Restoring Water Quality in the Lake Memphremagog Basin:

2012 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 MWA are: 1) to promote the ecological awareness of people who live in, work in, and visit the Memphremagog watershed; 2) to inform and educate the public and promote participation in the preservation of 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 the shoreline and river banks, 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 adjacent Canada. 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 a 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 protect and improve water quality; to protect and restore floodplain forests and wetlands; and to identify and protect critical wildlife habitat linkages across northern New England and eastern Canada.

Cover. *Large expanse of tussock sedge wetlands along the Black River in Craftsbury, Vermont on 24 May 2012. Protecting and restoring wetlands is a highly effective approach to protecting water quality, filtering nutrients and sediment, and storing excess floodwaters.*

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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 the lake. In 2012, we undertook a three-part project to continue efforts 1) to identify and assess water quality problems; 2) to identify and prioritize areas in which to undertake protection and restoration projects; and 3) to identify, prioritize, and implement wetland restoration projects in the Vermont portion of the Lake Memphremagog Basin.

2. First, we undertook a targeted water quality sampling program to further pinpoint 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 29 sites on eight dates during April-October 2012. Through this sampling, we further pinpointed phosphorus and turbidity sources along the main stem and several tributaries of the Black and Barton Rivers. In addition, we increased our knowledge about water quality conditions throughout the Barton River watershed where data were lacking previously. Finally, we determined that water quality conditions were improving along three of the four tributaries where remediation projects had been implemented to reduce high phosphorus levels.

3. Second, we conducted spatial and statistical analyses to identify and prioritize areas that likely export the greatest amounts of phosphorus into the surface waters of the Lake Memphremagog Basin. 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, mean total phosphorus concentrations were highest 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.

4. Finally, we developed a spatially-explicit model to identify and prioritize potential wetland restoration sites in the Vermont portion of the Lake Memphremagog Basin. These sites included areas >1.2 ha in size that were located on agricultural and other non-forested lands, hydric soils, slopes ≤6%, and disturbed wetlands. This model

identified 541 potential wetland restoration sites occupying 2,973 ha (2.4%) of the Vermont portion of the basin. Potential sites ranged in size from 1.2-48.4 ha with a mean area of 5.5 ha. We then used a qualitative approach to rank the sites according to potential to reduce sediment and nutrient loading into Lake Memphremagog. In 2012, prioritization was completed for the Black River and Johns River watersheds. Many of the medium- and high-priority sites were located along the main stem of the Black River, Lords Creek, and the lower reaches of several smaller tributaries. In contrast, low-priority sites were mostly situated in upland areas more distant from surface waters. Finally, we further evaluated and discussed potential protection and restoration opportunities for 24 high- and medium-priority sites in the Black River watershed.

5. Collectively, these data and analyses greatly increased our understanding of water quality problems and allowed us to identify priority areas for implementing protection and restoration projects to reduce nutrient and sediment inputs into the Vermont tributaries of Lake Memphremagog. In 2013, we will continue efforts to refine our knowledge about nutrient and sediment sources in the Vermont portion of the basin, and we will also expand efforts 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 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).

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 on-the-ground projects that 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. 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.

In 2008-2009, we expanded upon these earlier studies by focusing on identifying and assessing phosphorus and nitrogen sources along the Johns River as well as seven small tributaries that flow directly into Lake Memphremagog (Gerhardt 2009, 2010). Along the Johns River, the high phosphorus levels were the legacy of a failed manure lagoon, which was replaced in the summer of 2007, and runoff from a silage storage area, which was captured by a drainage system installed in the summer of 2009. Replacing the failed manure lagoon and curtailing runoff from the silage storage area dramatically improved water quality along Crystal Brook and, to a lesser degree, further downstream along the Johns River. Through these studies, we also pinpointed the sources of the high nitrogen levels in this area to several groundwater springs and seeps along the main stem of the Johns River and the Darling Hill and Sunset Acres tributaries. These results were consistent with the hypothesis that nitrogen was leaching into the groundwater from manure and/or synthetic fertilizers being applied to cornfields located on very porous sand and gravel deposits. In addition, high phosphorus and sediment levels were measured in five of the seven small tributaries that flow directly into Lake Memphremagog, including all three located at the southwestern corner of the lake in Newport City and Newport Town.

In 2010-2011, we refocused our efforts on identifying and assessing threats to water quality in the Black River watershed. The Black River has been targeted as a high priority for assessment due to the elevated phosphorus and sediment levels measured there previously and that were predicted to originate from this watershed by recent modeling efforts (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008, SMi 2009). Through this sampling, we identified a number of areas that were potential sources of the high nutrient and sediment levels flowing into Lake Memphremagog. In particular, phosphorus and turbidity levels were highest along the main stem of the Black River between the villages of Craftsbury and Albany and again downstream of the village of Irasburg. Phosphorus and sediment levels were also high along four tributaries to the Black River: Shalney Branch, Lords Creek, Brighton Brook, and Stony Brook. In 2012, we focused our sampling in these areas of the Black River watershed as well as several small tributaries that flow directly into Lake Memphremagog, where high phosphorus levels were measured previously (Gerhardt 2009, 2010). Furthermore, we expanded our sampling along the main stem and numerous tributaries of the Barton River, which had not been sampled since 2006.

Priority Phosphorus Reduction Areas

In addition to allowing us to assess water quality conditions and to pinpoint specific nutrient and sediment sources, the monitoring and assessment data can be used to identify and prioritize areas 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 Amenatech 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 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 focal areas for 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 are currently 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 a large amount of water quality data has been collected at numerous sites along the Vermont tributaries of Lake Memphremagog during 2005-2012, we undertook such an effort to identify subwatersheds to allow efficient targeting of implementation funds where they will likely be most effective in reducing phosphorus exports in the Lake Memphremagog Basin.

Protection and Restoration Strategies

Ultimately, the goal of all of these monitoring and assessment efforts is to better target protection and restoration projects, so that they will most effectively reduce nutrient and sediment exports into the surface waters of the Lake Memphremagog Basin. Efforts to protect and improve water quality in the Lake Memphremagog Basin have incorporated a number of strategies, including upgrading wastewater treatment facilities, septic systems, and solid waste facilities; better managing stormwater; reducing runoff from roads and other developed lands; improving bridges and culverts; and improving agricultural and forestry practices. Although much progress has been made in reducing point sources of pollution, nonpoint sources have been much more difficult to correct. Most nonpoint source pollution in the Lake Memphremagog Basin likely originates in surface runoff from developed (e.g.

urban, suburban, exurban, and transportation land uses) and agricultural lands, which cover a larger proportion of the basin [developed land = 6.1% vs. agricultural land = 15.5% (State of Vermont 2012b)].

One of the more effective strategies for reducing nonpoint source pollution and protecting and improving water quality is the protection and restoration of floodplain and shoreline habitats. Representing the interface between the terrestrial and aquatic environments, floodplain and shoreline habitats typically occupy low-lying areas adjacent to rivers, streams, lakes, and ponds and are subject to periodic flooding and dynamic patterns of erosion and sediment deposition (Figure 3). These habitats protect and improve water quality by reducing flooding; intercepting surface runoff; reducing shoreline erosion and stream channel migration; reducing water velocity; and capturing sediment, nutrients, and other pollutants that might otherwise enter surface waters. Depending upon their width and complexity, floodplain habitats can retain 50-100% of the sediment and nutrients in surface runoff (Connecticut River Joint Commissions 1998). Forested shorelines also shade surface waters and moderate water temperatures and, because cooler water holds more oxygen, create higher dissolved oxygen levels, which increase assimilation of organic wastes from wastewater treatment plants and other point and nonpoint sources. Thus, numerous public and private organizations have targeted the protection and restoration of floodplain and shoreline habitats as an important strategy for protecting and improving water quality.

Several strategies have been identified for protecting and restoring floodplain and shoreline habitats and the resulting water quality benefits. The first - and most obvious - is to protect existing floodplain forests and wetlands and the natural processes that maintain these habitats. The primary means for accomplishing this strategy is through land conservation (either easements or fee ownership) and limiting construction of new dams, levees, ditches, and other structures that alter floodplain hydrology. In the Lake Memphremagog Basin, floodplain forests and wetlands have already been protected in several areas, including the South Bay and Willoughby Falls Wildlife Management Areas and the Eagle Point Unit of the Missisquoi National Wildlife Refuge. The second strategy is to restore floodplain forests and wetlands in areas where they no longer exist, especially in areas immediately adjacent to surface waters or that reconnect and extend existing occurrences of these habitats. Restoring and reconnecting floodplain habitats has numerous ecological, economic, and aesthetic benefits, including moderating stream flows, reducing flooding, stabilizing shorelines, reducing erosion, filtering nutrients and sediment from floodwaters and surface runoff, reducing water temperatures, enhancing fish and wildlife habitat, restoring the wild character of rivers and streams, and enhancing recreational opportunities. Restoring floodplain habitats also allows the re-establishment of more natural flooding regimes and rates of erosion and sediment deposition that further protect and improve water quality.

Figure 3. *Flooded agricultural fields located on the floodplain of the Black River in Craftsbury, Vermont on 29 August 2011. Floodplains store excess floodwaters and capture nutrients and sediment from the water column.*

The Lake Memphremagog Basin is ideal for floodplain and shoreline protection and restoration projects due to the extensive flooding and sediment movement that still occurs along free-flowing stretches of many of its tributaries. Several previous efforts have been undertaken to identify areas that contain high-quality shoreline habitats and areas where shoreline habitats are lacking and would benefit from restoration. During 2004-2005, MCI and RAPPEL completed comprehensive habitat assessments of the littoral zones of Lake Memphremagog in both Quebec and Vermont (Rivard-Sirois 2005, Rivard-Sirois and Pouet 2006). Since 2005, the NorthWoods Stewardship Center has completed stream geomorphic assessments along all four principal Vermont tributaries of Lake Memphremagog (Gerhardt and Dyer 2006, Dyer 2008, Dyer et al. 2008, Dyer et al. 2011). Based on the results of these and other studies, shoreline habitats have already been restored in a number of areas along both the lakes and tributaries in Vermont [e.g. Northeast Kingdom Lakeshore Buffering (NEKLB), Trees for Streams Magog (TFSM), and Vermont Fish & Wildlife riparian buffer restoration programs]. In 2012, we continued and expanded these efforts by identifying and prioritizing areas where wetlands might be restored as part of efforts to protect and restore floodplains and shorelines.

Study Goals

In 2012, the Orleans County Natural Resources Conservation District (NRCD), Vermont DEC, Memphremagog Watershed Association (MWA), and Beck Pond LLC again partnered to undertake a three-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, especially in the Black River and Barton River watersheds. Second, we conducted spatial and statistical analyses of existing water quality data to identify and prioritize areas within the Vermont portion of the basin that are likely to export the greatest amounts of phosphorus into the surface waters of the Lake Memphremagog Basin. Third, we developed a spatially-explicit model to identify potential wetland restoration projects, prioritizing those projects that likely have the greatest potential to reduce sediment and nutrient loading 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 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 in Orleans, Essex, Caledonia, and Lamoille Counties in northeastern Vermont (Figure 4). As noted previously, the Southern Basin of Lake Memphremagog is fed by three major tributaries that lie entirely within the state of Vermont (the Black, Barton, and Clyde Rivers) and one medium-sized tributary that straddles the Quebec/Vermont border (the Johns River). In addition, numerous small tributaries flow from the eastern and western shores directly into Lake Memphremagog.

The Barton River (Waterbody ID VT17-07/08) drains an area of 445 km^2 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) and Crystal Lake (274 ha) 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 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.

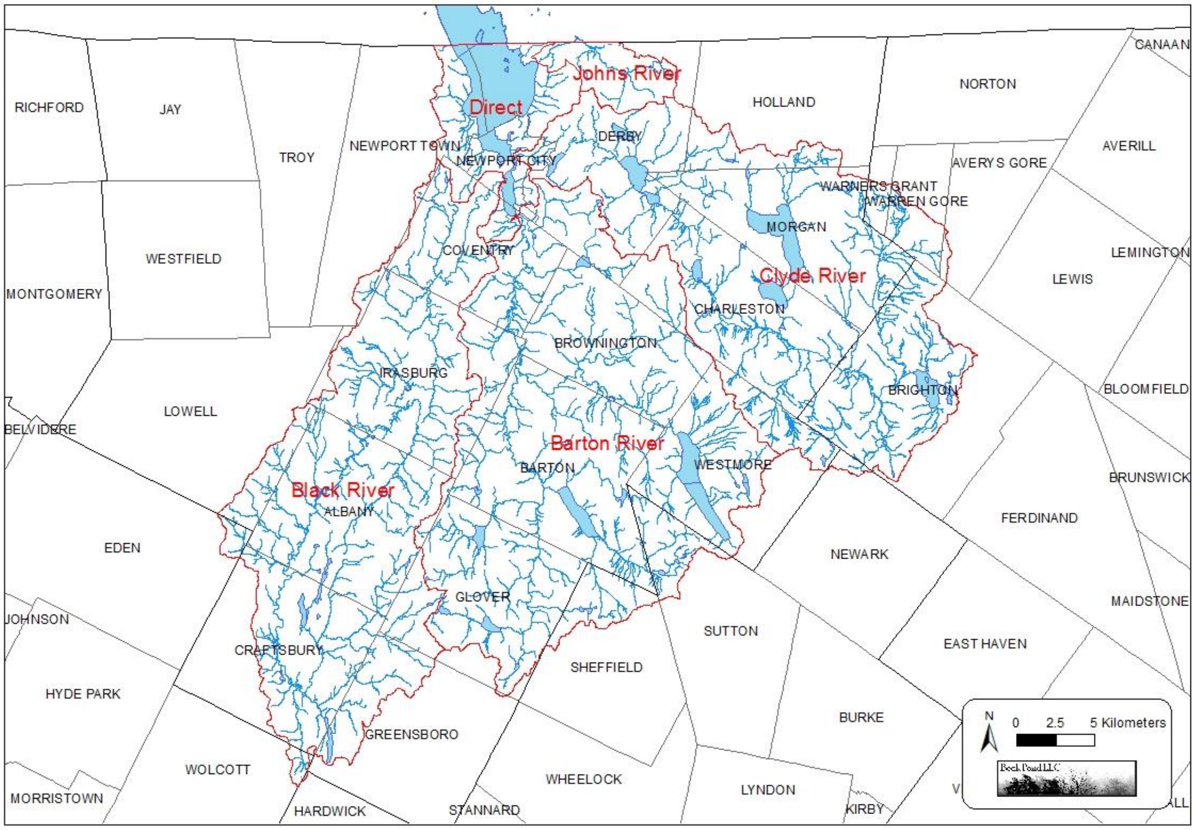

Figure 4. *The Vermont portion of the Lake Memphremagog Basin, including the watersheds of the four principal tributaries (Barton, Black, Clyde, and Johns Rivers).*

The Clyde River (Waterbody ID VT17-04) drains an area of 373 km^2 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), Lake Salem (232 ha), and Island Pond (221 ha) 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, 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 in and around Lake Memphremagog. 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 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 threaten 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).

Methods

Water Quality Sampling

To better pinpoint possible nutrient and sediment sources, we sampled water quality at 29 sites distributed throughout the Vermont portion of the Lake Memphremagog Basin (Figure 5; see Appendix A for descriptions of all sites). These 29 sites included 13 sites along the main stem and tributaries of the Barton River, twelve sites along the main stem and tributaries of the Black River, one site along a tributary of the Clyde River, and three sites along the small tributaries that flow directly into Lake Memphremagog. Because the Barton River watershed had not been sampled since 2006, we expanded our sampling beyond the four previously-sampled sites along the main stem and the Willoughby River (Orleans Wastewater, Barton Railroad Bridge, Glover Road, and Willoughby Falls) to include eight new sites along the main stem (Webster Road and Ethan Allen), the Willoughby River (Churchill Lane), and six smaller tributaries (Trout Brook, Hamel Marsh, Rock Junkyard, Country Club, Hogtrough Brook, and Roaring Brook). In the Black River watershed, we resampled two sites along the main stem between Craftsbury and Albany villages, where we had detected substantial increases in phosphorus and sediment levels in previous years (Mud Pond and Post Road), six sites along three tributaries where we had detected high phosphorus and sediment levels previously (Stony Brook, Brighton Brook, Brighton Brook North, Stony Hill, Shalney Branch, and Upper Shalney Branch), and two sites along tributaries that drain the eastern slopes of Lowell Mountain (Rogers Tributary and Seaver Branch). In addition, we added two sites in the Brighton Brook watershed to better pinpoint the source(s) of the high nutrient and sediment levels observed there previously (Robillard Flats and Upper Brighton Brook North). In the Clyde River watershed, we sampled a new site at the mouth of a small tributary that drained a highly developed area of Newport and Derby (Shattuck Hill). Along the small tributaries that flow directly into Lake Memphremagog, we resampled two sites (Holbrook Bay South and Upper Wishing Well) and added one new site (Upper Holbrook Bay South) along two small tributaries where we have measured high levels of nutrients and sediment previously. Finally, the Vermont DEC continued sampling 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.

To accomplish the goals of this study, we sampled water quality at these 29 sites on eight dates during 11 April-22 October 2012 (the four DEC-maintained sites were sampled separately and on a different schedule, and those data are not reported here). Due to very dry conditions during much of 2012, we were only able to capture one high-flow event during our sampling (5 September). We did, however, capture moderate flows on 2-3 regularly-scheduled sampling dates (11 April, 5 June, and 22 October). Due to the low flows resulting from these dry conditions, several sites were not sampled on 31 July (Rogers Tributary and Upper Brighton Brook North) or 28 August (Rogers Tributary, Upper Brighton Brook North, Holbrook Bay South, Upper Holbrook Bay South, and Upper Wishing Well). In addition, the Upper Brighton Brook North site was not sampled on the first two sample dates (11 April and 8 May).

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). We collected grab samples with a dip sampler at all sites. 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 two sites on small tributaries of the Black and Barton Rivers (Seaver Branch and Rock Junkyard, respectively). More importantly, the U.S. Geologic Survey maintained gauge stations that measured water depths and stream flows on the Barton, Black, and Clyde Rivers; and the Vermont DEC maintained a seasonal gauge 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). We used the daily stream flows measured at the U.S. Geological Survey gage station on the Black River in Coventry (USGS station 04296000) as a proxies for stream flows for all sites along the main stems of the Barton, Black, and Clyde Rivers, and we used daily stream flows measured on the Johns River in Beebe Plain by the Vermont DEC as proxies for stream flows for all sites along the smaller tributaries, including the main stem of the Johns River.

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 of the 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 during each sampling round, so that the LaRosa Analytical Laboratory could perform in-house quality assurance analyses.

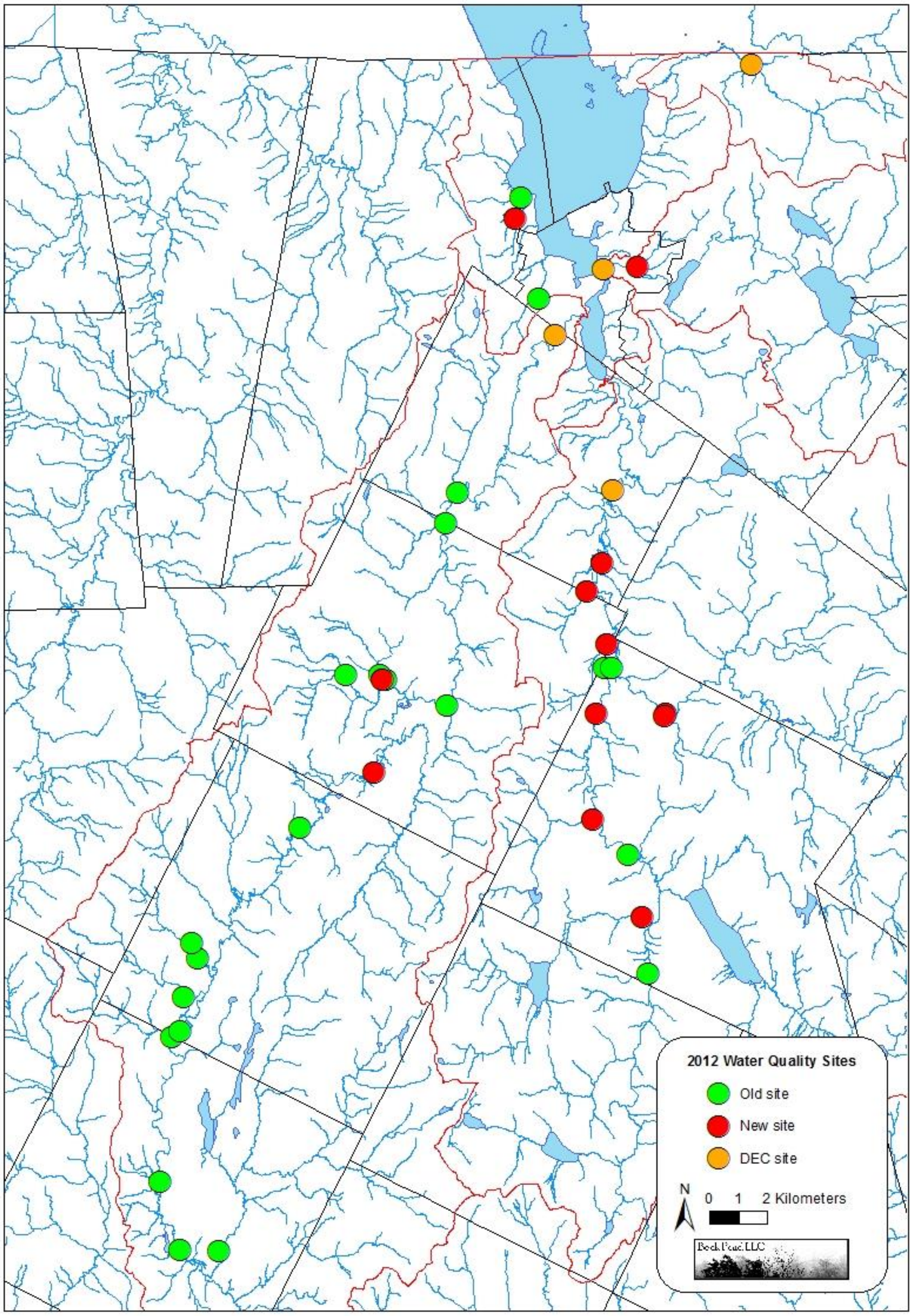

Figure 5. *Locations of the 29 sites where water quality was sampled along the Vermont tributaries of Lake Memphremagog during April-October 2012.*

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 electronic copies were submitted to the Vermont DEC for inclusion in their water quality database (WQX).

Priority Phosphorus Reduction Areas

In the second part of this project, we conducted spatial and statistical analyses to identify and prioritize subwatersheds that contribute the majority of the phosphorous flowing into Lake Memphremagog and its tributaries. To accomplish this goal, we 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 concentrations of total phosphorus. First, we used the U.S. Geological Survey's Streamstats program (available at http://streamstats.usgs.gov/) to delineate the boundaries of each subwatershed sampled by each water quality sample site and then imported and merged these boundaries in a Geographic Information System (ArcGIS 10, ESRI, Redlands, California). Second, to compensate for the different dates and stream flows sampled at each site, we calculated the arithmetic mean total phosphorus concentrations for each sample site separately for low flows and for high flows. For sites along the main stems of the three large tributaries of Lake Memphremagog (Barton, Black, and Clyde Rivers), we identified low and high flows based on daily stream flows measured at the U.S. Geological Survey gage station on the Black River in Coventry (USGS station 04296000). For sites along the smaller tributaries and the main stem of the Johns River, we identified low and high flows based on daily stream flows measured by the Vermont DEC on the Johns River in Beebe Plain or estimated from water depths measured just upstream at the Johns River water quality monitoring site. Finally, we calculated the mean rank of each site by ranking 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 high flows, the mean rank equaled that calculated for the low flows only).

Wetlands Restoration

In the third part of this project, we conducted spatial and statistical analyses to identify, prioritize, and cultivate wetland protection and restoration projects in the Vermont portion of the Lake Memphremagog Basin. First, we developed a spatially-explicit model to identify potential wetland restoration sites across the Vermont portion of the Lake Memphremagog Basin. Second, for the Black River and Johns River watersheds, we developed a qualitative approach for prioritizing potential wetland restoration sites. Both site selection and site prioritization were accomplished using spatially-explicit data incorporated into a Geographic Information System (ArcGIS 10; ESRI, Redlands, California). Third, we conducted on-the-ground evaluations to validate the model's predictions and to determine each site's suitability for protection and/or restoration. Finally, we met with a number of landowners to inform them about wetlands and their importance for water quality and to gauge their interest in undertaking wetland restoration or other conservation actions on their properties.

Site Selection Model

The site selection model identified areas that potentially could be restored to functional wetlands capable of reducing sediment and nutrient loads flowing into Lake Memphremagog. In 2012, we revised the site selection model that we had developed in 2011 (Gerhardt 2012b) to more accurately map land uses and to include portions of Essex County, that were excluded from the earlier model [that model was based on an earlier model developed to identify potential wetland restoration sites in the Lake Champlain Basin (State of Vermont 2007)]. In the site selection model, each 10-m^2 cell (the smallest grid unit from the four input data layers) in the basin was evaluated to determine whether or not it was a potential wetland restoration site (Table 1). Potential wetland restoration sites met one of two possible sets of criteria: 1) hydric soils; land cover types defined as barren, agriculture, or non-forested wetland; and slope ≤6% or 2) disturbed wetland; land cover types defined as barren, agriculture, or non-forested wetland; and slope ≤6%. Those cells satisfying either set of criteria were retained in the model; those cells failing to meet either set of criteria were excluded from further consideration. To complete the model, individual grid cells were aggregated into polygon features, and those polygons larger than 1.2 ha in size were retained in the final model.

Like any model, the accuracy and precision of the site selection model was limited by the quality of the data incorporated into the model. In this model, the most obvious limitation was the precision and accuracy of the 2002 land cover and land use data. The relatively large size of the individual grid cells (30 m^2) meant that land-use features were broadly categorized and often didn’t conform to the actual on-the-ground boundaries. At the broader scale, these data were very useful for characterizing land uses within a watershed, but, at the scale of individual sites, they occasionally misrepresented or misplaced the land uses actually observed on aerial photographs and on the ground. Although less obvious, the hydric soils and slope data likely had similar, although perhaps less marked, limitations imposed by both the resolution and mapping of the data. Nevertheless, the model did produce a preliminary data set of potential wetland restoration sites that could then be refined using the data layers combining the locations of hydric soils and slopes ≤6%, aerial photographs, and on-the-ground field assessments. Ultimately, delineation of the actual area suitable for wetland restoration will be defined by on-the-ground field assessments of the soil, vegetation, and hydrological characteristics of each site.

Table 1. Parameters and values incorporated into the site selection model used to identify potential wetland restoration sites in the Lake Memphremagog Basin in 2012. Sites >1.2 ha in size that had values marked "Yes" for all three parameters (either hydric soils, slope, and land cover or slope, land cover, and disturbed wetland) were retained in the model.

Parameter	Data Type	Scale/ Resolution	Data Source (Date)
Hydric soils	Vector	1:20,000	NRCS soil survey data (2011)
Values:	Yes	Hydric (Y)	
	No	Not hydric (N), water (w), unknown (U)	
Slope	Raster	10-m^2	USGS DEM10 data (2012)
Values:	Yes	0-2% (2), 2-4% (4), 4-6% (6)	
	No	All values >6% (all values >6)	
Land cover	Raster	30-m^2	NASS land cover land use data (2012)
Values:	Yes	Agricultural land uses (001-077 and 204-255), barren (131), herbaceous wetlands (195)	
	No	Water (111), developed lands (121-124), forests (141-143), shrubland (152), woody wetlands (190)	
Disturbed wetland	Vector	1:24,000	NWI maps (2011)
Values:	Yes	Diked/impounded (h), farmed (f), partially drained/ditched (d), excavated (x)	
	No	Beaver (b), artificial substrate (r), spoil (s)	

Site Prioritization

Unlike the site selection aspect of this project, we did not use a formal model to prioritize potential wetland restoration sites, although such a model was developed for the Lake Champlain Basin (State of Vermont 2007). Instead, we used a qualitative approach that prioritized potential wetland restoration sites based on their occurrence on floodplains, their proximity to rivers and stream, and their perceived ability to reduce phosphorus inputs into surface waters. In 2012, we prioritized all potential wetland restoration sites in the Black River and Johns River watersheds. Those sites located on the floodplains of the Black and Johns Rivers and Lords Creek were ranked as high-priority sites. Those sites located on the uplands immediately adjacent to the floodplains of the Black and Johns Rivers and Lords Creek or on the floodplains of other tributaries of the Black and Johns Rivers were ranked as medium-priority sites. Those sites located on uplands more distant from the floodplains of the Black and Johns Rivers and Lords Creek or on uplands adjacent to or more distant from the floodplains of other tributaries of the Black and Johns Rivers were ranked as low-priority sites.

Although not quantitative, this approach did allow us to prioritize those sites that were most likely to sequester nutrients and sediment from surface runoff and floodwaters and did incorporate some of the same general ideas used to develop the site prioritization model for the Lake Champlain Basin (State of Vermont 2007). That model quantitatively ranked potential wetland restoration sites based on their potential to mitigate phosphorus loading into Lake Champlain. That model scored sites based on eleven variables describing both the site itself as well as the drainage area upslope of each site. Our approach did qualitatively incorporate several of the site function variables, including proximity to surface water and flood risk (but not soil texture, erosion risk, or site area) but not the attributes describing the upslope drainage area (slope, erosion risk, estimated phosphorus load, hydrological soil group, land use, ratio of drainage area to site area, and area of developed land). Like the Lake Champlain Basin model, our approach did rank highly those sites that were most likely to capture phosphorus from floodwaters and surface runoff from the surrounding uplands.

Site Evaluation and Landowner Outreach

From the set of medium- and high-priority sites, we evaluated a number of sites in throughout the Black River watershed to assess their potential for wetland restoration and to gauge the landowners' interest in undertaking protection and restoration projects on their properties. The goals of these assessments and discussions were 1) to assess whether the site was accurately and precisely identified as a potential wetland restoration site, 2) to evaluate whether the site was suitable for restoration and/or protection, 3) to determine possible protection and/or restoration strategies for the site, and 4) to determine whether the landowner was interested in wetland restoration and/or other conservation actions on their property.

Prior to visiting individual sites, we screened the set of medium- and high-priority sites to evaluate their suitability for and possible landowner interest in restoration. First, we used aerial photographs to assess whether or not each site was accurately and precisely identified as a potential wetland restoration site. In particular, we eliminated sites that did not have the appropriate land cover type (e.g. areas that were forested or that were already unmanaged wetlands). In addition, we added or expanded sites to include all of the non-forested areas on a property that were identified by the GIS data or by photo-interpretation as having hydric soils, slopes ≤6%, and/or wetland vegetation. In most cases, these areas were located immediately adjacent to potential wetland restoration sites already identified by the site selection model. As another screening tool, we discussed potential wetland restoration sites with staff from the Vermont DEC, U.S. Natural Resources Conservation Service, Orleans County Natural Resources Conservation District (NRCD), and Vermont Association of Conservation Districts to determine the suitability of individual sites for restoration, the landowner's possible interest in protection or restoration opportunities, and the landowner's involvement in other agricultural improvement or conservation projects.

For the screened set of sites, we then initiated efforts to visit each site to assess their suitability for protection and/or restoration and to gauge the landowner's interest in undertaking protection and/or restoration projects. For each site, we created a map showing the boundaries of potential wetland restoration site(s) overlain on the 2011 aerial photograph. We then contacted the landowner in person to gain permission to access the property and to gauge their interest in undertaking restoration or other conservation actions on their property. In addition, we queried the landowner about existing and historical management practices and historical patterns of flooding and drainage. During the visit, we also walked as much of each site as possible with a specific focus on identifying current and historical land-use practices, historical hydrological alterations, and potential protection and/or restoration strategies. These field assessments also allowed us to refine the physical boundaries of the potential wetland restoration site based on field characteristics, including surface features and vegetation. However, these field assessments did not include actual wetland delineations or the development of detailed protection and restoration plans for each site.

Results and Discussion

Water Quality Sampling

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

<u>Stream Flow</u>

Stream flow measures the volume of water passing a specific location per unit of time and is calculated by multiplying the area of the stream cross-section 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 runoff 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 two gauges, one maintained by the U.S. Geological Survey on the Black

River and one maintained seasonally by the Vermont DEC on the Johns River. The 2012 sampling season was characterized by an early spring snowmelt and relatively low flows throughout the sampling season (Figure 6). Peak spring flows occurred during early and mid-March following snowmelt, and higher flows were recorded on only two dates (30 May and 5 September), both of which were relatively modest events. Otherwise, flows were generally low throughout the sampling season, especially during June, July, and August.

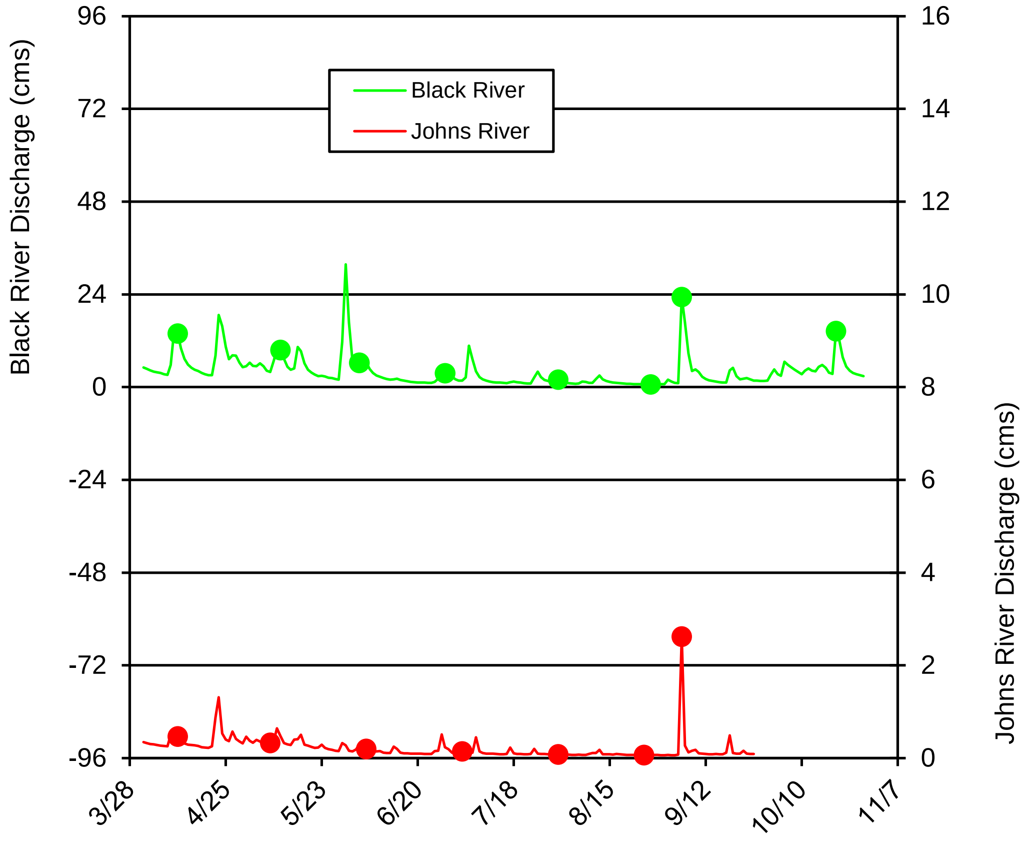

Figure 6. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2012. The eight dates on which water samples were collected are indicated by the circles. Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, VT)]; stream flows for the Johns River were measured by the Vermont DEC.*

Our sample dates reflected the limited variation in and relatively low stream flows in 2012 (Figure 6). We were only able to collect water samples during one high-flow event (5 September). The remaining water samples were collected at low or extremely low flows, except three dates on which we sampled moderately low flows during spring (11 April and 8 May) and late autumn (22 October). Collecting water samples across this limited range of stream flows diminished our ability to identify and assess water quality problems, especially those associated with higher flows. Low flows are most informative for identifying and assessing nutrient and sediment inputs originating from point and groundwater sources. In contrast, high flows are 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. Thus, the lack of high flows greatly diminished our ability to identify and assess nonpoint sources of sediment and nutrient inputs in 2012.

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, and synthetic fertilizers applied to lawns and agricultural fields.

Total phosphorus concentrations in this study ranged between 6.65-1740 μg/l. As in previous years, total phosphorus concentrations showed no marked seasonal pattern (Figure 7). The highest phosphorus levels were measured on the sample date with the highest stream flows (5 September), when surface runoff following heavy rains likely carried large amounts of soil and nutrients into the rivers and streams.

Total phosphorus concentrations were generally high (median values >20 μg/l) at one site along the main stem of the Black River (Post Road), at five sites along four tributaries of the Black and Barton Rivers (Brighton Brook, Roaring Brook, and the Rock Junkyard and Hamel Marsh tributaries), and at two sites 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.

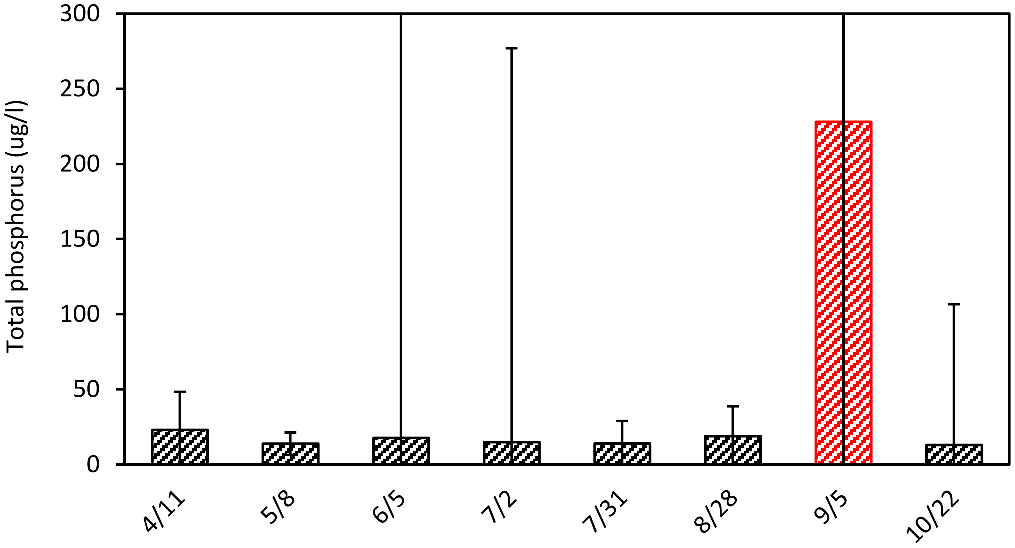

Figure 7. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Red hatching indicates the one high-flow event.*

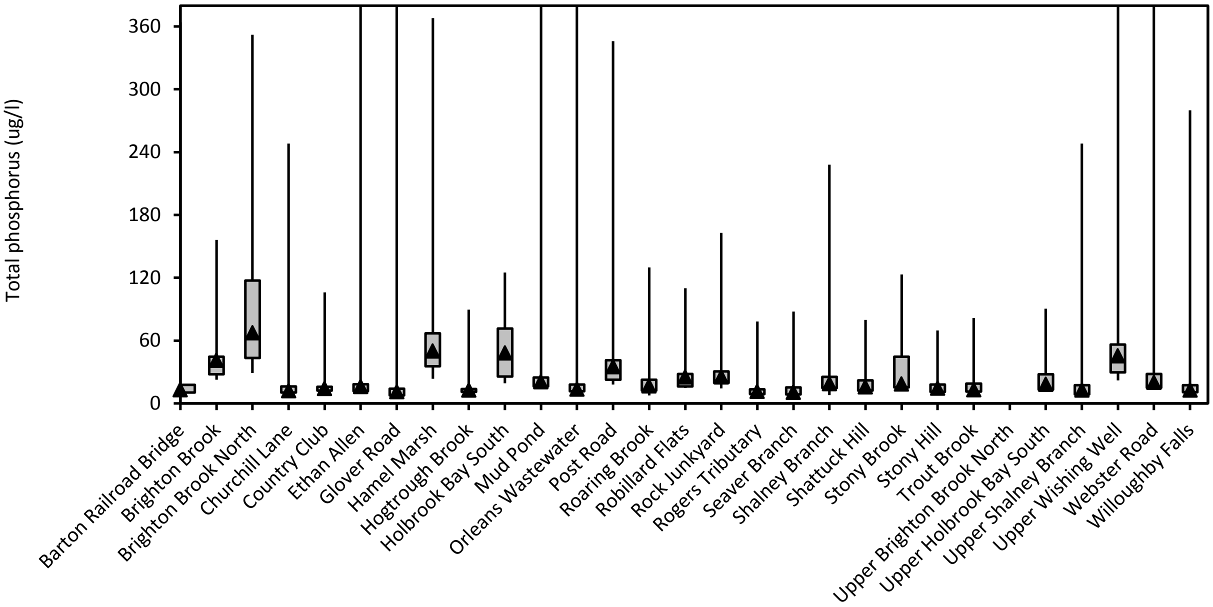

Figure 8. *Total phosphorus concentrations at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line). Note that the values for Upper Brighton Brook North greatly exceeded the vertical scale of this graph.*

Along the main stem of the Black River, total phosphorus concentrations rose dramatically between the Mud Pond and Post Road sites in 2012 as they did in 2011 (Figure 10). This pattern conformed to those observed in previous years (2005-2006 and 2010), when total phosphorus concentrations rose dramatically between the village of Craftsbury and Rogers Branch, just downstream of the Albany/Craftsbury town line. Between Craftsbury and Rogers Branch, the main stem is fed by only three notable tributaries (Seaver Branch, Cass Brook, and the outlet of Lake Elligo), all of which exhibited relatively low phosphorus levels in earlier studies (Gerhardt 2006, 2011), and many smaller tributaries. Thus, much of the phosphorus likely originated from the floodplain and uplands bordering this section of the main stem. At both the Mud Pond and Post Road sites, total phosphorus concentrations generally increased with increasing stream flows (Figure 11). This positive relationship suggests that the phosphorus inputs in this area are likely dominated by nonpoint sources, such as surface runoff at higher flows, but they may also include barnyard runoff and other point sources as well.

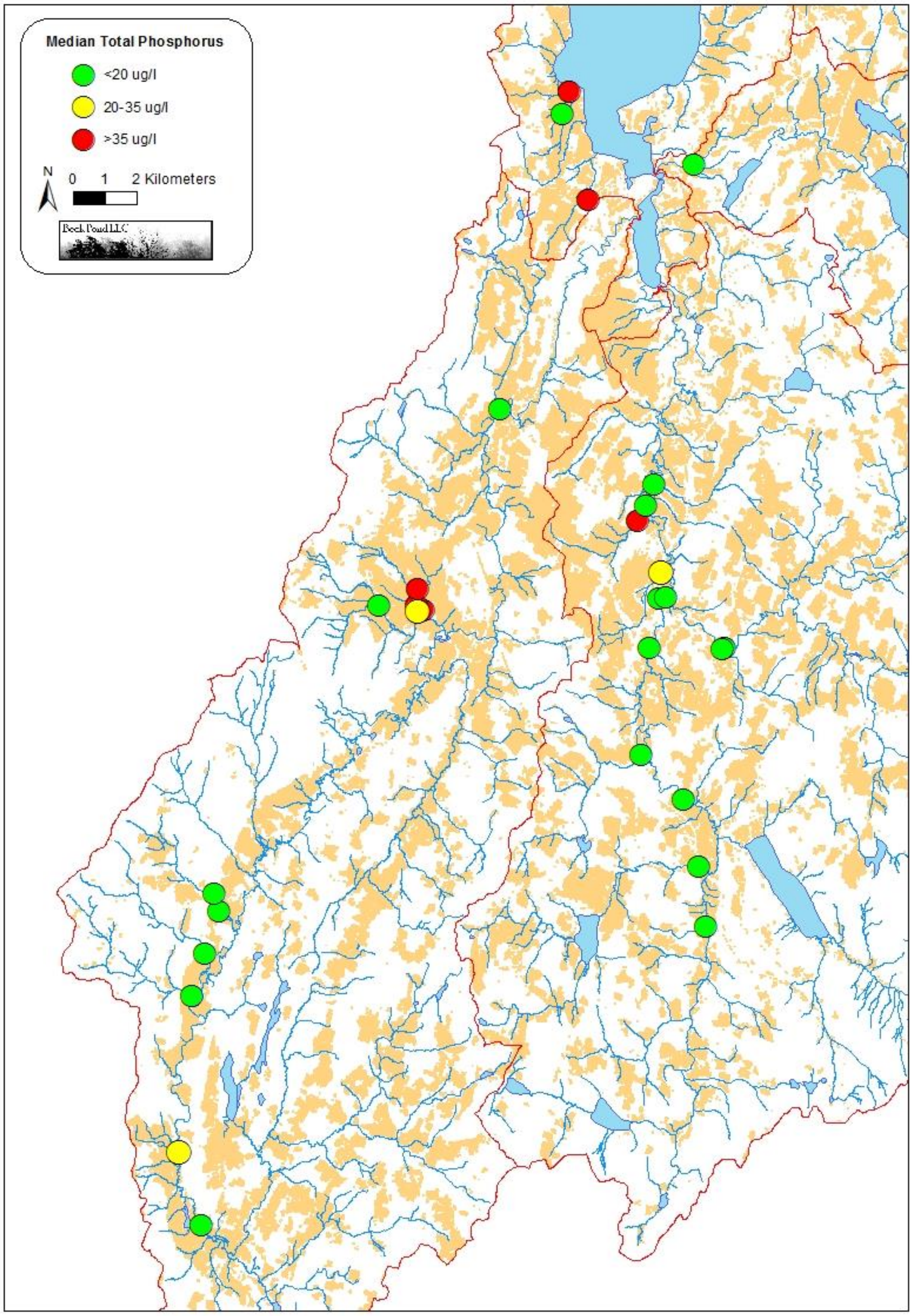

Figure 9. *Median total phosphorus concentrations at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Areas of agricultural land uses are shaded orange.*

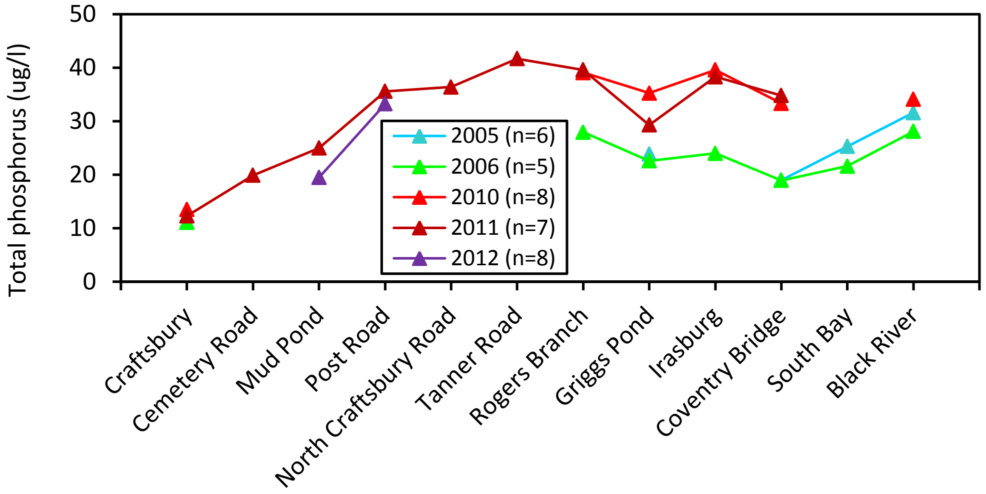

Figure 10. *Median total phosphorus "profile" along the main stem of the Black River from Craftsbury downstream to its mouth during 2005-2011. The sample size (n) is the number of dates sampled each year.*

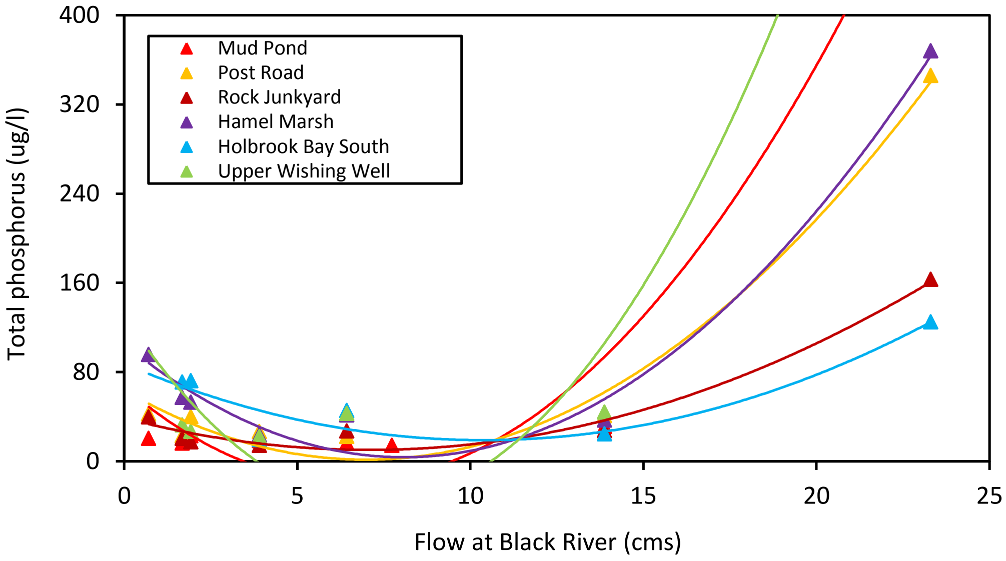

Figure 11. *Total phosphorus concentrations in relation to stream flow at five sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. The regression lines indicate the polynomial relationships between the two parameters.*

The 2012 water quality data further pinpointed the source(s) of the high phosphorus and nitrogen concentrations in Brighton Brook, a tributary of the Black River. As in 2010-

2011, total phosphorus concentrations were relatively high at the downstream-most Brighton Brook site (median = 30.3-102 ug/l during 2010-2012). However, along the main stem of Brighton Brook, total phosphorus concentrations were considerably lower at both the site immediately upstream of the confluence with a small tributary from the north (Robillard Flats) and even more so at the farthest upstream site (Stony Hill)(Figure 12). In contrast, total phosphorus concentrations along the small northern tributary were extremely high at the downstream site (Brighton Brook North) and even higher at the upstream site (Upper Brighton Brook North). Although total phosphorus concentrations generally showed a curvilinear relationship with stream flow at the three sites located along the main stem of Brighton Brook, they showed a positive relationship with stream flow at the Brighton Brook North site (Figure 13). Based on these data, it is clear that much of the phosphorus measured at the downstream-most site on the main stem of Brighton Brook is likely originating somewhere in the watershed of this small northern tributary of Brighton Brook. Possible phosphorus sources in this area include surface runoff from the many, large corn and hay fields and/or runoff from the barnyard and manure-composting areas (Figure 14). The Vermont Agency of Agriculture, Food and Markets and the Vermont Association of Conservation Districts have initiated discussions with the landowner to identify and implement projects and practices that will reduce runoff from this farm complex.

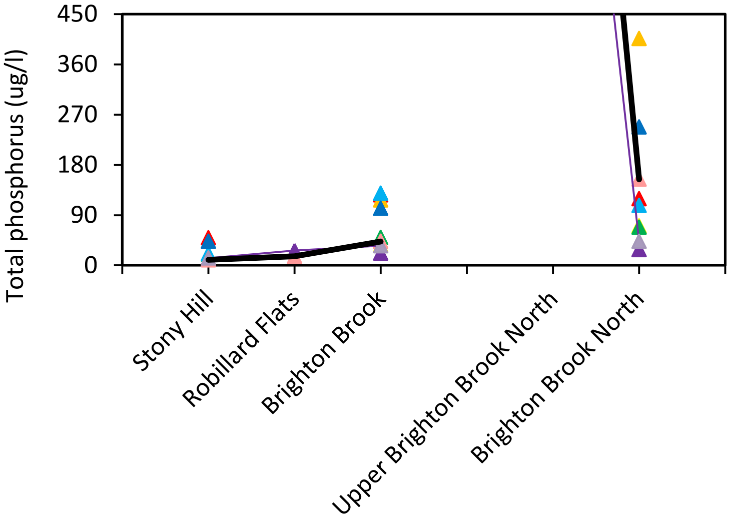

Figure 12. *Total phosphorus "profile" along Brighton Brook from Stony Hill downstream to Brighton Brook and from Upper Brighton Brook North downstream to Brighton Brook North in Irasburg, Vermont during April-October 2012.*

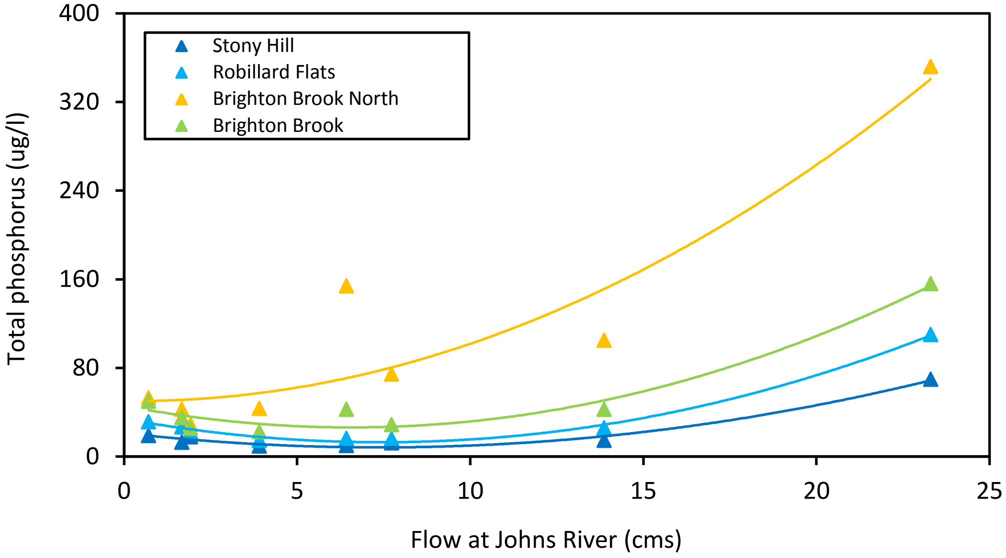

Figure 13. *Total phosphorus concentrations in relation to stream flow at four sites along Brighton Brook during April-October 2012. The regression lines indicate the polynomial relationships between the two parameters.*

Figure 14. *The large areas of agriculture, including hay, corn, and barnyards, may be the source(s) of the high nutrient and sediment levels measured in Brighton Brook.*

Along the main stem of the Barton River, total phosphorus concentrations rose slowly but steadily from Glover Road downstream to the confluence with the Willoughby River and then rose dramatically from there downstream to Coventry Station Road (Figure 15). This pattern was evident in both 2005-2006 and 2012. The downstream section of the main stem is fed by only three notable tributaries, including Trout Brook and the two tributaries sampled at Hamel Marsh and Rock Junkyard, and many smaller tributaries. These tributaries varied in their total phosphorus concentrations with the tributaries sampled at Hamel Marsh and, to a lesser extent, Rock Junkyard having the higher total phosphorus concentrations. At the Hamel Marsh site, total phosphorus concentrations showed a strong curvilinear relationship with stream flow (Figure 11). That is, they decreased with increasing stream flow at lower flows but increased with increasingly higher stream flows. This curvilinear relationship suggests that the phosphorus inputs may incorporate a combination of point and nonpoint sources, including barnyard runoff at lower flows and surface runoff at higher flows. In addition, although there is currently limited agricultural and other development along this stretch, the river was straightened in many areas, and much of the floodplain was farmed historically (Dyer 2008). Consequently, the river channel is currently undergoing considerable stream channel adjustment in response to these historical alterations, and the resulting streambank instability and erosion potentially supplies large amounts of nutrients and sediment into the water column, especially during high flows.

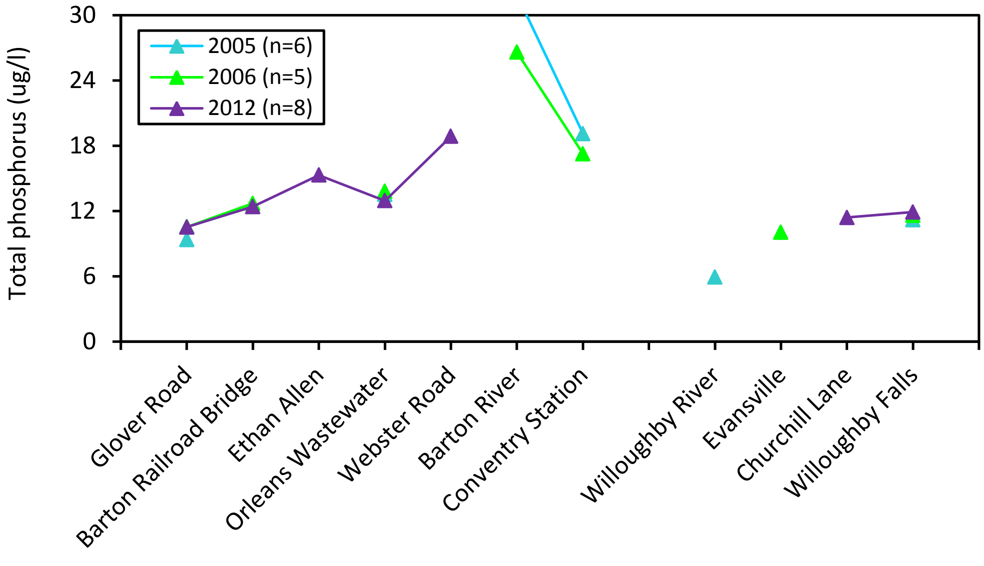

Figure 15. *Median total phosphorus "profile" along the main stem of the Barton River from Glover Road downstream to its mouth and along the Willoughby River from the outlet of Lake Willoughby (Willoughby River) downstream to its confluence with the Barton River (Willoughby Falls) during 2005-2011. The sample size (n) is the number of dates sampled each year.*

Finally, we resampled a number of sites in 2012 to assess the efficacy of several remediation projects that had been or were being undertaken in the Vermont portion of the Lake Memphremagog Basin. Along Shalney Branch, several barnyard and laneway improvement projects were implemented in 2009-2012, and total phosphorus concentrations there dropped dramatically between 2009-2010 and 2012, especially at the lowest stream flows (Figure 16a). Along the Holbrook Bay tributary, cattle were excluded from and trees were planted in the riparian zone in 2012, and total phosphorus concentrations there also appear to have dropped between 2010 and 2012, especially at the lowest stream flows (Figure 16b). Along the Wishing Well tributary, a grazing plan and clean water diversion projects were implemented in 2011-2012, and total phosphorus concentrations dropped dramatically between 2010 and 2012 but more so at higher stream flows (Figure 16c). Finally, no discernible changes in total phosphorus concentrations were observed along Stony Brook, where instream dredging was identified and investigated as a possible problem in 2011 (Figure 16d). However, we also identified another area where field cultivation and manure-spreading may be unresolved issues. Thus, our sampling indicated that the four remediation projects do, in fact, appear to be improving water quality in at least three of four tributaries, although perhaps not consistently across all flow levels. We will continue to monitor these sites to ensure that these improvements in water quality continue into the future.

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, which is an essential plant nutrient, 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.

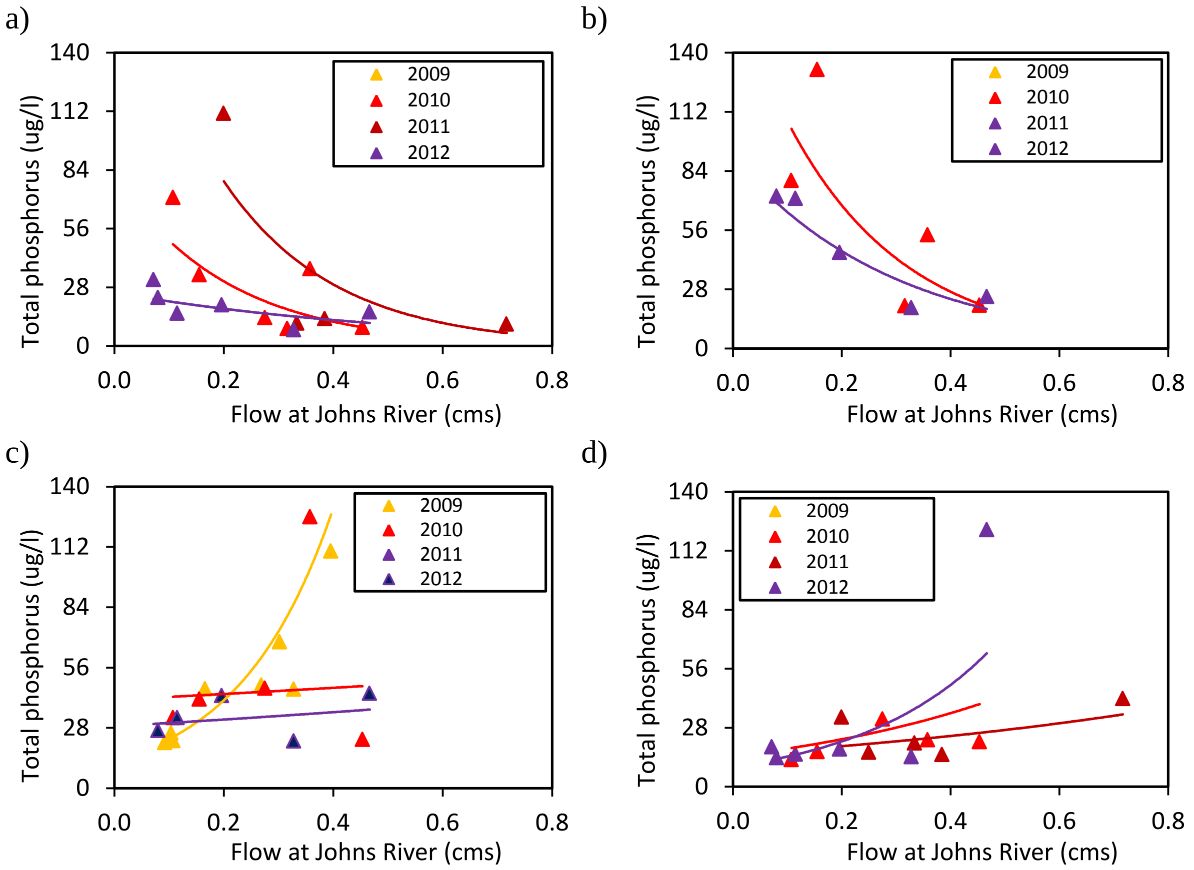

Figure 16. *Total phosphorus concentrations in relation to stream flow along a) Shalney Branch, b) the Holbrook Bay tributary, c) the Wishing Well tributary, and d) Stony Brook during 2009-2012. The regression lines indicate the polynomial relationships between the two parameters.*

Total nitrogen concentrations in this study ranged between 0.16-10.7 mg/l. As in previous years, total nitrogen concentrations showed no marked seasonal trend (Figure 17). The highest nitrogen levels were measured on the sample date with the highest stream flows (5 September), when surface runoff following heavy rains likely carried large amounts of both dissolved and particulate forms of nitrogen into rivers and streams.

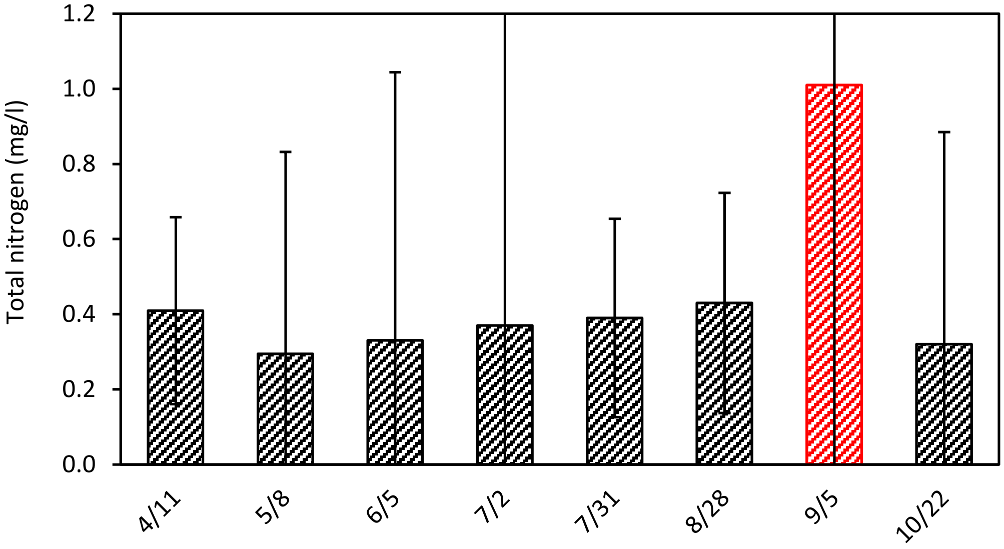

Figure 17. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Red hatching indicates the one high-flow event.*

In general, total nitrogen concentrations were relatively low (i.e. <1 mg/l) at most sites, although many sites exhibited higher total nitrogen concentrations during the high-flow event on 5 September (Figures 18-19). However, mean and median total nitrogen concentrations did exceed 1 mg/l at two sites. In the Brighton Brook watershed, the Upper Brighton Brook North site exhibited extremely high total nitrogen concentrations (median = 10.5 mg/l, range = 3.0-10.7 mg/l). These high nitrogen levels paralleled the extremely high total phosphorus and turbidity levels measured at that site and corroborate the possibility that there are problems with runoff from the barnyard or manure storage and composting areas. In addition, total nitrogen concentrations along this tributary appear to be negatively related to stream flow (Figure 20), and this negative relationship further suggests that the nitrogen inputs were derived from groundwater or point sources, rather than nonpoint sources such as agricultural or urban runoff. Unlike in 2011, total nitrogen concentrations were not noticeably higher at the Brighton Brook and Brighton Brook North sites, both of which were located downstream of the Upper Brighton Brook North site. These lower levels may have reflected the dry conditions and extremely low stream flows sampled in 2012, as the small tributary sampled at Upper Brighton Brook North had no flows on two dates in late summer, so that nutrients and sediment may not have been reaching the main tributary downstream.

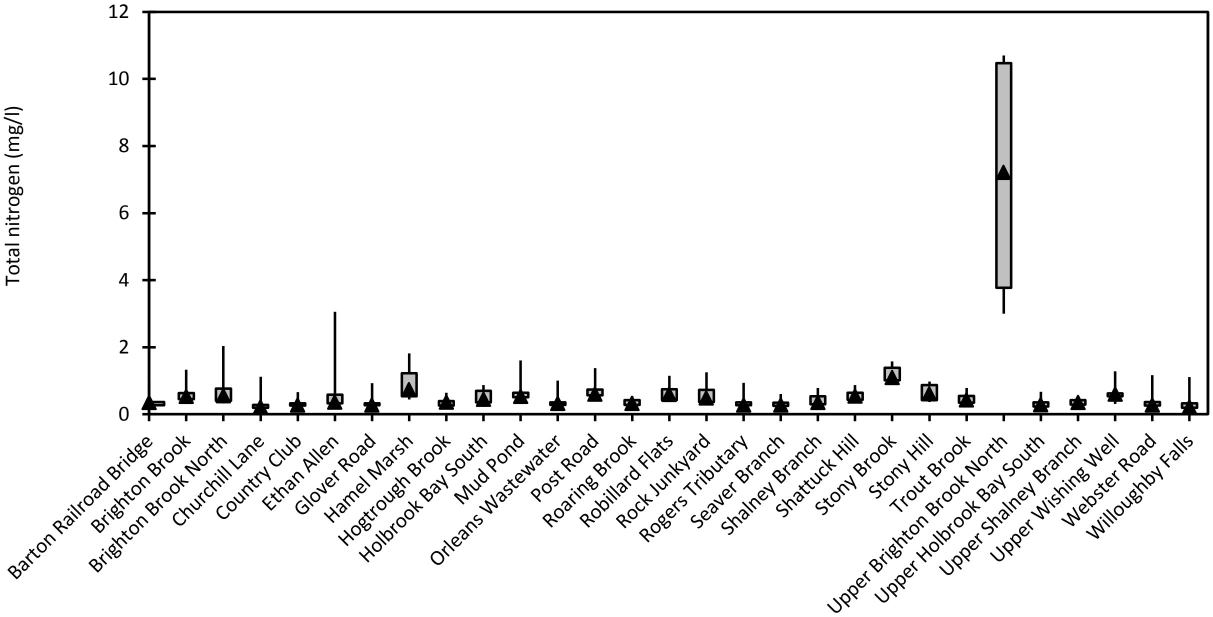

Figure 18. *Total nitrogen concentrations at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

The other site where we observed high nitrogen levels in 2012 - as well as in 2010 and 2011 - was near the mouth of Stony Brook, located in the town of Coventry. Total nitrogen concentrations along this tributary were also negatively related to stream flow (Figure 20). This negative relationship again suggests that the nitrogen inputs into this stream were derived from groundwater or point sources, rather than surface runoff from agricultural or urban areas. The high nitrogen levels in this tributary may have a similar origin to those measured in the Johns River watershed (Gerhardt 2009, 2010), as the watershed of Stony Brook is underlain by large areas of coarse sand and gravel deposits. Consequently, much of the nitrogen in this tributary 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.

The high nitrogen levels in these two tributaries may not be reaching levels that are harmful to aquatic life. Although high, the nitrogen levels in these two 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.

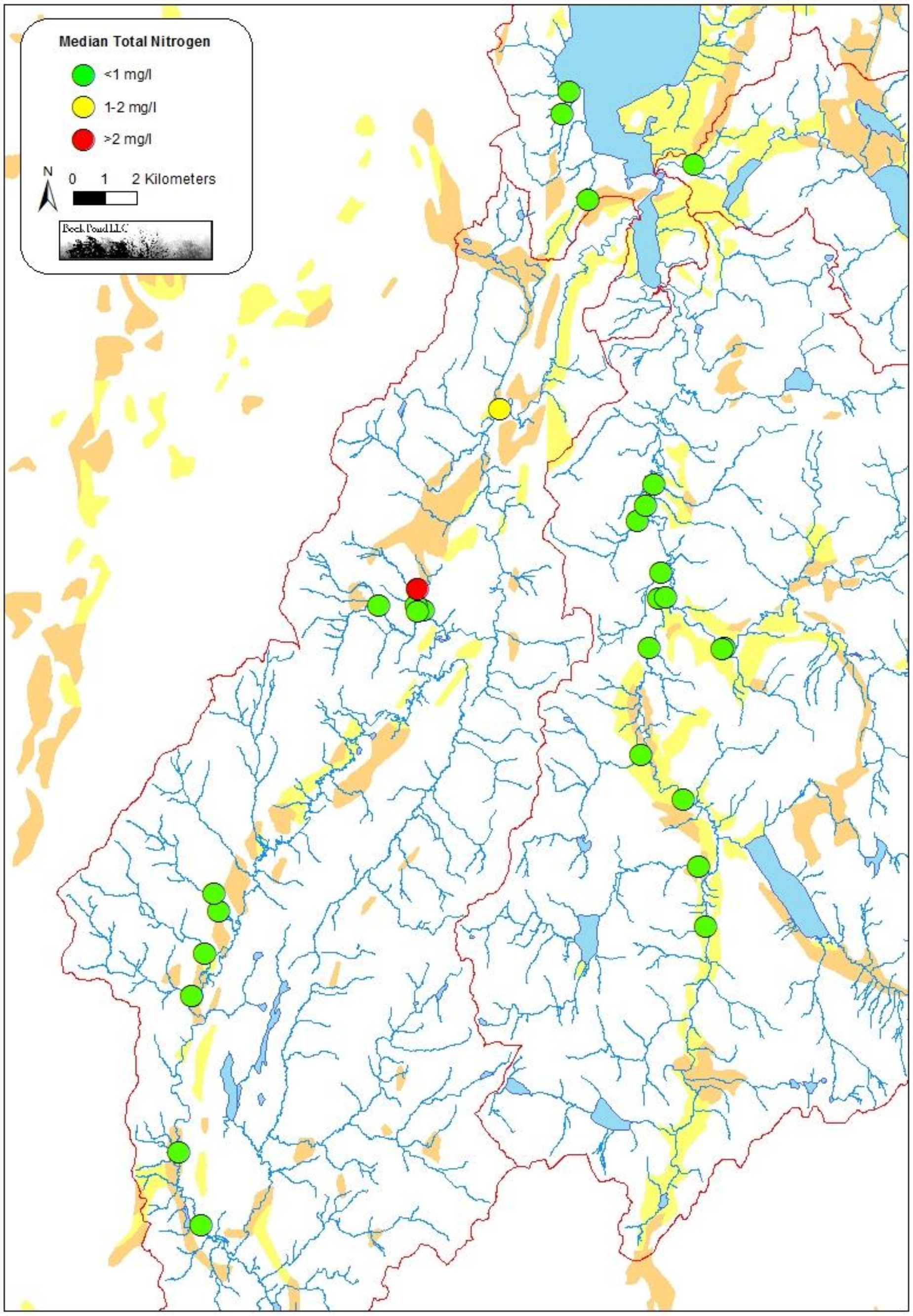

Figure 19. *Median total nitrogen concentrations at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. The locations of surficial sand and gravel deposits are shaded yellow and orange.*

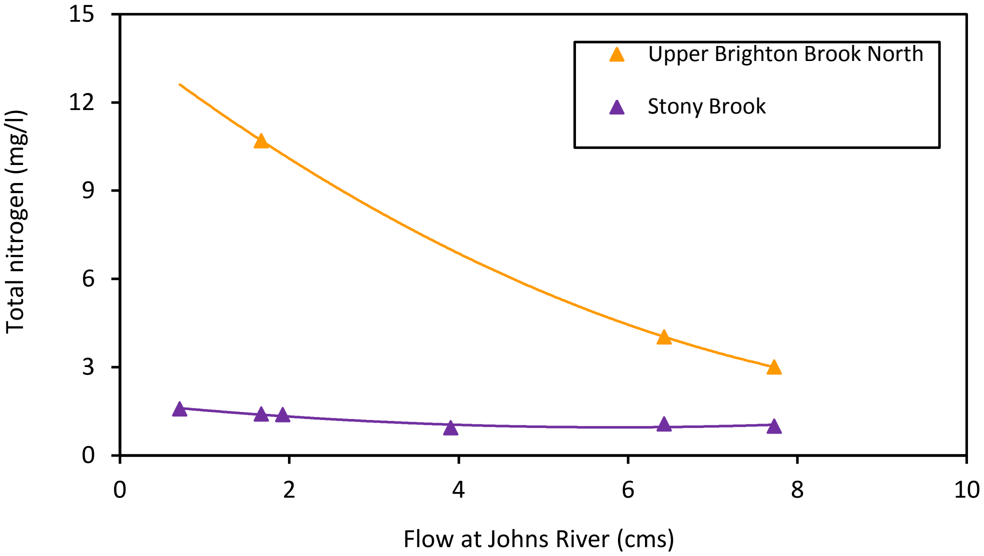

Figure 20. *Total nitrogen concentrations in relation to stream flow along two tributaries of the Black River during April-October 2012. The regression lines indicate the polynomial relationships between the two parameters.*

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 as the light-scattering properties of dissolved and suspended materials in Nephelometric Turbidity Units (NTU).

In 2012, we 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 0.26-396 NTU. Like total phosphorus and total nitrogen, turbidity levels showed no marked seasonal pattern (Figure 21). The highest turbidity levels were measured on the sample date with the highest stream flows (5 September), when surface runoff following heavy rains likely carried large amounts of soil and nutrients into the rivers and streams.

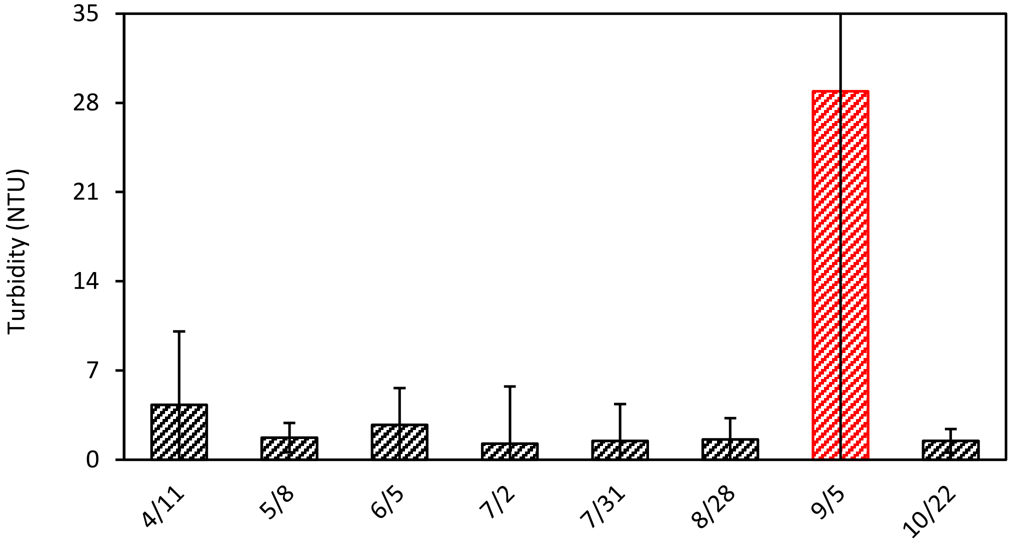

Figure 21. *Median turbidity levels (±1 SD) measured on each sample date at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Red hatching indicates the one high-flow event.*

Turbidity levels were generally higher at the same sites as total phosphorus levels (Figures 22-23). In general, the highest turbidity levels were observed at sites along the main stem of the Black River (Post Road), a tributary of the Black River (Upper Brighton Brook North), a tributary of the Barton River (Hamel Marsh), and a small tributary flowing directly into Lake Memphremagog (Holbrook Bay South). Turbidity levels at these four sites generally showed curvilinear relationships with stream flow (Figure 24). That is, they decreased as stream flow increased at lower flows but then increased rapidly at increasingly higher stream flows. These curvilinear relationships suggested that much of the dissolved and suspended materials were likely carried into the rivers and streams in surface runoff from nonpoint sources, especially following heavy rains. However, they also suggested that higher turbidity levels may have been caused by either point sources (e.g. barnyard runoff along Shalney Branch, Brighton Brook, and the Wishing Well tributary) or increased streambed erosion at the lower flows.

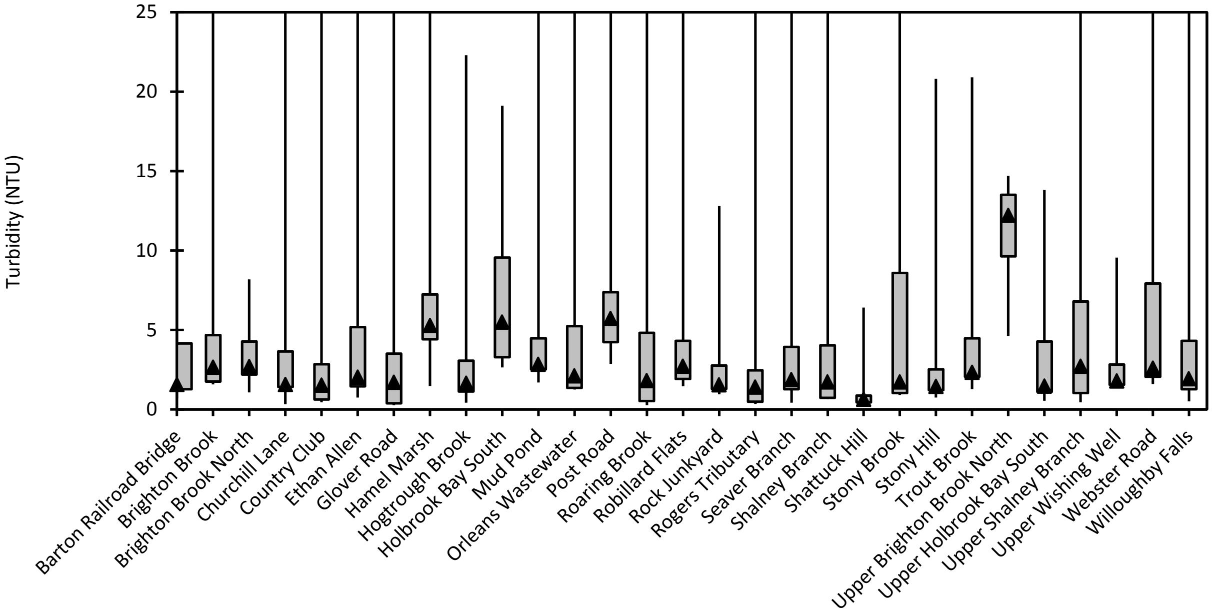

Figure 22. *Turbidity levels at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

As in previous years, turbidity levels increased dramatically between the Mud Pond and Post Road sites along the main stem of the Black River (Figure 25). This increase paralleled that observed for total phosphorus levels as well (Figure 10). This stretch of the main stem passes through large areas of agriculture, including a large barn complex as well as areas of corn and actively grazed pasture, located on and immediately adjacent to the floodplain. Although generally lower than those observed along the Black River, turbidity levels also increased from upstream to downstream areas along the main stem of the Barton River and along the Willoughby River, the major tributary of the Barton River (Figure 26).

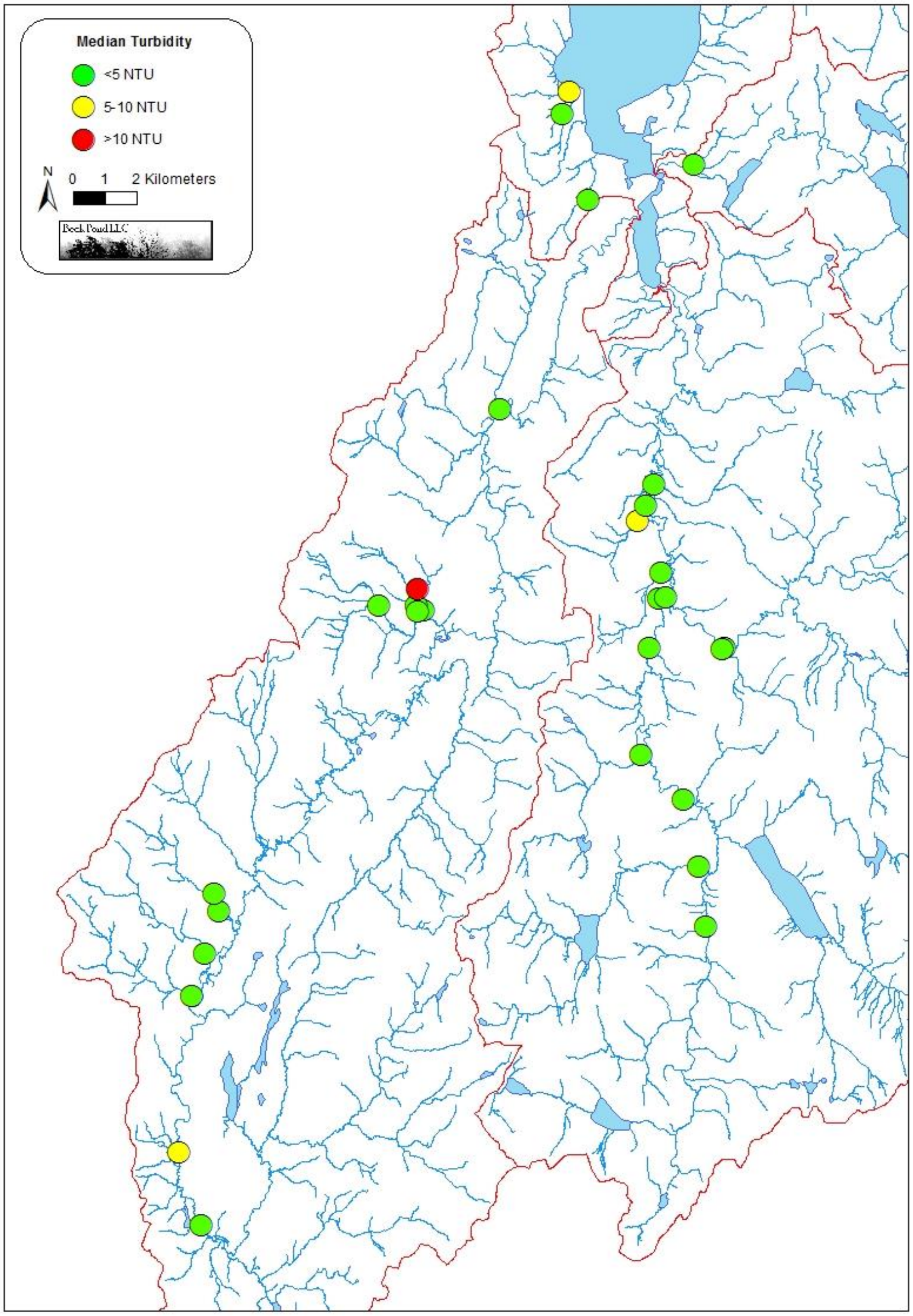

Figure 23. *Median turbidity levels at 29 sites along the Vermont tributaries of Lake Memphremagog during April-October 2012.*

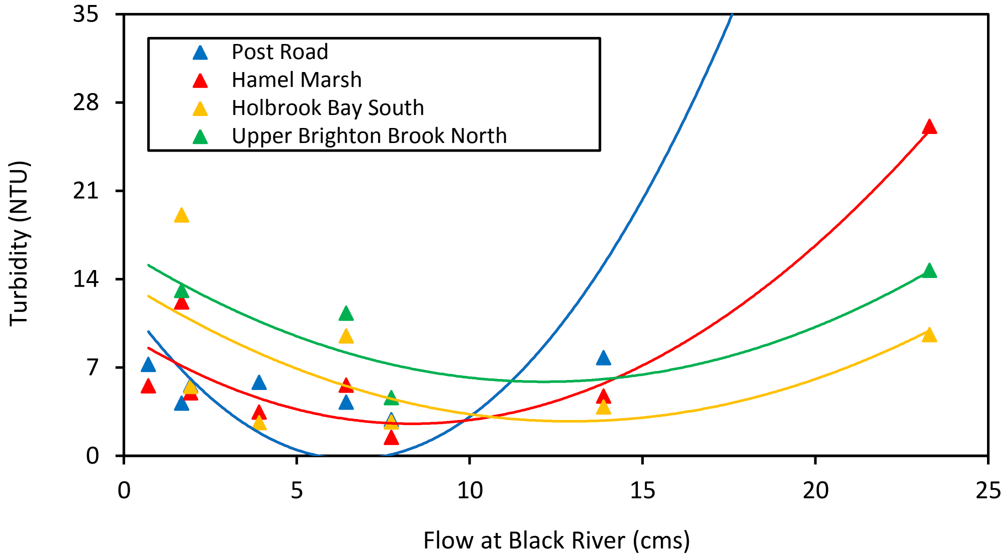

Figure 24. *Turbidity levels in relation to stream flow at four sites along the Vermont tributaries of Lake Memphremagog during April-October 2012. The regression lines indicate the polynomial relationships between the two parameters.*

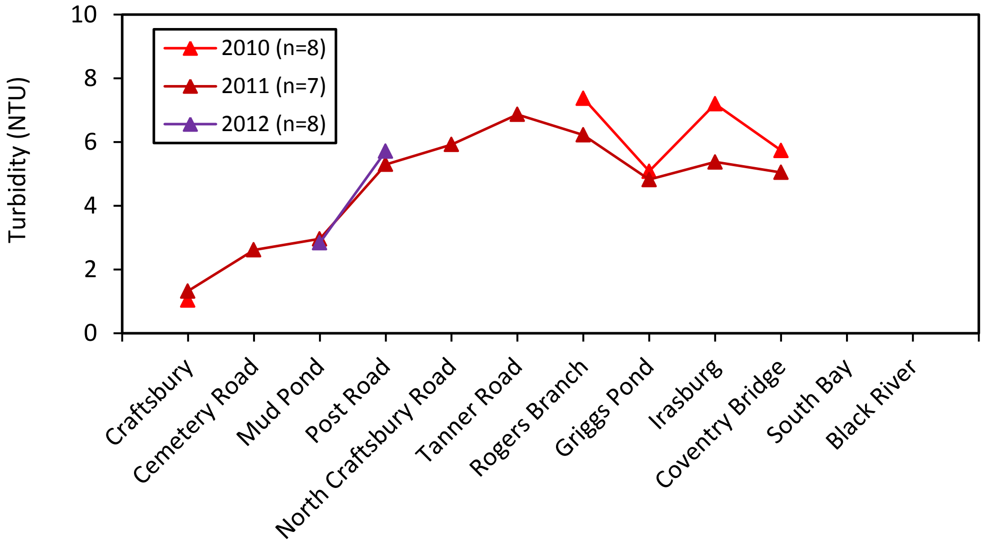

Figure 25. *Turbidity "profile" along the main stem of the Black River from Craftsbury downstream to Black River during 2010-2012.*

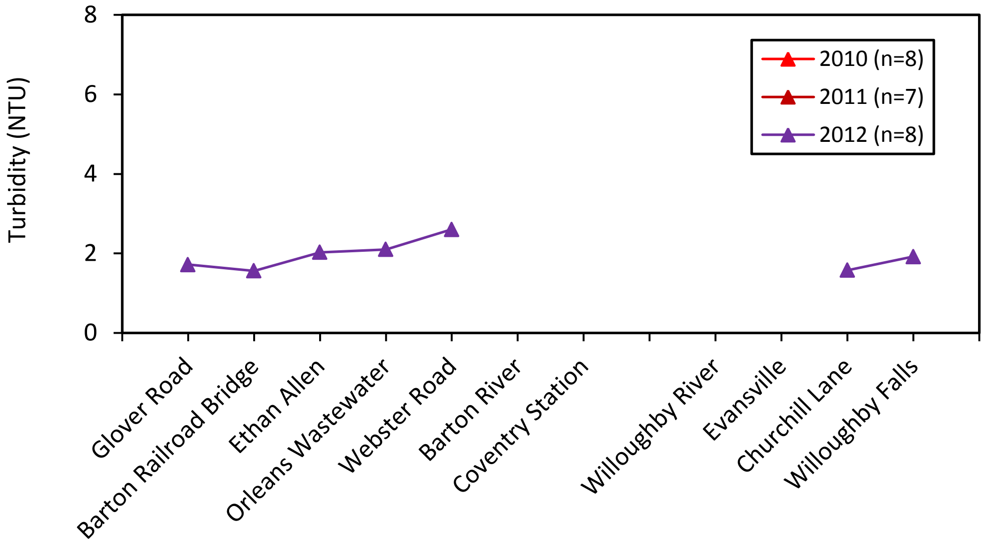

Figure 26. *Turbidity "profile" along the main stem of the Barton River from Glover Road downstream to Coventry Station and along the Willoughby River from Willoughby River (at the outlet of Lake Willoughby) downstream to Willoughby Falls during 2012.*

Along three smaller tributaries that also exhibited higher turbidity levels, patterns in turbidity levels suggested possible sources of impairment as well as the benefits of remediation projects. Along Shalney Branch, turbidity levels were slightly higher at the upstream than the downstream site, a pattern that was the reverse of what was observed in 2011 (Figure 27a). This reversal may reflect the several Best Management Practices (i.e. covered manure storage, laneway improvements) implemented at the dairy farm located along this stretch of Shalney Branch. Along the Holbrook Bay tributary, turbidity levels - like total phosphorus levels - increased from the upstream to the downstream site (Figure 27b). Unfortunately, we have been unable to identify a likely source for the high phosphorus and turbidity levels in this stream. Finally, we were able to better pinpoint the possible source(s) of the high nutrient and turbidity levels in the Brighton Brook watershed (Figure 27c). Although turbidity levels did increase somewhat from Stony Hill downstream to Robillard Flats along the main stem of Brighton Brook, they were dramatically higher in the upstream end of the small tributary that flows in from the north (Brighton Brook North and Upper Brighton Brook North). This area of the Brighton Brook watershed includes large areas of corn and hay as well as a large barn complex and barnyard, including areas for manure storage and composting.

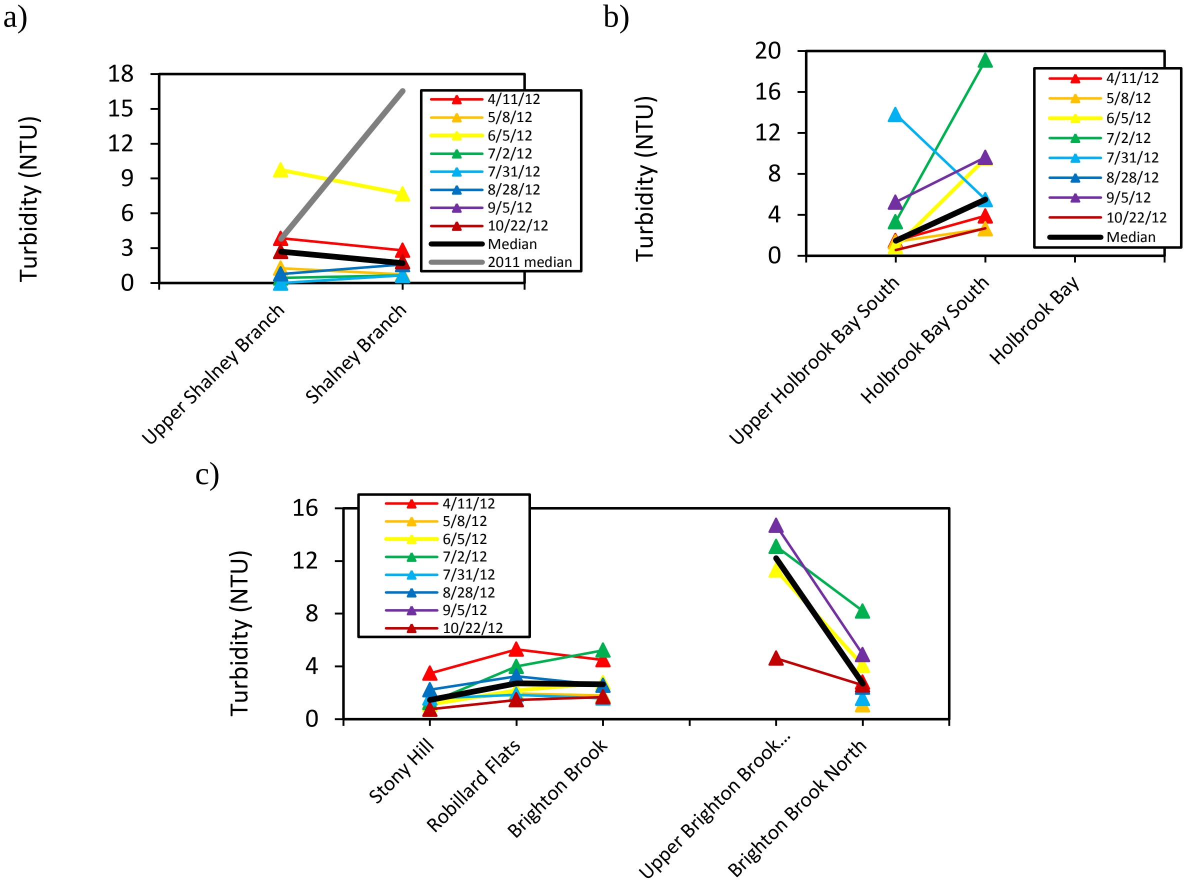

Figure 27. *Turbidity "profile" a) along Shalney Branch from Upper Shalney Branch downstream to Shalney Branch, b) along the Holbrook Bay South tributary from Upper Holbrook Bay South downstream to Holbrook Bay South, and c) along the main stem of Brighton Brook from Stony Hill downstream to Brighton Brook and along the northern tributary from Upper Brighton Brook North downstream to Brighton Brook North during April-October 2012.*

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, generally measured below the detection limits for two of the three parameters. All 24 field blanks for total phosphorus and all 22 field blanks for total nitrogen measured below the detection limit (5 µg/l for total phosphorus and 0.1 mg/l for total nitrogen). However, as in past years, the field blanks for turbidity were more problematic, as four of the 24 field blanks exceeded the detection limit (0.2 NTU for turbidity), although levels were still generally low (0.20-0.43 NTU). Similarly, the mean relative percent differences between duplicate samples were well within the prescribed differences for two of the three parameters [total phosphorus = 4% (prescribed difference <30%) and total nitrogen = 7% (prescribed difference <20%)]. No pairs of duplicate samples exceeded the prescribed difference for total phosphorus, and only two of the 22 pairs of duplicate samples exceeded the prescribed difference for total nitrogen (and those two differed by 24%). In contrast, the mean relative percent difference between the duplicate turbidity samples exceeded the prescribed difference [turbidity = 21% (prescribed difference <15%)], as ten of the 24 pairs of turbidity samples differed by >15%. 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 duplicates for turbidity indicated that we continue to encounter difficulties in collecting repeatable and untainted turbidity samples for some as-yet unidentified reason.

Priority Phosphorus Reduction Areas

In the second part of this project, we conducted spatial and statistical analyses to identify and prioritize subwatersheds within the Vermont portion of the Lake Memphremagog Basin that consistently had the highest total phosphorus concentrations. However, these analyses confronted a number of challenges, primarily related to the fact that not all sites were sampled on all dates in all years. As a consequence, sites differed dramatically in the number of years sampled; the number of dates sampled; the numbers of low, moderate, and high flows sampled; and the size of the subwatershed drained by each site. These differences made analyzing and interpreting the results of these analyses challenging. Nevertheless, these data do provide a good overview of those areas within the Vermont portion of the basin where phosphorus levels in the surface waters are noticeably higher and where protection and restoration projects might be most beneficial in reducing phosphorus exports and improving water quality.

During 2005-2012, we sampled water quality at a total of 121 sites in the Vermont portion of the Lake Memphremagog Basin (Figure 28). However, only 20-38 sites were sampled each year, and the geographic areas sampled differed among years (Table 2). Specifically, we sampled sites across the watersheds of all four principal tributaries during 2005-2006. During 2008-2009, we focused on the Johns River watershed, the small tributaries that flow directly into Lake Memphremagog, and the small tributaries that flow into Seymour Lake. In 2010, that focus broadened to include the Black River watershed, and, in 2011, we focused exclusively on the Black River watershed. Finally, in 2012, we again broadened the sampling to include sites in the watersheds of the Black and Barton Rivers as well as several of the small tributaries that flow directly into Lake Memphremagog.

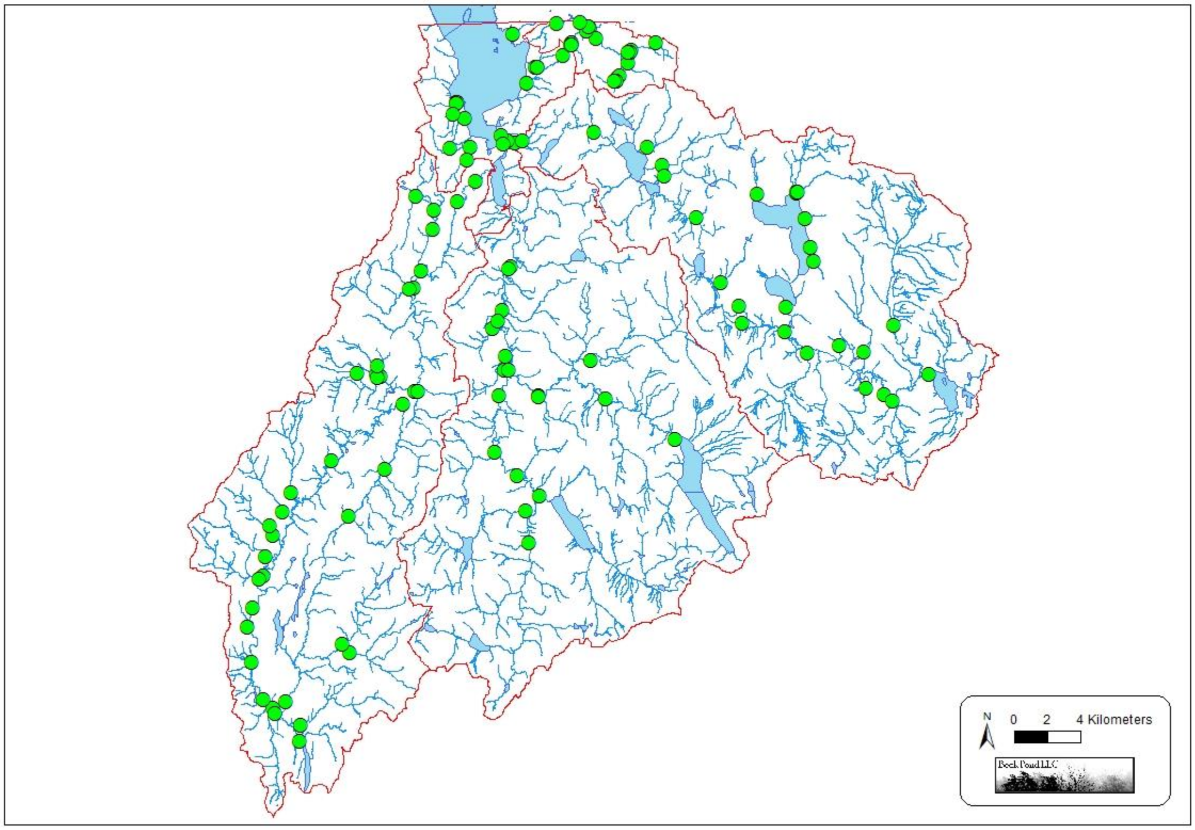

Figure 28. *Locations of the 121 sites where water quality was sampled in the Vermont portion of the Lake Memphremagog Basin during 2005-2012.*

Table 2. Number of sites and geographic area where water quality samples were collected each year along the Vermont tributaries of Lake Memphremagog during 2005-2012. “Direct Tributaries” refers to those small streams that flow directly into Lake Memphremagog, rather than into one of the four principal tributaries (Black, Barton, Clyde, or Johns Rivers).

Year	# Sites	General Areas Sampled
2005	22	Black, Barton, Clyde, and Johns Rivers
2006	38	Black, Barton, Clyde, and Johns Rivers
2008	26	Johns River, Direct Tributaries, Seymour Lake
2009	31	Johns River, Direct Tributaries, Seymour Lake
2010	33	Black and Johns Rivers, Direct Tributaries
2011	27	Black River
2012	29	Black and Barton Rivers, Direct Tributaries

Due to this large variation in the number of sites and geographic areas sampled each year, sample sites differed dramatically in the numbers of dates on which they were sampled across the seven years (Figure 29). Individual sites were sampled on 3-38 dates during 2005-2012 (several sites in the Johns River watershed were sampled even more, but we only included those data collected after 2007 in these analyses due to the dramatic improvements in water quality measured following the replacement of a manure lagoon along Crystal Brook). However, almost 80% of the sites were sampled on 5-20 dates. The sites sampled on >20 dates were concentrated in the Black River and Johns River watersheds and along several small tributaries that flow directly into Lake Memphremagog (Figure 30). In contrast, the sites that were sampled on <10 dates were distributed throughout the Vermont portion of the Lake Memphremagog Basin.

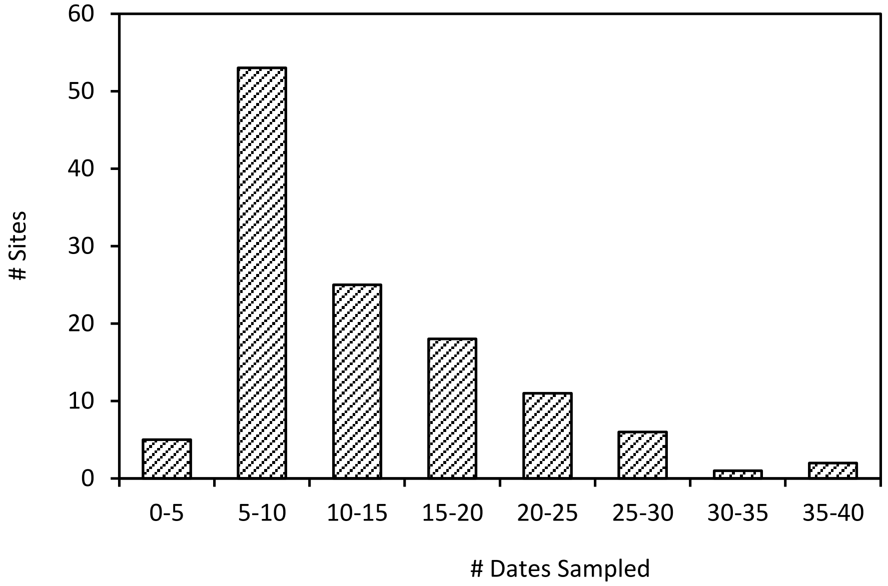

Figure 29. *Number of dates on which water quality was sampled at each of 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

In addition, the range of stream flows sampled differed dramatically among years (Table 3, Figure 31). Across all seven years, we sampled what might be considered high flows (i.e. flows >10 cms as measured at the USGS gage on the Black River in Coventry) on 0-3 dates in six of the seven years (no high-flow events were sampled in 2010). However, the only two high-flow events sampled in 2011 represented extremely high flows (i.e. 50-100-year flood events), far surpassing any other high flows sampled during 2005-2012. In general, low flows occurred on 43-71% of the sample dates in each year. However, it should be noted that local precipitation events affected flows in some but not all areas on some dates and that the smaller streams and larger rivers differed in their responses to snow melt and precipitation events. Thus, these general patterns may not be applicable to or representative of all sites sampled in any one year.

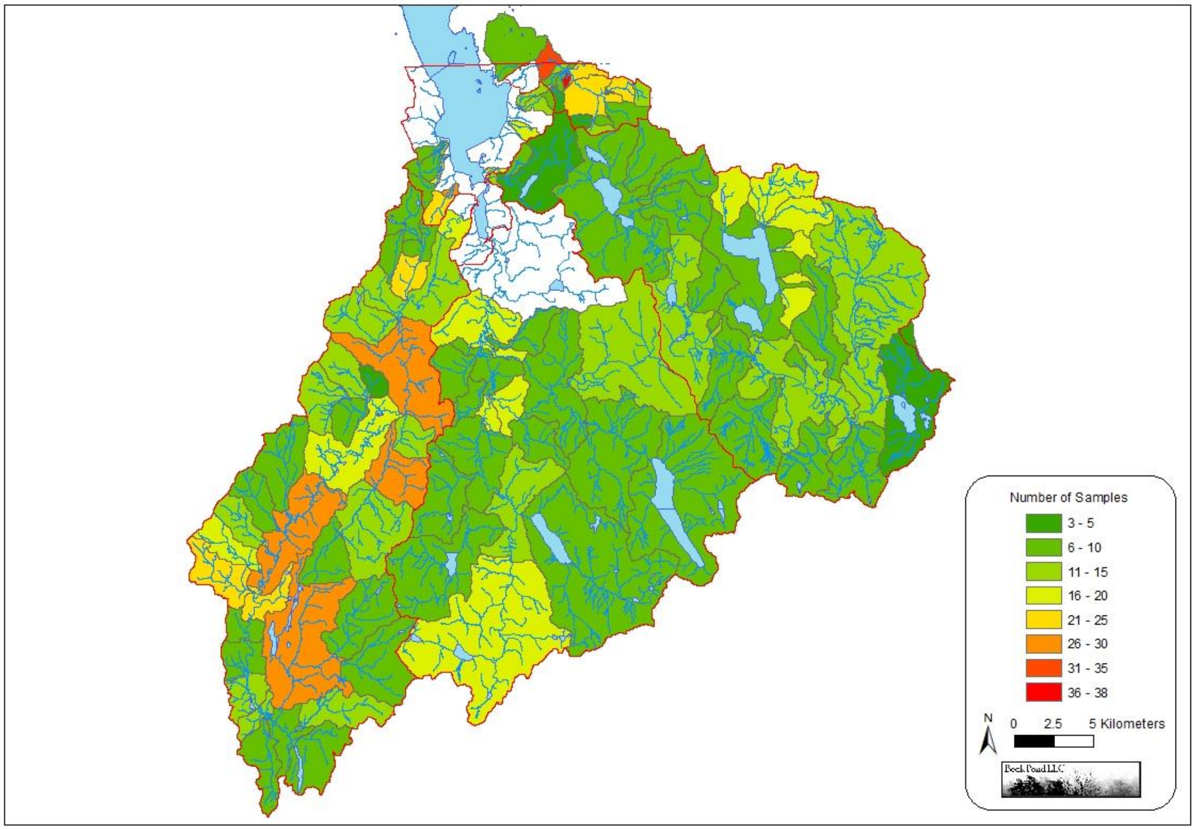

Figure 30. *Numbers of dates on which water quality was sampled at 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

Table 3. Numbers of low-, moderate-, and high-flow events sampled in Lake Memphremagog Basin during 2005-2012. For this analysis, flows were measured at the USGS gage on the Black River in Coventry.

Year	Low (<5 cms)	Moderate (5-10 cms)	High (>10 cms)	% Low Flows
2005	3	2	1	50
2006	4	0	2	67
2008	5	2	3	50
2009	10	2	2	71
2010	4	4	0	50
2011	3	2	2	43
2012	5	1	2	63

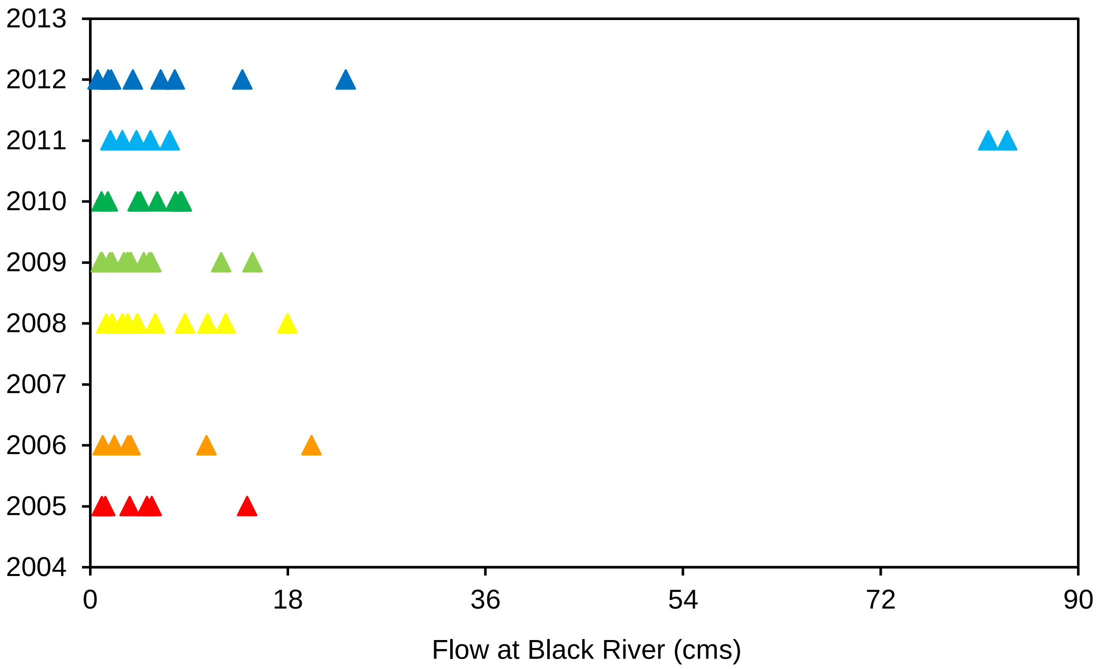

Figure 31. *Stream flows measured at the USGS gage on the Black River in Coventry on each sample date in the Vermont portion of the Lake Memphremagog Basin during 2005-2012.*

Because not all sites were sampled on all dates and in all years, the flows represented by the samples collected at different sites differed dramatically. Specifically, samples representing low flows were collected on 2-31 dates among the different sites. In contrast, samples representing moderate and high flows were collected on 0-13 dates among the different sites. Thus, individual sites differed in the proportions of samples collected at low vs. moderate and high flows (moderate and high flows were combined for this and subsequent analyses)(Figure 32). Moderate and high flows represented 0-60% of the samples collected at individual sites, and at least 20% of the samples were collected at moderate and high flows at the majority of the sites (63%). Sites at which a plurality (i.e. >76%) of the samples were collected at low flows were concentrated in the Barton River and Johns River watersheds, around Seymour Lake in the Clyde River watershed, and along many of the small tributaries that flow directly into Lake Memphremagog (Figure 33). Given that phosphorus concentrations are often strongly correlated with stream flows, this inconsistent sampling of flows among sites impacted both the mean concentrations and the ranking of concentrations among sites.

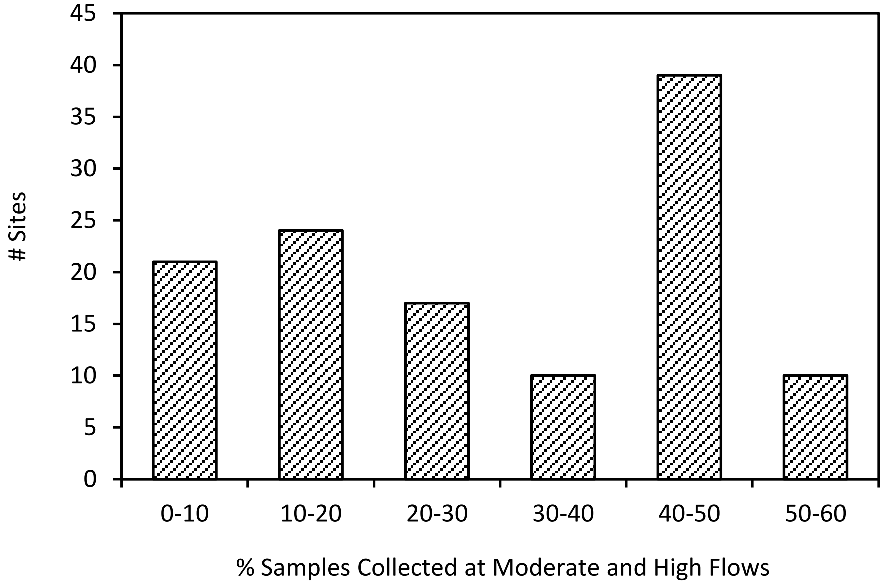

Figure 32. *Percentages of water quality samples collected at moderate and high flows at 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

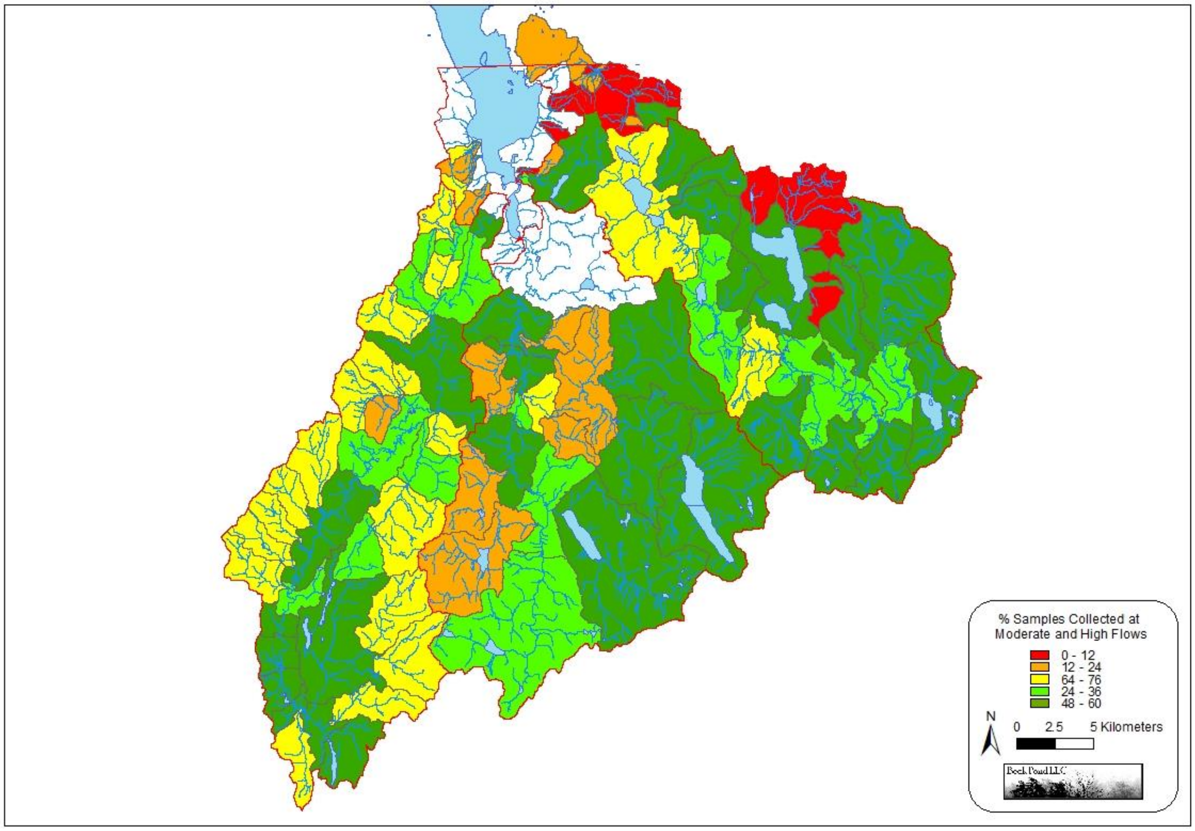

Figure 33. *Percentages of water quality samples collected at moderate and high flows at 121 sampling sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

Finally, the subwatersheds sampled by each of the 121 sites differed dramatically in size. For this analysis, the subwatershed is defined as the area drained by and located upstream of that site and downstream from the next site or sites upstream. Almost 68% of the 121 subwatersheds were <1,000 ha in size; however, 19% were 1,000-2,000 ha in size, and 13% were >2,000 ha in size (Figure 34). Most of the larger subwatersheds were located in the upstream parts of the Black River, Barton River, and Clyde River watersheds, although one was located along the lower main stem of the Clyde River (Figure 35). The sites draining many of these larger subwatersheds exhibited relatively low total phosphorus concentrations and, consequently, were not sampled to the same degree as those exhibiting relatively higher total phosphorus concentrations. In contrast, many of the smaller subwatersheds were concentrated in the upstream and downstream ends of the Black River watershed, the downstream parts of the Barton and Clyde River watersheds, the Johns River watershed, and along several small tributaries that flow directly into Lake Memphremagog. Many of the sites draining these subwatersheds exhibited relatively high total phosphorus concentrations, and sampling was concentrated in these areas to better pinpoint and assess potential phosphorus sources.

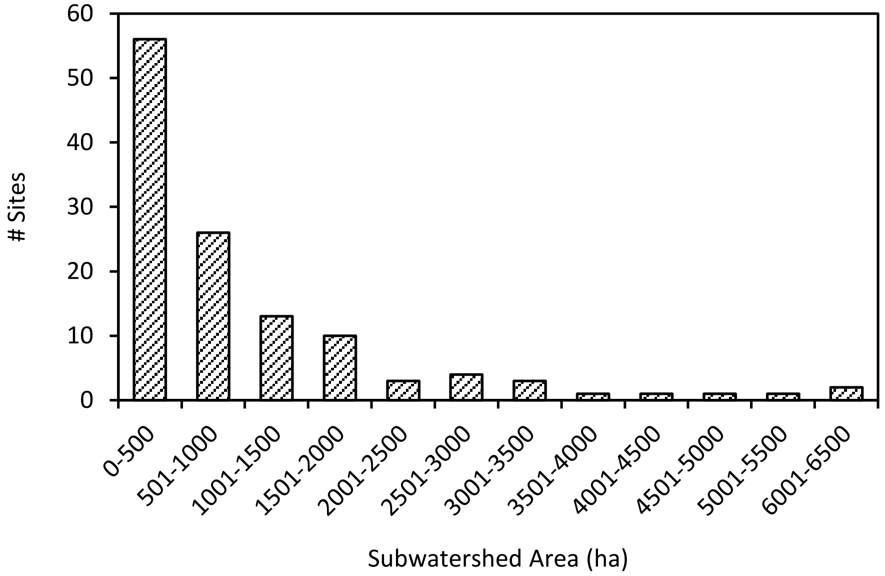

Figure 34. *Sizes of the subwatersheds associated with the 121 sites sampled along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

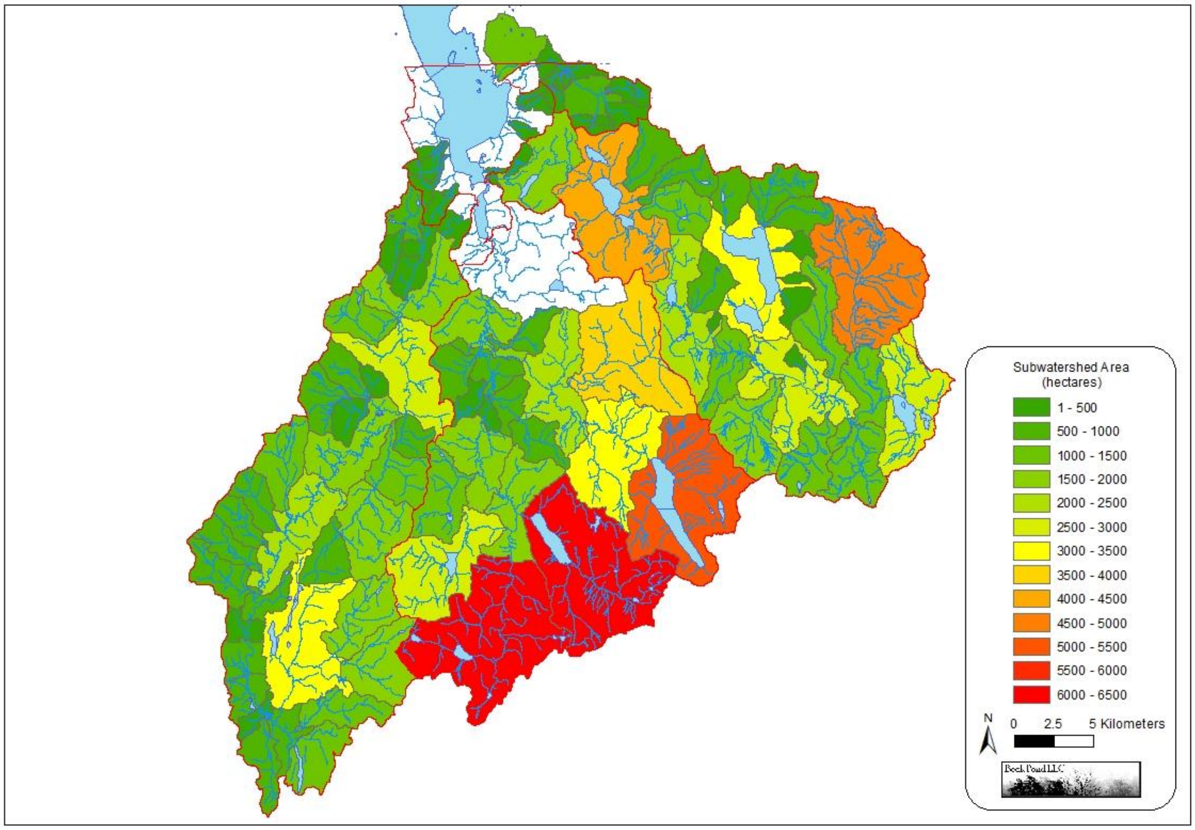

Figure 35. *Sizes of the subwatersheds associated with the 121 sites sampled along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

In general, the highest total phosphorus concentrations were measured at sites located in the Black River watershed, the downstream half of the Barton River watershed, the Johns River watershed, and along many of the small tributaries that flow directly into Lake Memphremagog. However, the exact ranking of each site and its associated watershed differed somewhat depending on the approach used to analyze the total phosphorus data. In the end, we used three approaches to analyze the total phosphorus data that we believed best identified those subwatersheds that were likely to be exporting large amounts of phosphorus: 1) mean total phosphorus concentration at low flows, 2) mean total phosphorus concentration at moderate and high flows, and 3) the average of each site's rank at low flow and at moderate and high flows. Although somewhat different, the results of all three approaches generally produced similar conclusions. For example, mean total phosphorus concentrations at low flows were moderately well correlated with mean total phosphorus concentrations at moderate and high flows ($R^2 = 0.32$; Figure 36). When the three sites with high mean total phosphorus concentrations at low flows but relatively low mean total phosphorus concentrations at high flows were excluded, the correlation was even stronger ($R^2 = 0.45$).

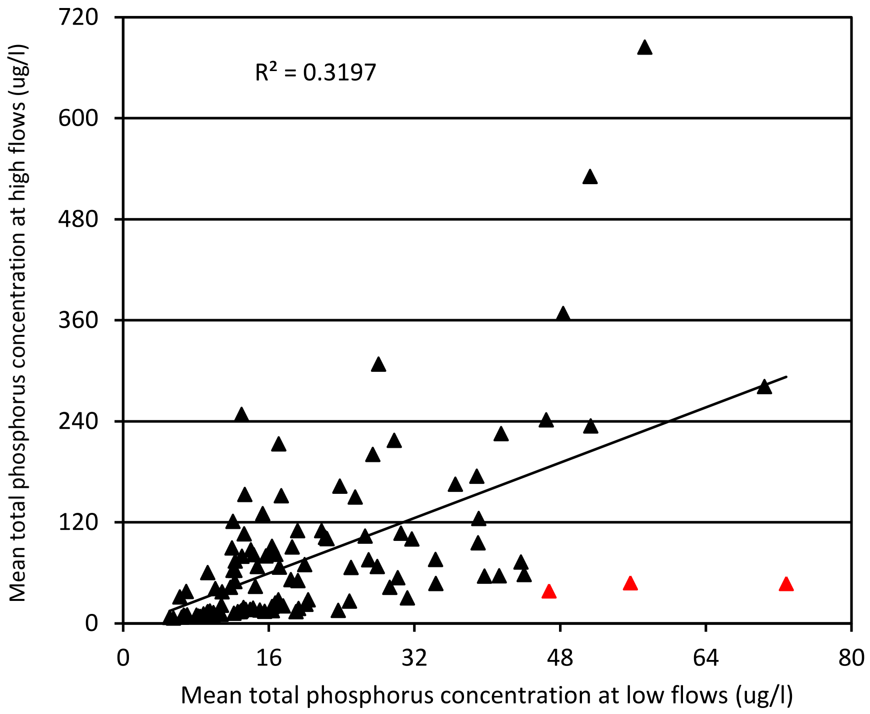

Figure 36. *Correlation between mean total phosphorus concentrations at low flows and mean total phosphorus concentrations at moderate and high flows at 111 sample sites along the Vermont tributaries of Lake Memphremagog during 2005-2012. The three sites with high mean total phosphorus concentrations at low flows but relatively low mean total phosphorus concentrations at high flows are shaded red.*

We were able to calculate the mean total phosphorus concentrations at low flows for all 121 sites. For sites along the main stems of the Black, Barton, and Clyde Rivers, low flows were defined as those dates on which daily flows at the USGS gage on the Black River measured <5 cms. For sites along the main stem of the Johns River and all other tributaries, low flows were defined as those dates on which daily flows at the Vermont DEC gage on the Johns River measured <0.5 cms. Mean total phosphorus concentrations at low flows were generally highest along much of the main stem of the Black River, the Brighton Brook and Stony Brook tributaries of the Black River, the Rock Junkyard and Hamel Marsh tributaries of the Barton River, a tributary of Seymour Lake in the Clyde River watershed, much of the Johns River watershed, and several small tributaries that flow directly into Lake Memphremagog (Figure 37). In contrast, mean total phosphorus concentrations at low flows were generally lowest across almost all of the Clyde River and Barton River watersheds and the numerous tributaries of the Black River.

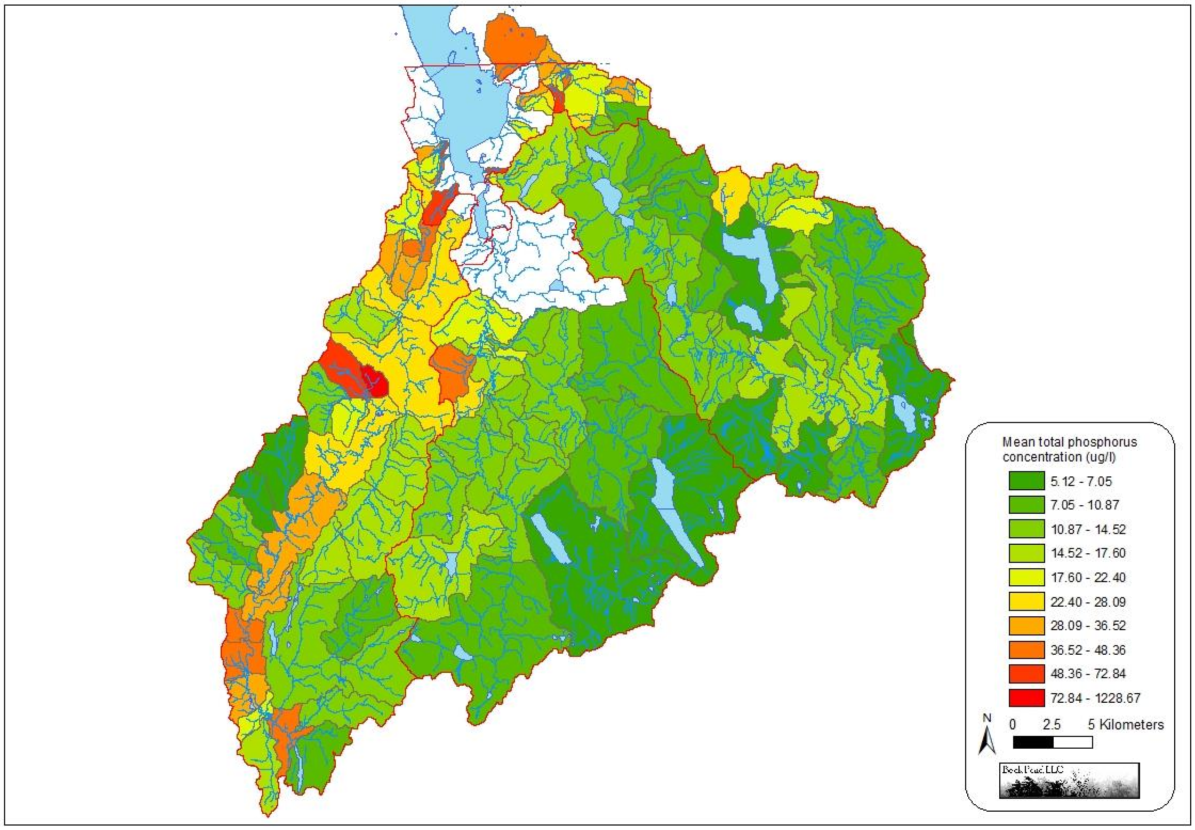

Figure 37. *Mean total phosphorus concentrations at low flows at 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

We were able to calculate the mean total phosphorus concentrations at moderate and high flows for 111 of the 121 sites (no samples were collected during moderate or high flows at the remaining ten sites). For sites along the main stems of the Black, Barton, and Clyde Rivers, moderate and high flows were defined as those dates on which daily flows at the USGS gage on the Black River measured >5 cms. For sites along the main stem of the Johns River and all other tributaries, moderate and high flows were defined as those dates on which daily flows at the Vermont DEC gage on the Johns River measured >0.5 cms. Mean total phosphorus concentrations at moderate and high flows were generally highest along the main stem of the Black River in Craftsbury, three tributaries of the Black River (Shalney Branch, Brighton Brook, and Stony Brook), the downstream part of the main stem of the Barton River and several of its tributaries (Willoughby River, Roaring Brook, and the Rock Junkyard and Hamel Marsh tributaries), the downstream half of the Johns River watershed, and several small tributaries that flow directly into Lake Memphremagog (Figure 38). In contrast, mean total phosphorus concentrations at moderate and high flows were generally lowest in almost all of the Clyde River watershed and the eastern half of the Barton River watershed.

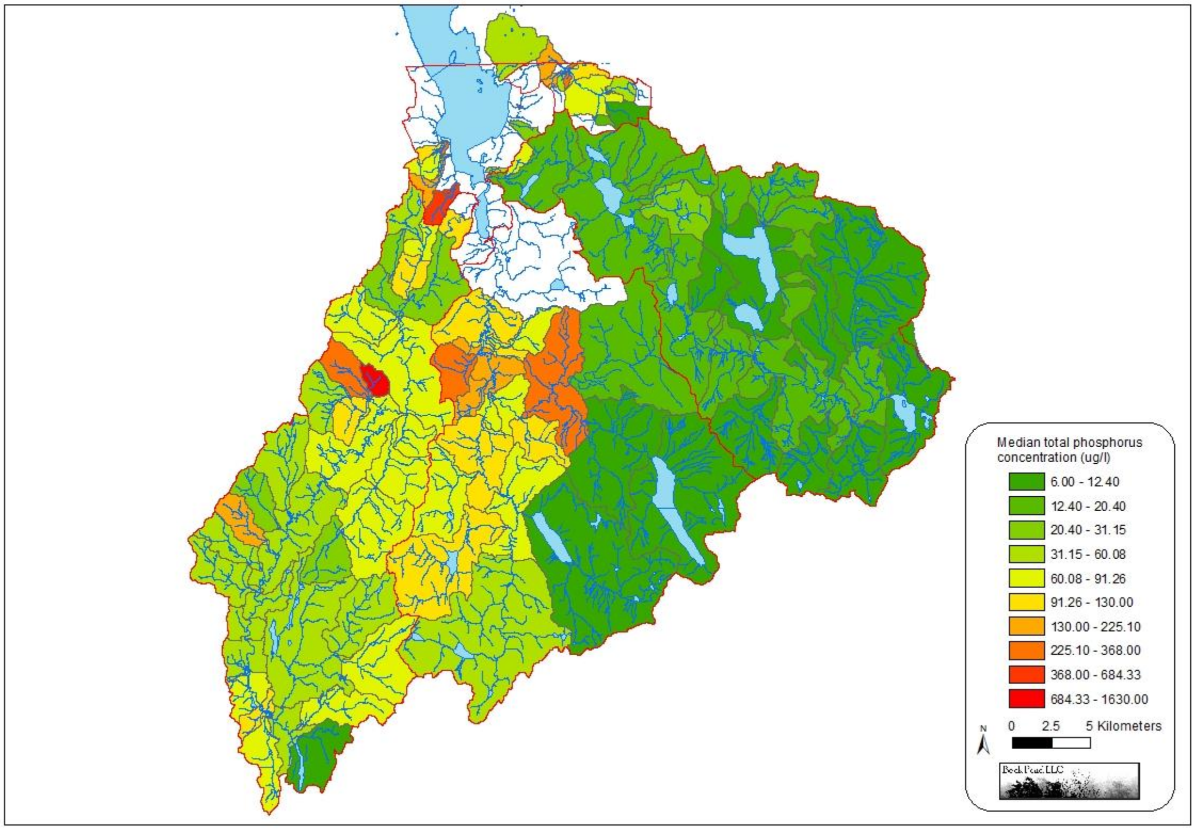

Figure 38. *Mean total phosphorus concentrations at moderate and high flows at 111 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012.*

We calculated the mean rank of each site as the average of each site's rank at low flows and its rank at moderate and high flows. For these analyses, 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 can be seen, the mean ranks corresponding to the highest total phosphorus concentrations occurred along many sections 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 downstream and several of its tributaries (Willoughby River, Roaring Brook, and the Rock Junkyard and Hamel Marsh tributaries), much of the Johns River watershed, and several small tributaries that flow directly into Lake Memphremagog (Figure

39). In contrast, the mean ranks corresponding to the lowest total phosphorus concentrations occurred throughout the Clyde River watershed, the eastern half of the Barton River watershed and many of the tributaries of the Black River.

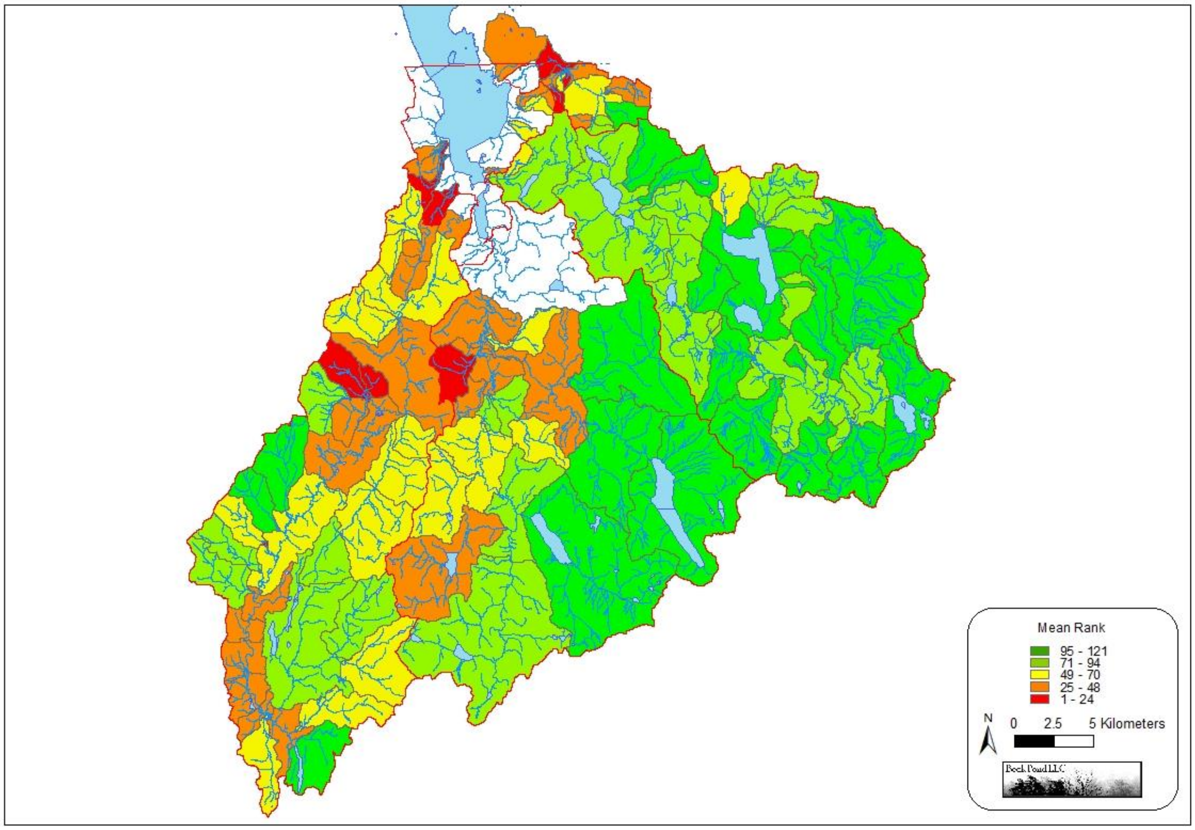

Figure 39. *Mean ranks based on mean total phosphorus concentrations at low and at high flows in 121 subwatersheds of the Lake Memphremagog Basin during 2005-2012. The lowest number (1) corresponds to the highest mean total phosphorus concentration, and the highest number (121) corresponds to the lowest mean total phosphorus concentration.*

Based on these analyses, we identified a set of focal subwatersheds (a.k.a. Priority Phosphorus Reduction Areas) where implementation of protection and restoration projects is likely to more effectively reduce phosphorus inputs into the surface waters of the Lake Memphremagog Basin. The Priority Phosphorus Reduction Areas were defined as those subwatersheds whose associated sample sites had the highest mean total phosphorus concentrations at low flows, the highest mean total phosphorus concentrations at high flows, and/or the highest mean rank. A total of 33 focal Priority Phosphorus Reduction Areas were ranked in the top 20 subwatersheds in one or more of the three analytical approaches (Table

4). These focal Priority Phosphorus Reduction Areas were concentrated in several areas of the Black River watershed, in the downstream parts of the Barton River and Johns River watersheds, and along several small tributaries that flow directly into Lake Memphremagog (Figure 40). None of the focal Priority Phosphorus Reduction Areas were located in the Clyde River watershed.

Table 4. Priority Phosphorus Reduction Areas identified by analyzing the total phosphorus data collected along the Vermont tributaries of Lake Memphremagog during 2005-2012. Subwatersheds identified in bold were ranked in the top 20 subwatersheds in all three analytical approaches.

Tributary	Site(s)
Barton River Watershed (5 subwatersheds)	
Main stem	Webster Road
Roaring Brook	Roaring Brook
Willoughby River	Churchill Lane
Hamel Marsh tributary	**Hamel Marsh**
Rock Junkyard tributary	Rock Junkyard
Black River Watershed (10 subwatersheds)	
Main stem	North Craftsbury Road, Tanner Road, Cemetery Road
Stony Brook	Stony Brook, Blake Road
Brighton Brook	**Brighton Brook**, **Brighton Brook North**, **Upper Brighton Brook North**
Shalney Branch	Shalney Branch, Upper Shalney Branch
Johns River Watershed (8 subwatersheds)	
Main stem	**North Derby Road**, Granite, Johns River
Darling Hill tributary	**Darling Hill**, Middle Darling Hill, Upper Darling Hill, DHM
Beebe Plain tributary	Beebe Plain
Direct Tributaries (10 subwatersheds)	
Hall’s Creek	Eagle Point
Sunset Acres tributary	Sunset Acres, Sunset Acres North
East Side tributary	East Side
Wishing Well tributary	**Wishing Well**, **Upper Wishing Well**
Strawberry Acres tributary	**Strawberry Acres**, Upper Strawberry Acres
Holbrook Bay tributary	Holbrook Bay, **Holbrook Bay South**

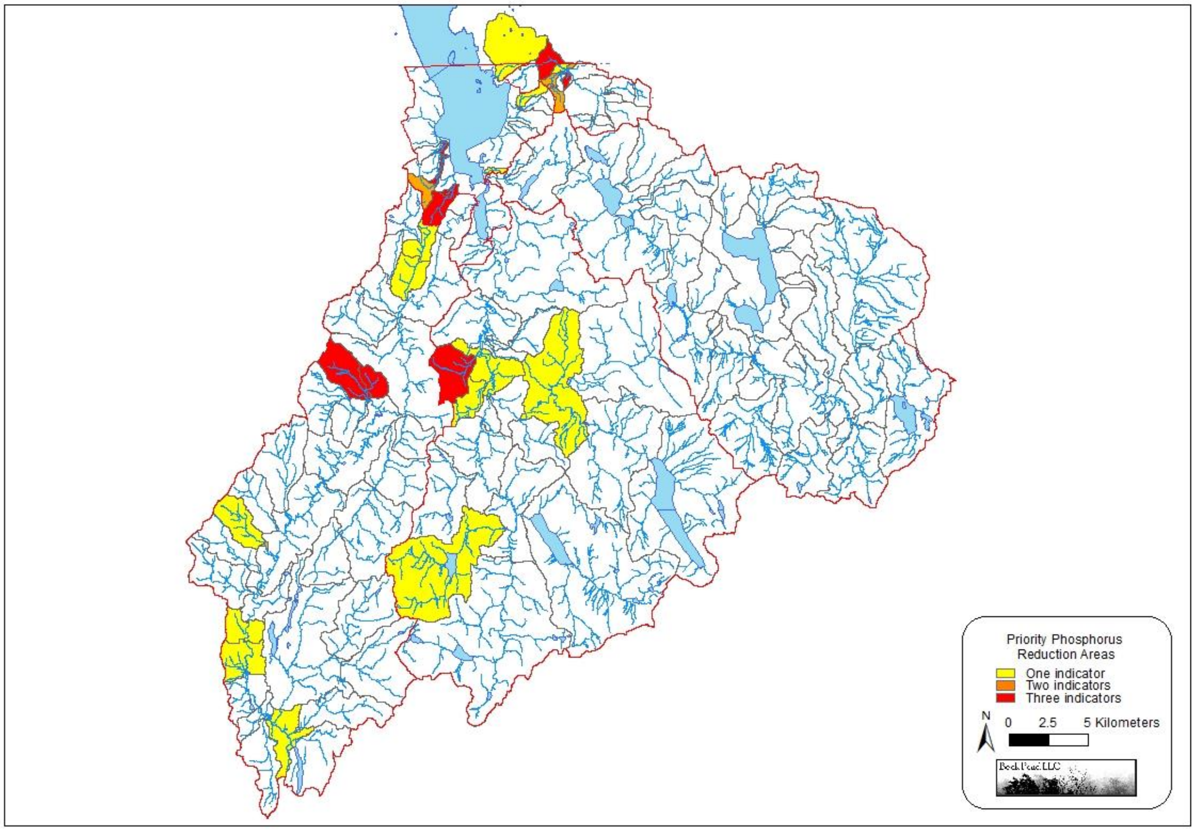

Figure 40. *The 33 Priority Phosphorus Reduction Areas identified through the analyses of total phosphorus data collected at 121 sites along the Vermont tributaries of Lake Memphremagog during 2005-2012. Subwatersheds are color-coded according to the number of analytical approaches in which their associated sample sites ranked in the top 20.*

As part of our efforts to identify potential phosphorus-reduction projects in these focal areas, we analyzed the relationship between mean total phosphorus concentrations and the land uses occurring upstream of each sample site. 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 individually, and for forest (Table 5). Agricultural land uses, including both hay and pasture, showed strong positive relationships with total phosphorus concentrations (Figure 40a-b). 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, the lack of adequate riparian buffers. In addition, the strong relationship between pasture and phosphorus levels may reflect the fact that pastures tend to be located near barnyards, which can also be significant sources of phosphorus exports.

In contrast, forest cover showed strong negative relationships with both mean and median total phosphorus concentrations (Figure 40c). These strong negative relationships likely reflected both the extent of forest in the basin [approximately 66.1% of the land surface in the basin was forest land (State of Vermont 2012b)] as well as the fact that forests likely export low levels of phosphorus due to the presence of abundant 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. These land uses generally covered relatively smaller proportions of the subwatersheds, so that their effects on phosphorus levels may be obscured by the effects of other, more widespread land uses. However, in other studies (e.g. Stone Environmental 2011), some of these land uses, particularly row crops and developed lands, were significant drivers of phosphorus exports.

Table 5. Slope and proportion of variation in total phosphorus concentrations explained by the proportions of different land uses in all of the subwatersheds located upstream of each of the 120 samples sites in the Vermont portion of the Lake Memphremagog Basin. These analyses did not include the Eagle Point subwatershed, which was located mostly in Quebec and for which land-use data were not available.

	Mean		Median	
Land Use	Slope	R^2	Slope	R^2
% developed lands	+0.65	0.078	+0.49	0.063
% agriculture	+1.10	0.337	+0.52	0.292
% row crops	+1.21	0.051	+0.87	0.090
% hay	+1.45	0.315	+0.67	0.269
% pasture	+5.49	0.334	+2.20	0.237
% forest	-0.83	0.276	-0.42	0.269
% wetlands	-6.40	0.055	-1.36	0.010
% water	-2.11	0.043	-1.27	0.056

Based on these land-use relationships, we identified a number of potential project types that might be implemented in priority subwatersheds to reduce phosphorus exports (Table 6). Although many of these project types are applicable to most or all land-use categories, other project types are relevant to only a subset of land uses. Due to the large proportion of the basin being used for agriculture and the strong positive relationships with total phosphorus concentrations, many of the potential project types involve improving agricultural facilities, implementing Best Management Practices (BMP), and protecting or restoring riparian buffers. However, other project types are better suited for forest lands or for urban and suburban land uses. Many of these 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 Department of Environmental Conservation; and U.S. Natural Resources Conservation Service. In addition, technical and financial assistance can also be provided by the Vermont Association of Conservation Districts, Natural Resources Conservation Districts, and various other public and private partners.

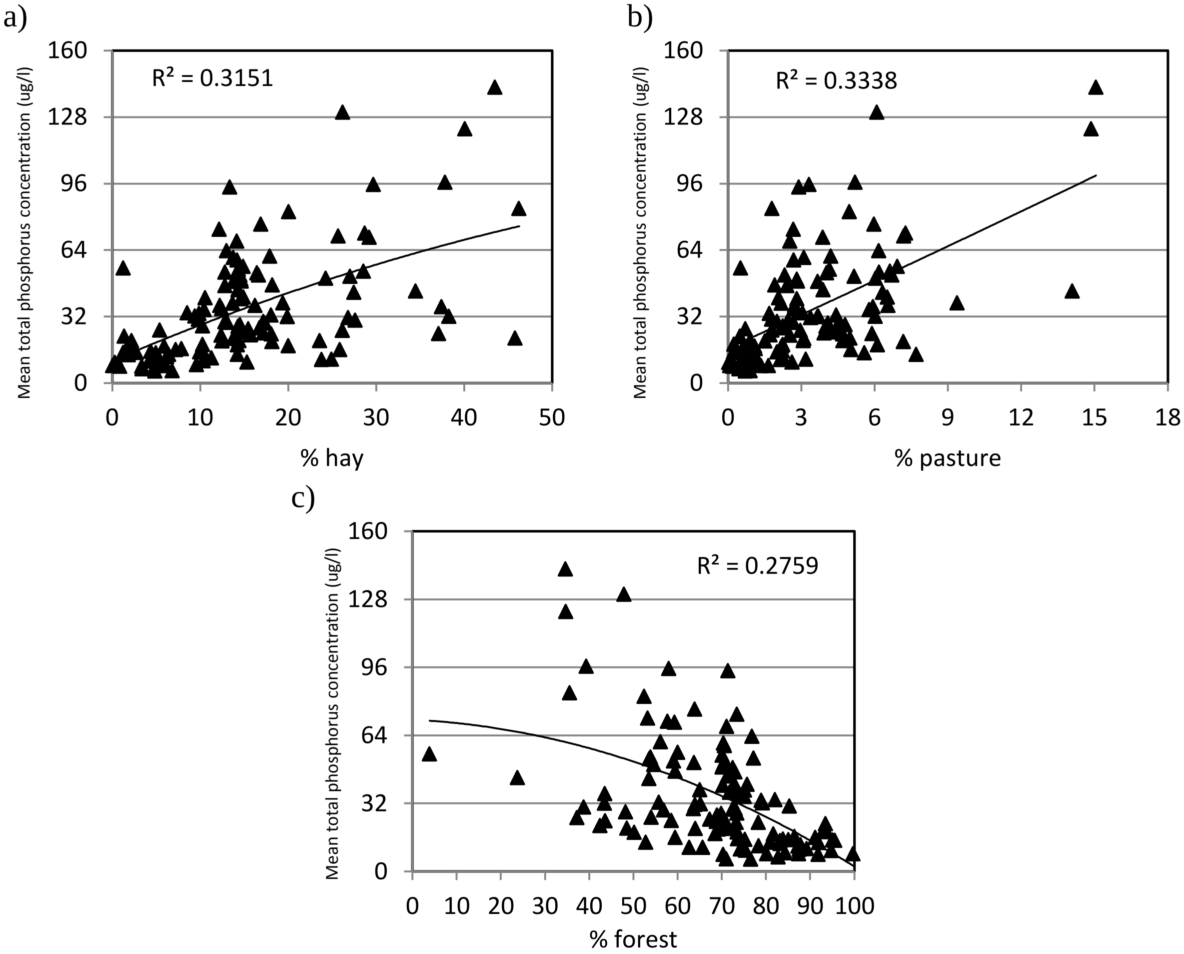

Figure 41. *Regressions between mean total phosphorus concentrations and percentage of the upstream subwatersheds occupied by a) hay, b) pasture, and c) forest for 120 sample sites located in the Vermont portion of the Lake Memphremagog Basin during 2005-2012.*

Table 6. Potential projects and practices that could be implemented in focal Priority Phosphorus Reduction Areas 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
Hay field	Riparian buffer restoration Appropriately timed manure and fertilizer applications
Cropland	Riparian buffer restoration Conservation tillage Contour plowing Appropriately timed manure and fertilizer applications Reduced pesticide applications Integrated pest management
Barnyards	Clean water diversion Barnyard runoff collection Appropriately sized and sited manure pits Silage/compost runoff collection
Residential	Riparian buffer restoration Appropriate lawn care practices Reduced fertilizer and pesticide applications Stormwater retention or diversion
Urban development	Riparian buffer restoration Road improvements Stormwater retention

Wetlands Restoration

Site Selection

In 2012, we continued our efforts to identify, prioritize, and implement wetland restoration projects by revising the site selection model that we developed in 2011 to identify and prioritize potential wetland restoration sites within the Vermont portion of the Lake Memphremagog Basin. The revised site selection model identified 541 potential wetland restoration sites occupying 2,973 ha (2.4%) of the Vermont portion of the Lake Memphremagog Basin (Figure 42). Potential restoration sites ranged in size from 1.2-106.4 ha with a mean area of 5.5 ha. In contrast, the model developed in 2011 identified 526 potential wetland restoration sites occupying 1,969 ha (1.6%) of the Vermont portion of the Lake Memphremagog Basin (Gerhardt 2012b). In that model, potential restoration sites ranged in size from 1.2-48.4 ha with a mean area of 3.7 ha. Thus, the difference in the areas covered by potential wetland restoration sites in the two models largely arose from the larger size of individual sites, rather than an increase in number of sites (the small increase in number of sites probably reflected the addition of the Essex County areas of the basin into the model, which were not included in 2011 due to the lack of digital soils data at that time).

The largest number and aerial extent of potential wetland restoration sites occurred in the Barton River watershed, but the Black River watershed and the sub-basin encompassing the small tributaries that flow directly into Lake Memphremagog had higher proportions of their areas identified as potential wetland restoration sites (Table 7). Potential wetland restoration sites were concentrated along the main stems of all four principal tributaries of Lake Memphremagog, especially in the downstream sections of the watersheds (Figure 42). In contrast, potential wetland restoration sites were generally lacking in the upstream sections of these watersheds, especially the Barton River, Clyde River, and Johns River watersheds. This distribution of sites likely reflected the fact that, except along the main stems of the Black, Barton, and Clyde Rivers and a few of the larger tributaries (e.g. Lords Creek), most of the basin was fairly steep (i.e. slope >6%) and had fewer and smaller areas of hydric soils. These areas also tended to have more forest cover and less open land that would qualify for selection as potential wetland restoration sites.

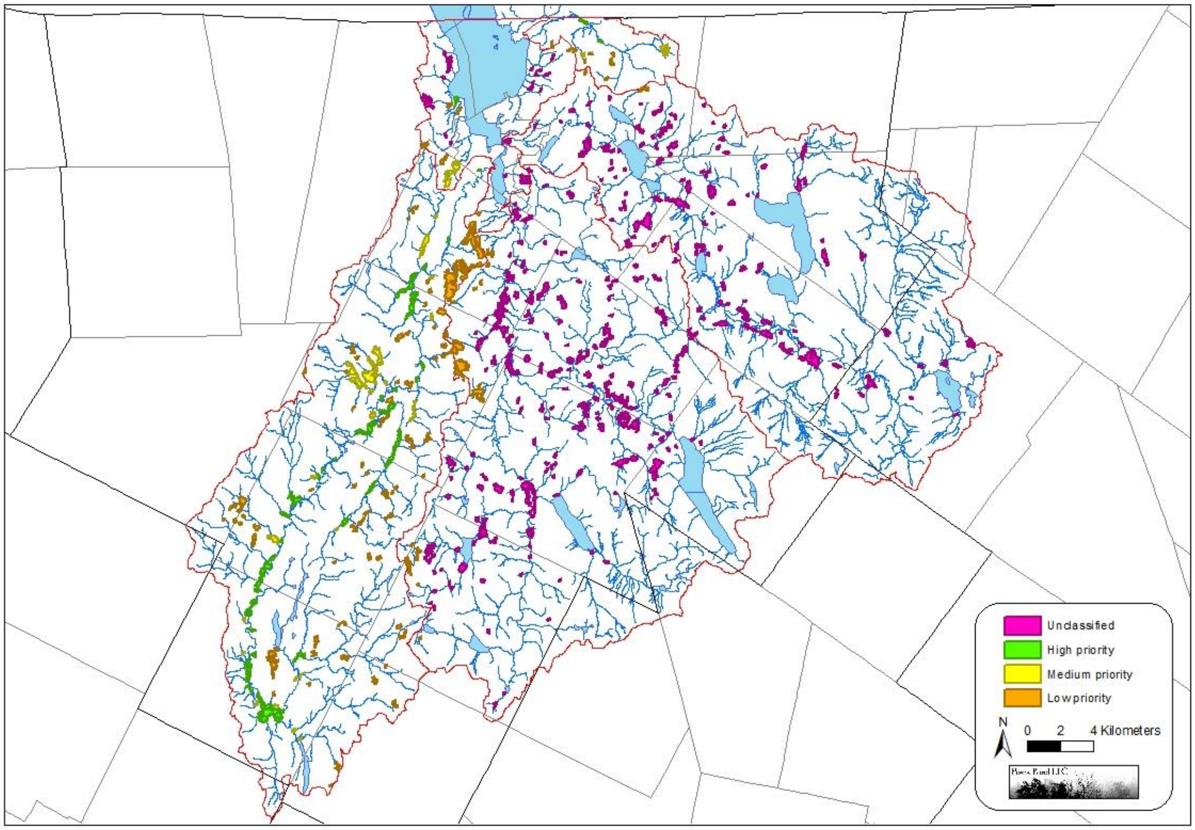

Figure 42. *Potential wetland restoration sites in the Vermont portion of the Lake Memphremagog Basin. Only those sites in the Black River and Johns River watersheds were assigned a priority ranking.*

Table 7. Site selection model results for the five sub-basins in the Vermont portion of the Lake Memphremagog Basin. These values do not include the parts of the Johns River and the watersheds of the Direct Tributaries that were located in Quebec.

Sub-Basin	Sub-Basin Area (ha)	# Sites	Area of Sites (ha)	% of Sub-Basin
Black River	34,922	164	1,198	3.4
Barton River	44,519	230	1,298	2.9
Clyde River	37,348	125	616	1.7
Johns River	2,500	17	63	2.5
Direct Tributaries	7,254	33	242	3.3

Potential wetland restoration sites occurred within 17 towns in the Vermont portion of Lake Memphremagog Basin (Table 8). The largest numbers, areas, and proportions of potential wetland restoration sites were located in the towns of Barton, Brownington, Coventry, Derby, and Irasburg. Collectively, these towns included areas in all five of the sub-basins, including most of the downstream sections of the Black River, Barton River, and Clyde River watersheds. The small areas and percentages of the town occupied by potential wetland restoration areas in several towns largely reflected the fact that much of the area in these towns lay outside of the Lake Memphremagog Basin (see footnote to Table 8).

Table 8. Site selection model results for 17 towns located in the Vermont portion of the Lake Memphremagog Basin in Vermont.

Town	Town Area (ha)	# Sites	Area of Sites (ha)	% of Town
Albany	10,096	43	232	2.3
Barton	11,488	65	351	3.1
Brighton[1]	14,075	9	60	0.4
Brownington	7,345	64	304	4.1
Charleston	9,981	49	267	2.7
Coventry	7,196	57	476	6.6
Craftsbury	10,245	36	264	2.6
Derby	14,859	75	325	2.2
Glover	9,979	36	142	1.4
Greensboro[1]	10,243	7	23	0.2
Holland[1]	10,019	7	22	0.2
Irasburg	10,560	76	544	5.2
Lowell[1]	14,602	6	28	0.2
Morgan	8,838	21	101	1.1
Newport City	1,975	6	49	2.5
Newport Town[1]	11,273	12	61	0.5
Westmore	9,732	10	55	0.6

[1] Much of the area in these towns is located outside the Lake Memphremagog Basin.

Site Prioritization

We assigned priority rankings to 202 of the 541 potential wetland restoration sites, including all of those located within the Black River and Johns River watersheds. The majority of the potential wetland restoration sites were ranked as low priorities for restoration (Table 9). Slightly more than half of the remaining sites were ranked as high priorities for restoration. The high-priority sites were generally large than the low-priority sites but smaller than the medium-priority sites. Not surprisingly given the approach undertaken to prioritize sites, the majority of the high-priority sites were located along the main stems of the Black and Johns Rivers and Lords Creek (Figure 42). In contrast, medium-priority sites were located along several other tributaries, including Brighton, Stony, Lamphear, and McCleary Brooks and the outlet of Lake Elligo. Finally, low-priority sites were situated in upland areas more distantly removed from surface waters. Many of the high-priority sites occurred in areas characterized by large areas of agricultural land uses located in close proximity to rivers, streams, and other surface waters. Restoration of these sites has the greatest potential for retaining nutrients and sediment and for improving water quality in the Lake Memphremagog Basin.

Table 9. Site prioritization results for potential wetland restoration sites in the Black River and Johns River watersheds.

Priority Ranking	# Sites	% of Sites	Area of Sites (ha)	% of Area	Mean Area (ha)
High	52	26	390	28	7.5
Medium	31	15	272	20	8.8
Low	119	59	714	52	6.0
Total	202		1,376		

Site Evaluation and Landowner Outreach

From the set of medium- and high-priority sites, we evaluated individual sites to further assess their potential for wetlands restoration and to gauge the landowner's interest in undertaking protection and/or restoration projects on their property. More specifically, the goals were 1) to assess whether the site was accurately and precisely identified as a potential wetland restoration site, 2) to evaluate whether the site was suitable for restoration and/or protection, 3) to determine possible protection and/or restoration strategies for the site, and 4) to determine whether the landowner was interested in wetland restoration and/or other conservation actions on their property.

During the two years of this study, we further evaluated a total of 24 medium- and high-priority sites in the towns of Coventry, Irasburg, Albany, and Craftsbury (Figure 43). Of these 24 sites, 15 sites were located on actively-used agricultural lands; the remaining nine sites were located on old fields no longer being used for agriculture. The 15 sites located on actively-used agricultural lands included land being used for hay (eight sites), pasture (five sites), and corn (two sites). The 24 sites varied from 2-83 ha in size. Many of the larger sites extended across more than one property, and, whenever possible, we discussed protection and restoration opportunities with as many of the owners as possible.

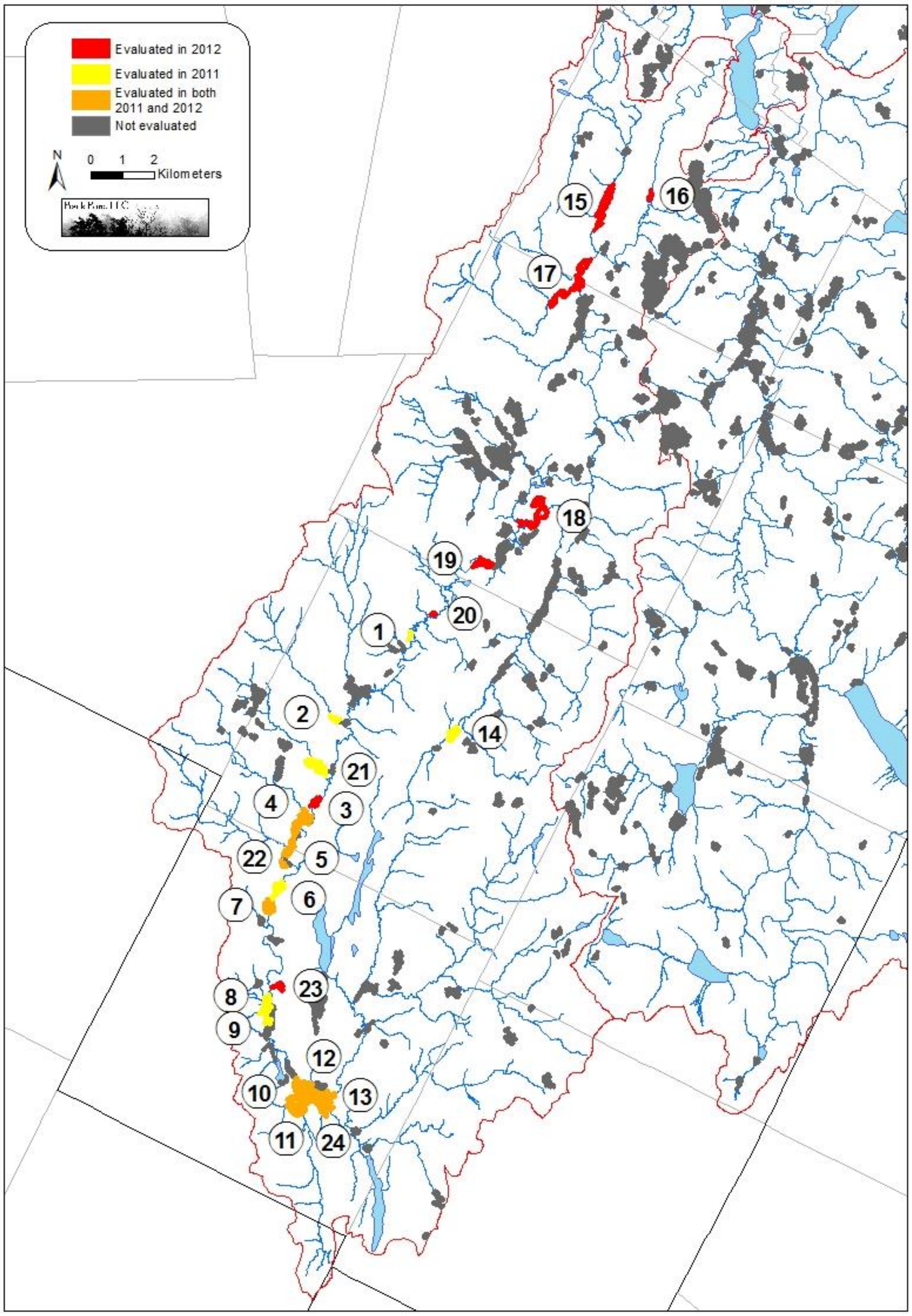

Figure 43. *Potential wetland restoration sites in the Black River watershed evaluated in terms of both their suitability for and landowner interest in protection or restoration. Numbers correspond to properties identified in Table 10 and discussed in the text of this report.*

Table 10. Potential wetland restoration sites evaluated as part of this project to assess their suitability for and the landowner's interest in undertaking wetland protection and/or restoration projects. The bold font indicates those sites that we visited.

Site #	Priority	Area (ha)	Land Use	Year	Status and Comments
Coventry (2 sites)					
15	Medium	23[1]	Corn	2012	CREP proposed but declined
16	**High**	**2**	**Old field**	**2012**	**TFSM proposed**
Irasburg (3 sites)					
17	**High**	**25[1]**	**Hay**	**2012**	**Undertaking TFSM in 2013**
18	**High**	**19**	**Old field**	**2012**	**TFSM proposed**
19	High	10	Hay	2012	Not interested
Albany (7 sites)					
20	High	2	Old field	2012	Not suitable
1	**High**	**2**	**Old field**	**2011**	**Possibly plug ditch or TFSM**
21	Medium	4	Old field	2012	TFSM completed
2	**Medium**	**16**	**Pasture**	**2011**	**Barnyard and laneway improvements completed, possibly CREP**
3	High	5	Pasture	2012	Not interested
4	High	31[1]	Hay	2011	Wetland mitigation completed, otherwise not interested
14	**High**	**9**	**Pasture**	**2011**	**Discussions ongoing**
Craftsbury (12 sites)					
5	**High**	**29[1]**	**Old field**	**2011**	**WRP application pending**
22	**High**	**2**	**Old field**	**2012**	**Discussions ongoing**
6	**High**	**15[1]**	**Hay/fallow**	**2011**	**Not currently interested**
7	**High**	**7[1]**	**Hay**	**2012**	**CREP proposed**
23	High	4	Hay	2012	TFSM completed
8	**High**	**8**	**Hay/fallow**	**2011**	**Not currently interested**
9	**High**	**3**	**Old field**	**2011**	**Interested in conserving full property**
10	High	83[1]	Pasture/hay	2011	Part of larger property
11	High	83[1]	Pasture/corn	2011	Barnyard runoff retention completed
12	**High**	**83[1]**	**Old field**	**2011**	**TFSM completed**
24	**High**	**83[1]**	**Pasture**	**2012**	**Would consider conservation**
13	**High**	**83[1]**	**Hay**	**2011**	**Not currently interested**

[1] Site includes large area that encompasses neighboring properties.

Prior to contacting landowners, we discussed the 24 potential wetland restoration sites with staff from the Vermont DEC; Vermont Association of Conservation Districts; Vermont Agency of Agriculture, Food and Markets; U.S. Natural Resources Conservation Service; and Orleans County NRCD. Based on these discussions, we eliminated eight sites from further consideration for the following reasons: 1) the owners of four sites (#4, #12, #21, and #23) had already undertaken one or more conservation or agricultural improvement projects and were unlikely to consider new projects at that time, 2) the owner of one site (#10) owns a large amount of agricultural land that will be targeted in a single, more comprehensive approach at a future date, 3) the owner of one site (#3) was unlikely to undertake protection or restoration projects at that time, and 4) the owners of two sites (#15 and #19) had already declined to undertake proposed conservation projects or practices.

For the remaining 16 sites, we initiated efforts to visit each site to assess their potential for and to gauge the landowners' interest in undertaking protection and/or restoration projects. All but one of these sites (#20) were deemed suitable for wetlands protection and/or restoration, and most would also benefit from other floodplain protection or restoration actions (e.g. restoration of floodplain forests or riparian buffers). Of the 16 landowners contacted, twelve expressed interest in learning more about wetland and other restoration opportunities, but the remaining three (#6, #8, and #13) were not interested in pursuing restoration projects at that time. The results of our discussions with the interested landowners are summarized as follows:

- The owner of one site (#5) submitted an application to enroll his property in the Wetland Reserve Program (WRP). Although the application has been approved, he was still awaiting the funding to move this project forward (Figure 44).

- The Trees for Streams Magog (TFSM) program was recommended for restoring riparian buffers at two sites (#16 and #18). The Orleans County NRCD and NorthWoods Stewardship Center are pursuing such projects at these two sites. A TFSM project is already planned for a third site in 2013 (#17), and a TFSM project was already completed at a fourth site (#12).

- The owner of one site (#7) was referred to the Vermont Association of Conservation Districts (VACD), and several agricultural improvement projects are being considered to improve both agricultural practices and the riparian buffer and wetlands on the site.

- The owner of one site (#2) has already undertaken several barnyard and laneway improvement projects that are benefitting water quality and may consider additional riparian and wetland restoration projects in the future.

- The owners of two sites (#9 and #24) expressed interest in learning more about restoration opportunities as part of broader efforts to conserve or sell their properties. One of these properties was referred to the Vermont Land Trust (VLT), and several options for conserving the other are being considered.

- Several options were discussed for protecting and restoring wetlands and riparian buffers on one site (#22), but no clear path was identified.

- Discussions are ongoing with the owner of one site (#14).

- One site (#1) was deemed a low priority for restoration, since it is currently part of an unmanaged wildlife management area.

We will continue to encourage the development and implementation of these and other protection and restoration projects as part of efforts to protect and improve water quality in the Vermont portion of the Lake Memphremagog Basin.

Figure 44. *Potential wetland restoration site along the Black River in Craftsbury, Vermont. The owner of this site has applied and been approved for the Wetland Reserve Program (WRP) but is still awaiting funding to restore the wetlands on this site.*

Recommendations

Future monitoring and assessment studies will continue to focus on pinpointing and assessing nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog, refining the identification of Priority Phosphorus-Reduction Areas, evaluating the success of ongoing phosphorus-reduction projects, and identifying and assessing water quality issues in areas where nutrient and sediment problems remain poorly understood. More specifically, we will focus on sampling water quality in 1) areas where we are still trying to pinpoint potential nutrient and sediment sources (e.g. Brighton Brook), 2) areas where we have little or no water quality data (e.g. Cobb and Day Brooks), 3) areas, especially those with high phosphorus levels, where we have no high-flow data, and 4) areas where remediation projects have already been undertaken in order to gauge the effectiveness of those projects in improving water quality. Although we have yet to finalize the specific sites, additional sampling will be undertaken along several tributaries of the Black River (Shalney Branch, Brighton Brook, and Stony Brook), the Barton River (Roaring Brook and the Rock Junkyard and Hamel Marsh tributaries), several small tributaries that flow into South Bay (Cobb and Day Brooks), and the small tributaries that flow directly into Lake Memphremagog (the Holbrook Bay and Wishing Well tributaries). We will continue to use these water quality data to identify and prioritize potential on-the-ground protection and/or restoration projects that can be implemented to reduce nutrient and sediment inputs in the Lake Memphremagog Basin.

Compiling the water quality data collected during 2005-2012 allowed us to identify subwatersheds where total phosphorus concentrations were relatively high. These Priority Phosphorus Reduction Areas were concentrated in a few areas of the Vermont portion of the Lake Memphremagog Basin (Figure 40). With this information, we can now begin to systematically identify and prioritize potential protection and restoration projects that will likely lead to the greatest improvements in water quality in these priority subwatersheds. To the extent possible, we will localize projects to specific sites within these subwatersheds, and we will identify specific project types that will be most effective in protecting and improving water quality [e.g. restoration of riparian buffers, floodplain forests, and/or wetlands and implementation of Best Management Practices (BMP)]. To that end, we will use all available data (water quality, Stream Geomorphic Assessments, wetlands assessments, aerial photos, and soil and other maps) to identify the appropriate protection and restoration project(s) for individual sites in these priority subwatersheds. We will then conduct on-the-ground assessments to verify the need for and feasibility of such projects in partnership with the appropriate agency and/or organizational staff, who will take the lead in working with landowners and land managers to implement these projects.

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. The results of this study 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 and earlier studies to advise efforts to improve water quality and to develop and implement protection and restoration projects by the Vermont DEC; Vermont Agency of Agriculture, Food and Markets; Vermont Association of Conservation Districts, Orleans County NRCD; U.S. Natural Resources Conservation Service; and NorthWoods Stewardship Center. 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 cities of Newport, Sherbrooke, and Magog.

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Appendix A. Descriptions of the 29 sites sampled along the Vermont tributaries of Lake Memphremagog during April-October 2012 (locations are mapped in Figure 5).

Black River (12 sites):

Site Name	Site Description
Post Road	Main stem downstream of Post Road in Craftsbury (also sampled in 2011)
Mud Pond	Main stem downstream of Black River Road in Craftsbury (also sampled in 2011)
Stony Brook	Stony Brook upstream of confluence with Black River in Coventry (also sampled in 2010-2011)
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
Robillard Flats	Brighton Brook upstream of Gage Road and its confluence with the Brighton Brook North tributary in Irasburg
Stony Hill	Brighton Brook upstream of Vermont Route 58 in Irasburg (also sampled in 2011)
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)
Rogers Tributary	Rogers Branch upstream of Vermont Route 14 in Albany (also sampled in 2010-2011)
Seaver Branch	Seaver Branch upstream of Vermont Route 14 in Craftsbury (also sampled in 2010-2011)

Barton River (13 sites):

Site Name	Site Description
Webster Road	Main stem upstream of Webster Road in Coventry
Orleans Wastewater	Main stem upstream of the Orleans Wastewater Treatment Plant in Barton (also sampled in 2005-2006)
Ethan Allen	Main stem upstream of the VAST snowmobile bridge upstream of the Ethan Allen plant in Barton

Barton Railroad Bridge	Main stem upstream of U.S. Highway 5 in Barton (also sampled in 2006)
Glover Road	Main stem at Glover Road Fishing Access in Barton (also sampled in 2005-2006)
Trout Brook	Trout Brook downstream of River Road in Coventry
Hamel Marsh	Unnamed tributary upstream along Hamel Road in Irasburg
Rock Junkyard	Unnamed tributary upstream of River Road in Irasburg
Willoughby Falls	Willoughby River upstream of its confluence with Barton River at Willoughby Falls Wildlife Management Area in Barton (also sampled in 2005-2006)
Churchill Lane	Willoughby River upstream of Churchill Lane in Barton
Country Club	Unnamed tributary upstream of Vermont Route 58 in Barton
Hogtrough Brook	Hogtrough Brook along Tanguay Road in Barton
Roaring Brook	Roaring Brook downstream of Interstate 91 in Barton

Clyde River (1 site):

Site Name	Site Description
Shattuck Hill	Unnamed tributary upstream of Clyde Street in Newport City

Direct Tributaries (3 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)
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)

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 29 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)**
Barton Railroad Bridge	4/11/2012	0.35	17.8	3.61
Barton Railroad Bridge	5/8/2012	0.24	10.3	1.69
Barton Railroad Bridge	6/5/2012	0.22	17.7	*5.79*
Barton Railroad Bridge	7/2/2012	0.35	10.3	0.86
Barton Railroad Bridge	7/31/2012	0.35	10	0.68
Barton Railroad Bridge	8/28/2012	0.42	14.5	1.43
Barton Railroad Bridge	9/5/2012	0.98	**364**	**175**
Barton Railroad Bridge	10/22/2012	0.28	10.3	1.4
Brighton Brook	4/11/2012	0.66	**42.5**	4.49
Brighton Brook	5/8/2012	0.42	*22.5*	1.79
Brighton Brook	6/5/2012	0.45	**42.7**	2.74
Brighton Brook	7/2/2012	0.57	**35.2**	*5.22*
Brighton Brook	7/31/2012	0.62	*25.5*	1.58
Brighton Brook	8/28/2012	0.49	**49.8**	2.56
Brighton Brook	9/5/2012	*1.33*	**156**	**26.2**
Brighton Brook	10/22/2012	0.45	*28.7*	1.67
Brighton Brook North	4/11/2012	0.93	**105**	2.79
Brighton Brook North	5/8/2012	0.33	**43.5**	1.08
Brighton Brook North	6/5/2012	0.72	**154**	4.07
Brighton Brook North	7/2/2012	0.44	**42.7**	*8.19*
Brighton Brook North	7/31/2012	0.42	*28.9*	1.56
Brighton Brook North	8/28/2012	0.37	**53**	2.41
Brighton Brook North	9/5/2012	**2.04**	**352**	4.89
Brighton Brook North	10/22/2012	0.66	**74.4**	2.58

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Churchill Lane	4/11/2012	0.42	*26*	*6.95*
Churchill Lane	5/8/2012	0.21	9.44	1.34
Churchill Lane	6/5/2012	0.19	11.4	2.56
Churchill Lane	7/2/2012	0.18	12.9	1.65
Churchill Lane	7/31/2012	0.24	9.49	0.33
Churchill Lane	8/28/2012	0.2	11.4	1.5
Churchill Lane	9/5/2012	*1.12*	**248**	**110**
Churchill Lane	10/22/2012	0.22	10.5	1.44
Country Club	4/11/2012	0.41	*20.5*	*5.49*
Country Club	5/8/2012	0.27	14.4	1.97
Country Club	6/5/2012	0.25	12.5	1.91
Country Club	7/2/2012	0.27	14	0.59
Country Club	7/31/2012	0.3	11.8	1.14
Country Club	8/28/2012	0.28	12.6	0.45
Country Club	9/5/2012	0.66	**106**	**34**
Country Club	10/22/2012	0.17	7.44	0.64
Ethan Allen	4/11/2012	0.38	*20.9*	*5.66*
Ethan Allen	5/8/2012	**3.06**	11.3	1.77
Ethan Allen	6/5/2012	0.25	17.5	*5.02*
Ethan Allen	7/2/2012	0.37	11.5	1.09
Ethan Allen	7/31/2012	0.34	10.2	0.74
Ethan Allen	8/28/2012	0.36	15.3	1.58
Ethan Allen	9/5/2012	*1.19*	**431**	**185**
Ethan Allen	10/22/2012	0.28	15.3	2.28
Glover Road	4/11/2012	0.33	13	2.39
Glover Road	5/8/2012	0.29	16.7	4.59
Glover Road	6/5/2012	0.26	12.6	3.14
Glover Road	7/2/2012	0.27	7.28	0.26
Glover Road	7/31/2012	0.27	6.96	0.31
Glover Road	8/28/2012	0.33	8.44	0.42
Glover Road	9/5/2012	0.93	**453**	**396**
Glover Road	10/22/2012	0.2	7.51	1.04

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Hamel Marsh	4/11/2012	*1.32*	**37**	4.73
Hamel Marsh	5/8/2012	0.71	*23.5*	3.47
Hamel Marsh	6/5/2012	*1.19*	**41.5**	*5.59*
Hamel Marsh	7/2/2012	0.55	**57.3**	**12.2**
Hamel Marsh	7/31/2012	0.44	**53**	*5*
Hamel Marsh	8/28/2012	0.51	**95.7**	*5.55*
Hamel Marsh	9/5/2012	*1.82*	**368**	**26.1**
Hamel Marsh	10/22/2012	0.76	*30.5*	1.48
Hogtrough Brook	4/11/2012	0.38	18.1	3.92
Hogtrough Brook	5/8/2012	0.27	12.4	2.23
Hogtrough Brook	6/5/2012	0.24	11.3	1.64
Hogtrough Brook	7/2/2012	0.37	11.2	0.42
Hogtrough Brook	7/31/2012	0.35	10.2	< 0.2
Hogtrough Brook	8/28/2012	0.44	12.4	1.05
Hogtrough Brook	9/5/2012	0.64	**89.4**	**22.3**
Hogtrough Brook	10/22/2012	0.23	8.24	1.21
Holbrook Bay South	4/11/2012	0.37	*24.7*	3.89
Holbrook Bay South	5/8/2012	0.22	19.3	2.64
Holbrook Bay South	6/5/2012	0.45	**45.5**	*9.5*
Holbrook Bay South	7/2/2012	0.55	**71**	**19.1**
Holbrook Bay South	7/31/2012	0.85	**72.1**	*5.49*
Holbrook Bay South	9/5/2012	0.87	**125**	*9.61*
Holbrook Bay South	10/22/2012	0.35	*26.3*	2.68
Mud Pond	4/11/2012	0.75	*31.2*	*7.22*
Mud Pond	5/8/2012	0.54	18.5	3.57
Mud Pond	6/5/2012	0.5	16.2	2.72
Mud Pond	7/2/2012	0.51	16.1	1.95
Mud Pond	7/31/2012	0.53	*22.7*	1.7
Mud Pond	8/28/2012	0.51	*20.5*	2.78
Mud Pond	9/5/2012	*1.61*	**575**	**339**
Mud Pond	10/22/2012	-	14.3	2.9

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Orleans Wastewater	4/11/2012	0.38	19.3	*5.35*
Orleans Wastewater	5/8/2012	0.29	11.8	1.39
Orleans Wastewater	6/5/2012	0.26	17.7	*5.22*
Orleans Wastewater	7/2/2012	0.33	11.4	1.25
Orleans Wastewater	7/31/2012	0.31	10.6	1.25
Orleans Wastewater	8/28/2012	0.35	13	1.88
Orleans Wastewater	9/5/2012	*1.01*	**408**	**186**
Orleans Wastewater	10/22/2012	0.27	12.9	2.32
Post Road	4/11/2012	0.79	**40.8**	*7.79*
Post Road	5/8/2012	0.6	*26.5*	*5.83*
Post Road	6/5/2012	0.53	*22.2*	4.26
Post Road	7/2/2012	0.5	*22.8*	4.19
Post Road	7/31/2012	0.6	**40**	*5.6*
Post Road	8/28/2012	0.69	**42.4**	*7.24*
Post Road	9/5/2012	*1.38*	**346**	**83**
Post Road	10/22/2012	-	18.1	2.87
Roaring Brook	4/11/2012	0.41	*22.6*	3.93
Roaring Brook	5/8/2012	0.28	17.2	2.5
Roaring Brook	6/5/2012	0.33	*22.7*	*7.46*
Roaring Brook	7/2/2012	0.22	12.7	0.58
Roaring Brook	7/31/2012	0.28	7.58	0.27
Roaring Brook	8/28/2012	0.46	10.4	0.38
Roaring Brook	9/5/2012	0.54	**130**	**40.2**
Roaring Brook	10/22/2012	0.32	14.2	1.12
Robillard Flats	4/11/2012	0.56	*25.8*	*5.3*
Robillard Flats	5/8/2012	0.43	14.6	1.94
Robillard Flats	6/5/2012	0.42	16.3	2.19
Robillard Flats	7/2/2012	0.63	*26.8*	4
Robillard Flats	7/31/2012	0.72	*22.1*	1.85
Robillard Flats	8/28/2012	0.82	*31.3*	3.25
Robillard Flats	9/5/2012	*1.15*	**110**	**32.3**
Robillard Flats	10/22/2012	0.42	15.9	1.46

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Rock Junkyard	4/11/2012	0.72	*27.3*	4.12
Rock Junkyard	5/8/2012	0.41	14.2	1.27
Rock Junkyard	6/5/2012	0.57	*27.2*	2.32
Rock Junkyard	7/2/2012	0.38	*20.6*	1.72
Rock Junkyard	7/31/2012	0.33	17.5	1.39
Rock Junkyard	8/28/2012	0.33	**39.7**	1.3
Rock Junkyard	9/5/2012	*1.25*	**163**	**12.8**
Rock Junkyard	10/22/2012	0.75	*20.3*	0.95
Rogers Tributary	4/11/2012	0.27	13.5	2.55
Rogers Tributary	5/8/2012	0.23	7.27	0.64
Rogers Tributary	6/5/2012	0.28	12.8	2.16
Rogers Tributary	7/2/2012	0.36	9.05	0.34
Rogers Tributary	9/5/2012	0.94	**78.1**	**25.6**
Rogers Tributary	10/22/2012	-	8.77	0.43
Seaver Branch	4/11/2012	0.35	*23.4*	*5.83*
Seaver Branch	5/8/2012	0.19	9.04	2.04
Seaver Branch	6/5/2012	0.27	12.5	1.81
Seaver Branch	7/2/2012	0.23	7.33	0.43
Seaver Branch	7/31/2012	0.28	6.65	< 0.2
Seaver Branch	8/28/2012	0.34	9.52	0.72
Seaver Branch	9/5/2012	0.61	**87.8**	**28.9**
Seaver Branch	10/22/2012	-	10.4	1.86
Shalney Branch	4/11/2012	0.4	16.2	2.82
Shalney Branch	5/8/2012	0.3	7.76	0.75
Shalney Branch	6/5/2012	0.29	19.6	*7.69*
Shalney Branch	7/2/2012	0.31	15.7	0.65
Shalney Branch	7/31/2012	0.79	*23.1*	0.66
Shalney Branch	8/28/2012	0.5	*31.7*	1.6
Shalney Branch	9/5/2012	0.67	**228**	**152**
Shalney Branch	10/22/2012	0.25	11	1.84

Site	Date	Total Nitrogen (mg/l)	Total Phosphorus (µg/l)	Turbidity (NTU)
Shattuck Hill	4/11/2012	0.39	12.2	0.73
Shattuck Hill	5/8/2012	0.45	17.4	1.11
Shattuck Hill	6/5/2012	0.58	11	0.55
Shattuck Hill	7/2/2012	0.87	*21.7*	0.4
Shattuck Hill	7/31/2012	0.63	12.4	0.45
Shattuck Hill	8/28/2012	0.67	*22.9*	0.8
Shattuck Hill	9/5/2012	0.51	**79.8**	*6.42*
Shattuck Hill	10/22/2012	0.35	12.2	0.36
Stony Brook	4/11/2012	*1.03*	**122**	**33.1**
Stony Brook	5/8/2012	0.94	14.2	1.05
Stony Brook	6/5/2012	*1.07*	17.8	2.29
Stony Brook	7/2/2012	*1.41*	15.5	1.01
Stony Brook	7/31/2012	*1.38*	13.7	0.92
Stony Brook	8/28/2012	*1.58*	18.9	1.8
Stony Brook	9/5/2012	*1.13*	**123**	**27.5**
Stony Brook	10/22/2012	0.99	17	1.65
Stony Hill	4/11/2012	0.53	14.7	3.47
Stony Hill	5/8/2012	0.44	9.4	1.31
Stony Hill	6/5/2012	0.37	9.96	1.1
Stony Hill	7/2/2012	0.88	12.9	1.24
Stony Hill	7/31/2012	0.98	17.8	1.58
Stony Hill	8/28/2012	0.87	18.8	2.22
Stony Hill	9/5/2012	0.69	**69.6**	**20.8**
Stony Hill	10/22/2012	0.37	11.4	0.74
Trout Brook	4/11/2012	0.66	15.4	4.81
Trout Brook	5/8/2012	0.51	9.97	2.33
Trout Brook	6/5/2012	0.35	12	2.33
Trout Brook	7/2/2012	0.48	12.5	2.23
Trout Brook	7/31/2012	0.38	11.7	1.58
Trout Brook	8/28/2012	0.33	*29*	4.38
Trout Brook	9/5/2012	0.79	**81.6**	**20.9**
Trout Brook	10/22/2012	0.35	10.1	1.28
Upper Brighton Brook North	6/5/2012	**4.03**	**1740**	**11.3**
Upper Brighton Brook North	7/2/2012	**10.7**	**1430**	**13.1**
Upper Brighton Brook North	9/5/2012	**10.4**	**1630**	**14.7**
Upper Brighton Brook North	10/22/2012	**3**	**516**	4.61

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Upper Holbrook Bay South	4/11/2012	0.3	17.1	1.47
Upper Holbrook Bay South	5/8/2012	0.21	13.1	1.36
Upper Holbrook Bay South	6/5/2012	0.23	13.2	0.88
Upper Holbrook Bay South	7/2/2012	0.29	*24.1*	3.33
Upper Holbrook Bay South	7/31/2012	0.42	*31.4*	**13.8**
Upper Holbrook Bay South	9/5/2012	0.67	**90.4**	*5.24*
Upper Holbrook Bay South	10/22/2012	0.23	12.6	0.54
Upper Shalney Branch	4/11/2012	0.39	15.3	3.86
Upper Shalney Branch	5/8/2012	0.29	8.54	1.28
Upper Shalney Branch	6/5/2012	0.28	*23.8*	*9.73*
Upper Shalney Branch	7/2/2012	0.31	8.46	0.44
Upper Shalney Branch	7/31/2012	0.39	8.58	< 0.2
Upper Shalney Branch	8/28/2012	0.51	11.8	0.78
Upper Shalney Branch	9/5/2012	0.55	**248**	**151**
Upper Shalney Branch	10/22/2012	0.2	12	2.71
Upper Wishing Well	4/11/2012	0.6	**44**	3.11
Upper Wishing Well	5/8/2012	0.31	*21.9*	1.48
Upper Wishing Well	6/5/2012	0.47	**42.9**	1.79
Upper Wishing Well	7/2/2012	0.6	*32.7*	1.63
Upper Wishing Well	7/31/2012	0.61	*26.8*	2.52
Upper Wishing Well	9/5/2012	*1.28*	**810**	*9.55*
Upper Wishing Well	10/22/2012	0.64	**68.1**	1.33
Webster Road	4/11/2012	0.42	*33.5*	**10.1**
Webster Road	5/8/2012	0.27	13.4	1.59
Webster Road	6/5/2012	0.25	*22.6*	*7.21*
Webster Road	7/2/2012	0.28	14.9	2.82
Webster Road	7/31/2012	0.35	15	2.12
Webster Road	8/28/2012	0.24	*26.2*	1.85
Webster Road	9/5/2012	*1.17*	**535**	**248**
Webster Road	10/22/2012	0.26	15.1	2.38
Willoughby Falls	4/11/2012	0.4	*27.2*	*7.48*
Willoughby Falls	5/8/2012	0.21	10.6	1.79
Willoughby Falls	6/5/2012	0.2	13	3.25
Willoughby Falls	7/2/2012	0.18	10.8	1.26
Willoughby Falls	7/31/2012	0.3	13.9	1.29
Willoughby Falls	8/28/2012	0.16	10.3	0.51
Willoughby Falls	9/5/2012	*1.11*	**280**	**107**
Willoughby Falls	10/22/2012	0.22	10.2	2.05

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)
Glover Road	4/11/2012	< 0.1	< 5	**0.21**
Stony Hill	4/11/2012	< 0.1	< 5	**0.43**
Webster Road	4/11/2012	< 0.1	< 5	**0.35**
Roaring Brook	5/8/2012	< 0.1	< 5	< 0.2
Robillard Flats	5/8/2012	< 0.1	< 5	< 0.2
Trout Brook	5/8/2012	< 0.1	< 5	< 0.2
Hogtrough Brook	6/5/2012	< 0.1	< 5	< 0.2
Holbrook Bay South	6/5/2012	< 0.1	< 5	< 0.2
Upper Shalney Brook	6/5/2012	< 0.1	< 5	< 0.2
Roaring Brook	7/2/2012	< 0.1	< 5	< 0.2
Robillard Flats	7/2/2012	< 0.1	< 5	< 0.2
Trout Brook	7/2/2012	< 0.1	< 5	< 0.2
Ethan Allen	7/31/2012	< 0.1	< 5	< 0.2
Shalney Brook	7/31/2012	< 0.1	< 5	< 0.2
Upper Holbrook Bay South	7/31/2012	< 0.1	< 5	**0.2**
Country Club	8/28/2012	< 0.1	< 5	< 0.2
Shalney Branch	8/28/2012	< 0.1	< 5	< 0.2
Trout Brook	8/28/2012	< 0.1	< 5	< 0.2
Post Road	9/5/2012	< 0.1	< 5	< 0.2
Upper Brighton Brook North	9/5/2012	< 0.1	< 5	< 0.2
Willoughby Falls	9/5/2012	< 0.1	< 5	< 0.2
Churchill Lane	10/22/2012	< 0.1	< 5	< 0.2
Seaver Branch	10/22/2012	-	< 5	< 0.2
Stony Brook	10/22/2012	-	< 5	< 0.2

Field Duplicates:

<u>Total Nitrogen</u>

Site	Date	1st Total Nitrogen (mg/l)	2nd Total Nitrogen (mg/l)	Relative % Difference
Glover Road	4/11/2012	0.33	0.33	0
Stony Hill	4/11/2012	0.53	0.48	10
Webster Road	4/11/2012	0.42	0.42	0
Roaring Brook	5/8/2012	0.28	0.27	4
Robillard Flats	5/8/2012	0.43	0.44	2
Trout Brook	5/8/2012	0.51	0.5	2
Hogtrough Brook	6/5/2012	0.24	0.27	12
Holbrook Bay South	6/5/2012	0.45	0.49	9
Upper Shalney Brook	6/5/2012	0.28	0.33	16
Roaring Brook	7/2/2012	0.22	0.21	5
Robillard Flats	7/2/2012	0.63	0.61	3
Trout Brook	7/2/2012	0.48	0.45	6
Ethan Allen	7/31/2012	0.34	0.31	9
Shalney Branch	7/31/2012	0.79	0.78	1
Upper Holbrook Bay South	7/31/2012	0.42	0.42	0
Country Club	**8/28/2012**	**0.28**	**0.22**	**24**
Shalney Branch	8/28/2012	0.5	0.5	0
Trout Brook	**8/28/2012**	**0.33**	**0.26**	**24**
Post Road	9/5/2012	1.38	1.53	10
Upper Brighton Brook North	9/5/2012	10.4	11.2	7
Willoughby Falls	9/5/2012	1.11	1.15	4
Churchill Lane	10/22/2012	0.22	0.21	5

Total Phosphorus

Site	**Date**	**1st Total Phosphorus (µg/l)**	**2nd Total Phosphorus (µg/l)**	**Relative % Difference**
Glover Road	4/11/2012	13	14.1	8
Stony Hill	4/11/2012	14.7	15.2	3
Webster Road	4/11/2012	33.5	33.2	1
Roaring Brook	5/8/2012	17.2	17.6	2
Robillard Flats	5/8/2012	14.6	15.8	8
Trout Brook	5/8/2012	9.97	10.5	5
Hogtrough Brook	6/5/2012	11.3	11	3
Holbrook Bay South	6/5/2012	45.5	44.3	3
Upper Shalney Brook	6/5/2012	23.8	24.7	4
Roaring Brook	7/2/2012	12.7	11.6	9
Robillard Flats	7/2/2012	26.8	28.4	6
Trout Brook	7/2/2012	12.5	12.2	2
Ethan Allen	7/31/2012	10.2	9.86	3
Shalney Branch	7/31/2012	23.1	24.8	7
Upper Holbrook Bay South	7/31/2012	31.4	31.1	1
Country Club	8/28/2012	12.6	12.9	2
Shalney Branch	8/28/2012	31.7	31.9	1
Trout Brook	8/28/2012	29	28.1	3
Post Road	9/5/2012	346	351	1
Upper Brighton Brook North	9/5/2012	1630	1650	1
Willoughby Falls	9/5/2012	280	286	2
Churchill Lane	10/22/2012	10.5	9.8	7
Seaver Branch	10/22/2012	10.4	9.88	5
Stony Brook	10/22/2012	17	16.2	5

Turbidity

Site	Date	1st Turbidity (NTU)	2nd Turbidity (NTU)	Relative % Difference
Glover Road	**4/11/2012**	**2.39**	**3.52**	**38**
Stony Hill	4/11/2012	3.47	3.16	9
Webster Road	**4/11/2012**	**10.1**	**8.38**	**19**
Roaring Brook	5/8/2012	2.5	2.7	8
Robillard Flats	**5/8/2012**	**1.94**	**2.42**	**22**
Trout Brook	**5/8/2012**	**2.33**	**1.5**	**43**
Hogtrough Brook	6/5/2012	1.64	1.6	2
Holbrook Bay South	6/5/2012	9.5	8.48	11
Upper Shalney Brook	6/5/2012	9.73	9.76	0
Roaring Brook	**7/2/2012**	**0.58**	**0.68**	**16**
Robillard Flats	7/2/2012	4	3.91	2
Trout Brook	7/2/2012	2.23	2.2	1
Ethan Allen	7/31/2012	0.74	0.69	7
Shalney Branch	7/31/2012	0.66	0.62	6
Upper Holbrook Bay South	7/31/2012	13.8	14.1	2
Country Club	**8/28/2012**	**0.45**	**0.2**	**77**
Shalney Branch	**8/28/2012**	**1.6**	**2.3**	**36**
Trout Brook	8/28/2012	4.38	4.32	1
Post Road	**9/5/2012**	**83**	**112**	**30**
Upper Brighton Brook North	9/5/2012	14.7	14.7	0
Willoughby Falls	**9/5/2012**	**107**	**25.6**	**123**
Churchill Lane	10/22/2012	1.44	1.45	1
Seaver Branch	10/22/2012	1.86	1.76	6
Stony Brook	**10/22/2012**	**1.65**	**1.12**	**38**

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.

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