Restoring Water Quality in the Lake Memphremagog Basin:
2015 Water Quality Report

Prepared for the

NorthWoods Stewardship Center and

Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

19 April 2016

Memphremagog Watershed Association

The Memphremagog Watershed Association (MWA), 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 Basin; 2) promoting efforts to preserve the environment and natural beauty of the basin; 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 basin; and 4) participating in efforts to monitor water quality in the lake and its tributaries, clean-up and re-naturalize shorelines, and protect local 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 Basin and other watersheds in Vermont; protect and restore floodplain forests and wetlands in the Lake Memphremagog Basin and along the Connecticut River; and identify and protect critical wildlife habitats across northern New England and eastern Canada.

Cover. *In 2015, the Gray Farm in Holland, Vermont undertook a large number of farmstead improvement and clean water diversion projects to improve water quality in an impaired tributary of Stearns Brook.*

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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 expended to identify, assess, and remediate nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. In 2015, we undertook a five-part project to continue these efforts by further pinpointing and assessing possible sources of water quality problems and identifying and developing projects to correct these 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 28 sites on eight dates during April-October 2015. With these data, we were able to further pinpoint and assess the sources of the high phosphorus and/or nitrogen levels measured previously in three tributaries (Airport and Hamel tributaries and the tributary of Stearns Brook). In addition, we assessed nutrient and sediment levels in two small tributaries of the Black River that had not been sampled previously (St. Onge and Sunrise Farm tributaries). Finally, we evaluated the success of water quality improvement projects and practices in several tributaries. In general, water quality conditions generally remained improved along Crystal Brook and the Strawberry Acres tributary, where phosphorus-reduction projects were implemented previously. On the other hand, water quality conditions remained poor at several sites along Brighton Brook and the Junkyard tributary.

3. 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 50 priority subwatersheds that had exhibited the highest total phosphorus concentrations along the Vermont tributaries of Lake Memphremagog during 2005-2014. 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, and residential, industrial, and urban areas lying within 25 m (82 ft) of mapped rivers and streams for further review of possible phosphorus sources. In 2015, we conducted field assessments in 18 of the 50 priority subwatersheds to ground-truth 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.

4. In the third part of this project, we continued to identify and scout potential wetland restoration opportunities in the 50 priority subwatersheds. Since many of the sites assessed previously were located in the Black River watershed, we focused our efforts in 2015 on those sites located in the priority subwatersheds located along the Barton and

Johns Rivers and the small tributaries that flow directly into Lake Memphremagog. Through these efforts, we identified six sites that may be suitable for wetland restoration projects. All six sites will need to be evaluated further to assess their suitability for wetlands restoration and to gauge landowner interest in undertaking any such projects.

5. In the fourth part of this project, we developed a spatially-explicit model to map areas of highly-erodible soils on croplands for further investigation of their potential for soil loss and phosphorus export. This model incorporated data layers mapping slopes, highly erodible land classes, and agricultural land uses. Ultimately, we identified 920 areas of cropland covering 262 hectares (635 acres) that were highly vulnerable to erosion and phosphorus loss. These 920 areas were concentrated in the downstream and upstream sections of the Black River watershed, the downstream section of the Barton River watershed, and the Johns River watershed.

6. Finally, we developed and tested a methodology for calculating the reductions in phosphorus loads that would be achieved by implementing Best Management Practices (BMP) as part of the Total Maximum Daily Load (TMDL) and Basin Plan being developed for Lake Memphremagog. To do this, we modified the BMP Scenario Tool developed for Lake Champlain to represent the land uses, projects and practices, and loading reductions that were most appropriate for the Lake Memphremagog Basin. In the two watersheds tested, we found that this tool allowed us to identify projects and practices that would potentially reduce phosphorus loads by 28-36% across a range of land uses, including farmsteads, cultivated lands, hay, pasture, dirt roads, and developed impervious surfaces.

7. In 2015, we continued to share the results of these water quality analyses with key project partners in order to identify and evaluate possible phosphorus sources, past and current efforts to develop and implement land-use and land management projects and practices, and possible approaches for engaging land owners and land managers in efforts to implement projects that most effectively protect and improve water quality. We also conducted a number of site visits to evaluate opportunities to develop and implement projects and practices to improve water quality conditions along the Vermont tributaries of Lake Memphremagog.

8. Collectively, these data and analyses greatly increased our understanding of water quality conditions and possible sources 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 to protect and improve water quality in the Vermont portion of the Lake Memphremagog Basin. In 2016, we will continue 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 inputs 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.*

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 tributaries of Lake Memphremagog in Vermont) 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 its tributaries serve important flood control and water filtration functions. In addition, the surface waters and associated habitats support a number of rare plants and animals and significant natural communities, which contribute greatly to regional biodiversity.

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 indicate that water quality is declining in Lake Memphremagog.*

Lake Memphremagog and its tributaries currently face a number of threats, including elevated sediment and nutrient levels, elevated mercury levels, excessive algal growth, eutrophication, and exotic species invasions (State of Vermont 2014b, 2014c, Quebec/Vermont Steering Committee 2008). The Southern Basin, which lies primarily in Vermont and is the shallowest segment of Lake Memphremagog, is listed by the State of Vermont as impaired and in need of a Total Maximum Daily Load (TMDL) due to elevated phosphorus levels, nutrient enrichment, and excessive algal growth (Part A, State of Vermont 2014b). Lake Salem, which is situated along the Clyde River, is already subject to an approved TMDL addressing elevated mercury levels in walleye (*Stizostedion vitrium*)(Part D, State of Vermont 2014b). 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 2014b). 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 2014b). Finally, a number of water bodies have been listed as stressed: 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 2014c).

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 to 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 tributaries of Lake Memphremagog in Vermont.

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, the Johns River exhibited 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 flows. 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) 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 several tributaries of the Barton River, which had not been sampled since 2006 (Gerhardt 2013, 2014). In 2014 and 2015, we continued our efforts to identify and assess possible nutrient and sediment sources along several tributaries of the Barton and Black Rivers as well as a small tributary of Stearns Brook, which flows into the Tomifobia River, rather than Lake Memphremagog (Gerhardt 2015).

Priority Subwatersheds

In addition to allowing us to assess 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 inputs 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 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. 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 and practices 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 exports of phosphorus. 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 inputs (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 and practices utilizes existing water quality monitoring and assessment data. In such an approach, spatial and statistical analyses use 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 concentrations and daily flows 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 and practices 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 and practices will most effectively reduce phosphorus exports from the Vermont portion of 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 moderate and at high flows. We then calculated the mean rank of each site by averaging the rankings of each site at low and moderate and at 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. In 2015, we updated and revised this model to incorporate the new sites sampled and the new data collected during 2013 and 2014. We then focused our efforts on identifying and evaluating possible sources of nutrients and sediment and developing and implementing projects and practices to reduce nutrient and sediment exports in the 50 priority subwatersheds exhibiting the highest phosphorus levels.

Study Goals

In 2015, the NorthWoods Stewardship Center, Memphremagog Watershed Association, Vermont DEC, and Beck Pond LLC again partnered to undertake a multi-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 2015, 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) two tributaries where high phosphorus levels had been measured previously but where they remained poorly understood, and 3) four tributaries where phosphorus-reduction projects and practices had been implemented previously. In addition, we sampled six sites along a tributary of Stearns Brook that is impaired and in need of a TMDL due to nutrients from agricultural runoff (Part A, State of Vermont 2014b). Second, we continued to map and evaluate possible sources of water quality problems and to identify and develop projects to reduce nutrient and sediment inputs in priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin. As part of these efforts, we developed spatially-explicit models for identifying agricultural fields that are most vulnerable to erosion and phosphorus export, for estimating the phosphorus load reductions that can be achieved through implementation of the Total Maximum Daily Load (TMDL), and for prioritizing wetland restoration opportunities that will best reduce phosphorus loading, protect and improve water quality, and improve floodplain and in-stream habitat. As in previous years, we continued to share this information with key agency and organizational partners, who were able to further evaluate the need for and implement projects and practices to reduce nutrient and sediment exports into the Lake Memphremagog Basin. Collectively, these efforts greatly increased our understanding of water quality problems and allowed us to continue developing and implementing protection and restoration projects and practices 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 (Barton, Black, and Clyde Rivers) and one medium-sized tributary that straddles the Quebec/Vermont border (Johns River). In addition, numerous small tributaries flow from the eastern and western shores directly into Lake Memphremagog.

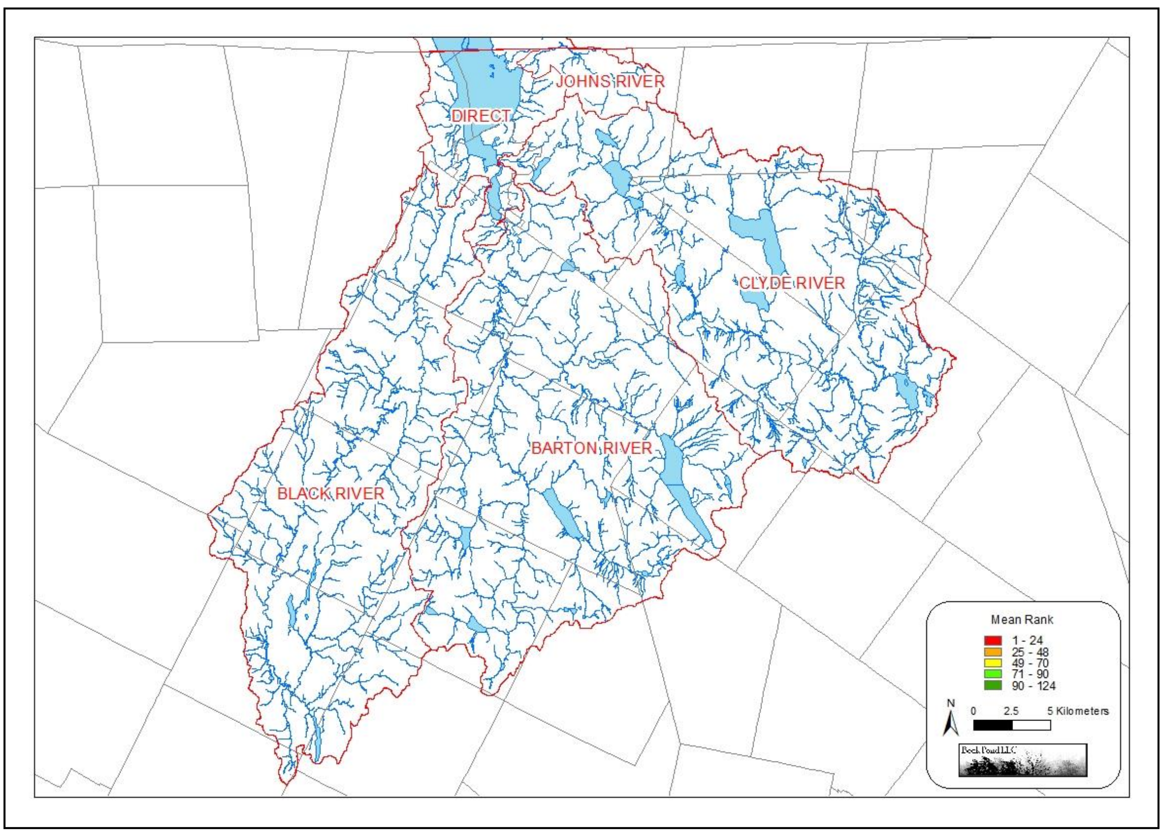

Figure 3. *The Vermont portion of the Lake Memphremagog Basin, including the watersheds of the four principal tributaries (Barton, Black, Clyde, and Johns Rivers).*

The 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 (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 2014c). Brownington Pond has been altered by invasive aquatic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2014b), 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 2014b).

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 medium-sized 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 2014b). In addition, rapidly expanding populations of several other invasive species (purple loosestrife, common reed, and Japanese knotweed) occur throughout the watershed.

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 medium-sized tributaries (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 is already part of an approved TMDL addressing elevated mercury levels in walleye (Part D, State of Vermont 2014b). Lake Derby has been altered by aquatic invasive species due to locally abundant Eurasian watermilfoil growth (Part E, State of Vermont 2014b). 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 2014c). 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 2014b). 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 2014c). 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 in need of a TMDL thanks to projects that reduced sediment and nutrient inputs 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 2014b, 2014c), although high nutrient and sediment levels have been measured in several of these tributaries (Gerhardt 2009, 2010).

Finally, we continued to assess water quality and to work with a landowner to implement phosphorus-reduction projects in a small tributary of Stearns Brook (Waterbody ID VT17-02), which is a tributary of Lac Massawippi. 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 2014b). Stearns Brook itself is also listed as stressed due to sediment eroding from streambanks, poor logging practices, and poor road maintenance (State of Vermont 2014c).

Water Quality Sampling

Methods

In 2015, we sampled and analyzed water quality at 28 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 28 sites included eight sites along tributaries of the Black River, six sites along tributaries of the Barton River, two sites along the Johns River and its tributary Crystal Brook, two sites along a small tributary that flows directly into Lake Memphremagog, and ten sites along the tributary of Stearns Brook. Sixteen of these sites were established to further pinpoint and assess the source(s) of the high phosphorus and sediment levels measured previously: one tributary of the Black River (Airport tributary), one tributary of the Barton River (Hamel tributary), and the tributary of Stearns Brook. Two new sites (Sunrise Farm and St. Onge Tributary) were established to sample small tributaries of the Black River that had not been sampled previously. Finally, ten sites were sampled to assess the success of a phosphorus-reduction projects and practices that had been or were being implemented on tributaries of the Black River (Brighton Brook), Barton River (Junkyard tributary) and Johns River (Crystal Brook) and a small tributary that flows directly into Lake Memphremagog (Strawberry Acres tributary). In addition, we sampled water quality during rain events at five other sites along small 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.

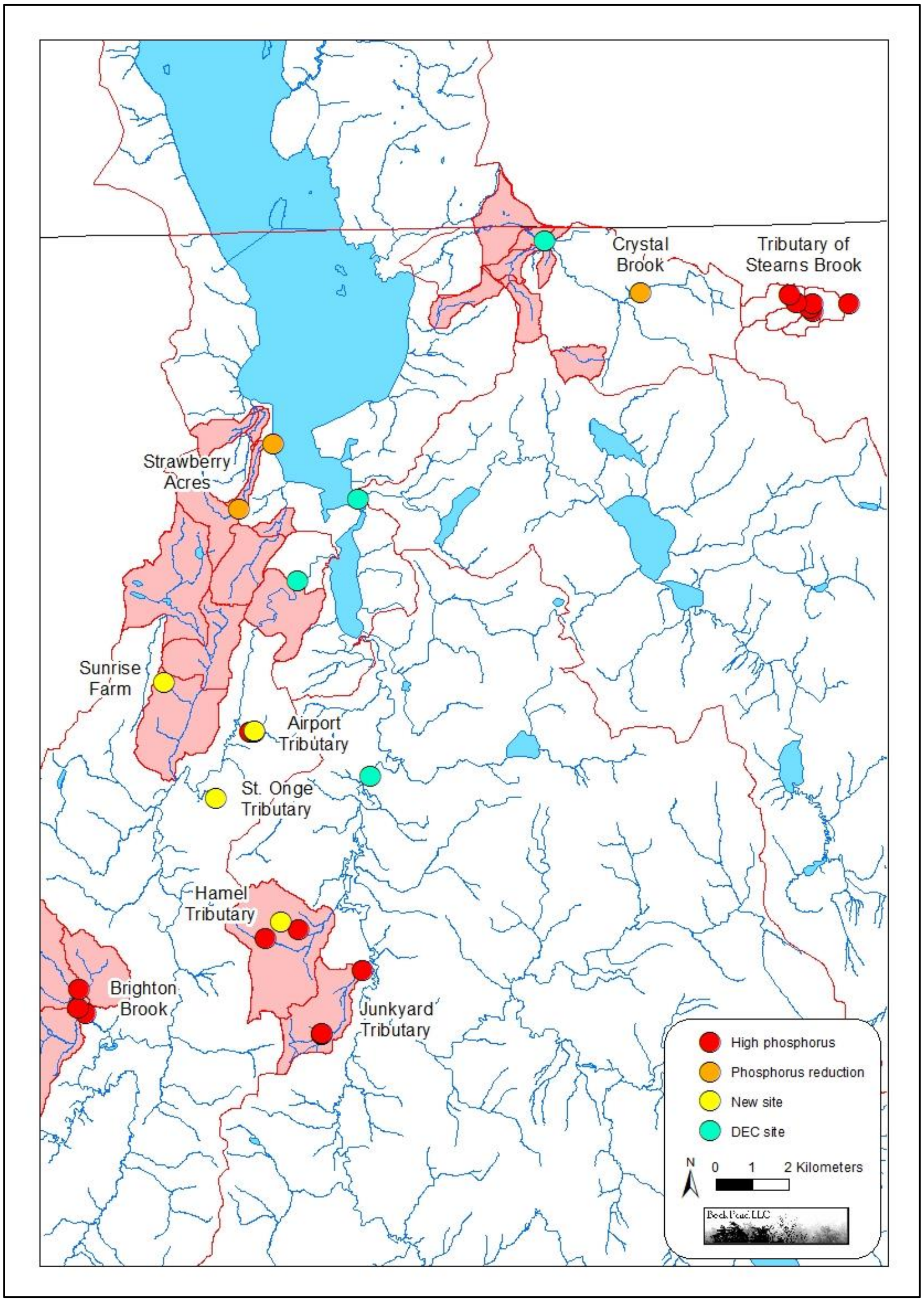

Figure 4. *Locations of the 28 sample sites (plus three Vermont DEC sites) where water quality was sampled along the Vermont tributaries of Lake Memphremagog during April-October 2015. The red shading outlines the 28 subwatersheds that exhibited the highest phosphorus levels during 2005-2012.*

To accomplish the goals of this study, we sampled water quality at these 28 sites on eight dates during 27 April-12 October 2015 (the four DEC-maintained sites were sampled separately and on a different schedule, and those data are not reported here). These sample dates included three moderately high-flow events (27 April, 9 June, and 22 June) and two moderate-flow events (21 July and 15 September). Two of the sample dates (27 April and 9 June) were ideally timed during rain events to allow us to pinpoint and assess nutrient and sediment sources, and a more limited rain event was sampled along the Johns River and the tributary of Stearns Brook on another date (21 July). The five additional sample sites were sampled during one or more of these rain events. Finally, due to low or nonexistent flows, three sites (Upper Brighton Brook North, Valley Road Ditch, and Valley Road Garage) were not sampled on one to five dates each.

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.

Prior to sampling, we prepared a Quality Assurance Project Plan (QAPP) 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 set of samples at the same time and place as the paired samples. 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.

To relate the water quality data to stream flows, we relied on a single source 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. Prior to 2015, the Vermont DEC also maintained a seasonal gage station that measured water depths on the Johns River. For the latter, daily stream flows for the entire sampling season had been 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). Since this gage station was not maintained in 2015, we used a linear regression to estimate stream flows for the Johns River based on those measured at the Black River (linear regression based on data collected during 2010-2014; $y = 0.089x^{0.7952}$, where x = flow at the Black River site and y = flow at the Johns River site; $R^2 = 0.7639$). Thus, for this study, we used the daily stream flows measured or estimated for 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.

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 (QAPP) developed in conjunction with the Vermont DEC. In general, our 2015 sampling met the quality assurance standards for two of the three parameters (quality assurance data are presented in Appendix C). The field blanks, which indicate possible contamination during sampling, exceeded the detection limits for only four of 69 samples and for two of the three parameters. All 23 field blanks for total nitrogen measured below the detection limit (0.1 mg/l). In contrast, two of the 23 field blanks for total phosphorus exceeded the detection limit (5 µg/l), although the excess values were relatively minor (5.92 and 6.43 µg/l), and two of the 23 field blanks for turbidity exceeded the detection limit (0.2 NTU), although again the excess values were relatively minor (0.30 and 0.32 NTU).

Likewise, the mean relative percent differences between duplicate samples were well below the prescribed differences for two of the three parameters [total phosphorus = 9% (prescribed difference <30%) and total nitrogen = 2% (prescribed difference <20%)]. In addition, none of the 24 pairs of total nitrogen samples exceeded the prescribed difference, and only two of the 24 pairs of total phosphorus samples exceeded the prescribed difference (39% and 68%). The mean relative percent difference between the duplicate turbidity samples also did not exceed the prescribed difference [turbidity = 14% (prescribed difference <15%)], but eight of the 24 pairs of turbidity samples did differ by >15% (range = 16-47%).

Thus, although the quality assurance samples, including both field blanks and field duplicates, indicated that the water samples were generally being collected in a repeatable manner and were generally not being contaminated during collection or processing, the results of the field blanks and field duplicates for turbidity indicated that we continue to encounter difficulties in collecting repeatable and uncontaminated turbidity samples for some unknown reason.

Stream Flow

Stream flow measures the volume of water passing a specific location per unit of time (usually as cubic feet or cubic meters per second) 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 (as estimated from the USGS gage on the Black River in 2015 but measured directly in 2010-2014). The 2015 sampling season was characterized by peak spring flows during April followed by a second peak in late June and early July (Figure 5). Otherwise, flows generally decreased throughout the summer and remained relatively low into the autumn, although higher flows were measured on several occasions during July, October, and early November following heavy rains.

Our sample dates largely reflected the variation in stream flows recorded in 2015 (Figure 5). We were able to collect water samples during the high flows following spring snowmelt and heavy rains (27 April) and during the moderate and high flows that occurred following repeated heavy rains during June (9 June and 22 June) and again later in July (21 July). 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.

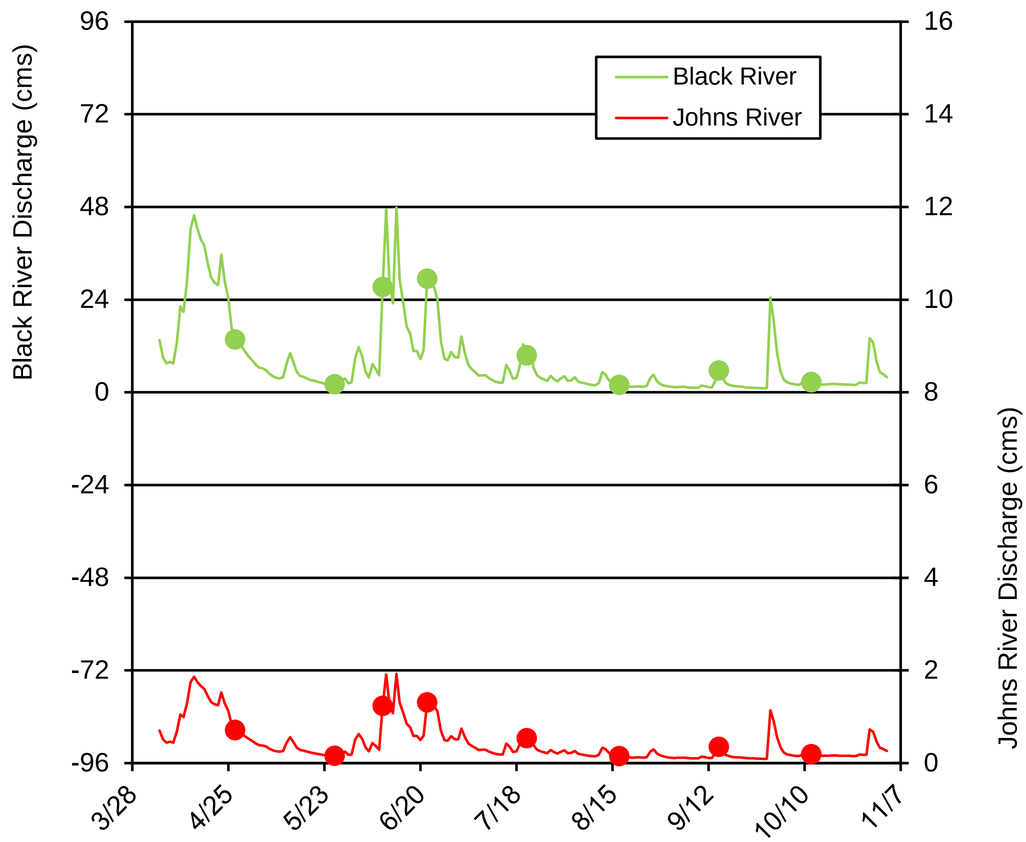

Figure 5. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2015. The eight dates on which water samples were collected are indicated by the circles. Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, Vermont)]; stream flows for the Johns River were estimated based on the measurements from the USGS gage on the Black River.*

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, elevated 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 2015, total phosphorus concentrations at the 28 sites ranged between 9.81-13,100 µg/l. As in previous years, total phosphorus concentrations showed no marked seasonal pattern

(Figure 6). Median total phosphorus concentrations were highest on the sample dates with the highest flows and during rain events (27 April, 9 June, 22 June, and 21 July), when surface runoff following heavy rains likely carried large amounts of sediment and nutrients into the rivers and streams.

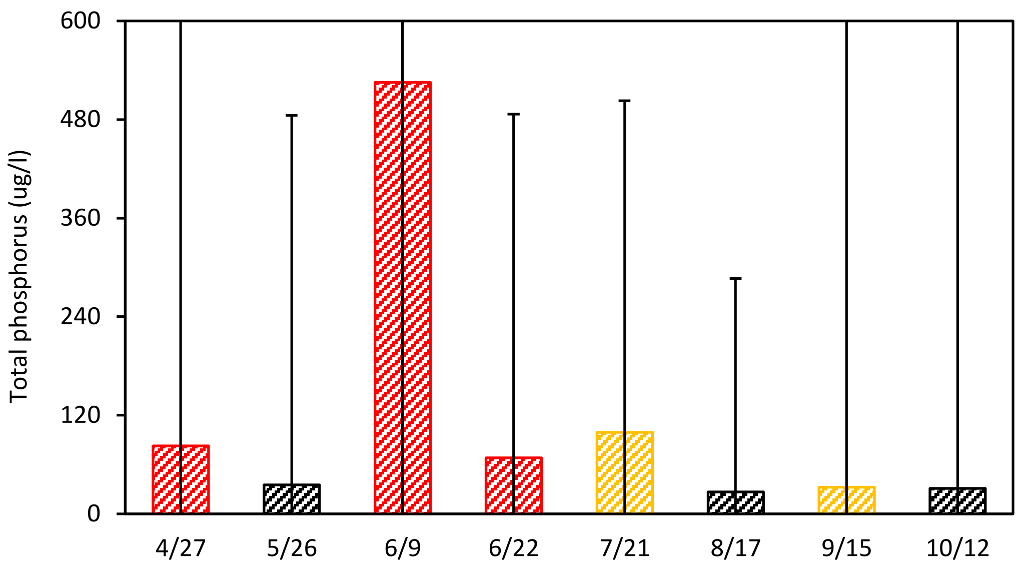

Figure 6. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Red hatching indicates the three high-flow events; orange hatching indicates the two moderate-flow events.*

Since our sampling was focused on assessing streams with high phosphorus levels, total phosphorus concentrations were high (median values >20 µg/l) at all but one site (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, St. Onge, Sunrise Farm, Junkyard, and Hamel tributaries) and the tributary of Stearns Brook. All of these tributaries drained areas of diverse land uses but included large areas of agricultural fields and concentrated agricultural production areas (e.g. barns, barnyards, and manure and silage storage). In contrast, total phosphorus concentrations were only low (median value <20 µg/l) at the upstream-most site along the tributary of Stearns Brook. The tributary at this site generally drained more limited areas of agricultural land uses and more extensive areas of residential and forested land uses. Finally, total phosphorus concentrations were intermediate (median values = 20-35 µg/l) at Crystal Brook, along the Strawberry Acres tributary, which flows directly into Lake Memphremagog, and selected sites along Brighton Brook, the Junkyard tributary, and the tributary of Stearns Brook. Individual watersheds and sites are discussed in greater detail later in this report.

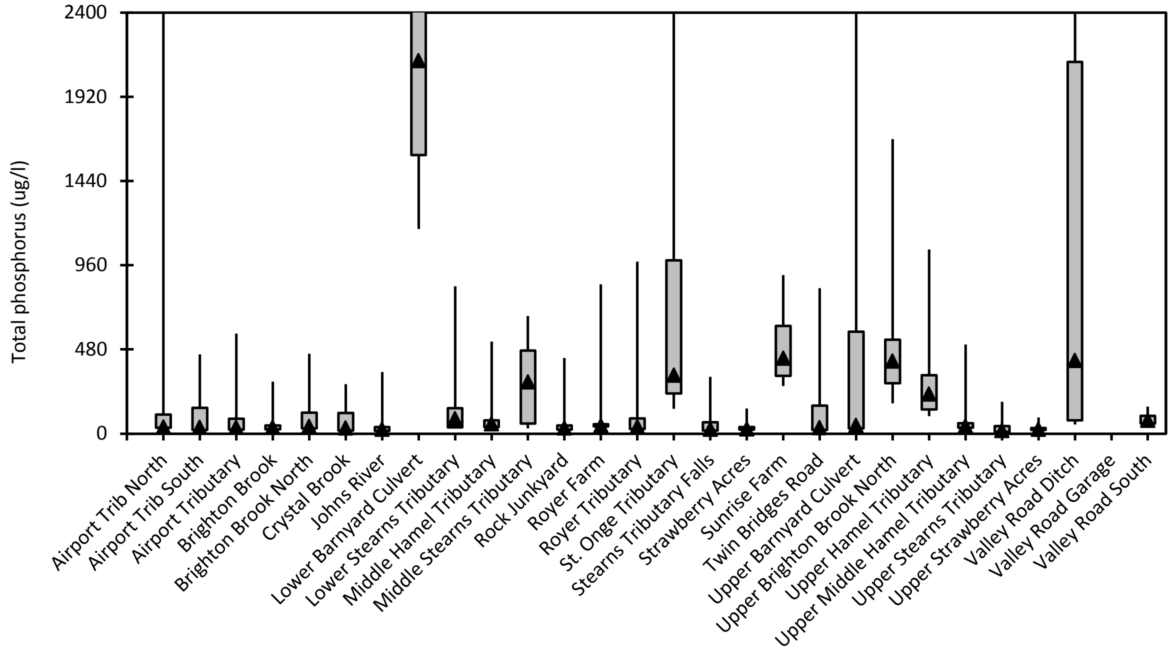

Figure 7. *Total phosphorus concentrations at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note that all values for the Valley Road Garage site, which was only sampled following heavy rains, exceed the range of the y-axis.*

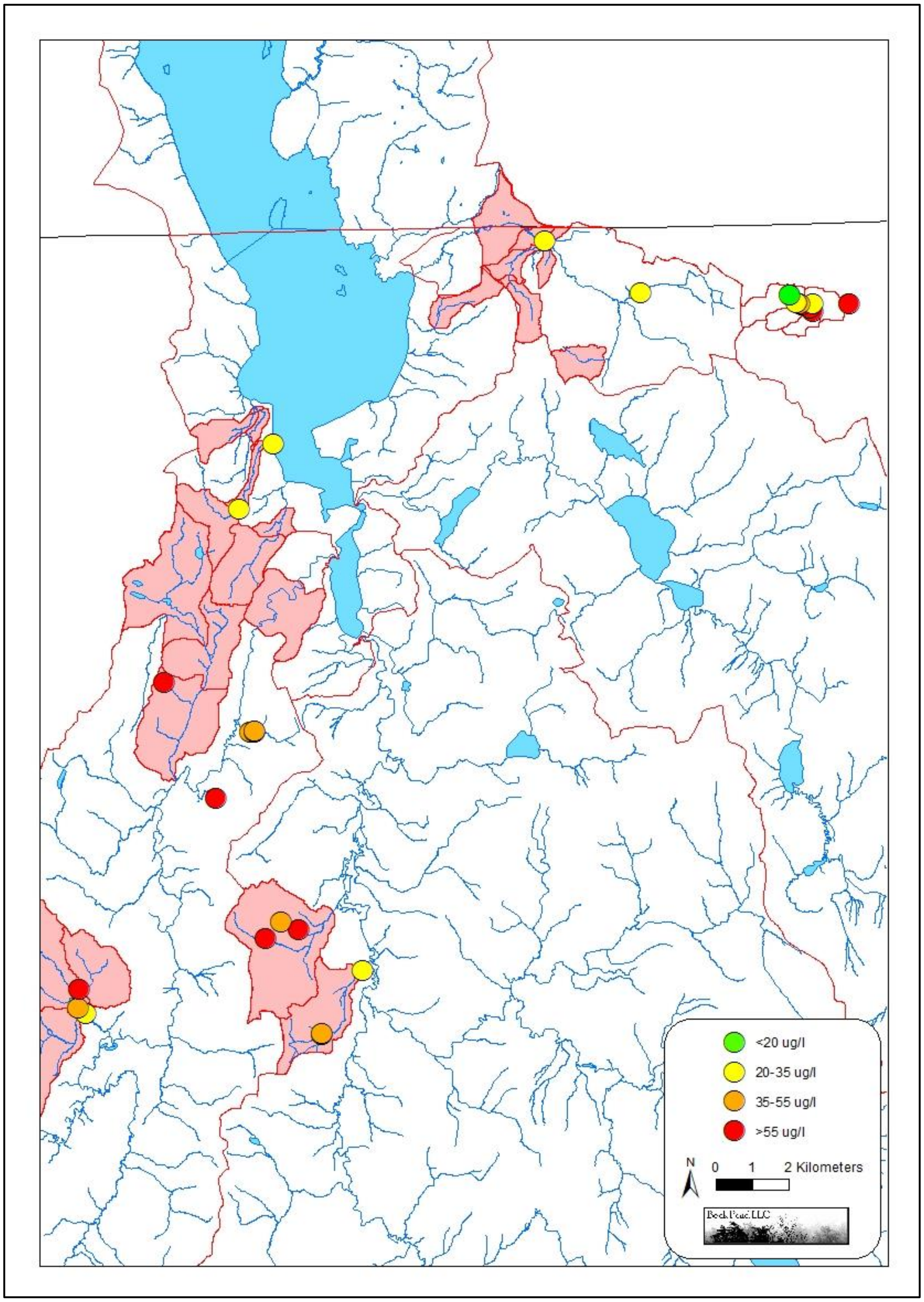

Figure 8. *Median total phosphorus concentrations at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. The red shading outlines the 28 subwatersheds that exhibited the highest phosphorus levels during 2005-2012.*

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 2015, total nitrogen concentrations at the 28 sites ranged between 0.11-124.75 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 sample dates with the highest flows and during rain events (27 April, 9 June, 22 June, and 21 July), when surface runoff following heavy rains likely carried large amounts of sediment and nutrients into the rivers and streams.

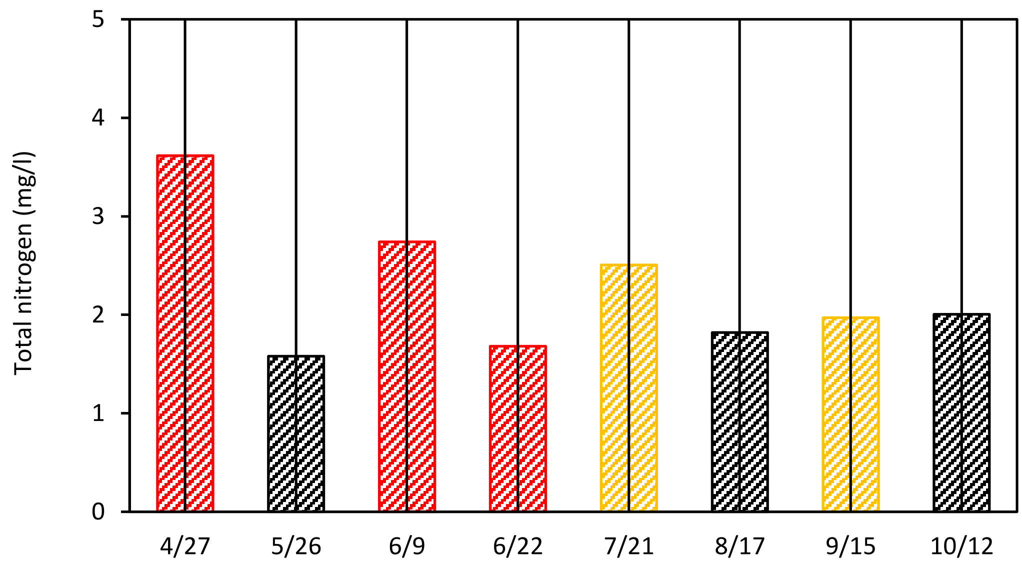

Figure 9. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Red hatching indicates the three high-flow events; orange hatching indicates the two moderate-flow events.*

Since our sampling was focused on assessing streams with high phosphorus levels, total nitrogen concentrations were also generally moderate to high (median values >1 mg/l) at many of these same sites (Figure 10-11). Total nitrogen concentrations were markedly high (median values >2 mg/l) along three tributaries of the Black and Barton Rivers (St. Onge, Sunrise Farm, and Hamel tributaries), the Johns River, and the tributary of Stearns Brook. All of these tributaries drained areas of diverse land uses but included large areas of agricultural fields and concentrated agricultural production areas (e.g. barns, barnyards, and manure and silage storage). In contrast, total nitrogen concentrations were generally low or intermediate (median values <2 mg/l) along several tributaries of the Black and Barton Rivers (Brighton Brook and the Airport and Junkyard tributaries) and the Strawberry Acres tributary, which drains directly into the southwest corner of Lake Memphremagog. These tributaries generally drained watersheds with fewer agricultural production areas and more limited areas of agricultural and other land uses. Individual watersheds and sites are discussed in greater detail later in this report.

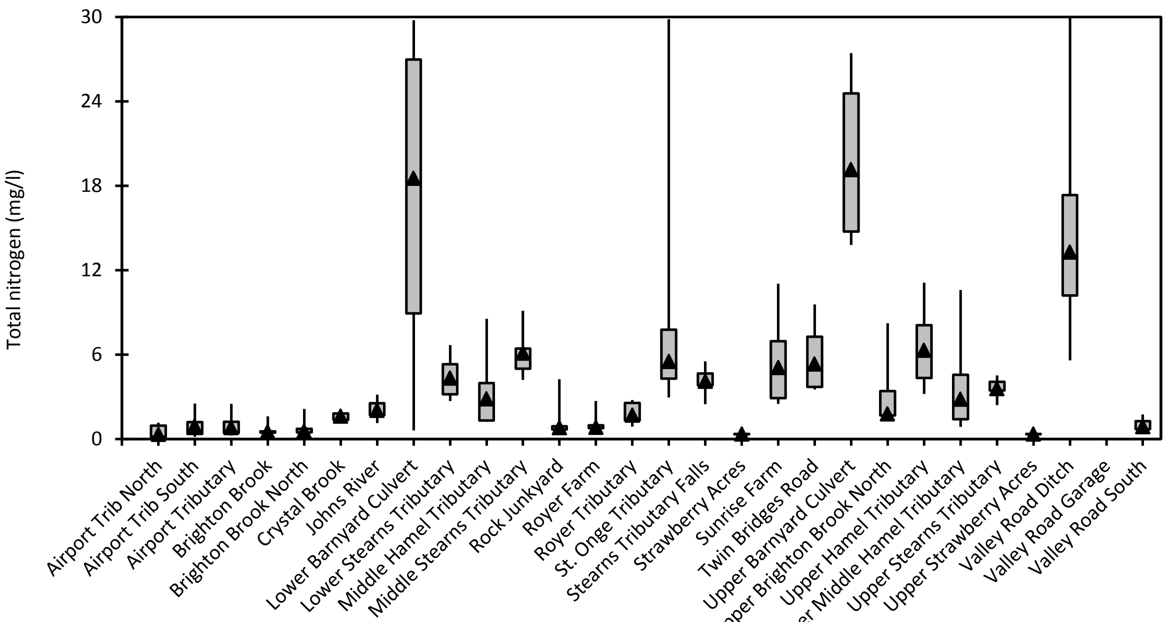

Figure 10. *Total nitrogen concentrations at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note that all values for the Valley Road Garage site, which was only sampled following heavy rains, exceed the range of the y-axis.*

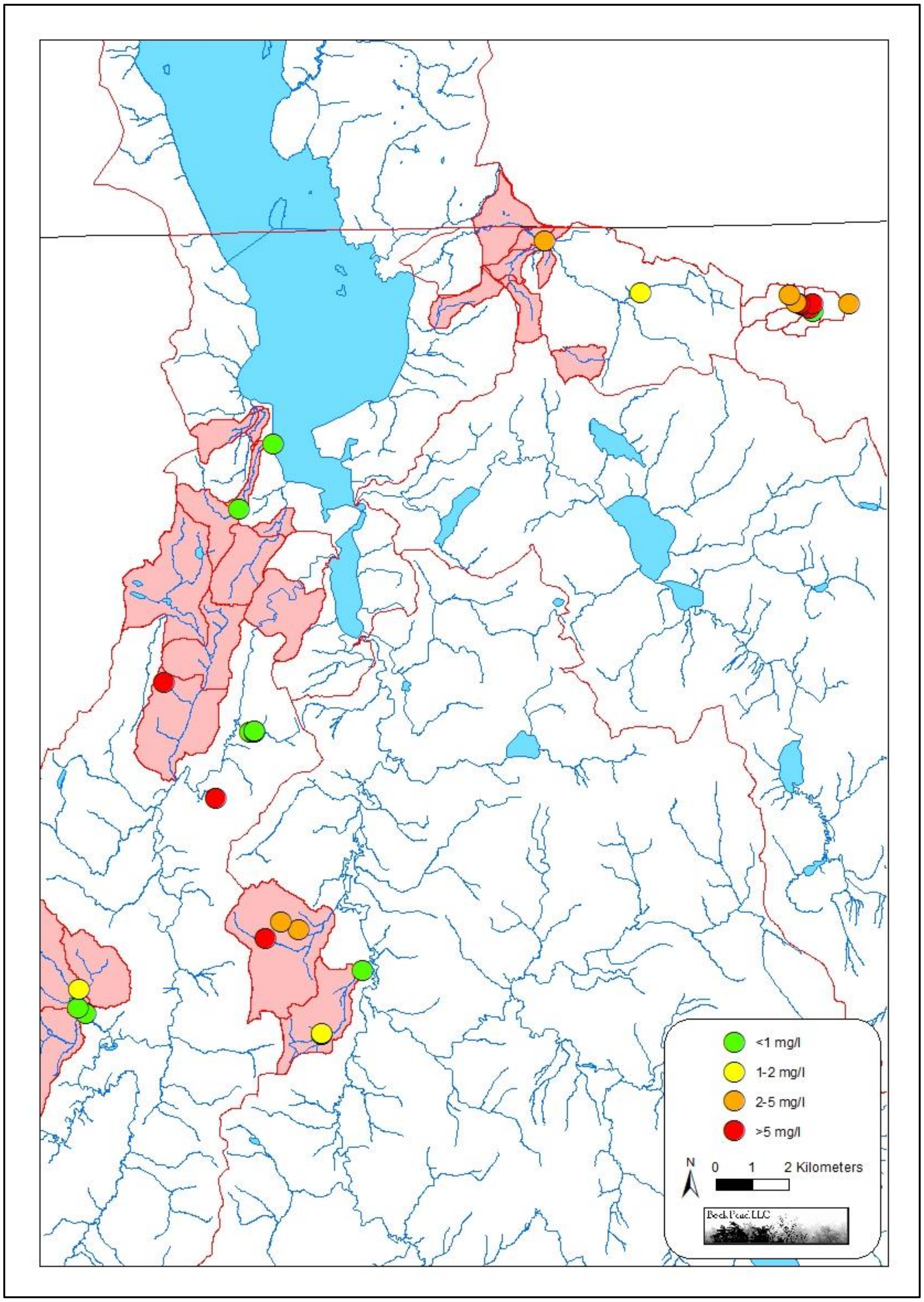

Figure 11. *Median total nitrogen concentrations at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. The red shading outlines the 28 subwatersheds that exhibited the highest phosphorus levels during 2005-2012.*

Turbidity

Turbidity, which is measured in Nephelometric Turbidity Units (NTU), 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.

In 2015, turbidity levels at the 28 sites ranged between 0.32-17,900 NTU. Like total phosphorus and total nitrogen, turbidity levels showed no marked seasonal pattern (Figure 12). Likewise, turbidity levels were highest on the sample dates with the highest flows and during rain events (27 April, 9 June, 22 June, and 21 July), when surface runoff following heavy rains likely carried large amounts of sediment and nutrients into the rivers and streams.

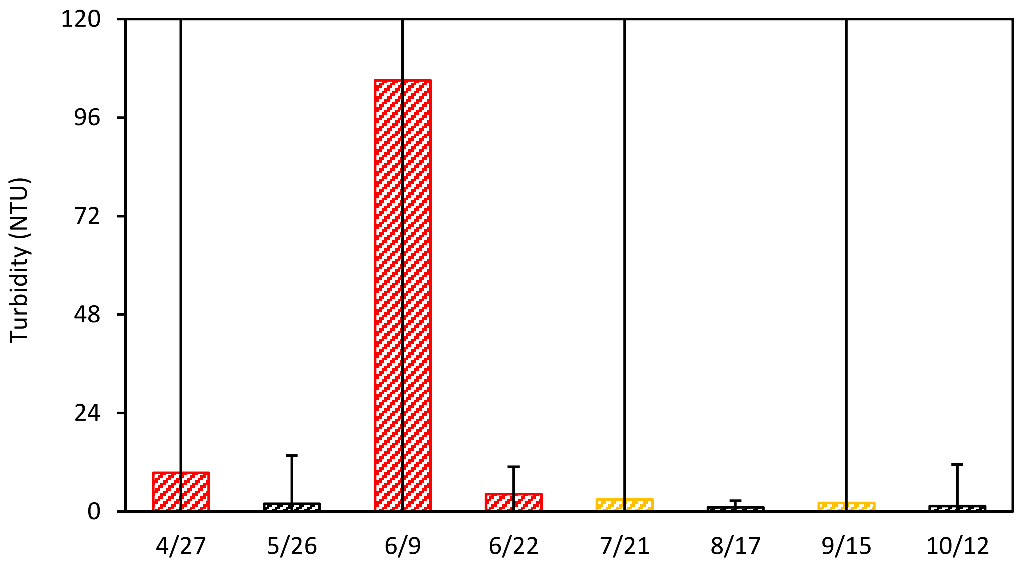

Figure 12. *Median turbidity levels (±1 SD) measured on each sample date at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Red hatching indicates the three high-flow events; orange hatching indicates the two moderate-flow events.*

Unlike total phosphorus and total nitrogen, turbidity levels were generally low at most sample sites along most tributaries (Figure 13-14). Turbidity levels were intermediate or high (median levels >5 NTU) at only seven sites, all of which were located along the northern branch of Brighton Brook, the St. Onge tributary, or the tributary of Stearns Brook. All of these sites were located immediately downstream of concentrated agricultural 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. Individual watersheds and sites are discussed in greater detail later in this report.

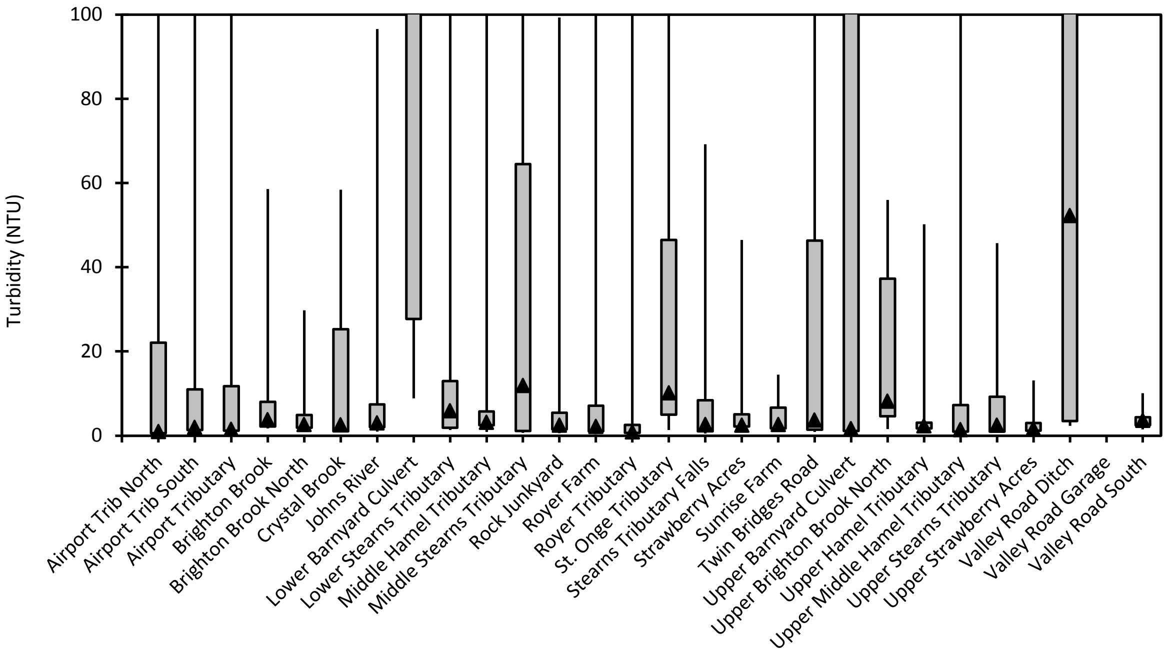

Figure 13. *Turbidity levels at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note that all values for the Valley Road Garage site, which was only sampled following heavy rains, exceed the range of the y-axis.*

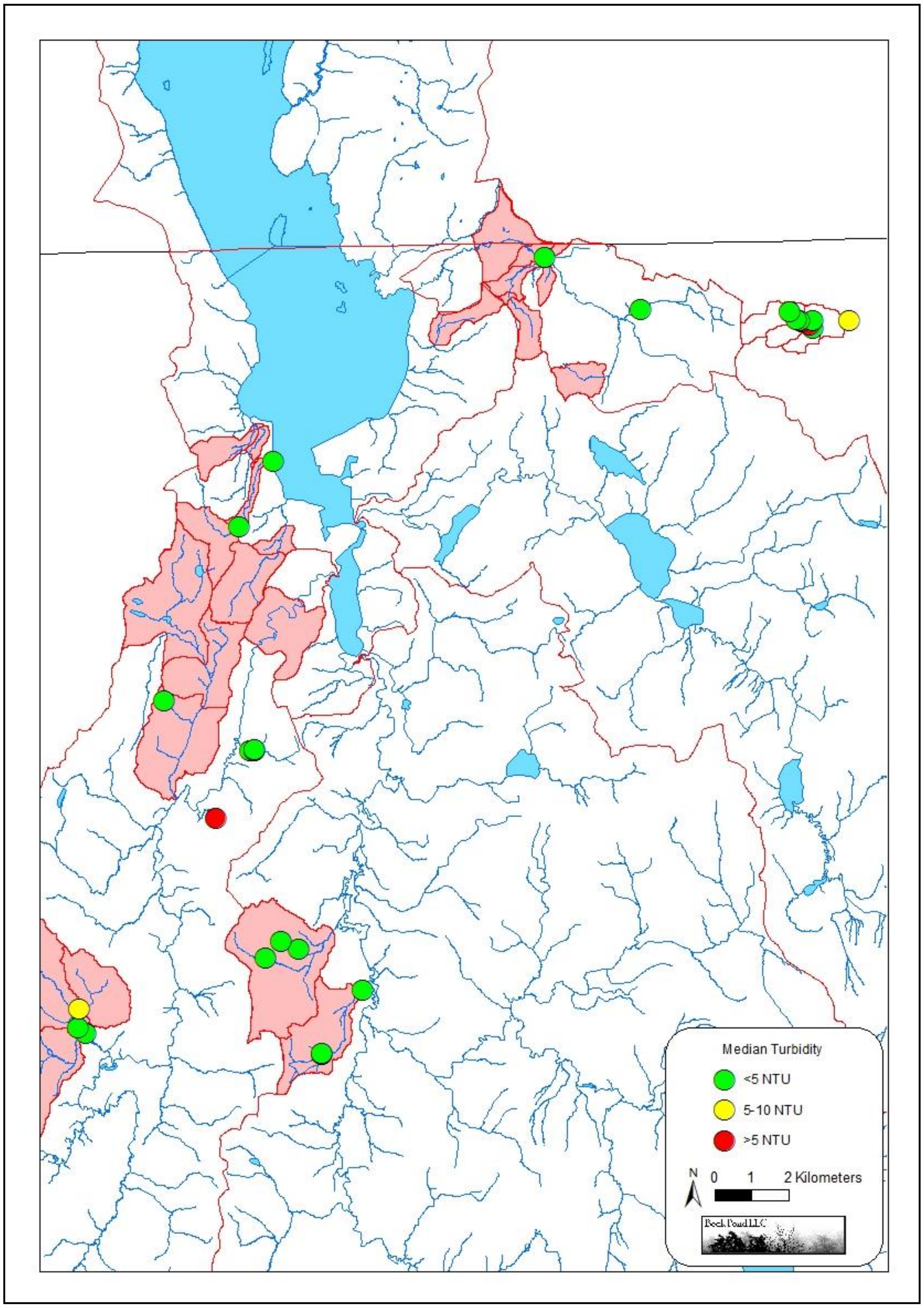

Figure 14. *Median turbidity levels at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. The red shading outlines the 28 subwatersheds that exhibited the highest phosphorus levels during 2005-2012.*

Phosphorus-Reduction Projects and Practices

In 2015, we continued our efforts to identify, develop, and implement phosphorus-reduction projects and practices that will most effectively reduce nutrient and sediment exports along the Vermont tributaries of Lake Memphremagog. As part of these efforts, we updated and revised our earlier analyses that had mapped and identified possible sources of water quality problems and potential phosphorus-reduction projects and practices (Gerhardt 2013, 2014). Since the GIS layers and supporting data had not been updated since 2012, we added the new subwatersheds that were first sampled in 2013 or 2014, and we added the water quality data collected during 2013-2014 to those collected during 2005-2012. With these updated data, we identified those subwatersheds exhibiting the highest total phosphorus concentrations, and we used aerial photographs and field surveys to identify and map land uses, land cover types, possible nutrient and sediment sources, and potential phosphorus-reduction projects and practices. Throughout this project, we 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 will work with landowners and land managers to design and implement the appropriate phosphorus-reduction projects and practices.

Methods

To accomplish this project, we used the water quality data collected along the Vermont tributaries of Lake Memphremagog during 2005-2014 to identify those subwatersheds that exhibited the highest phosphorus levels. First, 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 water quality sample site and then imported and merged these boundaries in a Geographic Information System (ArcGIS 10, ESRI, Redlands, California). Second, to compensate for the different dates and stream flows sampled at each site, we calculated the arithmetic mean total phosphorus concentrations for each sample site separately for low and moderate flows and for high flows. For sites along the main stems of the three large tributaries of Lake Memphremagog (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 smaller tributaries and the main stem of the Johns River, we identified low, moderate, and high flows based on daily stream flows measured by the Vermont DEC on the Johns River in Beebe Plain.

With these data and analyses, we then selected a subset of 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. These priority subwatersheds were those subwatersheds whose associated sample sites met one or both of two criteria: 1) the 30 highest mean total phosphorus concentrations at low and moderate flows or 2) the 30 highest mean total phosphorus concentration at high flows.

Within these priority subwatersheds, we identified and mapped land uses and land cover types and 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 2014 aerial photographs downloaded from the USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). 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). Once the land uses and land cover types were identified and mapped 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. Initially, we identified concentrated agricultural production areas (e.g. barns, 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.

Throughout this process, we discussed the priority subwatersheds, possible sources of water quality problems, and potential phosphorus-reduction projects and practices with key staff from the Vermont Department of Environmental Conservation (DEC); Vermont Agency of Agriculture, Foods and Markets (VAAFM); USDA Natural Resources Conservation Service (NRCS); Vermont Association of Conservation Districts (VACD); and Orleans County Natural Resources Conservation District (NRCD). Due to the large areas of agricultural land uses and their strong positive relationships with total phosphorus concentrations (Gerhardt 2013), we have focused our efforts on identifying and evaluating potential projects and practices that address agricultural sources of water quality problems [e.g. improvements to agricultural infrastructure, Best Management Practices (BMP), forested riparian buffers, and wetlands restoration]. Many of the proposed projects and practices can be implemented through existing grants or cost-share programs, including those administered by VAAFM, Vermont DEC, and NRCS. In addition, technical and financial assistance can be provided by the VACD, Orleans County NRCD, 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. stormwater issues, road erosion, etc.).

Results and Discussion

This project required multiple steps. First, we added 27 new subwatersheds that were first sampled in 2013 or 2014. These subwatersheds were located along three tributaries of South Bay (Day and Cobb Brooks and the Rediker Hill tributary), three tributaries of the Black River (the Airport, River of Life, and Lawson Lower Barn tributaries), one tributary of the Barton River (Alder Brook), and the tributary of Stearns Brook, which has been listed as impaired by the State of Vermont (Part A, State of Vermont 2014b). In addition, we further subdivided six subwatersheds, where we had added additional sample sites to better pinpoint and assess nutrient and sediment sources (Brighton and Roaring Brooks and the Hamel, Junkyard, Sunset Acres, and Holbrook Bay tributaries). In the end, we analyzed total phosphorus concentrations in 150 subwatersheds in the Vermont portion of the Lake Memphremagog Basin (Table 1, Figure 15).

Table 1. Numbers of subwatersheds sampled and mapped and assessed as part of efforts to identify possible phosphorus sources and to develop and implement phosphorus-reduction projects and practices in the Vermont portion of the Lake Memphremagog Basin and the watershed of the tributary of Stearns Brook during 2005-2014. The numbers for the revised analysis includes all subwatersheds examined in the previous analysis (numbers for the previous analyses were adjusted to reflect the fact that some subwatersheds were further subdivided during the revised analysis).

	Previous Analysis (2005-2012 Data)	Revised Analysis (2005-2014 Data)
Number of subwatersheds sampled	123	150
Barton River	19	31
Black River	37	44
Clyde River	29	29
Johns River	26	26
Direct tributaries	12	14
Stearns Brook tributary	0	6
Number of subwatersheds mapped and assessed	31	50
Barton River	9	10
Black River	14	15
Clyde River	0	0
Johns River	0	10
Direct tributaries	8	11
Stearns Brook tributary	0	4

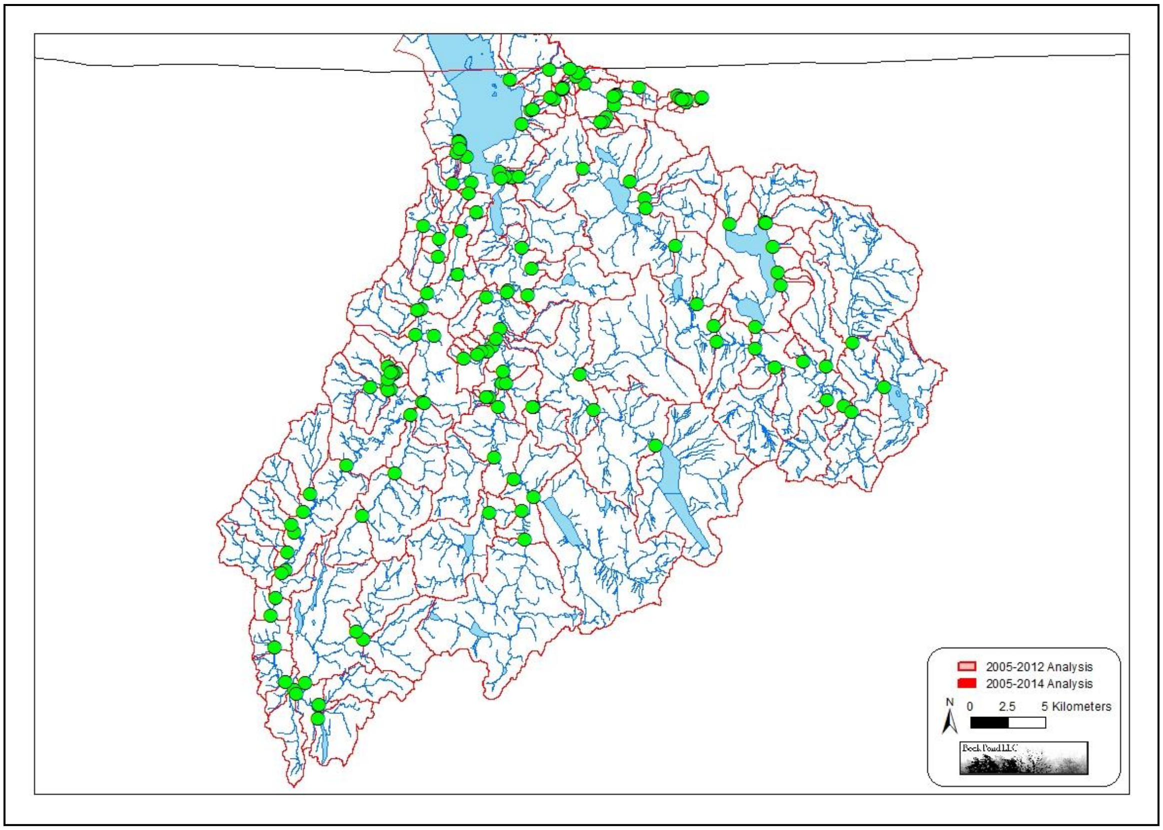

Figure 15. *The 150 sample sites and their associated subwatersheds in the Vermont portion of the Lake Memphremagog Basin and the watershed of the tributary of Stearns Brook during 2005-2014.*

Second, we incorporated the two most recent years of data (2013-2014) into our analyses of the water quality data collected during 2005-2012. We used all of these data (2005-2014) to calculate the mean and median total phosphorus concentrations for all 150 subwatersheds. In general, mean total phosphorus concentrations were highest in several areas of the Black River watershed, in the downstream sections of the Barton River watershed, throughout the Johns River watershed, and along several small tributaries that flow directly into Lake Memphremagog (Figure 16). More specifically, the subwatersheds with the highest total phosphorus concentrations occurred along two reaches of the main stem of the Black River and two of its tributaries (Brighton Brook and the Airport tributary), three reaches of the main stem of the Barton River and two of its tributaries (Junkyard and Hamel tributaries), several areas in the Johns River watershed, three small tributaries that flow directly into Lake Memphremagog (Wishing Well, Strawberry Acres, and Sunset Acres tributaries), and much of the watershed of the tributary of Stearns Brook. In contrast, the subwatersheds with the lowest total phosphorus concentrations occurred throughout the Clyde River watershed, the upstream section of the Barton River watershed, and some of the smaller tributaries of the Black and Johns Rivers.

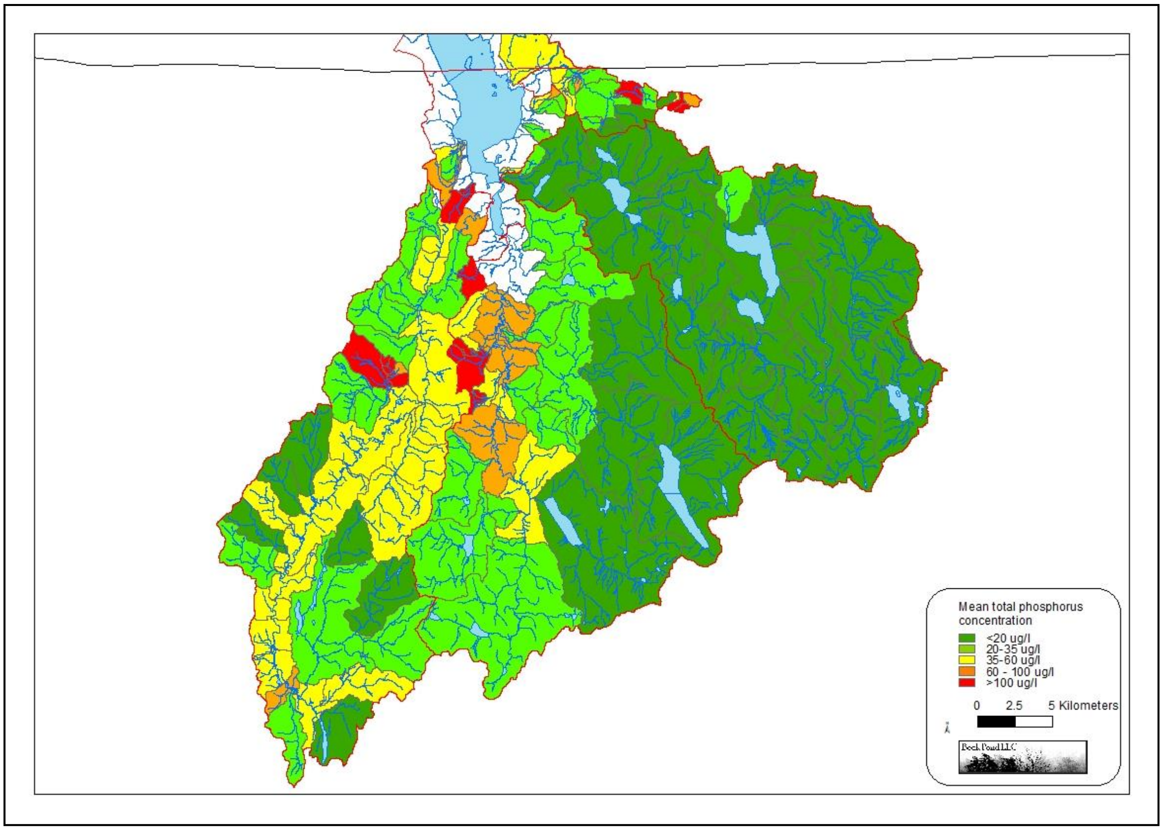

Figure 16. *Mean total phosphorus concentrations in 150 subwatersheds in the Vermont portion of the Lake Memphremagog Basin and the watershed of the tributary of Stearns Brook during 2005-2014.*

From these 150 subwatersheds, we identified 46 priority subwatersheds that exhibited the highest total phosphorus concentrations at low and moderate flows and/or at high flows (Table 2, Figure 17). In addition, eleven other subwatersheds that did not meet either of these two criteria were included in these analyses, because they had been identified and assessed as priority subwatersheds in the earlier analyses (Table 2; Gerhardt 2013, 2015). These 57 priority subwatersheds covered 139 km^2 (54 mi^2) or 11% of the Vermont portion of the Lake Memphremagog Basin and were distributed throughout the Black River watershed, the downstream half of the Barton River watershed, and the Johns River watershed and along several small tributaries that flow directly into Lake Memphremagog and the tributary of Stearns Brook (Figure 17). None of the priority subwatersheds were located in the Clyde River watershed.

Table 2. Priority subwatersheds identified by analyzing the total phosphorus data collected along the Vermont tributaries of Lake Memphremagog and the tributary of Stearns Brook during 2005-2014. The two criteria were 1) the 30 highest mean total phosphorus concentrations at low and moderate flows or 2) the 30 highest mean total phosphorus concentration at high flows. Subwatersheds identified in italics have not yet been mapped and assessed.

<u>Satisfy Both Criteria (14 Subwatersheds):</u>

Airport Tributary	Brighton Brook North
Crystal Brook	Darling Hill
Hamel Marsh	Holbrook Bay South
Lower Nelson Farm	Middle Hamel Tributary
Royer Farm	Strawberry Acres
Upper Brighton Brook North	Upper Hamel Tributary
Upper Wishing Well	Wishing Well

<u>Satisfy One Criterion (32 Subwatersheds):</u>

Barton Alder Brook	Barton River
Beebe Plain	Black River
Brighton Brook	*Churchill Lane*
DHM	*Eagle Point*
East Side	*Ethan Allen*
Holbrook Bay	Holbrook South Pond
Lower Hamel Tributary	Lower Stearns Tributary
Middle Darling Hill	Middle Stearns Tributary
Mud Pond	Nelson Northeast
Nelson Northwest	Post Road
Rock Junkyard	Royer Tributary
Shalney Branch	Sunset Acres
Twin Bridges Road	Upper Hamel Marsh
Upper Junkyard	Upper Nelson Northwest
Upper Strawberry Acres	Upper Sunset Acres North
Valley Road South	*Webster Road*

<u>Satisfy Neither Criterion But Were Prioritized in Earlier Analyses (11 Subwatersheds):</u>

Blake Road	Granite
Holbrook Bay North	Johns River
North Derby Road	Robillard Flats
Stony Brook	Sunset Acres North
Upper Darling Hill	Upper Quarry West
Walker Pond	

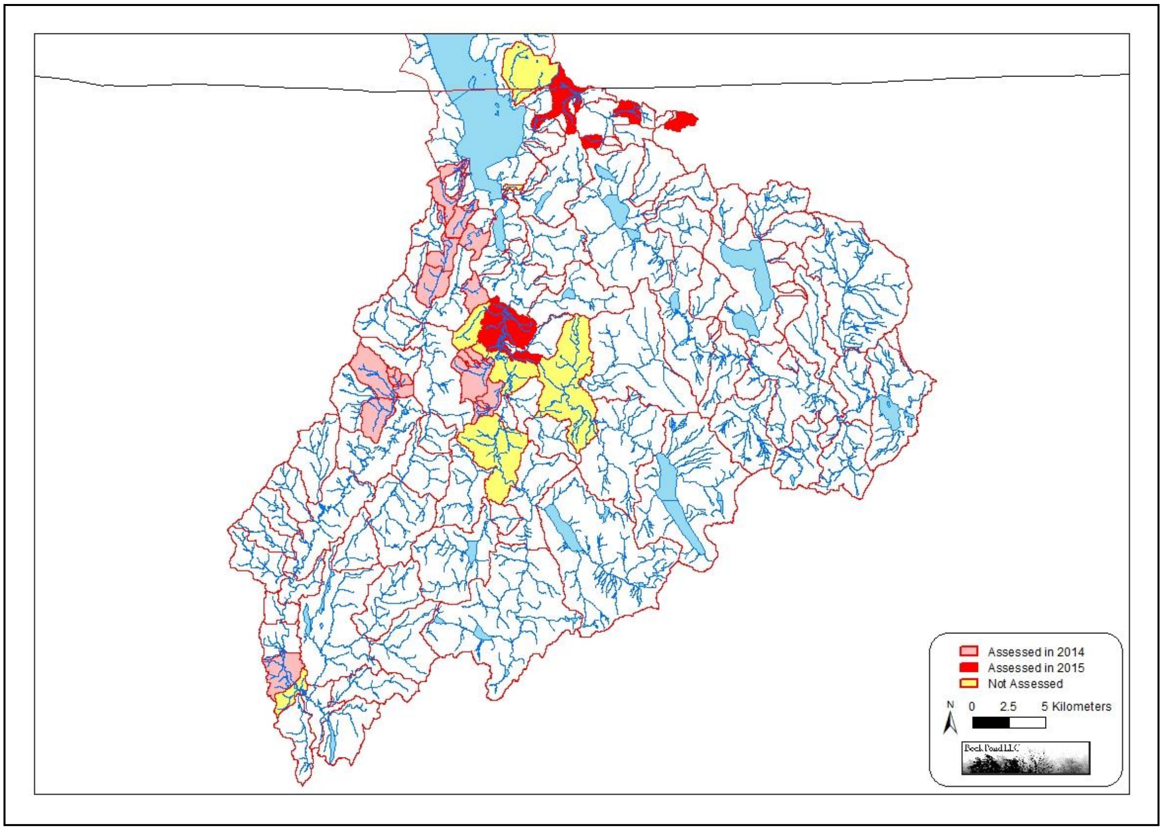

Figure 17. *Priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin and the watershed of the tributary of Stearns Brook during 2005-2014. The bold red subwatersheds were mapped and assessed in 2015 as part of this project.*

Third, for 50 of these 57 priority subwatersheds, we mapped land uses and possible nutrient and sediment sources. In previous years, we had focused our efforts on mapping and evaluating possible phosphorus sources in 31 priority subwatersheds in the watersheds of the Barton and Black Rivers and the small tributaries that flow directly into the western shore of Lake Memphremagog (Figure 17). In 2015, we expanded these efforts to map land uses and land cover types and identify possible sources of water quality problems and potential phosphorus-reduction projects and practices in the 19 priority subwatersheds located in the watersheds of the Barton and Johns Rivers, several small tributaries that flow directly into the eastern shore of Lake Memphremagog, and the tributary of Stearns Brook (Figure 17). In these 19 priority subwatersheds, we scouted possible sources of water quality problems and potential phosphorus-reduction projects and practices. Based on these field assessments, we identified seven possible nutrient and sediment sources for further evaluation (Table 3). In addition, we continued to work with landowners, land managers, and staff from State and federal agencies and other organizations to develop and implement projects to correct water quality problems that had been identified previously in other priority subwatersheds (Table 4). These water quality problems and their possible sources and solutions are discussed in greater detail later in this report.

As part of these efforts, we convened two meetings with key project 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 will be undertaken to address these problems. Throughout this project, we also met with individual project partners and landowners and land managers to discuss and evaluate specific priority subwatersheds, possible sources of water quality problems, and potential phosphorus-reduction projects and practices. Once specific projects and practices were identified, we continued to work with project partners and landowners to verify water quality problems, to assess the appropriateness and feasibility of projects and practices, to gauge landowner interest in undertaking these projects or practices, and to evaluate the success of projects and practices once they were implemented.

Table 3. Possible sources of and potential projects and practices to correct water quality problems identified in 57 priority subwatersheds along the Vermont tributaries of Lake Memphremagog and the watershed of the tributary of Stearns Brook.

Water Quality Problem	Owner	Lead Contact	Possible Solution(s)/Actions Taken to Date
Black River: Airport Tributary (North Branch)			
Excess stormwater causing severe erosion and incision	Newport State Airport	DEC, MWA	Problem has been discussed with airport authorities, included in MWA's stormwater planning project
Black River: Stony Brook			
Farmstead runoff, livestock in stream	Sunrise Farm	VAAFM?	None to date (stream first sampled in 2015)
Barton River: Barton River			
Unstable, migrating river channel	Couture Trucking	DEC, VFW	Evaluated for River Corridor Easement (VFW owns floating 1-rod width on each shore)
Clyde River: Sucker Brook			
Overflowing manure pit, livestock-induced streambank erosion	Farrow	VAAFM	VAAFM checked in 2015 but manure pit not overflowing at time, needs livestock exclusion fencing, will sample in 2016
Johns River: Darling Hill			
Leaking manure pit (in past), livestock in stream	Agawam Farm	VAAFM, NRCD?	Upgrade manure pit, install livestock exclusion fencing
Tributary of Stearns Brook			
Farmstead runoff	Gray Farm	VAAFM	Undertook numerous clean water diversion and runoff control projects in 2015, will resample in 2016
Tributary of Stearns Brook			
Stream channel erosion, serious overgrazing	Dairy Air Farm	VAAFM	Livestock exclusion fencing, grazing plan, will sample in 2016

Table 4. Updates concerning possible sources of and potential projects and practices to correct water quality problems identified in 57 priority subwatersheds located along the Vermont tributaries of Lake Memphremagog during 2011-2014.

Water Quality Problem	Owner	Lead Contact	Possible Solution(s)/Actions Taken
Black River: St. Onge Tributary			
Silage leachate, failing manure pit?	Nelson Farms (old St. Onge Farm)	VAAFM	Inspections revealed major issues, installed temporary barrier around silage, manure pit overflow pipe may not have been removed properly
Black River: Lawson Lower Barn			
Farmstead runoff	Lawson Farm (SFO)	VAAFM, DEC	Farm inspected but no enforcement or remediation actions undertaken
Black River: Walker Pond			
Farmstead runoff, possible failing manure pit(s)	Andrews Farm (old Petit Farm)	NRCD, NRCS	New owner developing nutrient management plan, considering improvement projects
Black River: Brighton Brook			
Mortality compost leachate, farmstead runoff	Nelson Farms (LFO)	DEC, VAAFM	Enforcement action completed, compost pile being relocated
Black River: Shalney Branch			
Roof runoff and saturated barnyard	Rowell Farm	NRCD	Engineering being completed to harden barnyard and install clean water diversion(s)
Barton River: Alder Brook			
Silage leachate (drain often plugged by debris)	Lawson Farm (LFO)	VAAFM	Drain not being managed properly, has been discussed with owner

Table 4. Continued.

Water Quality Problem	Owner	Lead Contact	Possible Solution(s)/Actions Taken
Barton River: Upper Hamel Tributary			
Abandoned manure pit	Rose (old Cook Farm)	VACD, NRCS	Landowner interested in NRCS program for decommissioning unused manure pits
Barton River: Royer Farm			
Inadequate buffers around corn fields on steep, erodible slopes	Royer Farm	VAAFM, NRCS	Developing nutrient management plan, expanded buffers where too narrow, added filter strip in lower corn field, began no-till and cover-cropping
Direct Tributaries: Glen Road			
Sediment erosion from steep field that was stumped, graded, and planted in 2014-2015	Roger	VAAFM, DEC	Problem ongoing, wetlands enforcement action being contemplated (large amounts of sediment deposited into wetlands), minimal but ineffective silt barriers re-installed in 2015

Wetland Restoration Opportunities

As part of our efforts to reduce nutrient and sediment inputs into Lake Memphremagog and its tributaries, we continued our efforts to identify and evaluate potential wetland restoration opportunities, especially in the priority subwatersheds. These efforts continued the analyses and evaluations started in 2011 when we originally developed and executed the site selection and prioritization models for identifying and prioritizing potential wetlands restoration sites (Gerhardt 2012b). In 2012, we had continued our efforts to identify, prioritize, develop, and implement wetland restoration projects in the Vermont portion of the Lake Memphremagog Basin by revising the site selection model that we developed in 2011 (Gerhardt 2013). In these models, potential wetland restoration sites were identified as those areas >1.2 ha (>3 acres) in size that were being used for agricultural and other non-forested land uses and that occurred on hydric soils with slopes ≤6%. The revised site selection model identified 541 potential wetland restoration sites occupying 2,973 ha (7,346 acres) or 2.4% of the Vermont portion of the Lake Memphremagog Basin (Figure 18). Potential restoration sites ranged in size from 1.2-106.4 ha (3-263 acres) with a mean area of 5.5 ha (13.6 acres). Potential wetland restoration sites were concentrated along the main stems of all four principal tributaries of Lake Memphremagog, especially in the downstream sections of their watersheds. In contrast, potential wetland restoration sites were generally lacking in the upstream sections of these watersheds, especially along the Barton, Clyde, and Johns Rivers.

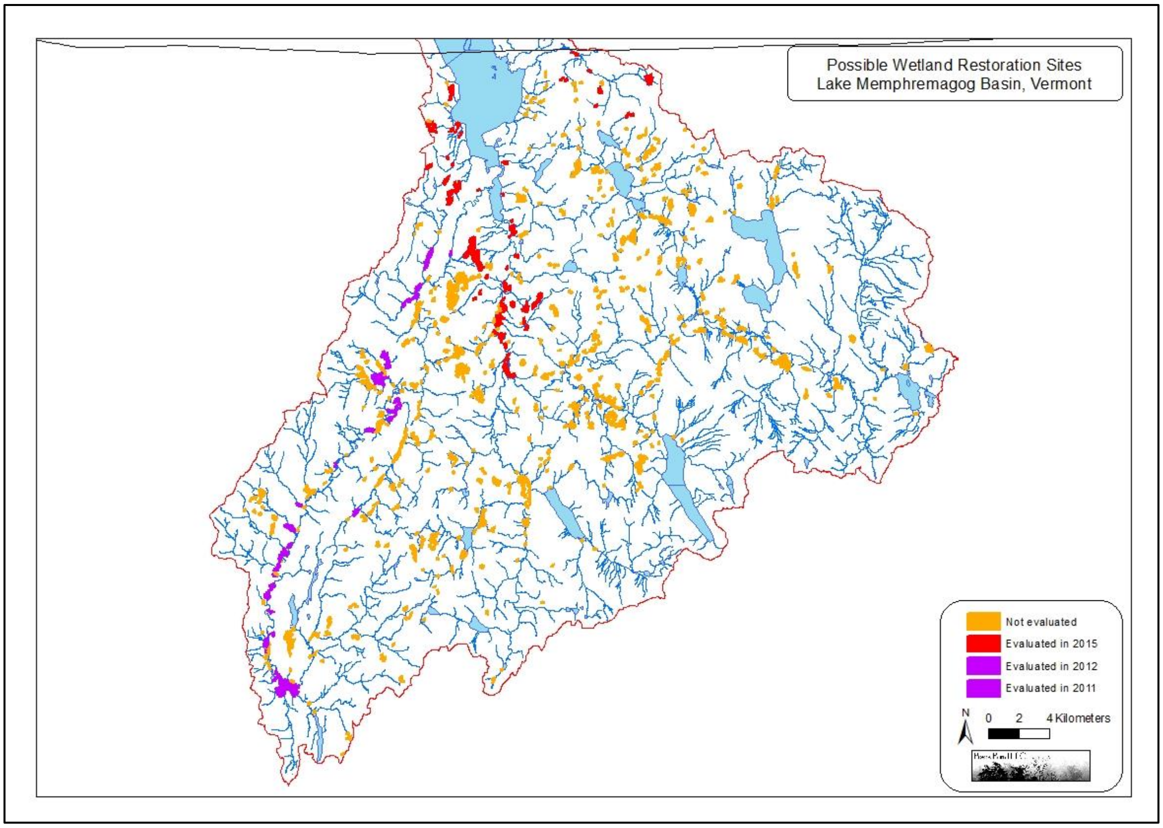

Figure 18. *Potential wetland restoration sites in the Vermont portion of the Lake Memphremagog Basin.*

We then ranked the potential wetland restoration sites based on their ability to reduce sediment and nutrient loading into the surface waters of the Lake Memphremagog Basin. Those sites occurring on the floodplains of the major tributaries of Lake Memphremagog were ranked as high priorities; those sites occurring on the floodplains of other tributaries or adjacent to the floodplains of the major tributaries were ranked as medium priorities. In 2011-2012, we had assigned priority rankings to 202 of the 541 potential wetland restoration sites, including all of those located within the Black River and Johns River watersheds. Given this qualitative approach to prioritization, the majority of the high-priority sites were located on the floodplains of the main stems of the Black and Johns Rivers and Lords Creek (Figure 18). In contrast, medium-priority sites were located along several smaller tributaries, including Brighton, Stony, Lamphear, and McCleary Brooks and the outlet of Lake Elligo. Finally, the low-priority sites were primarily located in upland areas more distantly removed from surface waters. Many of the high-priority sites occurred in areas characterized by large areas of agricultural land uses located in close proximity to rivers, streams, and other surface waters. Restoration of wetlands at these sites has the greatest potential for retaining nutrients and sediment and for improving water quality in the Lake Memphremagog Basin.

For the medium- and high-priority sites, we conducted field evaluations of individual sites to further assess their potential for wetlands restoration and to gauge the landowner's interest in undertaking protection and/or restoration projects. Specifically, the goals were 1) to assess whether the site was accurately and precisely identified as a potential wetland restoration site, 2) to evaluate whether the site was suitable for restoration and/or protection, 3) to determine possible protection and/or restoration strategies for the site, and 4) to determine whether the landowner was interested in wetlands restoration and/or other conservation actions. In 2011-2012, we had focused our field evaluations and outreach efforts on potential wetland restoration sites along the Black River in the towns of Coventry, Irasburg, Albany, and Craftsbury (Figure 18).

Methods

In 2015, we continued our efforts to identify and develop wetland restoration projects in the priority subwatersheds and elsewhere in the Vermont portion of the Lake Memphremagog Basin. Using the wetlands selection and prioritization models and maps developed previously (Gerhardt 2012b, 2013), we conducted field surveys to ground-truth and evaluate potential wetland restoration projects in the priority subwatersheds along the Barton and Johns Rivers and the small tributaries that flow directly into Lake Memphremagog.

Results and Discussion

In 2015, we prioritized, ground-truthed, and evaluated 51 potential wetland restoration sites, primarily in the priority subwatersheds occurring in the watersheds of the Barton and Johns Rivers and the small tributaries flowing directly into Lake Memphremagog (Figure 18). Through these efforts, we identified six sites that may be suitable for wetland restoration projects (Table 5). All six sites will need to be further evaluated to assess their suitability for wetlands restoration and to gauge landowner interest in undertaking such projects. We will continue to encourage the development and implementation of wetland restoration projects on these and other sites as part of efforts to protect and improve water quality in the Vermont portion of the Lake Memphremagog Basin. Several of these sites are discussed in greater detail later in this report.

Table 5. Descriptions of six potential wetland restoration sites that were assessed and deemed suitable for restoration in the Lake Memphremagog Basin during 2015 and one site that was first identified in 2011 and that is currently undergoing restoration.

Owner	Land Use	Description	Opportunities
Black River			
Ralya	Old field	Enrolled in Wetlands Reserve Easement program in 2014	Ongoing, trees planted in 2015 but drainage ditch not yet plugged
Barton River			
VFW (multiple sites)	Old fields	Wetland restoration projects completed at several sites	Other wetland restoration opportunities remain, primarily on the east side of the river
Johns River			
?	Pasture	Grazed wetland along North Derby Road	Remove livestock and restore wetlands vegetation
Binette	Pasture	Owner not interested previously but site was no longer being grazed in 2015	Combination wetland restoration/river corridor protection project, plug ditch, plant native trees and shrubs where appropriate
?	Hay	Located close to Beebe Plain Road and residences, may not be suitable	Stop mowing, plug ditch, restore wetlands vegetation
Spates	Hay	Unknown (barely visible from public road)	Stop mowing, plug ditch, restore wetlands vegetation
Tributary of Stearns Brook			
Gray Farm	Old field	Heavily disturbed area along Valley Road south of garage and barns	Fill excavations (?), plug ditch, restore wetlands vegetation

Highly-Erodible Soils

Another goal of this year's efforts was to map areas of highly-erodible soils on croplands for further investigation as possible sources of soil and phosphorus export. To accomplish this goal, we developed a spatially-explicit model to identify areas of highly-erodible soils on cropland across the Vermont portion of the Lake Memphremagog Basin. These data will be provided to landowners, land managers, and other agricultural and conservation professionals to identify possible areas for implementing field practices and projects that reduce soil erosion and phosphorus loss from cropped fields. We considered using an alternative approach that had been developed by the Natural Resources Conservation Service, which uses soil hydrological group (largely defined by soil texture), slope, and K-factor. However, developing such a model would have been considerably more time-consuming and computationally demanding, and the required data layers were not readily available.

Methods

Our model was developed using spatially-explicit data incorporated into a Geographic Information System (ArcGIS 10; ESRI, Redlands, California). In this model, three data layers were used to evaluate each 900-m^2 (9,688-ft^2) cell (the smallest grid unit from the three input data layers) in the basin in order to identify cropland areas characterized by highly-erodible soils. First, sites were classified by their highly erodible lands class (HELCLASS; not highly erodible, potentially highly erodible, highly erodible, and not ranked) based on the Natural Resource Conservation Service (NRCS) County Soil Survey Data (2011 edition)(Table 6). Second, sites were classified by the slope of the terrain generated from the USGS National Elevation Dataset digital elevation model using 10-m (33-ft) contour intervals (2012 edition)(Table 6). Third, sites were classified by the agricultural land uses mapped in the USDA National Agricultural Statistics Service (NASS) Cropland Data Layer (2012 Version)(Table 7). To develop this model, these three layers were merged into a single GIS layer, and the subset of cells that were classified as cropland and that had high, very high, or extreme erosion potential were retained in the final model.

Table 6. Highly-erodible soils were identified by classifying areas according to their highly erodible lands (HEL) class, slope, and agricultural land use (see Table 7 for suitable land uses). Highly-erodible soils were those whose erosion potential was high, very high, or extreme.

Erosion Potential	Not HEL	Potential HEL	HEL
Low	0-4%	-	-
Moderate	4-10%	0-4%	-
Moderate/High	10-16%	4-10%	0-4%
High	>16%	10-16%	4-10%
Very high	-	>16%	10-16%
Extreme	-	-	>16%

Table 7. Agricultural land uses that were retained in the model identifying highly erodible soils based on their high, very high, or extreme erosion potential in Table 6. These land uses were initially identified from the NASS Cropland Data Layer.

Land-Use GridCode	Land Use	Land-Use GridCode	Land Use
1	Corn	4	Sorghum
5	Soybeans	6	Sunflower
11	Tobacco	12	Sweet Corn
21	Barley	23	Spring Wheat
24	Winter Wheat	27	Rye
28	Oats	36	Alfalfa
42	Dry Beans	43	Potatoes
61	Fallow/Idle Cropland	131	Barren
222	Squash	229	Pumpkins

Like any model, the accuracy and precision of this site selection model was limited by the quality of the data incorporated into the model. In this model, the most obvious limitation was the precision and accuracy of the NASS Cropland Data Layer. The relatively large size of the individual grid cells [900-m^2 (9,688-ft^2)] meant that land-use features were broadly categorized and often did not conform to the actual on-the-ground boundaries. At the broader scale, these data were more useful for characterizing land uses across the landscape, but, at the scale of individual sites, they frequently mis-classified land uses, especially cropland land uses, actually observed on aerial photographs and through on-the-ground field surveys. Due to the large number of areas mis-classified as cropland in the NASS layer, we used the 2011, 2012, and 2014 aerial photographs to verify cropland land uses (if a site was cropped in any one of these years, we retained it in the final model). Although not visible on aerial photographs, the soils and slope data may have similar, although hopefully less marked, limitations imposed by both the resolution and classification of the data (e.g. the digital elevation model used to calculate slopes had a resolution of 100 m^2). Nevertheless, the model did produce a spatially-explicit data set of croplands that are potentially at risk of erosion and phosphorus loss and that can be further refined using aerial photographs and on-the-ground field assessments. Ultimately, delineation of the actual area of highly-erodible soils will be determined by on-the-ground field assessments of the soils and physical characteristics of each site.

Results and Discussion

The model initially identified 3,527 locations covering 547 ha (1,352 acres) that were classified as being cropland that was highly vulnerable to erosion in the Vermont portion of the Lake Memphremagog Basin. However, review of the GIS layer revealed that the NASS-based land uses were mis-classified as cropland in a large number of areas, where, in fact, the actual land uses were hay, pasture, old field, or even roads, residential areas, wetland, or forest. To correct these errors, we used the 2011, 2012, and 2014 aerial photographs to verify cropland land uses (if a site was cropped in any of these three years, we retained it in the final model). Ultimately, the revised model identified 920 locations covering 262 ha (635 acres) that were classified as being cropland that was highly vulnerable to erosion in the Vermont portion of the Lake Memphremagog Basin. These 920 locations were concentrated in the upstream and downstream sections of the Black River watershed, the downstream section of the Barton River watershed, and the Johns River watershed (Figure 19). Of the 262 ha (635 acres) in these 920 locations, approximately 25% occurred in areas with very high or extreme erosion potential, and the remaining 75% occurred in areas with high erosion potential (Table 8).

Table 8. Numbers of polygons and areal extent encompassed by three classes of highly-erodible soils on cropland in the Vermont portion of the Lake Memphremagog Basin. These 9,135 polygons were clustered into 920 locations.

Erosion Potential	# Polygons	Area (ha)	Area (acres)
High	5,738	193	469
Very high	2,679	55	133
Extreme	718	14	33
Total	9.135	262	635

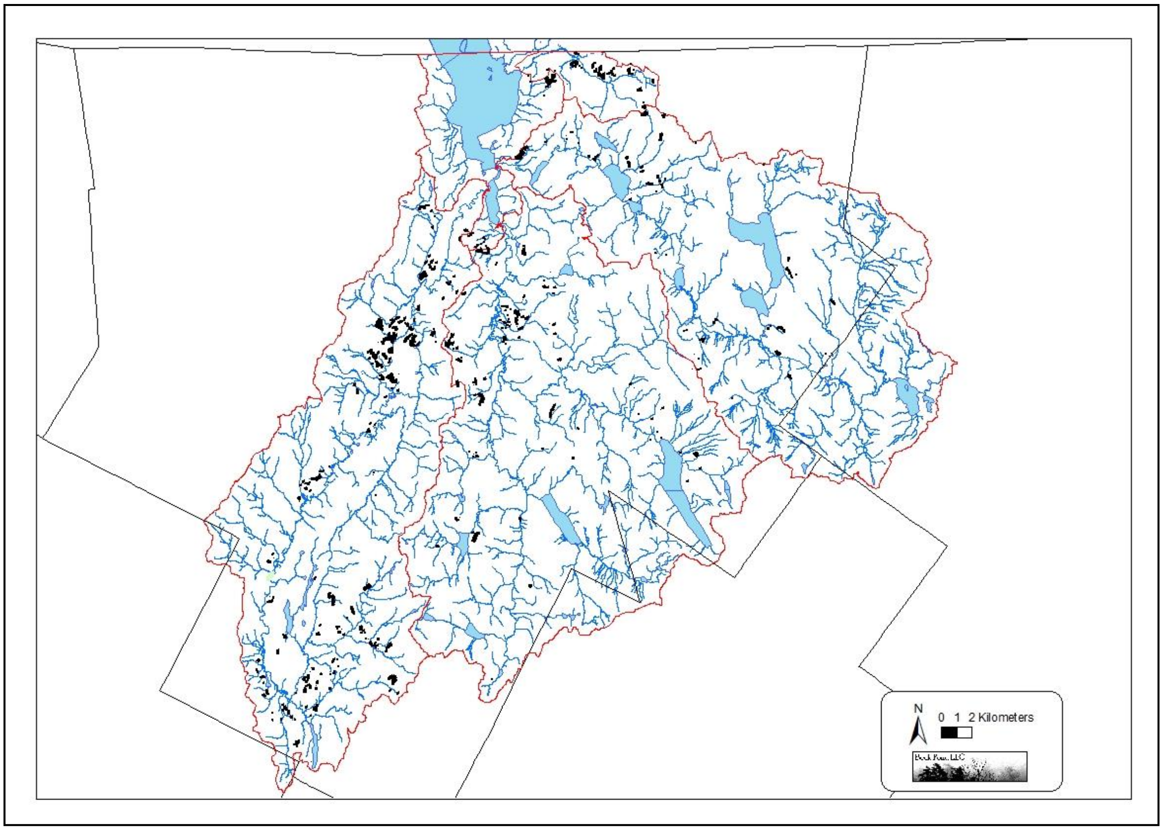

Figure 19. *Cropland areas that were modeled as being most vulnerable to soil erosion and phosphorus loss in the Vermont portion of the Lake Memphremagog Basin.*

Phosphorus Load Reductions

Finally, we developed and tested a methodology for calculating potential phosphorus load reductions that might be achieved by implementing various Best Management Practices (BMP) as part of the Total Maximum Daily Load (TMDL) and Basin Plan being developed for the Lake Memphremagog Basin.

Methods

To accomplish this task, we modified the Best Management Practices (BMP) Scenario Tool developed for the Lake Champlain Basin. For each watershed examined, we used the area of each land use as mapped in the Cropland Data Layer from the National Agricultural Statistics Service (NASS), the phosphorus load attributable to each land use based on the modified phosphorus export model (SMi 2009), a list of possible projects and practices that could be implemented in each land use, and the efficiency with which those projects and practices would reduce phosphorus loading from each land use. Collectively, these inputs allowed us to calculate the absolute and proportional reductions in phosphorus load that would be attained by implementing projects or practices on some or all of the area encompassed by each land use in each tributary watershed. In developing this approach, we used a subset of subwatersheds for which we had land-use data from both the NASS Cropland Data Layer and from aerial photographs and field assessments. Due to time constraints, however, we have so far used only two tributary subwatersheds to develop and test this methodology (Strawberry Acres and Wishing Well tributaries). We chose these two watersheds, because they had diverse land uses but included both concentrated agricultural production areas and significant areas of agricultural fields, including hay and pasture. In addition, both watersheds had already received considerable attention, including multiple years of water quality sampling and implementation of various phosphorus-reduction projects and practices over the past few years.

To assess the feasibility of using the BMP Scenario Tool to identify and prioritize projects and practices that might most effectively reduce phosphorus exports into the Lake Memphremagog Basin, we first examined the correlations between land uses mapped and classified by the NASS Cropland Data Layer and those mapped and classified from aerial photographs and field assessments. Second, in order to test the value of the BMP Scenario Tool in identifying and prioritizing projects and practices that will best improve water quality in the Lake Memphremagog Basin, we compared three different approaches to implementing phosphorus-reduction projects and practices: 1) full implementation of the optimal projects and/or practices across all areas of each land use, 2) implementation of only suitable projects and/or practices and only in the appropriate areas of each land use, and 3) implementation of only the projects and/or practices that have already been undertaken and completed. For many of the land uses, there were either no applicable best management practices (water, wetland, barren land, and herb/shrub) or only a single suitable practice (developed pervious, all four classes of dirt road, farmstead, and forest)(Table 9). For two of the land uses, we considered implementation of only a single surface infiltration practice applied to either 5% (developed pervious) or 10% (paved roads) of the area classified as that land use. Finally, for three of the agricultural land uses (cultivated land, hay, and pasture), multiple practices were possible, and so we used the land-use layer derived from the aerial photographs and field assessments to identify which areas were suitable for each of the possible projects and practices. For example, riparian and ditch buffers were only suitable for agricultural fields that were bisected by or bordered a stream or ditch. We then used this information to calculate the percentage of the area encompassed by that land use on which that project or practice could be applied.

Table 9. Best Management Practices applicable to each land use in the Lake Memphremagog Basin. Efficiency is the proportion of the phosphorus load that would be eliminated by implementing each project or practice on that land use.

Land Use	Project or Practice	Required Condition(s)	Efficiency (%)
Developed	No P fertilizer (pervious)	Fertilized lawn (max=12%)	50
Developed	Impervious area removal	Various	89
	Biofiltration with underdrains	Various (max=40%)	38-89
	Surface infiltration practices	Various (max=40%)	54-99
	Sand filter	Various (max=40%)	42-65
	Infiltration trench	Various (max=40%)	51-99
	Extended dry detention pond	Various (max=40%)	19
	Open channel/dry swale	Various (max=40%)	34
	Gravel wetland	Various (max=40%)	30-66
	Wet pond/created wetlands	Various (max=40%)	42-65
Paved road	Leaf litter collection	N/A	5
	Mechanical broom sweeper	N/A	1-3
	Regenerative air-vacuum	N/A	8
	Catch basin cleaning	Catch basins	2
	Biofiltration with underdrains	Various	38-89
	Surface infiltration practices	Various	54-99
	Infiltration trench	Various	51-99
	Extended dry detention pond	Various	19
	Gravel wetland	Various	30-66
	Wet pond/created wetlands	Various	42-65
Dirt road	Roadside erosion control	N/A	50
Farmstead	Barnyard management	N/A	80
Cultivated soil	Manure injection	N/A	9
	Reduced P manure	N/A	9
	Change in crop rotation	N/A	25
	Crop to Hay	N/A	80
	Conservation tillage	N/A	25
	Cover crop	N/A	28
	Grassed Waterways	Cropped wet swale	30
	Ditch buffer	Ditch in or beside field	51
	Riparian buffer	Stream in or beside field	41
Hay	Grassed waterways	Gully erosion	52
	Ditch buffer	Ditch in or beside field	51
	Riparian buffer	Stream in or beside field	41
	Manure injection	N/A	2
	Reduced P manure	N/A	2
Pasture	Fencing with riparian buffer	Stream in or beside field	74
	Fencing (no riparian buffer)	Stream in or beside field	55
Forest	Stream crossing controls	N/A	5

Results and Discussion

Land-Use Correlations

To assess the feasibility of using the BMP Scenario Tool to identify and prioritize projects and practices that might most effectively reduce phosphorus exports in the Lake Memphremagog Basin, we first examined the correlations between land uses mapped and classified by the NASS Cropland Data Layer and those mapped and classified from aerial photographs and on-the-ground field assessments. These analyses indicated that land uses differed greatly in how well they were correlated between the two approaches (Table 10): 1) forest, cultivated land, and hay field were generally well-correlated between the two approaches; 2) farmstead, pasture, and roads were moderately well-correlated; and 3) developed land, shrub/herb (old field), barren land, water, and wetlands were poorly correlated. Thus, using the BMP Scenario Tool based on the NASS Cropland Data Layer seemed a reasonable approach for some land uses (e.g. roads, cultivated land, hay, pasture, farmstead, and forest) and less well suited for the remaining land uses. Fortunately, our focus was on identifying projects and practices that could be implemented on agricultural lands.

Table 10. Correlations between land uses identified by the NASS Cropland Data Layer and by analyses of aerial photographs and on-the-ground field assessments in the Vermont portion of the Lake Memphremagog Basin. Well-correlated land uses are indicated by slopes and R^2 values near one (1); poorly-correlated land uses are indicated by R^2 values near zero (0).

Land Use	R^2	Slope
Forest	0.93	0.91
Cultivated land	0.94	0.88
Hay	0.71	0.88
Farmstead	0.95	0.43
Pasture	0.63	0.34
Roads	0.70	1.34
Developed land	<0.01	0.03
Shrub/herb (old field)	0.01	-0.35
Barren land	0.22	12.27
Water	0.34	0.44
Wetland	0.20	4.68

Strawberry Acres Tributary

The watershed of the Strawberry Acres tributary covers approximately 331 ha (818 acres) and drains directly into the southwest corner of Lake Memphremagog. Land uses in this watershed are dominated by forest [217 ha (536 acres)] and agriculture, primarily hay [42 ha (103 acres)]. For the Strawberry Acres tributary, we examined three scenarios for BMP implementation (Table 11). The total estimated phosphorus load for this watershed is 133 kg/year.

Table 11. Phosphorus load reductions potentially achieved by instituting various Best Management Practices and projects under three different scenarios in the watershed of the Strawberry Acres tributary. Reductions were calculated by the BMP Scenario Tool modified for the Lake Memphremagog Basin. Bold font indicates reductions greater than 5%.

Land Use	Project(s) and/or Practice(s)	Area (ha)	Load Reduction (kg)	% Reduction
Theoretical Maximum (100% Implementation of the Most Efficient Projects and Practices)				
Developed	Ban on phosphorus fertilizer (pervious)	1.4	0.4	0.3
Developed	Surface infiltration practices (impervious)	1.1	2.4	1.8
Paved roads	Surface infiltration practices	2.2	2.7	2.0
Dirt roads	Roadside erosion control	2.1	7.1	5.4
Farmstead	**Barnyard management**	**2.3**	**20.8**	**15.6**
Cultivated	Cover crop, conservation tillage, etc.	0.8	2.4	1.8
Hay	**Grassed waterways, riparian buffer**	**44.4**	**25.4**	**19.0**
Pasture	**Livestock fencing w/riparian buffer**	**13.5**	**8.0**	**6.0**
Forest	Stream crossing	188.8	0.7	0.5
Total		256.6	69.9	52.4
Feasible Projects and Practices				
Developed	Ban on phosphorus fertilizer (pervious)	1.4	0.4	0.3
Developed	Surface infiltration practices (impervious)	0.1	0.3	0.2
Paved roads	Surface infiltration practices	0.2	0.2	0.2
Dirt roads	Roadside erosion control	1.1	4.2	3.1
Farmstead	**Barnyard management**	**2.3**	**20.8**	**15.6**
Cultivated	Change in crop, conservation tillage	0.8	1.3	0.9
Hay	Manure injection/reduced P manure	41.3	0.7	0.5
Hay	Riparian buffer	3.1	1.0	0.8
Pasture	Livestock fencing (no buffer)	4.1	1.8	1.3
Pasture	Livestock fencing w/riparian buffer	9.5	5.6	4.2
Forest	Stream crossing	188.8	0.7	0.5
Total		253.0	37.0	27.7
Projects and Practices Implemented to Date				
Developed	Ban on phosphorus fertilizer (pervious)	1.4	0.4	0.3
Farmstead	**Barnyard management**	**2.3**	**20.8**	**15.6**
Pasture	Livestock fencing (no buffer)	4.1	1.8	1.3
Total		7.7	23.1	17.3

First, we evaluated the phosphorus load reductions that would result if only the optimal projects and practices that resulted in the largest reductions in phosphorus loads were applied across all the areas encompassed by the corresponding land use. In this scenario, the greatest reductions in phosphorus loads would occur if grassed waterways and riparian buffers were applied to all hay fields, barnyard improvement projects were applied to all farmsteads, and livestock exclusion fencing and riparian buffers were applied to all pasture. Collectively, these and the other "optimal" practices would be applied to 257 ha (634 acres) and would result in a phosphorus load reduction of 69.9 kg/year, a 52% reduction.

Second, we evaluated the phosphorus load reductions that would result if only the suitable projects and practices were applied to only the appropriate subset of areas of each corresponding land use. This set of projects and practices can only be implemented in more limited areas of their corresponding land uses due to financial, logistical, and other constraints. In this scenario, the greatest reductions in phosphorus loads would again occur if barnyard improvement projects were applied to all of the farmsteads and livestock exclusion fencing and riparian buffers were applied to 70% of the pasture. In addition, greater reductions in phosphorus loads would also be obtained from the application of roadside erosion controls to dirt roads, especially those at moderate to high risk of erosion. Collectively, these and the other "feasible" practices would be applied to 253 ha (624 acres) and would result in a phosphorus load reduction of 37.0 kg/year, a 28% reduction.

Third, we evaluated the phosphorus load reductions that should have resulted from the projects and practices that have already been implemented in this watershed. These projects and practices included barnyard improvement projects (hardened barnyard, new manure pit, new laneways) that were applied to all of the farmsteads and livestock exclusion fencing with no riparian buffers that were applied to 30% of the pasture. In addition, we assumed that there had been a 12% reduction in the area of developed, pervious lands that were receiving phosphorus fertilizer. Collectively, these projects and practices, which would have been applied to 7.7 ha (19 acres) of the watershed, should result in phosphorus load reductions of 23.1 kg/year, a 17% reduction. This modeled reduction is roughly similar to the 24-35% reductions in total phosphorus concentrations measured at the two sites on the Strawberry Acres tributary in 2015.

Thus, based on all three scenarios, it is clear that the greatest reductions in phosphorus loads would occur primarily through the implementation of barnyard management practices and secondarily through the creation of riparian buffers along streams in and along hay fields and pasture and the installation of roadside erosion controls along dirt roads, especially those at moderate to high risk of erosion.

Wishing Well Tributary

The watershed of the Wishing Well tributary covers approximately 317 ha (783 acres) and drains directly into the southwest corner of Lake Memphremagog. Land uses in this watershed are dominated by forest [111 ha (274 acres)], agriculture, primarily hay [90 ha (223 acres)], and developed land [38 ha (93 acres)]. For the Wishing Well tributary, we again examined three scenarios for BMP implementation (Table 12). The total estimated phosphorus load for this watershed is 249 kg/year.

Table 12. Phosphorus load reductions potentially achieved by instituting various Best Management Practices and projects under three different scenarios in the watershed of the Wishing Well tributary. Reductions were calculated by the BMP Scenario Tool modified for the Lake Memphremagog Basin. Bold font indicates reductions greater than 5%.

Land Use	Project(s) and/or Practice(s)	Area (ha)	Load Reduction (kg)	% Reduction
Theoretical Maximum (100% Implementation of the Most Efficient Projects and Practices)				
Developed	Ban on phosphorus fertilizer (pervious)	1.7	0.5	0.2
Developed	Surface infiltration practices (impervious)	3.2	7.0	2.8
Paved roads	Surface infiltration practices	5.5	6.5	2.6
Dirt roads	Roadside erosion control	3.0	8.2	3.4
Farmstead	**Barnyard management**	**3.3**	**30.7**	**12.3**
Cultivated	Cover crop, conservation tillage, etc.	2.0	7.0	2.8
Hay	**Grassed waterways, riparian buffer**	**126.1**	**72.1**	**28.9**
Pasture	**Livestock fencing w/riparian buffer**	**38.5**	**22.6**	**9.1**
Forest	Stream crossing	110.2	0.4	0.2
Total		293.6	155.1	62.3
Feasible Projects and Practices				
Developed	Ban on phosphorus fertilizer (pervious)	1.7	0.5	0.2
Developed	Surface infiltration practices (impervious)	0.4	0.8	0.3
Paved roads	Surface infiltration practices	0.6	0.6	0.2
Dirt roads	Roadside erosion control	1.2	3.8	1.4
Farmstead	**Barnyard management**	**3.3**	**30.7**	**12.3**
Cultivated	Change in crop, conservation tillage	2.1	3.4	1.4
Hay	Manure injection/reduced P manure	21.4	0.4	0.1
Hay	**Ditch buffer**	**104.7**	**42.7**	**17.2**
Pasture	Livestock fencing (no buffer)	12.3	5.4	2.2
Forest	Stream crossing	110.2	0.4	0.2
Total		257.9	88.7	35.6
Projects and Practices Implemented to Date				
Developed	Ban on phosphorus fertilizer (pervious)	1.7	0.5	0.2
Farmstead	Barnyard management	1.1	10.1	4.1
Hay	**Ditch buffer**	**104.7**	**42.7**	**17.2**
Pasture	Livestock fencing (no buffer)	12.3	5.4	2.2
Total		119.8	58.8	23.6

First, we evaluated the phosphorus load reductions that would result if only the optimal projects and practices that resulted in the largest reductions in phosphorus loads were applied across all the areas encompassed by the corresponding land use. In this scenario, the greatest reductions in phosphorus loads would occur if grassed waterways and riparian buffers were applied to all hay fields, barnyard improvement projects were applied to all farmsteads, and livestock exclusion fencing and riparian buffers were applied to all pastures. Collectively, these and the other "optimal" practices would be applied to 294 ha (726 acres) and would result in a phosphorus load reduction of 155.1 kg/year, a 62% reduction.

Second, we evaluated the phosphorus load reductions that would result if only the suitable projects and practices were applied to only the appropriate subset of areas of each corresponding land use. This set of projects and practices can only be implemented in more limited areas of their corresponding land uses due to financial, logistical, and other constraints. In this scenario, the greatest reductions in phosphorus loads would again occur if barnyard improvement projects were applied to all of the farmsteads and buffers were implemented along all of the ditches passing through the many large hay fields. Collectively, these and the other "feasible" practices would be applied to 258 ha (637 acres) and would result in a phosphorus load reduction of 88.7 kg/year, a 36% reduction.

Third, we evaluated the phosphorus load reductions that should have resulted from the projects and practices that have already been implemented in this watershed. These projects and practices included barnyard improvement projects (hardened barnyard and clean water diversions) that were applied to approximately half of one of the farmsteads, ditch buffers applied to 83% of the hay lands, and livestock exclusion fencing with no riparian buffers that were applied to 32% of the pasture. In addition, we assumed that there had been a 12% reduction in the area of developed, pervious lands that were receiving phosphorus fertilizer. Collectively, these projects and practices, which would have been applied to 119.8 ha (296 acres) of the watershed, should result in a phosphorus load reduction of 58.8 kg/year, a 24% reduction. Unfortunately, these modeled load reductions greatly exceeded the largely unchanged total phosphorus concentrations measured in this tributary following the implementation of these projects and practices (Gerhardt 2014).

Thus, based on all three scenarios, it is clear that the greatest reductions in phosphorus loads would occur primarily through the implementation of barnyard management practices and secondarily through the creation of riparian buffers along streams in and along hay fields and installation of livestock exclusion fencing in pasture. In addition, implementation of surface infiltration practices on developed impervious lands would also significantly reduce the phosphorus loads emanating from this watershed.

Conclusions

In general, using the BMP Scenario Tool to identify and prioritize actions to protect and improve water quality, especially by reducing phosphorus loads, seems to be a useful planning and implementation exercise. In our two tests using this approach, we were able to identify specific projects and practices that would likely lead to the greatest reductions in phosphorus exports from these two watersheds. Ultimately, however, this approach will only be useful if it translates into planning, development, and implementation of the appropriate projects and practices that best protect and improve water quality in the Lake Memphremagog Basin.

As with many modeling approaches, this approach has a number of limitations. First, this approach was highly dependent on accurate mapping and classification of land uses. The Cropland Data Layer from the National Agricultural Statistics Service (NASS) provided a fairly accurate mapping and classification of land uses across the broader landscape but was less satisfactory at the scale of individual sites and land uses. Thus, we found it necessary to cross-reference the NASS data and other land-use maps developed from aerial photographs and field assessments. This discrepancy was especially important when identifying the appropriate projects and practices that could be implemented on specific sites. Second, this approach did not incorporate any measures of distance to surface waters, possible pathways that would allow nutrients and sediment to move from their sources into surface waters, and other topographic elements (e.g. slope) that likely have significant impacts on the degree and extent of phosphorus loading from these watersheds. Third, this approach assumes an "average" loading and loading reduction efficiency across all sites of a particular land use, but, as alluded to in the previous point, individual sites likely differ in both their loading due to these and other factors and also the efficiency with which that loading can be reduced by implementation of the various projects and/or practices. Fourth, only a subset of projects and/or practices may be applicable across large areas of any one land use due to lack of opportunities (e.g. riparian buffers are not applicable in corn, hay, or pasture where no river or stream bisects or borders the site). Fifth, identifying the appropriate projects and/or practices that are suitable for several of the land uses required considerable effort, including reviewing aerial photographs and land-use maps and on-the-ground field assessments. For the larger watersheds, this step will be time-consuming, especially if the land uses in the watersheds have not been mapped accurately or precisely. Finally, implementation of many of these projects and practices will require willing landowners and land managers and may require considerable financial and other resources. However, implementation of these projects and practices will ultimately be necessary in order to protect and improve water quality conditions in Lake Memphremagog and its tributaries.

Individual Sites and Subwatersheds

In the sections that follow, we describe in greater detail possible sources of water quality problems, potential phosphorus-reduction projects and practices, wetland restoration opportunities, highly-erodible soils, and the current status of efforts to protect and improve water quality for selected individual subwatersheds and sites. Implementation of phosphorus-reduction projects and practices and wetland restoration projects at these sites and in these subwatersheds will likely be one of the most effective methods for reducing phosphorus exports into the surface waters of the Lake Memphremagog Basin.

Black River Watershed

Airport Tributary

The Airport Tributary, a small tributary of the Black River, drains approximately 296 ha (730 acres) in the town of Coventry. This small tributary includes two major branches, the northern branch, which drains part of the Newport State Airport, and the eastern branch, which drains part of the airport as well as wetlands, forests, and agricultural fields, some of which were cleared of forest in 2011. Water quality in this tributary was first sampled at one site in 2013 and identified elevated levels of phosphorus and turbidity as issues of concern. In 2015, two sites were added at the mouths of the northern and eastern branches of this tributary to further pinpoint and assess possible sources of the high nutrient and sediment levels. Furthermore, upon observing extremely turbid waters in the northern branch during a rain event, we scouted the length of this branch from its mouth upstream to the airport.

In 2015, we sampled water quality at three sites along this tributary to further pinpoint and assess possible nutrient and sediment sources in this watershed. In general, total phosphorus concentrations were moderately high at the Airport Tributary site (median = 35.2 μg/l, range = 18.7-570 μg/l) and Airport Trib South site (median = 35.6 μg/l, range = 16.9-452 μg/l) and were slightly higher at the Airport Trib North site (median = 37.4 μg/l, range = 29.0-2,920 μg/l). At all three sites, total phosphorus concentrations generally increased with increasing flows but most dramatically at the Airport Tributary and Airport Trib North sites (Figure 20). In contrast, total nitrogen concentrations were generally low or moderate at all three sites (range across all three sites = 0.11-2.50 mg/l). Turbidity levels, on the other hand, were generally low on six of the eight sample dates, except during two rain events, when turbidity levels were extremely high at the Airport Trib North site (27 April 2015 = 80.6 NTU and 9 June 2015 = 1,854 NTU)(Figure 21). Due to the extremely turbid waters in the northern branch following heavy rains on 9 June 2015, we scouted the length of this branch and observed numerous areas of extreme stream bank erosion, stream channel incision, and head-cutting in a series of gullies extending along much of the length of this branch (Figure 22). Based on our observations, we identified stormwater runoff from the southwest corner of the Newport State Airport as the likely cause of the excessive erosion of this stream channel, since much of the stormwater runoff from the hardened surfaces of the airport (e.g. runways, taxiways, etc.) and intervening grasslands appears to flow through culverts and into this tributary. Preliminary discussions to evaluate this issue have been held with the airport authority, and this site is being included in a stormwater study being undertaken by the Memphremagog Watershed Association.

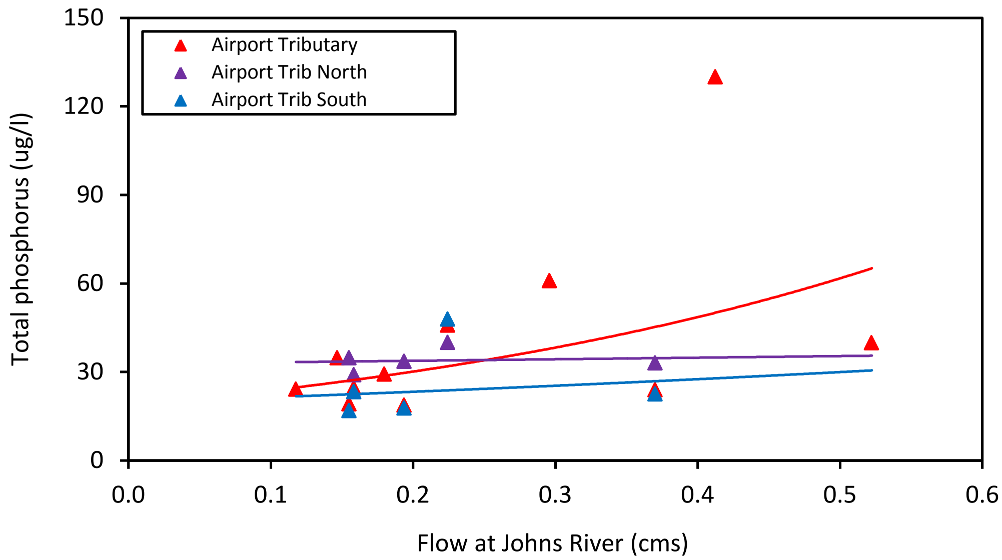

Figure 20. *Total phosphorus concentrations in relation to stream flow at three sites along the Airport tributary of the Black River during April-October 2015. Stream flows were estimated from the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Figure 21. *Extremely turbid, sediment-laden waters were flowing from the northern branch of the Airport tributary following heavy rains on 9 June 2015.*

Figure 22. *Extreme stream bank erosion and stream channel incision was noted along the northern branch of the Airport tributary on 9 June 2015, possibly due to excessive amounts of stormwater flowing from the Newport State Airport into this tributary.*

St. Onge Tributary

The St. Onge tributary, a small tributary of the Black River, drains a small area along Coventry Station Road in the town of Coventry. After concerns were raised regarding water quality conditions, staff from the Vermont DEC sampled water quality in this tributary in November 2014. These water quality samples revealed extremely high concentrations of both total phosphorus (3,820 µg/l) and total nitrogen (27 mg/l) along a branch of this tributary that drained an agricultural production area. In addition, extensive growths of "sewage fungus" (*Sphaerotilus natans*, a filamentous bacterium that is closely associated with polluted water) were observed completely covering the streambed along at least 100 m (328 ft) of this tributary (Figure 23). Based on these data and observations, staff from the Vermont DEC and VAAFM visited this site and identified serious issues with a farm operation located further upstream. First, leachate from a silage storage area was draining into the stream. To correct this problem, the owner installed a temporary barrier around the silage pad and is reportedly working on a permanent solution to this problem. Second, the manure pit may be leaking and an overflow pipe that was supposed to have been removed was plugged with clay instead. Staff from the VAAFM planned to conduct additional inspections of this farm in the spring of 2015, when the lack of vegetation will allow better assessment of these facilities.

Figure 23. *Extensive growths of Sphaerotilus natans, a bacterium associated with polluted waters, covered the bed of the St. Onge tributary on 12 November 2014 (photograph courtesy of Ben Copans).*

In 2015, we sampled one site to further assess the extremely high nutrient and sediment levels measured in this tributary . In 2015, the water samples collected at this site continued to exhibit extremely high total phosphorus concentrations (median = 332 µg/l, range = 142-5,180 µg/l), very high total nitrogen concentrations (median = 5.5 mg/l, range = 3.0-29.8 mg/l), and high turbidity levels (median = 10.1 NTU, range = 1.3-333 NTU). Total nitrogen and turbidity generally increased but total phosphorus generally decreased with increasing stream flows (Figure 24-26). In the Autumn of 2015, the Biomonitoring and Aquatic Studies Section (BASS) of Vermont DEC found that the macroinvertebrate community further downstream only ranked as "Fair". Although the flows from this stream are small, these high nutrient and sediment levels indicate that the total loading from this stream may still be substantial. Thus, we recommend continuing to sample water quality conditions at this site as well as along the main stem of this tributary to better pinpoint and assess nutrient and sediment inputs. In addition, State agency staff should continue to work with the owner of the farm to ensure that farm practices do not harm water quality in this tributary.

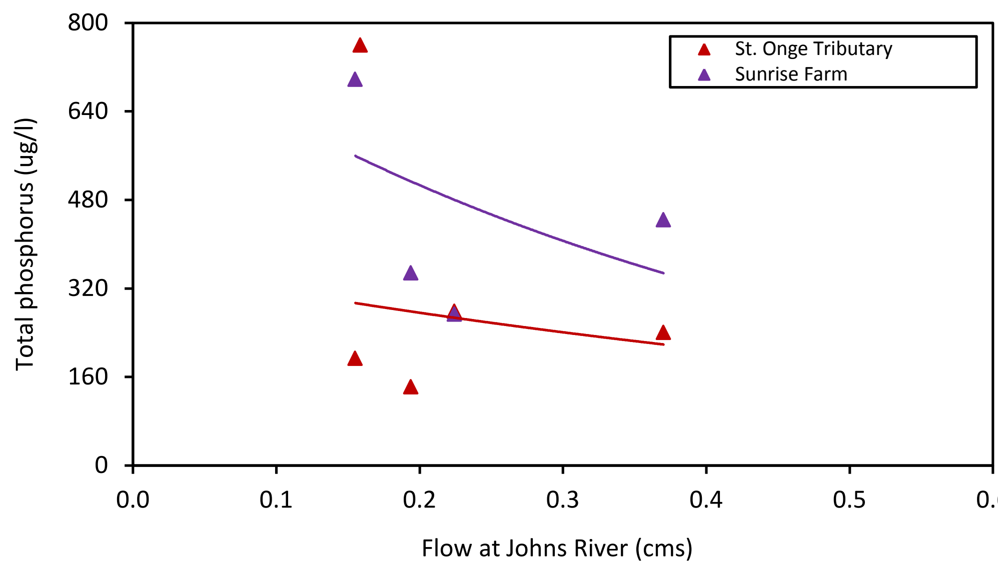

Figure 24. *Total phosphorus concentrations in relation to stream flow at the St. Onge Tributary and Sunrise Farm sites during April-October 2015. Stream flows were estimated from the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

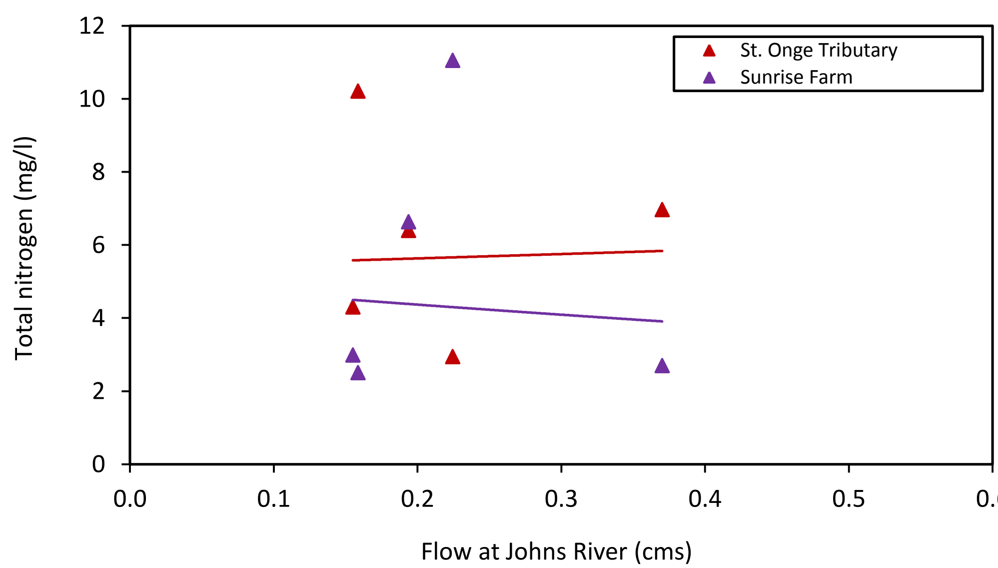

Figure 25. *Total nitrogen concentrations in relation to stream flow at the St. Onge Tributary and Sunrise Farm sites during April-October 2015. Stream flows were estimated from the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

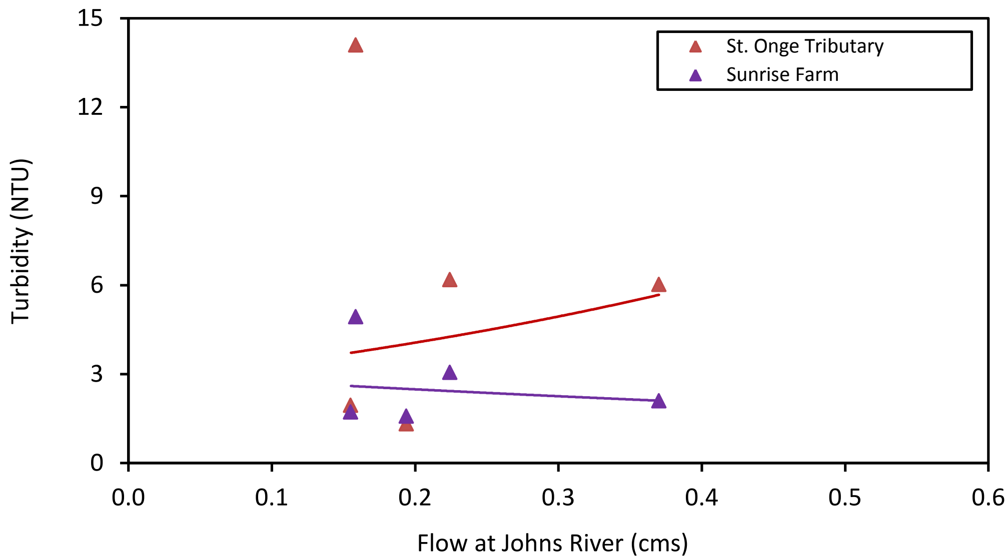

Figure 26. *Turbidity levels in relation to stream flow at the St. Onge Tributary and Sunrise Farm sites during April-October 2015. Stream flows were estimated from the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

<u>Sunrise Farm</u>

The Sunrise Farm tributary, a small tributary of Stony Brook, which is, itself, a tributary of the Black River, drains a small area along Hancock Hill Road in the town of Coventry. Previously, we had measured moderately high levels of phosphorus, nitrogen, and turbidity, and we had observed extremely turbid waters on several occasions further downstream along Stony Brook. Although we had identified several possible nutrient and sediment sources along Stony Brook, we had not conclusively identified and assessed all the possible nutrient and sediment sources. While scouting possible phosphorus sources in the Stony Brook watershed, we identified a small tributary flowing through a barnyard along Hancock Hill Road as another possible source of nutrients and sediment (Figure 27).

In 2015, we measured water quality at one site along this tributary. The water samples at this site exhibited very high total phosphorus concentrations (median = 428 µg/l, range = 271-905 µg/l) and very high total nitrogen concentrations (median = 5.1 mg/l, range = 2.5-11.1 mg/l) but relatively low turbidity levels (median = 2.6 NTU, range = 1.6-14.5 NTU). Total phosphorus, total nitrogen, and turbidity all generally decreased with increasing stream flows (Figure 24-26). Based on these measurements, it seems clear that this tributary is being impacted by activities in the upper watershed of this stream, including possibly the farmstead and the surrounding fields through which this stream flows. Thus, we recommend that staff from the VAAFM visit this farm to ensure that all required practices are being followed to protect water quality in this stream. Although the flows from this stream are small, the very high nitrogen and phosphorus levels indicate that the total loading may be substantial.

Figure 27. *Small stream draining Sunrise Farm along Hancock Hill Road in Coventry, Vermont on 12 October 2015. Runoff from the farmstead in the background and pastures in the foreground may be causing the high phosphorus and nitrogen levels measured in this tributary of Stony Brook.*

Brighton Brook

Brighton Brook, a tributary of the Black River, drains approximately 1,403 ha (3,466 acres) in the town of Irasburg. Water quality in Brighton Brook was first sampled in 2010 and exhibited very high levels of phosphorus, nitrogen, and turbidity. In subsequent years, we sampled water quality at additional sites along this stream and its tributaries in order to better pinpoint and assess possible nutrient and sediment sources. Total phosphorus and total nitrogen levels have been consistently high along the northern branch of Brighton Brook and extremely high in a small tributary that flows into this northern branch. This small tributary drains an area encompassing a large farmstead complex, including barns, manure pits, silage storage areas, and a mortality compost pile, as well as large areas of corn and hay. Identifying the source(s) of the high nutrient levels in this tributary was complicated by 1) the presence of a series of small ponds and wetlands that may store nutrients during high flows and release them during low flows in late summer, 2) the draining and filling of the large wetland formerly located in the upper watershed, and 3) rerouting the stream that drained these corn fields and wetlands through drain pipes. Nevertheless, following heavy rains in 2014, we were able to identify leachate from the large mortality compost pile as an important source of the nutrients flowing into the northern branch of Brighton Brook (Figure 28). Despite repeated requests to relocate and/or collect the leachate from this mortality compost pile, no actions were undertaken, and so the Vermont DEC pursued an enforcement action that resulted in an Assurance of Discontinuance (issued on 23 July 2015) to correct this problem.

Figure 28. *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 on 8 October 2013. Note the darkened ground where leachate from the compost pile has flowed down and puddled at the bottom of the farm road.*

In 2015, we resampled three sites along the main stem and northern branch of Brighton Brook in order to evaluate whether water quality conditions had improved as a result of the corrective actions. In 2015, water quality conditions at these three sites generally remained similar to those measured previously, possibly because the mortality compost pile had not been completely removed by the end of the growing season. As in 2010-2014, total phosphorus concentrations were relatively high at the downstream-most site along Brighton Brook (median = 34.8 µg/l, range = 23.5-297 µg/l). As in 2013-2014, total phosphorus concentrations along the northern branch of Brighton Brook were higher at the downstream site (Brighton Brook North; median = 40.6 µg/l, range = 26.0-456 µg/l) and even higher at the upstream site (Upper Brighton Brook North; median = 412.1 µg/l, range = 172-1,680 µg/l). Total phosphorus concentrations exhibited a negative relationship with stream flow at the Upper Brighton Brook North site, a positive relationship with stream flow at the Brighton Brook North site, and no relationship with stream flow at the Brighton Brook site (Figure 29). In 2015, median total phosphorus concentrations showed modest improvements at the two sites located along the northern branch but little, if any, improvement at the site on the main stem of Brighton Brook (Figure 30).

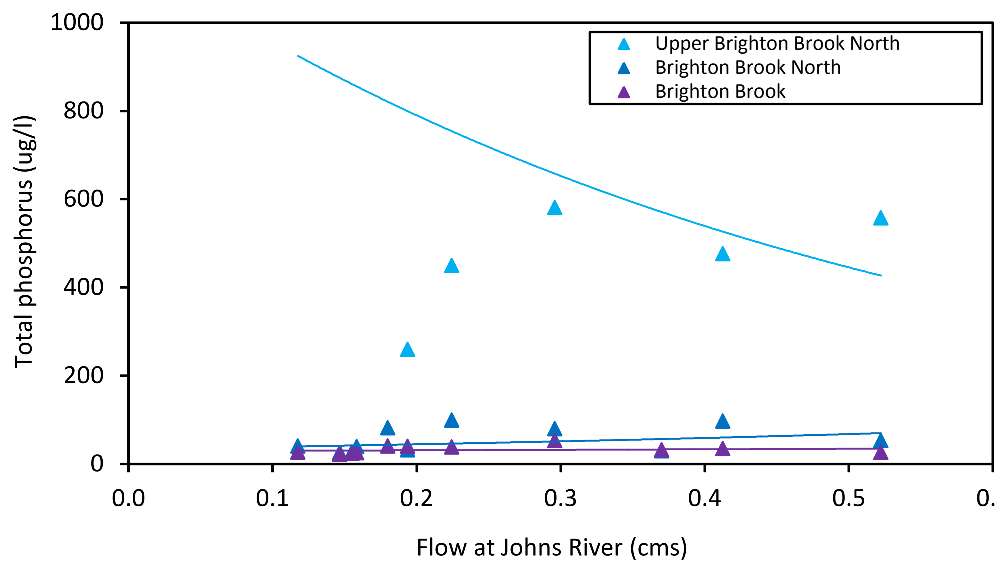

Figure 29. *Total phosphorus concentrations in relation to stream flow at three sites along the main stem and northern branch of Brighton Brook during April-October 2014 and 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters. Note that two low-flow values for the Upper Brighton Brook North site exceed the scale on the y-axis.*

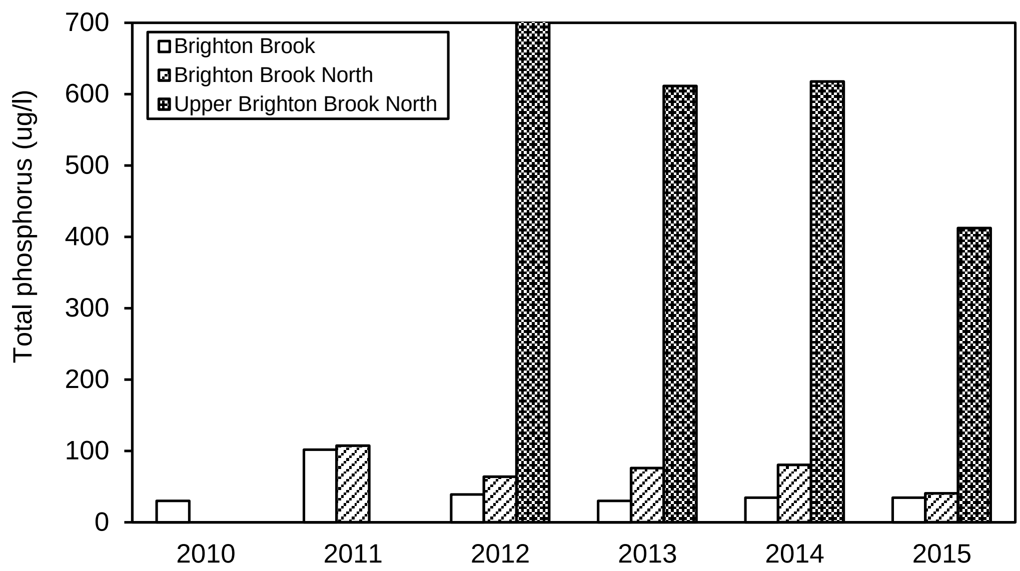

Figure 30. *Median total phosphorus concentrations at three sites along the main stem and northern branch of Brighton Brook during 2010-2015.*

Barton River Watershed

Hamel Tributary

The Hamel tributary, a small tributary of the Barton River, drains approximately 696 ha (1,721 acres) in the town of Irasburg. This small tributary includes three major branches that drain the eastern slopes of the ridge separating the Barton and Black Rivers. The entire watershed of this tributary is dominated by agricultural land uses but includes several blocks of forest as well as residential and other land uses. Water quality in this tributary was first sampled in 2012 and identified elevated phosphorus levels as an issue of concern. In 2013, additional sites were added along the three western branches of this tributary, and, based on these sites, we were able to further pinpoint and assess possible sources of the high phosphorus levels to the middle and upper branches of this tributary. In 2015, we continued our efforts to pinpoint and assess phosphorus and nitrogen sources along the middle and upper branches of this tributary.

As in previous years, both phosphorus and nitrogen levels were markedly higher at the site on the upper branch than the sites on the middle branch. At the Upper Hamel Tributary site, total phosphorus concentrations were high across all stream flows and showed a strong positive relationship with stream flow (Figure 31). Total nitrogen concentrations were also high across all stream flows but showed a strong negative relationship with stream flow (Figure 32). These high phosphorus and nitrogen levels, even at low flows, and strong relationships with stream flow suggested that phosphorus and nitrogen may be originating from both nonpoint and point sources in this watershed. Along this branch of the Hamel tributary, we have identified several possible sources of water quality problems. First, many of the corn fields along this tributary are located on steep slopes with shallow, highly-erodible soils. Consequently, the farmer has adopted no-till methods to crop many of the lower fields but still uses conventional methods to cultivate the upper fields. In addition, many of the fields have minimal buffers along this stream. 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, and, in the past, overflow from the manure pit and runoff and milkhouse waste have flowed into this stream. In 2015, the owner completed a clean-water diversion project to reduce the amount of water flowing into the manure pit. Finally, livestock graze directly in the stream just upstream of the sample site located on this tributary.

At the two sites along the middle branch of the Hamel tributary, total phosphorus and total nitrogen concentrations were remarkably similar and considerably lower than at the site along the upper branch. Collectively, these two sites provided a less clear picture of possible nutrient and sediment sources in this watershed (Figure 31-32). Along this branch, we have identified two possible sources of nutrients and sediment. First, there appears to be an area in the lower end of the hay field just upstream of the lower sample site where manure has been stacked and/or transferred to manure spreaders in the past. This site is located immediately upslope of and is separated by only a narrow band of trees from this tributary. Second, like the upper branch, a number of corn fields are located on steep slopes with highly-erodible soils in the headwaters of this tributary. However, the new site that we added further up this branch in

2015 exhibited very similar phosphorus and nitrogen levels to the lower site and, thus, did not allow us to further pinpoint possible nutrient and sediment sources along this stream.

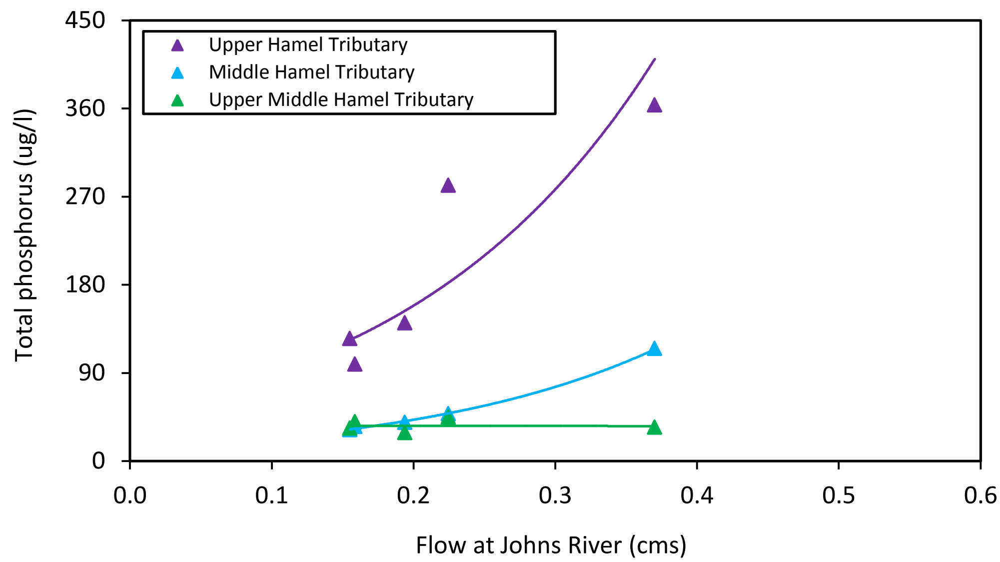

Figure 31. *Total phosphorus concentrations in relation to stream flow at three sites along two branches of the Hamel tributary during April-October 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

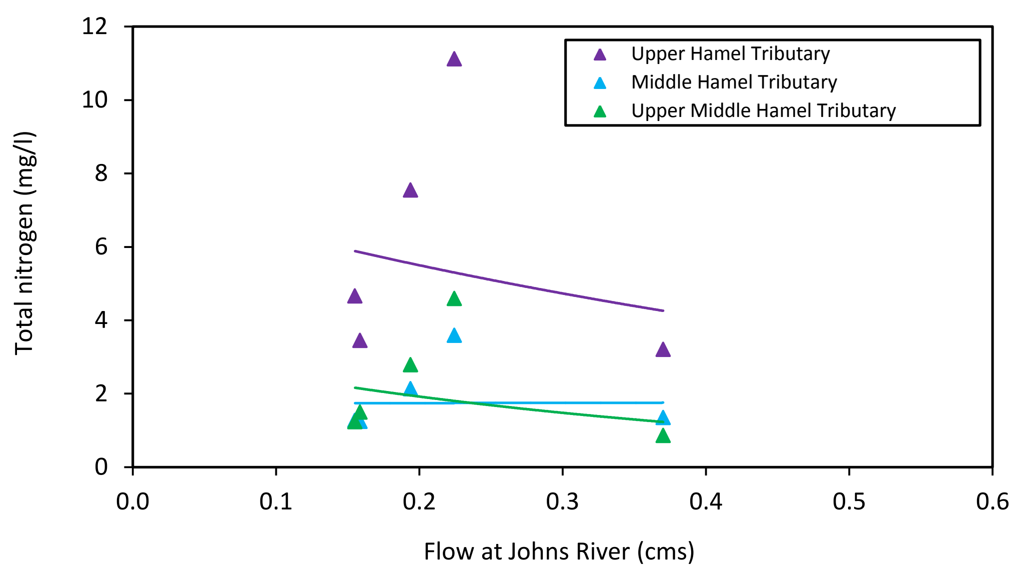

Figure 32. *Total nitrogen concentrations in relation to stream flow at three sites along two branches of the Hamel tributary during April-October 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Junkyard Tributary

The Junkyard tributary, a small tributary of the Barton River, drains approximately 348 ha (860 acres) in the towns of Irasburg and Barton. This small tributary drains large areas of agricultural land uses, almost 2 km (1.2 mi) of Interstate 91, small blocks of forest, and a residential area in the village of Orleans. Water quality in this tributary was first sampled in 2012 and identified elevated levels of phosphorus as an issue of concern. In 2013, we added an additional site further upstream, and, in 2014, we added two more sites where this tributary forks in order to better pinpoint and assess possible nutrient sources in the headwaters of this stream. Using our data and observations, staff from the VAAFM and Vermont DEC visited a medium farm operation (MFO) in this watershed on 14 November 2014 to discuss water quality problems and possible solutions. Subsequent to these discussions, the owner submitted an Environmental Quality Incentives Program (EQIP) application to fund improvements to the nutrient management plan (NMP) and field practices. Although the buffers around the corn and hay fields generally met BMP and regulatory requirements, the farmer widened the buffer in one area, undertook no-till cropping and cover-cropping, created a filter strip to capture runoff and sediment at the downhill edge of the steepest corn field, and moved the mortality pile. In the future, the owner hopes to build additional storage capacity and infrastructure to capture any overflow from the manure pit and leachate from the silage storage pad.

In 2015, we continued our efforts to pinpoint and assess phosphorus and nitrogen sources and to evaluate possible improvements in water quality along the main stem and two headwater branches of this tributary. In 2014 and 2015, total phosphorus and total nitrogen concentrations were generally higher at the two upstream sites (Royer Farm and Royer Tributary) than at the downstream site (Rock Junkyard)(Figure 33-34). In 2015, total phosphorus concentrations were intermediate at the downstream Rock Junkyard site (median = 31.5 μg/l, range = 18.2-432 μg/l), moderately high at the Royer Tributary site (median = 38.7 μg/l, range = 22.0-980 μg/l), and high at the Royer Farm site (median = 43.5 μg/l, range = 30.7-852 μg/l). Likewise, in 2015, total nitrogen concentrations were relatively low at the downstream Rock Junkyard site (median = 0.81 mg/l, range = 0.55-4.3 mg/l) and Royer Farm site (median = 0.83 mg/l, range = 0.48-2.7 mg/l) but intermediate at the Royer Tributary site (median = 1.7 mg/l, range = 0.89-2.8 mg/l). At the Royer Farm site, both total phosphorus and total nitrogen concentrations showed strong, positive relationships with stream flow (Figure 33-34). In contrast, total phosphorus and total nitrogen concentrations showed only slight, positive relationships with stream flow at the Rock Junkyard site. Finally, at the Royer Tributary site, total phosphorus showed a slight, positive relationship but total nitrogen showed a strong, negative relationship with stream flow. Thus, these data suggest that nonpoint source runoff is likely the dominant source of nutrients and sediment at the Royer Farm site, which drains several large agricultural fields but that a combination of nonpoint and point sources may be the source of the nutrients and sediment at the Royer Tributary site, which drains much of the farmstead, including the barns, barnyard, manure pit, and silage storage pad.

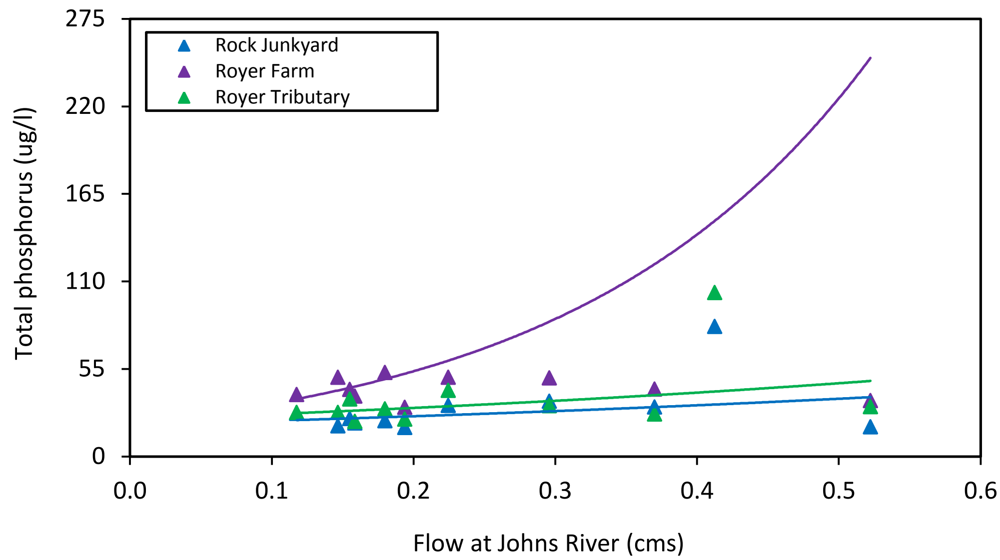

Figure 33. *Total phosphorus concentrations in relation to stream flow at three sites along the main stem and two branches of the Junkyard tributary during April-October 2014 and 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters. Note that one moderate-flow value for the Royer Farm site exceeds the scale on the y-axis.*

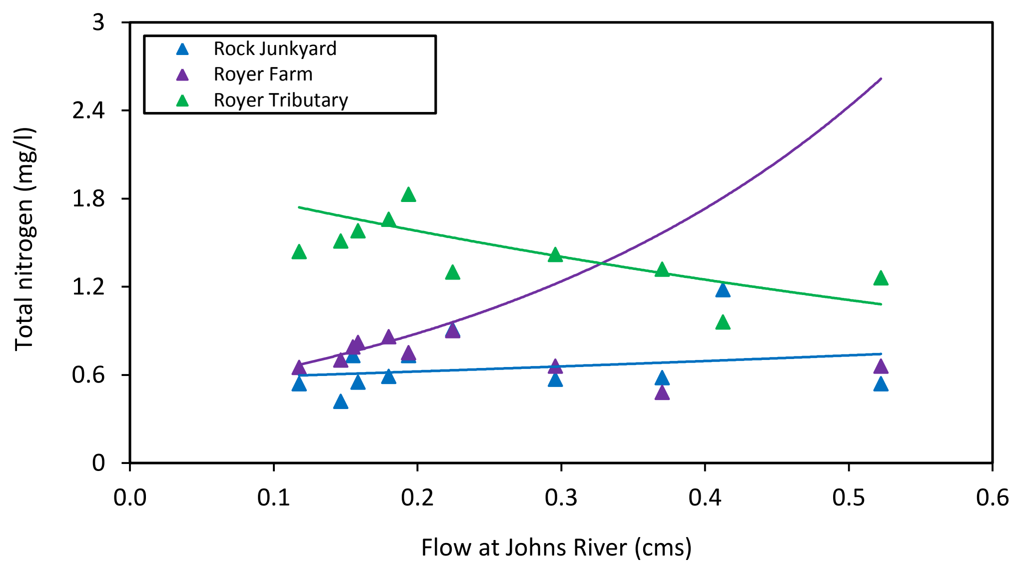

Figure 34. *Total nitrogen concentrations in relation to stream flow at three sites along the main stem and two branches of the Junkyard tributary during April-October 2014 and 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters. Note that one moderate-flow value for the Royer Farm site exceeds the scale on the y-axis.*

Johns River

Crystal Brook

Crystal Brook, which is the major tributary of the Johns River, drains approximately 356 ha (878 acres) in the town of Derby. This stream drains large areas of agricultural land uses but also forests on the western slope of the ridge separating the Lake Memphremagog and Tomifobia River basins. Water quality in this tributary was first sampled in 2006 after high phosphorus and nitrogen levels were measured further downstream in the Johns River. In 2006, we measured extremely high concentrations of total phosphorus and moderately high concentrations of total nitrogen at the Crystal Brook site (median total phosphorus = 128 μg/l, range = 29.1-655 μg/l); median total nitrogen = 1.6 mg/l, range = 1.3-3.2 mg/l). In addition, the Biomonitoring and Aquatic Studies Section of the Vermont DEC had designated this stream as impaired and in need of a TMDL due to nutrients and sediment from agricultural runoff (State of Vermont 2004). Based on these data and other assessments, it was determined that much of these nutrients were originating from a leaking manure pit located immediately alongside Crystal Brook, and so, with financial support from the NRCS and VAAFM, the owner replaced the leaking manure pit with a larger, sealed manure lagoon in 2007 and a new drainage system to capture leachate from the silage storage bunkers in 2009.

Following these projects, we have continued to monitor nutrient and sediment levels in Crystal Brook to ensure that these projects were successful in improving water quality conditions. Total phosphorus concentrations dropped dramatically between 2006 and 2008-2009 (Figure 35). In 2014, total phosphorus concentrations at both the Johns River and Crystal Brook sites remained low on all dates, except during two rain events. During the rain event on 28 July 2015, total phosphorus concentrations measured 2,940 μg/l and total nitrogen concentrations measured 14.2 mg/l at the Crystal Brook site. 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 during the one rain event suggested that there may still have been serious issues with runoff from a large 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 2013 and/or 2014. Subsequently, the VAAFM successfully undertook an enforcement action to correct water quality problems arising from barnyard runoff at this large barn complex.

In 2015, we resampled both the Crystal Brook and Johns River sites to further evaluate the success of these latest efforts to improve agricultural practices and the resulting water quality conditions in the Crystal Brook watershed. In 2015, total phosphorus concentrations were again relatively low at the Crystal Brook site (median = 30.2 μg/l, range = 14.3-282 μg/l) and Johns River site (median = 23.6 μg/l, range = 12.7-351 μg/l). Compared to 2006, total phosphorus concentrations at the Crystal Brook site have remained consistently low across most stream flows, except the high-flow events during 2014 (Figure 36). Likewise, total phosphorus concentrations also remained relatively low at the Johns River site, which is located approximately 3.75 km (2.3 mi) further downstream. In addition, total nitrogen concentrations at the Crystal Brook site have generally remained lower across most stream flows, especially the lowest flows (Figure 37). Thus, these data suggest that the earlier and more recent agricultural improvement projects and enforcement actions have resulted in improved water quality conditions in Crystal Brook and further downstream on the Johns River.

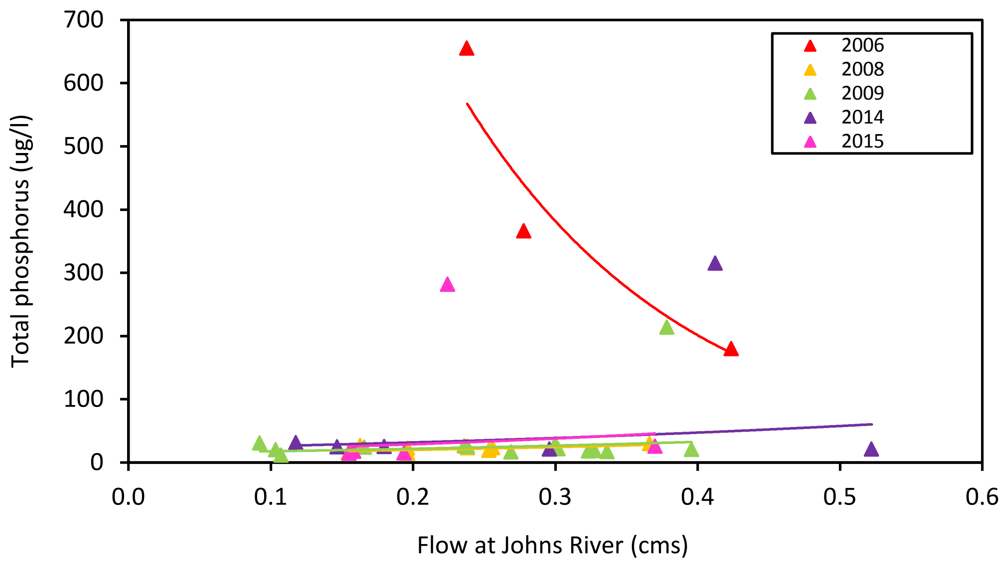

Figure 35. *Total phosphorus concentrations in relation to stream flow at the Crystal Brook site during 2006-2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

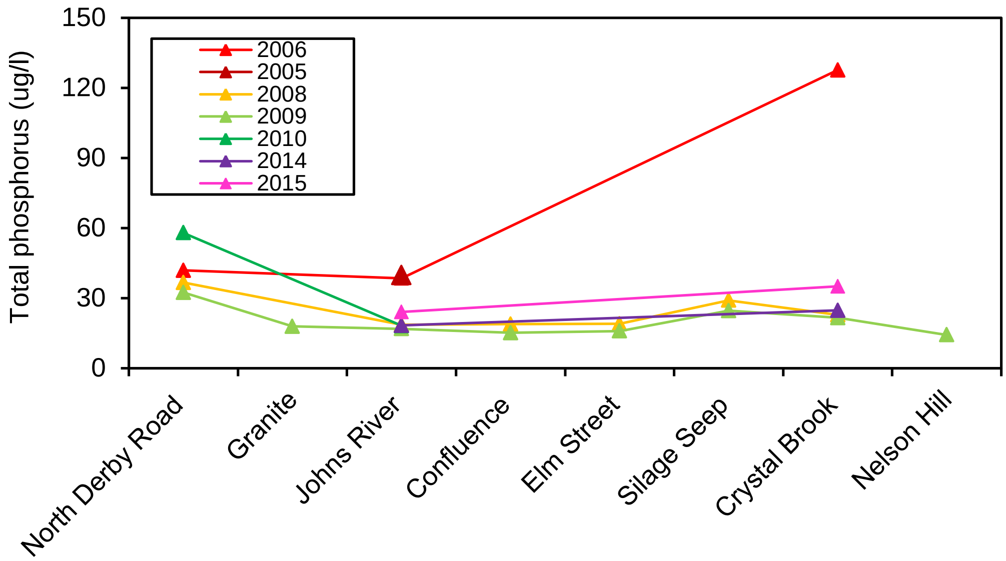

Figure 36. *Total phosphorus "profile" along Crystal Brook and the main stem of the Johns River from Nelson Hill downstream to North Derby Road during 2005-2015.*

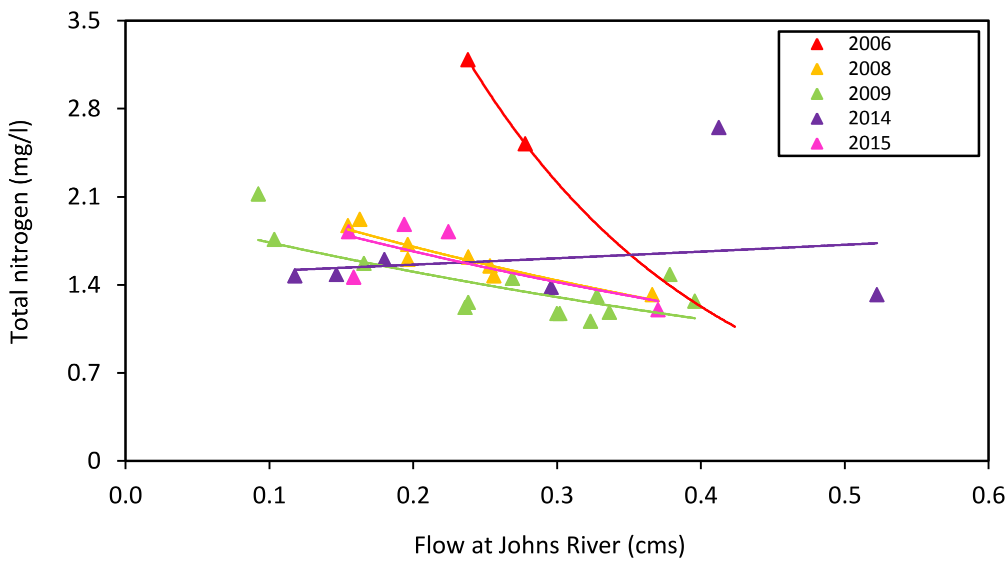

Figure 37. *Total nitrogen concentrations in relation to stream flow at the Crystal Brook site during 2006-2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters.*

Direct Tributaries

Strawberry Acres Tributary

The Strawberry Acres tributary, which is a small tributary that flows directly into the southwest corner of Lake Memphremagog, drains approximately 331 ha (818 acres) in the towns of Newport Town and Coventry. This stream drains agricultural and residential areas as well as extensive forests and wetlands, especially in its headwaters. Water quality in this tributary was first sampled at a downstream site near its mouth in 2008, and a second site was added further upstream in 2010. During 2008-2010, we measured elevated phosphorus levels at both of these sites (median total phosphorus concentrations during 2008-2010 = 36.8-45.7 µg/l at the downstream site and 32.4 µg/l at the upstream site). Based on conversations with staff from the NRCS, we identified a small dairy farm along the upper reaches of this tributary as a possible source of the elevated phosphorus levels measured in this tributary. In 2014, NRCS assisted the farmer with a number of farmstead improvement projects, including installing a new manure pit, concrete barnyard pad, laneways, and livestock exclusion fencing (Figure 38).

Figure 38. *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 on 4 November 2014.*

In 2015, we again sampled water quality at the two sites along this tributary to gauge whether or not these projects had measurably improved water quality in this tributary. Total phosphorus concentrations at both sites were markedly lower in 2015 than in 2010 (Figure 39). At the Strawberry Acres site, median total phosphorus concentrations were 38.5 µg/l in 2010 and 25.1 µg/l in 2015. At the Upper Strawberry Acres site, median total phosphorus concentrations were 32.4 µg/l in 2010 and 24.5 µg/l in 2015. Thus, median total phosphorus concentrations decreased 24-35% at distances of 1.2 km (0.75 mi) and 3.6 km (2.2 mi) downstream from the farmstead. In 2016, we will again sample water quality in this tributary to verify these improvements in water quality that were measured in 2015.

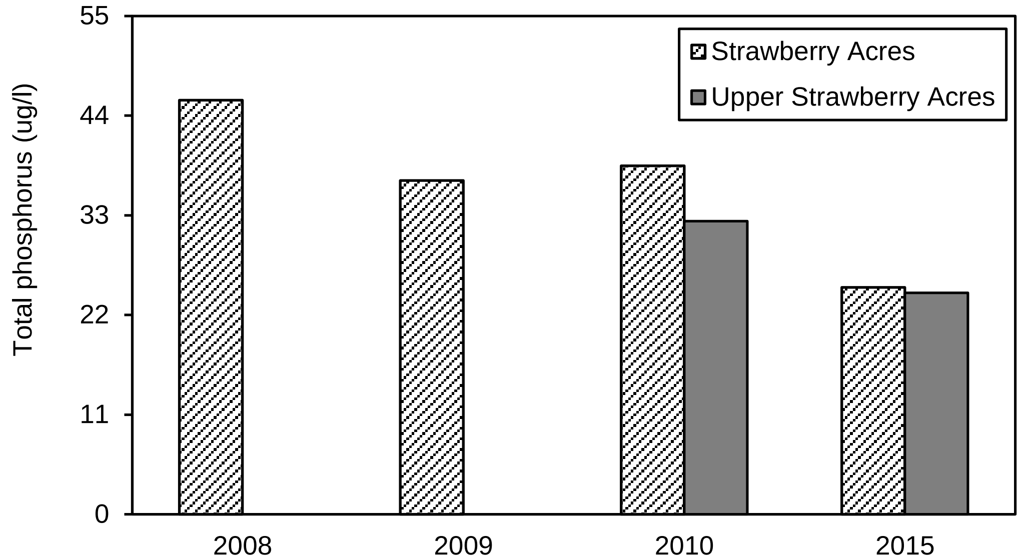

Figure 39. *Median total phosphorus concentrations at two sites along the Strawberry Acres Tributary during 2008-2015.*

Stearns Brook

Tributary of Stearns Brook

Stearns Brook is a tributary of the Tomifobia River, which flows north into Lac Massawippi, rather than into Lake Memphremagog. Based on their assessment of aquatic life, the Biomonitoring and Aquatic Studies Section of the Vermont DEC had designated a small tributary of Stearns Brook as impaired and in need of a TMDL due to nutrients and sediment from agricultural runoff (Part A, State of Vermont 2014b). This small tributary drains approximately 275 ha (679 acres) in the towns of Holland and Derby. Beginning in 2014, we analyzed water quality conditions at six sites along the main stem (four sites) and two smaller tributaries (two sites) in order to pinpoint and assess possible nutrient and sediment sources along this tributary. In addition, we sampled the outflow from two culverts and two ditches that drained the farmstead of a large farm operation (LFO) during two rain events on 28 July and 23 October 2014. Based on this 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). In addition, phosphorus levels were consistently high in one of the two small tributaries (Valley Road South) and extremely high during rainfall events in the other small 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. 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 one of the two small tributaries (Twin Bridges Road). During the two rain events (28 July and 23 October 2015), we also measured extremely high phosphorus and nitrogen levels in the water flowing from two culverts and two ditches that drained much of the farmstead area upstream of the Middle Stearns Tributary site. 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. In conjunction with staff and funding from the Vermont DEC and VAAFM, the owner developed and implemented a number of projects in 2015 to divert runoff from the driveways into hay fields, to divert clean water around the barnyards and laneways, and to collect contaminated runoff from the barnyards and laneways in the manure pits (Figure 40).

In 2015, we again analyzed water quality at these same six sites along the main stem (four sites) and two small tributaries (two sites) in order to better identify and assess possible nutrient and sediment sources along this tributary. In addition, we sampled the outflow from the two culverts and two ditches draining the farmstead on several sample dates during 2015. Based on this sampling, we were able to confirm 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 41). In addition, phosphorus levels were consistently high in one of the two small tributaries (Valley Road South) and extremely high during rainfall events in the other small tributary (Twin Bridges Road). Unlike 2014, total phosphorus concentrations showed strong positive relationships with stream flow at only two of the six sites (Middle Stearns Tributary and Twin Bridges Road) in 2015 (Figure 42). As in 2014, total nitrogen concentrations increased steadily from the upstream sites down to the Middle Stearns Tributary site and were again extremely high in one of the two small tributaries (Twin Bridges Road)(Figure 43). However, total nitrogen concentrations showed negative relationships with flow at three of the four main stem sites and positive relationships with stream flow at two other sites (Figure 44). On many sample dates, we also measured extremely high phosphorus and nitrogen levels in the water flowing from the two culverts and two ditches draining the farmstead upstream of the Middle Stearns Tributary site (Table 13). Thus, like 2014, the 2015 data suggested that much of the phosphorus and nitrogen in this tributary was originating from the large barn complex and surrounding agricultural fields located upstream of the Middle Stearns Tributary site.

Figure 40. *The Gray Farm undertook numerous clean water diversion and runoff control projects in 2015 to improve water quality conditions in a tributary of Stearns Brook. The top photo shows a barnyard area prior to construction on 3 July 2015, and the bottom photo shows the same barnyard area during construction of a barrier to separate clean and "dirty" water on 28 September 2015 (bottom photograph courtesy of Ben Copans).*

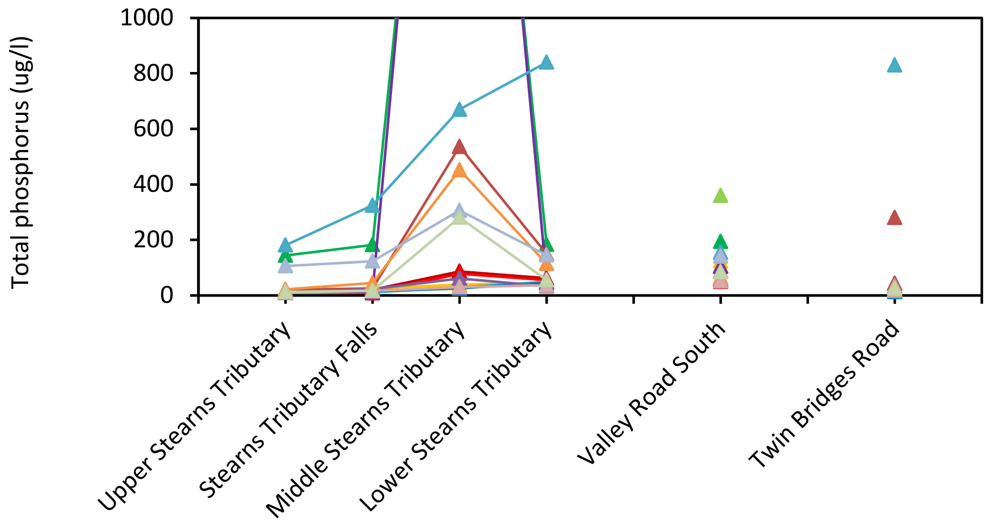

Figure 41. *Total phosphorus "profile" along the tributary of Stearns Brook from Upper Stearns Tributary downstream to Lower Stearns Tributary during April-October 2014 and 2015.*

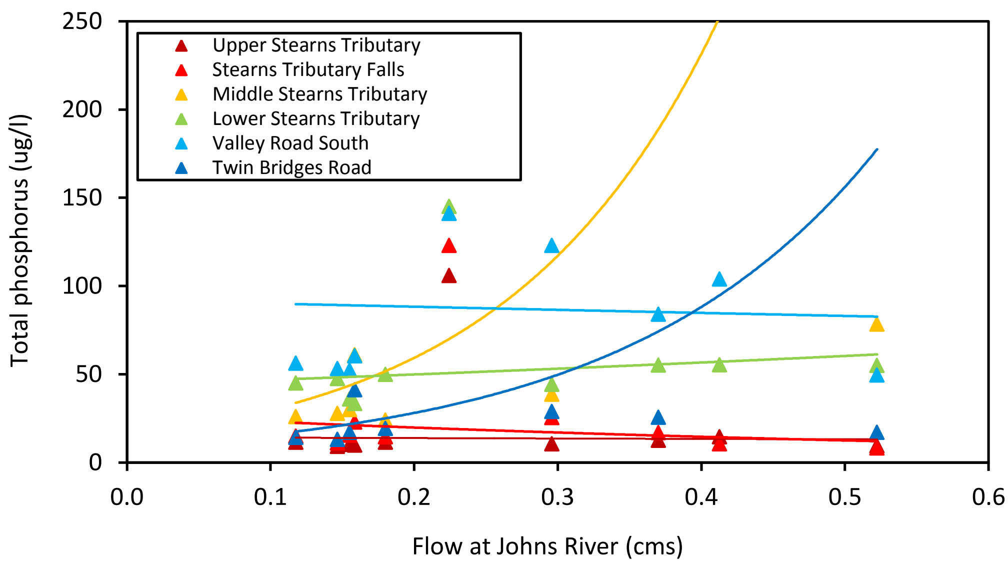

Figure 42. *Total phosphorus concentrations in relation to stream flow at six sites along the tributary of Stearns Brook during April-October 2014 and 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters. Note that one moderate-flow value for the Royer Farm site exceeds the scale on the y-axis. Note that one moderate-flow value for each of two sites (Middle Stearns Tributary and Twin Bridges Road) exceeds the scale on the y-axis.*

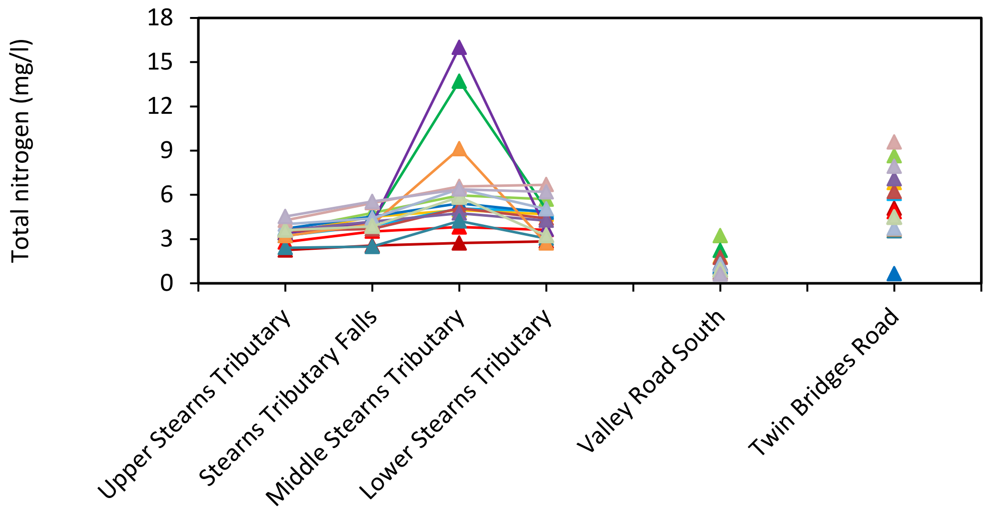

Figure 43. *Total nitrogen "profile" along the tributary of Stearns Brook from Upper Stearns Tributary downstream to Lower Stearns Tributary during April-October 2014 and 2015.*

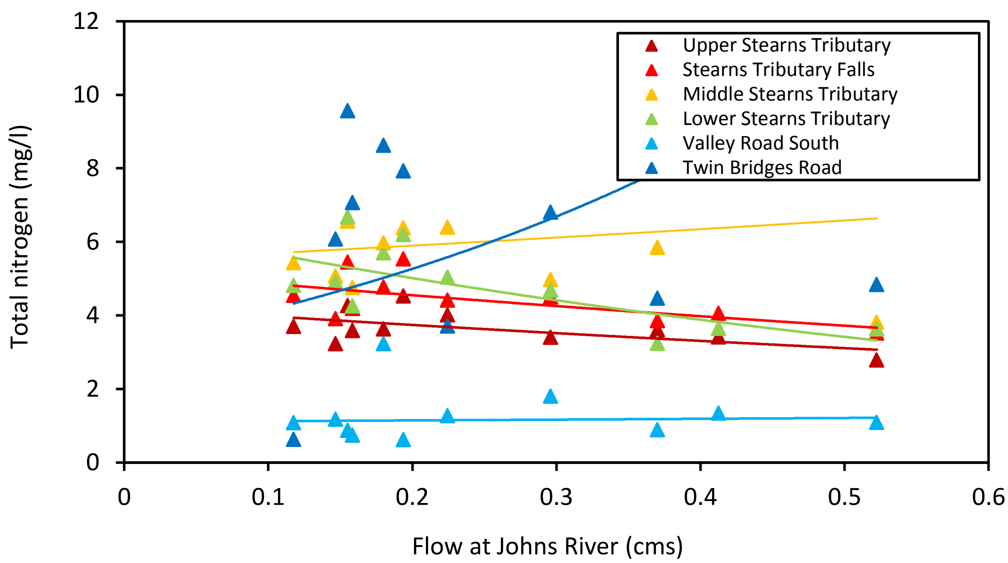

Figure 44. *Total nitrogen concentrations in relation to stream flow at six sites along the tributary of Stearns Brook during April-October 2014 and 2015. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the exponential relationships between the two parameters. Note that one moderate-flow value for each of two sites (Middle Stearns Tributary and Twin Bridges Road) exceeds the scale on the y-axis.*

Table 13. Water quality conditions in the water flowing out of two culverts and two ditches draining the farmstead of the large farm operation (LFO) along the tributary of Stearns Brook in Holland, Vermont during 2015.

Sample Site	N	Median	Range
Total Nitrogen Concentrations			
Upper Barnyard Culvert	8	19.2	13.8-27.4
Lower Barnyard Culvert	8	18.5	0.6-29.8
Valley Road Ditch	7	13.3	5.6-34.1
Valley Road Garage	3	111.5	65.3-124.8
Total Phosphorus Concentrations			
Upper Barnyard Culvert	8	45.4	22.5-6,200
Lower Barnyard Culvert	8	2,126	1,168-9,250
Valley Road Ditch	5	416	52.3-5,090
Valley Road Garage	2	8,760	4,420-13,100

Recommendations

Our efforts in 2015 were very successful for pinpointing and assessing possible nutrient and sediment sources, identifying and developing phosphorus-reduction and wetland restoration projects, identifying and mapping highly-erodible soils, and calculating phosphorus-reduction goals for individual subwatersheds. Nevertheless, many opportunities remain for additional work in all of these areas in order to protect and improve water quality in the Lake Memphremagog Basin.

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 focus efforts to identify and develop phosphorus-reduction projects and practices, and evaluating the success of previously-implemented phosphorus-reduction projects and practices. More specifically, we recommend sampling water quality conditions along the following tributaries in 2016 for the following reasons:

Airport Tributary - Our sampling in 2015 allowed us to further pinpoint and assess the source(s) of the high nutrient and sediment levels to the northern branch of this tributary of the Black River. Subsequently, on-the-ground field assessments identified severe streambank erosion and streambed incision as the likely causes of these high nutrient and sediment levels. Continued sampling at these sites would increase our understanding of the extent of these water quality problems and the success of any efforts undertaken to correct these problems.

St. Onge Tributary - This stream exhibited very high nutrient levels in 2015 and, in 2014, was filled with "sewage fungus", a biological indicator of seriously degraded water quality. Thus, despite limited efforts to correct their source(s), water quality problems persist in this stream. Thus, we recommend sampling two sites on the main stem and branch of this tributary in 2016 in order to better pinpoint and assess the source(s) of water quality problems in this stream.

Sunrise Farm - In 2015, we measured very high levels of nutrients in this small tributary of Stony Brook. Before conducting additional sampling, we recommend that VAAFM visit and assess the small farm operation (SFO) to identify any concerns and possible sources of water quality problems.

Brighton Brook - During 2010-2015, our sampling indicated that nutrient and sediment levels were extremely high in this tributary of the Black River. Furthermore, the sampling in 2014 confirmed that leachate flowing from a mortality compost pile at a large farm operation (LFO) was one of the major sources of the high phosphorus, nitrogen, and turbidity levels. In 2015, we continued to sample water quality at three sites along this tributary to assess whether the corrective actions had been successful in improving water quality in this tributary. Unfortunately, these actions did not occur until late in the growing season. Thus, we recommend resampling these three sites again in 2016 to gauge the success of these corrective actions.

Junkyard Tributary - Our sampling in 2014-2015 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. The 2015 data further suggested that there might have been some modest improvements in water quality along the southern branch of this tributary following improvements in agricultural field practices there. In order to further assess the success of any improvements in field practices and/or manure and leachate collection systems in the headwaters of this tributary, we recommend sampling all three sites again in 2016.

Crystal Brook - Our sampling in 2015 confirmed that water quality conditions remained generally improved in Crystal Brook since the manure lagoon was replaced in 2007, and, furthermore, that the problems indicated by the biological monitoring and water samples collected in 2014 appear to have been resolved. Nevertheless, we recommend resampling this stream again in 2016 to confirm that water quality conditions in this tributary have improved.

Strawberry Acres - Our sampling in 2008-2010 measured elevated phosphorus levels at the two sites located along the Strawberry Acres tributary, which flows directly into the southwest corner of Lake Memphremagog. In 2015, our sampling indicated that water quality conditions had improved somewhat following the completion of numerous improvements to the farmstead and fields along the upper reaches of this tributary. However, we recommend resampling these two sites in 2016 to further confirm the success of these improvements in improving water quality and to evaluate the need for additional improvements elsewhere along this tributary.

Tributary of Stearns Brook - Our sampling in 2014-2015 indicated that nutrient and sediment levels were extremely high in the tributary of Stearns Brook, especially along the main stem and two small tributaries draining a large farm operation (LFO). In 2015, the owners of the LFO undertook numerous farmstead improvement and clean water diversion projects. Thus, we recommend resampling these sites in 2016 in order to evaluate the success of these projects and to evaluate the need for additional projects and practices along this tributary.

In addition, we have identified three other tributaries where water quality sampling might be helpful in identifying and assessing possible water quality problems. In all three tributaries (two tributaries of Stearns Brook and Sucker Brook, which flows into Lake Seymour), field observations indicated that excessive streambank erosion, primarily caused by livestock grazing, and/or overflowing manure pits may be causing water quality issues.

Although water quality conditions remain poor along the two branches of the Hamel tributary, it is not clear that additional sampling will be beneficial in further identifying and assessing the possible source(s) of these water quality problems. Thus, these sites might be dropped in 2016, although they could be resampled again in future years if that was deemed useful. In the meantime, we encourage the appropriate agencies and organizations to work with the owner(s) of the farms in those watersheds to identify and implement projects to protect and improve water quality.

Phosphorus-Reduction Projects and Practices

In 2016, we will continue to use the water quality data and other analyses to identify, prioritize, and develop phosphorus-reduction projects and practices that will improve water quality conditions 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 57 priority subwatersheds as well as in additional subwatersheds. In particular, we recommend mapping land uses and land cover types and evaluating possible phosphorus sources and potential phosphorus-reduction projects and practices and wetland restoration opportunities in the seven priority subwatersheds not mapped and assessed to date (Mud Pond, Webster Road, Ethan Allen, Barton Alder Brook, Churchill Lane, East Side, and Eagle Point). As part of these efforts, we will incorporate the spatially-explicit information about wetland restoration opportunities and croplands located on highly-erodible soils into efforts to identify and assess possible sources of water quality problems and to develop and implement phosphorus-reduction projects and practices in the priority subwatersheds. Finally, we will continue to work with key 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.

Phosphorus-Reduction Goals

Our initial effort used a modified version of the Best Management Practices (BMP) Scenario Tool to highlight those projects and practices that would most effectively reduce phosphorus loading into Lake Memphremagog. In 2015, we developed and tested this tool to assess two tributary watersheds of Lake Memphremagog (the Strawberry Acres and Wishing Well tributaries). In the future, these efforts could be expanded to other watersheds in the Lake

Memphremagog Basin, although completing these analyses for all but the smallest watersheds - or for the entire Vermont portion of the Lake Memphremagog Basin - is not a trivial task. However, the information gained through developing this process will be helpful in creating a more realistic basin-wide BMP Scenario Tool that can be used to identify and implement the appropriate actions to best reduce phosphorus loading into Lake Memphremagog as required by the Total Maximum Daily Load (TMDL) and Basin Plan.

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 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 Newport/Derby/Stanstead Lecture Series of the University of Vermont's Osher Lifelong Learning Institute. 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 28 sites (plus three Vermont DEC sites) sampled along the Vermont tributaries of Lake Memphremagog during April-October 2015 (locations are mapped in Figure 4).

Black River (8 Sites):

Site Name	Site Description
Airport Tributary	Unnamed tributary along High Acres Road in Coventry (also sampled in 2013-2014)
Airport Trib North	Northern branch of unnamed tributary along woods road off of High Acres Road in Coventry
Airport Trib South	Southern branch of unnamed tributary along woods road off High Acres Road in Coventry
St. Onge Tributary	Northern branch of unnamed tributary behind residence on Coventry Station Road in Coventry
Sunrise Farm	Unnamed tributary to Stony Brook downstream of Hancock Hill Road in Coventry
Brighton Brook	Brighton Brook downstream of Gage Road in Irasburg (also sampled in 2010-2014)
Brighton Brook North	Northern branch of Brighton Brook upstream of Vermont Route 58 in Irasburg (also sampled in 2011-2014)
Upper Brighton Brook North	Northern branch of unnamed tributary to Brighton Brook downstream of Back Coventry Road in Irasburg (also sampled in 2012-2014)

Barton River (6 Sites):

Site Name	Site Description
Middle Hamel Tributary	Middle branch of unnamed tributary upstream of Bruneau Road in Irasburg (also sampled in 2013-2014)
Upper Middle Hamel Tributary	Middle branch of unnamed tributary upstream of Cooks Road in Irasburg
Upper Hamel Tributary	Upper branch of unnamed tributary upstream of Cooks Road in Irasburg (also sampled in 2013-2014)
Rock Junkyard	Unnamed tributary upstream of River Road in Irasburg (also sampled in 2012-2014)
Royer Farm	Main stem of unnamed tributary along Vermont Route 58 in Irasburg (also sampled in 2014)
Royer Tributary	Northern branch of unnamed tributary downstream of Vermont Route 58 in Irasburg (also sampled in 2014)

Johns River (1 Site):

Site Name	Site Description
Crystal Brook	Crystal Brook downstream of U.S. Route 5 and upstream of snowmobile bridge in Derby (also sampled in 2006, 2008-2009, and 2014)

Direct Tributaries (2 Sites):

Site Name	Site Description
Strawberry Acres	Unnamed tributary downstream of Fishing Access Road in Newport Town (also sampled in 2008-2010)
Upper Strawberry Acres	Unnamed tributary upstream of City Road in Newport Town (also sampled in 2010)

Tributary of Stearns Brook (10 Sites):

Site Name	Site Description
Upper Stearns Tributary	Upper site on unnamed tributary along Valley Road in Derby (also sampled in 2014)
Stearns Tributary Falls	Upper middle site on unnamed tributary along Valley Road in Holland (also sampled in 2014)
Middle Stearns Tributary	Lower middle site on unnamed tributary downstream of Twin Bridges Road in Holland (also sampled in 2014)
Lower Stearns Tributary	Lower site on unnamed tributary along Twin Bridges Road in Holland (also sampled in 2014)
Valley Road South	Unnamed tributary downstream of Valley Road in Holland (also sampled in 2014)
Twin Bridges Road	Unnamed tributary downstream of Twin Bridges Road in Holland (also sampled in 2014)
Upper Barnyard Culvert	Outflow of culvert at upper driveway of the Gray Farm along Valley Road in Holland
Lower Barnyard Culvert	Outflow of culvert at lower driveway of the Gray Farm along Valley Road in Holland
Valley Road Ditch	Ditch along north side of Valley Road west of intersection with Twin Bridges Road in Holland
Valley Road Garage	Ditch along south side of Valley Road across from intersection with Twin Bridges Road in Holland

Vermont DEC Sites (4 Sites):

Site Name	Site Description
Barton River	Main stem upstream of Coventry Station Road in Coventry (also sampled in 2005-2014)
Black River	Main stem upstream of Airport Road in Coventry (also sampled in 2005-2014)
Clyde River	Main stem upstream of Gardner Park Road in Newport City (also sampled in 2005-2014)
Johns River	Main stem beside old well house along Beebe Road in Derby (also sampled in 2005-2006 and 2008-2014)

Appendix B. Water quality data collected at 28 sites along the Vermont tributaries of Lake Memphremagog during April-October 2015. 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 Trib North	4/27/2015	*1.05*	**153**	**80.6**
Airport Trib North	5/26/2015	0.11	*29*	0.45
Airport Trib North	6/9/2015	*1.17*	**2920**	**1854**
Airport Trib North	6/22/2015	0.86	**94.3**	2.62
Airport Trib North	7/21/2015	0.34	**40**	0.99
Airport Trib North	8/17/2015	0.15	*34.8*	0.41
Airport Trib North	9/15/2015	0.19	*33.0*	0.65
Airport Trib North	10/12/2015	< 0.1	*33.6*	0.85
Airport Trib South	4/27/2015	0.95	**69.1**	**11.2**
Airport Trib South	5/26/2015	0.17	*23.2*	0.98
Airport Trib South	6/9/2015	**2.53**	**452**	**223**
Airport Trib South	6/22/2015	0.92	**382**	**10.9**
Airport Trib South	7/21/2015	0.94	**47.9**	1.78
Airport Trib South	8/17/2015	0.38	16.9	0.93
Airport Trib South	9/15/2015	**2.00**	*22.5*	2.03
Airport Trib South	10/12/2015	0.32	17.7	1.41
Airport Tributary	4/27/2015	0.74	**78.1**	**14.4**
Airport Tributary	5/26/2015	0.26	*24.6*	1.15
Airport Tributary	6/9/2015	**2.50**	**570**	**256**
Airport Tributary	6/22/2015	0.99	**106**	**10.9**
Airport Tributary	7/21/2015	0.90	**45.8**	1.43
Airport Tributary	8/17/2015	0.47	19.1	1.18
Airport Tributary	9/15/2015	*1.94*	*23.9*	1.41
Airport Tributary	10/12/2015	0.38	18.7	1.1

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Brighton Brook	4/27/2015	0.5	*23.8*	2.63
Brighton Brook	5/26/2015	0.48	*24.4*	1.95
Brighton Brook	6/9/2015	*1.62*	**296.7**	**58.6**
Brighton Brook	6/22/2015	0.55	**67.8**	*6.78*
Brighton Brook	7/21/2015	0.53	**38.1**	2.23
Brighton Brook	8/17/2015	0.43	*23.5*	1.7
Brighton Brook	9/15/2015	0.43	*31.5*	4.75
Brighton Brook	10/12/2015	0.59	**39.6**	**11.6**
Brighton Brook North	4/27/2015	0.61	**42.4**	2.35
Brighton Brook North	5/26/2015	0.39	**38.7**	1.86
Brighton Brook North	6/9/2015	**2.15**	**456**	**29.8**
Brighton Brook North	6/22/2015	*1.07*	**183**	*6.66*
Brighton Brook North	7/21/2015	0.62	**99**	2.82
Brighton Brook North	8/17/2015	0.43	*26*	0.97
Brighton Brook North	9/15/2015	0.5	*29.3*	1.87
Brighton Brook North	10/12/2015	0.51	*31.1*	4.33
Crystal Brook	4/27/2015	*1.84*	**77.9**	**15.1**
Crystal Brook	5/26/2015	*1.46*	17.2	1.03
Crystal Brook	6/9/2015	*1.42*	**238**	**58.4**
Crystal Brook	6/22/2015	*1.22*	*35*	3.2
Crystal Brook	7/21/2015	*1.82*	**281.7**	**55.7**
Crystal Brook	8/17/2015	*1.82*	14.3	0.92
Crystal Brook	9/15/2015	*1.2*	*25.4*	1.86
Crystal Brook	10/12/2015	*1.88*	15	1.06
Gray Silage Pit	6/22/2015	**34.16**	**49.8**	2.21
Johns River	4/27/2015	*1.73*	*26.4*	*5.44*
Johns River	5/26/2015	**2.42**	15.4	2.25
Johns River	6/9/2015	*1.64*	**351**	**96.6**
Johns River	6/22/2015	*1.15*	**68.2**	**13.3**
Johns River	7/21/2015	**2.06**	*23.1*	2.61
Johns River	8/17/2015	**2.96**	12.7	0.94
Johns River	9/15/2015	**2.04**	*24.1*	3.37
Johns River	10/12/2015	**3.17**	16.3	1.26
Lawson Lower Barn	4/27/2015	**42.89**	**3480**	**96.8**
Lawson Lower Barn	6/9/2015	**18.06**	**3670**	-

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Lower Barnyard Culvert	4/27/2015	**26.2**	**7760**	**1656**
Lower Barnyard Culvert	5/26/2015	**29.77**	**1470**	**31**
Lower Barnyard Culvert	6/9/2015	**7.32**	**2220**	**631**
Lower Barnyard Culvert	6/22/2015	**20.42**	**2200**	**17.8**
Lower Barnyard Culvert	7/21/2015	**9.49**	**2052.5**	**325**
Lower Barnyard Culvert	8/17/2015	**16.66**	**1167.5**	*8.86*
Lower Barnyard Culvert	9/15/2015	**29.32**	**1627.5**	**619**
Lower Barnyard Culvert	10/12/2015	0.61	**9250**	**53.1**
Lower Stearns Tributary	4/27/2015	**4.41**	**149**	*8.62*
Lower Stearns Tributary	5/26/2015	**4.26**	*33.4*	1.98
Lower Stearns Tributary	6/9/2015	**3.04**	**840**	**206**
Lower Stearns Tributary	6/22/2015	**3.74**	**70**	*8.41*
Lower Stearns Tributary	7/21/2015	**5.04**	**145**	**24.6**
Lower Stearns Tributary	8/17/2015	**6.68**	**35.9**	1.67
Lower Stearns Tributary	9/15/2015	**3.24**	**55.2**	3.08
Lower Stearns Tributary	10/12/2015	**6.2**	*33*	1.34
Middle Hamel Tributary	4/27/2015	**3.75**	**62.2**	**10.2**
Middle Hamel Tributary	5/26/2015	*1.24*	*35*	2.78
Middle Hamel Tributary	6/9/2015	**8.55**	**525**	**110.8**
Middle Hamel Tributary	6/22/2015	**2.72**	**114**	*9.06*
Middle Hamel Tributary	7/21/2015	**3.59**	**48.3**	2.58
Middle Hamel Tributary	8/17/2015	*1.27*	*31.8*	0.86
Middle Hamel Tributary	9/15/2015	*1.35*	**115**	4.29
Middle Hamel Tributary	10/12/2015	**2.13**	**39.4**	3.52
Middle Stearns Tributary	4/27/2015	**5.1**	**536**	**313.2**
Middle Stearns Tributary	5/26/2015	**4.75**	**61**	1.14
Middle Stearns Tributary	6/9/2015	**4.22**	**670**	**156.6**
Middle Stearns Tributary	6/22/2015	**4.68**	**62.4**	2.17
Middle Stearns Tributary	7/21/2015	**6.4**	**306**	**33.8**
Middle Stearns Tributary	8/17/2015	**6.56**	*30*	0.68
Middle Stearns Tributary	9/15/2015	**5.85**	**281.1**	**21.7**
Middle Stearns Tributary	10/12/2015	**6.38**	**47.6**	0.96
Nancy's Culvert	6/9/2015	**32.5**	**2440**	**389.2**
Nancy's Culvert	6/22/2015	**9.12**	**452**	1.95
Nancy's Culvert	7/21/2015	**25.13**	**595**	2.55

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Rock Junkyard	4/27/2015	0.93	**43.6**	*5.31*
Rock Junkyard	5/26/2015	0.55	*21*	1.84
Rock Junkyard	6/9/2015	**4.25**	**432**	**99.3**
Rock Junkyard	6/22/2015	0.88	**58.4**	*5.89*
Rock Junkyard	7/21/2015	0.91	*32*	1.65
Rock Junkyard	8/17/2015	0.73	*23.7*	1.12
Rock Junkyard	9/15/2015	0.58	*30.9*	3.05
Rock Junkyard	10/12/2015	0.73	6.43	0.54
Royer Farm	4/27/2015	0.83	**44.7**	*6.54*
Royer Farm	5/26/2015	0.82	**37.8**	1.29
Royer Farm	6/9/2015	**2.71**	**852**	**187.8**
Royer Farm	6/22/2015	*1.21*	**68**	*8.75*
Royer Farm	7/21/2015	0.9	**49.6**	3.01
Royer Farm	8/17/2015	0.79	**42.1**	0.32
Royer Farm	9/15/2015	0.48	**42.3**	0.95
Royer Farm	10/12/2015	0.75	*30.7*	1.02
Royer Tributary	4/27/2015	**2.78**	**167**	3.73
Royer Tributary	5/26/2015	*1.58*	*22*	0.53
Royer Tributary	6/9/2015	**2.77**	**980**	**169**
Royer Tributary	6/22/2015	0.89	**59.2**	2.16
Royer Tributary	7/21/2015	*1.3*	**41.5**	0.37
Royer Tributary	8/17/2015	**2.52**	**35.9**	0.87
Royer Tributary	9/15/2015	*1.32*	*26.6*	0.66
Royer Tributary	10/12/2015	*1.83*	*23.4*	0.78
St. Onge Main	6/9/2015	**2.66**	**525**	**105.6**
St. Onge Tributary	4/27/2015	**29.84**	**5180**	**86.8**
St. Onge Tributary	5/26/2015	**10.22**	**760**	**14.1**
St. Onge Tributary	6/9/2015	**4.64**	**1670**	**332.5**
St. Onge Tributary	6/22/2015	**4.28**	**384.8**	**33.1**
St. Onge Tributary	7/21/2015	**2.95**	**278.4**	*6.18*
St. Onge Tributary	8/17/2015	**4.31**	**193.6**	1.95
St. Onge Tributary	9/15/2015	**6.97**	**240**	*6.02*
St. Onge Tributary	10/12/2015	**6.4**	**142**	1.32

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Stearns Tributary Falls	4/27/2015	**3.68**	*24.8*	*5.51*
Stearns Tributary Falls	5/26/2015	**4.19**	*22.8*	1.13
Stearns Tributary Falls	6/9/2015	**2.49**	**324**	**69.2**
Stearns Tributary Falls	6/22/2015	**4.01**	**44.4**	4.03
Stearns Tributary Falls	7/21/2015	**4.41**	**123**	**17.2**
Stearns Tributary Falls	8/17/2015	**5.45**	15.4	0.53
Stearns Tributary Falls	9/15/2015	**3.86**	16.9	1.18
Stearns Tributary Falls	10/12/2015	**5.54**	12	0.71
Strawberry Acres	4/27/2015	0.35	*23.2*	3.77
Strawberry Acres	5/26/2015	0.35	*24.2*	2
Strawberry Acres	6/9/2015	0.75	**143**	**46.5**
Strawberry Acres	6/22/2015	0.38	**50.6**	*8.89*
Strawberry Acres	7/21/2015	0.38	*32.5*	2.26
Strawberry Acres	8/17/2015	0.31	*20.6*	1.95
Strawberry Acres	9/15/2015	0.35	*25.9*	2.57
Strawberry Acres	10/12/2015	0.25	17.3	2.26
Sunrise Farm	4/27/2015	**4**	**585**	**14.5**
Sunrise Farm	5/26/2015	**2.51**	**905**	4.93
Sunrise Farm	6/9/2015	**6.18**	**412**	**11.9**
Sunrise Farm	6/22/2015	**7.95**	**270.9**	1.62
Sunrise Farm	7/21/2015	**11.06**	**273**	3.06
Sunrise Farm	8/17/2015	**2.99**	**698**	1.72
Sunrise Farm	9/15/2015	**2.7**	**444**	2.1
Sunrise Farm	10/12/2015	**6.64**	**348**	1.58
Town Line Tributary	7/21/2015	**3.57**	**164**	2.79
Twin Bridges Road	4/27/2015	**6.22**	**279.6**	**162.4**
Twin Bridges Road	5/26/2015	**7.07**	**41.1**	*5.71*
Twin Bridges Road	6/9/2015	**3.54**	**830**	**368.5**
Twin Bridges Road	6/22/2015	**3.68**	*33.7*	1.66
Twin Bridges Road	7/21/2015	**3.71**	-	*7.65*
Twin Bridges Road	8/17/2015	**9.57**	17	1.01
Twin Bridges Road	9/15/2015	**4.47**	*25.5*	1.51
Twin Bridges Road	10/12/2015	**7.93**	11.5	0.85

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Upper Barnyard Culvert	4/27/2015	**14.33**	**1040**	**686**
Upper Barnyard Culvert	5/26/2015	**22.35**	**39.8**	0.75
Upper Barnyard Culvert	6/9/2015	**13.81**	**6200**	**3836**
Upper Barnyard Culvert	6/22/2015	**23.74**	*32.3*	1.19
Upper Barnyard Culvert	7/21/2015	**14.91**	**428**	**333**
Upper Barnyard Culvert	8/17/2015	**27.09**	*26.6*	0.37
Upper Barnyard Culvert	9/15/2015	**15.98**	**51**	1.92
Upper Barnyard Culvert	10/12/2015	**27.44**	*22.5*	1.31
Upper Brighton Brook North	4/27/2015	**3.93**	**172**	3.46
Upper Brighton Brook North	5/26/2015	**8.23**	**1680**	**56**
Upper Brighton Brook North	6/9/2015	*1.71*	**564**	**47**
Upper Brighton Brook North	6/22/2015	*1.68*	**375.2**	*8.21*
Upper Brighton Brook North	7/21/2015	*1.86*	**449**	1.53
Upper Brighton Brook North	10/12/2015	*1.59*	**259.2**	*8.12*
Upper Hamel Tributary	4/27/2015	**6.15**	**166**	4.12
Upper Hamel Tributary	5/26/2015	**3.45**	**98.9**	0.55
Upper Hamel Tributary	6/9/2015	**9.8**	**1050**	**50.2**
Upper Hamel Tributary	6/22/2015	**6.46**	**324**	2.69
Upper Hamel Tributary	7/21/2015	**11.12**	**281.4**	1.65
Upper Hamel Tributary	8/17/2015	**4.66**	**125**	1.78
Upper Hamel Tributary	9/15/2015	**3.2**	**363.6**	2.15
Upper Hamel Tributary	10/12/2015	**7.54**	**141**	2.43
Upper Middle Hamel Tributary	4/27/2015	**4.57**	**60.1**	**12.1**
Upper Middle Hamel Tributary	5/26/2015	*1.49*	**39.9**	0.69
Upper Middle Hamel Tributary	6/9/2015	**10.59**	**508**	**118.2**
Upper Middle Hamel Tributary	6/22/2015	**2.88**	**60**	*5.66*
Upper Middle Hamel Tributary	7/21/2015	**4.59**	**44.5**	1
Upper Middle Hamel Tributary	8/17/2015	*1.23*	*33.6*	1.3
Upper Middle Hamel Tributary	9/15/2015	0.86	*34.6*	1.41
Upper Middle Hamel Tributary	10/12/2015	**2.78**	*29*	0.7
Upper Stearns Tributary	4/27/2015	**3.55**	*20.1*	3.32
Upper Stearns Tributary	5/26/2015	**3.59**	9.81	0.99
Upper Stearns Tributary	6/9/2015	**2.41**	**181**	**45.7**
Upper Stearns Tributary	6/22/2015	**3.21**	*21.4*	3.51
Upper Stearns Tributary	7/21/2015	**4.01**	**106**	**26.5**
Upper Stearns Tributary	8/17/2015	**4.27**	10.1	0.87
Upper Stearns Tributary	9/15/2015	**3.6**	12.5	1.57
Upper Stearns Tributary	10/12/2015	**4.53**	10.8	0.8

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Upper Strawberry Acres	4/27/2015	0.3	*23.8*	2.59
Upper Strawberry Acres	5/26/2015	0.35	*21.1*	1
Upper Strawberry Acres	6/9/2015	0.54	**91.5**	**13.1**
Upper Strawberry Acres	6/22/2015	0.38	**40.3**	4.23
Upper Strawberry Acres	7/21/2015	0.38	*28.9*	1.21
Upper Strawberry Acres	8/17/2015	0.35	*21.1*	0.74
Upper Strawberry Acres	9/15/2015	0.38	*25.1*	1.83
Upper Strawberry Acres	10/12/2015	0.28	13.4	1.37
Valley Road Ditch	4/27/2015	**20.41**	**2120**	**863**
Valley Road Ditch	5/26/2015	**13.3**	**416**	3.46
Valley Road Ditch	6/9/2015	**5.59**	-	**88.2**
Valley Road Ditch	6/22/2015	**14.29**	**76.4**	2.31
Valley Road Ditch	7/21/2015	**7.93**	-	**52.2**
Valley Road Ditch	9/15/2015	**34.14**	**5090**	**568**
Valley Road Ditch	10/12/2015	**12.5**	**52.3**	3.42
Valley Road Garage	4/27/2015	**111.45**	**13100**	**17900**
Valley Road Garage	6/9/2015	**65.28**	**4420**	**1608**
Valley Road Garage	7/21/2015	**124.75**	-	**1730**
Valley Road South	4/27/2015	*1.75*	**86.9**	2.31
Valley Road South	5/26/2015	0.74	**60.4**	3.28
Valley Road South	6/9/2015	*1.32*	**154**	**10.1**
Valley Road South	6/22/2015	0.66	**64.3**	3.95
Valley Road South	7/21/2015	*1.27*	**141**	*5.79*
Valley Road South	8/17/2015	0.87	**52.2**	2.57
Valley Road South	9/15/2015	0.89	**83.9**	3.93
Valley Road South	10/12/2015	0.62	*31.1*	1.48

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	4/27/2015	< 0.1	< 5	< 0.2
Lower Stearns Tributary	4/27/2015	< 0.1	< 5	< 0.2
Strawberry Acres	4/27/2015	< 0.1	**5.92**	< 0.2
Middle Hamel Tributary	5/26/2015	< 0.1	< 5	< 0.2
Middle Stearns Tributary	5/26/2015	< 0.1	< 5	< 0.2
Sunrise Farm	5/26/2015	< 0.1	< 5	< 0.2
Brighton Brook	6/9/2015	< 0.1	< 5	< 0.2
Twin Bridges Road	6/9/2015	< 0.1	< 5	< 0.2
Upper Strawberry Acres	6/9/2015	< 0.1	< 5	< 0.2
Airport Tributary	6/22/2015	< 0.1	< 5	**0.30**
Upper Middle Hamel Tributary	6/22/2015	< 0.1	< 5	< 0.2
Valley Road South	6/22/2015	< 0.1	< 5	< 0.2
Airport Trib North	7/21/2015	< 0.1	< 5	< 0.2
Stearns Tributary Falls	7/21/2015	< 0.1	< 5	< 0.2
Upper Hamel Tributary	7/21/2015	< 0.1	< 5	**0.32**
Airport Trib North	8/17/2015	< 0.1	< 5	< 0.2
Stearns Tributary Falls	8/17/2015	< 0.1	< 5	< 0.2
Upper Hamel Tributary	8/17/2015	< 0.1	< 5	< 0.2
Crystal Brook	9/15/2015	< 0.1	< 5	< 0.2
Royer Tributary	9/15/2015	< 0.1	< 5	< 0.2
St. Onge Tributary	9/15/2015	< 0.1	< 5	< 0.2
Johns River	10/12/2015	< 0.1	< 5	< 0.2
Rock Junkyard	10/12/2015	< 0.1	**6.43**	< 0.2

Field Duplicates:

Total Nitrogen

Site	Date	1st Total Nitrogen (mg/l)	2nd Total Nitrogen (mg/l)	Relative % Difference
Brighton Brook North	4/27/2015	0.61	0.61	0
Lower Stearns Tributary	4/27/2015	4.41	4.52	2
Strawberry Acres	4/27/2015	0.35	0.36	3
Middle Hamel Tributary	5/26/2015	1.24	1.24	0
Middle Stearns Tributary	5/26/2015	4.75	4.78	1
Sunrise Farm	5/26/2015	2.51	2.5	0
Airport Tributary	6/22/2015	0.99	0.93	6
Upper Middle Hamel Tributary	6/22/2015	2.88	2.88	0
Valley Road South	6/22/2015	0.66	0.73	10
Brighton Brook	6/9/2015	1.62	1.54	5
Twin Bridges Road	6/9/2015	3.54	3.51	1
Upper Strawberry Acres	6/9/2015	0.54	0.51	6
Airport Trib North	7/21/2015	0.34	0.34	0
Stearns Tributary Falls	7/21/2015	4.41	4.43	0
Upper Hamel Tributary	7/21/2015	11.12	11.06	1
Airport Trib North	8/17/2015	0.15	0.15	0
Stearns Tributary Falls	8/17/2015	5.45	5.48	1
Upper Hamel Tributary	8/17/2015	4.66	4.67	0
Crystal Brook	9/15/2015	1.2	1.14	5
Royer Tributary	9/15/2015	1.32	1.32	0
St. Onge Tributary	9/15/2015	6.97	6.96	0
Upper Brighton Brook North	10/12/2015	1.59	1.6	1
Rock Junkyard	10/12/2015	0.73	0.75	3
Johns River	10/12/2015	3.17	3.26	3

Total Phosphorus

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Brighton Brook North	4/27/2015	42.4	39.2	8
Lower Stearns Tributary	4/27/2015	149	158	6
Strawberry Acres	4/27/2015	23.2	21.4	8
Middle Hamel Tributary	5/26/2015	35	34.4	2
Middle Stearns Tributary	5/26/2015	61	30.2	**68**
Sunrise Farm	5/26/2015	905	900	1
Airport Tributary	6/22/2015	106	105	1
Upper Middle Hamel Tributary	6/22/2015	60	61.9	3
Valley Road South	6/22/2015	64.3	66.7	4
Brighton Brook	6/9/2015	296.7	291.6	2
Twin Bridges Road	6/9/2015	830	770	8
Upper Strawberry Acres	6/9/2015	91.5	84.3	8
Airport Trib North	7/21/2015	40	59.1	**39**
Stearns Tributary Falls	7/21/2015	123	126	2
Upper Hamel Tributary	7/21/2015	281.4	282.9	1
Airport Trib North	8/17/2015	34.8	35.3	1
Stearns Tributary Falls	8/17/2015	15.4	16.4	6
Upper Hamel Tributary	8/17/2015	125	153	20
Crystal Brook	9/15/2015	25.4	24.6	3
Royer Tributary	9/15/2015	26.6	26	2
St. Onge Tributary	9/15/2015	240	271.5	12
Upper Brighton Brook North	10/12/2015	259.2	259.5	0
Rock Junkyard	10/12/2015	18.2	18.4	1
Johns River	10/12/2015	16.3	16.9	4

Turbidity

Site	**Date**	**1st Turbidity (NTU)**	**2nd Turbidity (NTU)**	**Relative % Difference**
Brighton Brook North	4/27/2015	2.35	2.52	7
Lower Stearns Tributary	4/27/2015	8.62	8.4	3
Strawberry Acres	4/27/2015	3.77	3.46	9
Middle Hamel Tributary	5/26/2015	2.78	2.88	4
Middle Stearns Tributary	5/26/2015	1.14	1.07	6
Sunrise Farm	5/26/2015	4.93	4.9	1
Airport Tributary	6/22/2015	10.9	11.7	7
Upper Middle Hamel Tributary	6/22/2015	5.66	3.7	**42**
Valley Road South	6/22/2015	3.95	4.46	12
Brighton Brook	6/9/2015	58.6	56.4	4
Twin Bridges Road	6/9/2015	368.5	298	**21**
Upper Strawberry Acres	6/9/2015	13.1	13.7	4
Airport Trib North	7/21/2015	0.99	1.16	**16**
Stearns Tributary Falls	7/21/2015	17.2	25.4	**38**
Upper Hamel Tributary	7/21/2015	1.65	1.58	4
Airport Trib North	8/17/2015	0.41	0.43	5
Stearns Tributary Falls	8/17/2015	0.53	0.61	14
Upper Hamel Tributary	8/17/2015	1.78	1.82	2
Crystal Brook	9/15/2015	1.86	1.7	9
Royer Tributary	9/15/2015	0.66	0.88	**29**
St. Onge Tributary	9/15/2015	6.02	7.59	**23**
Upper Brighton Brook North	10/12/2015	8.12	8.18	1
Rock Junkyard	10/12/2015	0.54	0.87	**47**
Johns River	10/12/2015	1.26	1.62	**25**

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 whereby nutrients and sediments increase in a water body 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. a discharge pipe 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 numbers.

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.

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