Restoring Water Quality in the Lake Memphremagog Basin:

2013 Memphremagog Water Quality Project

Prepared for the
Orleans County Natural Resources Conservation District and
Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

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Memphremagog Watershed Association

The Memphremagog Watershed Association, founded in 2007, is a nonprofit organization dedicated to the preservation of the environment and natural beauty of the Lake Memphremagog Basin. The Memphremagog Watershed Association achieves this mission through public education, water quality monitoring, shoreline cleanup and renaturalization, and protection of local wildlife. The specific goals of the Memphremagog Watershed Association are: 1) to promote the ecological awareness of people who live in, work in, and visit the Lake Memphremagog watershed; 2) to inform and educate the public and promote participation in efforts to preserve the environment and natural beauty of the watershed; 3) to work with area lake associations; local, state, and federal governments; and businesses to develop guidelines and policies that protect and improve the quality of life in and around the watershed; and 4) to participate in efforts to monitor water quality in the lake and its tributaries, clean-up and re-naturalize shorelines, and protect area plants and wildlife.

Beck Pond LLC

Beck Pond LLC partners with public and private organizations to conduct scientific research that guides on-the-ground conservation in northern New England and the Eastern Townships. Founded in 2009, Beck Pond LLC is a limited liability company organized in the state of Vermont and owned and operated by Dr. Fritz Gerhardt. Dr. Gerhardt has been working as an ecologist and conservation scientist since 1987 and is dedicated to conducting scientific research that not only increases our understanding of the natural environment but also informs on-the-ground conservation. Among other projects, he has conducted scientific studies to assess the impacts of historical land uses on forest plant communities; to assess the impacts of invasive plants on grasslands and forests; to identify, assess, and propose solutions to water quality problems; to protect and restore floodplain forests and wetlands; and to identify and protect critical wildlife habitats across northern New England. In all of these projects, Beck Pond LLC has partnered with other public and private organizations to ensure that these studies are effectively translated into on-the-ground conservation actions.

Cover. *Large farm operations can impact water quality through both nonpoint sources, such as surface runoff from agricultural fields, and point sources, such as runoff from barnyards, manure pits, and composting areas.*

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

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Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially the high phosphorus and turbidity levels and more frequent and widespread algal and cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, considerable effort has been undertaken to identify and remediate nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. In 2013, we undertook a two-part project to continue these efforts by 1) further identifying and assessing potential nutrient and sediment sources and 2) identifying and mapping possible sources of water quality problems and identifying and prioritizing potential projects to correct those problems.

2. In the first part of this project, we undertook targeted water quality sampling to further identify and assess potential 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 32 sites on eight dates during April-October 2013. With these data, we were able to further pinpoint and assess the sources of the high phosphorus levels measured previously in six tributaries: Brighton, Stony, and Roaring Brooks and the Holbrook Bay South, Hamel Marsh, and Junkyard tributaries. In addition, we assessed nutrient and sediment levels in five small tributaries that had not been sampled previously, including two tributaries of the Barton and Black Rivers (Alder Brook and the Airport tributary) and three tributaries that flow directly into South Bay (Cobb and Day Brooks and the Rediker Hill tributary). Finally, we were able to determine that water quality conditions were improving in Shalney Branch, one of two tributaries where phosphorus-reduction projects had been implemented previously.

3. In the second part of this project, we conducted spatially-explicit analyses to identify and map possible sources of water quality problems and potential projects and practices to correct those problems in 28 subwatersheds that exhibited the highest total phosphorus concentrations along the Vermont tributaries of Lake Memphremagog during 2005-2012. Within these subwatersheds, we mapped and prioritized barns, barnyards, manure pits, silage storage areas, composting areas, and wetlands as possible phosphorus sources. In addition, we mapped and prioritized areas of corn, other crops, hay, pasture, lawns, and residential, industrial, and urban areas lying within 25 m (<82 ft) of mapped rivers and streams as possible phosphorus sources. We then shared all of this information with key project partners in order to discuss likely phosphorus sources, any past or current efforts to improve land-use and land management practices, and possible approaches for engaging land owners and land managers in efforts to implement projects that will protect and improve water quality.

4. Collectively, these data and analyses greatly increased our understanding of water quality problems and allowed us to identify 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 2014, we will continue efforts to refine our knowledge about nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog and to identify and implement on-the-ground protection and restoration projects that will most effectively reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin.

Introduction

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

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

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

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

Lake Memphremagog and its tributaries currently face a number of threats, including high sediment and nutrient levels, elevated mercury levels, excessive algal growth, eutrophication, and exotic species invasions (State of Vermont 2012a, Quebec/Vermont Steering Committee 2008). The Southern Basin, which lies primarily in Vermont and is the shallowest section of Lake Memphremagog, is listed by the State of Vermont as an impaired surface water needing a Total Maximum Daily Load (TMDL) due to elevated phosphorus levels, nutrient enrichment, and excessive algal growth (Part A, State of Vermont 2012a). In addition, both the Southern Basin of Lake Memphremagog and South Bay are listed by the State of Vermont as needing further assessment due to elevated mercury levels in walleye (*Stizostedion vitrium*; Part C, State of Vermont 2012a). The Southern Basin is fed by three large tributaries that lie entirely within Vermont (the Black, Barton, and Clyde Rivers), one medium-sized tributary that straddles the Quebec/Vermont border (the Johns River), and numerous small tributaries that flow directly into the lake. The three large tributaries have been identified as priority surface waters outside the scope of Clean Water Act Section 303(d). Identified threats include elevated mercury levels in walleye, contamination by *Escherichia coli*, the presence of toxins and solvents, invasions of Eurasian watermilfoil (*Myriophyllum spicatum*), altered stream flows, and seasonal water level fluctuations (Parts C, E, and F; State of Vermont 2012a).

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 the on-the-ground projects and practices that will protect and improve water quality in the basin.

Past monitoring and assessment efforts have been undertaken by a number of governmental and non-governmental organizations (Quebec/Vermont Steering Committee 2008). The Quebec Ministère du Développement durable, de l'Environnement, Faune et des Parcs (MDDEFP) and Memphrémagog Conservation Inc. (MCI) have monitored water quality in the open waters of Lake Memphremagog in Quebec since 1996. The Vermont Department of Environmental Conservation (DEC) has monitored water quality in the open waters of the lake in Vermont and at the outlets of the Barton, Black, Clyde, and Johns Rivers since 2005. Since 1999, the Municipalités régionales de comté (MRC) de Memphrémagog has monitored water quality in the Quebec tributaries of Lake Memphremagog. Since 2005, the NorthWoods Stewardship Center, Memphremagog Watershed Association, and Beck Pond LLC have partnered with the Vermont DEC to monitor water quality in the Vermont tributaries of Lake Memphremagog. During 2004-

2005, MCI and the Regroupement des Associations pour la Protection de l'Environnement des Lacs (RAPPEL) completed comprehensive habitat assessments along the littoral zones of Lake Memphremagog in both Quebec and Vermont (Rivard-Sirois 2005, Rivard-Sirois and Pouet 2006). Finally, in partnership with the Vermont DEC, the NorthWoods Stewardship Center has completed stream geomorphic assessments along all four principal Vermont tributaries of Lake Memphremagog.

Although 73% of Lake Memphremagog is located in Quebec, 71% of the basin lies in Vermont. Thus, previous monitoring efforts have focused on assessing water quality conditions and identifying nutrient and sediment sources along the four principal 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 of these tributaries (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008). Specifically, these efforts indicated that water quality conditions were poorest in the Johns River watershed, which suffered from extremely high phosphorus and nitrogen levels. The Black River watershed, where agricultural development was most extensive, exhibited high phosphorus and sediment levels at numerous sites, especially during high-flow conditions. The Barton River watershed, which also had extensive areas of agriculture, occasionally exhibited high phosphorus and sediment levels, especially at the downstream-most sites. Finally, the Clyde River, especially the upper watershed, 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 runoff 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 was originating from groundwater springs and seeps, and 3) that high levels of phosphorus and sediment were originating in five of the seven small tributaries that flow directly into Lake Memphremagog. In 2010-2011, we refocused our efforts towards identifying and assessing the high phosphorus and sediment levels measured in the Black River watershed previously (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008). Through this sampling, we identified a number of areas that were potential 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 (Shalney Branch, Lords Creek, Brighton Brook, and Stony Brook)(Gerhardt 2011, 2012a). Most recently, in 2012, we continued our efforts to pinpoint and assess possible phosphorus and sediment sources along several tributaries of the Black River, but we also extended our sampling to the main stem and numerous tributaries of the Barton River, which had not been sampled since 2006 (Gerhardt 2013).

Priority Phosphorus-Reduction Areas

In addition to allowing us to assess overall water quality conditions and to pinpoint specific nutrient and sediment sources, the monitoring and assessment data can be used to identify and prioritize subwatersheds where protection and restoration projects will most effectively reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin. Identifying and prioritizing such focal areas can be 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 throughout the Lake Memphremagog Basin. Subsequently, staff from the Vermont DEC revised and updated this model by incorporating more accurate land-use data, phosphorus-export coefficients, and retention equations. In general, these models indicated that phosphorus exports were greatest in urban and suburban areas (e.g. especially around Newport, Derby, Barton, and Irasburg), intermediate in the Johns River watershed and more agricultural areas in the downstream sections of the Barton River and Black River watersheds, and least in the more forested upstream areas of the Barton River and Clyde River watersheds.

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

An alternative, less complex approach for identifying and prioritizing areas in which to focus phosphorus-reduction projects utilizes existing water quality monitoring and assessment data. In such an approach, spatial and statistical analyses incorporate existing water quality data to identify and prioritize areas that are likely to export the largest amounts of phosphorus. At the watershed scale, staff from the Vermont DEC have used a flux model incorporating phosphorus concentration and daily flow data to calculate the average annual phosphorus loadings from the four principal Vermont tributaries of Lake Memphremagog during 2005-2011: Black River (20,934 kg/year) > Barton River (17,223 kg/year) >> Clyde River (6,917 kg/year) >>> Johns River (1,292 kg/year). However, identifying areas where phosphorus-reduction projects should be targeted within these watersheds requires a more fine-scale, subwatershed approach.

Because such a large amount of water quality data has been collected along the Vermont tributaries of Lake Memphremagog, we were able to develop and execute a spatially-explicit approach for identifying and prioritizing subwatersheds in which phosphorus-reduction projects will most effectively reduce phosphorus exports into the Lake Memphremagog Basin (Gerhardt 2013). 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 high flows. We then calculated the mean rank of each site by averaging the rankings of each site at low and high flows. 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 and Johns River watersheds, and along several small tributaries that flow directly into Lake Memphremagog. Thus, in 2013, we focused our efforts on identifying possible sources of water quality problems and developing and implementing projects and practices to reduce nutrient and sediment exports in these priority subwatersheds.

Study Goals

In 2013, the Orleans County Natural Resources Conservation District, Vermont DEC, Memphremagog Watershed Association, and Beck Pond LLC again partnered to undertake a two-part program to protect and improve water quality in the Lake Memphremagog Basin. First, we undertook targeted water quality sampling to further pinpoint and assess nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog. In 2013, we focused this sampling on three categories of sites: 1) five tributaries where nutrient and sediment data were lacking because they had not been sampled previously (e.g. several small tributaries that flow directly into South Bay), 2) six tributaries where high phosphorus levels had been measured previously but where they remained poorly understood (e.g. Brighton Brook), and 3) two tributaries where phosphorus-reduction projects had been undertaken previously (e.g. Wishing Well tributary and Shalney Branch). Second, we identified and mapped possible sources of water quality problems and potential phosphorus-reduction projects and practices in 28 priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin. Collectively, these two efforts greatly increased our understanding of water quality problems and allowed us to identify and prioritize locations where protection and restoration projects will most effectively reduce nutrient and sediment inputs into the Vermont tributaries of Lake Memphremagog.

Study Area

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

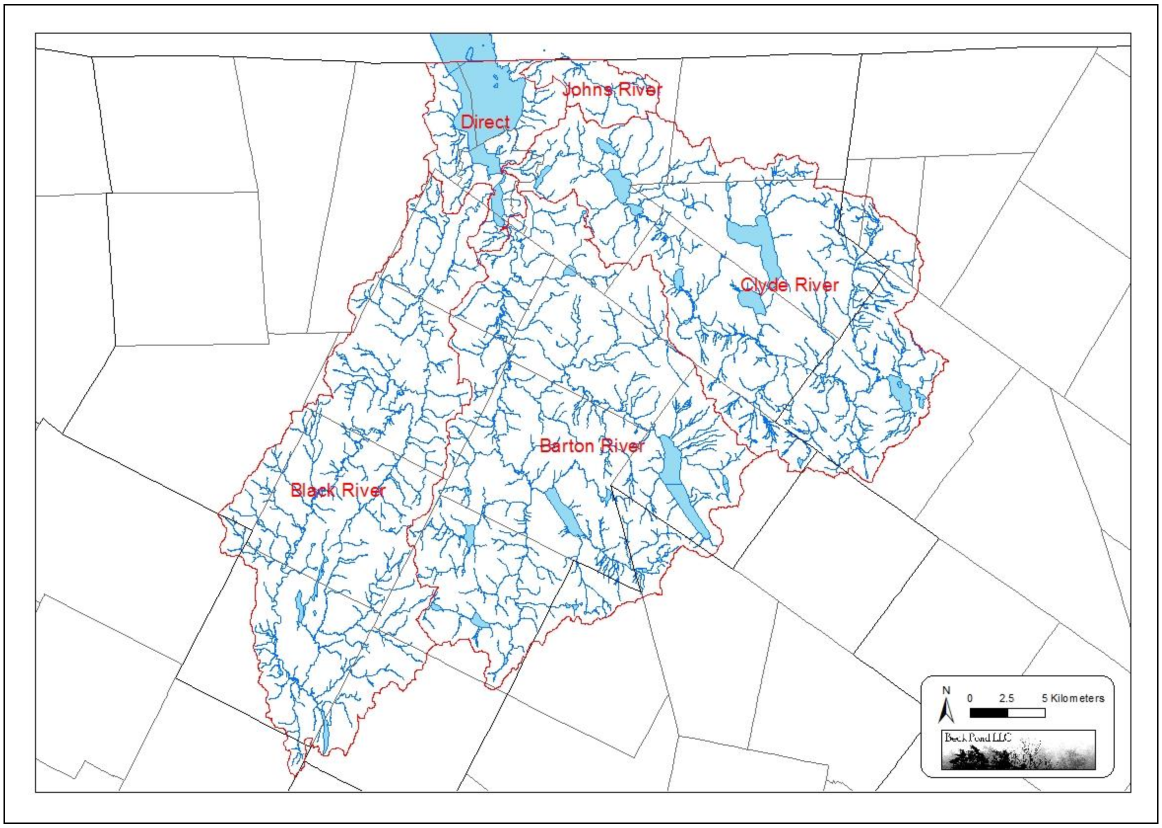

Figure 3. *The Vermont portion of the Lake Memphremagog Basin, including the watersheds of the four principal tributaries (Barton, Black, Clyde, and Johns Rivers).*

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 southern end of South Bay in Coventry. This watershed includes one large tributary (the Willoughby River) and several large lakes, including Lake Willoughby [657 ha (1,623 acres)] and Crystal Lake [274 ha (677 acres)] among others. The Barton River is listed as a priority surface water in need of further assessment due to the presence of toxic compounds in wetlands near Orleans village (Part C, State of Vermont 2012a). Brownington Pond is listed as a priority surface water altered by exotic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2012a). In addition, 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 is listed as a priority surface water altered by flow regulation due to seasonal water level fluctuations that may be impacting aquatic habitats and aesthetics (Part F, State of Vermont 2012a).

The Black River (Waterbody ID VT17-09/10) drains an area of 349 km^2 (135 mi^2) extending from its headwaters in the towns of Craftsbury and Greensboro downstream to the western shore of South Bay in Newport City. The watershed includes one large tributary (Lords Creek) and several small lakes and ponds. The Black River is listed as a priority surface water in need of further assessment due to elevated mercury levels in walleye from the mouth upstream to Coventry Falls (Part C, State of Vermont 2012a). Lake Elligo is listed as a priority surface water altered by exotic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2012a). Rapidly expanding populations of several other invasive species (purple loosestrife, common reed, and Japanese knotweed) also 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 large tributaries (the Pherrins River and the outlet of Seymour and Echo Lakes) and numerous large lakes, including Seymour Lake [667 ha (1,648 acres)], Lake Salem [232 ha (573 acres)], and Island Pond [221 ha (546 acres)] among others. The Clyde River is listed as a priority surface water in need of further assessment due to unidentified solvents dumped along an unnamed tributary in Newport City, the presence of *E. coli* and other bacterial contamination in the inlet streams and open waters of Lake Salem, and elevated mercury levels in walleye from the mouth upstream to West Charleston (Part C, State of Vermont 2012a). In addition, a TMDL has already been completed and approved to address elevated mercury levels in walleye in Lake Salem (Part D, State of Vermont 2012a). Lake Derby in Derby is listed as a priority surface water altered by exotic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2012a). Small but rapidly expanding populations of purple loosestrife, common reed, and Japanese knotweed occur throughout the watershed but are most abundant in the lower watershed. Finally, an unnamed tributary of the Clyde River in Brighton is listed as a priority surface water altered by flow regulation due to the possible lack of minimum flows below a water supply withdrawal point (Part F, State of Vermont 2012a). 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 is not listed as a priority surface water outside the scope of Clean Water Act Section 303(d)(State of Vermont 2012a). However, Crystal Brook in Derby, which is one of three main tributaries of the Johns River, was recently removed from the list of impaired surface waters needing a TMDL due to excessive sediments and nutrients from agricultural runoff.

In addition to these four principal tributaries, the Southern Basin of Lake Memphremagog is fed by numerous small tributaries that flow directly into the 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 priority surface waters outside the scope of Clean Water Act Section 303(d)(State of Vermont 2012a), although high nutrient and sediment levels have been measured in several of these (Gerhardt 2009, 2010).

Water Quality Sampling

Methods

In 2013, we sampled water quality at 32 sites distributed throughout the Vermont portion of the Lake Memphremagog Basin to better pinpoint possible nutrient and sediment sources (Figure 4; see Appendix A for descriptions of all sites). These 32 sites included twelve sites along tributaries of the Black River, 13 sites along tributaries of the Barton River, three sites along three small tributaries that flow directly into South Bay, and four sites along two small tributaries that flow directly into Lake Memphremagog. Twenty-four of these sites were established to further pinpoint the source(s) of the high phosphorus and sediment levels measured previously: two tributaries of the Black River (Stony and Brighton Brooks), three tributaries of the Barton River (Roaring Brook and the Hamel Marsh and Junkyard tributaries), and one small tributary that flows directly into Lake Memphremagog (the Holbrook Bay South tributary). Five sites were established to sample tributaries that had not been sampled previously: one small tributary each of the Black River (the Airport tributary) and the Barton River (Alder Brook) and three small tributaries that flow directly into South Bay (Cobb and Day Brooks and the Rediker Hill tributary). Finally, we sampled three sites to assess the success of phosphorus-reduction projects that had been implemented previously: two sites on a tributary of the Black River (Shalney Branch) and one site on a small tributary that flows directly into Lake Memphremagog (the Wishing Well tributary). In a separate study, the Vermont DEC continued to sample water quality at four sites near the mouths of the four principal tributaries of Lake Memphremagog (Barton, Black, Clyde, and Johns Rivers), which have been sampled every year since 2005.

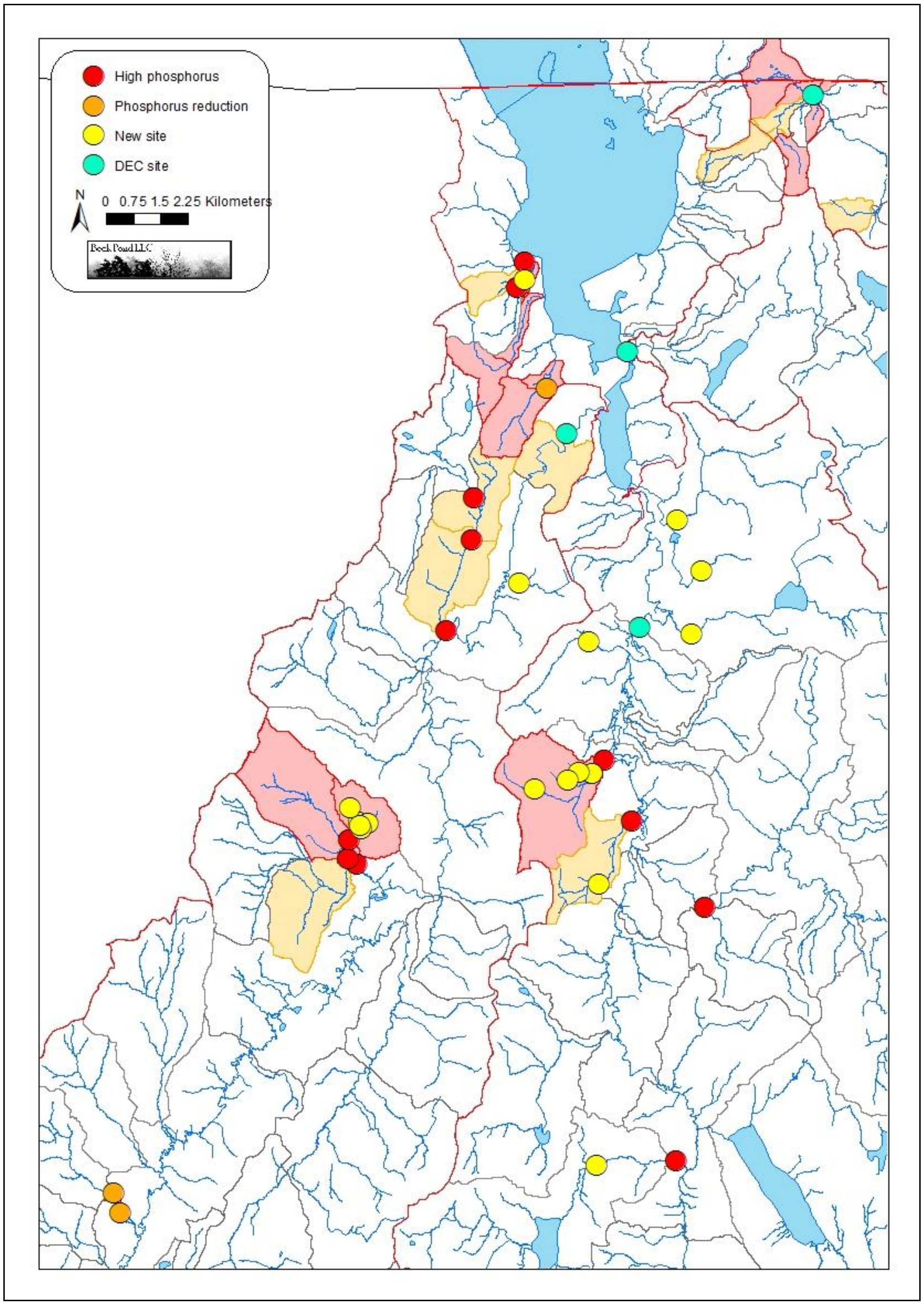

Figure 4. *Locations of the 32 sites where water quality was sampled along the Vermont tributaries of Lake Memphremagog during April-October 2013. The red and orange shading outlines the 28 subwatersheds with that exhibited the highest phosphorus concentrations during 2005-2012.*

To accomplish the goals of this study, we sampled water quality at these 32 sites on eight dates during 23 April-8 October 2013 (the four DEC-maintained sites were sampled separately and on a different schedule, and those data are not reported here). These sample dates included two moderately high-flow events (23 April and 11 June) and two moderate-flow events (18 June and 8 October). One of our sample rounds (11 June) was ideally timed during a rainfall event to allow us to pinpoint and assess phosphorus and sediment sources. Three of the sites were sampled on only the first sample date (Nelson Northwest) or first three dates (Upper Nelson Northwest and Upper Hamel Marsh). Due to filling of the stream upstream and downstream of the Nelson Northwest site, this site was replaced by the Nelson NW Pipe site, which was located approximately 98 m (322 ft) further downstream and which sampled water flowing out of the drainage pipe buried in the former stream channel (Figure 5). In addition, three sites (Lower Hamel Tributary, Middle Hamel Tributary, and Upper Hamel Tributary) were not sampled prior to 11 June and so were only sampled on six dates. Finally, due to low flows, the Nelson Northeast site was not sampled on four dates (21 May, 16 July, 13 August, and 10 September); the Lower Hamel Tributary was not sampled on two dates (13 August and 10 September); and the Upper Brighton Brook North site was not sampled on one date (10 September).

Figure 5. *The Nelson Northwest site was replaced by the Nelson NW Pipe site following filling of the stream during May 2013. The pipe laid in the streambed was perforated, at least in some locations, and, thus, sampled both water draining out of the former wetland upstream and groundwater draining the large barn complex to the north.*

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 morning. This schedule ensured that the laboratory was able to process the samples in a timely manner. On each sample date, we also measured water depth with a meter stick at one site on a small tributary of the Barton River (Rock Junkyard). More importantly, the U.S. Geologic Survey maintained gage stations that measured water depths and stream flows on the Barton, Black, and Clyde Rivers; and the Vermont DEC maintained a seasonal gage station that measured water depths on the Johns River. For the latter, daily stream flows for the entire sampling season were estimated based on a rating curve developed from the water depths recorded by a YSI 600 LS vented sonde (YSI, Yellow Springs, Ohio) and stream flows measured with a SonTek Acoustic Doppler Flowtracker (SonTek, San Diego, California). In this study, we used the daily stream flows measured on the Johns River by the Vermont DEC as a proxy for stream flows for all sites.

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

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

Results and Discussion

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

Stream Flow

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

To approximate stream flows at our sample sites, we relied on stream flow measurements from the gage maintained seasonally by the Vermont DEC on the Johns River. The 2013 sampling season was characterized by an early spring snowmelt and relatively low to moderate flows throughout the sampling season (Figure 6). Peak spring flows occurred during the first half of April following snowmelt. Higher flows caused by heavy rains were also recorded on 26 May, 29 July, 12 September, and 22 September following heavy rains. Otherwise, flows were generally low to moderate throughout the sampling season. The lowest flows were recorded during late May, August, and September.

Our sample dates largely reflected the variation in stream flows recorded in 2013 (Figure 6). We were able to collect water samples during two high-flow events (following snowmelt on 23 April and during heavy rains on 11 June). Although both events were relatively modest in terms of flows, the event on 11 June was sampled during and immediately following heavy rains, so that nutrient and sediment levels were relatively high compared to those measured following snowmelt on 23 April. We also were able to collect water samples during two moderate-flow events following light rains (18 June and 8 October). The remaining water samples were collected during low flows, although the low flows in 2013 were not as extreme as those observed during previous years. Collecting water samples across this broader 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.

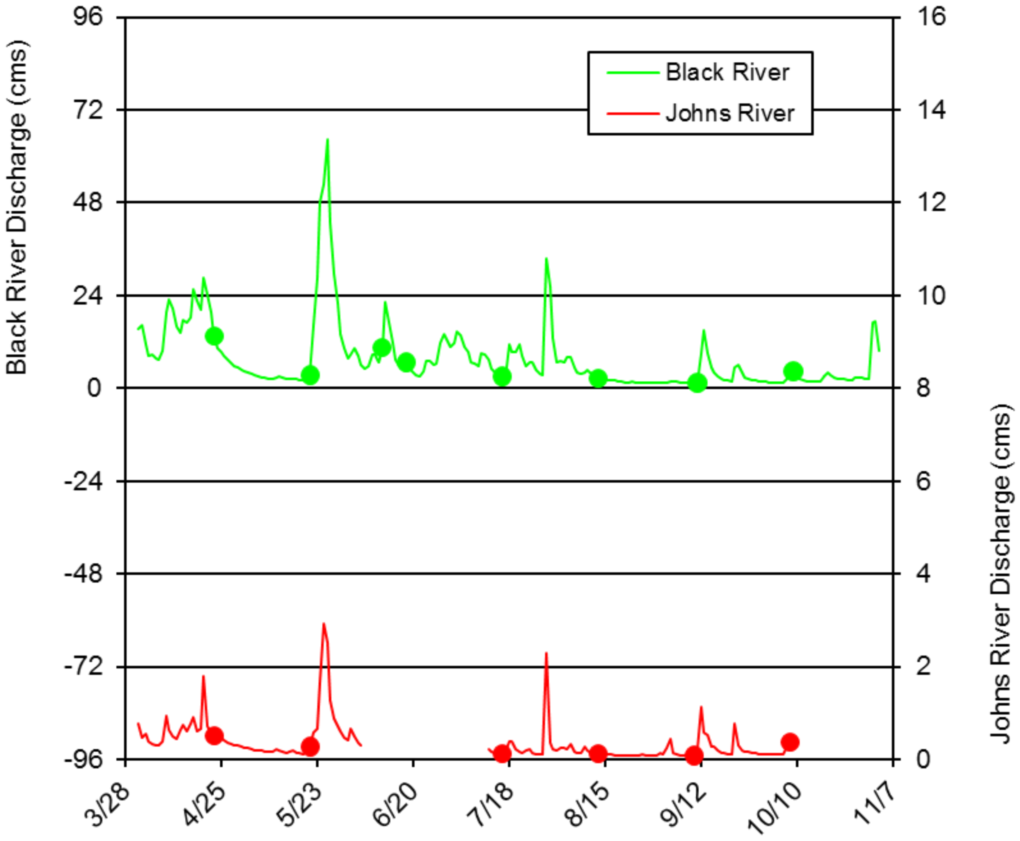

Figure 6. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2013. The eight dates on which water samples were collected are indicated by the circles. Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, Vermont)]; stream flows for the Johns River were measured by the Vermont DEC.*

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, high phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to oxygen depletion and increased mortality of aquatic life. In Vermont, most phosphorus originates from soil erosion, wastewater, manure, and synthetic fertilizers applied to lawns and agricultural fields.

Total phosphorus concentrations in this study ranged between 8.55-2,760 µg/l. As in previous years, total phosphorus concentrations showed no marked seasonal pattern (Figure 7). The highest total phosphorus concentrations were measured on one of the two sample dates with the highest stream flows (11 June), when surface runoff following heavy rains likely carried large amounts of soil and nutrients into the rivers and streams. Despite equally high flows on the first sample date (23 April), total phosphorus levels were markedly lower on that date, possibly because this date sampled the falling limb of the high flows following snowmelt.

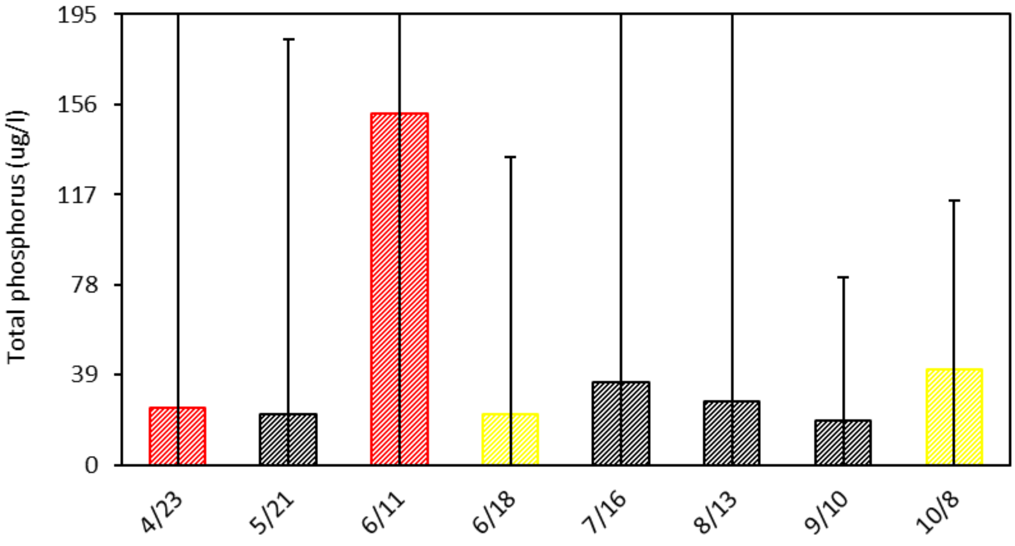

Figure 7. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Red hatching indicates the two high-flow events; yellow hatching indicates the two moderate-flow events.*

Since our sampling was focused on assessing streams with high phosphorus levels, total phosphorus concentrations were generally high (median values >20 µg/l) at most of the sites. Total phosphorus concentrations were markedly high along several tributaries of the Black and Barton Rivers (Brighton and Roaring Brooks and the Airport, Junkyard, and Hamel Marsh tributaries) and along two small tributaries that flow directly into Lake Memphremagog (the Holbrook Bay South and Wishing Well tributaries)(Figures 8-9). All of these tributaries drained areas of diverse land uses, including large areas of agriculture. In contrast, total phosphorus concentrations were generally low (median values <20 µg/l) along the three small tributaries that flow directly into South Bay (Cobb and Day Brooks and the Rediker Hill tributary) and one other tributary of the Barton River (Alder Brook). These tributaries generally drained more forested areas with limited areas of agricultural and other land uses.

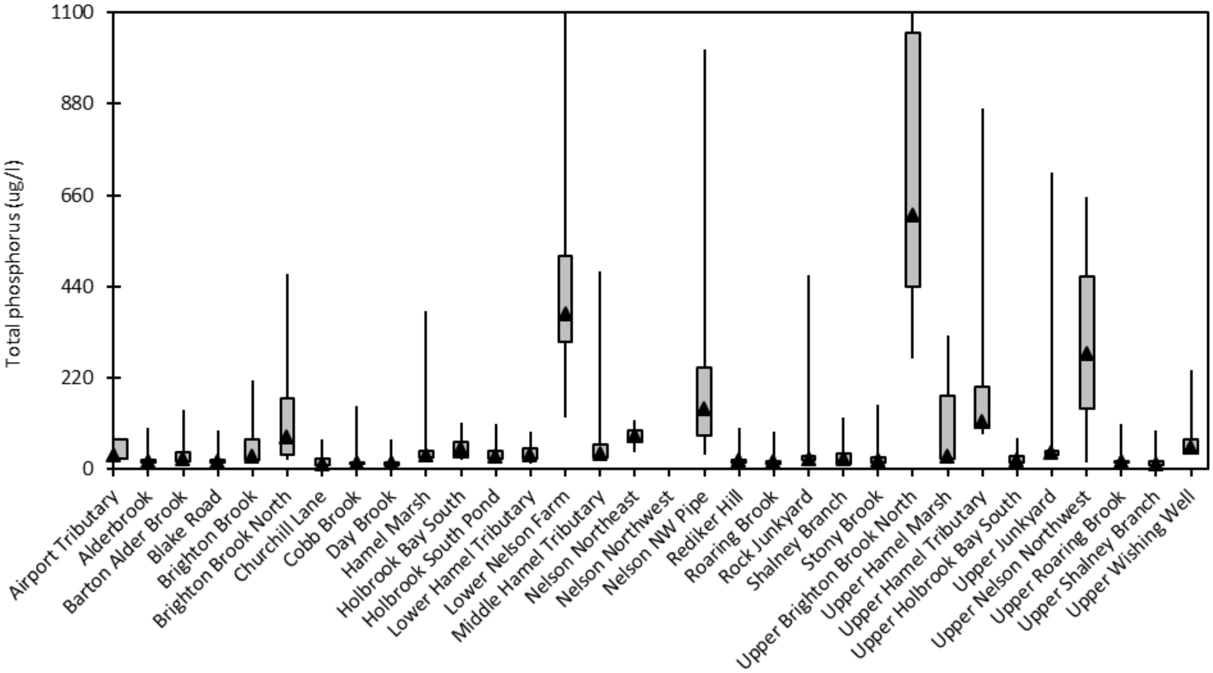

Figure 8. *Total phosphorus concentrations at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

One new site exhibiting high total phosphorus concentrations was the Airport Tributary site on a small tributary of the Black River. Total phosphorus concentrations at this site generally showed a positive relationship with stream flow (Figure 10). This positive relationship suggested that the high phosphorus levels may be originating from nonpoint source surface runoff, possibly flowing from either the paved and grassy surfaces of the Newport State Airport or the several large cornfields that were recently created from previously forested wetlands on the ridge to the south.

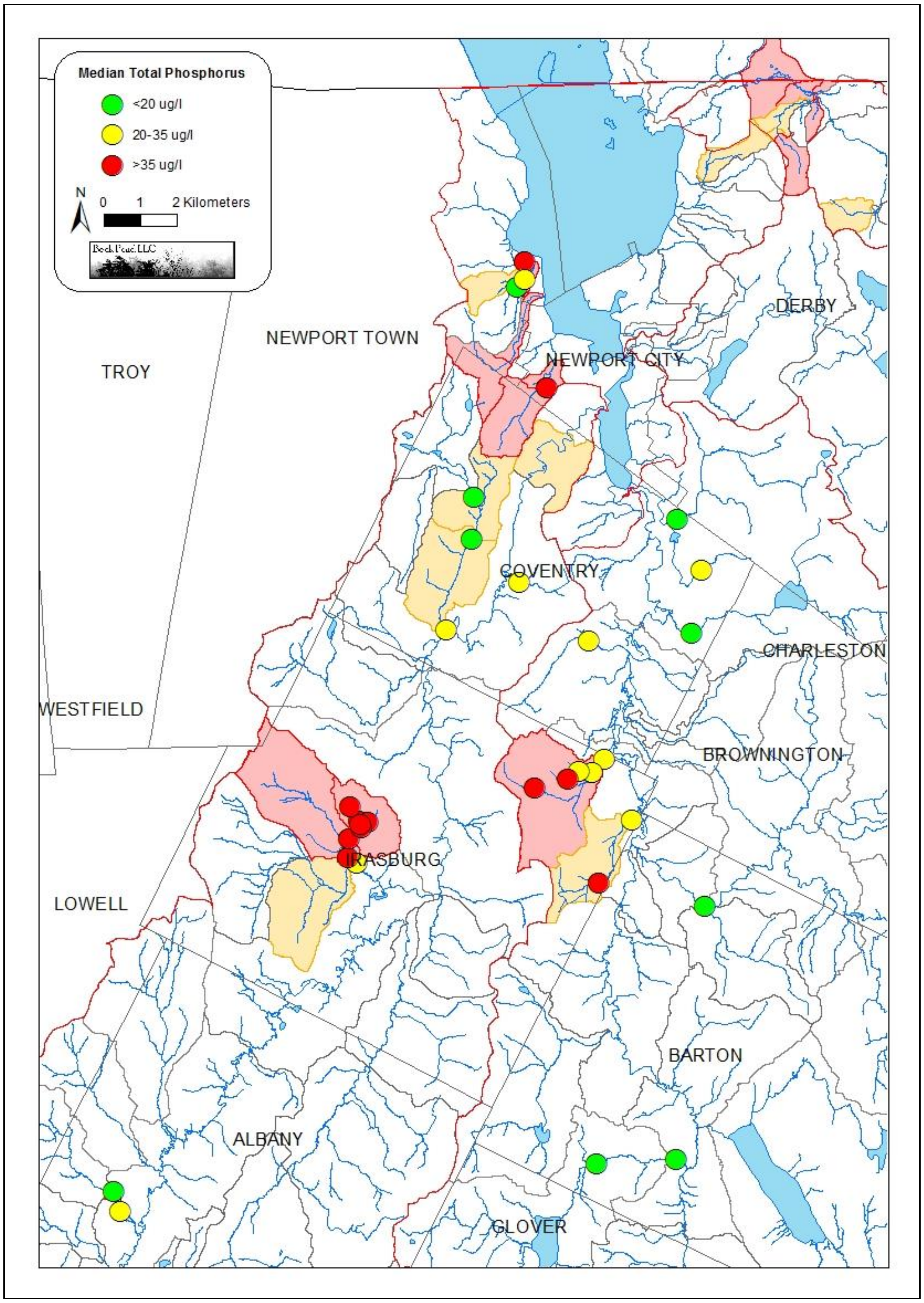

Figure 9. *Median total phosphorus concentrations at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. The red and orange shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

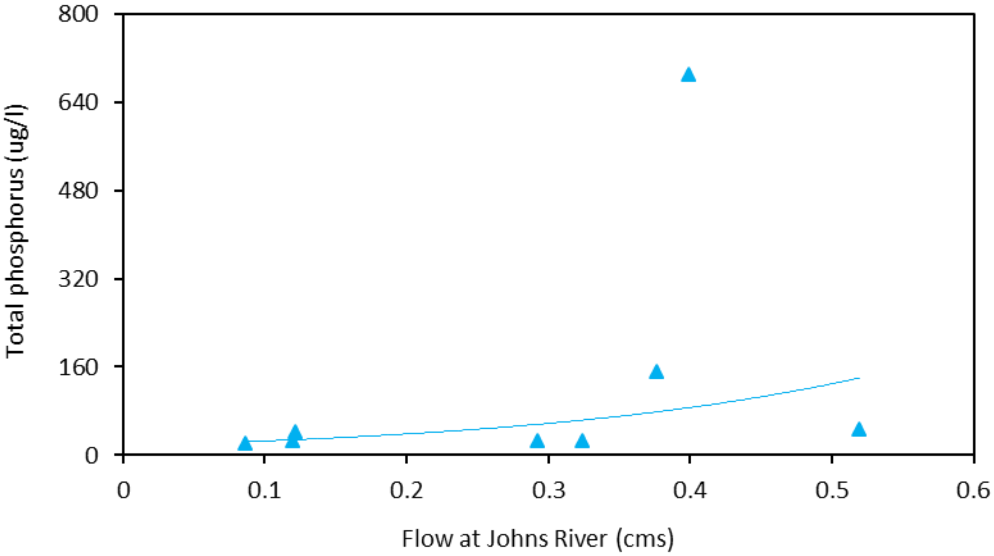

Figure 10. *Total phosphorus concentrations in relation to stream flow at the Airport Tributary site during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

The 2013 water quality data allowed us to further pinpoint the source(s) of the high phosphorus and nitrogen concentrations in Brighton Brook, a tributary of the Black River. As in 2010-2012, total phosphorus concentrations were relatively high at the downstream-most Brighton Brook site (median = 30.1-102 µg/l during 2010-2013). In 2011-2012, we had observed that total phosphorus concentrations were considerably higher in a small tributary that flowed into Brighton Brook from the north and that they were lower further up the main stem of Brighton Brook (Gerhardt 2012a, 2013). Thus, in 2013, we focused our sampling along this small northern tributary. Total phosphorus concentrations along this tributary were high at the downstream-most site (Brighton Brook North) and was even higher at sites located further upstream (Upper Brighton Brook North, Lower Nelson Farm, and Nelson Northwest)(Figure 11). Based on these data, it was clear that much of the phosphorus was originating somewhere in the upper watershed of the small northern tributary. Total phosphorus concentrations showed very different relationships with stream flow among the different sites (Figure 12). In particular, total phosphorus concentrations decreased with increasing flows at two sites lying downstream of wetlands (Upper Nelson Northwest and Upper Brighton Brook North), increased with increasing flows at two sites downslope of the barn complex and cornfields (Nelson NW Piper and Lower Nelson Farm), and showed no relationship with flow at the two downstream-most sites (Brighton Brook North and Brighton Brook). Collectively, these data suggest that the high phosphorus levels in the upper reaches of this tributary were originating from surface runoff from the barnyard and mortality composting areas and also possibly from the large cornfields, which were often heavily manured in the spring (Figure 13). In contrast, the high phosphorus concentrations at the Upper Brighton Brook North site on the two low-flow dates in mid-summer suggest that phosphorus may also be stored in and released from two small ponds and wetlands located between there and the next site upstream (Figure 14). Unfortunately, the filling of the wetlands and stream channel during the sampling season greatly diminished our ability to conclusively pinpoint the source(s) of these high phosphorus levels. Nevertheless, we will continue to work with the landowner, the Vermont DEC, and the Vermont Agency of Agriculture, Food and Markets to identify and develop projects and practices that will reduce nutrient and sediment exports from this farm.

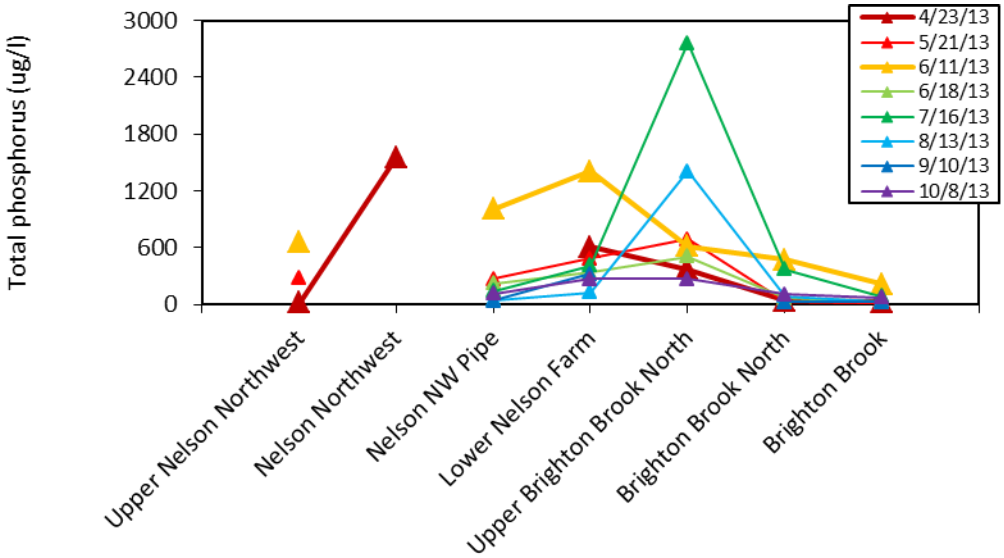

Figure 11. *Total phosphorus "profile" along the main stem and northern tributary of Brighton Brook from Upper Nelson Northwest downstream to Brighton Brook during April-October 2013.*

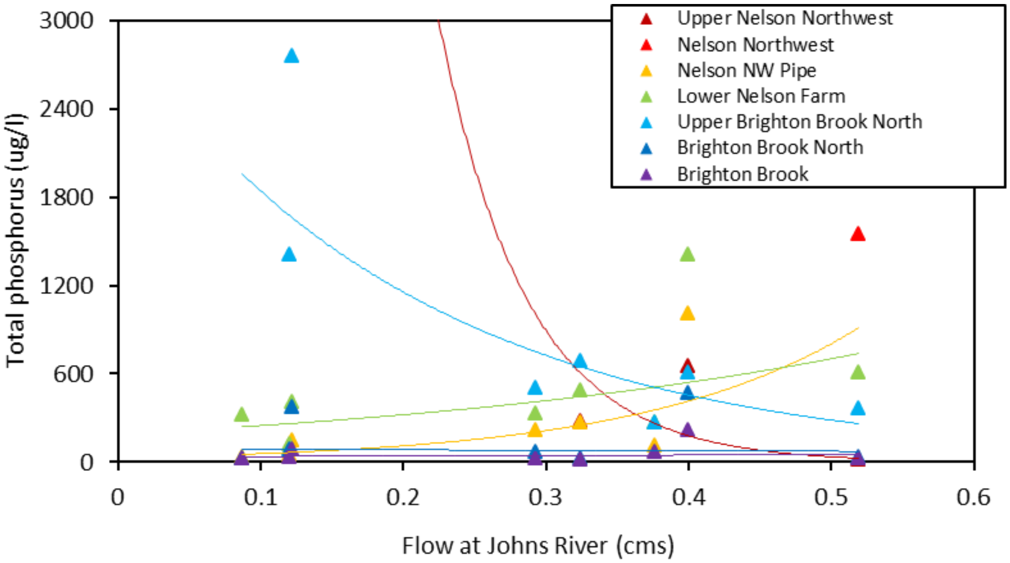

Figure 12. *Total phosphorus concentrations in relation to stream flow at seven sites along Brighton Brook and its northern tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

Figure 13. *The large areas of agriculture - including the large cornfields, barnyards, and associated manure pits and mortality composting sites - may be the source(s) of the high phosphorus and nitrogen levels measured along the upstream reaches of the northern tributary of Brighton Brook.*

Figure 14. *These ponds and wetlands may be the source(s) of the high phosphorus levels measured on some sample dates along the downstream reaches of the northern tributary of Brighton Brook.*

In contrast, we were able to positively identify the source area, but not the specific source, of the high phosphorus levels measured in the small tributary that flows directly into Holbrook Bay in the southwest corner of Lake Memphremagog. Total phosphorus concentrations along this tributary have remained fairly constant during 2010-2013, although they may have decreased slightly at the lowest flows. On all but two late season, low-flow sample dates, total phosphorus concentrations increased between the upstream-most site, located just upstream of a man-made pond, and the site located just downstream of that pond and generally remained constant from there downstream, except on two low-flow, late-season sample dates, when they increased further downstream (Figure 15). The two upstream sites were only 290 m (950 ft) apart and were separated by only a culvert beneath a paved road and the man-made pond. Thus, it seems likely that the high phosphorus levels in this tributary were originating from the pond itself, although the reasons for this remain unclear. The pond is located just downslope of an old dairy barn that was still being used to house beef cattle, but no obvious site for manure storage was observed on the aerial photographs or from the road. From the shoreline, it was clear that both nutrient levels and algal growth (primarily brown algae) were high in this pond (Figure 16). In addition, we observed two aerators operating in this pond, presumably to oxygenate the water column, and it is possible that these aerators are stirring and releasing phosphorus from the sediment (Figure 16). On the two low-flow, late-season sample dates, total phosphorus concentrations actually increased further downstream (Figure 15). That area had been grazed historically but was restored as part of a Conservation Reserve Enhancement Program (CREP) project that excluded cattle from and planted trees and shrubs in the riparian corridor along this tributary.

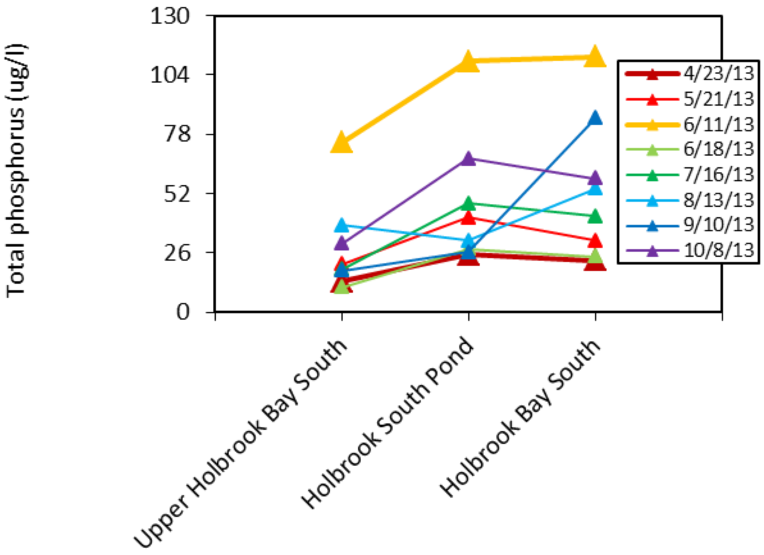

Figure 15. *Total phosphorus "profile" along the Holbrook Bay South tributary from Upper Holbrook Bay South downstream to Holbrook Bay South during April-October 2013.*

Figure 16. *Aerator (upper photo) and brown algae (lower photo) in man-made pond on the Holbrook Bay South tributary in Newport Town, Vermont on 8 October 2013.*

We also attempted to further pinpoint the phosphorus sources along several other tributaries, where higher total phosphorus concentrations were measured previously. Along Stony Brook, total phosphorus concentrations have remained fairly constant during 2009-2013, especially at lower flows, and there were no consistent or pronounced increase in phosphorus concentrations among the three sites sampled (Figure 17a). Based on our sampling in 2012, we had also measured elevated phosphorus levels along three tributaries of the Barton River. In 2013, we sampled additional sites on all three tributaries to better pinpoint the sources of these high phosphorus levels. Along Roaring Brook, we measured a slight but consistent decrease in total phosphorus concentrations from the Upper Roaring Brook site downstream to the Roaring Brook site [the two sites were separated by approximately 2.3 km (1.4 mi)](Figure 17b). The consistency of this decrease suggested that there may be a phosphorus source somewhere in the upper watershed of Roaring Brook. Along the Junkyard tributary, total phosphorus concentrations were generally 50% greater at the upstream vs. the downstream site, and these higher concentrations occurred across all sample dates and at all flows (Figure 17c). Thus, much of the phosphorus in this stream may also be originating from the upper watershed, where there is a medium-sized farm operation and several large cornfields. Finally, we were also able to further pinpoint the source(s) of the high phosphorus levels to one of three small tributaries that flow into the Hamel Marsh tributary (Figure 17d). At the Upper Hamel Tributary site, total phosphorus concentrations were high on all sample dates and increased with increasing stream flows (Figure 18). These high levels, even at low flows, and this positive relationship with flow suggests that the phosphorus may be originating from both nonpoint and point sources. Possible sources include surface runoff from the large cornfields as well as runoff from the large barn complex located at the height of this subwatershed. The Middle Hamel Tributary site also exhibited elevated phosphorus levels, although mostly at higher stream flows.

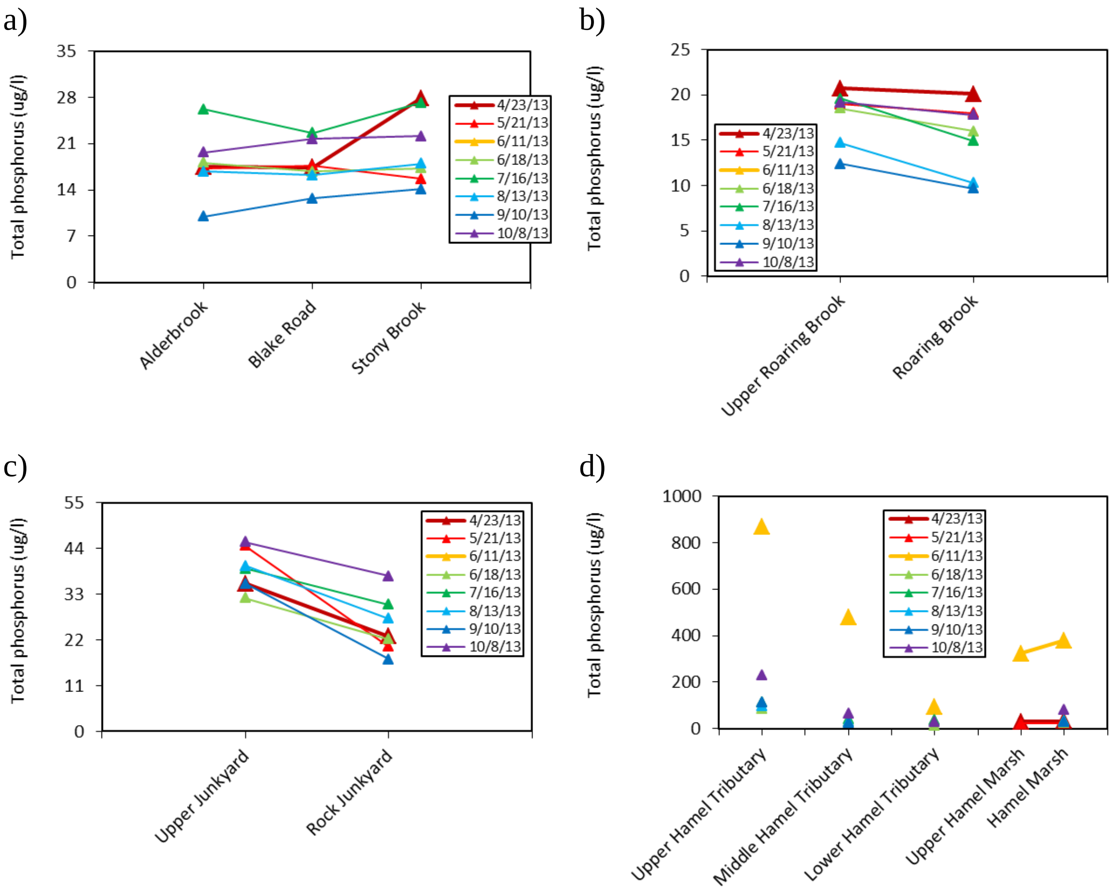

Figure 17. *Total phosphorus "profiles" along four tributaries of the Black and Barton Rivers during April-October 2013: a) Stony Brook, b) Roaring Brook, 3) the Junkyard tributary, and 4) the Hamel Marsh tributary.* Upstream to downstream is left to right in all four graphs.

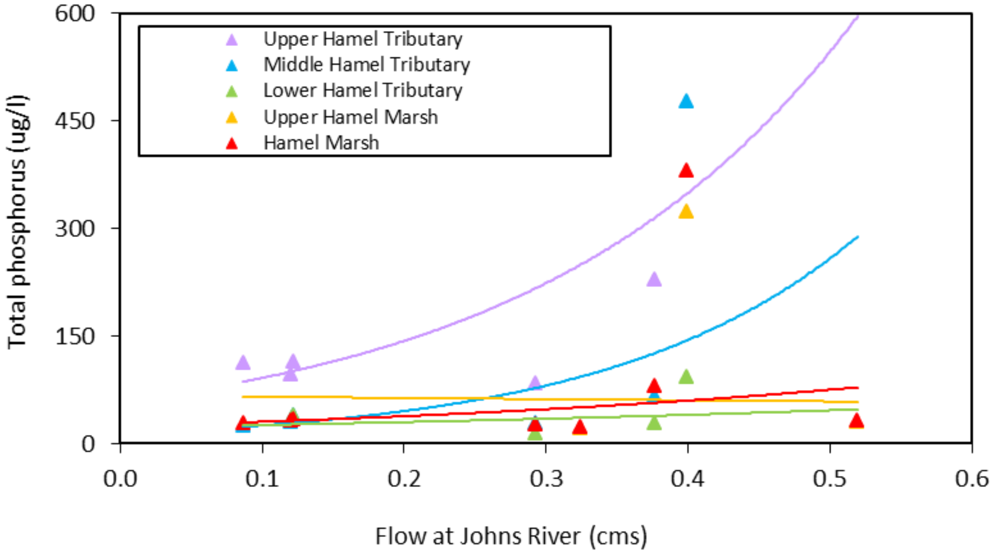

Figure 18. *Total phosphorus concentrations in relation to stream flow at five sites along the Hamel Marsh tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

Finally, we resampled three sites along two tributaries to assess the efficacy of previously-implemented phosphorus-reduction projects and practices. Along Shalney Branch, several barnyard and laneway improvement projects were implemented during 2009-2012 (Figure 19). Total phosphorus concentrations in this stream dropped dramatically between 2009-2010 and 2012-2013, especially at the lowest stream flows (Figure 20). Thus, it appears that these projects have benefitted water quality in Shalney Branch. In addition, the farmer and the Vermont Association of Conservation Districts are discussing another barnyard project that may further reduce phosphorus exports into this stream. In contrast, total phosphorus concentrations have not decreased consistently along the Wishing Well tributary, where a grazing plan and clean-water diversion projects were implemented during 2011-2012 (Figure 19). Although water quality appeared to have improved along this tributary during 2009-2012, total phosphorus concentrations in 2013 were slightly higher, especially at lower stream flows (Figure 20). This lack of further improvement may reflect the intensive grazing that occurs in the pastures located along this tributary, the lack of unmanaged riparian buffers, and the clearing of 2.6 ha (6.5 acres) of forested wetlands between 2009 and 2011. Thus, our sampling indicated that water quality was improving along only one of the two tributaries where phosphorus-reduction projects and practices were implemented previously.

Figure 19. *Two phosphorus-reduction projects completed along two Vermont tributaries of Lake Memphremagog included an improved laneway on a farm along Shalney Branch diverted barnyard and laneway runoff into the surrounding forest (upper photo) and a clean-water diversion project at a barn complex along the Wishing Well tributary (lower photo).*

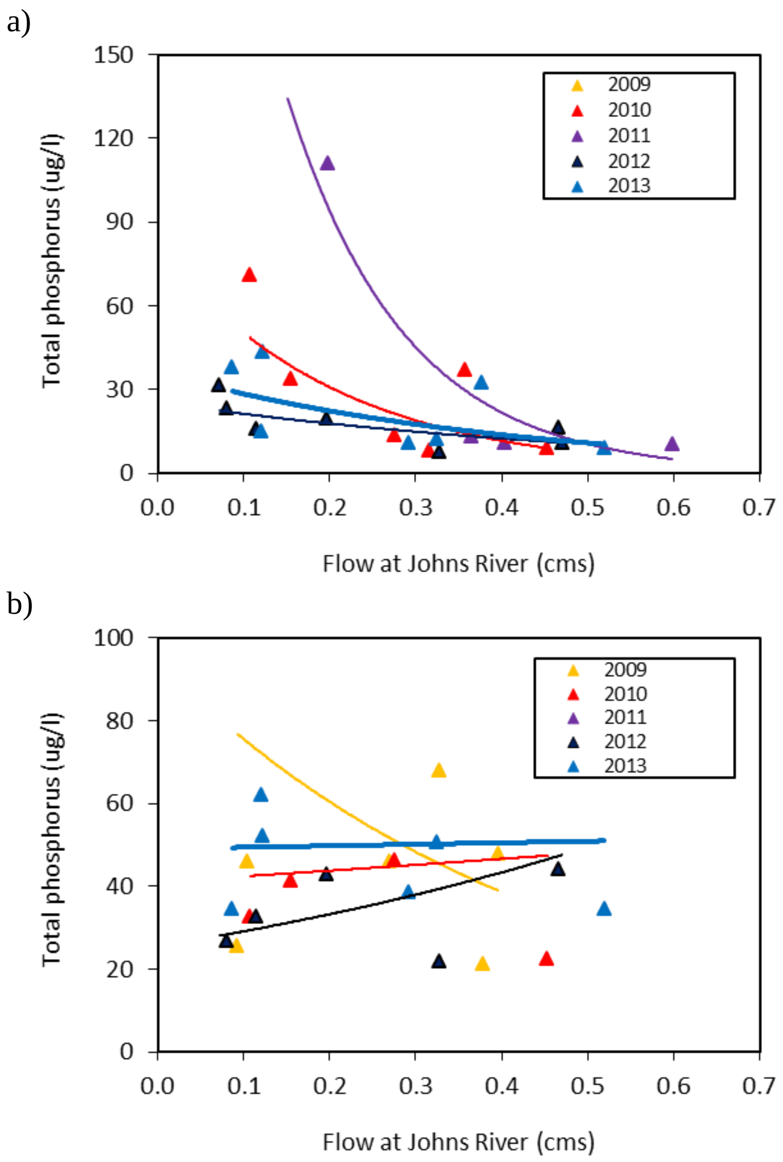

Figure 20. *Total phosphorus concentrations in relation to stream flow along a) Shalney Branch and b) the Wishing Well tributary during 2009-2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

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.

Total nitrogen concentrations in this study ranged between 0.14-25.9 mg/l. As in previous years, total nitrogen concentrations showed no marked seasonal trend (Figure 21). The highest nitrogen levels were measured on the sample date with the highest stream flow (11 June), when surface runoff following heavy rains likely carried large amounts of both dissolved and particulate forms of nitrogen into rivers and streams. However, the next highest nitrogen levels were observed on sample dates with low to moderate flows.

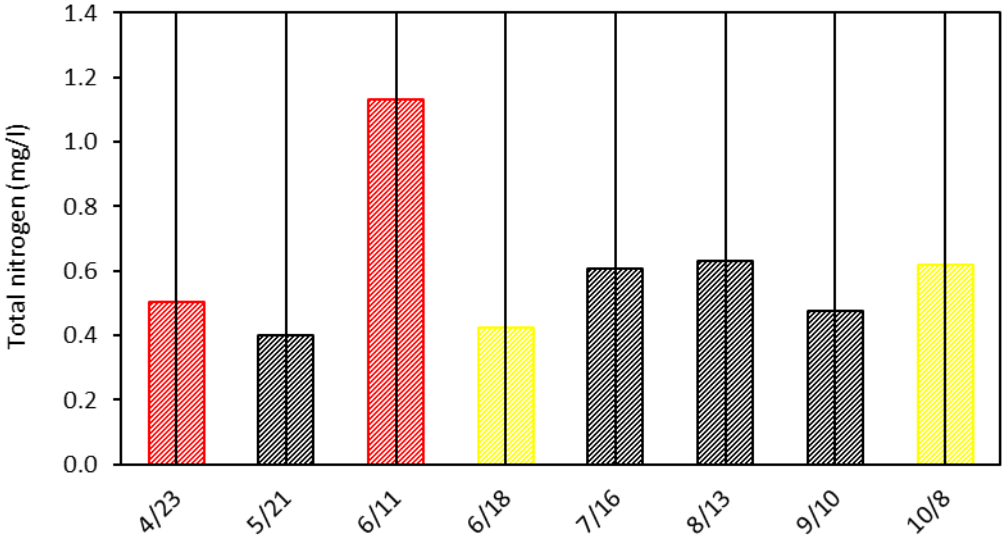

Figure 21. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Red hatching indicates the two high-flow events; yellow hatching indicates the two moderate-flow events.*

In general, total nitrogen concentrations were relatively low (i.e. <1 mg/l) at many sites, although many of those sites did exhibit higher total nitrogen concentrations during the high-flow event on 11 June (Figures 22-23). However, median total nitrogen concentrations did exceed 1 mg/l at twelve sites. All twelve of these sites were located along one of three tributaries: Brighton Brook, Stony Brook, and the Hamel Marsh tributary.

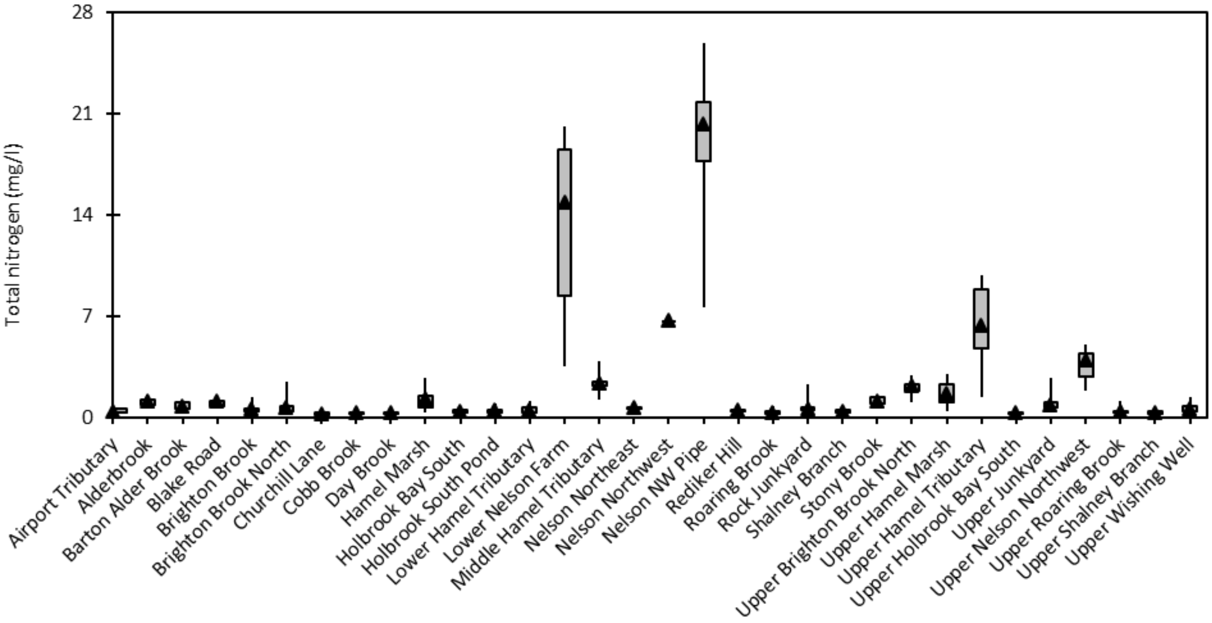

Figure 22. *Total nitrogen concentrations at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Values are the median (triangle), 1*st *and 3*rd *quartiles (rectangle), and minimum and maximum values (line).*

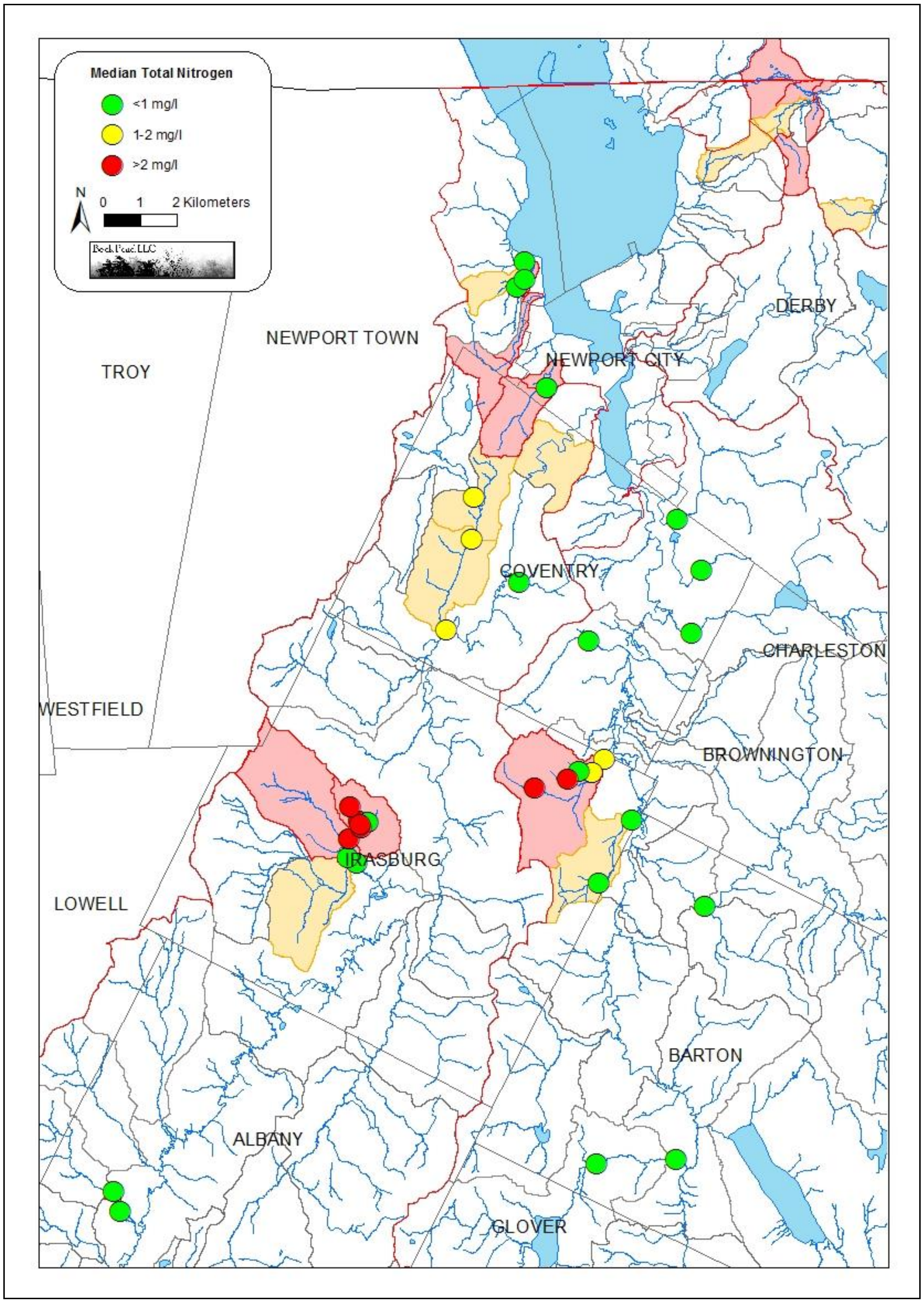

Figure 23. *Median total nitrogen concentrations at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. The red and orange shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

Along Brighton Brook, total nitrogen concentrations were extremely high at two sites along the northern tributary: Nelson NW Pipe [median = 19.8 mg/l (range = 6.63-25.9mg/l)] and Lower Nelson Farm [median = 14.8 mg/l (range = 3.50-20.1 mg/l)]. These high nitrogen levels paralleled the extremely high total phosphorus and turbidity levels also measured at these two sites. As in 2012, total nitrogen concentrations decreased dramatically further downstream and were markedly lower at the Brighton Brook North and Brighton Brook sites (Figure 24). Total nitrogen concentrations at Nelson NW Pipe and Lower Nelson Farm were more-or-less negatively related to stream flow (Figure 25). Collectively, these results suggest that the nitrogen in this tributary was derived from surface or groundwater runoff from nonpoint sources, such as the large cornfields, or point sources, such as the large barnyard, manure pit, or composting areas.

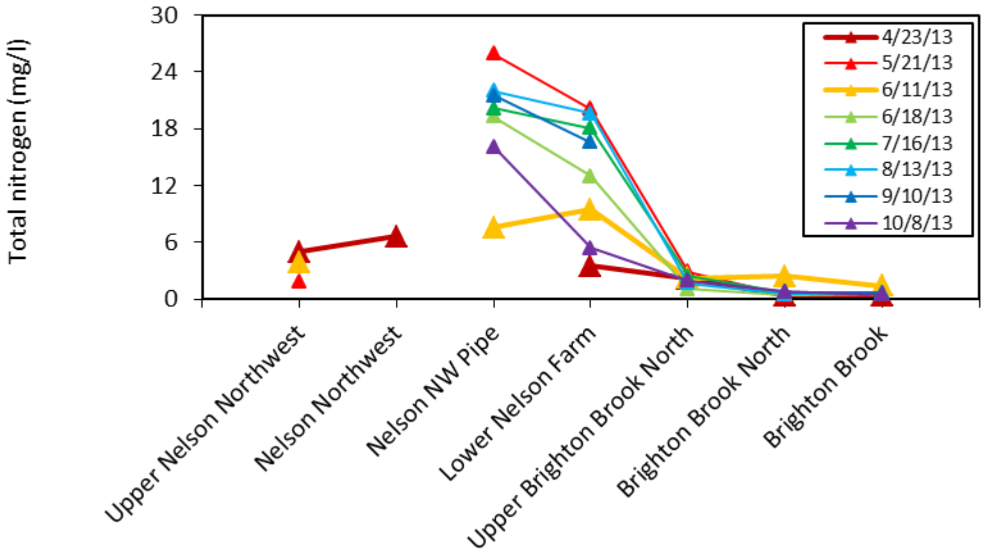

Figure 24. *Total nitrogen "profile" along the main stem and northern tributary of Brighton Brook from Upper Nelson Northwest downstream to Brighton Brook during April-October 2013.*

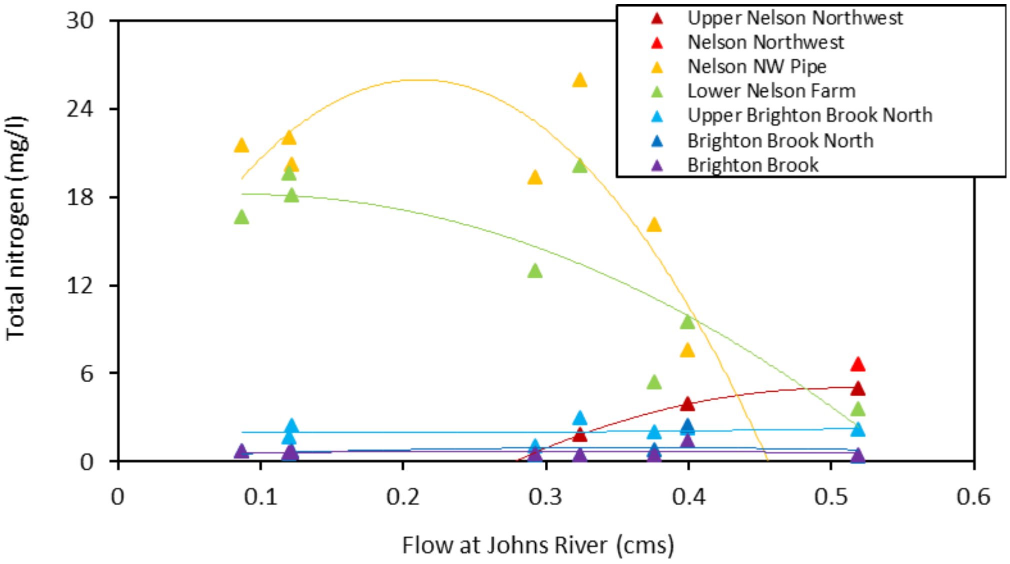

Figure 25. *Total nitrogen concentrations in relation to stream flow at seven sites along Brighton Brook and its northern tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

Along the Hamel Marsh tributary, total nitrogen concentrations were highest at the Upper Hamel Tributary site, slightly elevated at the Middle Hamel Tributary site, and considerably lower at the Lower Hamel Tributary site and further downstream (Figure 26). At the Upper Hamel Tributary site, total nitrogen concentrations generally decreased with increasing stream flow across all stream flows (Figure 27). This negative relationship suggested that the nitrogen in this stream may be originating from groundwater or point sources, rather than from nonpoint sources. The watershed of this tributary includes large areas of corn as well as a large barn complex that includes barnyards, manure pits, and silage storage. Thus, the nitrogen may be originating from nitrogen fertilizers applied onto these cornfields or from manure-laden runoff originating from the barn complex.

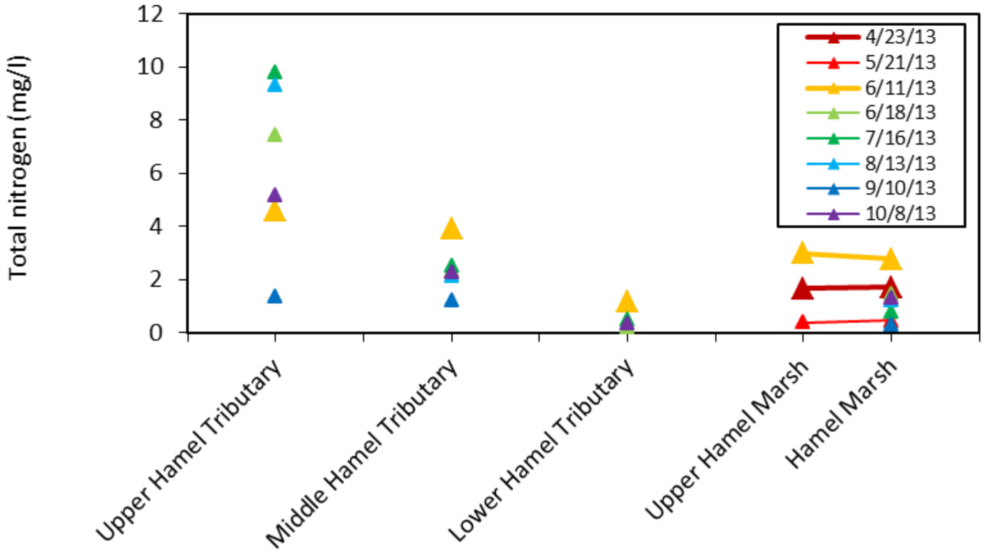

Figure 26. *Total nitrogen "profile" along the main stem and three small tributaries of the Hamel Marsh tributary from Upper Hamel Tributary downstream to Hamel Marsh during April-October 2013.*

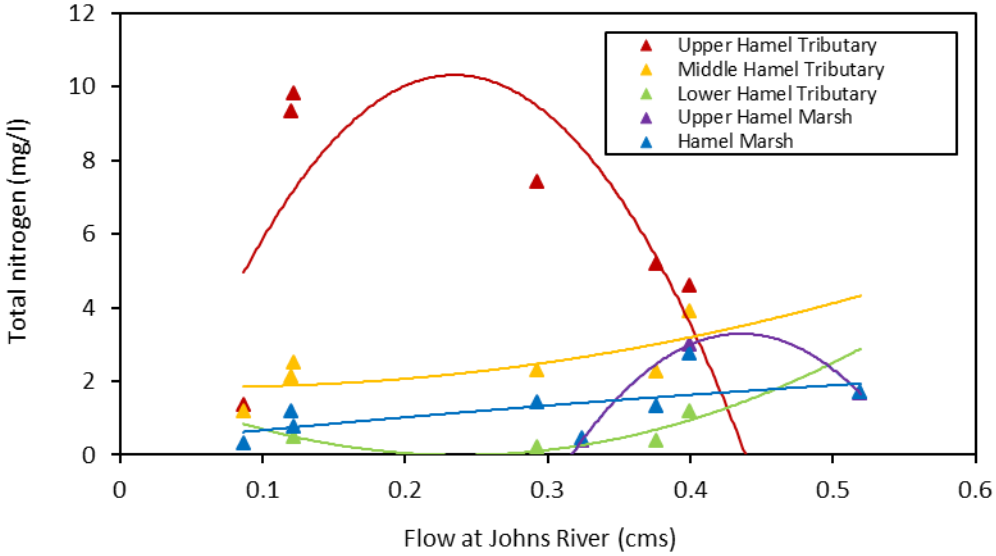

Figure 27. *Total nitrogen concentrations in relation to stream flow at five sites along the main stem and three branches of the Hamel Marsh tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

Along Stony Brook, we also observed fairly consistent but slightly elevated nitrogen concentrations at all three sites. As in 2011, the total nitrogen concentrations at all three sites were negatively related to stream flow (Figure 28). These negative relationships suggest that the nitrogen inputs into Stony Brook were derived from groundwater or point sources, rather than nonpoint sources. Thus, the elevated nitrogen levels in this stream may have a similar origin to those measured in the Johns River watershed (Gerhardt 2009, 2010), as much of the watershed of Stony Brook is underlain by coarse sand and gravel deposits. That is, much of the nitrogen in Stony Brook may originate in groundwater that contains nitrogen that was applied as manure and/or synthetic fertilizers to cornfields located on coarse sand and gravel deposits.

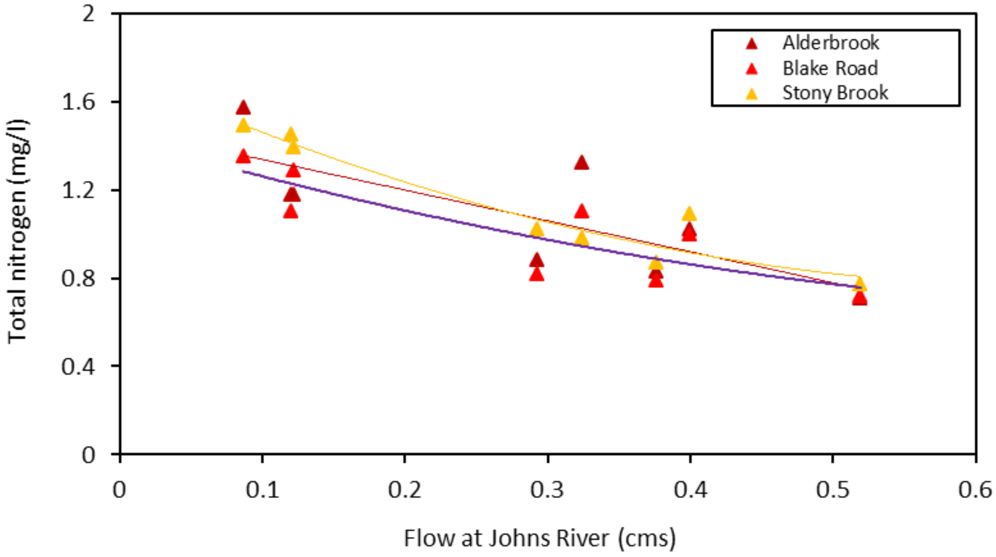

Figure 28. *Total nitrogen concentrations in relation to stream flow at three sites along Stony Brook during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

The high nitrogen levels measured along these three tributaries may not be reaching levels that are harmful to aquatic life. Although high, the nitrogen levels in two of the three tributaries were similar to or lower than those observed in the Johns River watershed (Gerhardt 2009, 2010). Based on recent biological assessments of the Johns River and its tributaries, even the higher nitrogen levels measured there did not appear to be harming the aquatic communities in those streams. Thus, we recommend continuing to monitor total nitrogen levels in these two tributaries while working with landowners to reduce the amounts of nitrogen being lost into both the groundwater and surface waters. In contrast, the high nitrogen levels measured along the northern tributary of Brighton Brook exceeded those measured elsewhere and may indicate a significant pollution problem, especially when considered along with the extremely high phosphorus and turbidity levels also measured there. In this tributary, it is imperative that we continue to pinpoint and assess the source(s) of these high nutrient and sediment levels and identify and develop projects or practices to mitigate those sources.

Turbidity

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

In 2013, we again had significant quality assurance issues with our turbidity samples (see following section). Consequently, the turbidity results must be viewed and interpreted with caution. Turbidity levels in this study ranged between 0.22-579 NTU. Like total phosphorus and total nitrogen, turbidity levels showed no marked seasonal pattern (Figure 29). The highest turbidity levels were measured on the sample date with the highest stream flows (11 June), when surface runoff following heavy rains likely carried large amounts of soil and nutrients into the rivers and streams. The lowest turbidity levels were recorded on several dates with relatively low flows, when there likely would have been little or no surface runoff.

Median turbidity concentrations were high (i.e. >10 NTU) at only a few sites concentrated along two tributaries that also exhibited higher total phosphorus and/or total nitrogen levels: Brighton Brook and the Holbrook Bay South tributary (Figures 30-31).

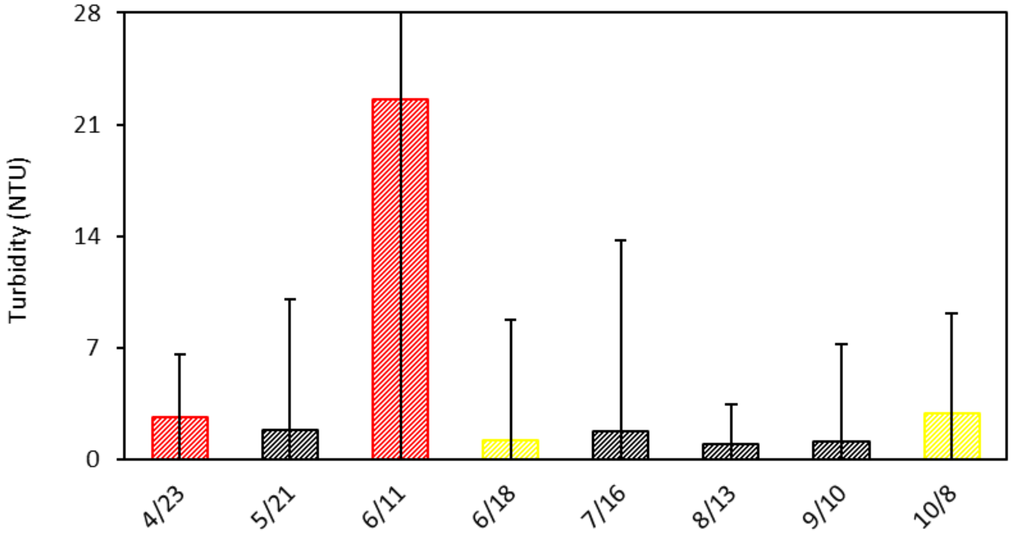

Figure 29. *Median turbidity levels (±1 SD) measured on each sample date at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Red hatching indicates the two high-flow events; yellow hatching indicates the two moderate-flow events.*

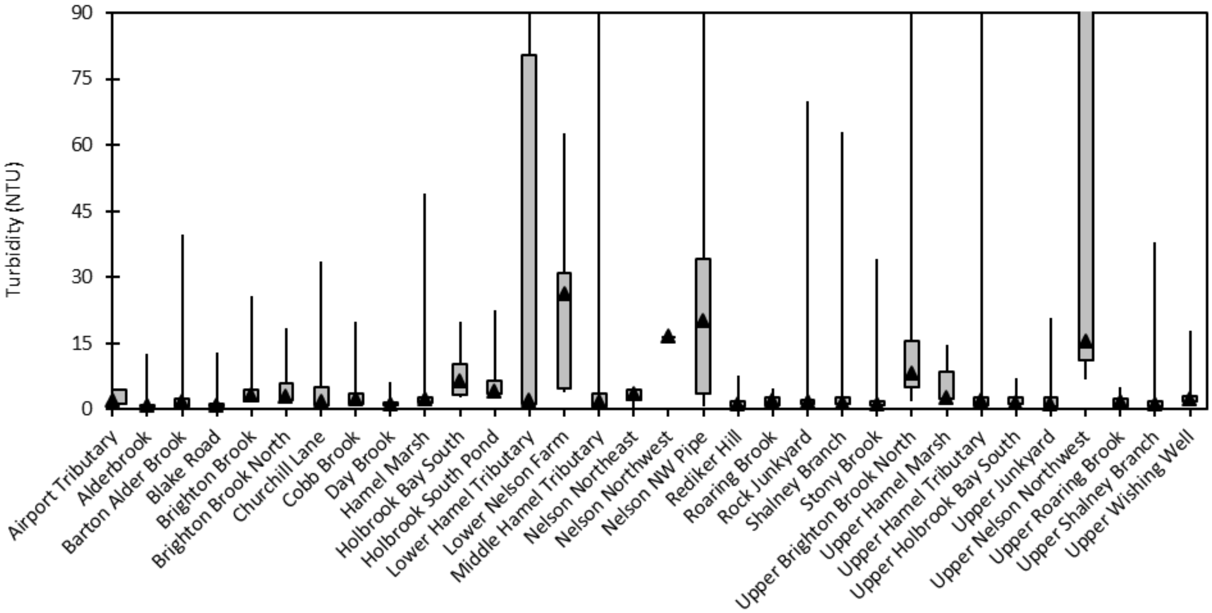

Figure 30. *Turbidity levels at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

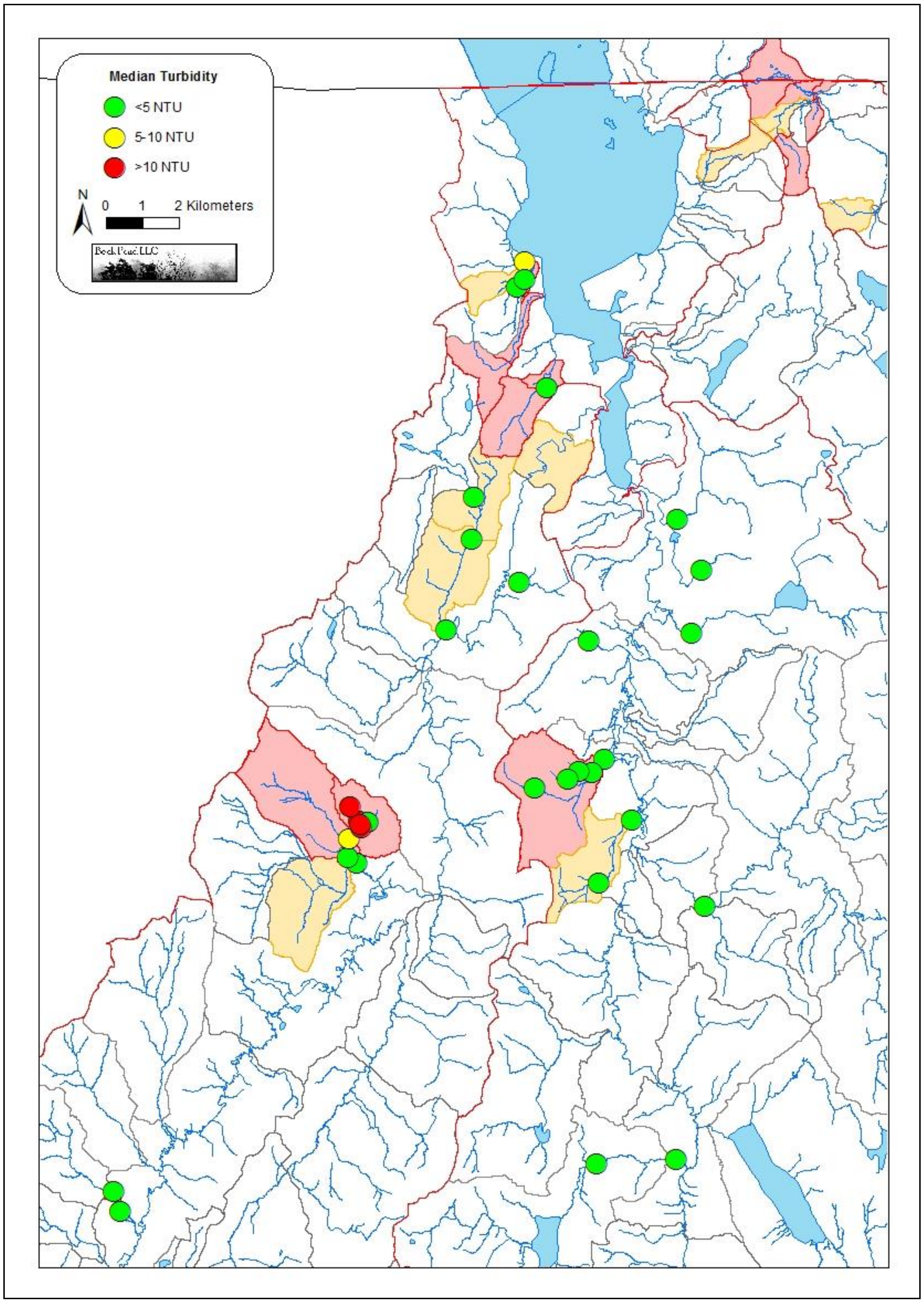

Figure 31. *Median turbidity levels at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2013. The red and orange shading outlines the 28 subwatersheds that exhibited the highest total phosphorus concentrations during 2005-2012.*

High turbidity levels were measured at several sites along the northern tributary of Brighton Brook. Turbidity levels were generally highest in the area immediately downslope of the barn complex (Nelson Northwest, Nelson NW Pipe, and Lower Nelson Farm) and decreased from there downstream (Figure 32). However, turbidity levels at these sites showed no clear or consistent relationships with stream flow (Figure 33). This lack of clear relationships suggested that there may be multiple sources of turbidity, including both point and nonpoint sources, along this tributary. This area of the Brighton Brook watershed includes large areas of corn as well as a large barn complex and barnyard, including areas for manure storage, silage storage, and mortality composting. All of these areas generally slope downhill towards this tributary.

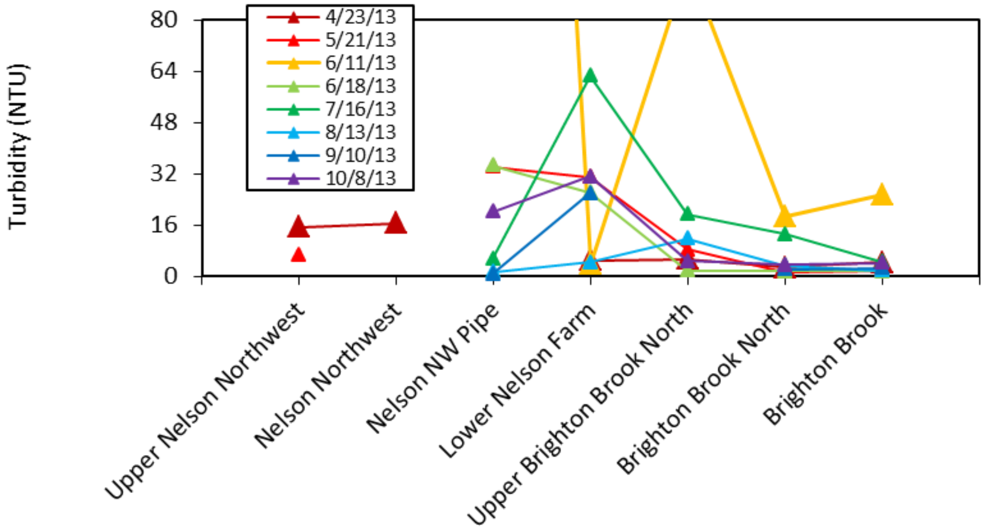

Figure 32. *Turbidity "profile" along Brighton Brook and its northern tributary from Upper Nelson Northwest downstream to Brighton Brook during April-October 2013.*

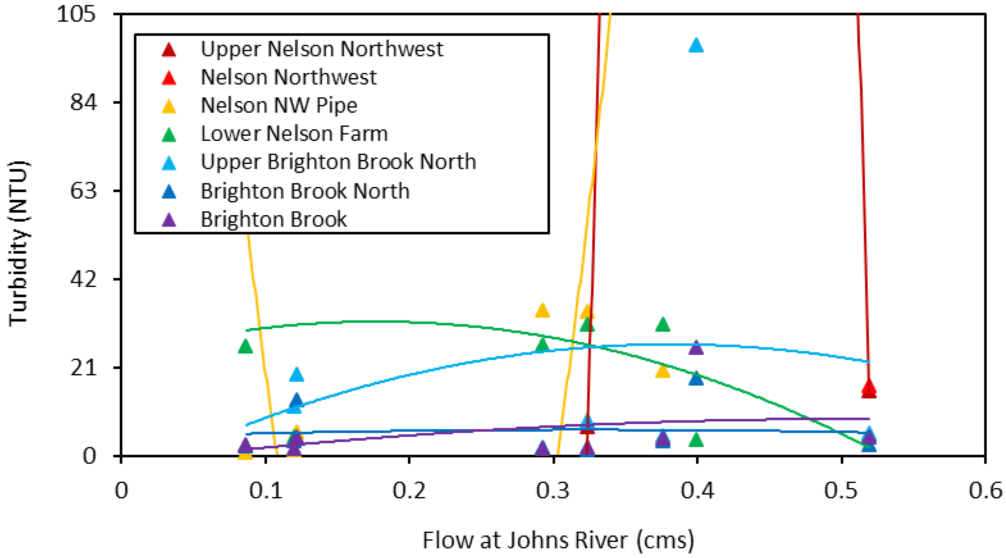

Figure 33. *Turbidity levels in relation to stream flow at seven sites along Brighton Brook and its northern tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

High turbidity levels were also measured at one site along the Holbrook Bay South tributary. Along this tributary, turbidity levels rose between the Upper Holbrook Bay South site immediately upstream and the Holbrook Pond South site just downstream of the man-made pond but were more variable from there downstream (Figure 34). Like Brighton Brook, turbidity levels at these three sites showed no consistent relationships with stream flow (Figure 35). The upstream-most site (Upper Holbrook Bay South) showed no relationship with stream flow. In contrast, the intermediate site just downstream of the man-made pond (Holbrook Pond South) showed a variable but largely positive relationship with stream flow, but the downstream-most site (Holbrook Bay South) showed a variable but largely negative relationship with stream flow. These relationships suggested that turbidity levels emanating from the man-made pond may be more similar to nonpoint sources but that the turbidity levels further downstream may also incorporate point sources of turbidity.

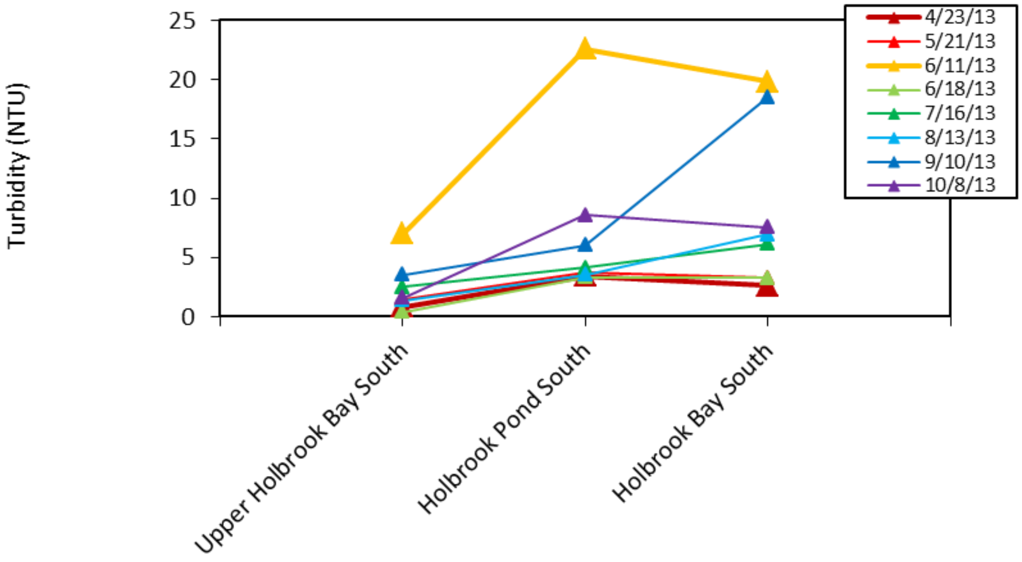

Figure 34. *Turbidity "profile" along the Holbrook Bay South tributary from Upper Holbrook Bay South downstream to Holbrook Bay South during April-October 2013.*

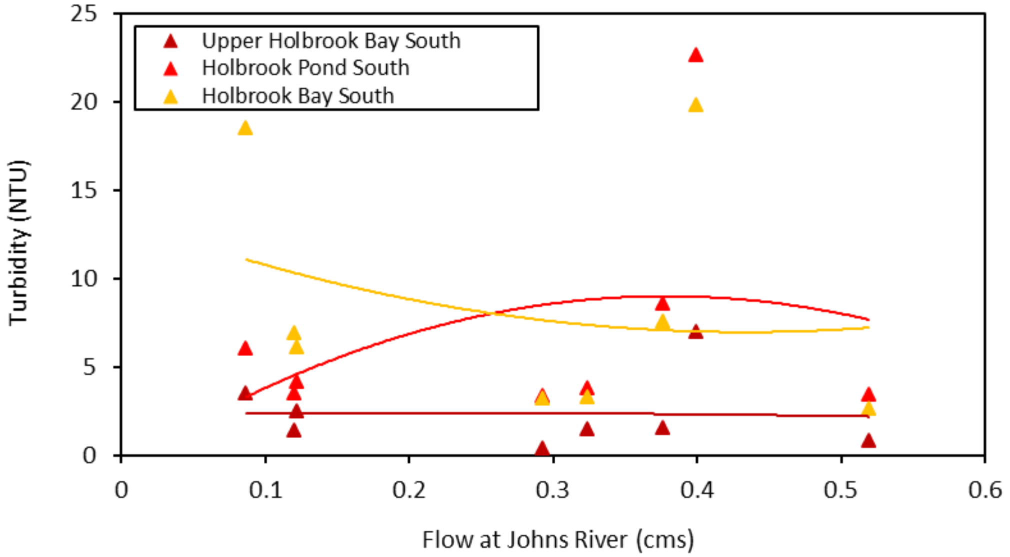

Figure 35. *Turbidity levels in relation to stream flow at three sites along the Holbrook Bay South tributary during April-October 2013. Stream flows were measured at the Vermont DEC gage on the Johns River. The regression lines indicate the polynomial relationships between the two parameters.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with the Vermont DEC. Our 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 the sampling process, measured below the detection limits for two of the three parameters. All 23 field blanks for total nitrogen measured below the detection limit (0.1 mg/l). Twenty-one of the 23 field blanks for total phosphorus measured below the detection limit (5 µg/l). However, while sampling, we had noted that there was grit in the bottom of the bottle of distilled water that was used to fill the two field blanks for total phosphorus that exceeded the detection limit. Thus, the high phosphorus levels in these two samples were likely caused by contaminated distilled water, rather than to problems with field sampling techniques. As in past years, the field blanks for turbidity were more problematic: Four of the 23 field blanks exceeded the detection limit (0.2 NTU), although levels were still relatively low (0.20-0.79 NTU). The reason(s) for the continued problems with the turbidity field blanks remain unknown.

Similarly, the mean relative percent differences between duplicate samples were well within the prescribed differences for two of the three parameters [total phosphorus = 7% (prescribed difference <30%) and total nitrogen = 5% (prescribed difference <20%)]. No pairs of duplicate samples exceeded the prescribed difference for total nitrogen, and only one of the 23 pairs of duplicate samples exceeded the prescribed difference for total phosphorus (those two differed by 43%). In contrast, the mean relative percent difference between the duplicate turbidity samples exceeded the prescribed difference [turbidity = 24% (prescribed difference <15%)], as nine of the 23 pairs of turbidity samples differed by >15% . Seven of the nine pairs of turbidity samples differed by 20-45%; however, two of the pairs of samples collected during the high-flow event on 11 June differed by 102-109%, possibly due to the greater variability of turbidity during high-flow events. 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 untainted turbidity samples for some as-yet unidentified reason.

Phosphorus-Reduction Projects

In 2013, we continued our efforts to identify and implement phosphorus-reduction projects and practices that will most effectively reduce phosphorus and sediment inputs along the Vermont tributaries of Lake Memphremagog. In the second year of this project, we focused on identifying, mapping, and prioritizing possible causes of water quality problems and potential phosphorus-reduction projects and practices in the 28 subwatersheds that exhibited the highest total phosphorous concentrations in the Vermont portion of the Lake Memphremagog Basin. In these priority subwatersheds, we identified and mapped land uses, land cover types, and other possible causes of the high phosphorus levels. To the extent possible, possible causes of water quality problems were localized to specific sites within the priority subwatersheds. We then shared information about possible causes of water quality problems and potential phosphorus-reduction projects and practices with the appropriate agency and/or organizational staff, who can take the lead in working with landowners and land managers to implement these projects.

Background

In the first stage of this project, we had used all of the water quality data collected along the Vermont tributaries of Lake Memphremagog during 2005-2012 to identify those subwatersheds that exhibited the highest total phosphorus concentrations [these analyses are presented in greater detail in Gerhardt (2013)]. 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 sample site and then imported and merged these boundaries in a single Geographic Information System layer. Second, to compensate for the different dates and stream flows sampled at each site, we calculated the arithmetic mean total phosphorus concentrations for each site separately for low flows and for moderate and high flows. For sites along the main stems of the three largest tributaries (Barton, Black, and Clyde Rivers), we identified low, moderate, and high flows based on daily stream flows measured at the U.S. Geological Survey gage station on the Black River in Coventry (USGS station 04296000). For sites along the main stem of the Johns River and other small tributaries, we identified low, moderate, and high flows based on daily stream flows measured by the Vermont DEC on the Johns River in Beebe Plain. Finally, we calculated the mean rank of each site by ranking the mean total phosphorus concentrations for all sites at low flows and at high flows and then calculating the average of those two ranks (for the twelve sites for which we collected no samples at moderate or high flows, the mean rank equaled the rank calculated for the low flows only).

In general, mean total phosphorus concentrations were highest in several areas of the Black River watershed, in the downstream halves of the Barton River and Johns River watersheds, and along several small tributaries that flow directly into Lake Memphremagog

(Figure 36). More specifically, the subwatersheds with the highest total phosphorus concentrations occurred along several reaches of the main stem of the Black River, three tributaries of the Black River (Shalney Branch, Brighton Brook, and Stony Brook), the downstream half of the main stem of the Barton River and several of its tributaries (Willoughby River, Roaring Brook, and the Junkyard and Hamel Marsh tributaries), much of the Johns River watershed, and several small tributaries that flow directly into Lake Memphremagog. In contrast, the subwatersheds with the lowest total phosphorus concentrations occurred throughout the Clyde River watershed, the upstream half of the Barton River watershed, and many of the smaller tributaries of the Barton, Black, and Clyde Rivers.

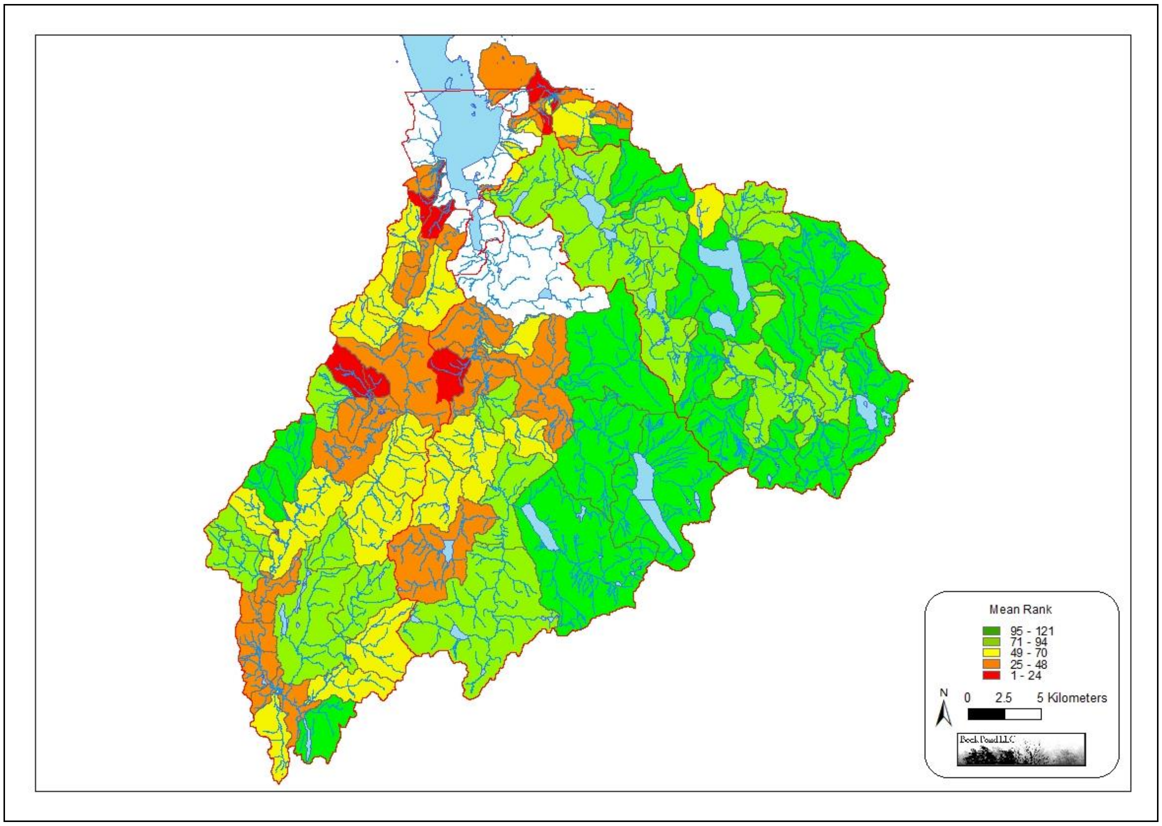

Figure 36. *Mean ranks based on mean total phosphorus concentrations at low and at high flows in 121 subwatersheds of the Lake Memphremagog Basin during 2005-2012. The lowest number (1) corresponds to the highest mean total phosphorus concentration, and the highest number (121) corresponds to the lowest mean total phosphorus concentration.*

As a first step towards identifying possible sources of water quality problems and potential phosphorus-reduction projects and practices, we analyzed the relationships between mean total phosphorus concentrations and the land uses occurring upstream of each sample site [these analyses are described in greater detail in Gerhardt (2013)]. The most pronounced relationships occurred between mean and median total phosphorus concentrations and the percentages of the subwatersheds being used for agriculture as a whole, for hay and pasture separately, and for forest. Total phosphorus concentrations generally increased with increasing amounts of agricultural land uses, including both hay and pasture. These strong positive relationships likely reflected both the extent of these two land uses in the basin [approximately 11.5% of the land surface in the basin was used for hay and pasture (State of Vermont 2012b)] as well as the fact that these land uses are likely to be net sources of phosphorus exports due to increased soil erosion and surface runoff, manure and fertilizer applications, and, in many cases, lack of adequate riparian buffers. In addition, the strong relationship between pasture and phosphorus levels may reflect the fact that pastures were often located near barnyards, which can also be significant sources of phosphorus exports. In contrast, total phosphorus concentrations generally decreased with increasing forest cover. This strong negative relationship likely reflected both the extent of forest in the basin [approximately 66.1% of the land surface in the basin was classified as forest (State of Vermont 2012b)] as well as the fact that forests likely export low levels of phosphorus due to the presence of more soil organic matter, greater soil permeability, and the general lack of soil erosion (except where forests are badly managed). The remaining land uses (developed lands, row crops, wetlands, and open water) were not significantly related to total phosphorus concentrations.

Methods

In this next stage of this project, we selected a subset of priority subwatersheds in which to focus our efforts to map and identify possible causes of water quality problems and to identify and develop phosphorus-reduction projects and practices. These priority subwatersheds were defined as those subwatersheds whose associated sample sites exhibited the highest mean total phosphorus concentrations at low flows, the highest mean total phosphorus concentrations at high flows, and/or the highest mean rank. From these lists, we selected the 28 subwatersheds that were ranked in the top 20 subwatersheds in one or more of the three analytical approaches. Implementation of phosphorus-reduction projects and practices in these priority subwatersheds is likely to be most effective for reducing phosphorus exports into the surface waters of the Lake Memphremagog Basin.

Within the 28 priority subwatersheds, we used ArcGIS 10 (ESRI, Redlands, California) to identify and map possible sources of water quality problems. To do this, we identified and drew polygons outlining the different land uses and land cover types observed on the 2012 aerial photographs downloaded from the USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). We created polygons for every land use and land cover type, except forests (including forested wetlands) and shrublands, as the latter land cover types are not likely to export large amounts of phosphorus and sediment into the surface waters of the basin (Table 1). We supplemented these data and maps with the data and maps available in the Stream Geomorphic Assessments that were completed for the Barton, Black, Clyde, and Johns Rivers and some of their tributaries (Gerhardt and Dyer 2006, Dyer 2008, Dyer et al 2008, 2011). Finally, we created a database that listed potential phosphorus-reduction projects and practices by town, subwatershed, land owner, water quality problem/issue, possible projects or practices, lead agency/organization, project priority, and current status.

Table 1. Land uses and land cover types identified and mapped as part of efforts to identify and map the sources of water quality problems in 28 priority subwatersheds in the Vermont portion of the Lake Memphremagog Basin. Asterisks (*) indicate those land uses and land cover types deemed high priorities for further evaluation.

<u>Agricultural Land Uses</u>
Barn and associated infrastructure *
Manure storage *
Silage storage *
Composting areas *
Corn (within 25-m buffer) *
Hay (within 25-m buffer) *
Pasture (within 25-m buffer) *
Abandoned agricultural fields (a.k.a. old fields)

<u>Residential, Commercial, and Industrial Land Uses</u>
Residential areas (within 25-m buffer) *
Commercial areas (within 25-m buffer) *
Urban areas (within 25-m buffer) *
Industrial areas *
Sand and gravel pits *
Lawns (within 25-m buffer) *
Church (within 25-m buffer) *
Municipal (within 25-m buffer) *
Landfills *

<u>Right-of-Ways</u>
Roads (within 25-m buffer) *
Utility right of ways
Railroads (within 25-m buffer) *

<u>Other Land Cover Types</u>
Ponds
Non-forested wetlands

Once we had identified and mapped the land uses and land cover types in each priority subwatershed, we then prioritized those land uses and land cover types that are likely to export the largest amounts of phosphorus and other nutrients and sediments into the surface waters of the Lake Memphremagog Basin. Initially, we identified barns and their associated infrastructure (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 into the watershed. We also prioritized industrial areas, sand and gravel pits, and landfills, as those areas have the potential to export large amounts of phosphorus 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. To identify the latter, we created a 25-m (82-ft) wide buffer on each side of all of the river and stream centerlines mapped in the 2010 Vermont Hydrography Dataset. We then overlaid the GIS layer containing these buffers onto the GIS layer containing the maps of land uses and land cover types. However, since we have mapped the entire area 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 that are located on highly-erodible soils on steep slopes) that may raise the importance of these areas as part of efforts to reduce phosphorus exports.

Based on these maps and the land-use relationships described previously, we identified a number of potential projects and practices that will be most effective for correcting water quality problems and reducing nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin (Table 2). Although many of these projects and practices are applicable to most or all land uses, other projects and practices are relevant to only a subset of land uses. Due to the large areas of agricultural land uses and the strong positive relationships with total phosphorus concentrations, agricultural sources are likely to be the most important sources of water quality problems in many of the priority subwatersheds. Thus, many of the potential project and practices were designed to improve agricultural facilities, implement Best Management Practices (BMP), and protect or restore riparian buffers. However, we have also identified other projects and practices that are better suited for correcting water quality problems caused by industrial, commercial, urban, and suburban land uses. Many of the proposed projects and practices can be implemented through existing grants or cost-share programs, including those administered by the Vermont Agency of Agriculture, Foods and Markets; Vermont DEC; and USDA Natural Resources Conservation Service. In addition, technical and financial assistance can be provided by the Vermont Association of Conservation Districts, Natural Resources Conservation Districts, and various other public and private partners.

Table 2. Potential projects and practices that can be implemented in the 28 priority subwatersheds in order to reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin.

Land Use	Project or Practice
Forest	Logging road improvements Stream crossing improvements Wetland delineation and avoidance Appropriate forestry treatments Appropriately timed logging operations
Shrubland	Floodplain forest restoration Wetland restoration
Old field	Riparian buffer restoration Floodplain forest restoration Wetland restoration
Pasture	Riparian buffer restoration Livestock exclusion Alternative watering sources
Hayfield	Riparian buffer restoration Appropriately timed manure and fertilizer applications
Cropland	Riparian buffer restoration Conservation tillage Cover cropping Contour plowing Appropriately timed manure and fertilizer applications Reduced pesticide applications Integrated pest management
Barnyards	Clean-water diversion Barnyard runoff collection Silage/compost runoff collection Appropriately sized and sited manure storage facilities
Industrial	Riparian buffer restoration Stormwater retention or diversion
Urban development	Riparian buffer restoration Road improvements Stormwater retention
Residential	Riparian buffer restoration Appropriate lawn care practices Reduced fertilizer and pesticide applications Road improvements Stormwater retention or diversion

Throughout this process, we discussed the proposed project, the priority subwatersheds, possible sources of water quality problems, and potential phosphorus-reduction projects and practices with key staff from the Vermont DEC; Vermont Agency of Agriculture, Food and Markets; Vermont Association of Conservation Districts; Orleans County Natural Resources Conservation District; and USDA Natural Resources Conservation Service. Early in the project (15 January and 6 May), we met with potential project partners to develop a collaborative approach that engaged them from the start in identifying priority subwatersheds, identifying and mapping possible sources of water quality problems, identifying and prioritizing potential projects and/or practices, and defining the role(s) of key partners in this project. Later in the project (19 December), we again met with the project partners to communicate the results of these analyses, to discuss specific water quality problems and their possible sources, and to identify potential phosphorus-reduction projects and practices. Throughout the project, we have also met with individual project partners to discuss individual priority subwatersheds, possible sources of water quality problems, and potential phosphorus -reduction projects and practices. Once potential phosphorus-reduction projects and practices are identified, we will work with project partners to verify water quality problems, to identify their possible causes, to assess the appropriateness and feasibility of potential projects and practices, and to gauge landowner interest in undertaking projects or practices to address the problems.

Results and Discussion

Priority Subwatersheds

Based on the analyses completed in the first stage of this project, we identified and selected a subset of 28 priority subwatersheds that exhibited the highest total phosphorus concentrations in the Vermont portion of the Lake Memphremagog Basin (Table 3).These 28 priority subwatersheds included all 20 of the highest ranked subwatersheds (that is, ranked by the average of the rank at low flows and the rank at high flows). They also included 15 of the 20 subwatersheds with the highest mean total phosphorus concentrations at low flows and 15 of the 20 subwatersheds with the highest mean total phosphorus concentrations at high flows. The 28 priority subwatersheds were concentrated in eight areas (Figure 37): 1) Johns River and tributaries, 2) the small tributaries that flow directly into the southwest corner of Lake Memphremagog, 3) two small tributaries of the Barton River just downstream of Orleans village, 4) the mouth of the Black River, 5) main stem of Black River downstream of Craftsbury, 6) Stony Brook, 7) Brighton Brook and tributaries, and 8) Shalney Branch in Albany village. None of the priority subwatersheds were located in the Clyde River watershed. In the sections that follow, we describe the possible sources of water quality problems, potential phosphorus-reduction projects and practices to correct those problems, and the current status of efforts to protect and improve water quality in each of the 28 priority subwatersheds.

Table 3. The 28 priority subwatersheds identified by analyzing and ranking the total phosphorus data collected at 122 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.

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

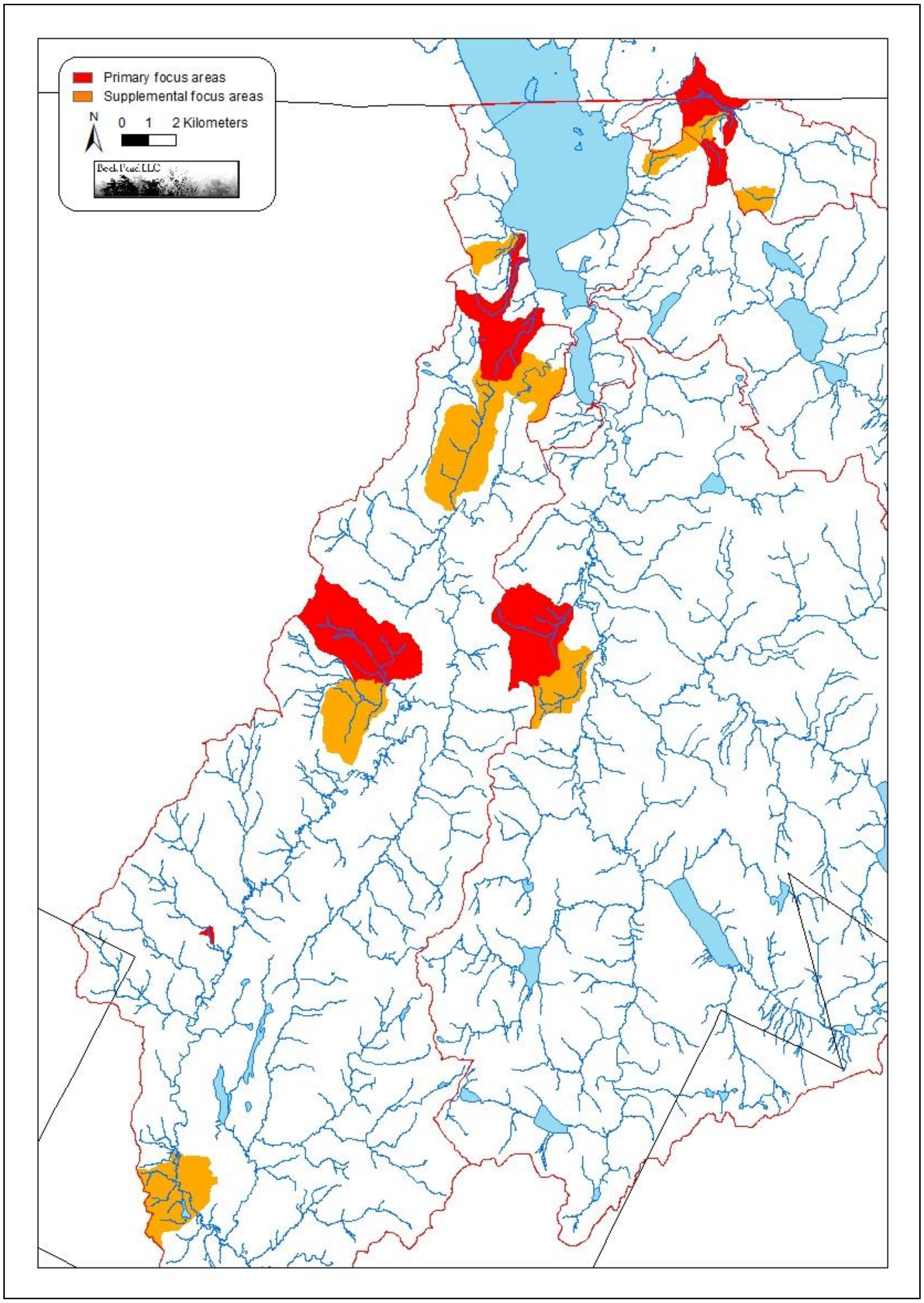

Figure 37. *The 28 priority subwatersheds that exhibited the highest total phosphorus concentrations in the Vermont portion of the Lake Memphremagog Basin during 2005-2012. These 28 subwatersheds had the highest mean rank calculated by averaging the ranked total phosphorus concentrations at low and at high flows.*

Barton River Watershed

Within the Barton River watershed, we selected subwatersheds along two tributaries for further mapping and identification of possible sources of water quality problems and potential phosphorus-reduction projects and practices (Table 4).

Table 4. Possible sources of water quality problems in two priority subwatersheds located in the Barton River watershed.

Subwatershed	Possible Source(s)
Hamel Marsh	Barns (3) and manure pit (1) Corn, hay, and pasture within 25-m buffer
Rock Junkyard	Barn (1), manure storage (1), and silage storage (1) Corn, hay, pasture, residences, and roads within 25-m buffer

Along the Hamel Marsh tributary, we identified and mapped a number of possible sources of water quality problems (Table 4, Figure 38). Most of these sources were agricultural in nature and included three barns and barnyards, one of which also included a large manure pit. In addition, large fields of corn [82 ha (202 acres)], hay [176 ha (436 acres)], and pasture [46 ha (113 acres)] were being farmed in this subwatershed. Several of these fields were located <25 m (<82 ft) from streams, and many were also located on steep slopes (i.e. gradients >6%). According to our project partners, a project was already underway to improve drainage issues around one of these barn complexes. In addition, drainage from the storage bunkers at another barn complex was already diverted into a new pond, although that barn complex was located just over the divide separating this from the adjacent subwatershed. Thus, we recommend that additional efforts be undertaken to identify and assess possible sources of water quality problems associated with the barn complexes and the agricultural fields located <25 m (<82 ft) from surface waters, especially those located along the upper branch of this tributary.

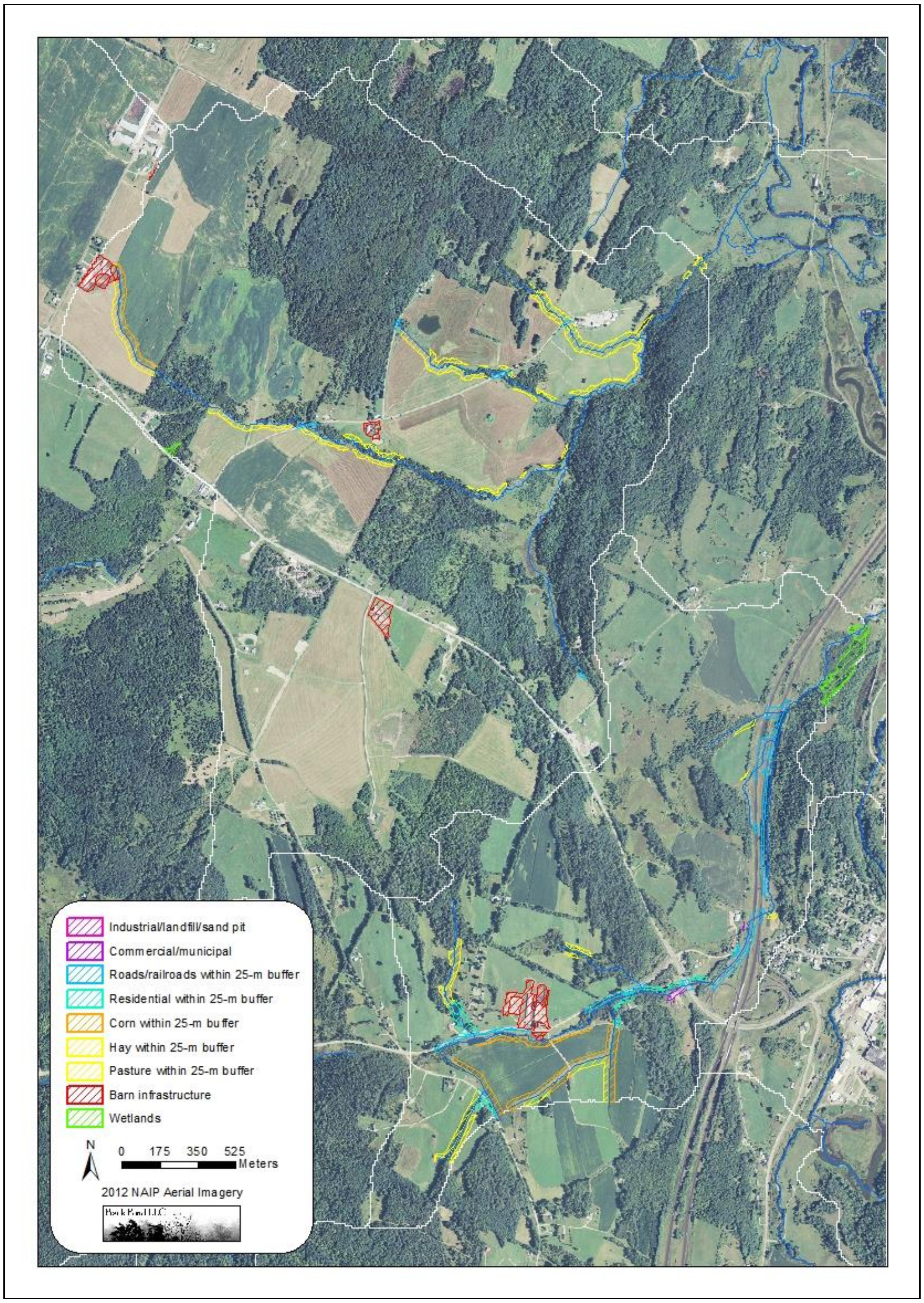

Figure 38. *Possible sources of water quality problems in two priority subwatersheds along the Hamel Marsh and Junkyard tributaries of the Barton River.*

Along the Junkyard tributary, we identified and mapped a number of possible sources of water quality problems (Table 4, Figure 38). Most of these sources were agricultural in nature and included a large barn complex, including silage and manure storage areas. In addition, large fields of corn [42 ha (103 acres)], hay [76 ha (187 acres)], and pasture [14 ha (35 acres)] were being farmed in this subwatershed. Several of these fields were located <25 m (<82 ft) from streams, and some were also located on steep slopes (i.e. gradients >6%). According to our project partners, a small pond that was previously located immediately alongside this tributary used to receive runoff and wastes from the main barnyard but that runoff and waste had since been diverted and the pond had been filled. Nevertheless, residual wastes may be draining from that former pond site into the stream. Thus, we recommend that additional efforts be undertaken to identify and assess possible sources of water quality problems associated with the barn complex, the former waste pond along the stream, and the agricultural fields located <25 m (<82 ft) from surface waters.

Black River Watershed

Within the Black River watershed, we selected nine subwatersheds in five areas for further mapping and identification of possible sources of water quality problems and potential phosphorus-reduction projects and practices (Table 5).

Main Stem

We selected two subwatersheds along the main stem of the Black River for further analysis. In the downstream Black River subwatershed, we identified and mapped only a few possible sources of water quality problems (Table 5, Figure 39). Most of this subwatershed was covered by wetlands [132 ha (327 acres)], which can be a significant source of phosphorus, especially late in the growing season, and upland forest, which is not likely to export much phosphorus. The other significant land use was the Waste USA Landfill, which covered approximately 57 ha (140 acres) straddling a ridge in the southeast corner of this subwatershed (Figure 40). However, this landfill is subject to considerable oversight and permitting that should require detection of any water quality problems. There was also a very small area of paved road within 25 m (82 ft) of the river. The other land uses that might impact water quality were all limited in extent and were distantly located from all surface waters. Thus, this subwatershed does not seem to warrant additional efforts to identify and assess possible sources of water quality problems, unless an obvious problem is identified.

Table 5. Possible sources of water quality problems in nine priority subwatersheds located in the Black River watershed.

Subwatershed	Possible Source(s)
Main Stem	
Black River	Landfill Wetlands Roads within 25-m buffer
Post Road	Barns (2), manure storage (1), and silage storage (1) Wetlands Corn, hay, pasture, and residences within 25-m buffer
Stony Brook	
Stony Brook	Sand/gravel pits Barn (1), manure storage (1), and silage storage (1) Wetlands Corn, residences, and roads within 25-m buffer
Blake Road	Sand/gravel pits Wetlands Corn, residences, and roads within 25-m buffer
Brighton Brook	
Brighton Brook	Wetlands Hay, pasture, and roads within 25-m buffer
Robillard Flats	Barns (2) and manure pit (1) Wetlands Corn, hay, pasture, and residences within 25-m buffer
Brighton Brook North	Wetlands Corn, hay, pasture, and residences within 25-m buffer
Upper Brighton Brook North	Barns (2), composting area (1), manure pit (1), and silage storage (1) Corn, hay, pasture, and roads within 25-m buffer
Shalney Branch	
Shalney Branch	Barn (1) Pasture, municipal, residences, and roads within 25-m buffer

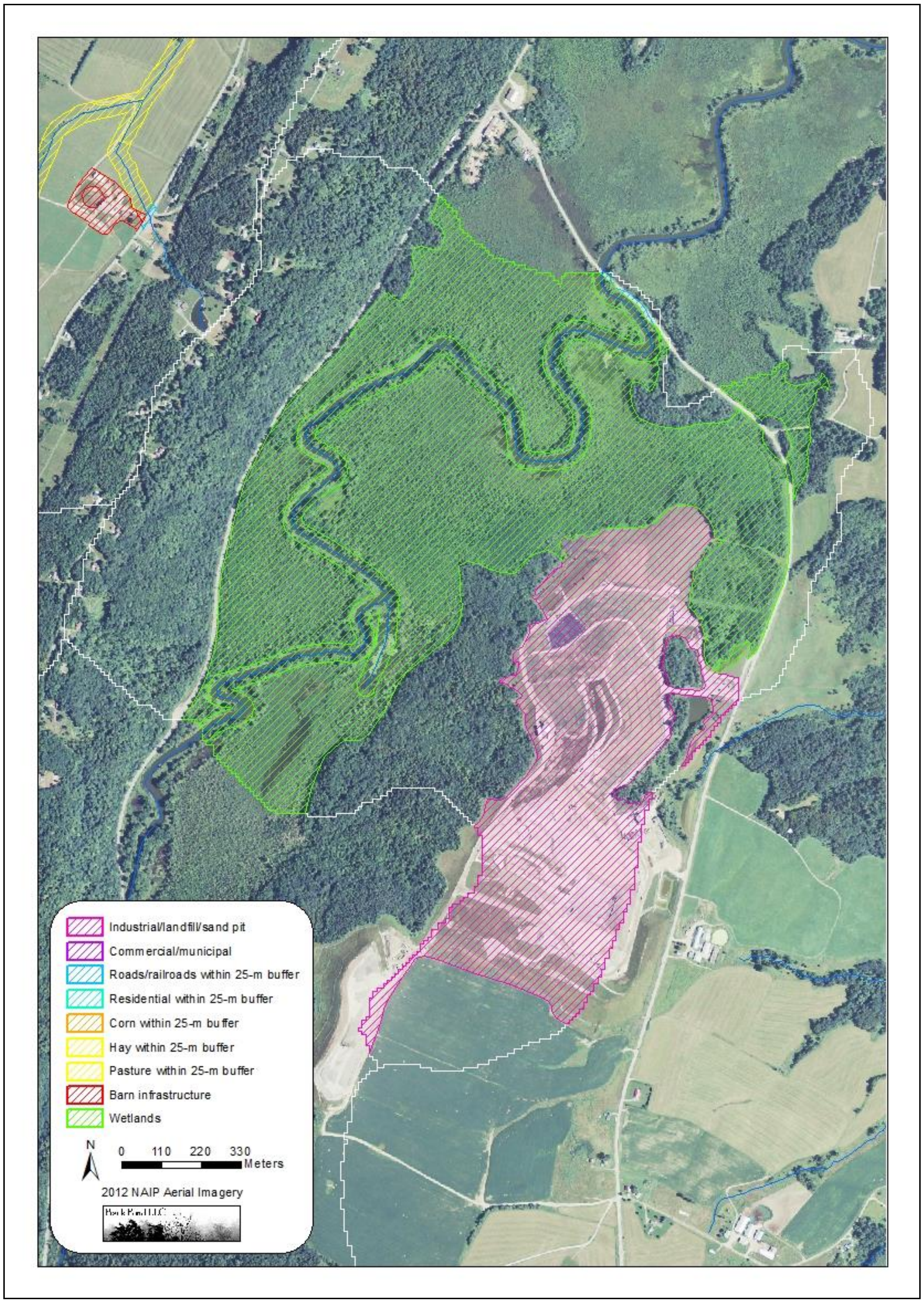

Figure 39. *Possible sources of water quality problems in the priority subwatershed located near the mouth of the Black River.*

Figure 40. *The Waste USA Landfill is one possible source of nutrient and sediment pollution in the downstream-most section of the Black River.*

In the Post Road subwatershed located further upstream along the main stem, we identified and mapped a number of possible sources of water quality problems (Table 5, Figure 41). Like the previous subwatershed, wetlands, which can be a significant source of phosphorus, covered approximately 56 ha (138 acres) along the main stem of the Black River. Most of the other possible sources of water quality problems were agricultural in nature and included two barns and barnyards, one of which also included a large manure pit and silage storage area. In addition, large fields of corn [34 ha (84 acres)], hay [58 ha (144 acres)], and pasture [27 ha (67 acres)] were being farmed in this subwatershed. Many of these fields were located <25 m (<82 ft) from several small tributaries that flowed into the main stem. Mud Pond, a large pond covering approximately 14 ha (35 acres), was also located in this subwatershed and was surrounded by and abutted the large barn complex and associated barnyards at the upstream end of this subwatershed. Water samples collected from this pond during 2002-2007 measured high in both total phosphorus (range = 39-86 μg/l) and total nitrogen (range = 1.10-2.02 mg/l)(Ben Copans, personal communication). None of the project partners have worked with the owner of the larger farm, and past discussions had indicated that the owners and lessors of the smaller farm were not likely to undertake water quality improvement projects. Nevertheless, we recommend that discussions be continued with the owners and lessors of the smaller farm and that additional efforts be made to identify and assess possible sources of water quality problems associated with the large barn complex bordering Mud Pond, including possibly sampling spring phosphorus levels in Mud Pond.

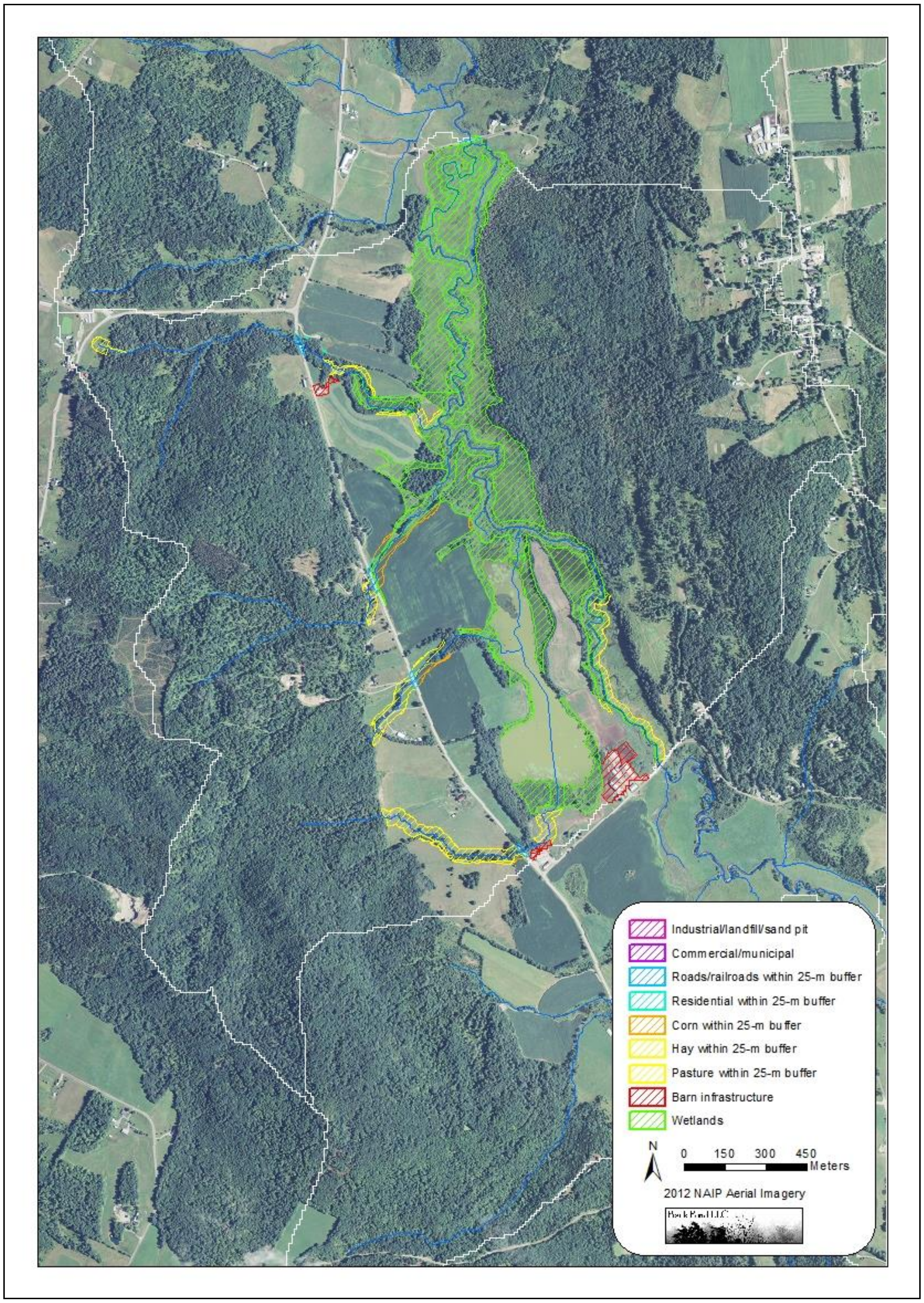

Figure 41. *Possible sources of water quality problems in the priority subwatershed located upstream of Post Road along the main stem of the Black River.*

Stony Brook

Along Stony Brook, we identified and mapped a number of possible sources of water quality problems in two priority subwatersheds (Table 5, Figure 42). Possible agricultural sources included one barn complex, which also included a manure pit and silage storage area. In addition, large fields of corn [64 ha (158 acres)] and hay [28 ha (69 acres)] were being farmed in this subwatershed. Several of these fields were located <25 m (<82 ft) from streams, although slopes were generally flat (i.e. gradients <6%). The other significant land uses were the large areas of gravel and sand pits, especially in the upper of the two subwatersheds. Like the Waste USA Landfill, the sand and gravel pits are likely to be subject to considerable oversight and permitting, and surface runoff and stormwater were already being collected by a large number of settling ponds and other stormwater structures. In addition, our sampling indicated that the high phosphorus levels in this tributary were originating downstream of these sand and gravel operations. During our sampling, we also observed that several wetlands had been filled or were excavated to create a new pond. These activities, which have since ceased, may have caused nutrients and sediments to flow into Stony Brook. Finally, according to our project partners, the owner or lessor of many of the agricultural fields had previously declined to undertake a project to expand and restore the riparian buffers along Stony Brook. Nevertheless, we recommend that additional efforts be made to identify and assess possible sources of water quality problems associated with the barn complex and the agricultural fields located <25 m (<82 ft) from surface waters.

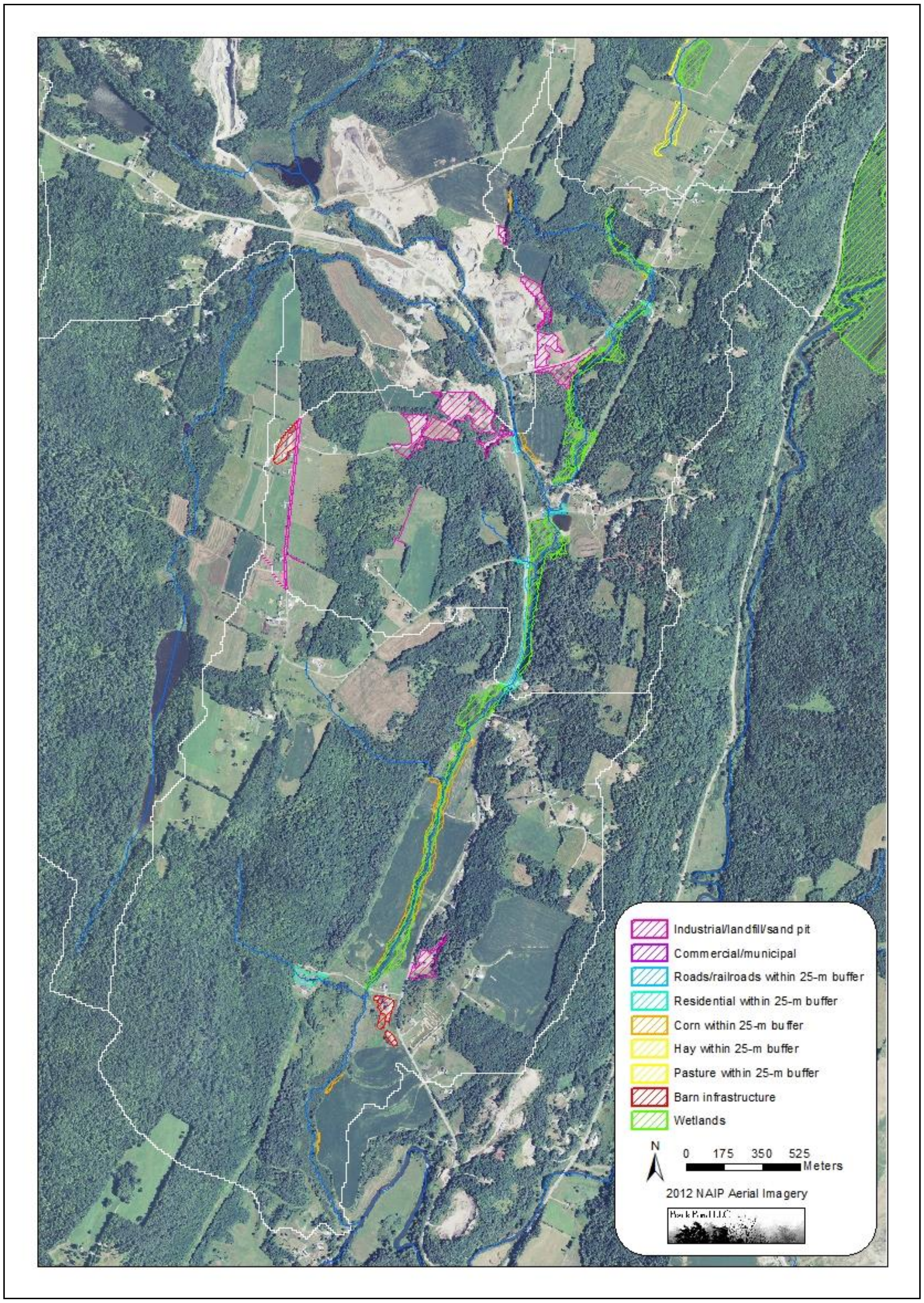

Figure 42. *Possible sources of water quality problems in two priority subwatersheds along Stony Brook.*

Brighton Brook

Along Brighton Brook, we identified and mapped a number of possible sources of water quality problems in three priority subwatersheds (Table 5, Figure 43). These subwatersheds, more than many others, were dominated by agricultural land uses, and most of the possible sources of water quality problems were agricultural in nature. Possible sources included two large barn complexes, including their associated manure storage, silage storage, and mortality composting areas, and two smaller barn complexes (see photograph on front cover). In addition, large fields of corn [158 ha (390 acres)], hay [188 ha (463 acres)], and pasture [44 ha (109 acres)] were being farmed in these three subwatersheds. Many of these fields were located <25 m (<82 ft) from streams as were small areas of paved and gravel roads and residences. Large areas of wetlands [77 ha (189 acres)] also occurred within these three subwatersheds. We have discussed water quality issues with the owners of the two largest farms in these subwatersheds, and both have allowed us to sample water quality in the streams running through their properties. Through this sampling, we have been able to pinpoint the source(s) of the high nutrient and sediment levels to an area along the northern tributary of Brighton Brook. Over the past two years, the owner of the large farm along this tributary has been encouraged to expand the unmanaged buffer along this and other streams flowing through his farm. This past spring, he buried a perforated drainage pipe in the stream channel and planted a grass-lined waterway along this tributary. However, it was not clear from our sampling data whether or not these projects actually improved water quality in this tributary. Thus, we recommend continuing to engage the owner of this farm in efforts to further identify and assess possible sources of water quality problems associated with the large barn complex and the many corn and hayfields located <25 m (<82 ft) from this stream.

Shalney Branch

Along Shalney Branch, we identified and mapped only a few possible sources of water quality problems (Table 5, Figure 44). These sources included a mix of agricultural, residential, and municipal land uses, including a small barn complex and its associated manure storage area and small areas of pasture, paved and gravel roads, residences, and the former town garage, all of which were situated <25 m (<82 ft) from Shalney Branch. However, our water quality sampling, which bracketed these possible sources, indicated that phosphorus levels have been declining in Shalney Branch since 2009, possibly due to the completion of several remediation projects on the small dairy farm in this subwatershed. These projects have included construction of a covered manure storage area and laneway improvements (Figure 19). In addition, concerns about a saturated area of the barnyard have prompted the farmer to consider pouring a concrete pad in this area to resolve this problem. Further improvements might be gained by developing a grazing plan for this farm and by excluding livestock from the stream and the bordering wetlands. We encourage our project partners to continue working with this farmer to complete these and any other necessary projects and practices.

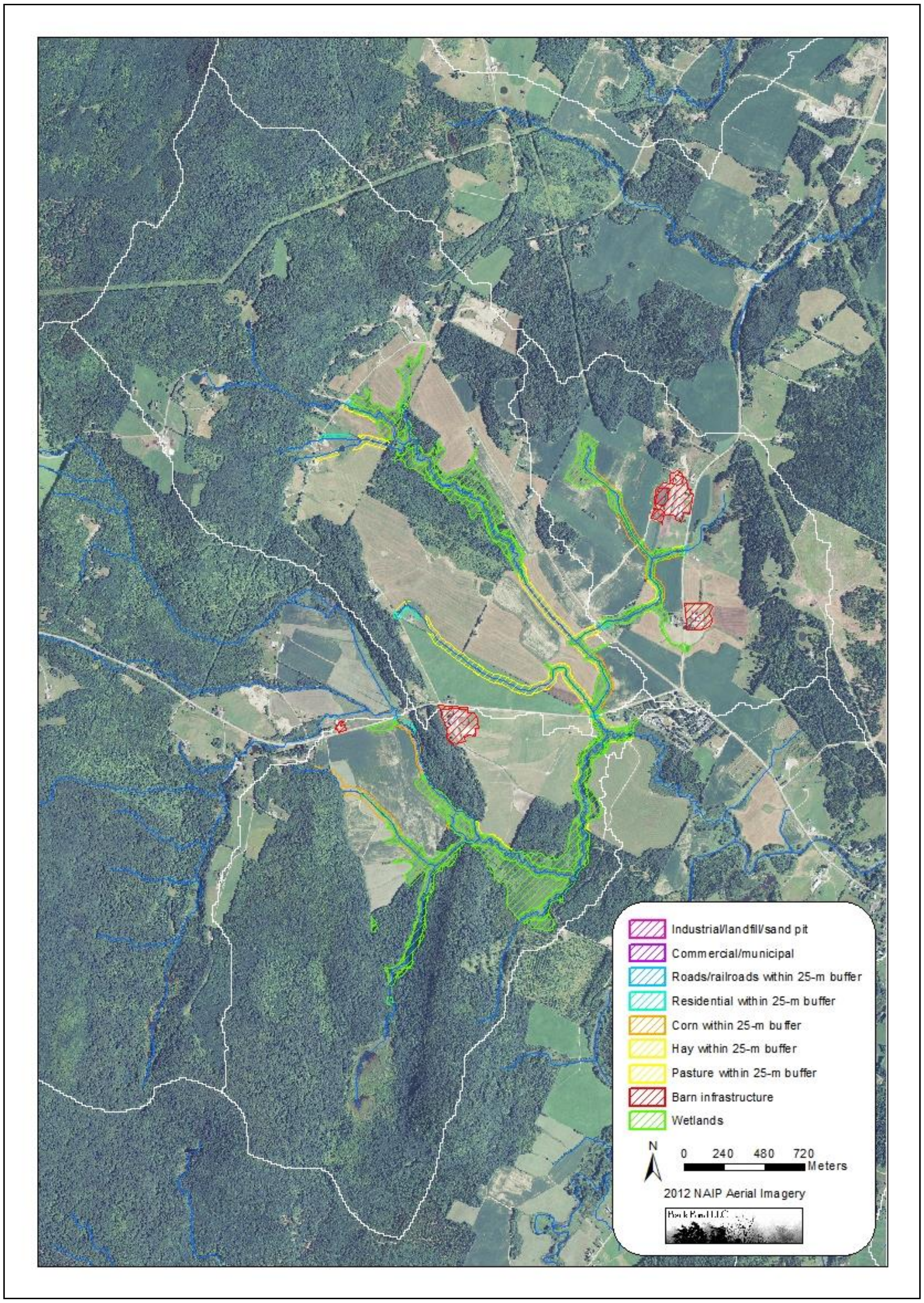

Figure 43. *Possible sources of water quality problems in the three priority subwatersheds along Brighton Brook.*

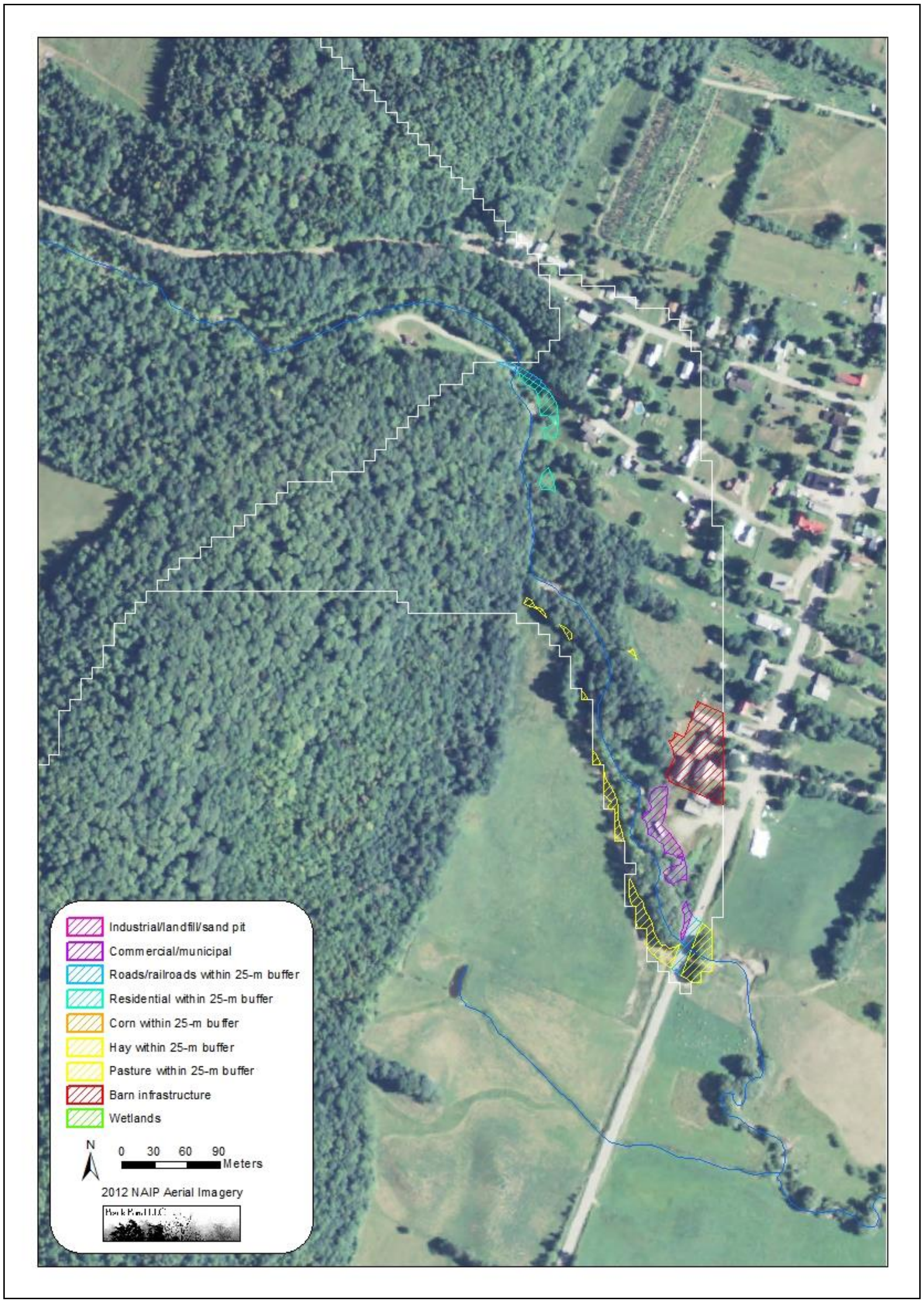

Figure 44. *Possible sources of water quality problems in the priority subwatershed along Shalney Branch.*

Johns River Watershed

Within the Johns River watershed, we selected nine subwatersheds in four areas for further mapping and identification of possible sources of water quality problems and potential phosphorus-reduction projects and practices (Table 6).

Table 6. Possible sources of water quality problems in nine priority subwatersheds located in the Johns River watershed.

Subwatershed	Possible Source(s)
Main Stem	
North Derby Road	Industrial Wetlands Pasture and roads within 25-m buffer
Granite	Industrial Barns (2) Pasture, residences, and roads within 25-m buffer
Johns River	Residences and roads within 25-m buffer
Beebe Plain Tributary	
Beebe Plain	Wetlands Hay and roads within 25-m buffer
Darling Hill Tributary	
Darling Hill	Corn, residences, and roads within 25-m buffer
Middle Darling Hill	Pasture, residences, and roads within 25-m buffer
Upper Darling Hill	Roads within 25-m buffer
DHM	Barns (2) and manure pit (1) Hay, pasture, and roads within 25-m buffer
Quarry Tributary	
Upper Quarry West	Wetlands Corn and roads within 25-m buffer

Main Stem

We selected three adjoining subwatersheds along the main stem of the Johns River for further analysis. In these three subwatersheds, we identified and mapped a number of possible sources of water quality problems (Table 6, Figure 45). These sources included a mix of industrial, agricultural, residential, and municipal land uses. Much of the downstream-most subwatershed was covered by wetlands [20 ha (50 acres)], which can be a significant source of phosphorus, especially late in the growing season. The other major land use in these subwatersheds was the Rock of Ages granite operations in Stanstead, Quebec, which were located on a terrace immediately upslope of the main stem. However, these operations are likely to be subject to considerable oversight and permitting, and, although tailings from the granite operations were dumped along the slopes of this terrace, several settling ponds were located at the base of these slopes. Possible agricultural sources of water quality problems included two barn complexes and small fields of hay [6 ha (15 acres)] and pasture [14 ha (34 acres)]. Parts of two pastures were located <25 m (<82 ft) from the river as were small areas of paved roads and residences (Figure 46). Thus, we recommend that additional efforts be undertaken to identify and assess possible sources of water quality problems associated with the barn complex and the pastures located <25 m (<82 ft) from surface waters. Although prior discussions with the owner of one of these pastures were not fruitful, we recommend encouraging this landowner to consider undertaking projects or practices that will improve water quality in the Johns River.

Beebe Plain Tributary

Along the Beebe Plain tributary, we identified and mapped only a few possible sources of water quality problems (Table 6, Figure 45). A small part of the downstream end of this subwatershed was covered by wetlands [1 ha (3 acres)], which can be a significant source of phosphorus, especially late in the growing season. Although parts of this subwatershed were mown for hay [6 ha (16 acres)], only limited areas of hay in one field and a small section of paved road were located <25 m (<82 ft) from surface waters. Since the tributary borders the edge of one hayfield, we recommend encouraging the creation of a riparian buffer along the edge of this hayfield.

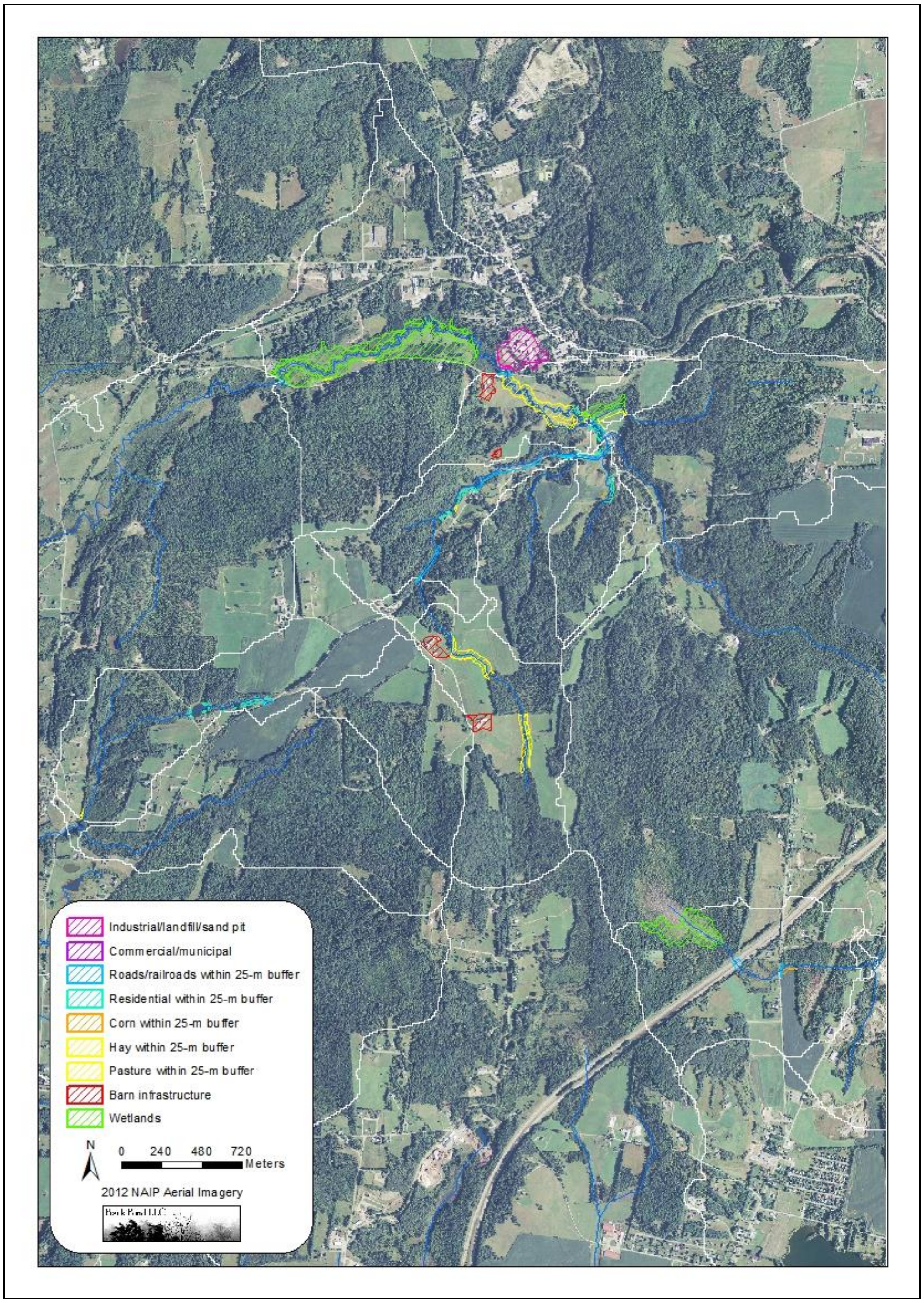

Figure 45. *Possible sources of water quality problems in the nine priority subwatersheds along the Johns River and its tributaries.*

Figure 46. *Pasture located along the main stem of the Johns River in Beebe Plain, Vermont. Note the cattle grazing and resting in the river.*

Darling Hill tributary

Along the Darling Hill tributary, we identified and mapped a number of possible sources of water quality problems (Table 6, Figure 45). Most of these sources were agricultural in nature and included two barns and barnyards, one of which also included a manure pit. In addition, large fields of corn [9 ha (22 acres)], hay [41 ha (101 acres)], and pasture [8 ha (19 acres)] were being farmed in this subwatershed. Several of these fields, especially in the upper part of these subwatersheds, were located <25 m (<82 ft) from streams. There were also extensive areas of paved roads and less extensive residential areas located <25 m (<82 ft) from this tributary, especially in downstream areas of these subwatersheds. We have explored much of the main stem of this tributary while trying to identify the source(s) of the high nitrogen levels measured there previously, and we have identified several concerns: 1) the lack of riparian buffers along many of the hayfields and pastures, especially in the upper parts of these subwatersheds, 2) the lack of riparian buffers along Darling Hill Road and the neighboring residential areas, 3) the proximity of a manure pit that had previously overflowed to the stream, and 4) a large gully that drained one of the cornfields overlooking this tributary (although this gully appears to have largely stabilized). Although it may be difficult to create wider buffers between the paved roads and the streams, other opportunities exist to create broader riparian buffers where these streams pass through agricultural fields and residential areas, and efforts should be undertaken to ensure that manure is no longer leaking from the manure pit and that runoff is no longer eroding the gully below the cornfield.

Quarry Tributary

Along the Quarry tributary, we identified and mapped only a few possible sources of water quality problems (Table 6, Figure 45). Much of the upstream end of this subwatershed was covered by wetlands [6 ha (14 acres)], which can be a significant source of phosphorus, especially late in the growing season. Although parts of this subwatershed were planted in corn [10 ha (24 acres)] or mown for hay [7 ha (17 acres)], only a small area of corn in one field and small sections of paved road were located <25 m (<82 ft) from surface waters. Since the tributary borders the edge of one cornfield, we recommend discussing the possibility of creating a broader riparian buffer along the edge of that cornfield and evaluating any possible runoff originating from the largest of the two roads (Interstate 91).

Direct Tributaries

Along the small tributaries that flow directly into Lake Memphremagog, we selected eight subwatersheds for further mapping and identification of possible sources of water quality problems and potential phosphorus-reduction projects and practices (Table 7).

Sunset Acres Tributary

Along the Sunset Acres tributary, we identified and mapped only a few possible sources of water quality problems (Table 7, Figure 45). Most of these sources were residential in nature, as residential areas covered 21 ha (52 acres) in this subwatershed. However, large fields of corn [29 ha (72 acres)] and hay [19 ha (48 acres)] were being farmed along this tributary, especially upstream of the mapped tributary. Some of the residential areas - as well as more limited areas of paved and gravel roads and a small area of hayfield - were located <25 m (<82 ft) from this tributary. In addition, staff from the Vermont DEC observed that large amounts of manure were being stacked in some of the cornfields near the headwaters of this tributary during the winter months and that significant amounts of manure-laden runoff were flowing downstream during heavy winter rains. Vermont DEC staff also observed significant soil erosion in the cornfields along Darling Hill Road. Thus, we recommend that discussions be initiated with the farmer(s) using these fields to discuss options for relocating the manure stacks farther from the stream and re-establishing unmanaged buffers along any surface waters draining or bordering these fields.

Table 7. Possible sources of water quality problems in eight priority subwatersheds located along four small tributaries that flow directly into Lake Memphremagog.

Subwatershed	Possible Source(s)
Sunset Acres Tributary	
Sunset Acres North	Hay, residences, and roads within 25-m buffer
Holbrook Bay Tributary	
Holbrook Bay	Wetlands Road within 25-m buffer
Holbrook Bay North	Wetlands Hay, pasture, residences, and roads within 25-m buffer
Holbrook Bay South	Barn (1) Wetlands Hay, residences, and roads within 25-m buffer
Strawberry Acres Tributary	
Strawberry Acres	Wetlands Hay, residences, and roads within 25-m buffer
Upper Strawberry Acres	Barn (1) Wetlands Hay, residences, and roads within 25-m buffer
Wishing Well Tributary	
Wishing Well	Barn Residences and roads within 25-m buffer
Upper Wishing Well	Barn (1) and manure pit (1) Wetlands Hay, pasture, residences, and roads within 25-m buffer

Holbrook Bay Tributary

Along the Holbrook Bay tributary, we identified and mapped a number of possible sources of water quality problems (Table 7, Figure 47). Most of these sources were agricultural in nature and included one small barn complex and fields of hay [23 ha (57 acres)] and pasture [1 ha (2 acres)]. Several of these fields were located <25 m (<82 ft) from surface waters. Extensive residential areas [7 ha (16 acres)] also occurred in these subwatersheds, and some of the residential areas and paved and gravel roads were located <25 m (<82 ft) from these tributaries. Much of the downstream end of these subwatersheds was covered by wetlands [9 ha (21 acres)], which can be a significant source of phosphorus, especially late in the growing season. Although some of the gravel roads might be improved through Better Back Roads projects and several of the fields would benefit from broader riparian buffers, our sampling has narrowed the source of the high phosphorus and turbidity levels in this tributary to a man-made pond on the Holbrook Bay South tributary (Figure 16). This pond was recently reconstructed, and the former pastures downstream of this pond were enrolled in and planted through a Conservation Reserve Enhancement Program project. We have already discussed the possible water quality issues in this pond with the owners and hope to propose possible solutions to these issues in the near future.

Strawberry Acres Tributary

Along the Strawberry Acres tributary, we identified and mapped a number of possible sources of water quality problems (Table 7, Figure 47). Most of these sources were either agricultural or residential in nature. Possible agricultural sources included one small barn complex and fields of hay [36 ha (88 acres)] and pasture [8 ha (20 acres)], small areas of which were located <25 m (<82 ft) from surface waters. Extensive residential areas also covered approximately 22 ha (55 acres) in these subwatersheds, and both residential areas and paved and gravel roads were located <25 m (<82 ft) from these tributaries in many places. Small areas of these subwatersheds were covered by wetlands [4 ha (9 acres)], which can be a significant source of phosphorus, especially late in the growing season. Our sampling data suggested that the phosphorus sources were distributed along the length of this tributary. Thus, possible projects and practices to reduce phosphorus exports may include working with the owners of the farm in the upper watershed and the many hayfields and the residences along this tributary. The establishment of forested, or at least unmanaged, riparian buffers would serve to filter nutrients and sediments from surface runoff emanating from these fields and residences. Based on discussions with project partners, we understand that projects are already being planned to improve barnyard and farm facilities in the upper subwatershed, including improving a stream crossing and upgrading the manure pit.

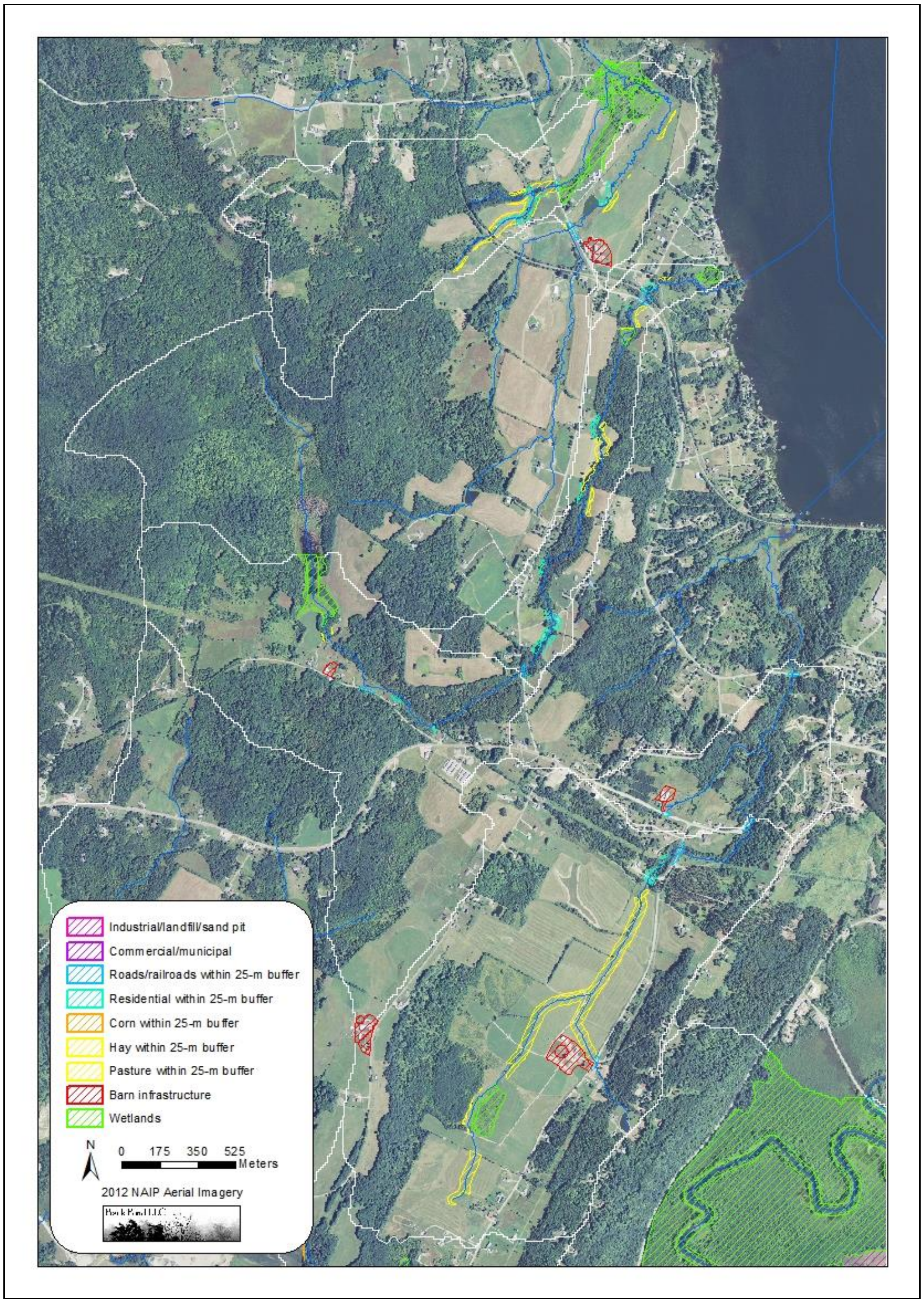

Figure 47. *Possible sources of water quality problems in the six priority subwatersheds along three small tributaries that flow directly into the southwest corner of Lake Memphremagog.*

Wishing Well Tributary

Along the Wishing Well tributary, we identified and mapped a number of possible sources of water quality problems, especially in the upstream subwatershed (Table 7, Figure 47). Most of these sources were agricultural in nature and included two small and one large barn complex (the latter included a manure pit). In addition, large fields of hay [63 ha (156 acres)] and pasture [22 ha (54 acres)] were being farmed along this tributary, primarily in the upstream subwatershed. Many of these fields were located <25 m (<82 ft) from streams. Extensive residential areas [28 ha (70 acres)] also occurred in these subwatersheds, and some of the residential areas and paved roads were located <25 m (<82 ft) from these tributaries. A forested wetland [2.2 ha (5.5 acres)], which had been cleared recently, also occurred in the upper subwatershed. Given that total phosphorus levels were consistently higher in the upstream vs. the downstream subwatershed, much of the phosphorus in this subwatershed likely originated from the large farm in the upper subwatershed. The farmer there has already completed both a grazing plan and clean-water diversion projects (Figure 19), but the pastures and hayfields on this farm were intensively used and managed, and little or no unmanaged riparian buffer bordered many of the fields along this tributary. Thus, we encourage the farmer to consider undertaking projects that will increase the width and revegetate the buffers along these streams as one possible solution to the high phosphorus levels there.

Wetlands Restoration

In our previous studies, we had identified, prioritized, and evaluated potential wetlands restoration sites along the Black River in the towns of Coventry, Irasburg, Albany, and Craftsbury (Gerhardt 2012b, 2013). The owner of one of the sites in Craftsbury submitted an application to enroll his property in the Wetland Reserve Program (WRP). This site was ranked as a high priority for restoration, because it was located on the floodplain adjacent to the main stem of the Black River at its confluence with Seaver Branch (Figure 48). This property was pastured as recently as eight years ago and was planted in potatoes prior to that. The western half of the site at the base of the valley wall was relatively dry and mostly vegetated by old field vegetation, but the eastern and southern parts were fairly wet and vegetated by a mix of old field and wetland vegetation (mostly sedge meadow). Potential restoration projects included plugging the ditch that drains the western half of the site, re-establishing a forested riparian buffer in the drier areas along the main stem and Seaver Branch, and removing the Japanese knotweed growing along Seaver Branch. Although the application was submitted and approved in 2012, funding was not available to move the project forward until this year. Based on recent conversations, it appears that the easement will close in early 2014, that the ditch-plugging and other physical site work will occur in 2014, and that tree-planting will occur in 2015. Restoring this site will not only more effectively filter nutrients and sediment from surface runoff and floodwaters but will also improve fish and wildlife habitat along the Black River.

Figure 48. *Potential wetland restoration site along the Black River in Craftsbury, Vermont.*

Starting in 2014, this site will be restored through a Wetlands Reserve Easement.

Recommendations

Monitoring and Assessment

Future monitoring and assessment studies 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, and evaluating the success of previously-implemented phosphorus-reduction projects. More specifically, we recommend sampling water quality along the following tributaries for the following reasons:

Brighton Brook - Our prior sampling indicated that nutrient and sediment levels were extremely high in this tributary of the Black River during 2010-2013. Furthermore, the sampling in 2013 allowed us to pinpoint the source(s) of these high phosphorus, nitrogen, and turbidity levels to two source areas along the northern tributary of Brighton Brook: one area immediately downslope of the large barn complex, large manure pit, silage storage area, and mortality composting area and a second area further downstream where wetlands and two small ponds may be releasing previously-sequestered phosphorus during the growing season. Further sampling is needed to further pinpoint and assess the possible nutrient and sediment source(s) along this tributary.

Airport tributary - Nutrient and sediment levels were sufficiently high at one new site, so that additional sampling should be conducted along this tributary of the Black River to better pinpoint and assess the source(s) of these high levels.

Hamel Marsh tributary - Our sampling in 2013 allowed us to further pinpoint and assess the source(s) of the high nutrient and sediment levels to the uppermost branch of this tributary of the Barton River. Additional sampling is needed to further pinpoint and assess the possible source(s) of nutrients and sediments in this tributary.

Junkyard tributary - Our sampling in 2013 allowed us to further pinpoint and assess the source(s) of the high nutrient and sediment levels to the upper watershed of this tributary of the Barton River. Additional sampling is needed to further pinpoint and assess the possible source(s) of nutrients and sediments in this tributary.

Crystal Brook - Although our previous sampling indicated that water quality conditions had dramatically improved in Crystal Brook since the manure lagoon there was relocated in 2007, concerns have recently been expressed that other agricultural practices in the watershed may be impacting water quality in Crystal Brook. Thus, we recommend resampling this site to evaluate the current state of water quality conditions in this tributary of the Johns River.

Sunset Acres North tributary - Observations this past winter indicated that large amounts of manure were being stacked along this tributary that flows directly into Lake Memphremagog. In addition, significant amounts of soil erosion have been observed in the cornfields located uphill of this tributary. Since we had previously measured slightly elevated phosphorus levels in this tributary, we recommend resampling this tributary to assess any possible impacts of these manure stacks and soil erosion.

Mud Pond - Due to the high phosphorus levels measured in previous years at the Post Road site along the main stem of the Black River, we recommend sampling spring phosphorus levels in Mud Pond if at all possible. Phosphorus levels in this pond have not been measured since 2007, and, if they remain high, they may indicate that much of the phosphorus in this section of the Black River is originating from the farm immediately surrounding and draining into this pond.

On the other hand, we no longer recommend sampling water quality in several other tributaries at this time. First, we have identified the man-made pond as the likely source of the high phosphorus levels measured in the Holbrook Bay South tributary, so that efforts should now be undertaken to reduce the phosphorus and turbidity levels emanating from this pond. Second, we were able to document that the phosphorus-reduction projects that were implemented on the farm along Shalney Branch have indeed improved water quality there. In contrast, total phosphorus concentrations remained high along the Upper Wishing Well tributary, despite several improvements to the farm facilities and practices there (e.g. grazing plan and clean-water diversion project). Additional sampling at the existing site is unlikely to allow us to further pinpoint and assess nutrient and sediment sources along this tributary. However, sampling the many ditches that drain the farm might allow us to identify nutrient and sediment sources and might be warranted if the landowner is willing to implement projects or practices that address any problems identified through such sampling. In the meantime, we encourage the landowner to consider additional projects and practices that might improve water quality in the streams flowing from this farm. Finally, nutrient and sediment levels were well below levels of concern in several of the tributaries first sampled in 2013 (Cobb Brook, Day Brook, Alder Brook, and the Rediker Hill tributary), so that additional sampling is not warranted at this time. In addition, nutrient and sediment levels were sufficiently low at three sites along Stony Brook and two sites along Roaring Brook, so that these two tributaries do not need additional sampling at this time.

Project Development and Implementation

With the information collected through these studies, we were able to identify and prioritize several potential protection and restoration projects that will likely improve water quality in the priority subwatersheds. To the extent possible, we localized these projects to specific sites within these subwatersheds and identified specific project types that will be most effectively protect and improve water quality. Based on the results of this study, we recommend that the following projects and/or practices be developed and implemented in the following areas:

Holbrook Bay South tributary - Since we have pinpointed the man-made pond as the source area of the high phosphorus levels in the Holbrook Bay South tributary, efforts should be undertaken to reduce the phosphorus and turbidity emanating from this pond. It seems likely that nutrients are recycling from the sediments into the water column, possibly because the aerators may be creating currents that are stirring up the sediments and releasing phosphorus. Three possible solutions for reducing nutrient levels in this pond include: 1) dredging the nutrient-rich sediments from the bottom of the pond, 2) sealing the phosphorus in the sediments through alum treatments, and 3) installing a compost media filter to absorb the phosphorus at the outlet of this pond. All of these approaches are potentially costly and, at least the first two would likely require permits and the last one would require active maintenance. Given that phosphorus loading from this tributary may be relatively small [estimates are that they represent 0.2-0.25% of the total phosphorus loading into the lake (Ben Copans, personal communication)], it may not be cost-effective to apply any of these solutions. In the meantime, we might consider assisting the landowners to ensure that the aerators are installed correctly and properly sized for the pond and to assess their impacts on water quality in and downstream of the pond.

Brighton Brook - During the growing season of 2013, the owners of the large farm along the northern tributary of Brighton Brook made a number of significant changes in land uses and land cover types along this tributary. In particular, they filled approximately 3.6 ha (9.0 acres) of wetlands along the upper end of the tributary and laid a perforated drainage pipe in, filled the stream channel, and planted a grass-lined waterway along 840 m (2,750 ft) of this tributary. These actions diminished our ability to accurately pinpoint and assess the source(s) of the high nutrient and sediment levels in this stream, but they did not eliminate the extremely high levels of phosphorus and nitrogen that continued to be exported from this watershed. Thus, a number of projects and practices could be implemented on this farm to improve water quality in this stream: 1) collecting the surface runoff draining the barnyard, silage storage area, and mortality composting area and pumping the effluent into the manure pit or other collection site, 2) contour-plowing and cover-cropping along the slopes lying uphill of this stream to reduce and filter runoff from the large cornfields in this area, 3) establishing unmanaged - or better yet forested - riparian buffers along the stream to reduce and filter runoff from the large cornfields in this area, and 4) restoring the wetlands that were filled in the upper reaches of this tributary. We will continue to work with our project partners and the owners of this farm to undertake projects and practices that will reduce nutrient and sediment losses into this tributary of Brighton Brook.

Beyond these specific projects and practices, we will continue to use the water quality data and other analyses to identify and prioritize potential phosphorus-reduction projects and practices in the priority subwatersheds and elsewhere in the Lake Memphremagog Basin. As part of these efforts, we will continue to update and revise the GIS shapefiles showing possible sources of water quality problems and potential phosphorus-reduction projects and practices in both the current 28 priority subwatersheds and in additional high-priority subwatersheds. One new step in these analyses will be to integrate the wetlands selection and prioritization models that were developed previously (Gerhardt 2012b, 2013) with the project identification and prioritization efforts, so that both of these tools for identifying potential protection and restoration projects can be “housed” in a single database. We will also continue to work with project partners to identify, develop, and implement phosphorus-reduction projects and practices in the priority subwatersheds. We will also continue to encourage landowners and land managers to consider undertaking wetlands protection and restoration projects in the Vermont portion of the Lake Memphremagog Basin. With the recent passage of the new federal Farm Bill, the Wetlands Reserve Program has been rolled into the Agricultural Conservation Easement Program, but the “new” Wetland Reserve Easements appear to be similar, if not identical, to the earlier Wetlands Reserve Program easements.

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. We also presented the results of this study to the Memphremagog Agricultural Work Group, a partnership of the Vermont DEC; Vermont Agency of Agriculture, Food and Markets; Vermont Association of Conservation Districts, Orleans County Natural Resources Conservation District; and USDA Natural Resources Conservation Service that shares information about and coordinates efforts to develop and implement agricultural projects and practices that protect and improve water quality. We also presented the results of this and earlier studies at the 2014 New England Association of Environmental Biologists Annual Conference. 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 Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs; 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 32 sites sampled along the Vermont tributaries of Lake Memphremagog during April-October 2012 (locations are mapped in Figure 4).

Black River (13 sites):

Site Name	Site Description
Airport Tributary	Unnamed tributary along High Acres Road
Stony Brook	Stony Brook upstream of confluence with Black River in Coventry (also sampled in 2010-2011)
Blake Road	Stony Brook downstream of Vermont Route 14 and Blake Road in Coventry
Alderbrook	Stony Brook upstream of Nadeau Road in Coventry
Brighton Brook	Brighton Brook downstream of Gage Road in Irasburg (also sampled in 2010-2011)
Brighton Brook North	Unnamed tributary to Brighton Brook upstream of Vermont Route 58 in Irasburg (also sampled in 2011)
Upper Brighton Brook North	Unnamed tributary to Brighton Brook downstream of Back Coventry Road in Irasburg
Lower Nelson Farm	Unnamed tributary downstream of confluence of northeast and northwest tributaries on Nelson Farm
Nelson Northeast	Unnamed tributary proceeding northeast of the Nelson Farm barns
Nelson Northwest	Unnamed tributary proceeding northwest of the Nelson Farm barns
Nelson NW Pipe	Outflow from pipe on unnamed tributary proceeding northwest of the Nelson Farm barns (replaced Nelson Northwest site)
Upper Nelson Northwest	Unnamed tributary northwest of Nelson Farm fields
Shalney Branch	Shalney Branch downstream of Vermont Route 14 in Albany (also sampled in 2010-2011)
Upper Shalney Branch	Shalney Branch upstream of Old Street in Albany (also sampled in 2011)

Barton River (11 sites):

Site Name	Site Description
Barton Alder Brook	Alder Brook upstream of Airport Road
Hamel Marsh	Unnamed tributary upstream along Hamel Road in Irasburg
Upper Hamel Marsh	Unnamed tributary downstream of abandoned section of Hamel Road

Barton River (continued):

Lower Hamel Tributary	Unnamed tributary upstream of Bruneau Road
Middle Hamel Tributary	Unnamed tributary upstream of Bruneau Road
Upper Hamel Tributary	Unnamed tributary upstream of Cooks Road
Rock Junkyard	Unnamed tributary upstream of River Road in Irasburg
Upper Junkyard	Unnamed tributary upstream of Vermont Route 14/58
Churchill Lane	Willoughby River upstream of Churchill Lane in Barton
Roaring Brook	Roaring Brook downstream of Interstate 91 in Barton
Upper Roaring Brook	Roaring Brook upstream of East Albany Road

Smaller tributaries (7 sites):

Site Name	Site Description
Holbrook Bay South	Southern branch of unnamed tributary upstream of Beaver Cove Road in Newport Town (also sampled in 2010)
Holbrook South Pond	Unnamed tributary downstream of pond below Lake Road
Upper Holbrook Bay South	Southern branch of unnamed tributary upstream of Lake Road in Newport Town
Upper Wishing Well	Unnamed tributary downstream of Vermont Route 105 in Newport City (also sampled in 2009-2010)
Cobb Brook	Cobb Brook upstream of Glen Road
Rediker Hill	Unnamed tributary upstream of Rediker Hill Road
Day Brook	Day Brook downstream of Pine Hill Road

Vermont DEC sites (4 sites):

Site Name	Site Description
Barton River	Main stem upstream of Coventry Station Road in Coventry (also sampled in 2005-2011)
Black River	Main stem upstream of Airport Road in Coventry (also sampled in 2005-2011)
Clyde River	Main stem upstream of Gardner Park Road in Newport City (also sampled in 2005-2011)
Johns River	Main stem beside old well house along Beebe Road in Derby (also sampled in 2005-2006 and 2008-2011)

Appendix B. Water quality data collected at 32 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Bold or italicized fonts highlight concentrations greater than Vermont water quality standards (State of Vermont 2011) or what might be considered elevated concentrations if no water quality standards apply: total phosphorus >20 µg/l (italics) or >35 µg/l (bold), total nitrogen >1 mg/l (italics) or >2 mg/l (bold), and turbidity >5 NTU (italics) or >10 NTU (bold).

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Airport Tributary	4/23/2013	0.51	**46.5**	*8.59*
Airport Tributary	5/21/2013	0.34	*25.4*	1.73
Airport Tributary	6/11/2013	**4.45**	**690**	**265**
Airport Tributary	6/18/2013	0.4	*26.3*	1.01
Airport Tributary	7/16/2013	0.4	**41**	2.21
Airport Tributary	8/13/2013	0.3	*24.2*	0.94
Airport Tributary	9/10/2013	0.29	19.7	1.24
Airport Tributary	10/8/2013	0.8	**151**	3.29
Alderbrook	4/23/2013	0.71	17.5	0.86
Alderbrook	5/21/2013	*1.32*	17.2	0.78
Alderbrook	6/11/2013	*1.02*	**99.4**	**12.5**
Alderbrook	6/18/2013	0.88	18.1	0.72
Alderbrook	7/16/2013	*1.18*	*26.2*	1.19
Alderbrook	8/13/2013	*1.18*	16.8	0.66
Alderbrook	9/10/2013	*1.57*	9.99	0.31
Alderbrook	10/8/2013	0.83	19.7	1.15
Barton Alder Brook	4/23/2013	*1.11*	*24.8*	1.81
Barton Alder Brook	5/21/2013	0.59	*24.1*	2.02
Barton Alder Brook	6/11/2013	*1.13*	**143**	**39.7**
Barton Alder Brook	6/18/2013		19	0.71
Barton Alder Brook	7/16/2013	0.77	*31.7*	1.88
Barton Alder Brook	8/13/2013	0.64	19.3	0.58
Barton Alder Brook	9/10/2013	0.49	17.3	0.87
Barton Alder Brook	10/8/2013	*1.02*	**74.8**	3.39

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Blake Road	4/23/2013	0.72	17.4	1.19
Blake Road	5/21/2013	*1.1*	17.6	1.01
Blake Road	6/11/2013	*1*	**93.8**	**12.8**
Blake Road	6/18/2013	0.82	16.8	0.91
Blake Road	7/16/2013	*1.29*	*22.6*	0.87
Blake Road	8/13/2013	*1.1*	16.2	0.55
Blake Road	9/10/2013	*1.35*	12.7	0.4
Blake Road	10/8/2013	0.79	*21.7*	1.59
Brighton Brook	4/23/2013	0.41	*24.3*	4.37
Brighton Brook	5/21/2013	0.43	*20.6*	1.85
Brighton Brook	6/11/2013	*1.42*	**213**	**25.6**
Brighton Brook	6/18/2013	0.55	*27*	1.58
Brighton Brook	7/16/2013	0.6	**83**	4.46
Brighton Brook	8/13/2013	0.63	*33.1*	1.68
Brighton Brook	9/10/2013	0.67	*22.2*	2.48
Brighton Brook	10/8/2013	0.47	**70.3**	4.16
Brighton Brook North	4/23/2013	0.38	**36.7**	2.68
Brighton Brook North	5/21/2013	0.4	*23.7*	1.41
Brighton Brook North	6/11/2013	**2.44**	**470**	**18.5**
Brighton Brook North	6/18/2013	0.43	**66.2**	1.59
Brighton Brook North	7/16/2013	0.72	**370**	**13.2**
Brighton Brook North	8/13/2013	0.51	**85.8**	3.32
Brighton Brook North	9/10/2013	0.72	*25.9*	2.21
Brighton Brook North	10/8/2013	0.77	**103**	3.58
Churchill Lane	4/23/2013	0.29	*29.4*	*7.94*
Churchill Lane	5/21/2013	0.26	10.7	1.05
Churchill Lane	6/11/2013	0.35	**71.5**	**33.5**
Churchill Lane	6/18/2013	0.21	10.9	1.92
Churchill Lane	7/16/2013	0.14	13	1.59
Churchill Lane	8/13/2013	0.19	11.9	0.7
Churchill Lane	9/10/2013	0.15	11.1	0.56
Churchill Lane	10/8/2013	0.32	*25.7*	3.95

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Cobb Brook	4/23/2013	0.27	16.4	4.46
Cobb Brook	5/21/2013	0.27	14.9	2.7
Cobb Brook	6/11/2013	0.63	**152**	**20**
Cobb Brook	6/18/2013	0.24	11.1	1.12
Cobb Brook	7/16/2013	0.29	15.1	1.7
Cobb Brook	8/13/2013	0.34	14.6	1.05
Cobb Brook	9/10/2013	0.27	13.1	1.51
Cobb Brook	10/8/2013	0.29	*20.9*	3.18
Day Brook	4/23/2013	0.31	14.4	2.42
Day Brook	5/21/2013	0.32	8.78	1.46
Day Brook	6/11/2013	0.58	**72.4**	*6.36*
Day Brook	6/18/2013	0.29	10.8	0.89
Day Brook	7/16/2013	0.24	15.1	0.94
Day Brook	8/13/2013	0.34	*21.5*	0.96
Day Brook	9/10/2013	0.28	9.01	1.21
Day Brook	10/8/2013	0.23	13.1	0.72
Hamel Marsh	4/23/2013	*1.71*	*32.4*	2.2
Hamel Marsh	5/21/2013	0.45	*23.5*	1.81
Hamel Marsh	6/11/2013	**2.76**	**380**	**49.1**
Hamel Marsh	6/18/2013	*1.44*	*26.4*	1.15
Hamel Marsh	7/16/2013	0.77	*33*	2.22
Hamel Marsh	8/13/2013	*1.19*	*32.8*	1.53
Hamel Marsh	9/10/2013	0.32	*28.4*	2.39
Hamel Marsh	10/8/2013	*1.32*	**80.8**	3.57
Holbrook Bay South	4/23/2013	0.26	*22.6*	2.62
Holbrook Bay South	5/21/2013	0.35	*31.3*	3.26
Holbrook Bay South	6/11/2013	0.58	**112**	**19.8**
Holbrook Bay South	6/18/2013	0.28	*24.4*	3.25
Holbrook Bay South	7/16/2013	0.38	**42**	*6.11*
Holbrook Bay South	8/13/2013	0.41	**54**	*6.94*
Holbrook Bay South	9/10/2013	0.46	**85**	**18.5**
Holbrook Bay South	10/8/2013	0.54	**58.7**	*7.55*

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Holbrook South Pond	4/23/2013	0.27	*25.2*	3.44
Holbrook South Pond	5/21/2013	0.38	**41.5**	3.76
Holbrook South Pond	6/11/2013	0.48	**110**	**22.6**
Holbrook South Pond	6/18/2013	0.31	*27.6*	3.35
Holbrook South Pond	7/16/2013	0.53	**47.6**	4.13
Holbrook South Pond	8/13/2013	0.47	*31.3*	3.52
Holbrook South Pond	9/10/2013	0.94	*26.2*	*6.01*
Holbrook South Pond	10/8/2013	0.62		*8.59*
Lower Hamel Tributary	6/11/2013	*1.17*	**91.9**	**314**
Lower Hamel Tributary	6/18/2013	0.2	14.2	0.8
Lower Hamel Tributary	7/16/2013	0.48	**38.4**	1.48
Lower Hamel Tributary	8/13/2013	0.29	*25.6*	0.28
Lower Hamel Tributary	10/8/2013	0.37	*28.2*	2.63
Lower Nelson Farm	4/23/2013	**3.52**	**610**	4.88
Lower Nelson Farm	5/21/2013	**20.1**	**483**	**31**
Lower Nelson Farm	6/11/2013	**9.47**	**1410**	3.84
Lower Nelson Farm	6/18/2013	**13**	**334**	**26.2**
Lower Nelson Farm	7/16/2013	**18.1**	**410**	**62.6**
Lower Nelson Farm	8/13/2013	**19.6**	**124**	4.3
Lower Nelson Farm	9/10/2013	**16.6**	**320**	**25.9**
Lower Nelson Farm	10/8/2013	**5.37**	**267**	**31.1**
Middle Hamel Tributary	6/11/2013	**3.89**	**477**	**105**
Middle Hamel Tributary	6/18/2013	**2.31**	*29.1*	1.52
Middle Hamel Tributary	7/16/2013	**2.51**	**39.8**	1.85
Middle Hamel Tributary	8/13/2013	**2.13**	*30.6*	0.36
Middle Hamel Tributary	9/10/2013	*1.19*	*24.2*	0.22
Middle Hamel Tributary	10/8/2013	**2.26**	**66.2**	4.12
Nelson Northeast	4/23/2013	0.87	**39.9**	0.48
Nelson Northeast	6/11/2013	0.66	**86.5**	*5.14*
Nelson Northeast	6/18/2013	0.68	**117**	4.24
Nelson Northeast	7/16/2013	*1.58*	**459**	**21.4**
Nelson Northeast	8/13/2013	*1.24*	**198**	*9.56*
Nelson Northeast	10/8/2013	0.67	**74.9**	2.89
Nelson Northwest	4/23/2013	**6.63**	**1550**	**16.6**
Nelson Northwest	5/21/2013	**25.9**	**272**	**34.1**

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Nelson NW Pipe	6/11/2013	**7.56**	**1010**	**524**
Nelson NW Pipe	6/18/2013	**19.3**	**220**	**34.5**
Nelson NW Pipe	7/16/2013	**20.2**	**143**	*5.61*
Nelson NW Pipe	8/13/2013	**22**	**47.6**	1.43
Nelson NW Pipe	9/10/2013	**21.5**	**36**	0.84
Nelson NW Pipe	10/8/2013	**16.1**	**113**	**20.1**
Rediker Hill	4/23/2013	0.38	*23.4*	2.25
Rediker Hill	5/21/2013	0.43	*21.6*	1.68
Rediker Hill	6/11/2013	0.68	**100**	*7.64*
Rediker Hill	6/18/2013	0.41	15.8	1.04
Rediker Hill	7/16/2013	0.47	18.8	0.67
Rediker Hill	8/13/2013	0.53	18.4	0.38
Rediker Hill	9/10/2013	0.42	14.4	0.34
Rediker Hill	10/8/2013	0.41	*21.6*	1.02
Roaring Brook	4/23/2013	0.5	*20.1*	3.77
Roaring Brook	5/21/2013	0.34	18	2.54
Roaring Brook	6/11/2013	0.77	**89.2**	4.7
Roaring Brook	6/18/2013	0.28	16	1.57
Roaring Brook	7/16/2013	0.25	14.9	1.07
Roaring Brook	8/13/2013	0.31	10.3	0.38
Roaring Brook	9/10/2013	0.24	9.66	0.22
Roaring Brook	10/8/2013	0.26	17.8	2.47
Rock Junkyard	4/23/2013	0.73	*22.8*	3.01
Rock Junkyard	5/21/2013	0.39	*20.4*	1.89
Rock Junkyard	6/11/2013	**2.28**	**468**	**69.8**
Rock Junkyard	6/18/2013	0.58	*22.2*	1.46
Rock Junkyard	7/16/2013	0.58	*30.5*	1.43
Rock Junkyard	8/13/2013	0.73	*27.1*	0.96
Rock Junkyard	9/10/2013	0.35	17.3	0.63
Rock Junkyard	10/8/2013	0.54	**37.4**	1.94
Shalney Branch	4/23/2013	0.32	9.15	1.42
Shalney Branch	5/21/2013	0.23	12.2	1.33
Shalney Branch	6/11/2013	0.51	**125**	**63**
Shalney Branch	6/18/2013	0.24	10.6	1.19
Shalney Branch	7/16/2013	0.61	**43.3**	2.78
Shalney Branch	8/13/2013	0.32	15	0.29
Shalney Branch	9/10/2013	0.71	**37.8**	1.11
Shalney Branch	10/8/2013	0.41	*32.5*	2.88

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Stony Brook	4/23/2013	0.77	*27.9*	2.31
Stony Brook	5/21/2013	0.98	15.7	1.27
Stony Brook	6/11/2013	*1.09*	**154**	**34.1**
Stony Brook	6/18/2013	*1.02*	17.3	1.24
Stony Brook	7/16/2013	*1.39*	*27.2*	1.25
Stony Brook	8/13/2013	*1.45*	18	0.58
Stony Brook	9/10/2013	*1.49*	14.1	0.56
Stony Brook	10/8/2013	0.87	*22.1*	1.73
Upper Brighton Brook North	4/23/2013	**2.17**	**368**	*5.35*
Upper Brighton Brook North	5/21/2013	**2.92**	**690**	*8.27*
Upper Brighton Brook North	6/11/2013	**2.22**	**611**	**97.6**
Upper Brighton Brook North	6/18/2013	*1.07*	**508**	1.82
Upper Brighton Brook North	7/16/2013	**2.41**	**2760**	**19.4**
Upper Brighton Brook North	8/13/2013	*1.66*	**1410**	**11.7**
Upper Brighton Brook North	10/8/2013	*1.96*	**266**	4.66
Upper Hamel Marsh	4/23/2013	*1.66*	*30.6*	2.67
Upper Hamel Marsh	5/21/2013	0.39	*21.9*	2
Upper Hamel Marsh	6/11/2013	**2.98**	**323**	**14.6**
Upper Hamel Tributary	6/11/2013	**4.58**	**868**	**102**
Upper Hamel Tributary	6/18/2013	**7.42**	**83.8**	0.63
Upper Hamel Tributary	7/16/2013	**9.81**	**115**	1.71
Upper Hamel Tributary	8/13/2013	**9.31**	**97.1**	0.46
Upper Hamel Tributary	9/10/2013	*1.36*	**112**	2.59
Upper Hamel Tributary	10/8/2013	**5.17**	**228**	2.68
Upper Holbrook Bay South	4/23/2013	0.26	13.4	0.82
Upper Holbrook Bay South	5/21/2013	0.36	*21*	1.49
Upper Holbrook Bay South	6/11/2013	0.56	**74.3**	*6.99*
Upper Holbrook Bay South	6/18/2013	0.22	10.8	0.42
Upper Holbrook Bay South	7/16/2013	0.31	18.6	2.52
Upper Holbrook Bay South	8/13/2013	0.35	**38.1**	1.37
Upper Holbrook Bay South	9/10/2013	0.23	18.1	3.53
Upper Holbrook Bay South	10/8/2013	0.34	*29.9*	1.58

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Upper Junkyard	4/23/2013	0.81	**35.6**	3.37
Upper Junkyard	5/21/2013	0.7	**44.6**	1.15
Upper Junkyard	6/11/2013	**2.72**	**714**	**20.9**
Upper Junkyard	6/18/2013	0.69	*32.1*	0.94
Upper Junkyard	7/16/2013	0.9	**39.2**	0.58
Upper Junkyard	8/13/2013	*1.03*	**39.8**	0.32
Upper Junkyard	9/10/2013	0.99	**35.6**	< 0.2
Upper Junkyard	10/8/2013	0.57	**45.6**	2.21
Upper Nelson Northwest	4/23/2013	**4.99**	16	**15.4**
Upper Nelson Northwest	5/21/2013	*1.82*	**276**	*6.8*
Upper Nelson Northwest	6/11/2013	**3.9**	**655**	**579**
Upper Roaring Brook	4/23/2013	0.49	*20.7*	3.7
Upper Roaring Brook	5/21/2013	0.36	19	1.67
Upper Roaring Brook	6/11/2013	*1.12*	**108**	*5.11*
Upper Roaring Brook	6/18/2013	0.34	18.5	1.85
Upper Roaring Brook	7/16/2013	0.29	19.6	0.87
Upper Roaring Brook	8/13/2013	0.35	14.7	0.58
Upper Roaring Brook	9/10/2013	0.35	12.4	0.54
Upper Roaring Brook	10/8/2013	0.24	19.2	1.96
Upper Shalney Branch	4/23/2013	0.29	10.1	1.6
Upper Shalney Branch	5/21/2013	0.25	12.4	1.15
Upper Shalney Branch	6/11/2013	0.48	**94.3**	**37.8**
Upper Shalney Branch	6/18/2013	0.21	11.2	1.02
Upper Shalney Branch	7/16/2013	0.4	16.6	0.37
Upper Shalney Branch	8/13/2013	0.33	13	0.24
Upper Shalney Branch	9/10/2013	0.28	8.55	< 0.2
Upper Shalney Branch	10/8/2013	0.39	*29*	1.92
Upper Wishing Well	4/23/2013	0.42	*34.4*	2.61
Upper Wishing Well	5/21/2013	0.49	**50.5**	4.03
Upper Wishing Well	6/11/2013	*1.37*	**240**	**17.9**
Upper Wishing Well	6/18/2013	0.42	**38.6**	1.09
Upper Wishing Well	7/16/2013	0.66	**52**	2.45
Upper Wishing Well	8/13/2013	0.77	**61.9**	2.06
Upper Wishing Well	9/10/2013	0.45	*34.4*	2.01
Upper Wishing Well	10/8/2013	0.75	**105**	2.02

Appendix C. Quality assurance data, including field blanks and field duplicates, collected from 29 sample sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. 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)
Blake Road	4/23/2013	< 0.1	< 5	< 0.2
Holbrook Bay South	4/23/2013	< 0.1	< 5	< 0.2
Upper Roaring Brook	4/23/2013	< 0.1	< 5	< 0.2
Stony Brook	5/21/2013	< 0.1	< 5	< 0.2
Upper Hamel Marsh	5/21/2013	< 0.1	< 5	< 0.2
Upper Wishing Well	5/21/2013	< 0.1	< 5	**0.2**
Alderbrook	6/11/2013	< 0.1	< 5	< 0.2
Cobb Brook	6/11/2013	< 0.1	< 5	< 0.2
Upper Roaring Brook	6/11/2013	< 0.1	< 5	< 0.2
Airport Tributary	6/18/2013	< 0.1	< 5	< 0.2
Brighton Brook	6/18/2013	< 0.1	< 5	< 0.2
Churchill Lane	6/18/2013	< 0.1	< 5	< 0.2
Alderbrook	7/16/2013	< 0.1	**9.42**	< 0.2
Brighton Brook North	7/16/2013	< 0.1	< 5	**0.79**
Upper Junkyard	7/16/2013	< 0.1	**9.94**	< 0.2
Rock Junkyard	8/13/2013	< 0.1	< 5	< 0.2
Stony Brook	8/13/2013	< 0.1	< 5	< 0.2
Upper Shalney Branch	8/13/2013	< 0.1	< 5	< 0.2
Shalney Branch	9/10/2013	< 0.1	< 5	< 0.2
Stony Brook	9/10/2013	< 0.1	< 5	< 0.2
Airport Tributary	10/8/2013	< 0.1	< 5	< 0.2
Hamel Marsh	10/8/2013	< 0.1	< 5	**0.24**
Upper Holbrook Bay South	10/8/2013	< 0.1	< 5	**0.42**

Field Duplicates:

Total Nitrogen

Site	Date	1st Total Nitrogen (mg/l)	2nd Total Nitrogen (mg/l)	Relative % Difference
Blake Road	4/23/2013	0.72	0.71	1
Holbrook Bay South	4/23/2013	0.26	0.26	0
Upper Roaring Brook	4/23/2013	0.49	0.51	4
Stony Brook	5/21/2013	0.98	1.03	5
Upper Hamel Marsh	5/21/2013	0.39	0.39	0
Upper Wishing Well	5/21/2013	0.49	0.47	4
Alderbrook	6/11/2013	1.02	1.09	7
Cobb Brook	6/11/2013	0.63	0.72	13
Upper Roaring Brook	6/11/2013	1.12	1	11
Airport Tributary	6/18/2013	0.4	0.37	8
Brighton Brook	6/18/2013	0.55	0.47	16
Churchill Lane	6/18/2013	0.21	0.19	10
Alderbrook	7/16/2013	1.18	1.27	7
Brighton Brook North	7/16/2013	0.72	0.66	9
Upper Junkyard	7/16/2013	0.9	0.94	4
Rock Junkyard	8/13/2013	0.73	0.72	1
Stony Brook	8/13/2013	1.45	1.38	5
Upper Shalney Branch	8/13/2013	0.33	0.34	3
Shalney Branch	9/10/2013	0.71	0.72	1
Stony Brook	9/10/2013	1.49	1.49	0
Airport Tributary	10/8/2013	0.8	0.81	1
Hamel Marsh	10/8/2013	1.32	1.31	1
Upper Holbrook Bay South	10/8/2013	0.34	0.34	0

Total Phosphorus

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Blake Road	4/23/2013	17.4	19	9
Holbrook Bay South	4/23/2013	22.6	23	2
Upper Roaring Brook	4/23/2013	20.7	19.1	8
Stony Brook	5/21/2013	15.7	15.6	1
Upper Hamel Marsh	5/21/2013	21.9	22.4	2
Upper Wishing Well	5/21/2013	50.5	49.3	2
Alderbrook	6/11/2013	99.4	103	4
Cobb Brook	6/11/2013	152	169	11
Upper Roaring Brook	6/11/2013	108	116	7
Airport Tributary	6/18/2013	26.3	28.3	7
Brighton Brook	6/18/2013	27	27.5	2
Churchill Lane	6/18/2013	10.9	10.5	4
Alderbrook	7/16/2013	26.2	27	3
Brighton Brook North	7/16/2013	370	313	17
Upper Junkyard	7/16/2013	39.2	45.4	15
Rock Junkyard	8/13/2013	27.1	24.9	8
Stony Brook	8/13/2013	18	19.5	8
Upper Shalney Branch	**8/13/2013**	**13**	**8.36**	**43**
Shalney Branch	9/10/2013	37.8	37.9	0
Stony Brook	9/10/2013	14.1	14.1	0
Airport Tributary	10/8/2013	151	152	1
Hamel Marsh	10/8/2013	80.8	84.7	5
Upper Holbrook Bay South	10/8/2013	29.9	30.3	1

Turbidity

Site	Date	1st Turbidity (NTU)	2nd Turbidity (NTU)	Relative % Difference
Blake Road	**4/23/2013**	**1.19**	**1.82**	**42**
Holbrook Bay South	4/23/2013	2.62	2.44	7
Upper Roaring Brook	4/23/2013	3.7	3.33	11
Stony Brook	**5/21/2013**	**1.27**	**1**	**24**
Upper Hamel Marsh	**5/21/2013**	**2**	**1.6**	**22**
Upper Wishing Well	5/21/2013	4.03	4.61	13
Alderbrook	6/11/2013	12.5	12.9	3
Cobb Brook	**6/11/2013**	**20**	**68.1**	**109**
Upper Roaring Brook	**6/11/2013**	**5.11**	**15.7**	**102**
Airport Tributary	6/18/2013	1.01	1.17	15
Brighton Brook	6/18/2013	1.58	1.67	6
Churchill Lane	**6/18/2013**	**1.92**	**1.22**	**45**
Alderbrook	**7/16/2013**	**1.19**	**0.94**	**23**
Brighton Brook North	**7/16/2013**	**13.2**	**10.8**	**20**
Upper Junkyard	**7/16/2013**	**0.58**	**0.44**	**27**
Rock Junkyard	8/13/2013	0.96	1.03	7
Stony Brook	8/13/2013	0.58	0.63	8
Upper Shalney Branch	8/13/2013	0.24	0.26	8
Shalney Branch	9/10/2013	1.11	1.16	4
Stony Brook	9/10/2013	0.56	0.49	13
Airport Tributary	10/8/2013	3.29	3.53	7
Hamel Marsh	10/8/2013	3.57	3.19	11
Upper Holbrook Bay South	10/8/2013	1.58	1.81	14

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 region or area bounded peripherally by a divide and draining into a particular water course or 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 amount of a dissolved substance contained per unit of volume.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Watershed – See basin.

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

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

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