogen concentrations at this site were relatively high on three of the eight sample dates (median = 0.59 mg/l, range = 0.38-6.51 mg/l). Turbidity levels, on the other hand, were generally low, except during the two rain events. Both total phosphorus and total nitrogen concentrations showed markedly positive relationships with stream flow (Figure 15-16). These positive relationships suggested that the phosphorus and nitrogen were originating from nonpoint source surface runoff, possibly flowing from either the paved and grassy surfaces of the Newport State Airport or, more likely, the several large corn fields that were recently created on previously forested wetlands along the ridge to the south.

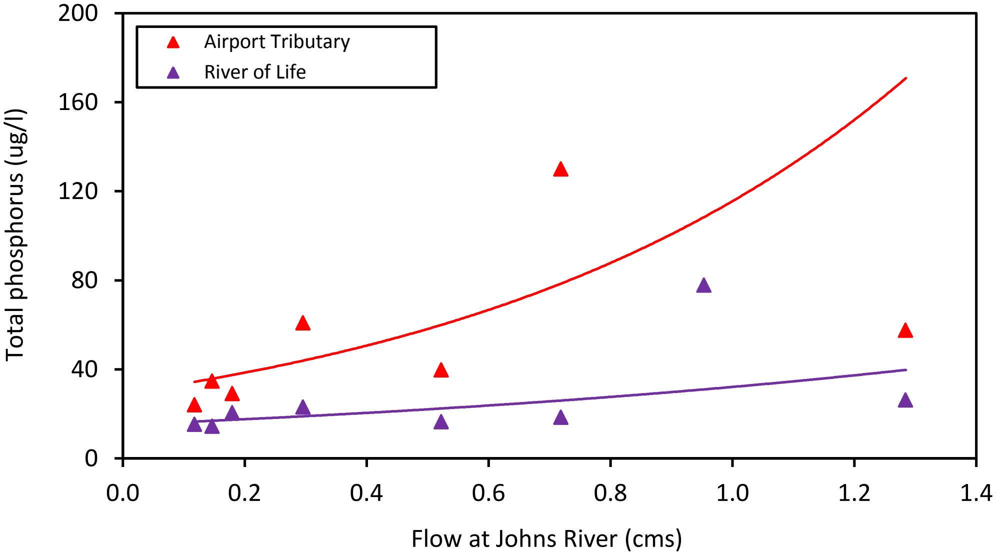

Figure 15. *Total phosphorus concentrations in relation to stream flow at two sites along tributaries of the Black River during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

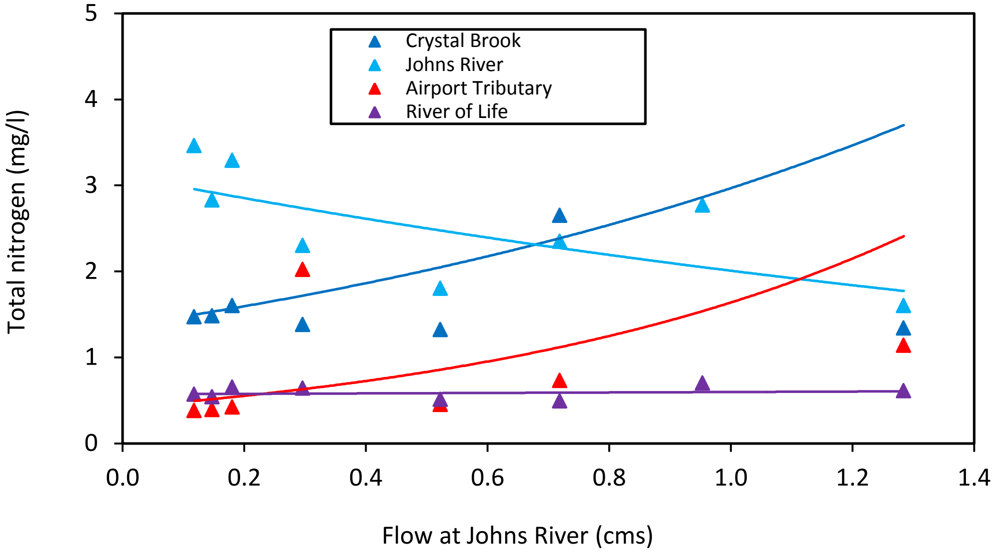

Figure 16. *Total nitrogen concentrations in relation to stream flow at four sites along tributaries of the Black River during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Brighton Brook

In 2014, we continued our efforts to further pinpoint the source(s) of the high phosphorus and nitrogen levels in Brighton Brook, a tributary of the Black River. As in 2010-2013, total phosphorus concentrations were relatively high at the downstream-most Brighton Brook site (median = 34.4 µg/l, range = 21.4-61 µg/l). As in 2013, we continued to focus our efforts along a small tributary that flowed into Brighton Brook from the north. Total phosphorus concentrations along this tributary were high at the downstream-most site (Brighton Brook North) and were even higher at the two sites located further upstream (Upper Brighton Brook North and Lower Nelson Farm); however, they were considerably lower in the water flowing out of a drainage pipe at the upstream end of this tributary (Figure 17). Total phosphorus concentrations exhibited a negative relationship with stream flow at the Upper Brighton Brook North site but positive relationships with stream flow at the Nelson NW Pipe, Lower Nelson Farm, and Brighton Brook North sites (Figure 18). In contrast, total nitrogen concentrations were highest in the water flowing out of the drainage pipe and decreased dramatically and consistently further downstream and were markedly lower at the Brighton Brook North and Brighton Brook sites (Figure 19). Total nitrogen concentrations at Nelson NW Pipe and Lower Nelson Farm but not the other three sites exhibited pronounced negative relationships with stream flow (Figure 20).

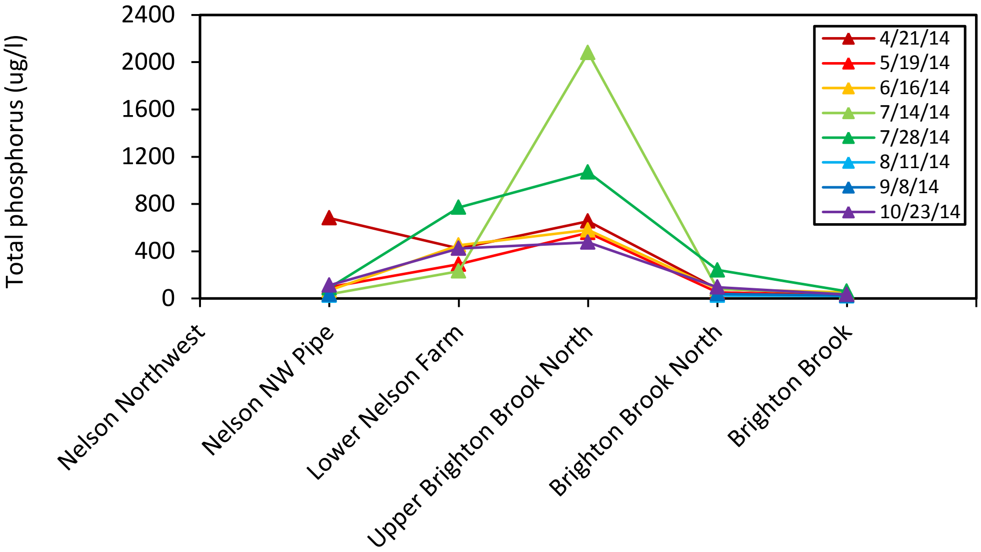

Figure 17. *Total phosphorus "profile" along the main stem and northern tributary of Brighton Brook from Nelson NW Pipe downstream to Brighton Brook during April-October 2014.*

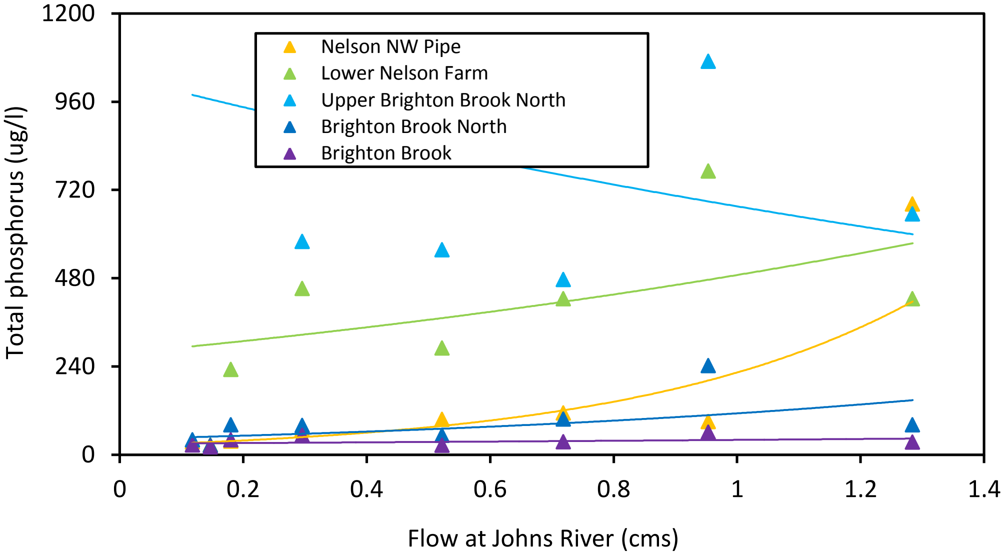

Figure 18. *Total phosphorus concentrations in relation to stream flow at five sites along Brighton Brook and its northern tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

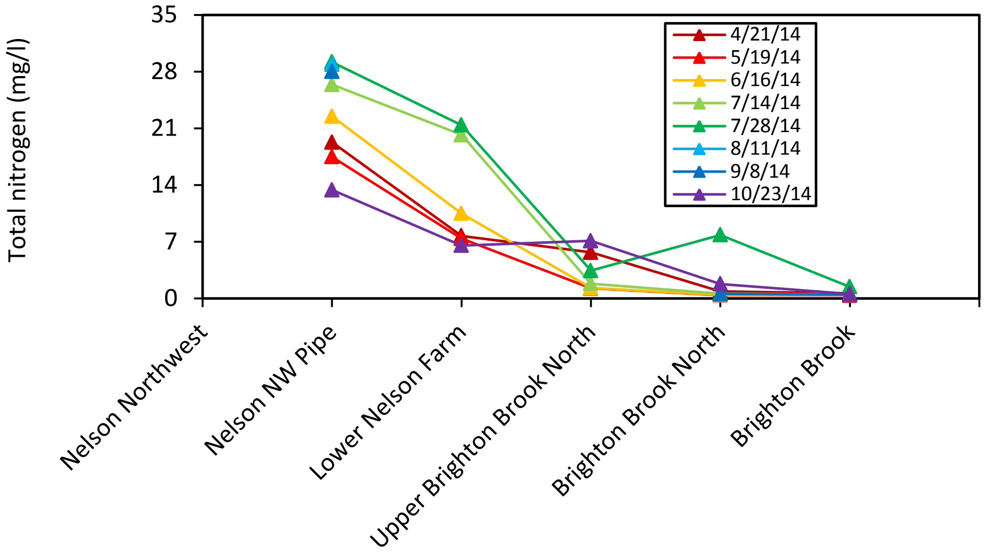

Figure 19. *Total nitrogen "profile" along the main stem and northern tributary of Brighton Brook from Nelson NW Pipe downstream to Brighton Brook during April-October 2014.*

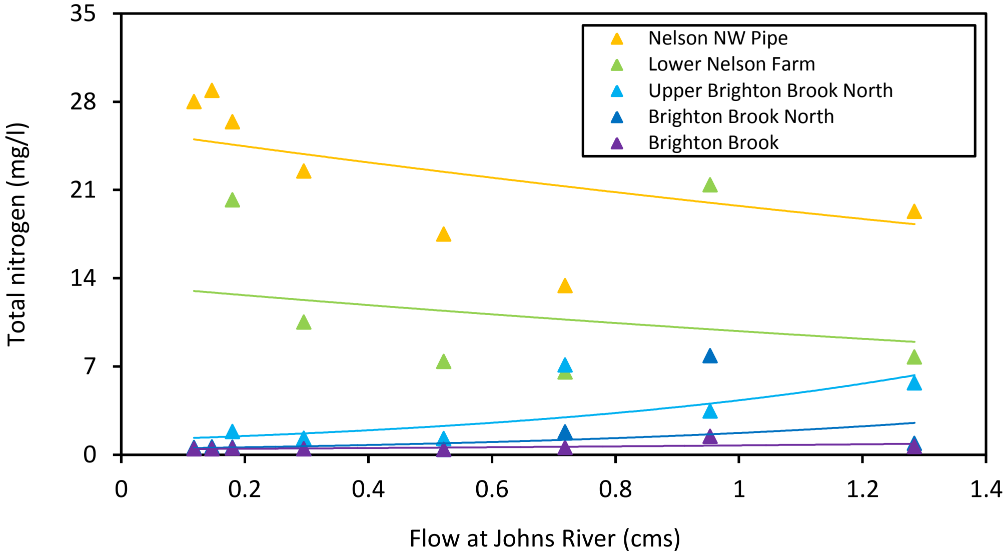

Figure 20. *Total nitrogen concentrations in relation to stream flow at five sites along Brighton Brook and its northern tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Collectively, these data suggest that the high phosphorus and nitrogen levels in this tributary were originating from the upper watershed of the small northern tributary, where there were both large fields of corn and a large barnyard, manure pit, silage storage pad, and mortality compost pile. All of these areas generally slope downhill towards this tributary. The relationships between the nutrient concentrations and stream flows suggest that much of the phosphorus was originating from nonpoint source runoff but that much of the nitrogen was derived from point or groundwater sources. Collectively, these data suggest that the high phosphorus levels in the upper reaches of this tributary were originating from surface runoff from the barnyard and mortality composting areas and also possibly from the large corn fields, which were heavily manured each fall and spring. The rain event on 28 July 2014 allowed us to further pinpoint and confirm at least one source of the high phosphorus and nitrogen levels in this tributary. During this event, we observed and sampled very dark brown liquid flowing from the mortality compost pile into this tributary (Figure 21). The analyses of these samples indicated that this liquid contained extremely high levels of nutrients (total nitrogen concentration = 217 mg/l and total phosphorus concentration = 13,000 µg/l). Thus, we were able to confirm that the mortality compost pile was a significant source of the phosphorus and nitrogen flowing into this tributary.

Figure 21. *Dark liquid draining from large mortality compost pile down farm road and into the northern tributary of Brighton Brook during the rain event on 28 July 2014.*

Hamel Marsh Tributary

In 2014, we continued our efforts to further pinpoint nutrient and sediment sources along two small tributaries that flow into a small tributary of the Barton River (the "Hamel Marsh tributary"). Both total phosphorus and total nitrogen concentrations were generally higher at the site on the Upper Hamel Tributary than on the Middle Hamel Tributary (Figure 22-23). At the Upper Hamel Tributary site, both total phosphorus and total nitrogen concentrations were high at all stream flows and also showed strong positive relationships with stream flow (Figure 24-25). These high phosphorus and nitrogen levels, even at low flows, and strong positive relationships with flow suggested that the phosphorus and nitrogen may be originating from both nonpoint and point sources. These sources may include runoff from several large corn fields located on steep slopes as well as from a large barn complex that included barnyards, a manure pit, and silage storage. At the Middle Hamel Tributary site, the moderately high phosphorus and nitrogen levels and the less marked but still positive relationships with stream flow provided a less clear picture of possible source(s), but possible nonpoint sources include surface runoff from the hay and corn fields located further upstream.

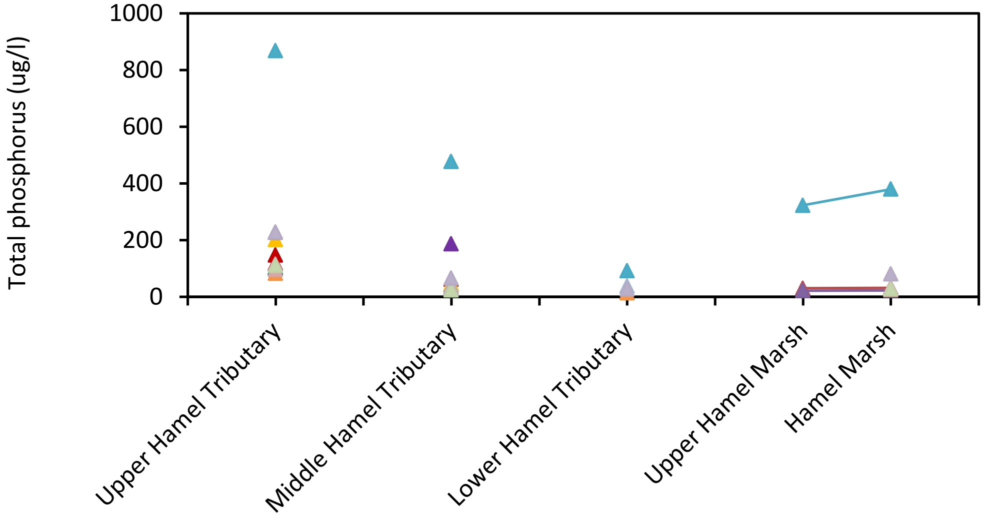

Figure 22. *Total phosphorus "profile" along the main stem and three small tributaries of the Hamel Marsh tributary from Upper Hamel Tributary downstream to Hamel Marsh on 16 dates during April-October 2013 and 2014.*

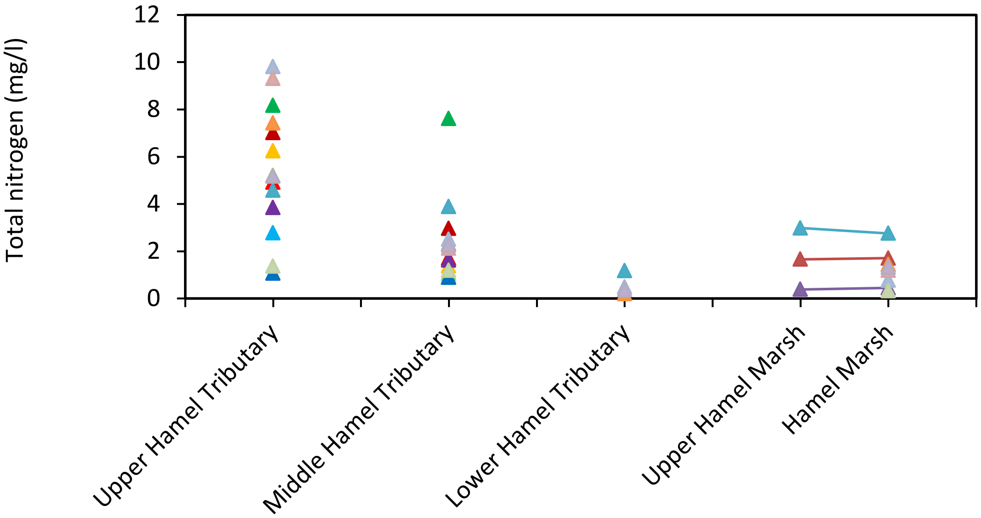

Figure 23. *Total nitrogen "profile" along the main stem and three small tributaries of the Hamel Marsh tributary from Upper Hamel Tributary downstream to Hamel Marsh on 16 dates during April-October 2013 and 2014.*

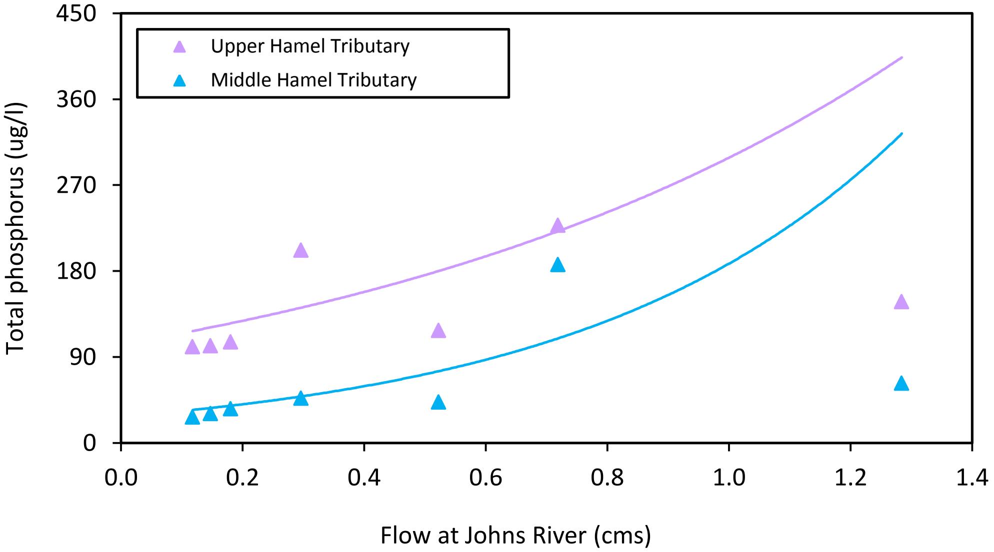

Figure 24. *Total phosphorus concentrations in relation to stream flow at two sites along two branches of the Hamel Marsh tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

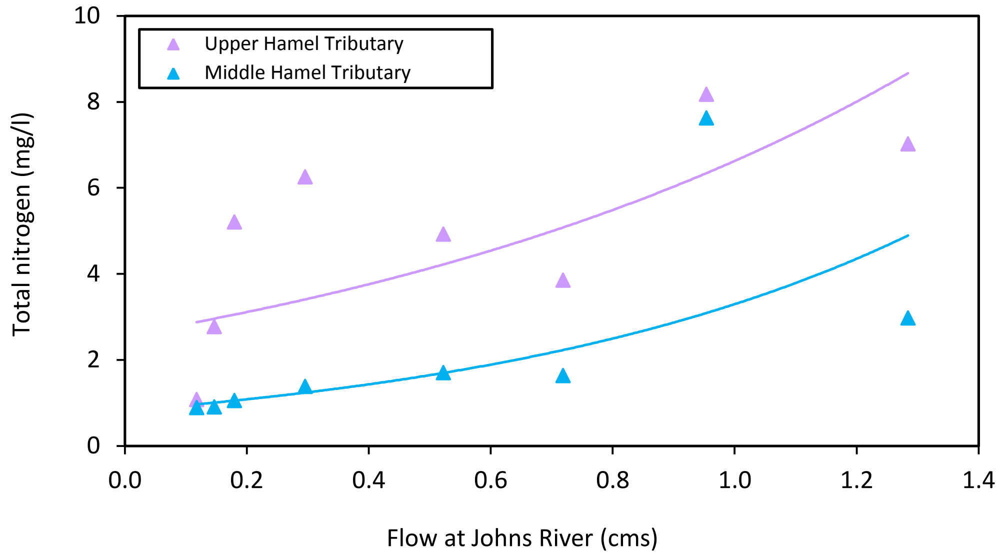

Figure 25. *Total nitrogen concentrations in relation to stream flow at two sites along two branches of the Hamel Marsh tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Junkyard Tributary

In 2014, we continued our efforts to pinpoint possible nutrient and sediment sources along another small tributary of the Barton River (the "Junkyard tributary"), where high phosphorus levels had been measured previously. In 2013, total phosphorus concentrations were generally 50% greater at an upstream vs. a downstream site, and so we added two sites further upstream where this tributary forked into two branches. At the two upstream sites, total phosphorus concentrations were higher at the Royer Farm site than at the Royer Tributary site on all but the three dates with the highest flows, when they were higher at the Royer Tributary site (Figure 26). In contrast, total nitrogen concentrations were higher at the Royer Tributary site on all but one of the sample dates (Figure 27). Both total phosphorus and total nitrogen concentrations showed positive relationships with stream flows at all three sites, especially the Royer tributary site (Figure 28-29). Given the consistently higher nutrient concentrations at the two upper sites, much of the phosphorus and nitrogen in this stream is likely originating from the upper watershed, where there is a medium-sized farm operation with its associated infrastructure and several large corn fields located on fairly steep slopes. The higher nitrogen levels at the Royer Tributary site suggested possible pollution by leachate from the silage storage pad and/or overflow from the manure pit.

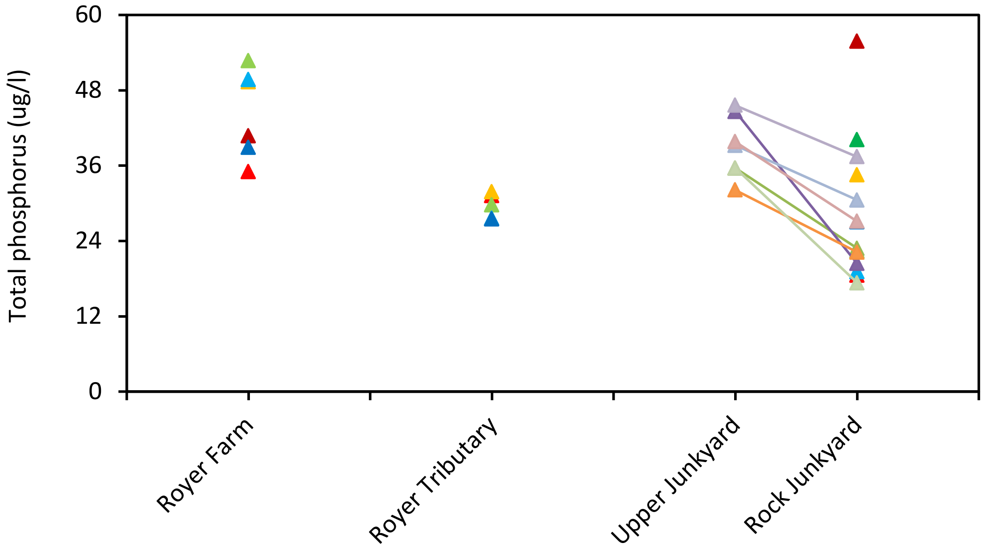

Figure 26. *Total phosphorus "profile" along the main stem and a small tributary of the Junkyard tributary from Royer Farm and Royer Tributary downstream to Rock Junkyard during April-October 2013 and 2014.*

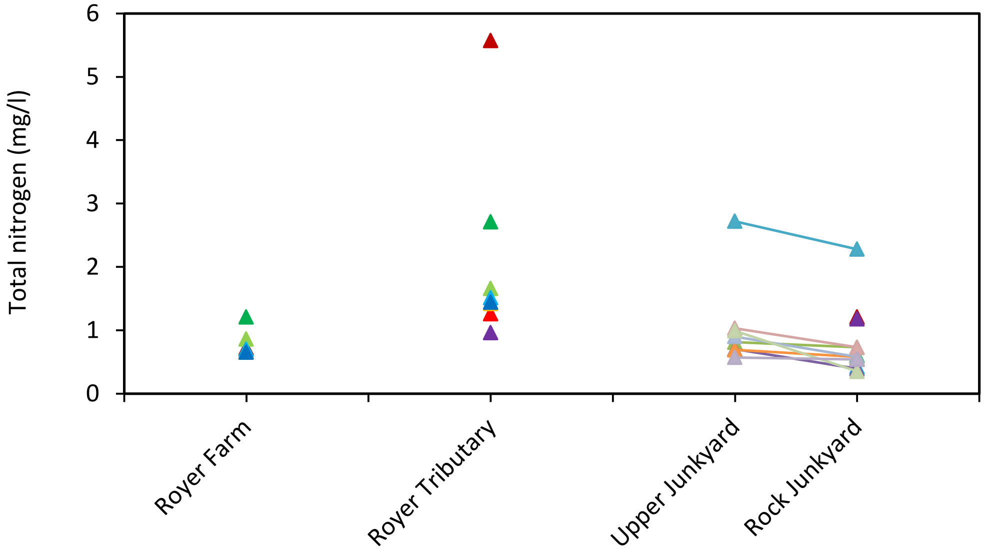

Figure 27. *Total nitrogen "profile" along the main stem and a small tributary of the Junkyard tributary from Royer Farm and Royer Tributary downstream to Rock Junkyard during April-October 2013 and 2014.*

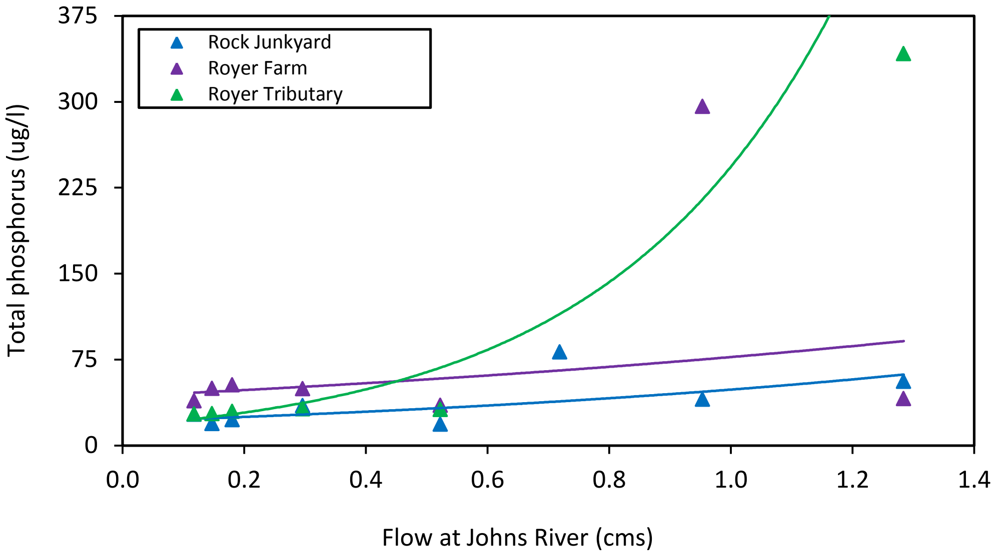

Figure 28. *Total phosphorus concentrations in relation to stream flow at three sites along the main stem and two branches of the Junkyard tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

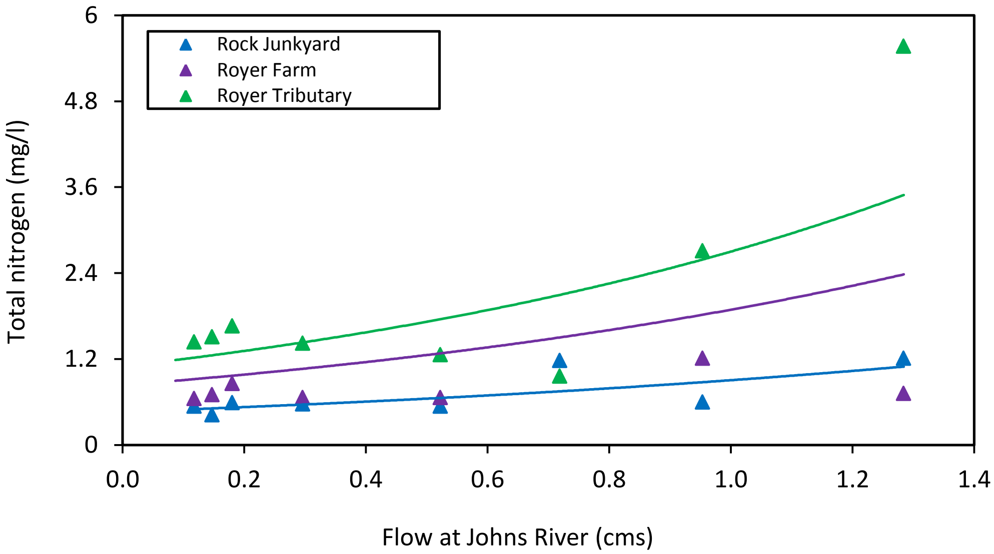

Figure 29. *Total nitrogen concentrations in relation to stream flow at three sites along the main stem and two branches of the Junkyard tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Sunset Acres North Tributary

Due to observations of runoff from manure stacked in a field and previously measured elevated phosphorus levels, we again sampled the Sunset Acres tributary, which flows directly into the east side of Lake Memphremagog. Along this tributary, we sampled two sites: the Sunset Acres North site (downstream) and the Upper Sunset Acres North site (upstream). Both total phosphorus and total nitrogen concentrations were slightly elevated at these two sites. Total phosphorus concentrations were generally similar and exhibited positive relationships with stream flow at both sites (Figure 30-31). In contrast, total nitrogen concentrations were consistently higher at the upstream vs. the downstream site but again exhibited generally positive relationships with stream flow at both sites (Figure 32-33). Thus, although there did not appear to be serious water quality issues, improvements in field practices (e.g. relocating the manure stacks and increasing buffer widths) would likely benefit water quality in this stream.

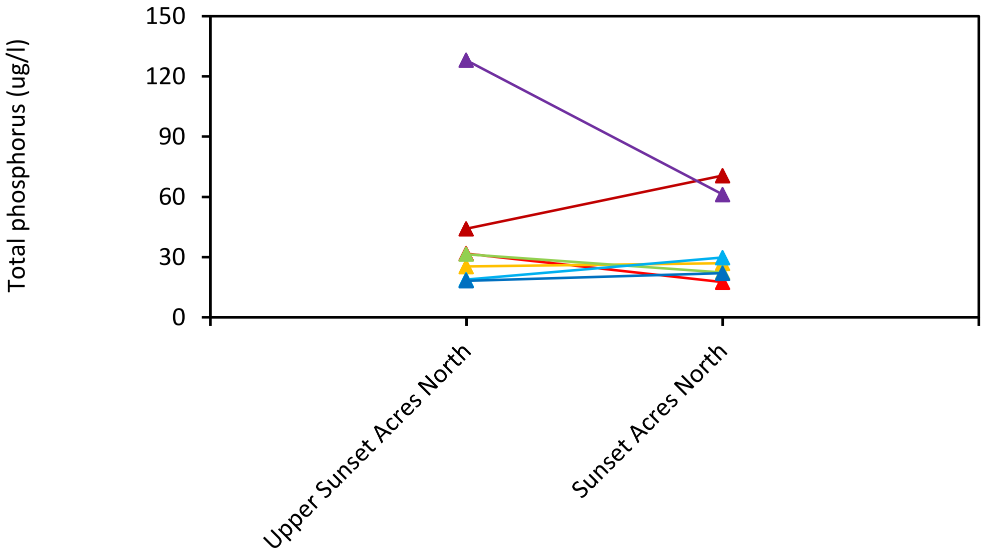

Figure 30. *Total phosphorus "profile" along the Sunset Acres North tributary from Upper Sunset Acres North downstream to Sunset Acres North during April-October 2014.*

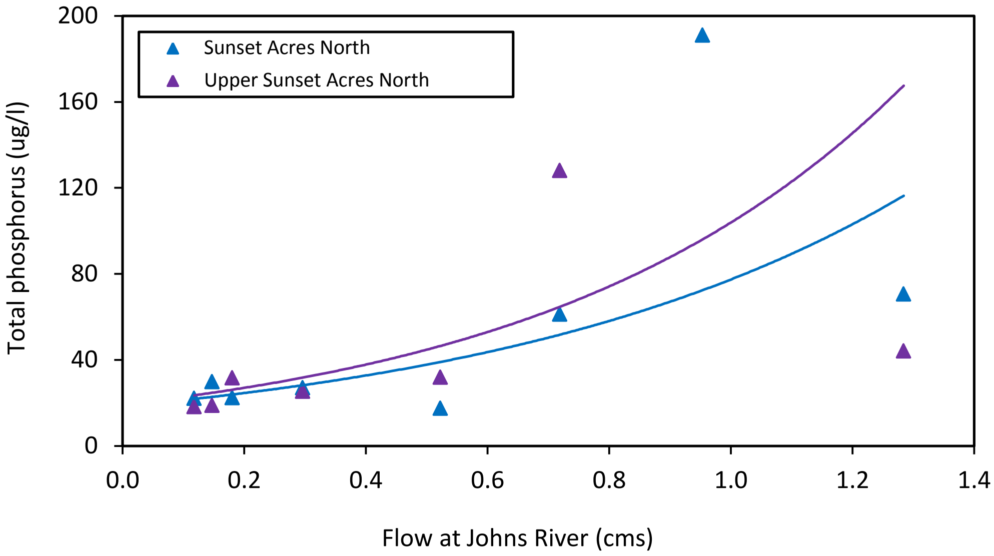

Figure 31. *Total phosphorus concentrations in relation to stream flow at two sites along the Sunset Acres North tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

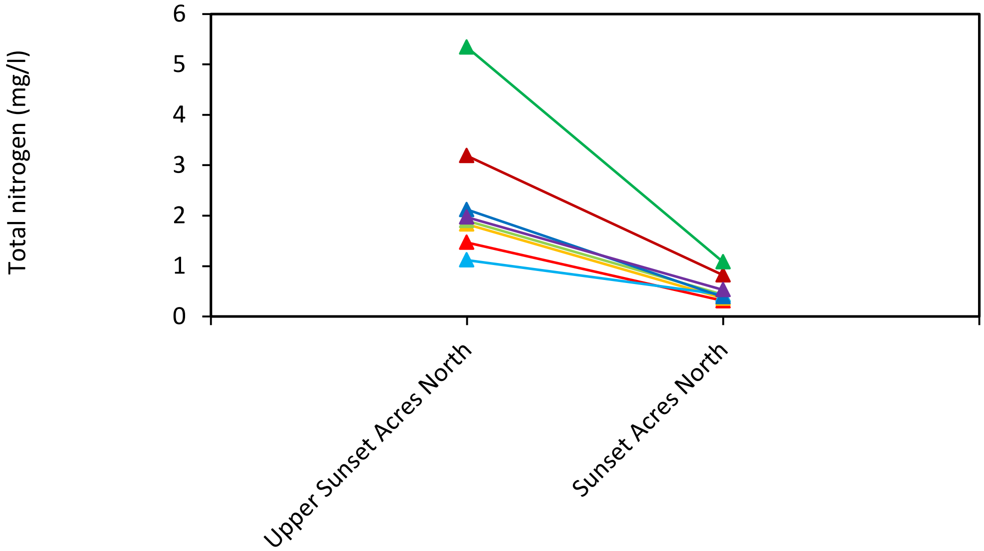

Figure 32. *Total nitrogen "profile" along the Sunset Acres North tributary from Upper Sunset Acres North downstream to Sunset Acres North during April-October 2014.*

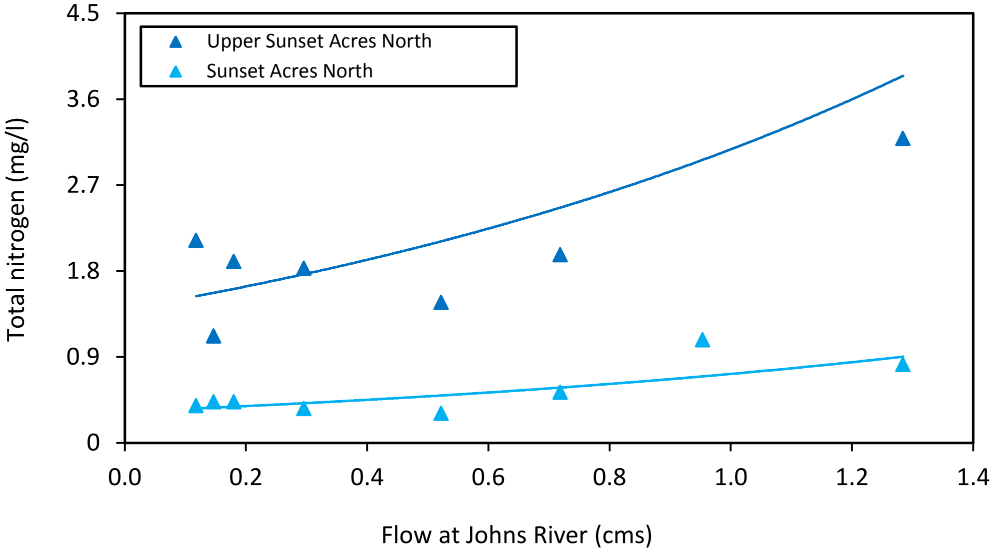

Figure 33. *Total nitrogen concentrations in relation to stream flow at two sites along the Sunset Acres North tributary during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Johns River and Crystal Brook

In 2014, we resampled two sites along the Johns River and its tributary, Crystal Brook, to assess the efficacy of a previously-implemented phosphorus-reduction project. In addition, there had been recent reports of issues with barnyard runoff flowing into Crystal Brook. Following the replacement of a failed manure lagoon that was leaking into Crystal Brook in 2007, total phosphorus concentrations had dropped dramatically between 2006 and 2008-2009 (Figure 34). In 2014, total phosphorus concentrations at both the Johns River and Crystal Brook sites remained low on all dates, except during the two rain events. During the rain event on 28 July 2014, total phosphorus concentrations measured 2,940 µg/l and total nitrogen concentrations measured 14.2 mg/l at the Crystal Brook site (Figure 35). Otherwise, total nitrogen concentrations remained elevated at both the Crystal Brook and especially the Johns River sites, as has been documented in earlier studies (Gerhardt 2009, 2010). In general, these data suggested that phosphorus levels in Crystal Brook and the Johns River remained improved over those measured prior to the replacement of the manure lagoon. However, the extremely high phosphorus and nitrogen levels measured at the Crystal Brook site during the one rain event suggested that there may be serious issues with runoff from a barn complex along Crystal Brook. In addition, biomonitoring data collected by the Vermont DEC in 2014 indicated that both the macroinvertebrate and especially the fish communities had declined in health since the previous sampling done in 2010 (Steve Fiske and Rich Langdon, personal communication). Collectively, these data suggested that one or more acute toxicity events may have occurred in this stream during that time.

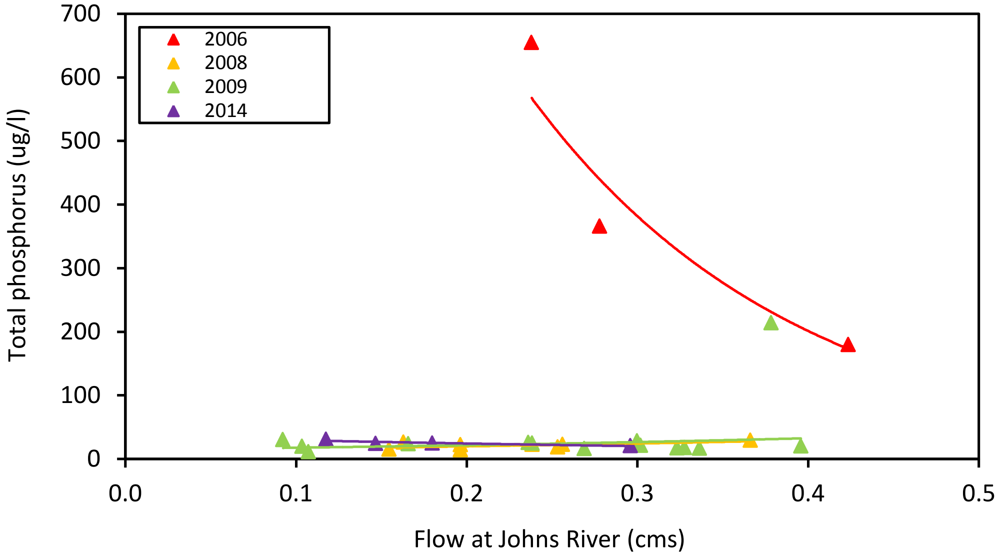

Figure 34. *Total phosphorus concentrations in relation to stream flow at the Crystal Brook site during 2006-2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Figure 35. *The extremely heavy rains on 28 July 2014 flushed large amounts of sediment and nutrients into Crystal Brook (photo courtesy of Ben Copans).*

Tributary of Stearns Brook

In 2014, we initiated water quality sampling along a tributary of Stearns Brook that has been declared impaired and in need of a TMDL due to nutrients from agricultural runoff (State of Vermont 2014). In order to identify and assess possible nutrient sources along this tributary, we analyzed water quality at six sites along the main stem (four sites) and smaller tributaries (two sites) of this tributary. In addition, we sampled the outflow from two culverts and two ditches during the two rain events on 28 July and 23 October 2014. Based on our sampling, we were able to determine that phosphorus levels increased dramatically downstream of the two upstream-most sites (Upper Stearns Tributary and Stearns Tributary Falls) and upstream of the next site downstream (Middle Stearns Tributary)(Figure 36). In addition, phosphorus levels were consistently high in one of the two smaller tributaries (Valley Road South) and extremely high during rainfall events in the other smaller tributary (Twin Bridges Road). Total phosphorus concentrations showed positive relationships with stream flow at all six sites, especially the Middle Stearns Tributary and Twin Bridges Road sites (Figure 37). Like total phosphorus, total nitrogen concentrations increased steadily from the upstream sites down to the Middle Stearns Tributary site, but they were also extremely high in the other smaller tributary (Twin Bridges Road)(Figure 38). However, total nitrogen concentrations showed no relationships with stream flow at two of the six sites, negative relationships with flow at three of the four main stem sites, and a positive relationship with stream flow at one other site (Figure 39). During the two rain events (28 July and 23 October 2014), we measured extremely high phosphorus and nitrogen levels in the water flowing from two culverts located immediately upstream of the Middle Stearns Tributary site (Table 1). Collectively, these data suggested that much of the phosphorus and nitrogen in this tributary may be originating from the large barn complex and surrounding agricultural fields located upstream of the Middle Stearns Tributary site.

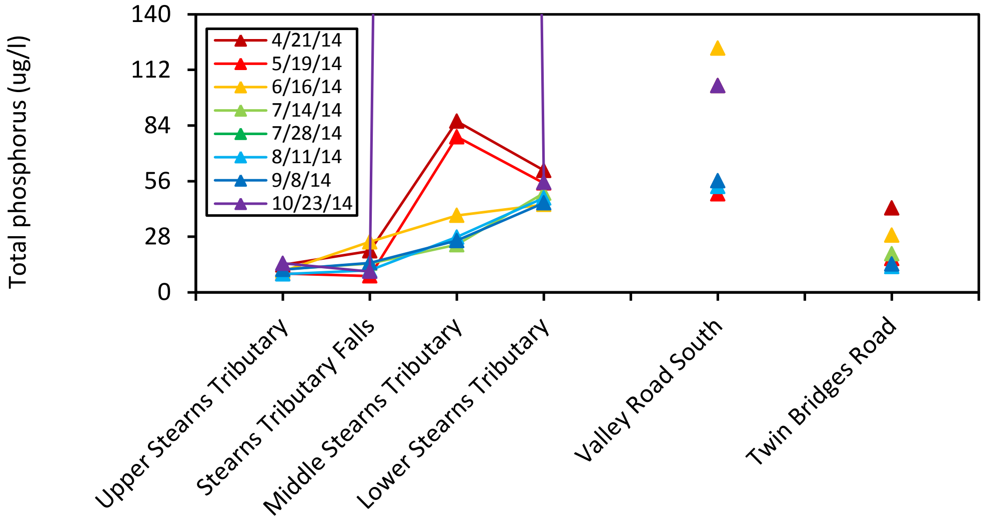

Figure 36. *Total phosphorus "profile" along the tributary of Stearns Brook from Upper Stearns Tributary downstream to Lower Stearns Tributary during April-October 2014.*

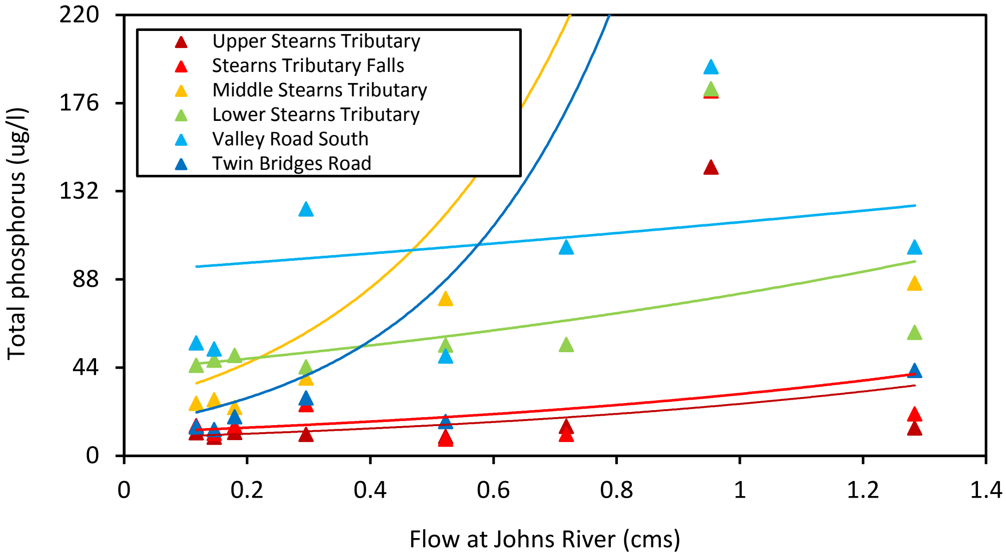

Figure 37. *Total phosphorus concentrations in relation to stream flow at six sites along the tributary of Stearns Brook during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

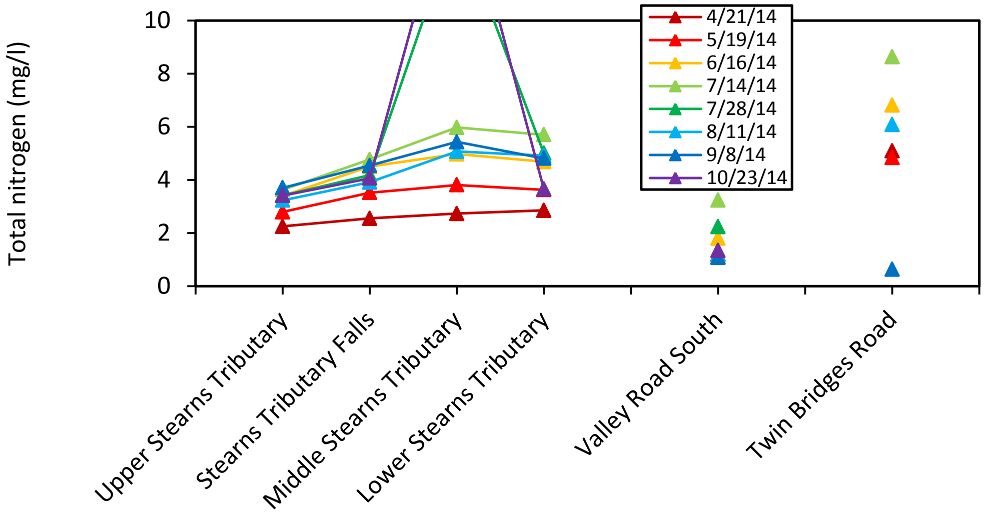

Figure 38. *Total nitrogen "profile" along the tributary of Stearns Brook from Upper Stearns Tributary downstream to Lower Stearns Tributary during April-October 2014.*

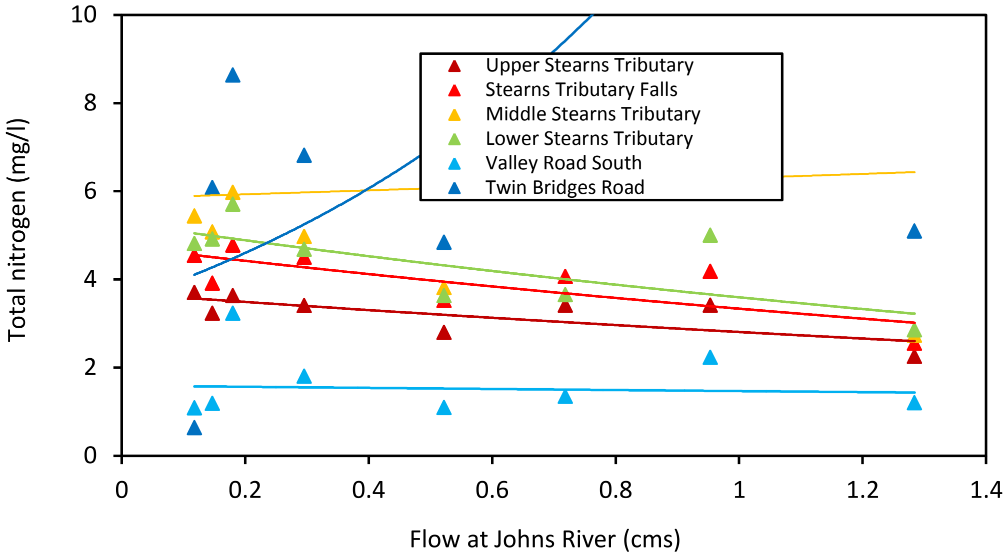

Figure 39. *Total nitrogen concentrations in relation to stream flow at six sites along the tributary of Stearns Brook during April-October 2014. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Table 1. Water quality data for samples collected from water flowing out of two culverts into the tributary of Stearns Brook in Holland, Vermont during two high-flow events on 28 July and 23 October 2014. Both culverts were located between the Stearns Tributary Falls and Middle Stearns Tributary sites.

Sample Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Upper Barnyard Culvert	7/28/2014	5.93	2,380	963
Upper Barnyard Culvert	10/23/2014	24.9	17,300	9,090
Lower Barnyard Culvert	7/28/2014	13.9	4,960	67.8
Lower Barnyard Culvert	10/23/2014	18.0	3,610	705

Phosphorus-Reduction Projects

In 2014, we continued our efforts to identify, develop, and implement potential phosphorus-reduction projects and practices that will most effectively reduce phosphorus and sediment inputs along the Vermont tributaries of Lake Memphremagog. In the second year of this project, we focused on identifying, mapping, and prioritizing possible causes of water quality problems and potential phosphorus-reduction projects and practices in the 28 subwatersheds that exhibited the highest total phosphorous concentrations in the Vermont portion of the Lake Memphremagog Basin. In these priority subwatersheds, we identified and mapped land uses, land cover types, and possible sources of the high phosphorus levels and other water quality problems. To the extent possible, possible causes of water quality problems were localized to specific sites within the priority subwatersheds. We then shared information about possible sources of water quality problems and potential phosphorus-reduction projects and practices with the appropriate agency and/or organizational staff, who can take the lead in working with landowners and land managers to design and implement phosphorus-reduction projects and practices.

Background

In the first stage of this project, we used the water quality data collected along the Vermont tributaries of Lake Memphremagog during 2005-2012 to identify those subwatersheds that exhibited the highest total phosphorus concentrations [these analyses were presented in greater detail in Gerhardt (2014)]. To start, we used the U.S. Geological Survey's StreamStats program (available at http://streamstats.usgs.gov/) to delineate the boundaries of each subwatershed sampled by each sample site. These boundaries were then imported and merged into a single Geographic Information System (GIS) shapefile. Second, to compensate for the different dates and stream flows sampled at each site, we calculated the arithmetic mean total phosphorus concentrations for each site separately for low flows and for moderate and high flows. For sites along the main stems of the three largest tributaries (Barton, Black, and Clyde Rivers), we identified low, moderate, and high flows based on daily stream flows measured at the U.S. Geological Survey gage station on the Black River in Coventry (USGS station 04296000). For sites along the main stem of the Johns River and the other smaller tributaries, we identified low, moderate, and high flows based on daily stream flows measured by the Vermont DEC on the Johns River in Beebe Plain. Finally, we calculated the mean rank of each site by ranking the mean total phosphorus concentrations for all sites at low flows and at moderate and high flows and then calculating the average of the two ranks (for the twelve sites at which we collected no samples at moderate or high flows, the mean rank equaled the rank calculated for the low flows only).

In general, mean total phosphorus concentrations were highest in several areas of the Black River watershed, in the downstream sections of the Barton River and Johns River watersheds, and along several small tributaries that flow directly into Lake Memphremagog (Figure 40). More specifically, the subwatersheds with the highest total phosphorus concentrations occurred along several reaches of the main stem of the Black River, three tributaries of the Black River (Shalney Branch and Brighton and Stony Brooks), the downstream sections of the main stem of the Barton River and several of its tributaries (Willoughby River, Roaring Brook, and the Junkyard and Hamel Marsh tributaries), much of the Johns River watershed, and several small tributaries that flow directly into Lake Memphremagog. In contrast, the subwatersheds with the lowest total phosphorus concentrations occurred throughout the

Clyde River watershed, the upstream sections of the Barton River watershed, and many of the smaller tributaries of the Barton, Black, and Clyde Rivers.

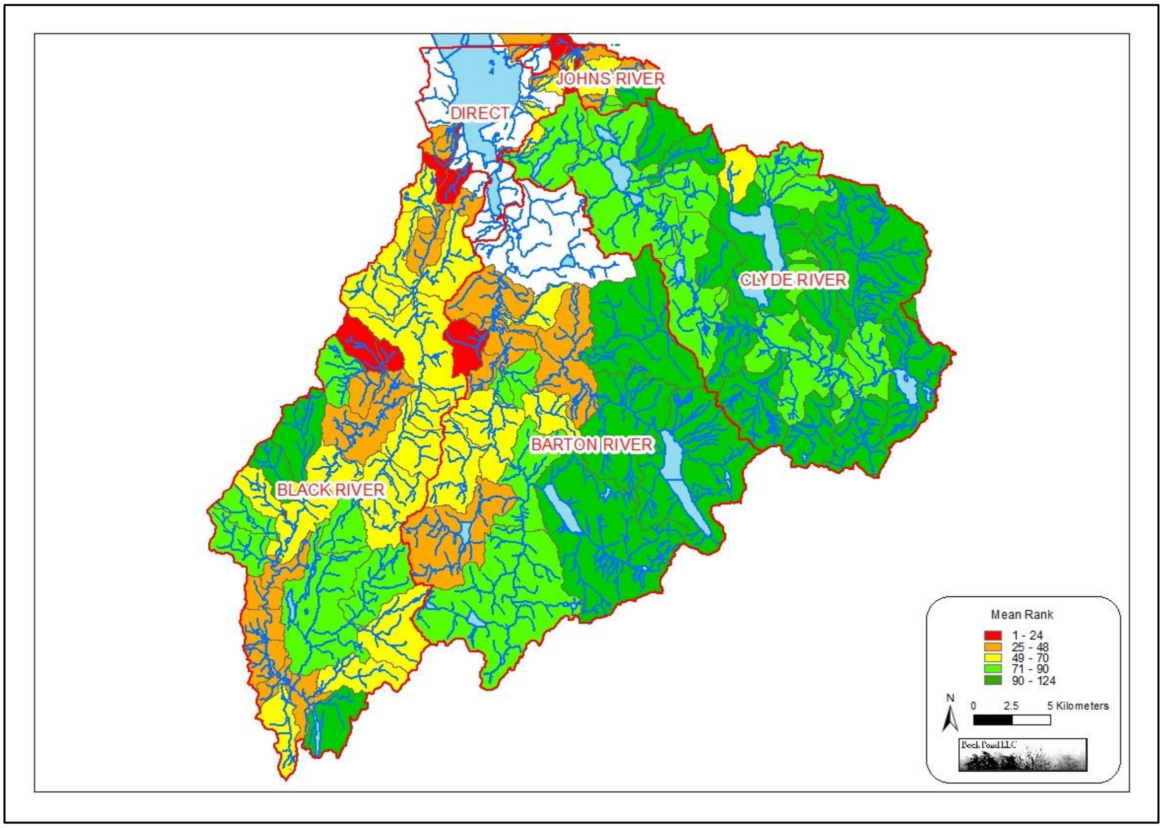

Figure 40. *Mean ranks based on the average of the mean total phosphorus concentrations at low and at moderate and high flows in 121 subwatersheds in the Vermont portion of the Lake Memphremagog Basin during 2005-2012. The lowest number (1) corresponds to the highest mean total phosphorus concentration, and the highest number (121) corresponds to the lowest mean total phosphorus concentration.*

Methods

In the next stage of this project, we selected a subset of 28 priority subwatersheds in which to map and identify possible causes of water quality problems and to identify and develop potential phosphorus-reduction projects and practices (Table 2). These priority subwatersheds were those subwatersheds whose associated sample sites exhibited the highest mean total phosphorus concentrations at low flows, the highest mean total phosphorus concentrations at moderate and high flows, and/or the highest mean rank. Thus, these 28 priority subwatersheds included all 20 of the highest ranked subwatersheds (that is, ranked by the average of the rank at low flows and the rank at moderate and high flows). They also included 15 of the 20 subwatersheds with the highest mean total phosphorus concentrations at low flows and 15 of the 20 subwatersheds with the highest mean total phosphorus concentrations at moderate and high flows. The 28 priority subwatersheds were concentrated in eight areas (Figure 41): 1) Johns River and tributaries, 2) three small tributaries that flow directly into the southwest corner of Lake Memphremagog, 3) two small tributaries of the Barton River just downstream of Orleans village, 4) the mouth of the Black River, 5) main stem of Black River downstream of Craftsbury village, 6) Stony Brook, 7) Brighton Brook and tributaries, and 8) Shalney Branch. None of the priority subwatersheds were located within the Clyde River watershed. In 2014, we focused our efforts on identifying possible sources of water quality problems and potential phosphorus-reduction projects and practices in the 18 priority subwatersheds encompassed by the Barton River and Black River watersheds as well as the three small tributaries that flow directly into the southwest corner of Lake Memphremagog.

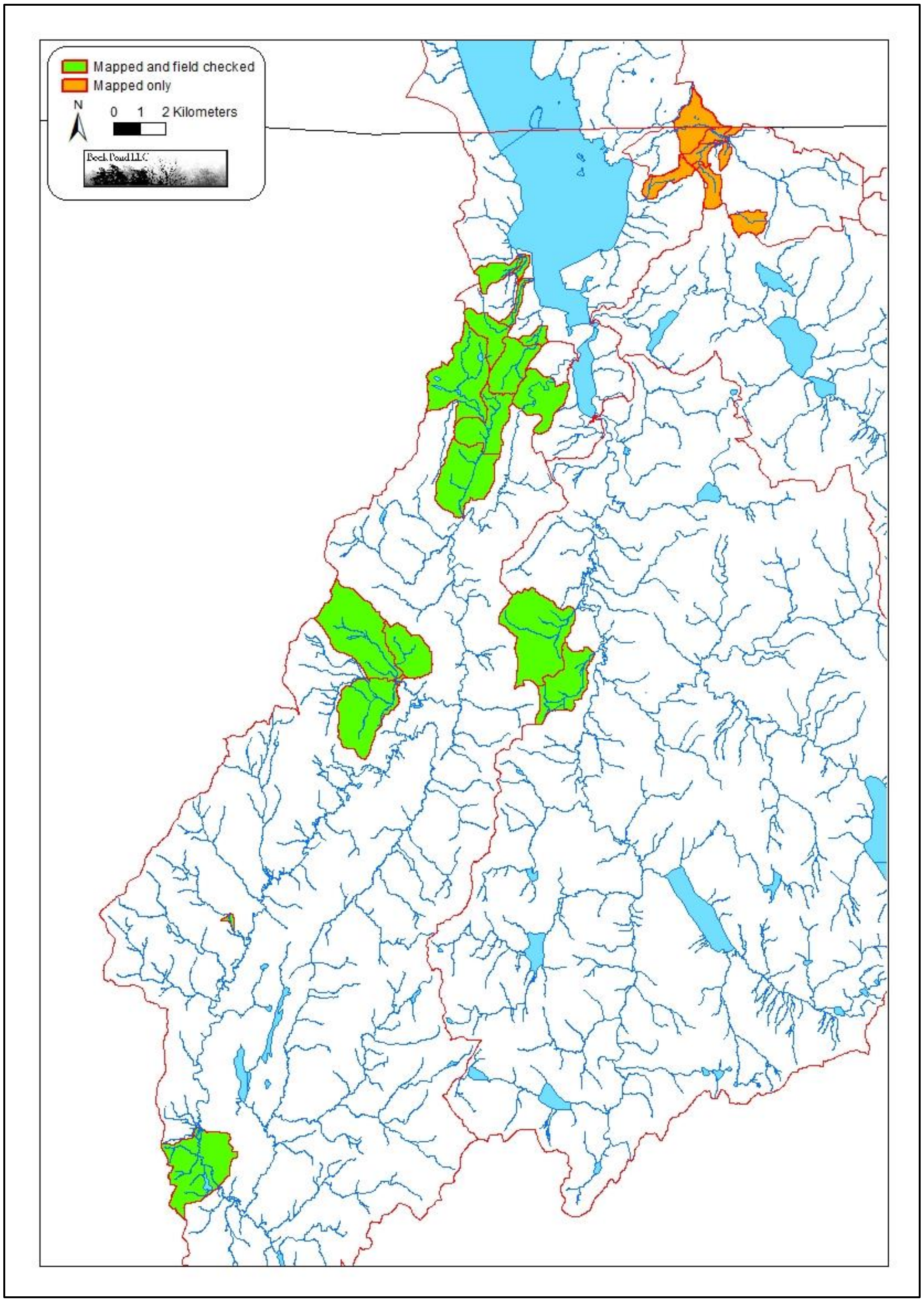

Figure 41. *The 28 priority subwatersheds exhibiting the highest total phosphorus concentrations in the Vermont portion of the Lake Memphremagog Basin during 2005-2012.*

Table 2. The 28 priority subwatersheds exhibiting the highest total phosphorus concentrations in the Vermont portion of the Lake Memphremagog Basin during 2005-2012.

River or Stream	Subwatersheds (Names of Sample Sites)
Barton River Watershed (2 Subwatersheds)	
Hamel Marsh tributary	Hamel Marsh
Junkyard tributary	Rock Junkyard
Black River Watershed (9 Subwatersheds)	
Main stem	Black River, Post Road
Stony Brook	Stony Brook, Blake Road
Brighton Brook	Brighton Brook, Robillard Flats, Brighton Brook North, Upper Brighton Brook North
Shalney Branch	Shalney Branch
Johns River Watershed (9 Subwatersheds)	
Main stem	North Derby Road, Granite, Johns River
Beebe Plain tributary	Beebe Plain
Darling Hill tributary	Darling Hill, Middle Darling Hill, Upper Darling Hill, DHM
Quarry tributary	Upper Quarry West
Direct Tributaries (8 Subwatersheds)	
Sunset Acres tributary	Sunset Acres North
Wishing Well tributary	Wishing Well, Upper Wishing Well
Strawberry Acres tributary	Strawberry Acres, Upper Strawberry Acres
Holbrook Bay tributary	Holbrook Bay, Holbrook Bay North, Holbrook Bay South

Within the 28 priority subwatersheds, we used ArcGIS 10 (ESRI, Redlands, California) to identify and map possible sources of water quality problems. To do this, we first identified and mapped the different land uses and land cover types observed on the 2012 aerial photographs downloaded from the USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). For all 28 priority subwatersheds, we created polygons for every land use and land cover type, except forests, forested wetlands, and shrublands, as the latter land cover types were not likely to export large quantities of phosphorus and sediment into the surface waters of the basin (Table 3). We supplemented these data and maps with information provided by the Stream Geomorphic Assessments that were completed for the Barton, Black, Clyde, and Johns Rivers and some of their tributaries (Gerhardt and Dyer 2006, Dyer 2008, Dyer et al 2008, 2011). Finally, we created a database that listed potential phosphorus-reduction projects and practices by subwatershed, water quality problem(s), possible source(s) of the water quality problems, land owner, lead contact (e.g. agency and/or organization), and actions to be taken and/or taken to date.

Table 3. Land uses and land cover types identified and mapped as part of efforts to identify and map possible sources of water quality problems in 28 priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin. Asterisks (*) indicate those land uses and land cover types that were deemed high priorities for further evaluation.

<u>Agricultural Land Uses</u>

Barn and/or barnyard *
Manure storage *
Silage storage *
Composting area *
Abandoned agricultural field (a.k.a. old field)
Corn (within 25-m buffer) *
Hay (within 25-m buffer) *
Pasture (within 25-m buffer) *
Row crop (within 25-m buffer) *

<u>Residential, Commercial, and Industrial Land Uses</u>

Residential area (within 25-m buffer) *
Commercial area (within 25-m buffer) *
Urban area (within 25-m buffer) *
Municipal park
Industrial area *
Sand or gravel pit *
Lawn (within 25-m buffer) *
Church (within 25-m buffer) *
Municipal (within 25-m buffer) *
Solar power facility (within 25-m buffer) *
Landfill *
Dirt bike track *

<u>Transportation and Utility Right-of-Ways</u>

Road (within 25-m buffer) *
Utility right-of-way
Railroad (within 25-m buffer) *
Airport (within 25-m buffer) *

<u>Other Land Cover Types</u>

Pond
Non-forested wetland
Clear-cut (within 25-m buffer)

Once we identified and mapped the land uses and land cover types in each priority subwatershed, we then prioritized those land uses and land cover types that were most likely to export the largest amounts of phosphorus and other nutrients and sediment into the surface waters of the Lake Memphremagog Basin (Table 3). Initially, we identified barns and their associated infrastructure (barnyards, manure storage, silage storage, and composting areas) as high priorities for further evaluation, as those areas have the potential to export large quantities of nutrients and sediment if not managed properly. We also prioritized industrial areas, sand and gravel pits, landfills, and dirt bike tracks, as those areas also have the potential to export large amounts of phosphorus, sediment, and other pollutants through surface runoff, stormwater, and groundwater. Finally, for those land uses that covered large expanses (e.g. agricultural fields such as corn, hay, and pasture and residential and commercial areas), we prioritized those areas lying within 25 m (82 ft) of rivers and streams. However, since we mapped the full extent covered by these land uses and land cover types, both inside and outside the 25-m (82-ft) buffers, we will continue to evaluate other factors (e.g. agricultural fields located on steep, highly-erodible soils) that may raise the importance of these areas.

Due to the large areas of agricultural land uses and the strong positive relationships with total phosphorus concentrations (Gerhardt 2013), we focused our efforts on identifying and evaluating potential projects and practices that address agricultural sources of water quality problems [e.g. improvements to agricultural structures, Best Management Practices (BMP), and riparian buffers]. Many of the proposed projects and practices can be implemented through existing grants or cost-share programs, including those administered by the Vermont Agency of Agriculture, Foods and Markets (VAAFM); Vermont DEC; and USDA Natural Resources Conservation Service (NRCS). In addition, technical and financial assistance can be provided by the Vermont Association of Conservation Districts (VACD), Natural Resources Conservation Districts, and various other public and private partners. Despite this focus on agriculture, we also continued to pursue projects and practices that addressed other sources of water quality problems (e.g. wetlands loss and road erosion).

Throughout this process, we have discussed the priority subwatersheds, possible sources of water quality problems, and potential phosphorus-reduction projects and practices with key staff from the Vermont DEC, VAAFM, VACD, Orleans County NRCD, and NRCS. During this project, we convened two meetings with these key partners to discuss the results of these analyses, to discuss specific water quality problems and their possible sources, to identify potential phosphorus-reduction projects and practices, and to create a list of actions that were to be undertaken to address these problems through phosphorus-reduction projects and practices. Throughout this project, we have also met with individual project partners to discuss and tour specific priority subwatersheds, possible sources of water quality problems, and potential phosphorus-reduction projects and practices. Once specific phosphorus-reduction projects and practices were identified, we continued to work with project partners to verify water quality problems, to assess the appropriateness and feasibility of potential projects and practices, to gauge landowner interest in undertaking projects or practices, and to evaluate the success of projects and practices once they were implemented.

Results and Discussion

In the sections that follow, we describe possible sources of water quality problems, potential phosphorus-reduction projects and practices, and the current status of efforts to protect and improve water quality in each of the 18 priority subwatersheds evaluated in 2014. Implementation of phosphorus-reduction projects and practices in these priority subwatersheds will likely be one of the most effective methods for reducing phosphorus exports into the surface waters of the Lake Memphremagog Basin.

Barton River Watershed

Hamel Marsh Tributary

Along the Hamel Marsh tributary, we identified and mapped a number of possible sources of water quality problems. In general, these sources were concentrated in the headwaters of two branches of this tributary.

Along the Upper Hamel Tributary, we measured high concentrations of both total phosphorus (median = 118.0 µg/l in 2014) and total nitrogen (median = 5.2 mg/l in 2014). In the watershed of this branch of the Hamel Marsh tributary, we identified several possible sources of water quality problems. First, many of the corn fields are located on steep slopes with shallow, highly-erodible soils. Consequently, the farmer there uses no-till methods to crop many of the lower fields but uses conventional methods to cultivate the upper fields (David Blodgett, personal communication). In addition, many of the fields lack wide buffers along this stream, although they may satisfy Best Management Practices and regulatory requirements. Second, another possible source of sediment and nutrients is runoff and poor practices at a heifer barn and associated facilities in the headwaters of this stream. The stream itself originates in this production area of the heifer facility, and, in the past, overflow from the manure pit and runoff and milkhouse waste have flowed into this stream. In 2014, the owner completed a clean-water diversion project to reduce the amount of water flowing into and overflowing the manure pit. Third, livestock graze directly in the stream just upstream of the sample site on this tributary. Finally, we observed an unused but full manure pit that was located just downstream of that sample site (Figure 42). According to the renter, the pit has not been used in at least 15 years, and we have referred this pit to the local Agricultural Resource Specialist for possible removal. Although no State funding is available, the NRCS does have a program for decommissioning unused manure pits. Finally, we recommend walking the entire length of this stream in order to better identify and assess these and any other sources of nutrients and sediment flowing into this stream.

Along the Middle Hamel Tributary, we measured slightly better water quality (median total phosphorus concentration = 43.0 µg/l and median total nitrogen concentration = 1.4 mg/l in 2014). In the watershed of this tributary, we have identified two possible sources of nutrients and sediment. First, there appears to be an area in the lower of the hay field just upstream of the sample site on this tributary where manure has been stacked and/or transferred to manure spreaders in the past (Figure 43). This site is located immediately upslope of and is separated by only a narrow band of trees from this tributary. Second, as along the Upper Hamel Tributary, a number of corn fields are located on steep slopes with highly-erodible soils in the headwaters of this tributary. In 2015, we plan to add an additional sample site further up this tributary, as that will allow us to segregate possible source areas along this stream. In addition, we will continue to evaluate the use of the hay field for stacking and/or transferring manure (as of 9 February 2015, no manure was stacked there).

Figure 42. *Unused manure pit located immediately upslope of the Upper Hamel Tributary in Irasburg, Vermont. Note that, although unused, the pit remains filled with water, algae, and plant growth.*

Figure 43. *Area where manure appears to have stacked or transferred to manure spreaders at the lower end of a hay field along the Middle Hamel Tributary in Irasburg, Vermont. Note that the tributary is located approximately 15 m (50 ft) downslope through the trees in the background.*

Junkyard Tributary

Along the Junkyard tributary, we identified and mapped a number of possible sources of water quality problems. In general, these sources were concentrated in the headwaters of two branches of this tributary.

Water samples collected from the southern branch of the Junkyard tributary contained high levels of total phosphorus (median concentration = 49.5 µg/l in 2014 but mean concentration = 1,214 µg/l due to extremely high concentrations during the two rain events). This southern branch drains the southern edge of the production area of a medium farm operation (MFO) as well as large areas of corn and hay fields to the south of Vermont Route 58, and we identified several possible sources of water quality problems: 1) several large corn fields located on steep slopes with highly-erodible soils, 2) narrow riparian buffers in some locations along the edges of the corn and hay fields, 3) a mortality pile located near the stream, and 4) possible failing septic systems draining into an algae-filled pond at the height of this stream. In addition, staff from the VAAFM indicated that there had been problems with runoff from the production area draining into this stream previously but that those problems had been corrected.

Water samples collected at the northern branch of this tributary also contained higher levels of total phosphorus (median concentration = 31.5 µg/l in 2014 but mean concentration = 146 µg/l)). The northern branch of this tributary drains the majority of the production area of a medium farm operation (MFO) as well as several pastures and hay fields (Figure 44). Based on our analyses, we identified runoff from the barnyard, manure pit, and/or silage pad as possible sources of the water quality problems. In addition, livestock were able to walk in a ditch that drained the barnyard and then flowed through a wet meadow before entering this stream.

Based on these observations, staff from the VAAFM and Vermont DEC visited the farm and met with the owner on 14 November 2014 to discuss the water quality problems and possible solutions. Through these discussions, they confirmed several of these problems, and, subsequently, the owner submitted an Environmental Quality Incentives Program (EQIP) application to the NRCS to fund improvements to the nutrient management plan and field practices. Although the buffers around the corn and hay fields generally met BMP and regulatory requirements, the farmer also proposed to widen the buffer in one area that lacked a sufficiently wide buffer for a medium farm operation (MFO) and will also consider creating a wide hay buffer to capture runoff and sediment from the steepest corn field. Finally, the owner would like to relocate the mortality pile and to build additional storage capacity to capture any overflow from the manure pit and leachate from the silage storage pad and mortality compost piles.

Figure 44. *Production area of a medium farm operation that is drained by the northern branch of the Junkyard tributary in Irasburg, Vermont.*

Black River Watershed

Post Road and Mud Pond

In the Post Road subwatershed located along the main stem of the Black River in Craftsbury, we identified and mapped a number of possible sources of water quality problems. Water samples collected at the downstream end of this stretch of the Black River exhibited high phosphorus levels (median total phosphorus concentration = 33.3 µg/l in 2012); whereas, those collected at the next site approximately 2.5 km (1.6 miles) further upstream exhibited significantly lower levels (median total phosphorus concentration = 19.5 µg/l in 2012). In addition, water samples collected from Mud Pond, a large pond covering approximately 14 ha (35 acres), during the spring of 2014 exhibited very high total phosphorus concentrations (135 and 140 µg/l) and total nitrogen concentrations (1.27 mg/l), and the phosphorus, but not nitrogen, levels greatly exceeded those measured previously (range in total phosphorus concentrations = 39-86 µg/l and range in total nitrogen concentrations = 1.10-2.02 mg/l during 2002-2007).

Most of the possible sources of water quality problems in this subwatershed were agricultural in nature and were concentrated on the medium farm operation (MFO) located along Black River Road at the upstream end of this subwatershed and surrounding Mud Pond. These possible sources included 1) a production area that has no milk house waste system and drains into a settling pond along the main stem of the Black River, 2) overgrazed paddocks that abut Mud Pond and through which an unfenced, small stream flows (Figure 45), 3) leachate from a silage storage area located uphill from the stream that flows through the overgrazed paddock, and 4) narrow buffers around several corn and hay fields, especially those abutting Mud Pond. None of the project partners have worked with the owner of this farm. Currently, we and our project partners are discussing how to best approach the owner of this farm to identify and assess possible sources of water quality problems associated with the large barn complex and surrounding fields.

Figure 45. *Overgrazed paddock abutting the wetlands and open waters of Mud Pond along Black River Road in Craftsbury, Vermont. Note the absence of vegetation and the trampling in many areas.*

Stony Brook

Although phosphorus and nitrogen levels along Stony Brook were only slightly elevated (median total phosphorus concentration = 20.1 µg/l and median total nitrogen concentration = 1.1 mg/l in 2013), we observed extremely turbid waters at the downstream-most site on several occasions. Based on field observations, we identified three possible sources of water quality problems in this watershed. First, in 2012-2013, we observed that several wetlands had been filled or were being excavated to create a new pond along Nadeau Road in Coventry (Figure 46). Staff from the Vermont DEC investigated this situation and sent a notice of alleged violation. Subsequently, some restoration of the site was completed, and no further alterations of the wetland have been observed. Second, in 2012, we observed significant runoff and erosion occurring along a farm road that connected a ford across Stony Brook and an area where manure was being transferred for spreading (Figure 47). We have not observed that this practice has continued in subsequent years, although farm machinery continues to cross the ford on Stony Brook at this location. Unfortunately, the owner of these fields has declined to undertake any projects to protect and restore the riparian buffers along this stretch of Stony Brook. Finally, while scouting possible phosphorus sources in this subwatershed, we identified a small tributary stream flowing through a barnyard along Hancock Hill Road as another possible source of sediment and nutrients. Thus, we are proposing to sample water quality in this tributary downstream of this barnyard in 2015.

Figure 46. *Area where wetlands had been excavated and filled along Nadeau Road in Coventry, Vermont.*

Figure 47. *Farm road with significant erosion and runoff of manure leading down to Stony Brook in Coventry, Vermont.*

Brighton Brook

During 2010-2014, we sampled water quality at numerous sites along Brighton Brook and its tributaries in Irasburg. Through these efforts, we were able to pinpoint and assess the source(s) of the extremely high nutrient and sediment levels to an area along the northern-most branch of Brighton Brook (median total phosphorus concentrations = 655 µg/l and median total nitrogen concentrations = 1.8 mg/l at the Upper Brighton Brook North site in 2014). These possible sources are concentrated on a large farm operation (LFO) and include: 1) leachate from the large mortality compost piles (Figure 48); 2) runoff from the barns, barnyards, and associated facilities; 3) manure-laden corn fields located downslope of the barns, and 4) narrow or non-existent buffers around the corn and hay fields. In response to these determinations, the owner of this large farm installed a drain pipe, buried the stream that drained these corn fields, and planted grass buffers along the former streambed. However, despite repeated requests to relocate and/or collect the leachate from the mortality compost piles, no actions were undertaken, and so the Vermont DEC is currently pursuing an enforcement action to correct this problem.

Figure 48. *Mortality compost pile (in front of barns to left) and production area on the large farm operation along the headwaters of the northern-most branch of Brighton Brook in Irasburg, Vermont. Note the darkened ground where leachate from the compost pile has flowed down and puddled at the bottom of the farm road.*

Shalney Branch

In 2011, total phosphorus levels increased markedly along Shalney Branch between the upstream and downstream sample sites (median concentrations = 61.8 µg/l at the downstream site but only 16.9 µg/l at the upstream site). We and our project partners have worked with the owner of a small dairy farm to make a number of structural improvements, including the construction of a covered manure storage area between 2009-2011 and hardening and adding water barriers to a laneway linking the barnyard and a stream crossing in 2012 (Figure 49). Following these improvements, phosphorus levels dropped markedly at the downstream site (median total phosphorus concentration = 23.8 µg/l in 2013 after these projects were completed). Currently, staff from the VACD are working with the farmer to design and implement a project to divert clean water away from and to pour a concrete pad in a saturated area of the barnyard at the top of the laneway. Completing this project should protect both the health of the dairy animals and lessen runoff from the barnyard and tracking of manure onto the hardened laneway. Further improvements to water quality in Shalney Branch might be gained by developing a grazing plan for this farm and by excluding livestock from the stream and the bordering wetlands, especially upstream of Vermont Route 14, which is located on a highly-unstable alluvial fan.

Figure 49. *Hardened laneway and water barriers installed on a small dairy farm in Albany, Vermont to reduce runoff flowing into Shalney Branch (in background).*

Direct Tributaries

Holbrook Bay Tributary

Along the Holbrook Bay tributary, which drains directly into Holbrook Bay in the southwestern corner of Lake Memphremagog, we identified and mapped a number of possible sources of water quality problems. Our water quality sampling indicated that phosphorus levels were elevated in both branches of this tributary (median total phosphorus concentration = 35.4 µg/l in the northern branch in 2010 and 48.0 µg/l in the southern branch in 2013). Although both branches drained limited areas of more developed land uses (e.g. residential areas and roads), we focused our efforts on identifying possible agricultural sources of water quality problems along this tributary. Along the northern branch, we observed that livestock were grazing in and along the stream, and there have been issues with manure storage on this same small farm. Currently, staff from the VACD are assisting the owner to field stack manure in a nearby hay field.

Along the southern branch of this tributary, our water quality sampling narrowed the source of the high phosphorus levels to a small man-made pond (Figure 50). This pond was rebuilt in 2010 and has two aerators that help to circulate water in the pond. Nevertheless, there is abundant brown algae growing in the pond (Figure 51). Although we have narrowed the source area of phosphorus to this pond, we have not been able to determine if the phosphorus was originating from the sediment in the bottom of the pond (perhaps from historical deposition of manure and other wastes from the neighboring farm) or if it continues to enter the pond from the neighboring farm or some other source. Despite scouting around the pond on at least two occasions, we have been unable to identify a pathway whereby phosphorus and sediment would be moving from the neighboring farm into the pond. Although cattle also grazed in this branch further upstream, our water quality data indicated that they were not the primary source of phosphorus in this tributary (although obviously water quality would be improved by fencing the cattle out of the stream). Manure has also been stacked further upstream along this tributary. We have discussed this situation with the owners of the pond but have not identified any obvious, inexpensive solutions for reducing the phosphorus levels in the pond. Thus, we have referred this problem to the Lakes and Ponds Program of the Vermont DEC for follow-up, and staff from the VACD plan to contact the owner of the neighboring farm to evaluate and discuss possible projects and practices that might improve water quality in this tributary.

Figure 50. *Pond and nearby barn and pastures along the southern branch of the Holbrook Bay tributary in Newport Town, Vermont. Note the aerator in the pond to the right and rear of the boulder.*

Figure 51. *Abundant brown algae grows in the pond along the southern branch of the Holbrook Bay tributary in Newport Town, Vermont. The abundant algae reflect the high nutrient levels in this pond.*

Strawberry Acres Tributary

During 2008-2010, we measured elevated phosphorus levels at two sites along the Strawberry Acres tributary, which flows directly into the southwest corner of Lake Memphremagog (median total phosphorus concentrations in 2010 = 38.5 µg/l at lower site and 32.4 µg/l at upper site). Given the relatively similar values at the two sites, we were not able to pinpoint possible phosphorus sources to a specific part of this subwatershed. Two possible sources of water quality problems were identified along this tributary: 1) a small "backyard barnyard" in the lower reaches of this watershed and 2) the barnyard and pastures of a small dairy farm in the upper reaches. For the former, staff from the VAAFM and VACD have assessed the site visually but have been unable to determine if there are any water quality issues or to contact the landowner. For the latter, the NRCS assisted the farmer in 2014 with a number of farm improvements, including a new manure pit, concrete barnyard pad, laneways, and livestock exclusion fencing (Figure 52). In 2015, we will again sample water quality at the two sites along this tributary to assess whether these projects measurably improved water quality in this tributary.

Figure 52. *New, improved barnyard (foreground) and manure lagoon (background) at a small dairy farm along the upper reaches of the Strawberry Acres tributary in Coventry, Vermont.*

Wishing Well Tributary

During 2008-2010, we measured elevated phosphorus levels at two sites along the Wishing Well tributary, which flows into the southern end of Lake Memphremagog. Although phosphorus levels were slightly higher at the downstream site (median total phosphorus concentrations in 2010 = 38.5 µg/l at the downstream site and 32.4 µg/l at the upstream site), we focused our efforts on identifying and assessing possible sources of water quality problems along the upper reaches of this subwatershed. Although there were large numbers of residences and limited amounts of commercial development in the upper watershed, most of the possible sources that we identified were agricultural in nature. In particular, large areas of the upper watershed were occupied by a small dairy farm. On this farm, possible sources of the elevated phosphorus levels included 1) the clearing of 2.2 ha (5.5 acres) of forested wetlands between 2009-2011, 2) narrow buffers around the hay fields and pastures, 3) livestock grazing in ditches that drain the pastures, and 4) runoff from the production areas. However, the owner of this farm already completed a grazing plan and installed concrete barnyard pads and clean-water diversion projects in 2012 (Figure 53). Despite these improvements, phosphorus levels remained high (median total phosphorus concentrations at the upper site = 42.9 µg/l in 2012 prior to the projects and 51.3 µg/l in 2013 after the projects were completed). A number of project partners have noted that the pastures and hay fields on this farm were intensively managed, and only narrow strips of unmanaged buffer bordered many of these fields. Thus, we encourage the owner of this farm to increase the widths and revegetate the buffers along these streams as the next step in reducing the high phosphorus levels in this tributary of Lake Memphremagog.

Figure 53. *Clean water diversion project and concrete barnyard pad installed on a small dairy farm in the upper watershed of the Wishing Well tributary in Coventry, Vermont.*

Other Phosphorus Sources and Project Opportunities

In addition to the priority subwatersheds, we subsequently identified a number of other tributaries - some sampled, some not - where there was clear evidence of water quality problems, so that we have focused additional efforts on identifying and assessing those problems and their possible sources.

Alder Brook

Although not one of the priority subwatersheds (median total phosphorus concentration = 24.5 µg/l in 2013), we identified a possible water quality problem along Alder Brook, which is a tributary of the Barton River in Irasburg. In the upper reaches of this subwatershed, there is a large concrete-lined silage storage pad that is part of the production area of a large farm operation (LFO). Leachate from this storage pad is supposed to flow into a drain and be piped to a settling pond across the road. Unfortunately, the drain is often plugged by debris, so that the leachate from the storage pad overflows into a roadside ditch that drains into the upper reaches of Alder Brook (Figure 54). Staff from the VAAFM has discussed this ongoing problem with owner, but the drain continues to be managed improperly.

Figure 54. *When debris plugs the drain, leachate from this silage storage pad flows into a roadside ditch and then into Alder Brook, a tributary of the Barton River. Note the soil erosion indicating the large quantities of water that flow into the roadside ditch and then Alder Brook.*

Airport Tributary

Subsequent to identifying the priority subwatersheds, we began sampling the Airport Tributary, a small tributary of the Black River. Water samples collected from this tributary exhibited moderately elevated phosphorus levels (median total phosphorus concentration = 39.8 µg/l in 2014). This tributary drains two significant areas. First, the northern branches of this tributary drain much of the Newport State Airport. Although there are large areas of hardened surfaces at the airport (e.g. runways, taxiways, etc.), the entire airport is surrounded by fields of grass and hay, so that runoff from these surfaces is unlikely to reach the tributary, unless there are unidentified-as-of-yet pathways. Second, much of the area drained by the southern branches of this tributary were converted from forested wetlands to large fields of corn and hay in 2011 (Figure 55). Two possible sources of phosphorus in these fields included: 1) soil erosion and nutrient runoff, especially since the ditches and streams draining these fields have only narrow or non-existent buffers, and 2) phosphorus release from the deforested wetland soils. In 2015, we may add 1-2 water quality sample sites upstream and downstream of these fields to better pinpoint and assess the source(s) of the high phosphorus levels in this tributary.

Figure 55. *Large corn and hay fields that were planted on recently-cleared forested wetlands along Coventry Station Road in Coventry, Vermont.*

St. Onge Tributary

In 2014, we also identified another tributary of the Black River in which runoff and/or leachate from an agricultural production area appears to be causing water quality problems. In this small tributary, staff from the Vermont DEC observed mats of "sewage fungus" covering the entire streambed (Figure 56). "Sewage fungus" is a filamentous bacterium of the species, *Sphaerotilus natans*, which is closely associated with polluted water. Water samples collected on 12 November 2014 from the small stream draining the barnyard measured very high in both total phosphorus (3,820 µg/l) and total nitrogen (27 mg/l). Staff from both the Vermont DEC and VAAFM have visited this site and identified serious issues a farm operation located further upstream. First, leachate from a silage storage area was draining into the stream. To correct this problem, the owner has installed a temporary barrier around the silage pad and is reportedly working on a permanent solution to this problem. Second, VAAFM staff indicated that the manure pit may be leaking and that an overflow pipe on the manure pit was supposed to have been removed but was plugged with clay instead. Staff from the VAAFM will conduct additional inspection(s) in the spring of 2015, when the lack of vegetation will allow better assessment of these facilities. In addition, we will sample water quality in this stream in 2015 to further assess the situation.

Figure 56. *"Sewage fungus" covers the bed of this small stream flowing from a barnyard and associated production facilities along Coventry Station Road in Coventry, Vermont (photo courtesy of Ben Copans).*

Walker Pond

In the headwaters of Stony Brook, we identified serious water quality issues in Walker Pond. While requesting permission to access this pond, staff from Vermont DEC learned that a fish die-off had occurred in this pond previously, and so they sampled water quality in the pond and a small tributary in the spring of 2014. Both of these samples exhibited very high total phosphorus concentrations (pond = 93 µg/l and tributary = 127 µg/l). Reviews of aerial photographs and field surveys identified two possible sources of the high phosphorus levels in this pond. First and foremost, a barn and associated facilities are located upslope of the tributary to the east of Walker Pond and along Lane Road in Coventry. Although we only viewed this farm from the road, it was clear that runoff from the barn and barnyard flowed down a laneway towards this tributary (Figure 57). In addition, runoff from other parts of this production area may also drain towards this tributary. Staff from the VACD plan to contact the farmer that uses this facility to further evaluate possible phosphorus sources and potential projects and practices to improve these facilities. Second, several lawns that slope steeply down towards Walker Pond have been cleared to the north and west. Soil erosion and runoff of fertilizers and pesticides, if applied to these lawns, may also flow downhill into this pond.

Figure 57. *Barns, barnyard, and laneway at a small farm that drains downhill towards a small tributary that flows into Walker Pond in Coventry, Vermont. Note the clear evidence of erosion caused by water flowing down the laneway.*

Lawson Lower Barn

While sampling water quality during the two rain events, we observed significant quantities of extremely dark liquid flowing in a small tributary that drained a barn and barnyard and flowed downhill directly into the Black River (Figure 58-59). The water samples collected from this stream during these two rain events contained extremely high nutrient concentrations: total phosphorus = 49,300 and 22,400 µg/l and total nitrogen = 360 and 75.8 mg/l on 28 July and 23 October 2014, respectively. Subsequent inspections by staff from the VAAFM and Vermont DEC indicated that there were serious problems with the management of these production areas, and efforts are continuing to correct these significant pollution problems as soon as possible.

Figure 58. *Very dark liquid flowing from a barn and barnyard through a roadside ditch into a tributary that flows directly into the Black River in Irasburg, Vermont.*

Figure 59. *Phosphorus sample bottle showing the extremely dark liquid that was flowing from a barn and barnyard through a roadside ditch into a tributary that flows directly into the Black River in Irasburg, Vermont (photo courtesy of Ben Copans).*

Glen Road

Along the eastern shore of South Bay, we observed significant erosion of sediment from a steeply-sloping hay field that was stumped, graded, and planted in the fall of 2014 along Glen Road in Coventry (Figure 60). Responding to concerns expressed by staff from the VAAFM and VACD, the owner installed three sections of silt barrier along approximately 120 m (394 ft) of the 267-m (877-ft) lower edge of the new field. Unfortunately, the barriers were insufficient to stop the erosion of this hillside and the deposition of the eroded sediment in the roadside ditch and the wetlands located on the other side of Glen Road (Figure 61). During the rain event on 23 October 2014, we sampled the water flowing into the ditch along Glen Road and measured very high nutrient and sediment levels (total phosphorus concentration = 984 µg/l, total nitrogen concentration = 4.56 mg/l, and turbidity = 4,550 NTU). However, the water flowing out of a drain pipe that was buried beneath this field but emptied into the same roadside ditch exhibited much lower nutrient and sediment levels (total phosphorus concentration = 64.5 µg/l, total nitrogen concentration = 0.77 mg/l, and turbidity = 49.5 NTU). Since the landowner intends to stump, grade, and plant the remainder of this former woodlot, staff from the VACD are working with him to develop and obtain funding for a project to install additional, staggered silt barriers and to plant cover crops to reduce erosion in these fields.

Figure 60. *Rill erosion on steeply-sloped and newly-cleared hay field on a hillside along Glen Road in Coventry, Vermont.*

Figure 61. *Sediment deposited in the wetlands downslope of Glen Road in Coventry, Vermont. Much or all of this sediment eroded from the newly-cleared fields located on the uphill side of Glen Road.*

Recommendations

Monitoring and Assessment

Future monitoring and assessment efforts should continue to focus on pinpointing and assessing nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog, refining the identification of priority subwatersheds in which to identify and develop phosphorus-reduction projects, and evaluating the success of previously-implemented phosphorus-reduction projects and practices. More specifically, we recommend sampling water quality along the following tributaries in 2015 for the following reasons:

<u>Hamel Marsh Tributary</u> - Our sampling in 2014 allowed us to further pinpoint and assess the source(s) of the high nutrient and sediment levels along the two uppermost branches of this tributary of the Barton River. Additional sampling is needed to further pinpoint and assess the possible source(s) of nutrients and sediments along these two branches of this tributary. In particular, we recommend adding a second site further upstream along the Middle Hamel tributary, where it flows under Cooks Road.

Junkyard Tributary - Our sampling in 2014 allowed us to further pinpoint and assess the source(s) of the high nutrient and sediment levels to the two upstream branches of this tributary of the Barton River. Additional sampling is needed to further pinpoint and assess the possible source(s) of nutrients and sediment in this tributary and to evaluate the success of any improvements in field practices and/or manure and leachate collection systems on the medium farm operation at the headwaters of this tributary.

St. Onge Tributary - As noted earlier, we observed that this stream was filled with "sewage fungus" and exhibited very high nutrient levels. Thus, we recommend thoroughly sampling water quality this stream in 2015 to better characterize the water quality problems and to provide baseline data against which to evaluate the success of any projects undertaken to improve water quality in this stream.

Airport Tributary - In order to better understand the elevated nutrient and sediment levels in this tributary of the Black River, we recommend adding two additional sites along the southern branch of this tributary, one upstream of and one downstream of the large corn and hay fields along Coventry Station Road. These two sites would allow us to determine if the corn and hay fields that were established on these recently-cleared forested wetlands are exporting significant amounts of nutrients and sediment.

Brighton Brook - Our prior sampling indicated that nutrient and sediment levels were extremely high in this tributary of the Black River during 2010-2014. Furthermore, the sampling in 2014 allowed us to confirm that one of the major sources of these high phosphorus, nitrogen, and turbidity levels was leachate flowing from a mortality compost pile at a large farm operation (LFO). Future sampling at one or more sites along this tributary will allow us to assess whether this problem is ongoing and whether any corrective actions have been successful in improving water quality in this tributary.

Crystal Brook - Although our sampling in 2014 confirmed that water quality conditions remained generally improved in Crystal Brook since the manure lagoon there was replaced in 2007, biological monitoring and water samples collected during a heavy rain event indicated that there may be ongoing problems in the watershed of this tributary. Additional sampling would allow us to further evaluate the current state of water quality conditions in this tributary and to evaluate the success of agricultural improvements agreed to as part of the settlement of an enforcement action addressing water quality issues on a medium farm operation (MFO) along this tributary.

Strawberry Acres - Our sampling in 2008-2010 measured elevated phosphorus levels at two sites along the Strawberry Acres tributary, which flows directly into Lake Memphremagog. With the completion of numerous farm improvements in the upper watershed of this tributary, we recommend resampling the two sites on the tributary to evaluate the success of these improvements in improving water quality in this tributary and to evaluate the need for additional improvements elsewhere along this tributary.

Tributary of Stearns Brook - Our sampling in 2014 indicated that nutrient and sediment levels were extremely high in the tributary of Stearns Brook, especially in the main stem and small tributaries draining a large farm operation (LFO). Future sampling along this tributary will allow us to further assess and pinpoint the source(s) of these water quality problems and to provide baseline data against which to evaluate the success of any projects undertaken to improve water quality in this stream.

On the other hand, we no longer recommend sampling water quality along two other tributaries at this time. First, nutrient and sediment levels were well below levels of concern in the River of Life tributary in 2014, so that additional sampling is not warranted at this time. Second, although somewhat elevated, phosphorus and nitrogen levels at the two sites along the Sunset Acres North tributary were fairly similar among the two sites and did not indicate ongoing problems from the manure stacks that leached into this stream last winter. However, we will continue to work with the farmer to identify a better location in which to stack manure in these fields.

Project Identification and Development

In 2015, we will continue to use the water quality data and other analyses to identify and prioritize phosphorus-reduction projects and practices in the priority subwatersheds and elsewhere in the Vermont portion of the Lake Memphremagog Basin. As part of these efforts, we will continue to update and revise the GIS shapefiles showing possible sources of water quality problems and potential phosphorus-reduction projects and practices in both the current 28 priority subwatersheds and in additional high-priority subwatersheds. In particular, we recommend mapping land uses and land cover types and possible phosphorus sources in the subwatersheds drained by Walker Pond; the Airport, St. Onge, and Lawson Lower Barn tributaries; and the tributary of Stearns Brook. With these and the earlier data, we then recommend conducting further field assessments to evaluate possible phosphorus sources and to identify and develop potential phosphorus-reduction projects and practices along these tributaries. This focus will be particularly important for these newly-identified priorities as well as for those subwatersheds in the Johns River watershed and those tributaries that flow directly into the eastern side of Lake Memphremagog, as the latter two have not been field-assessed to date.

In the next stage of this project, we also recommend incorporating three additional sources of information to help further identify and prioritize possible phosphorus-reduction projects and practices in the priority subwatersheds:

1) First, we recommend adding spatially-explicit information on the locations of steep, erodible soils as identified by the NRCS.

2) Second, we recommend adding the Class 3 and 4 Road Erosion Risk layer developed for the Vermont DEC, so that we can identify areas where runoff from roads, especially gravel roads, may be an important source of phosphorus and sediment.

3) Third, we recommend integrating the wetlands selection and prioritization models that were developed previously (Gerhardt 2012b, 2014) with the project identification and prioritization efforts, so that both of these tools for identifying potential protection and restoration projects and practices can be "housed" in a single database.

Finally, we will continue to work with the project partners to pinpoint and assess water quality problems and to develop and implement projects or practices to correct water quality problems in the Lake Memphremagog Basin.

Education and Outreach

As an integral part of this project, we continued our efforts to educate local communities and stakeholders about water quality issues and efforts to protect and improve water quality in the Lake Memphremagog Basin. First, several individuals from the local community volunteered to collect and process water samples, and their efforts and their interactions with the salaried employees, paid consultants, and other volunteers working on this project furthered the education and outreach objectives of this project. Second, the results of this and prior studies were presented to both the Steering and Technical Committees of the Quebec/Vermont Steering Committee on Lake Memphremagog, which coordinates efforts to protect and improve water quality in the Lake Memphremagog Basin. Third, we also presented the results of this study to the Memphremagog Agricultural Work Group, a partnership of the Vermont DEC, VAAFM, VACD, Orleans County NRCD, and NRCS that shares information about and coordinates efforts to develop and implement agricultural projects and practices that protect and improve water quality. Fourth, we presented the results of this and earlier studies to the leadership team of the Vermont DEC, including the Commissioner, Deputy Commissioner, Director of Compliance & Enforcement, and Director and Assistant Director of the Watershed Management Division. Finally, we continued to develop collaborative relationships with other agencies and organizations working to protect and improve water quality in the Lake Memphremagog Basin, including the Quebec MDDELCC; Municipalités régionales de comté de Memphrémagog; Memphrémagog Conservation Inc. (MCI); and the cities of Newport, Sherbrooke, and Magog.

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Appendix A. Descriptions of the 21 sites (plus four Vermont DEC sites) sampled along the Vermont tributaries of Lake Memphremagog during April-October 2014 (locations are mapped in Figure 4).

Black River (7 sites):

Site Name	Site Description
Airport Tributary	Unnamed tributary along High Acres Road (also sampled in 2013)
River of Life	Unnamed tributary downstream of access road to River of Life summer camp in Irasburg
Brighton Brook	Brighton Brook downstream of Gage Road in Irasburg (also sampled in 2010-2013)
Brighton Brook North	Unnamed tributary to Brighton Brook upstream of Vermont Route 58 in Irasburg (also sampled in 2011-2013)
Upper Brighton Brook North	Unnamed tributary to Brighton Brook downstream of Back Coventry Road in Irasburg (also sampled in 2012-2013)
Lower Nelson Farm	Unnamed tributary downstream of confluence of northeast and northwest tributaries on Nelson Farm (also sampled in 2013)
Nelson NW Pipe	Outflow from pipe on unnamed tributary proceeding northwest of the Nelson Farm barns (also sampled in 2013)

Barton River (5 sites):

Site Name	Site Description
Middle Hamel Tributary	Unnamed tributary upstream of Bruneau Road in Irasburg (also sampled in 2013)
Upper Hamel Tributary	Unnamed tributary upstream of Cooks Road in Irasburg (also sampled in 2013)
Rock Junkyard	Unnamed tributary upstream of River Road in Irasburg (also sampled in 2012-2013)
Royer Farm	Unnamed tributary along Vermont Route 58 in Irasburg
Royer Tributary	Unnamed tributary downstream of Vermont Route 58 in Irasburg

Johns River (1 site):

Site Name	Site Description
Crystal Brook	Main stem downstream of North Derby Road in Derby (also sampled in 2006 and 2008-2009)

Direct Tributaries (2 sites):

<u>Site Name</u>	<u>Site Description</u>
Sunset Acres North	North branch of unnamed tributary upstream of North Derby Road in Derby (also sampled in 2008-2009)
Upper Sunset Acres North	North branch of unnamed tributary along Darling Hill Road in Derby

Tributary of Stearns Brook (6 sites):

<u>Site Name</u>	<u>Site Description</u>
Upper Stearns Tributary	Upper site on unnamed tributary along Valley Road in Derby
Stearns Tributary Falls	Upper middle site on unnamed tributary along Valley Road in Holland
Middle Stearns Tributary	Lower middle site on unnamed tributary along Valley Road in Holland
Lower Stearns Tributary	Lower site on unnamed tributary along Twin Bridges Road in Holland
Valley Road South	Unnamed tributary downstream of Twin Bridges Road in Holland
Twin Bridges Road	Unnamed tributary downstream of Valley Road in Holland

Vermont DEC Sites (4 sites):

<u>Site Name</u>	<u>Site Description</u>
Barton River	Main stem upstream of Coventry Station Road in Coventry (also sampled in 2005-2013)
Black River	Main stem upstream of Airport Road in Coventry (also sampled in 2005-2013)
Clyde River	Main stem upstream of Gardner Park Road in Newport City (also sampled in 2005-2013)
Johns River	Main stem beside old well house along Beebe Road in Derby (also sampled in 2005-2006 and 2008-2013)

Appendix B. Water quality data collected at 22 sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Bold or italicized fonts highlight concentrations greater than Vermont water quality standards (State of Vermont 2014c) or what might be considered elevated concentrations if no water quality standards apply: total phosphorus >20 µg/l (italics) or >35 µg/l (bold), total nitrogen >1 mg/l (italics) or >2 mg/l (bold), and turbidity >5 NTU (italics) or >10 NTU (bold).

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Airport Tributary	4/21/2014	*1.14*	**57.6**	*8.58*
Airport Tributary	5/19/2014	0.45	**39.8**	2.35
Airport Tributary	6/16/2014	**2.02**	**60.9**	1.44
Airport Tributary	7/14/2014	0.42	*29.2*	1.07
Airport Tributary	7/28/2014	**6.51**	**399**	**169**
Airport Tributary	8/11/2014	0.39	*34.7*	1.14
Airport Tributary	9/8/2014	0.38	*24.1*	0.9
Airport Tributary	10/23/2014	0.73	**130**	**19.6**
Brighton Brook	4/21/2014	0.64	*34.3*	4.11
Brighton Brook	5/19/2014	0.4	*25.6*	2.77
Brighton Brook	6/16/2014	0.45	**52.4**	2.09
Brighton Brook	7/14/2014	0.52	**40.3**	3.54
Brighton Brook	7/28/2014	*1.44*	**61**	*9.25*
Brighton Brook	8/11/2014	0.47	*21.4*	2.85
Brighton Brook	9/8/2014	0.47	*26.2*	2.61
Brighton Brook	10/23/2014	0.55	*34.5*	*6.06*
Brighton Brook North	4/21/2014	0.9	**81.3**	2.81
Brighton Brook North	5/19/2014	0.42	**52.4**	2.56
Brighton Brook North	6/16/2014	0.46	**78.9**	2.14
Brighton Brook North	7/14/2014	0.59	**81.4**	4.9
Brighton Brook North	7/28/2014	**7.85**	**242**	**63.6**
Brighton Brook North	8/11/2014	0.6	*25.3*	2.92
Brighton Brook North	9/8/2014	0.55	**39.9**	2.31
Brighton Brook North	10/23/2014	*1.8*	**96.7**	4.52

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (μg/l)**	**Turbidity (NTU)**
Crystal Brook	4/21/2014	*1.34*	*24.7*	1.41
Crystal Brook	5/19/2014	*1.32*	*21.1*	0.45
Crystal Brook	6/16/2014	*1.38*	*20.8*	0.59
Crystal Brook	7/14/2014	*1.6*	*24.8*	1.42
Crystal Brook	7/28/2014	**14.2**	**2,940**	**136**
Crystal Brook	8/11/2014	*1.48*	*24.7*	0.61
Crystal Brook	9/8/2014	*1.47*	*31.2*	0.59
Crystal Brook	10/23/2014	**2.65**	**315**	**27.1**
Johns River	4/21/2014	*1.6*	*27.6*	-
Johns River	5/19/2014	*1.8*	16.9	1.28
Johns River	6/16/2014	**2.3**	16.6	0.88
Johns River	7/14/2014	**3.29**	19.7	0.94
Johns River	7/28/2014	**2.77**	**345**	**209**
Johns River	8/11/2014	**2.83**	12.6	0.76
Johns River	9/8/2014	**3.46**	15.9	0.98
Johns River	10/23/2014	**2.35**	*26.9*	*6.17*
Lower Nelson Farm	4/21/2014	**7.74**	**424**	*5.23*
Lower Nelson Farm	5/19/2014	**7.4**	**290**	3.87
Lower Nelson Farm	6/16/2014	**10.5**	**452**	**20.5**
Lower Nelson Farm	7/14/2014	**20.2**	**232**	**12.7**
Lower Nelson Farm	7/28/2014	**21.4**	**771**	**129**
Lower Nelson Farm	10/23/2014	**6.54**	**424**	**56.4**
Lower Stearns Tributary	4/21/2014	**2.85**	**61.4**	1.99
Lower Stearns Tributary	5/19/2014	**3.63**	**55**	0.65
Lower Stearns Tributary	6/16/2014	**4.68**	**44.2**	0.45
Lower Stearns Tributary	7/14/2014	**5.7**	**49.9**	1.5
Lower Stearns Tributary	7/28/2014	**5**	**183**	**67.8**
Lower Stearns Tributary	8/11/2014	**4.91**	**47.5**	1.02
Lower Stearns Tributary	9/8/2014	**4.81**	**45**	0.9
Lower Stearns Tributary	10/23/2014	**3.65**	**55.4**	*9.52*
Middle Hamel Tributary	4/21/2014	**2.97**	**62.8**	**10.1**
Middle Hamel Tributary	5/19/2014	*1.7*	**43**	3.25
Middle Hamel Tributary	6/16/2014	*1.38*	**46.8**	2.06
Middle Hamel Tributary	7/14/2014	*1.05*	**35.8**	1.18
Middle Hamel Tributary	7/28/2014	**7.62**	**1,540**	**46.7**
Middle Hamel Tributary	8/11/2014	0.9	*30.9*	0.67
Middle Hamel Tributary	9/8/2014	0.89	*27*	0.65
Middle Hamel Tributary	10/23/2014	*1.63*	**187**	**44.8**

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Middle Stearns Tributary	4/21/2014	**2.73**	**86.1**	2.58
Middle Stearns Tributary	5/19/2014	**3.81**	**78.3**	1.46
Middle Stearns Tributary	6/16/2014	**4.97**	**38.7**	0.66
Middle Stearns Tributary	7/14/2014	**5.97**	*23.9*	1.23
Middle Stearns Tributary	7/28/2014	**13.7**	**3,240**	**676**
Middle Stearns Tributary	8/11/2014	**5.07**	*27.8*	0.66
Middle Stearns Tributary	9/8/2014	**5.43**	*26*	0.53
Middle Stearns Tributary	10/23/2014	**16**	**3,450**	**2,740**
Nelson NW Pipe	4/21/2014	**19.3**	**682**	**20.6**
Nelson NW Pipe	5/19/2014	**17.5**	**96.2**	*6.58*
Nelson NW Pipe	6/16/2014	**22.5**	**68.1**	2.3
Nelson NW Pipe	7/14/2014	**26.4**	**37**	1.5
Nelson NW Pipe	7/28/2014	**29.2**	**90.1**	**12.1**
Nelson NW Pipe	8/11/2014	**28.9**	*26.5*	2.32
Nelson NW Pipe	9/8/2014	**28**	*34.9*	3.11
Nelson NW Pipe	10/23/2014	**13.4**	**113**	*5.87*
River of Life	4/21/2014	0.61	*26.3*	2.82
River of Life	5/19/2014	0.51	16.5	0.35
River of Life	6/16/2014	0.64	*23.1*	0.7
River of Life	7/14/2014	0.65	*20.5*	1.61
River of Life	7/28/2014	0.7	**77.9**	**18.7**
River of Life	8/11/2014	0.54	14.5	1.24
River of Life	9/8/2014	0.57	15.4	0.94
River of Life	10/23/2014	0.49	18.5	3.07
Rock Junkyard	4/21/2014	*1.21*	**55.8**	4.08
Rock Junkyard	5/19/2014	0.54	18.5	1.06
Rock Junkyard	6/16/2014	0.57	*34.5*	1.37
Rock Junkyard	7/14/2014	0.59	22.4	0.98
Rock Junkyard	7/28/2014	0.6	**40.1**	*6.19*
Rock Junkyard	8/11/2014	0.42	19.1	1.62
Rock Junkyard	9/8/2014	0.54	*27*	2.26
Rock Junkyard	10/23/2014	*1.18*	**81.6**	*8.1*

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Royer Farm	4/21/2014	0.72	**40.7**	*8.14*
Royer Farm	5/19/2014	0.66	**35**	3.14
Royer Farm	6/16/2014	0.66	**49.3**	0.96
Royer Farm	7/14/2014	0.86	**52.7**	1.94
Royer Farm	7/28/2014	*1.21*	**296**	**121**
Royer Farm	8/11/2014	0.7	**49.7**	2.36
Royer Farm	9/8/2014	0.65	**38.9**	0.45
Royer Farm	10/23/2014	**49.8**	**9,150**	**1,740**
Royer Tributary	4/21/2014	**5.57**	**342**	**16.3**
Royer Tributary	5/19/2014	*1.26*	*31.2*	0.89
Royer Tributary	6/16/2014	*1.42*	*31.8*	1.25
Royer Tributary	7/14/2014	*1.66*	*29.7*	0.45
Royer Tributary	7/28/2014	**2.71**	**575**	**155**
Royer Tributary	8/11/2014	*1.51*	*27.6*	0.32
Royer Tributary	9/8/2014	*1.44*	*27.5*	0.24
Royer Tributary	10/23/2014	0.96	**103**	**11.2**
Stearns Tributary Falls	4/21/2014	**2.55**	*20.8*	2.9
Stearns Tributary Falls	5/19/2014	**3.52**	8.22	0.62
Stearns Tributary Falls	6/16/2014	**4.5**	*25.4*	2.39
Stearns Tributary Falls	7/14/2014	**4.77**	14.5	1.47
Stearns Tributary Falls	7/28/2014	**4.18**	**182**	**55.8**
Stearns Tributary Falls	8/11/2014	**3.91**	11	0.37
Stearns Tributary Falls	9/8/2014	**4.54**	14.8	1.39
Stearns Tributary Falls	10/23/2014	**4.06**	10.5	1.6
Sunset Acres North	4/21/2014	0.82	**70.6**	**16.7**
Sunset Acres North	5/19/2014	0.31	17.5	1.75
Sunset Acres North	6/16/2014	0.36	*26.9*	1.01
Sunset Acres North	7/14/2014	0.43	*22.4*	1.46
Sunset Acres North	7/28/2014	*1.08*	**191**	**79.3**
Sunset Acres North	8/11/2014	0.43	*29.8*	3.23
Sunset Acres North	9/8/2014	0.39	*22*	1.56
Sunset Acres North	10/23/2014	0.53	**61.2**	**17.2**

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Twin Bridges Road	4/21/2014	**5.09**	**42.4**	*6.29*
Twin Bridges Road	5/19/2014	**4.84**	17	1.76
Twin Bridges Road	6/16/2014	**6.81**	*28.8*	0.8
Twin Bridges Road	7/14/2014	**8.63**	19.3	0.38
Twin Bridges Road	7/28/2014	**38**	**6,400**	**8,390**
Twin Bridges Road	8/11/2014	**6.08**	13	0.42
Twin Bridges Road	9/8/2014	0.63	14.2	0.33
Twin Bridges Road	10/23/2014	**35.5**	**8,480**	**5,070**
Upper Brighton Brook North	4/21/2014	**5.69**	**655**	*5.88*
Upper Brighton Brook North	5/19/2014	*1.26*	**557**	3.54
Upper Brighton Brook North	6/16/2014	*1.3*	**580**	3.36
Upper Brighton Brook North	7/14/2014	*1.84*	**2,080**	**15.4**
Upper Brighton Brook North	7/28/2014	**3.45**	**1,070**	**307**
Upper Brighton Brook North	10/23/2014	**7.12**	**476**	*6.22*
Upper Hamel Tributary	4/21/2014	**7.02**	**148**	**12.6**
Upper Hamel Tributary	5/19/2014	**4.92**	**118**	1.41
Upper Hamel Tributary	6/16/2014	**6.25**	**202**	0.67
Upper Hamel Tributary	7/14/2014	**5.2**	**106**	1.61
Upper Hamel Tributary	7/28/2014	**8.17**	**1310**	**41.3**
Upper Hamel Tributary	8/11/2014	**2.77**	**102**	0.91
Upper Hamel Tributary	9/8/2014	*1.07*	**101**	1.98
Upper Hamel Tributary	10/23/2014	**3.85**	**228**	**26.4**
Upper Stearns Tributary	4/21/2014	**2.25**	13.8	1.48
Upper Stearns Tributary	5/19/2014	**2.79**	9.41	0.75
Upper Stearns Tributary	6/16/2014	**3.4**	10.6	0.69
Upper Stearns Tributary	7/14/2014	**3.63**	11.5	1.38
Upper Stearns Tributary	7/28/2014	**3.41**	**144**	**44.8**
Upper Stearns Tributary	8/11/2014	**3.23**	9.17	0.44
Upper Stearns Tributary	9/8/2014	**3.7**	11.4	0.37
Upper Stearns Tributary	10/23/2014	**3.41**	14.6	*5.11*
Upper Sunset Acres North	4/21/2014	**3.19**	**44.1**	1.68
Upper Sunset Acres North	5/19/2014	*1.47*	*31.8*	*5.58*
Upper Sunset Acres North	6/16/2014	*1.83*	*25.3*	3.6
Upper Sunset Acres North	7/14/2014	*1.9*	*31.5*	*5.13*
Upper Sunset Acres North	7/28/2014	**5.34**	**476**	**20.5**
Upper Sunset Acres North	8/11/2014	*1.12*	18.8	1.86
Upper Sunset Acres North	9/8/2014	**2.12**	18.2	0.55
Upper Sunset Acres North	10/23/2014	*1.97*	**128**	*8.22*

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Valley Road South	4/21/2014	*1.2*	**104**	2.55
Valley Road South	5/19/2014	*1.09*	**49.6**	2.86
Valley Road South	6/16/2014	*1.8*	**123**	*9.44*
Valley Road South	7/14/2014	**3.23**	**360**	*5.49*
Valley Road South	7/28/2014	**2.23**	**194**	**13.1**
Valley Road South	8/11/2014	*1.18*	**53.2**	2.23
Valley Road South	9/8/2014	*1.08*	**56.2**	1.98
Valley Road South	10/23/2014	*1.34*	**104**	*7.39*
Glen Road Ditch	10/23/2014	**4.56**	**984**	**4,550**
Glen Road Pipe	10/23/2014	0.77	**64.5**	**49.5**
Lawson Lower Barn	7/28/2014	**360**	**49,300**	**2,310**
Lawson Lower Barn	10/23/2014	**75.8**	**22,400**	-
Lawson Lower Stream	10/23/2014	**37.1**	**10,800**	-
Nelson Road North	7/28/2014	**217**	**13,000**	**256**
Nelson Road South	7/28/2014	**9.07**	**2,430**	**551**
Upper Barnyard Culvert	7/28/2014	**5.93**	**2,380**	**963**
Upper Barnyard Culvert	10/23/2014	**24.9**	**17,300**	**9,090**
Lower Barnyard Culvert	7/28/2014	**13.9**	**4,960**	**67.8**
Lower Barnyard Culvert	10/23/2014	**18**	**3,610**	**705**
Stearns Road Ditch	7/28/2014	*1.23*	**472**	**369**

Appendix C. Quality assurance data, including field blanks and field duplicates, collected at 22 sample sites along the Vermont tributaries of Lake Memphremagog during April-October 2014. Bold values indicate field blanks that exceeded detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.2 NTU for turbidity) or field duplicates that differed by >30% for total phosphorus, >20% for total nitrogen, and >15% for turbidity.

Field Blanks:

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Brighton Brook North	4/21/2014	< 0.1	< 5	< 0.2
Lower Stearns Tributary	4/21/2014	< 0.1	**7.56**	< 0.2
Upper Sunset Acres North	4/21/2014	< 0.1	**6.82**	< 0.2
Brighton Brook	5/19/2014	< 0.1	< 5	< 0.2
Middle Stearns Tributary	5/19/2014	< 0.1	< 5	**0.39**
Sunset Acres North	5/19/2014	< 0.1	< 5	< 0.2
Airport Tributary	6/16/2014	< 0.1	**5.04**	< 0.2
Middle Hamel Tributary	6/16/2014	< 0.1	**5.47**	< 0.2
Valley Road South	6/16/2014	< 0.1	**6.52**	< 0.2
Lower Nelson Farm	7/14/2014	< 0.1	< 5	< 0.2
Royer Farm	7/14/2014	< 0.1	< 5	< 0.2
Upper Stearns Tributary	7/14/2014	< 0.1	< 5	< 0.2
River of Life	7/28/2014	< 0.1	< 5	< 0.2
Stearns Tributary Falls	7/28/2014	< 0.1	< 5	< 0.2
Upper Hamel Tributary	7/28/2014	< 0.1	< 5	**0.24**
Crystal Brook	8/11/2014	< 0.1	**5.78**	< 0.2
Royer Tributary	8/11/2014	< 0.1	< 5	< 0.2
Brighton Brook North	9/8/2014	< 0.1	< 5	< 0.2
Sunset Acres North	9/8/2014	< 0.1	< 5	< 0.2
Glen Road	10/23/2014	< 0.1	< 5	**0.62**
Rock Junkyard	10/23/2014	< 0.1	< 5	-
Upper Brighton Brook North	10/23/2014	< 0.1	< 5	< 0.2
Upper Sunset Acres North	10/23/2014	< 0.1	< 5	< 0.2

Field Duplicates:

Total Nitrogen

Site	Date	1st Total Nitrogen (mg/l)	2nd Total Nitrogen (mg/l)	Relative % Difference
Brighton Brook North	4/21/2014	0.9	0.9	0
Lower Stearns Tributary	4/21/2014	2.85	2.97	4
Upper Sunset Acres North	4/21/2014	3.19	3.23	1
Brighton Brook	5/19/2014	0.4	0.42	5
Middle Stearns Tributary	5/19/2014	3.81	3.8	0
Sunset Acres North	5/19/2014	0.31	0.29	7
Airport Tributary	6/16/2014	2.02	1.98	2
Middle Hamel Tributary	6/16/2014	1.38	1.37	1
Valley Road South	6/16/2014	1.8	1.95	8
Lower Nelson Farm	7/14/2014	20.2	20.2	0
Royer Farm	7/14/2014	0.86	0.9	5
Upper Stearns Tributary	7/14/2014	3.63	3.67	1
River of Life	7/28/2014	0.7	0.66	6
Stearns Tributary Falls	7/28/2014	4.18	4.13	1
Upper Hamel Tributary	7/28/2014	8.17	8.12	1
Crystal Brook	8/11/2014	1.48	1.45	2
Nelson NW Pipe	8/11/2014	28.9	29.1	1
Royer Tributary	8/11/2014	1.51	1.51	0
Brighton Brook North	9/8/2014	0.55	0.56	2
Lower Stearns Tributary	9/8/2014	4.81	4.73	2
Sunset Acres North	9/8/2014	0.39	0.4	3
Rock Junkyard	10/23/2014	1.18	1.14	3
Upper Brighton Brook North	10/23/2014	7.12	7.3	2
Upper Sunset Acres North	10/23/2014	1.97	1.99	1

Total Phosphorus

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Brighton Brook North	4/21/2014	81.3	81.9	1
Lower Stearns Tributary	4/21/2014	61.4	65.7	7
Upper Sunset Acres North	4/21/2014	44.1	46.3	5
Brighton Brook	5/19/2014	25.6	26.7	4
Middle Stearns Tributary	5/19/2014	78.3	75.9	3
Sunset Acres North	5/19/2014	17.5	16.8	4
Airport Tributary	6/16/2014	60.9	59	3
Middle Hamel Tributary	6/16/2014	46.8	50.5	8
Valley Road South	6/16/2014	123	132	7
Lower Nelson Farm	7/14/2014	232	268	14
Royer Farm	7/14/2014	52.7	55.4	5
Upper Stearns Tributary	7/14/2014	11.5	11.2	3
River of Life	7/28/2014	77.9	79.5	2
Stearns Tributary Falls	7/28/2014	182	180	1
Upper Hamel Tributary	7/28/2014	1310	1320	1
Crystal Brook	8/11/2014	24.7	27.3	10
Nelson NW Pipe	8/11/2014	26.5	25.6	3
Royer Tributary	8/11/2014	27.6	34	21
Brighton Brook North	9/8/2014	39.9	44.8	12
Lower Stearns Tributary	9/8/2014	45	45.2	0
Sunset Acres North	9/8/2014	22	21.9	0
Rock Junkyard	10/23/2014	81.6	81.1	1
Upper Brighton Brook North	10/23/2014	476	476	0
Upper Sunset Acres North	10/23/2014	128	140	9

Turbidity

Site	Date	1st Turbidity (NTU)	2nd Turbidity (NTU)	Relative % Difference
Brighton Brook North	4/21/2014	2.81	2.78	1
Lower Stearns Tributary	4/21/2014	1.99	1.96	2
Upper Sunset Acres North	4/21/2014	1.68	1.64	2
Brighton Brook	**5/19/2014**	**2.77**	**2.31**	**18**
Middle Stearns Tributary	5/19/2014	1.46	1.51	3
Sunset Acres North	5/19/2014	1.75	1.82	4
Airport Tributary	6/16/2014	1.44	1.48	3
Middle Hamel Tributary	6/16/2014	2.06	2.09	1
Valley Road South	6/16/2014	9.44	9.68	3
Lower Nelson Farm	7/14/2014	12.7	14.7	15
Royer Farm	7/14/2014	1.94	1.94	0
Upper Stearns Tributary	**7/14/2014**	**1.38**	**1.1**	**23**
River of Life	7/28/2014	18.7	18.2	3
Stearns Tributary Falls	7/28/2014	55.8	52.9	5
Upper Hamel Tributary	7/28/2014	41.3	45.2	9
Crystal Brook	8/11/2014	0.61	0.64	5
Nelson NW Pipe	8/11/2014	2.32	2.48	7
Royer Tributary	8/11/2014	0.32	0.35	9
Brighton Brook North	**9/8/2014**	**2.31**	**2.71**	**16**
Lower Stearns Tributary	9/8/2014	0.9	0.96	6
Sunset Acres North	9/8/2014	1.56	1.64	5
Upper Brighton Brook North	10/23/2014	6.22	6.55	5

Appendix D. Glossary [based largely on Picotte and Boudette (2005) and Dyer and Gerhardt (2007)].

Algae – Aquatic organisms that generally are capable of photosynthesis but lack the structural complexity of plants. Algae range from single-celled to multicellular organisms and can grow on the substrate or suspended in the water column (the latter are also known as phytoplankton).

Algal bloom – A population explosion of algae usually in response to high nutrient levels (particularly phosphorus and nitrogen), warm water temperatures, and long periods of sunlight. When these algae die, their decomposition can deplete oxygen to levels that are too low to support most aquatic life.

Basin – A geographic area bounded peripherally by a divide and draining into a particular water body. The relative size of a basin and the human alterations to that basin greatly affect water quality in the water body into which it drains.

Concentration – The quantity of a dissolved substance per unit of volume.

Detection limit – The lowest value of a physical or chemical parameter that can be measured reliably and reported as a value greater than zero by a given method or piece of equipment.

Erosion – The loosening and transport of soil and other particles. Erosion is a natural process but can be accelerated by human activities, such as forest clearance and stream channel alteration.

Eutrophication – The natural aging process of a water body whereby nutrients and sediments increase in the lake over time, increase its productivity and eventually turn it into a wetland. Human activities often accelerate this process.

Flow – The volume of water moving past a given location per unit of time (usually measured as cubic meters or feet per second).

Groundwater – Water that lies beneath the earth's surface in porous layers of clay, sand, gravel, and bedrock.

Limiting nutrient – A nutrient that is scarce relative to demand and that limits plant and animal growth in an ecosystem.

Load – The total amount of a physical or chemical substance, such as sediment or a nutrient, being transported in the water column per unit of time.

Median – A number describing the central tendency of a group of numbers and defined as the value in an ordered set of numbers below and above which there are equal numbers of values.

Nonpoint source pollution – Pollution that originates from many, diffuse sources spread across the landscape (e.g. in surface runoff from lawns or agricultural fields).

Nutrient – A chemical required for growth, development, or maintenance of a plant or animal. Nutrients are essential for sustaining life, but too much of any one nutrient can upset the balance of an ecosystem.

Photosynthesis – The biological process by which plants, algae, and some other organisms convert sunlight, carbon dioxide, and water into sugar and oxygen.

Point source pollution – Pollution that originates from a single location or source (e.g. discharge pipes from a wastewater treatment plant or industrial facility).

Quality assurance (QA) – An integrated system of measures designed to ensure that data meet predefined standards of quality with a stated level of confidence.

Quartile – The value at the boundary of the 25th, 50th, or 75th percentiles of an ordered set of numbers divided into four equal parts, each containing one quarter of the numbers.

Riparian buffer – A strip of unmanaged vegetation growing along the shoreline of a river or stream. Riparian buffers reduce erosion, filter sediments and pollutants, and provide important aquatic and riverine habitats.

Standard deviation (SD) – A statistic that measures the variability of a set of data.

Surface waters – Water bodies that lie on top of the earth's surface, including lakes, ponds, rivers, streams, and wetlands.

Tributary – A water body, such as a river or stream, that flows into another body of water.

Total Maximum Daily Load (TMDL) – The maximum amount of a pollutant that a water body can receive in order to meet water quality standards.

Watershed – See basin.

Wetland – Land on which water saturation is the dominant factor determining the nature of soil development and the types of plant and animal communities that live there.

Memphremagog Watershed Association
P. O. Box 1071
Derby, VT 05829
memphremagogwatershedassociation.com

Beck Pond LLC
394 Beck Pond Road
Newark, VT 05871
beckpond@gmail.com