Restoring Water Quality in the Lake Memphremagog Basin:

Black River Protection and Restoration Project

Prepared for Memphrémagog Conservation Inc., Orleans County Natural Resources Conservation District, Northeastern Vermont Development Association, and the Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

15 February 2011

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 accomplishes this mission through public education, water quality monitoring, shoreline cleanup and renaturalization, and protection of local wildlife. Specific projects include 1) promoting ecological awareness of the people who live in, work in, and visit the Lake Memphremagog Basin and enjoy all that it offers; 2) informing and educating the public and promoting participation in efforts to preserve the environment and natural beauty of the basin; 3) working with other lake associations; local, state and federal governments; and businesses to develop guidelines and policies that protect and improve the quality of life in and around the basin; and 4) participating in efforts to monitor water quality in the lake and its tributaries, cleanup and renaturalize lake and river shorelines, and protect local wildlife.

Beck Pond LLC

Founded in 2009, Beck Pond LLC partners with public agencies and nonprofit organizations to conduct scientific research that increases our understanding of and informs on-the-ground actions to protect and restore the natural environment of northern New England and adjacent Canada. Beck Pond LLC is a limited liability company organized in the state of Vermont and is owned and operated by Dr. Fritz Gerhardt. Dr. Gerhardt has been working as an ecologist and conservation scientist since 1987 and has a wealth of experience applying ecological research to the conservation and restoration of natural ecosystems. He completed his B.A. in Religious Studies at Grinnell College, his M.F.S. in Forest Ecology at Harvard University, and his Ph.D. in Community Ecology at the University of Colorado. He has also worked with the U.S. Fish and Wildlife Service in Alaska, Harvard Forest in Massachusetts, and the Vermont Institute of Natural Science and NorthWoods Stewardship Center in Vermont. Dr. Gerhardt is dedicated to conducting scientific research that not only increases our understanding of the natural environment but also informs science-based conservation. Among other projects, he has conducted scientific studies to assess the impacts of historical land uses and invasive plants on native plant communities; to protect and improve water quality in the Lake Memphremagog Basin and White River Watershed; to protect and restore floodplain forests and wetlands along the Connecticut River and its tributaries; and to identify and protect wildlife habitat corridors across northern New England and eastern Canada.

Cover. *Black River flowing north of Wylie Hill Road in Albany, Vermont on 7 July 2010. Much of the floodplain of the Black River is currently used for agriculture, mostly as cropland and hayfields like those pictured here. If not properly buffered, these land uses can encroach on and harm water quality and habitat quality along rivers and wetlands.*

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Acknowledgments

This project would not have been possible without the actions and support of many individuals and organizations. Annalei Babson, Gisèle Benoit, King Boyd, Dayna Cole, Ben Copans, Don Hendrich, Neil Kamman, and Johanne Lavoie were all instrumental in developing and implementing this project. Ben Copans participated in all aspects of this project, including obtaining funding and support from the LaRosa Analytical Laboratory, designing and implementing the study, collecting water samples, compiling and analyzing the data, and calculating stream flows and nutrient loads for the sample sites. Neil Kamman, Jim Kellogg, and Jerry Divincenzo enabled establishment of the Analytical Services Partnership with the LaRosa Analytical Laboratory to fund analyses of the water samples. Dan McAvinney and Alison Farnsworth provided valuable administrative and logistical support in terms of analyzing the water samples at the LaRosa Analytical Laboratory. Numerous individuals helped collect water samples: Bob Bowman, Ginnie Bowman, King Boyd, Don Chapdelaine, Ben Copans, Karen Lippens, Jim Ryan, Jack Watson, and Susan Watson. Numerous landowners graciously gave us permission to sample water quality on their properties. Memphrémagog Conservation Inc., the Vermont Agency of Natural Resources, and the Northeastern Vermont Development Association provided financial support for this project. The assistance and support of all of these individuals and organizations are greatly appreciated.

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Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially high phosphorus and turbidity levels and more frequent and widespread occurrences of algal and cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, previous studies have focused on identifying the sources of nutrients and sediments originating along the Vermont tributaries of the lake. These studies have identified the Black River, Johns River, and several smaller tributaries as potentially important sources of the high phosphorus, nitrogen, and sediment levels.
2. In 2010, we measured water quality at 33 sites distributed throughout the watersheds of the Black River, Johns River, and four smaller tributaries of Lake Memphremagog. The goal of these efforts was to further identify and assess potential sources of phosphorus, nitrogen, and sediment flowing into the Southern Basin of Lake Memphremagog. To accomplish this goal, we collected and analyzed water samples for total phosphorus, total nitrogen, and turbidity. In addition, we measured water depth at numerous sites and stream flow at one site along the Johns River.
3. Through this sampling, we identified a number of areas that were potential sources of the high nutrient and sediment levels flowing into Lake Memphremagog. Along the Black River, phosphorus levels were highest along the main stem between the villages of Craftsbury and Albany and along four tributaries (Brighton, Shalney, and Stony Brooks and Lords Creek). Along the three smaller tributaries flowing directly into Lake Memphremagog, median total phosphorus concentrations were higher in the southern vs. the northern branch of the Holbrook Bay tributary, the upper vs. the lower site of the Wishing Well tributary, and the lower vs. upper sites of the Strawberry Acres tributary. Along the Johns River, reduced phosphorus levels at the Johns River site in 2010 confirmed that past remediation efforts have effectively reduced phosphorus levels flowing out of Crystal Brook; however, high phosphorus levels at the downstream-most site (North Derby Road) indicated that high phosphorus levels continued to flow into Lake Memphremagog. Finally, nitrogen levels in the Johns River and adjacent watersheds were similar to those observed in 2009 but remained lower than those observed in previous years.
4. Collectively, these data greatly increased our understanding of water quality problems and their sources along the Vermont tributaries of Lake Memphremagog. However, additional studies are needed to further pinpoint the sources of the elevated phosphorus levels along the main stem and four tributaries of the Black River and the downstream-most section of the Johns River. In the meantime, protection and restoration projects can be undertaken to reduce nutrient and sediment inputs in several areas, where specific problems were identified through this study.

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 incidence 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 nutrient and sediment inputs are responsible for increasing plant and algal growth and decreasing 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 inputs and suggest that water quality is declining in Lake Memphremagog.*

Lake Memphremagog and its tributaries support a wide array of recreational opportunities, 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 2008a, 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 phosphorus pollution, nutrient enrichment, and excessive algal growth (Part A, State of Vermont 2008a). 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 2008a). The Southern Basin is fed by three major 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 smaller tributaries that flow directly into the lake. All four of the larger tributaries have been identified as priority surface waters outside the scope of Clean Water Act Section 303(d). Identified threats include elevated phosphorus and nitrogen levels, elevated mercury levels in walleye, contamination by *Escherichia coli*, the presence of toxins and solvents, invasions of Eurasian watermilfoil (*Myriophyllum spicatum*), and altered stream flows (State of Vermont 2008a).

Efforts to assess these 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 Vermont and Quebec. 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 and support 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, determining whether a comprehensive pollution control plan was needed 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 agencies and non-governmental organizations (Quebec/Vermont Steering Committee 2008). The Quebec Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP) and Memphrémagog Conservation Inc. (MCI) have been monitoring water quality in the open waters of Lake Memphremagog in Quebec since 1996. The Vermont Department of Environmental Conservation (DEC) has been monitoring water quality in the open waters of the lake in Vermont and the outlets of the Barton, Black, and Clyde Rivers since 2005. Since 1999, the Municipalités régionales de comté (MRC) de Memphrémagog has been monitoring water quality in the tributaries draining the Quebec portion of the Lake Memphremagog Basin. Since 2005, the NorthWoods Stewardship Center, Memphremagog Watershed Association, and Beck Pond LLC have been partnering with the Vermont DEC to monitor water quality in the tributaries draining the Vermont portion of the basin. 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 major Vermont tributaries of Lake Memphremagog.

Although 73% of Lake Memphremagog is located in Quebec, 71% of the watershed is located 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 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 smaller 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 starting in the summer of 2009. Replacing the failed manure lagoon and curtailing the runoff from the silage storage area dramatically improved water quality conditions along Crystal Brook and further downstream. Through these studies, we were also able to pinpoint 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. This result supported our hypothesis that the high nitrogen levels were arising from nitrogen that leached into the groundwater from manure or synthetic fertilizers applied to cornfields located atop porous sand and gravel deposits. In addition, high phosphorus and sediment levels were measured in five of the seven smaller tributaries that flowed directly into Lake Memphremagog, including all four located at the southern end of the lake in Newport City and Newport Town.

Study Goals

In 2010, we continued our efforts to identify and assess threats to water quality and to identify and implement protection and restoration projects along the Vermont tributaries of Lake Memphremagog. In this year's project, the Memphremagog Watershed Association, Vermont DEC, and Beck Pond LLC partnered to sample water quality along the Black River, one of the three largest tributaries of Lake Memphremagog in Vermont. This river has been targeted as a high priority for assessment due to the elevated phosphorus and sediment levels that were observed 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). As part of this project, we also continued to assess and monitor phosphorus and nitrogen levels along the Johns River and four smaller tributaries of Lake Memphremagog, all of which had exhibited high nutrient and sediment levels previously (Gerhardt 2009, 2010). Thus, the overall goal of this project was to assess water quality conditions in the watersheds of the Black River, the Johns River, and four smaller tributaries of Lake Memphremagog and to further identify the sources of water quality problems in those watersheds, so that we can develop and implement protection and restoration projects to reduce nutrient and sediment inputs into Lake Memphremagog.

The specific goals of this year's project were four-fold:

1) To identify specific locations along the Black River and its tributaries where phosphorus and sediment were entering the surface waters,

2) To further pinpoint phosphorus and sediment sources along three smaller tributaries of Lake Memphremagog, where high nutrient and turbidity levels were observed in 2008-2009,

3) To continue monitoring phosphorus levels along the Johns River to verify that past remediation efforts have effectively reduced phosphorus levels flowing out of Crystal Brook and into Lake Memphremagog,

4) To continue monitoring long-term trends in nitrogen levels along the Johns River and adjacent tributaries, where extremely high nitrogen levels were observed previously.

To accomplish these goals, we measured water quality at 33 sites distributed throughout the watersheds of the Black River, Johns River, and four smaller tributaries of Lake Memphremagog. The geographic distribution of these sites allowed us to address these four goals and to develop recommendations for projects that will ultimately protect and restore the most degraded rivers and streams flowing into Lake Memphremagog.

Study Area

The Lake Memphremagog Basin is located in the Northeast Kingdom of Vermont and the Eastern Townships of Quebec and is a tributary watershed of the St. Francis River, which flows into the St. Lawrence River. As noted previously, the Southern Basin of Lake Memphremagog is fed by three major tributaries that lie entirely within Vermont (the Black, Barton, and Clyde Rivers) and one medium-sized tributary that straddles the Quebec/Vermont border (the Johns River). In addition, numerous smaller 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 to its mouth at the southern end of South Bay near Newport City. 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 2008a). Brownington Pond in Brownington is listed as a priority surface water altered by exotic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2008a). 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 in Glover is listed as a priority surface water altered by flow regulation due to seasonal water level fluctuations that may impact aquatic habitat and aesthetics (Part F, State of Vermont 2008a). In 2010, we sampled water quality at one site along the lower main stem of the Barton River.

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 to its mouth at South Bay near 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 2008a). Lake Elligo in Greensboro is listed as a priority surface water altered by exotic species due to locally abundant Eurasian watermilfoil (Part E, State of Vermont 2008a). Rapidly expanding populations of several other invasive species (purple loosestrife, common reed, and Japanese knotweed) also occur throughout the watershed. In 2010, we sampled 21 sites along the main stem and all of the larger tributaries of the Black River.

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 to its mouth in Newport City. The watershed includes two large tributaries (the Pherrins River and Seymour Lake Outlet) 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, 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 2008a). 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 2008a). 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 2008a). Lake Salem in Derby is also infested by Eurasian watermilfoil (Ann Bove, personal communication), and 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 2008a). 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. In 2010, we sampled water quality at one site near the mouth of the Clyde River.

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 small 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 listed as a priority surface water in need of further assessment due to elevated nitrogen levels that may be impacting fish communities (Part C, State of Vermont 2008a). In addition, Crystal Brook in Derby, which is one of the three main tributaries of the Johns River, is listed as an impaired surface water needing a TMDL due to excessive sediments and nutrients from agricultural runoff (Part A, State of Vermont 2008a). In 2010, we sampled water quality at three sites in the Johns River Watershed.

In addition to these four larger tributaries, the Southern Basin of Lake Memphremagog is fed by numerous smaller 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 2008a). In 2010, we sampled water quality at seven sites along four of these tributaries: the Sunset Acres tributary, which flows from Darling Hill on the eastern shore into Derby Bay; the Holbrook Bay tributary, which flows from Coburn Hill on the western shore into Holbrook Bay; the Strawberry Acres tributary, which flows from Coburn Hill on the western shore into the southern end of the lake; and the Wishing Well tributary, which flows from the southern shore into the southern end of the lake.

Methods

In this project, we sampled water quality at 33 sites distributed throughout the watersheds of the Black River, Johns River, and four smaller tributaries of Lake Memphremagog (Figure 3; see Appendix A for descriptions of all sites). To better pinpoint possible phosphorus and sediment sources in the Black River Watershed, we sampled water quality at six sites along the main stem and 15 sites along the major tributaries of the Black River. All sites along the main stem (Black River, Coventry Bridge, Irasburg, Griggs Pond, Rogers Branch, and Craftsbury) were sampled previously in 2005 and/or 2006, but only one site along the tributaries (Lords Creek) was sampled previously (2005-2006). All of the sites along the major tributaries were located near their confluences with the Black River, so that we could identify specific tributaries that were sending large amounts of nutrients and sediments into the Black River. Along the four smaller tributaries that flow directly into Lake Memphremagog, we sampled water quality at seven sites: Three of the sites (Strawberry Acres, Wishing Well, and Sunset Acres) were sampled previously in 2008-2009, and one site (Upper Wishing Well) was sampled in 2009. Three new sites were added along the Holbrook Bay and Wishing Well tributaries (Holbrook Bay North, Holbrook Bay South, and Upper Strawberry Acres) to better pinpoint phosphorus sources in these watersheds. In the Johns River Watershed, we sampled water quality at three sites, all of which had been sampled previously (Johns River in 2005-2006 and 2008-2009 and North Derby Road and Darling Hill in 2006 and 2008-2009). Finally, we also sampled water quality at three sites near the mouths of the three major tributaries of Lake Memphremagog (Barton, Black, and Clyde Rivers), which have been sampled by the Vermont DEC since 2005.

To accomplish the goals of this study, we sampled water quality at all 33 sites on seven dates every four weeks during 14 April-29 September 2010 (the three DEC-maintained sites were also sampled on additional dates and for a longer sampling season). Since only one high-flow event occurred on the seven, regularly-scheduled sample dates, we also sampled a high-flow event on one other date, since both phosphorus and sediment levels typically are highest during these events. On two dates with extremely low flows, no samples were collected at the following sites: Rogers Tributary (7 July and 1 September), McCleary Brook (1 September), and Strawberry Acres (1 September).

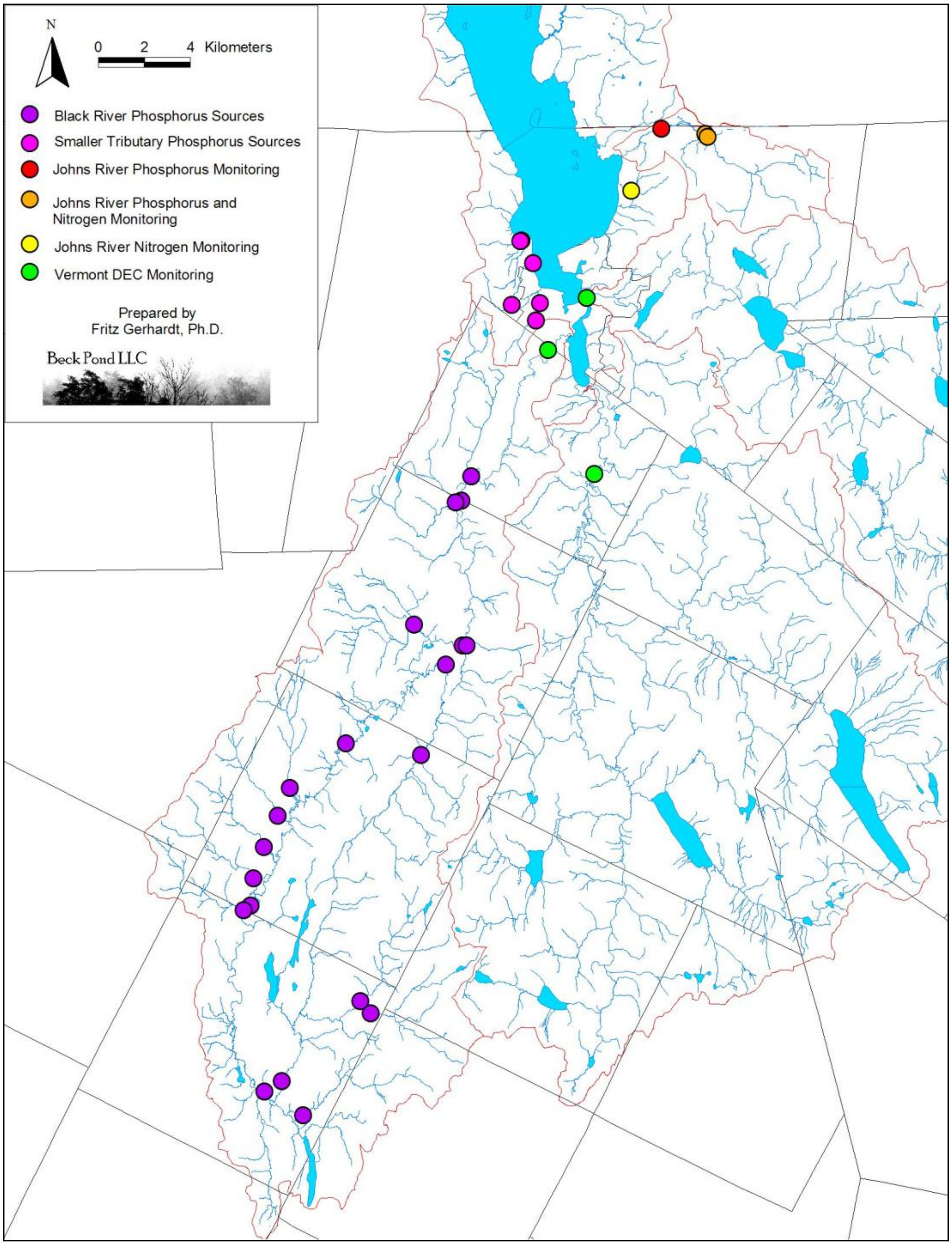


Figure 3. *Locations of the 33 sites sampled along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010.*

On each sample date, we measured water depth with a meter stick at seven sites along the four smaller tributaries, three sites in the Johns River Watershed, and 11 sites along the Black River and its tributaries. We also measured stream flow on several sample dates near the Johns River site with a SonTek Acoustic Doppler Flowtracker (SonTek, San Diego, CA). In order to develop a continuous record of stream flow, we also placed a data logger (YSI 600 LS vented sonde; YSI, Yellow Springs, Ohio) that recorded water depths every 20 minutes near the Johns River site. Using the stream flow and water depth measurements, we developed a rating curve that allowed us to estimate flow levels for the entire sampling season. In addition, the U.S. Geologic Survey maintains gauge stations that measure water depths and stream flows on the Barton, Black, and Clyde Rivers. When combined with the phosphorus and nitrogen concentrations, these flow measurements will ultimately allow us to calculate daily phosphorus and nitrogen loads for each sample site.

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 for quality assurance analyses. 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 :g/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.2 NTU for turbidity). Field duplicates involved 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.

Both field and laboratory data were entered into Microsoft Excel spreadsheets. All data sheets and analyses were archived by the author, and electronic copies were submitted to the Vermont DEC.

Results and Discussion

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

Stream Flow

Stream flow measures the volume of water passing a specific location per unit of time and is calculated by multiplying the 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 gauge 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 by the Vermont DEC on the Johns River. As in 2009, stream flows were generally at or near base-flow levels throughout much of the 2010 sampling season (Figure 4). As in 2009, spring snowmelt and the associated high flows occurred extremely early this year (mid- to late March). Stream flows did peak on numerous dates, primarily following heavy rains in the summer and autumn (Figure 5). Peak flows occurred on 7 June (Black River only), 28 June, 10 July (Johns River only), 2-5 August, and 1 October (the differences between the two rivers likely reflected the localized nature of the precipitation events and/or the different amounts of time that it takes the two rivers to fill with runoff from rainfall event). However, even after those heavy rains and the associated high flows, water levels quickly returned to base-flow levels. Correspondingly, five of our eight sample dates occurred during low flows; however, we did collect water samples during high flows on one regularly-scheduled sample date (3 August) and on another targeted sample date (28 June). We also collected water samples during intermediate flows on a third, regularly-scheduled sample date (29 September). Collecting water samples across this range of flows allowed us to better identify and assess potential nutrient and sediment sources in these watersheds.

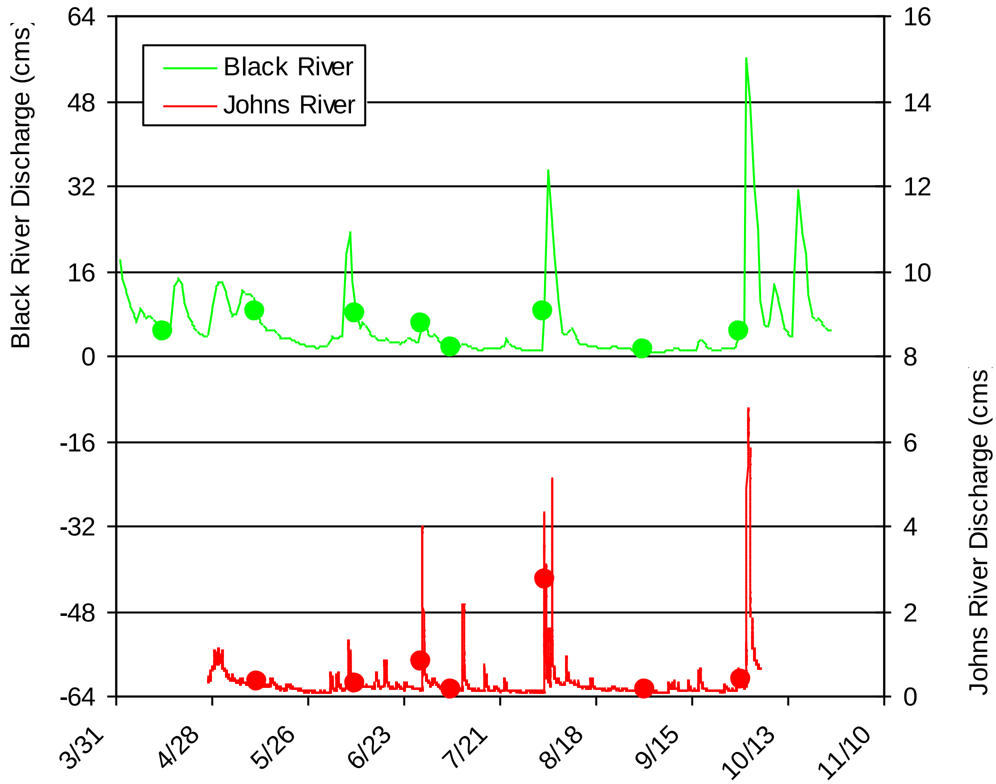


Figure 4. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2010. The eight dates on which water samples were collected are indicated by the circles on the two graphs. Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, VT)]; stream flows for the Johns River were measured by the Vermont DEC.*

Seasonal patterns in water levels have varied dramatically among the five years that we have been sampling water quality in the Vermont tributaries of Lake Memphremagog (Figure 6). In 2005, water levels were low in spring and late summer, moderately high in early summer, and highest in October, when heavy rains caused widespread but minor flooding (Gerhardt 2006). In 2006, water levels were highest in May when heavy rains fell on soils already saturated by spring snowmelt, decreased throughout the summer, and rose again in the autumn (Dyer and Gerhardt 2007). In 2008, water levels were highest in the spring and generally low throughout summer and autumn, except following heavy rains in early August (Gerhardt 2009). In 2009, water levels were generally low throughout the sampling season, except following heavy rains in June, July, and October (Gerhardt 2010). Finally, in 2010, water levels were generally low throughout the sampling season, except following heavy rains during June, August, and, to a lesser extent, October.

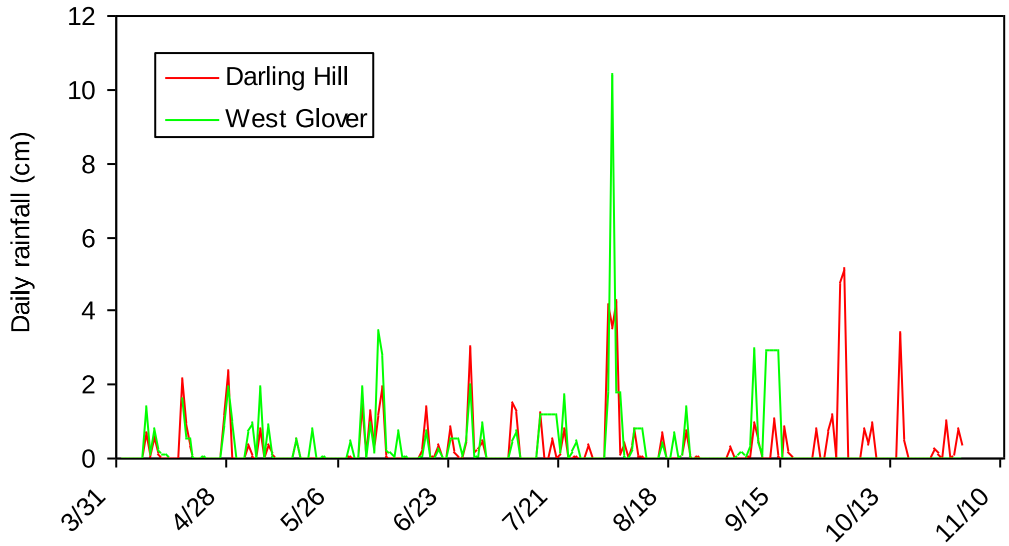


Figure 5. *Daily rainfall measured at two automated weather stations in Derby Line, Vermont [Darling Hill Road (KVTNEWPO4)] and West Glover, Vermont [Downtown West Glover (KVTWESTG1)] during April-October 2010. The Derby Line station is located along the eastern shore of Lake Memphremagog just south of the Johns River Watershed. The West Glover station is located in the southern (upper) end of the Barton River Watershed. Data were downloaded from http://www.wunderground.com. No data were available for one week in June from the Derby Line station and for the last month from the West Glover station.*

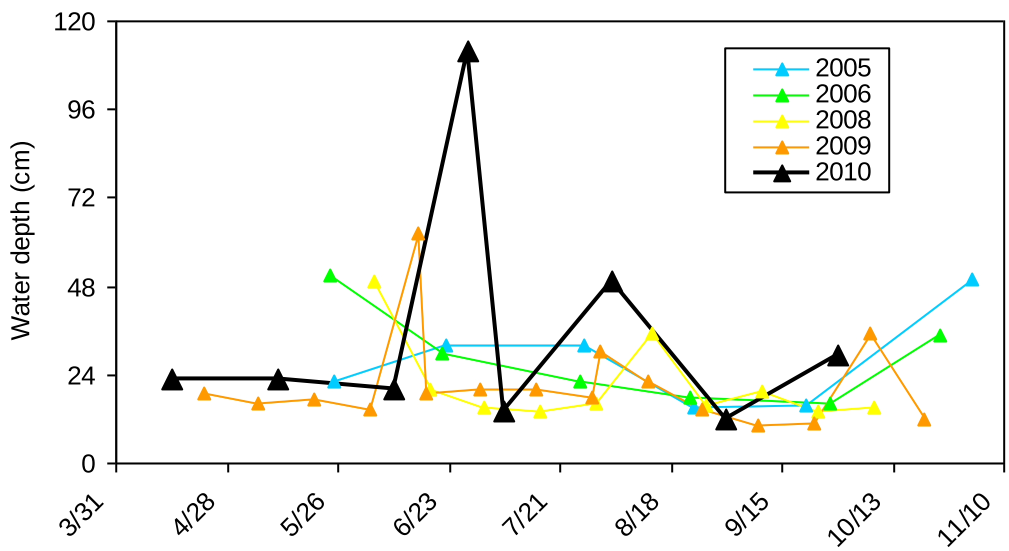


Figure 6. *Water depths at the Johns River site on each sample date during 2005-2010.*

This seasonal and annual variation in stream flows reflects the dynamic nature of stream flow and its sensitivity to both short- and long-term changes in temperature and precipitation. In this region, stream flows generally are greatest following spring snowmelt and secondarily during the autumn, when lower temperatures decrease evaporation rates and plants no longer photosynthesize and transpire water. In contrast, stream flows are generally lowest during late summer when evaporation and transpiration rates are highest even though precipitation levels are typically higher then also (often in the form of heavy downpours during thunderstorms). In our sampling, this seasonal pattern was most evident in 2006 and least evident in 2009 and 2010 (Figure 6). In 2009-2010, little snow fell in late winter (February and March), and the spring thaw and associated snowmelt and runoff occurred earlier than in other years. In addition, precipitation levels in 2009 were very low during May and again in August. During 2008-2010, water levels reached base-flow conditions for much of the summer, and, even following heavy rains, they either would not reach peak levels or would peak quickly and then return to base-flow levels, presumably due to less groundwater and other inputs, which were depleted by the dry spring and lack of snowmelt.

This seasonal and annual variation has greatly affected our ability to consistently sample moderate- and high-flow events and to identify and assess water quality problems, especially those originating from nonpoint sources. Because we sampled water quality according to a regular schedule each year, this seasonal and annual variation in stream flow meant that we sampled only one high-flow event (i.e. water depth >45 cm at the Johns River site) and 1-2 moderate-flow events (i.e. water depth 25-45 cm) each year. On the remaining 3-12 sample dates each year, we sampled water quality during low flows (i.e. water depth <25 cm). Thus, our sampling has been heavily biased towards low flows, which are informative in regards to nutrients and sediments originating from point and groundwater sources but less so for those originating from nonpoint sources, which are far more important at moderate and high flows and typically generate the majority of the sediment and nutrient pollution exported from these watersheds. Thus, in 2010, we did target a second high-flow event outside of our regularly-scheduled sampling to better sample nutrient and sediment levels under high-flow conditions.

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 growing in northern freshwater aquatic ecosystems. Consequently, high phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to oxygen depletion and 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 5.12-989 :g/l and showed no marked seasonal pattern, except possibly a slight increase from spring to autumn (Figure 7). This lack of a seasonal pattern may reflect the generally low flows observed throughout the sampling season, especially in the spring, and the consequent lack of surface runoff carrying sediment and nutrients into water bodies. As expected, the highest total phosphorus levels were observed on the two sample dates with the highest stream flows (28 June and 3 August). Both median and individual phosphorus concentrations were generally much greater on those than the other sample dates. The next highest median total phosphorus concentrations occurred on 29 September, which was the one moderate-flow event sampled in 2010.

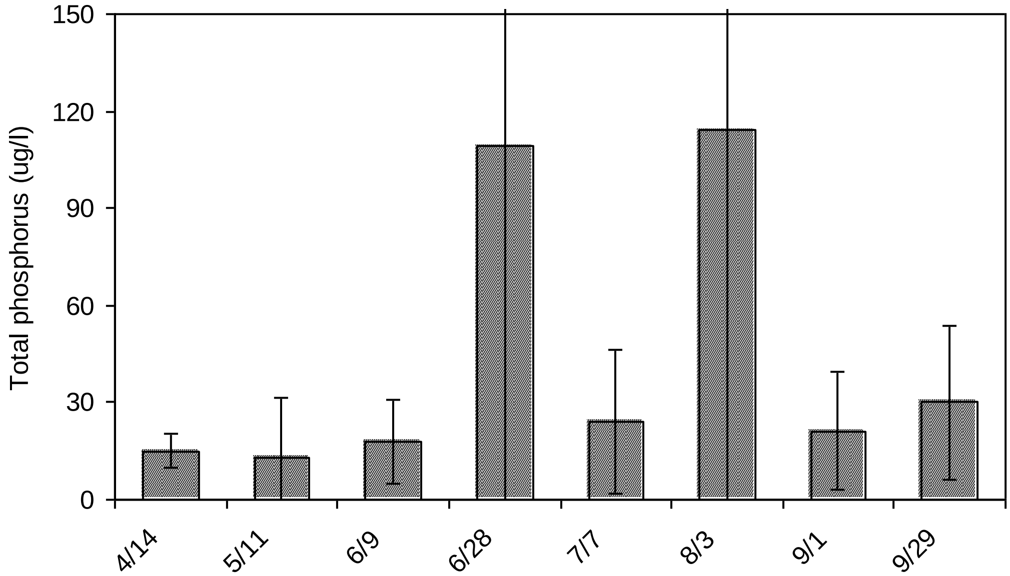


Figure 7. *Median total phosphorus concentrations (∀1 SD) measured on each sample date at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010.*

In 2010, we sampled total phosphorus to accomplish three objectives: 1) to identify possible phosphorus sources along the Black River and its tributaries, 2) to further pinpoint phosphorus sources along three smaller tributaries that flow directly into Lake Memphremagog, and 3) to continue monitoring phosphorus levels along the Johns River, where the highest phosphorus levels were measured previously.

Black River

In order to identify areas in the Black River Watershed that were possible sources of the high phosphorus levels flowing into Lake Memphremagog, we measured total phosphorus at six sites along the main stem and 15 sites along 14 of the larger tributaries of the Black River (Figure 8-9). Total phosphorus concentrations were generally high (median values >20 :g/l) throughout much of the length of the main stem of the Black River, especially in Newport, Irasburg, and Albany but not in Craftsbury (the upstream-most site on the main stem). Of the major tributaries, Shalney Brook, Stony Brook, Brighton Brook, and Upper Lords Creek exhibited the highest phosphorus levels. All four of these tributaries drained areas of diverse land uses, including large areas of agriculture on Shalney and Brighton Brooks and Upper Lords Creek and large areas of agriculture and gravel mining on Stony Brook. In contrast, two tributaries that drained the forested slopes of Lowell Mountain (Lamphear and McCleary Brooks) exhibited the lowest total phosphorus concentrations (median values <10 :g/l).

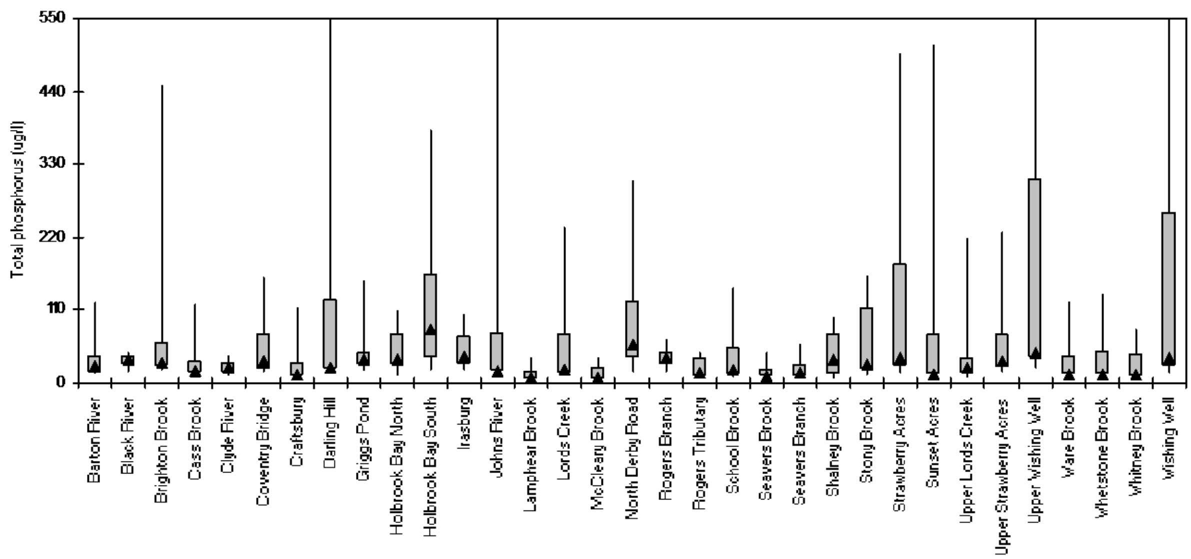


Figure 8. *Total phosphorus concentrations at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

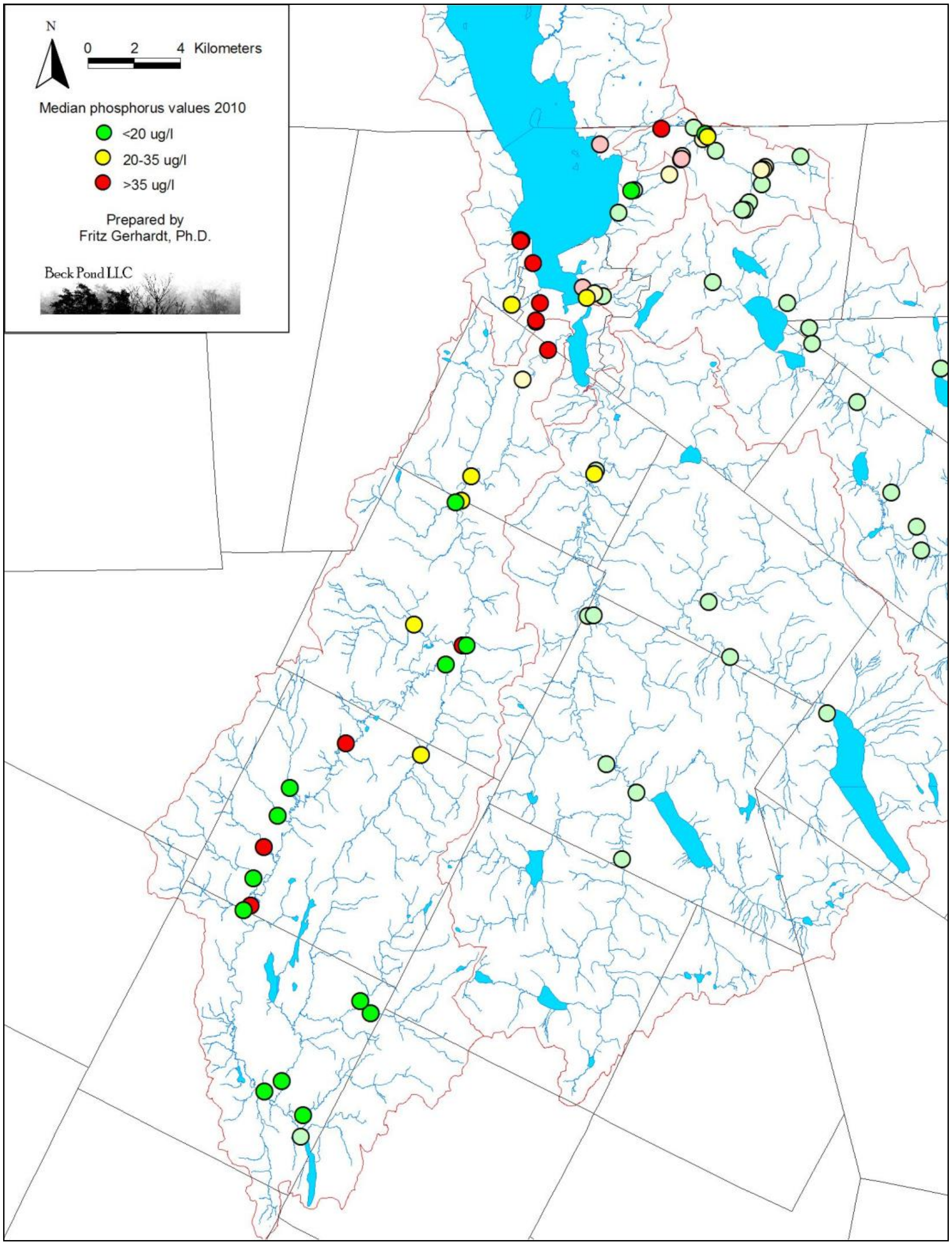


Figure 9. *Median total phosphorus concentrations at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. The faint dots depict sites sampled in previous years but not in 2010.*

Along the main stem of the Black River, median total phosphorus concentrations showed the greatest increase between the Craftsbury and Rogers Branch sites and remained high from there downstream to the mouth of the Black River (Figure 10). This pattern paralleled that observed in 2005-2006, although, in those two years, total phosphorus concentrations did not rise as dramatically between Craftsbury and Rogers Branch but did rise again between Coventry Bridge and the mouth of the Black River. Between the Craftsbury and Rogers Branch sites, the main stem is fed by only two larger tributaries (Cass Brook and the outlet of Lake Elligo), both of which exhibited relatively low total phosphorus concentrations, and many smaller tributaries. Thus, much of the phosphorus likely originates from the floodplain and uplands bordering this stretch of the main stem. Among other land uses, this stretch of the main stem passes through the village of Craftsbury with its associated commercial and residential development, large areas of agriculture on both the floodplain and adjacent uplands, large areas of fallow fields, and abundant wetlands and forests. Thus, likely sources of phosphorus include runoff from paved and gravel roads, lawns, gardens, and agricultural fields.

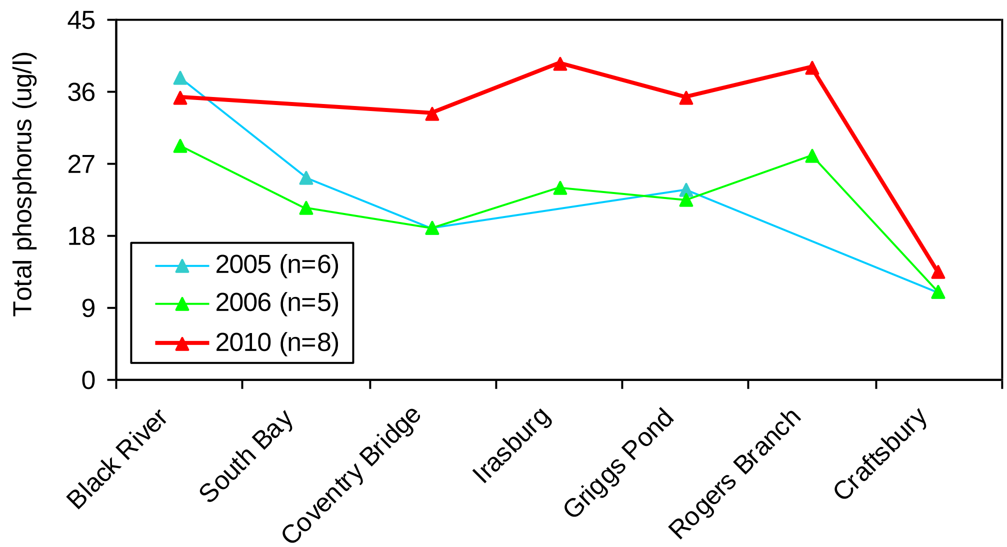
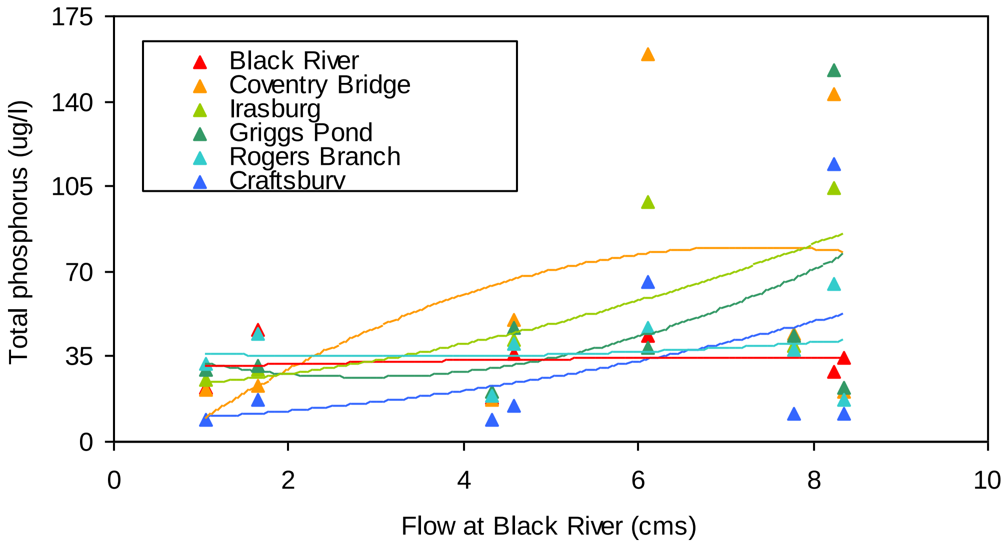


Figure 10. *Median total phosphorus "profile" along the main stem of the Black River from Craftsbury downstream to its mouth during 2005-2010. The sample size (n) is the number of dates sampled each year (note that individual sites were sampled 1-3 years during 2005-2010).*

At most sites along the Black River and its tributaries, total phosphorus concentrations generally increased with increasing water depth. This pattern was evident for all of the sites located along the main stem of the Black River, except the downstream-most site, which drained a large wetlands as well as the entire watershed (Figure 11a). This pattern was also evident for three of the four tributaries with the highest phosphorus levels (Stony and Brighton Brooks and Upper Lords Creek; Figure 11b). This positive relationship is fairly typical of rivers and streams in which most of the phosphorus originates from nonpoint sources, such as runoff from agricultural fields and urban and suburban areas (Figure 12). In contrast, phosphorus levels in the other tributary with high phosphorus levels (Shalney Brook) exhibited more curvilinear relationships (Figure 11b). At this site, phosphorus levels decreased with increasing water depths at low flows but increased with increasing water depths at higher flows. Such curvilinear relationships are more typical of streams with a combination of point and nonpoint sources of phosphorus. At Shalney Brook, we observed cattle grazing in the stream itself; and a cattle crossing, barnyard, and manure lagoon were all located just upstream of the sample site. All of these land uses may have contributed to the higher phosphorus levels measured in this stream.



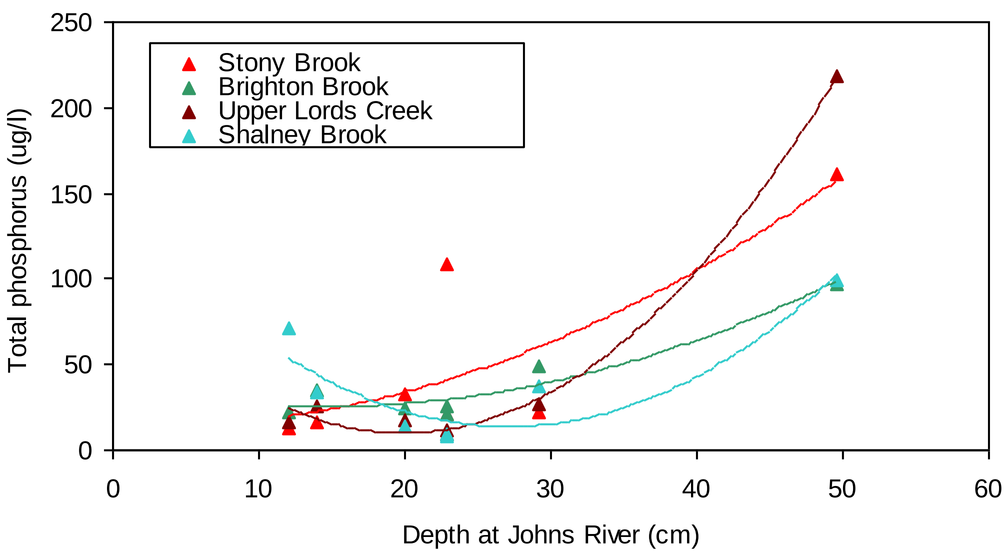


Figure 11. *Total phosphorus concentrations in relation to water level along a) the main stem and b) four tributaries of the Black River during April-September 2010. The regression lines indicate the polynomial relationships between the two parameters.*

Figure 12. *The large area of cropland drained by Brighton Brook near Irasburg, Vermont may contribute to the high phosphorus levels measured in this tributary (photographed on 7 July 2010).*

Smaller Tributaries

Another objective of this study was to further pinpoint possible phosphorus sources along three smaller tributaries that flow directly into Lake Memphremagog. Although small, these tributaries all exhibited some of the highest phosphorus levels measured during 2008-2009, and they all deliver their phosphorus loads directly into the open waters of Lake Memphremagog. Specifically, we focused our efforts on three smaller tributaries located at the southwestern corner of Lake Memphremagog in Newport City and Newport Town.

The 2010 sampling allowed us to identify areas along two of the three tributaries that were the likely sources of the high phosphorus levels observed in those tributaries previously (Figure 13). Median total phosphorus concentrations exceeded 35 :g/l [what might be considered an elevated level in this watershed (Ben Copans, personal communication)] at six of the seven sites along these three tributaries. On the Holbrook Bay tributary, total phosphorus concentrations were higher in the southern vs. the northern branch. Much of the area along the southern branch was occupied by a former dairy farm that recently ceased operation, although many of the fields along both branches were still mown for hay. On the Strawberry Acres tributary, total phosphorus concentrations were slightly higher at the lower vs. upper site, although both sites drained areas dominated by a mix of suburban development and agricultural fields (primarily hay fields). Finally, on the Wishing Well tributary, total phosphorus concentrations were generally higher at the upper vs. the lower site. The lower part of this tributary was dominated by a mix of suburban and commercial development, but the upper part drained a large area of actively-grazed pasture and hayfields (Figure 14). In suburban and urban areas, likely sources of phosphorus included synthetic fertilizers being applied to lawns and gardens as well as runoff from paved surfaces and gravel roads. In the Lake Champlain Basin, studies have shown that these land uses exported three times more phosphorus per acre on average than did agricultural land uses (State of Vermont 2002). However, the many hayfields and actively-grazed pastures may also export large amounts of phosphorus, especially in surface runoff following snowmelt and heavy rains.

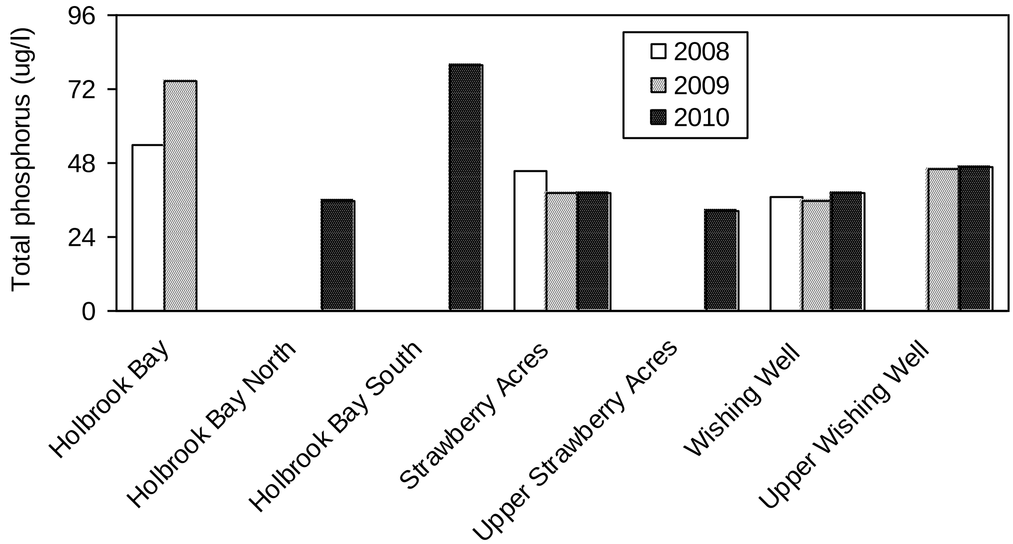


Figure 13. *Median total phosphorus concentrations measured at seven sites along three smaller tributaries of Lake Memphremagog during 2008-2010.*

Figure 14. *The large area of actively-grazed pasture and hayfield along the upper end of the Wishing Well tributary may be one source of the high phosphorus levels measured in this tributary (photographed on 16 November 2009).*

Like the majority of the sites in the Black River Watershed, many of the sites along the smaller tributaries exhibited positive relationships between total phosphorus concentrations and water depths (Figure 15). This positive relationship, in which phosphorus concentrations increase with increasing stream flows, was most pronounced at the two sites on the Wishing Well tributary but was also apparent at the two sites on the Strawberry Acres tributary. This positive relationship is characteristic of rivers and streams in which most of the phosphorus originates from nonpoint sources, such as runoff from agricultural and urban and suburban land uses. Such sources may include surface runoff from the actively-grazed pastures and hayfields at the upper end of the Wishing Well tributary and from agricultural fields and suburban development along the Strawberry Acres tributary. In contrast, the two sites along the Holbrook Bay tributary, especially the southern branch, exhibited more curvilinear relationships between total phosphorus concentrations and water depth. At these two sites, phosphorus levels decreased with increasing water depths at lower flows but increased with increasing water depths at higher flows. Such curvilinear relationships typically characterize streams incorporating a combination of point and nonpoint sources of phosphorus. Along this tributary, these sources may include surface runoff from the former dairy farm as well as from hayfields and residential areas in the watershed. In addition, a large pond in this drainage was reconstructed during July 2010 just prior to several heavy rainstorms that overflowed the pond and carried large amounts of sediment downstream (King Boyd, personal communication).

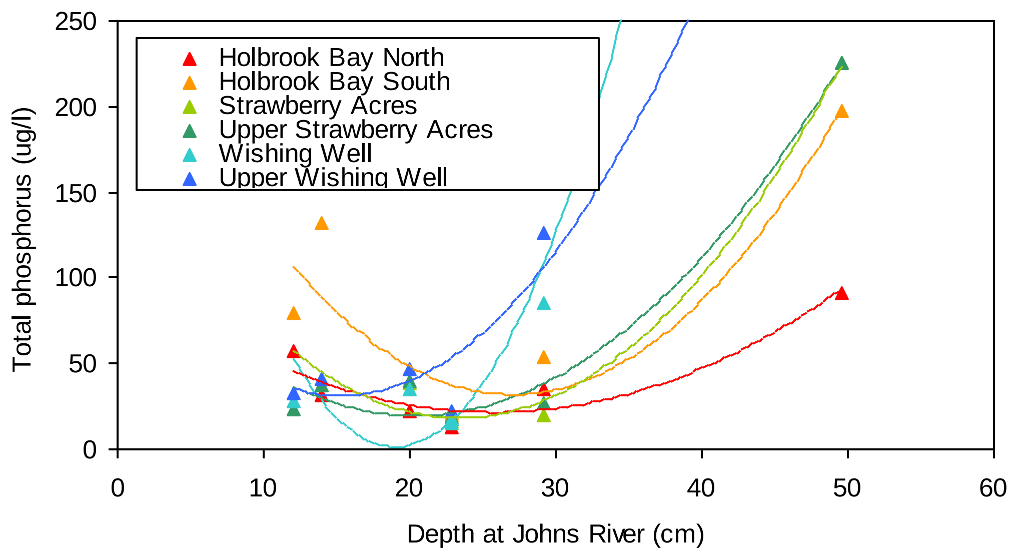


Figure 15. *Total phosphorus concentrations in relation to water depth at six sites along three smaller tributaries of Lake Memphremagog during April-September 2010. The regression lines indicate the polynomial relationships between the two parameters.*

<u>Johns River</u>

The final goal of the phosphorus studies was to continue monitoring phosphorus levels along the Johns River, where extremely high levels were observed in 2005-2006 prior to the replacement of the failed manure lagoon along Crystal Brook. In 2010, we sampled two downstream sites along the Johns River (Johns River and North Derby Road). Like Crystal Brook, total phosphorus concentrations at the Johns River site had decreased dramatically following the replacement of the manure lagoon in 2007. In 2010, the improvement in water quality at the Johns River site remained evident, as total phosphorus concentrations were similar to those in 2008-2009 and considerably less than those in 2005-2006 (Table 1, Figure 16). In all three years since the replacement of the failed manure lagoon, median total phosphorus concentrations at the Johns River site measured <50% of the 2005-2006 values, even though the failed manure lagoon was located >4 km upstream of the Johns River site and although numerous other tributaries entered the Johns River between the Crystal Brook and Johns River sites.

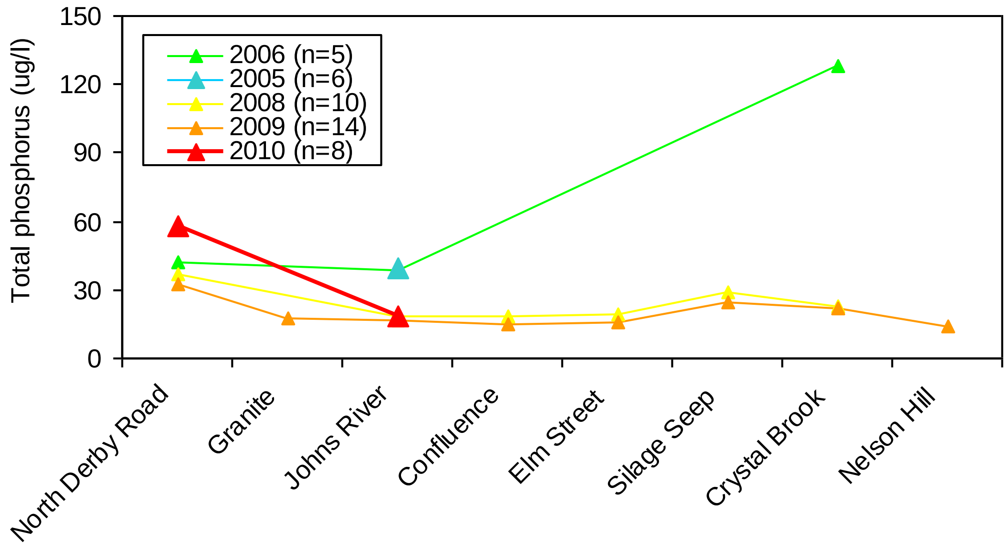


Figure 16. *Median total phosphorus "profile" along Crystal Brook and the main stem of the Johns River from Nelson Hill downstream to North Derby Road during 2005-2010. The sample size (n) is the number of dates sampled each year (note that individual sites were sampled 1-5 years during 2005-2010).*

As in 2008 and 2009, total phosphorus concentrations at the Johns River site generally increased with increasing water depth (Figure 17). This positive relationship is fairly typical of rivers and streams in which most of the phosphorus originates from nonpoint sources, such as agricultural and urban and suburban runoff, and contrasts sharply with the negative relationship between total phosphorus concentration and water depth observed in 2005-2006, when much of the phosphorus likely originated from the failed manure lagoon along Crystal Brook (Dyer and Gerhardt 2007). Consequently, the reductions in total phosphorus concentrations were most apparent at low flows (water depth <20 cm), at which total phosphorus concentrations were lower in 2008-2010 than in 2005-2006. In contrast, at moderate and high flows (water depth >20 cm), results were more mixed, and phosphorus concentrations were actually higher in 2008-2010 than in 2005-2006. In part, these contrasting results may reflect the limited number of samples collected at high flows (1-2 times per year during 2005-2010) and the importance of the timing of sampling relative to the timing of precipitation in measuring phosphorus levels. However, these results were also consistent with the reduced phosphorus inputs from the failed manure lagoon along Crystal Brook, which represented a majority of the phosphorus inputs at low flows, and the increased importance of nonpoint sources, such as surface runoff from urban, suburban, and agricultural land uses, at high flows. Thus, these data support the conclusion that past remediation efforts have effectively reduced phosphorus levels in Crystal Brook and the upper reaches of the Johns River.

Table 1. Median, range, and percent change in total phosphorus concentrations at three sites along the Johns River and Crystal Brook during 2006-2010. Note that the 2010 data include two high-flow events vs. only a single high-flow event in 2006, 2008, and 2009.

	2006 (n=5)	2008 (n=10)	2009 (n=14)	2010 (n=8)
Crystal Brook				
Median (:g/l)	128	22.9	21.6	-
Range (:g/l)	29-655	14-87	11-214	-
% of 2006 value		18	17	-
Johns River				
Median (:g/l)	38.5	18.6	16.9	18.2
Range (:g/l)	21-51	10-204	10-376	13-680
% of 2006 value		48	44	47
North Derby Road				
Median (:g/l)	41.9	36.7	32.4	58.0
Range (:g/l)	35-62	32-128	20-60	19-306
% of 2006 value		88	77	138

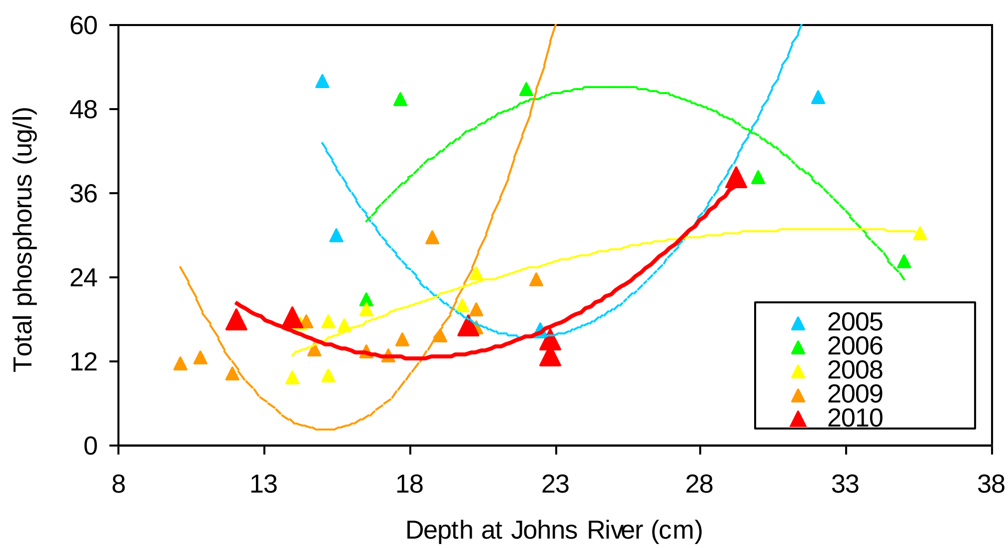


Figure 17. *Total phosphorus concentrations in relation to water depth at the Johns River site during 2005-2010. The regression lines indicate the polynomial relationships between the two parameters.*

Unfortunately, similar reductions in phosphorus levels were not observed at the downstream-most site (North Derby Road), even though it was located only 3 km further downstream of the Johns River site and there were few additional tributary inputs between the two sites. In fact, total phosphorus concentrations at the North Derby Road site have consistently been higher than those at the Johns River site in all years sampled thus far (2006-2010), and, in 2010, levels were even higher than those observed in all previous years, including 2006 (Figure 16). Median total phosphorus concentrations at the North Derby Road site declined to 88% of the 2006 value in 2008 and 77% of the 2006 value in 2009 but actually increased to 138% of the 2006 value in 2010 (Table 1). In contrast to the Johns River site, the relationship between total phosphorus concentrations and water depth at the North Derby Road site was strongly curvilinear with the relationship being negative at lower flows (e.g. water depth <20 cm at the Johns River site) and positive at higher flows (e.g. water depth >20 cm; Figure 18). This curvilinear relationship, in contrast to the positive relationship at the Johns River site, suggested that additional sources of phosphorus occur between the Johns River and North Derby Road sites. Unfortunately, the high phosphorus levels at North Derby Road also indicated that the Johns River was still sending significant amounts of phosphorus into Lake Memphremagog.

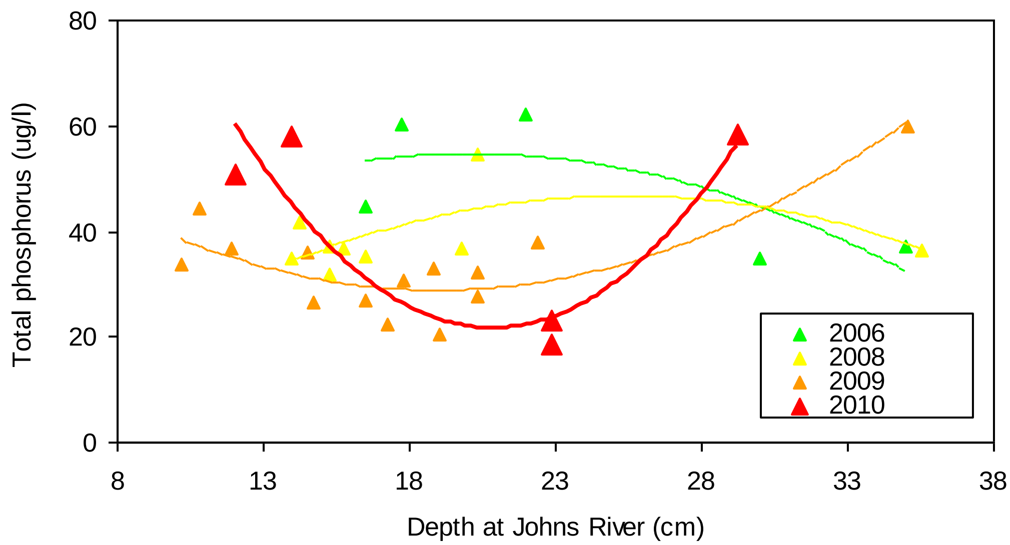


Figure 18. *Total phosphorus concentrations in relation to water depth at the North Derby Road site during 2006-2010. The regression lines indicate the polynomial relationships between the two parameters.*

There are several possible explanations for the elevated phosphorus levels at the North Derby Road site. The most likely explanation is that the phosphorus was being released through decomposition of organic matter in the large area of wetlands upstream of the North Derby Road site. Such a phosphorus source would be most important during low stream flows late in the growing season. In both 2009 and 2010, not only did phosphorus levels show a negative relationship with water depth at low flows but they also increased throughout the growing season (Figure 18-19). Large amounts of phosphorus likely accumulated in these wetlands historically due to the failed manure lagoon along Crystal Brook, and much of this phosphorus may not have been flushed out of these wetlands at this time. In addition, as noted by Dyer (2008), abundant beaver activity in these wetlands may disturb in-stream and streambank sediments and release additional sediment and phosphorus into the river. If this scenario is correct, the high phosphorus levels at the North Derby Road site may ultimately decline once much of the phosphorus that accumulated historically has been flushed from these wetlands.

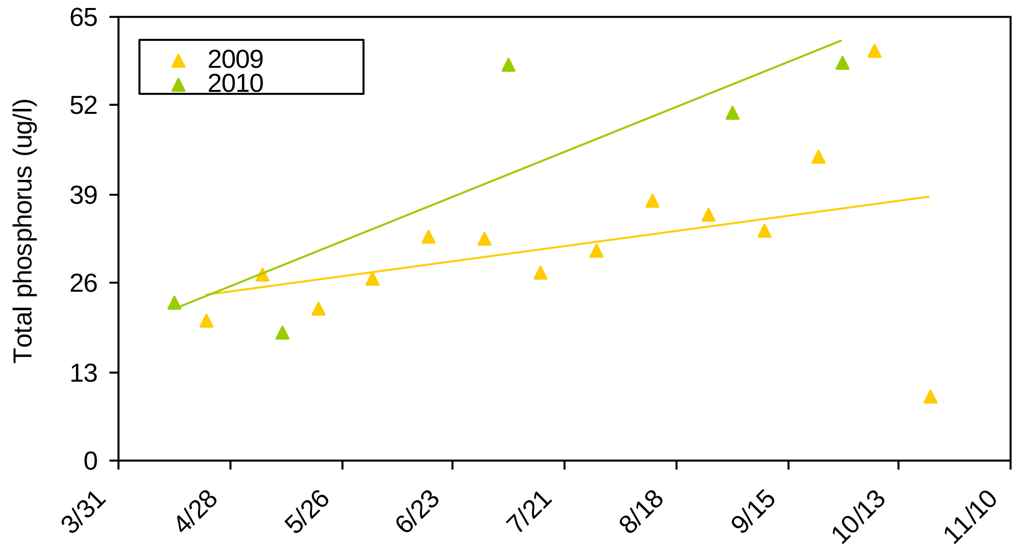


Figure 19. *Total phosphorus concentrations in relation to sample date at the North Derby Road site during 2009-2010. The 2010 data do not include the two high-flow events, when total phosphorus levels were exceedingly high and likely included large amounts of phosphorus from nonpoint sources. The regression lines indicate the linear relationships between the two parameters.*

Phosphorus Modeling

Using all of the phosphorus data collected along the Vermont tributaries during 2005-2010, we developed maps illustrating the relative phosphorus levels for many of the sub-watersheds in the basin. To do this, we calculated the arithmetic mean total phosphorus concentrations for sample sites that corresponded to 112 sub-watersheds delineated as part of a broader phosphorus modeling project (SMi 2009). Although not an actual measure of phosphorus load, the arithmetic mean does provide a general approximation of the relative amount of phosphorus being exported from each sub-watershed, especially when the sampling has specifically included high-flow events (Eric Smeltzer, personal communication). In sub-watersheds containing more than one sample site, we used the downstream-most site to represent that sub-watershed (e.g. data from the North Derby Road site were used for the Johns River sub-watershed). For most sites, we calculated the arithmetic mean using all of the data collected during 2005-2010. However, for the sites corresponding to the Crystal Brook and Johns River sub-watersheds, we included only those data collected after the failed manure lagoon on Crystal Brook was replaced in 2007. Thus, for any one site and sub-watershed, the arithmetic mean was calculated using 1-5 years of data and 5-14 sample dates per year.

Based on these calculations, we identified a number of sub-watersheds in the Lake Memphremagog Basin where phosphorus levels were relatively high as well as numerous sub-watersheds where phosphorus levels were relatively low (Figure 20). In particular, the highest mean total phosphorus concentrations occurred in the sub-watersheds encompassing much of the Black River and Johns River Watersheds and the downstream part of the Barton River Watershed. In contrast, the lowest mean total phosphorus concentrations were located throughout the upper part of the Barton River Watershed and almost all of the Clyde River Watershed. The sub-watersheds with the highest mean total phosphorus concentrations were the downstream section of the main stem of the Johns River (sampled at North Derby Road); Brighton and Stony Brooks, both tributaries of the Black River; and the four smaller tributaries of Lake Memphremagog in Newport City and Newport Town (East Side, Wishing Well, Strawberry Acres, and Holbrook Bay tributaries). As noted previously, the high phosphorus levels in these three areas were likely caused by a variety of historical and current land-use practices and will likely require a variety of strategies to be effectively reduced.

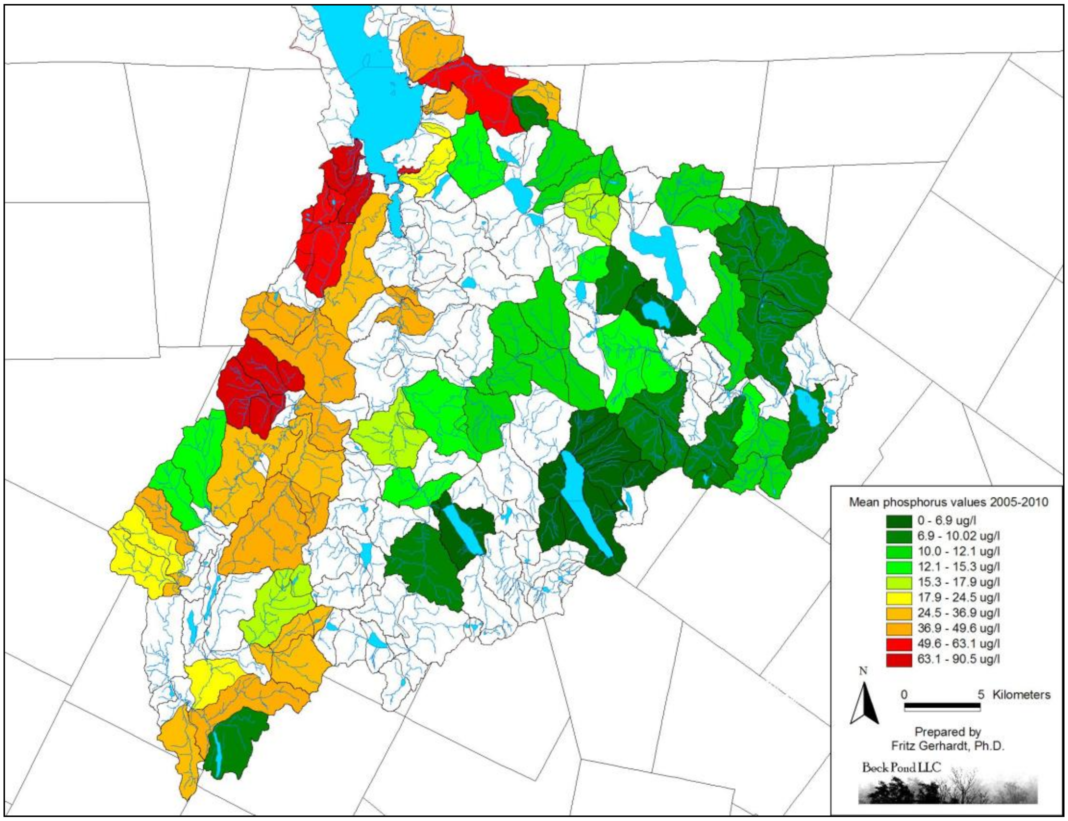


Figure 20. *Mean total phosphorus concentrations measured at sample sites in 112 sub-watersheds of the Lake Memphremagog Basin during 2005-2010. Arithmetic means were only calculated for those sub-watersheds in which a sample site was located near the downstream-end of that sub-watershed. Mean values for each site/sub-watershed were calculated using 1-5 years of data collected during 2005-2010.*

Total Nitrogen

Although typically not the limiting nutrient in northern freshwater aquatic 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, including nitrogen gas (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), ammonium (NH_4), and particulate nitrogen. Total nitrogen measures the concentration of all forms of nitrogen in the water column. In Vermont, most nitrogen in surface waters originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

Total nitrogen concentrations in this study ranged between 0.10-6.86 mg/l. In contrast to total phosphorus, total nitrogen concentrations did show a slight seasonal trend, as median total nitrogen values peaked slightly during mid-summer (Figure 21). This seasonal peak may have reflected not only the increased importance of groundwater during mid-summer low flows but also increased rates of leaching following the heavy mid-summer rains (Figure 5). In addition to dissolved forms of nitrogen, higher inputs of particulate nitrogen likely contributed to the higher total nitrogen levels measured following the heavy rains on 28 June and 3 August.

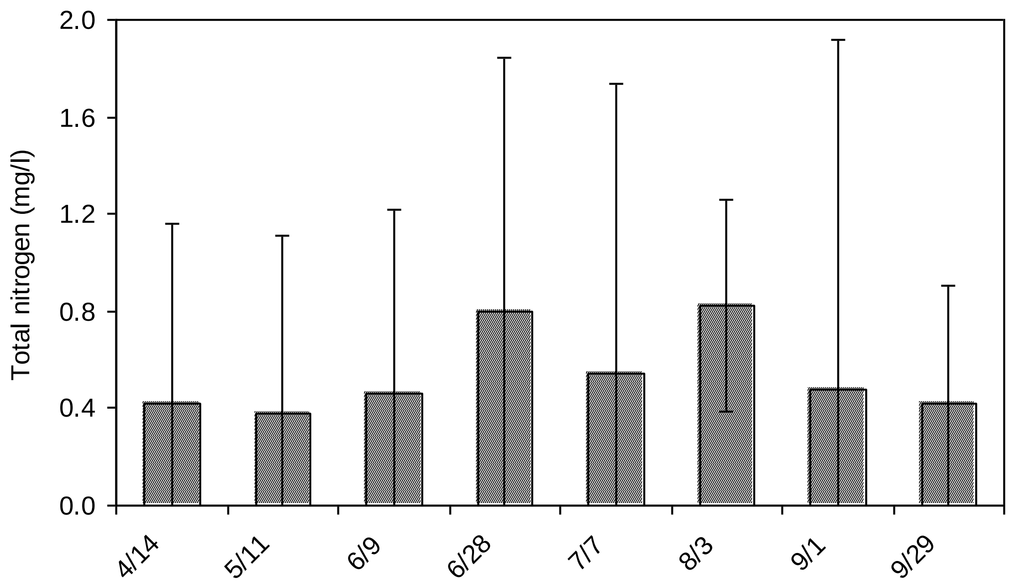


Figure 21. *Median total nitrogen concentrations (∀1 SD) measured on each sample date at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010.*

Johns River and Adjacent Tributaries

Based on our previous sampling, we had observed that the Johns River and the adjacent Sunset Acres tributary exhibited extremely high nitrogen levels, especially at low flows (Gerhardt 2009, 2010). Based on these earlier surveys, we had also determined that much of the nitrogen entering these rivers and streams was originating from groundwater, and we had hypothesized that the nitrogen was originating from manure and/or agricultural fertilizers being applied to cornfields located on coarse sand and gravel deposits. In 2009, we were able to confirm that the high nitrogen levels along both the Sunset Acres and Darling Hills tributaries was, in fact, originating from groundwater springs and seeps surfacing in these two areas, both of which were located downslope of large cornfields located on sand and gravel deposits (Gerhardt 2010). However, preliminary biological assessments indicated that the high nitrogen levels did not appear to be harming the aquatic communities in these streams. Thus, based on these observations and an observed decline in total nitrogen levels during 2006-2009, we decided to continue monitoring nitrogen levels in these streams but not to undertake more in-depth surface water and groundwater studies at this time.

In 2010, median total nitrogen concentrations were relatively high (e.g. >2 mg/l) at three of the four sites located within or adjacent to the Johns River Watershed. At the Johns River site, total nitrogen concentrations were similar in 2009 and 2010 but remained lower than those observed in 2005-2008 (Figure 22a). In contrast, total nitrogen concentrations were slightly higher at the Darling Hill and Sunset Acres sites in 2010 than in 2009 but were still lower than those observed in 2006 and 2008 (Figure 22b-c). As in previous years, total nitrogen concentrations decreased with increasing stream flows, a result that is consistent with nitrogen inputs originating from groundwater sources. Thus, although total nitrogen levels did not continue to decline as they did between 2006 and 2009, they remained considerably lower than those observed during the first two years of this study.

Although nitrogen levels were clearly lower in 2009 and 2010 than in previous years, we do not know the cause(s) of these declines or their ramifications. On one hand, these lower levels may reflect decreased amounts of nitrogen entering the groundwater and surface waters due to better nutrient management practices (e.g. lower nitrogen fertilizer application rates). On the other hand, these lower levels may reflect some other, more “global” factor (e.g. atypical precipitation patterns during 2009-2010), especially given that the declines in nitrogen levels were widespread and occurred across all sites. Ultimately, identifying the cause(s) of these declines will require that we understand the underlying groundwater and nitrogen dynamics (e.g. residence times, flow rates and directions) as well as historical and current management practices in the area. Such studies, however, would be expensive and time-consuming and should only be undertaken if these high nitrogen levels continue unabated and negatively impact ecosystem and/or human health.

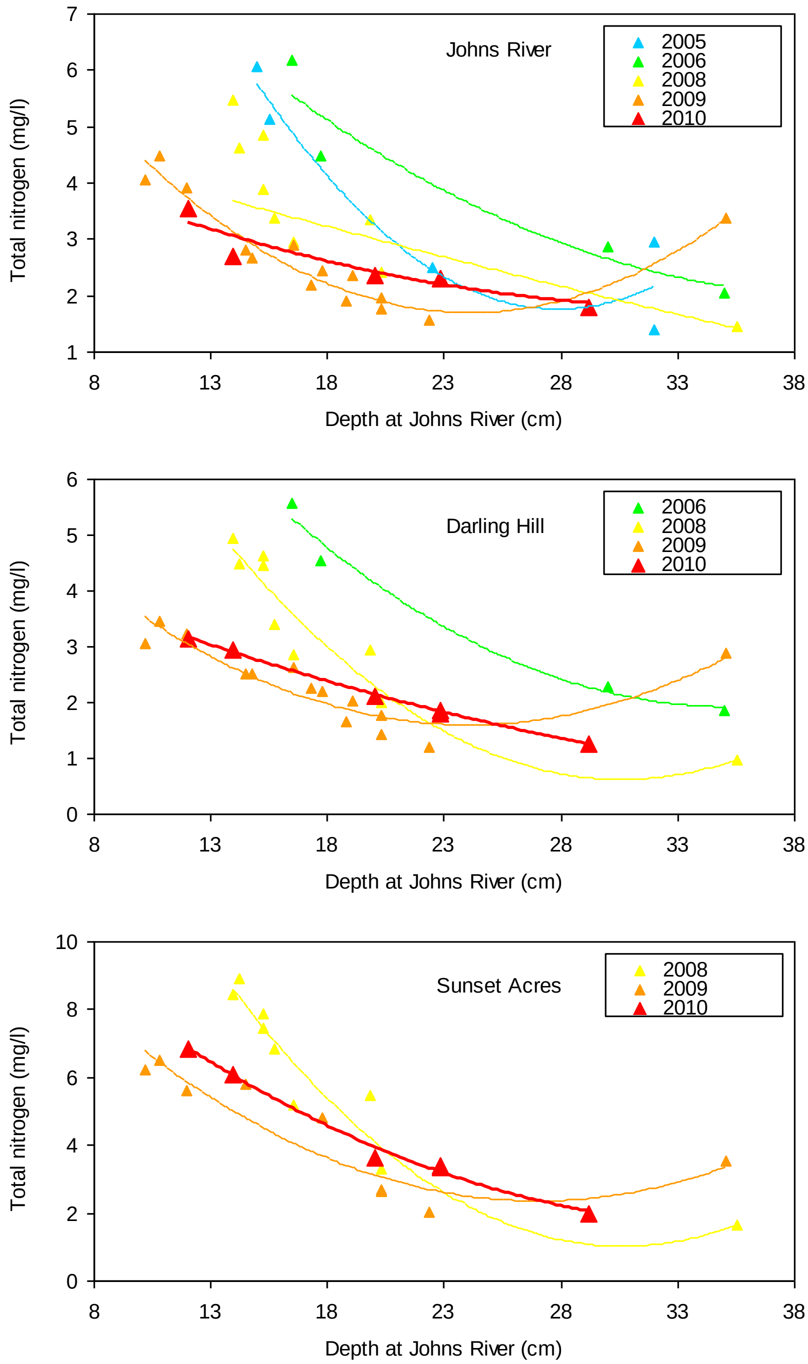


Figure 22. *Total nitrogen concentrations in relation to water depth at three sites along the Johns River and adjacent tributaries during 2005-2010. The regression lines indicate the polynomial relationships between the two parameters in each year.*

Black River Watershed

In the Black River Watershed, median total nitrogen concentrations were relatively low (i.e. <1 mg/l) at most sites; however, they did exceed 1 mg/l at two sites located in the town of Coventry (Stony and Ware Brooks; Figure 23-24). Like the sites in the Johns River Watershed, these two sites were underlain by areas of coarse sand and gravel deposits, and total nitrogen concentrations at these two sites were negatively related to stream flow (Figure 25). These negative relationships suggested that the nitrogen inputs in these two stream were derived from groundwater or point sources, rather than nonpoint sources such as agricultural or urban runoff. Thus, the source(s) of these high nitrogen levels may reflect a similar mechanism to that proposed for the Johns River Watershed. In addition, total nitrogen concentrations were high (>2 mg/l) at three sites (Brighton Brook, Wishing Well, and Upper Wishing Well) following extremely heavy rains on 28 June. These high concentrations may have been caused by surface runoff of manure from the large farms located in these watersheds.

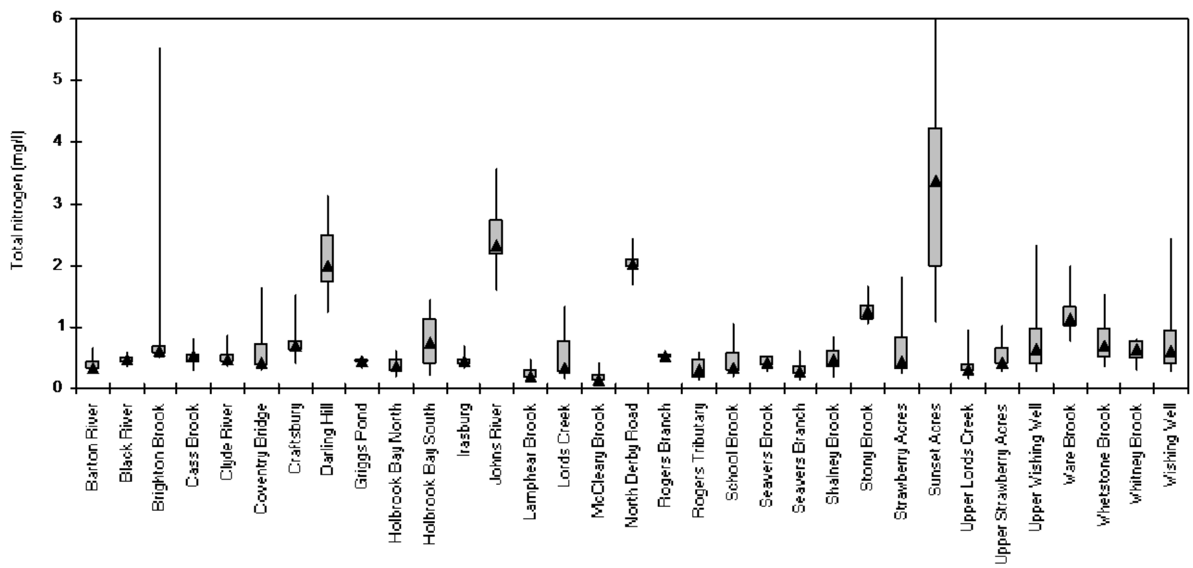


Figure 23. *Total nitrogen concentrations at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

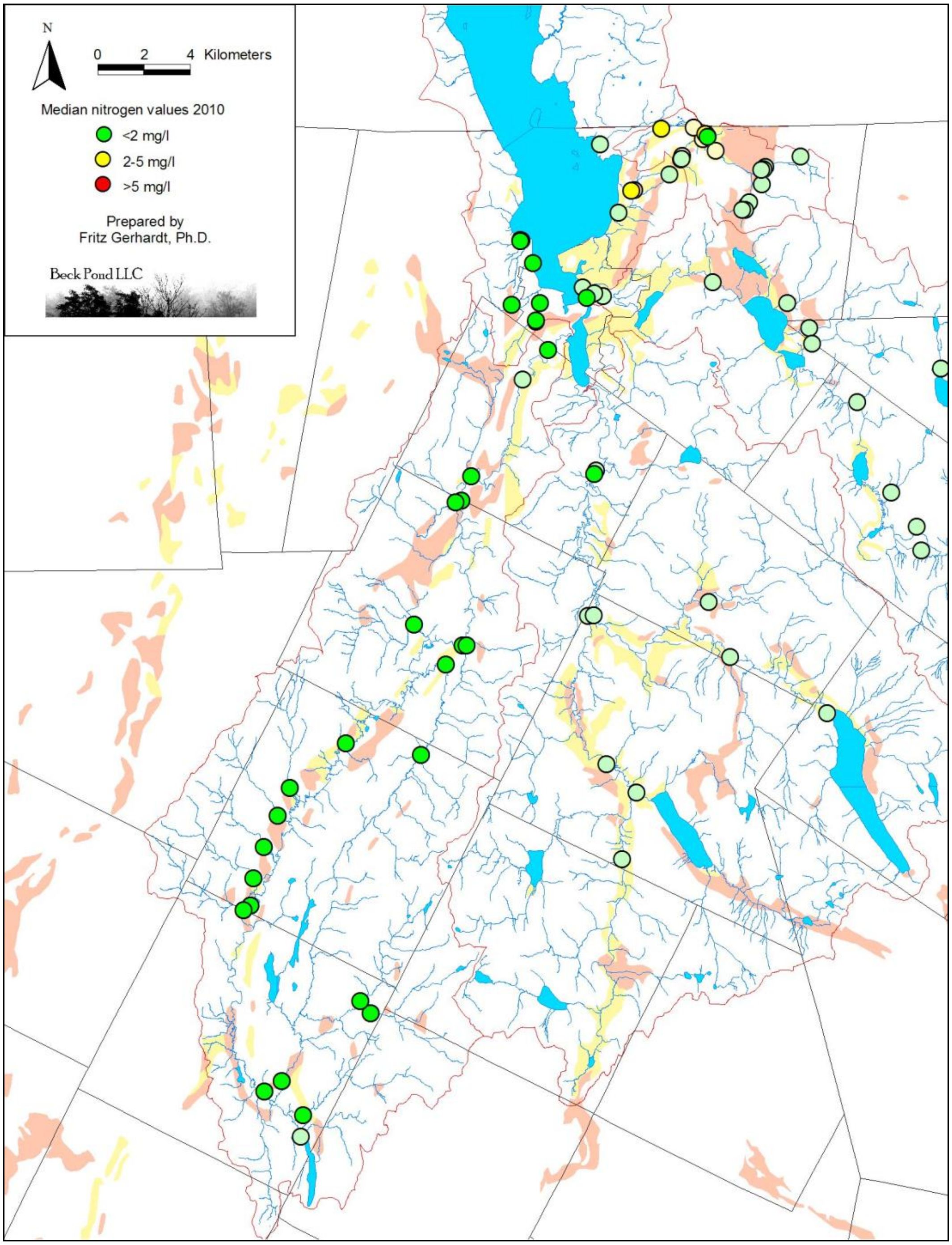


Figure 24. *Median total nitrogen concentrations at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. The faint dots depict sites sampled in previous years but not in 2010. The locations of surficial sand and gravel deposits are also shown (shaded yellow and orange).*

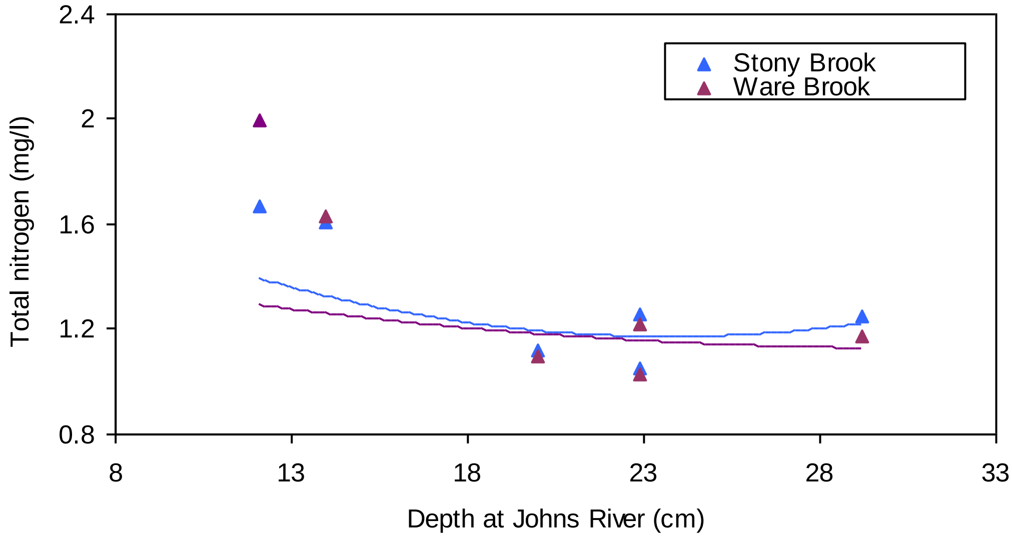


Figure 25. *Total nitrogen concentrations in relation to water depth at two sites with high nitrogen levels in the Black River Watershed during April-September 2010. The regression lines indicate the polynomial relationships between the two parameters.*

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 are less clear, allow less light to penetrate into the water column, and transport more pollutants, nutrients, and sediments. Sediments and other suspended materials that settle out of the water column also 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 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).

Turbidity levels in this study ranged between 0.22-498 NTU and showed no marked seasonal pattern, except perhaps a slight increase from spring to autumn (Figure 26). Like total phosphorus, the highest turbidity levels were observed on the two sample dates with the highest flows (28 June and 3 August), when both median and individual turbidity values were 2-3 orders of magnitude greater than on other dates.

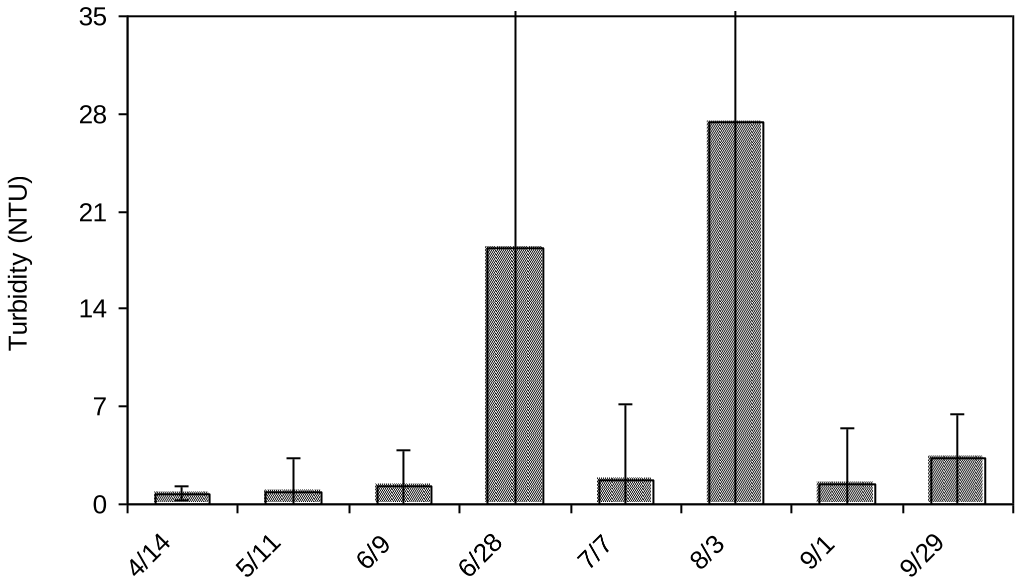


Figure 26. *Median turbidity levels (∀1 SD) measured on each sample date at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010.*

Turbidity levels were generally higher at many of the same sites as total phosphorus levels (Figure 27-28). The highest levels were observed at the Holbrook Bay South site (median = 17.9 NTU), which drained an area that included a former dairy farm and a large pond that was reconstructed this past summer. Median turbidity levels exceeded 5 NTU at eight other sites, including several sites along the main stem of the Black River (Coventry Bridge, Irasburg, Griggs Pond, and Rogers Branch), the downstream-most sites on the Johns and Barton Rivers (North Derby Road and Barton River, respectively), and two sites on the smaller tributaries (Strawberry Acres and Holbrook Bay North). In addition, an extremely high turbidity level (498 NTU) was observed at the Wishing Well site during the high-flow event on 3 August. This value, which was more than double any other value measured in 2010, likely reflected the very turbid stormwater runoff from a large road reconstruction project upstream of this site.

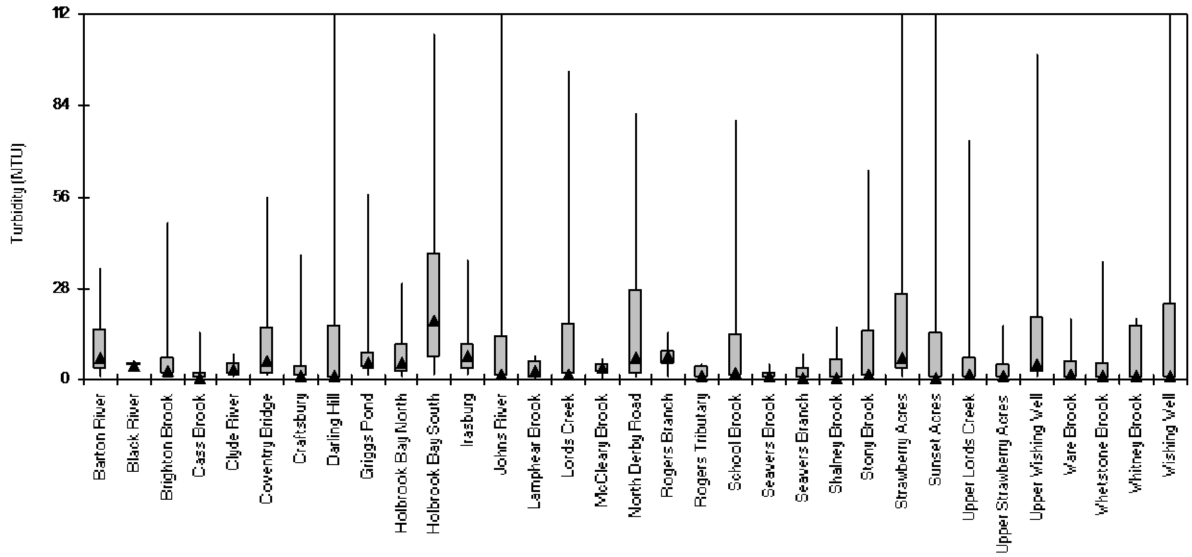


Figure 27. *Turbidity levels at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

Like total phosphorus, turbidity levels almost universally increased with increasing water depths or stream flows, especially at the sites with the highest turbidity levels (Figure 29). This positive relationship was to be expected, as much of the dissolved and suspended materials were likely carried into the rivers and streams in surface runoff, especially following heavy rains. The only exception to this general pattern was at the Holbrook Bay South site, where a more curvilinear relationship was observed. At this site, turbidity levels were higher at low and high flows but lower at intermediate flows. Although the reason(s) for the increase at lower flows was unclear, the increase in turbidity levels at higher flows paralleled that observed at the other sites.

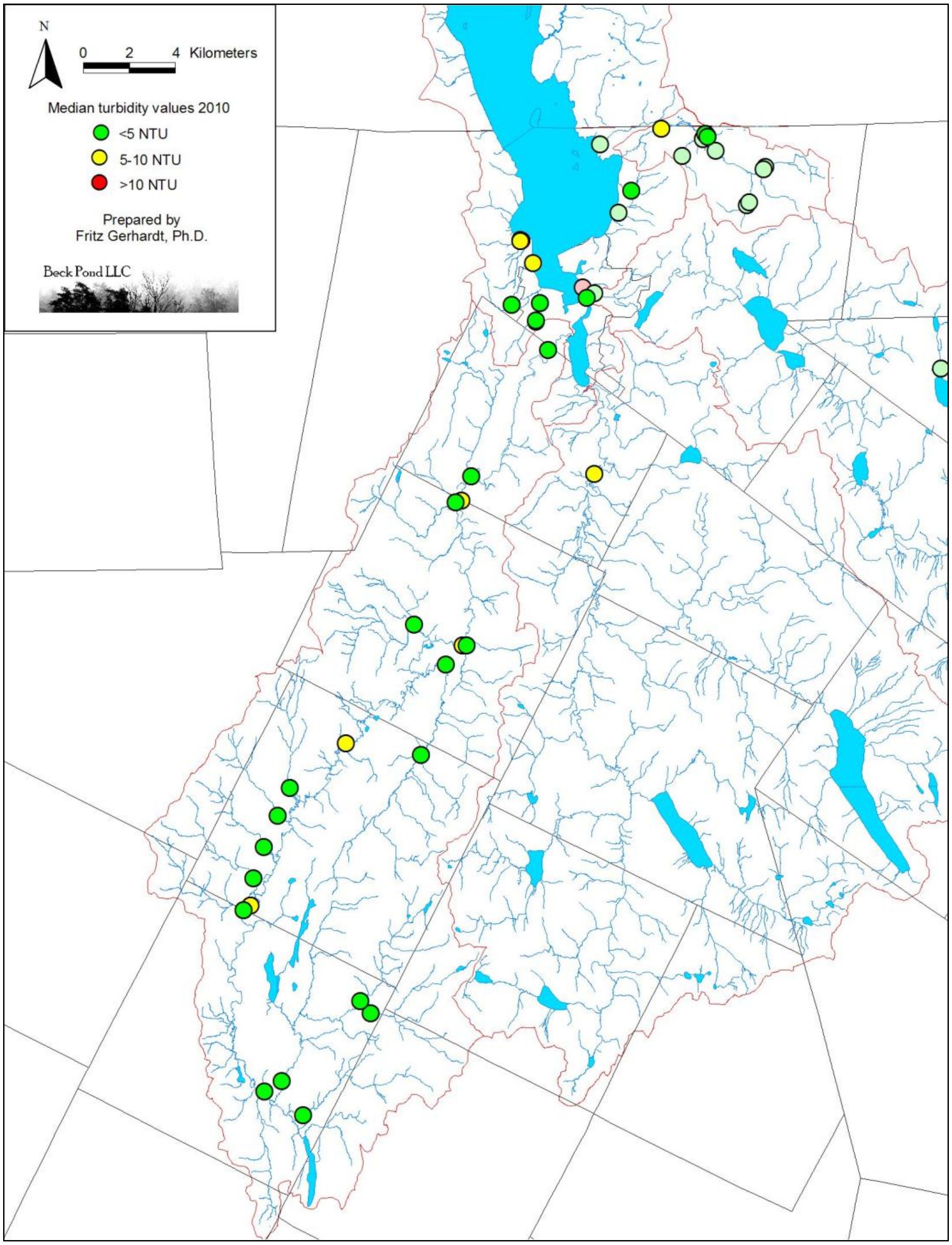


Figure 28. *Median turbidity levels at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. The faint dots depict sites sampled in previous years but not in 2010.*

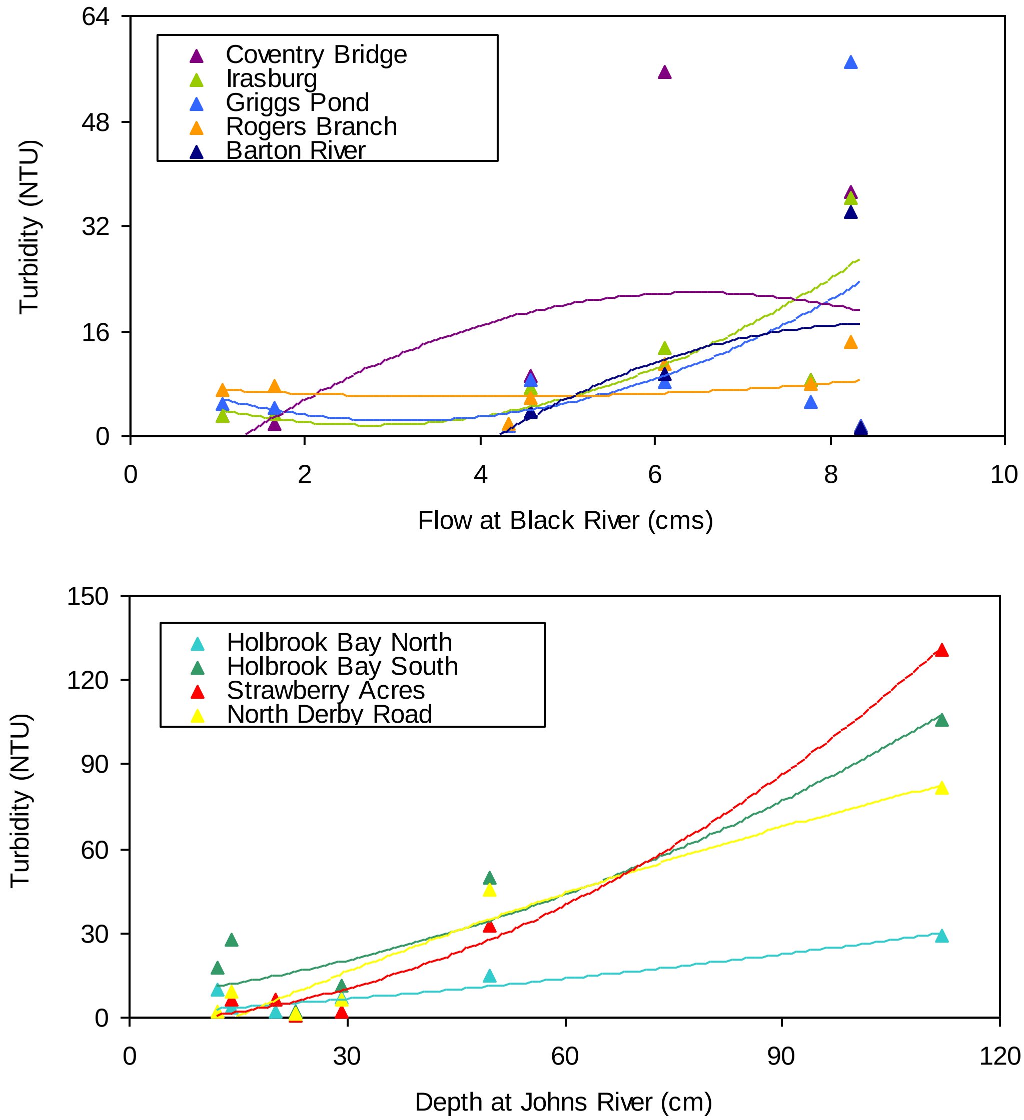


Figure 29. *Turbidity levels in relation to water level at a) five sites along the Barton, Black, and Johns Rivers and b) four sites along two smaller tributaries of Lake Memphremagog during April-September 2010. The regression lines indicate the polynomial relationships between the two parameters.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with the Vermont DEC. Our sampling generally met the quality assurance standards for all three parameters (quality assurance data are presented in

Appendix C). All of the blank samples measured below the detection limits for all three parameters (<5 :g/l for total phosphorus, <0.1 mg/l for total nitrogen, and <0.2 NTU for turbidity). Similarly, the mean relative percent differences between duplicate samples were well within the prescribed differences for all three parameters: total phosphorus = 7% (prescribed difference <30%), total nitrogen = 3% (prescribed difference <20%), and turbidity = 11% (prescribed difference <15%). However, one of the 25 pairs of total phosphorus samples differed by >30%, and four of the 24 pairs of turbidity samples differed by >15%. These differences suggested that, at least on some dates, nutrient and sediment levels in these rivers and streams may have been more heterogeneous than on other dates. Nevertheless, the quality assurance samples, including both field blanks and field duplicates, indicated that the water samples were being collected in a repeatable manner and were not being contaminated during collection or processing.

Recommendations

Monitoring and Assessment Studies

Future studies should focus on further pinpointing and assessing potential nutrient and sediment sources along the Vermont tributaries of Lake Memphremagog, so that protection and restoration projects can be identified and implemented to reduce the amounts of nutrients and sediments being sourced from those areas. In particular, additional sampling and field surveys should be undertaken along the main stem and four of the tributaries of the Black River. Along the main stem, additional sampling should be focused between Craftsbury and Albany villages, as this is where phosphorus levels increase most dramatically (Figure 10). Specifically, additional sampling could be undertaken at the five bridges that cross the Black River between Craftsbury village and the Rogers Branch site. Along the four tributaries, additional sites should be sampled upstream and along the major branches of Brighton, Shalney, and Stony Brooks and Upper Lords Creek. In addition, on-the-ground field surveys should be undertaken along the main stem and these tributaries to identify potential point and nonpoint sources of phosphorus and sediment inputs. Similar efforts should be undertaken along the southern branch of the Holbrook Bay tributary, as the source(s) of the high phosphorus and turbidity levels in this tributary remained unclear.

In addition to these focused studies, we also recommend continuing to monitor phosphorus and nitrogen levels in the Johns River and adjacent watersheds as well as further evaluating possible sources of the high phosphorus levels observed in the downstream-most section of the Johns River. For the latter, further sampling - and perhaps more importantly - on-the-ground field surveys are needed to verify that the wetlands along this stretch of river and not some other, as-yet-unidentified source are indeed the source of the high phosphorus levels observed at the North Derby Road site. Continued monitoring of phosphorus levels at 2-3 sites along Johns River will allow us to verify that the manure lagoon replacement project on Crystal Brook remains effective in reducing the phosphorus levels flowing into the Johns River. In addition, we recommend continued monitoring of nitrogen levels at 3-4 sites in the Johns River and adjacent watersheds in order to evaluate long-term trends in nitrogen levels, assess the potential impacts of these high levels on aquatic health, better understand the nitrogen and groundwater dynamics in these watersheds, and identify and mitigate possible nitrogen sources.

Protection and Restoration Projects

Although additional studies are still needed, our results did suggest several protection and restoration projects and practices that can be implemented immediately to improve water quality in the Lake Memphremagog Basin. Although the focus of the sampling in 2010 was initial identification of possible phosphorus and sediment sources in the Black River Watershed, this year's sampling did allow us to identify a number of specific on-the-ground projects that would reduce nutrient and sediment inputs and improve water quality in the Lake Memphremagog Basin. Specifically, the 2010 sampling confirmed that the high phosphorus and sediment levels were originating in the upper end of the Wishing Well tributary. Field observations indicated that a number of opportunities exist to improve agricultural practices on a large dairy farm there to improve water quality in the Wishing Well tributary. Thus, we recommend that efforts be undertaken to contact the landowner(s) in order to discuss management projects and practices that would best reduce phosphorus and sediment runoff from that farm.

In addition, we observed cattle grazing in several tributaries of Lake Memphremagog, including Shalney Brook, Lords Creek, the Johns River, and the north branch of the Holbrook Bay tributary (Figure 30). Although we have not confirmed that in-stream grazing was the primary source of the high phosphorus and sediment levels in these tributaries, we do recommend undertaking projects to exclude cattle from these tributaries to reduce fecal contamination and erosion of the streambanks and stream channels. We also recommend planting riparian buffers in these same areas to minimize streambank erosion, filter sediments and pollutants from runoff, shade the stream channel, and reduce water temperatures. Such projects could be funded by existing federal cost-share or other programs (e.g. Conservation Reserve Enhancement Program, Trees for Streams Memphremagog). In addition, a barnyard and manure lagoon were located adjacent to Shalney Brook, and we would encourage efforts to evaluate and, if necessary, modify or relocate these facilities, so that runoff or overflows do not threaten water quality in this tributary of the Black River.

Figure 30. *Cattle grazing and streambank erosion along Shalney Brook near Albany, Vermont may contribute to the high phosphorus levels measured in this tributary (photographed on 1 September 2010).*

Although we have not undertaken the studies needed to prove that the high nitrogen levels in the Johns River and adjacent tributaries are originating from nitrogen-based fertilizers being applied to cornfields located on porous sand and gravel deposits, we do recommend continuing to develop partnerships with the Newport field office of the Natural Resources Conservation Service, Vermont Agency of Agriculture, Orleans County Natural Resources Conservation District, and local farmers to further evaluate this scenario and to implement nutrient management practices that would reduce the amounts of nitrogen leaching from these cornfields. This reduction would benefit both water quality and the farmers, who are paying the costs for the nitrogen that is leaching into the groundwater and being lost to their crops. However, because we have not affirmed the source(s) of the high nitrogen levels in these streams, we do not recommend undertaking drastic and expensive changes in agricultural practices until we confirm that 1) nitrogen-based fertilizers being applied to the cornfields are the source of the problem and 2) recently-implemented practices are not already reducing nitrogen levels in the groundwater and surface waters in this area.

Finally, in urban and suburban areas, a number of projects and practices can be implemented immediately to reduce nutrient and sediment inputs into rivers and streams and ultimately into Lake Memphremagog. One immediate step would be to stop mowing and to plant riparian buffers along river shorelines in order to reduce erosion, filter nutrients and sediments from stormwater and other runoff, shade the stream channel, and reduce water temperatures. Such projects have already been completed along the Clyde River in 2009 and 2010 by the Memphremagog Watershed Association. In addition, land owners and land managers should be encouraged to use rain barrels and to plant rain gardens to capture stormwater runoff and to reduce or eliminate the use of synthetic fertilizers and pesticides on their lawns and gardens, especially those located near or bordering rivers and streams. These efforts would be greatly facilitated by educational and outreach programs and demonstration projects that provide property owners with the necessary tools and information to undertake these projects and practices. The Memphremagog Watershed Association and Orleans County Natural Resources Conservation District are ideally situated to coordinate and implement any such workshops and demonstration projects.

Education and Outreach

As an integral part of this project, we incorporated the implementation and results of this study into several educational and outreach activities. First, numerous 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. In addition, the results of this and previous water quality studies were incorporated into two public outreach activities. First, we presented information about the present condition of and challenges to the Black River and its watershed to approximately 40 participants at a public outreach meeting held at Sterling College in Craftsbury Common. Second, we led a canoe/kayak trip down the Black River to acquaint the roughly 30 participants with the natural history and current condition of the river and its associated habitats, especially the many wetlands near the mouth of the river. Not only did these two programs acquaint participants with the natural history of and water quality conditions in the Black River Watershed, but they also informed them about opportunities to protect and restore water quality in the river and its watershed.

In addition to the public outreach efforts, the results of this study were incorporated into a variety of efforts by project partners to protect and improve water quality in the Lake Memphremagog Basin. First, 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 monitor and improve water quality in the Lake Memphremagog Basin. We also used the results of this and previous studies to advise the basin planning process being undertaken by the Vermont DEC and the Memphremagog-Tomifobia-Coaticook Watershed Council. Furthermore, we discussed the results of this study and their implications for protecting and improving water quality in the Lake Memphremagog Basin with staff from the Northeastern Vermont Development Association, the Orleans County Natural Resources Conservation District, the Vermont Association of

Conservation Districts, the Vermont DEC, and the Vermont Agency of Agriculture. 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 Water Quality Division of the Vermont DEC; Quebec Ministère du Développement durable, de l'Environnement et des Parcs; Municipalités régionales de comté de Memphrémagog; cities of Newport, Sherbrooke, and Magog; Memphrémagog Conservation Inc., and the NorthWoods Stewardship Center.

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Appendix A. Descriptions of the 33 sites sampled along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010 (locations are mapped in Figure 3).

Black River (20 sites):

Site name	Site description
Stony Brook	Stony Brook upstream of confluence with Black River in Coventry
Ware Brook	Ware Brook upstream of Chilafoux Road in Irasburg
Coventry Bridge	Main stem downstream of Back Coventry Road in Irasburg (also sampled in 2005-2006)
School Brook	Unnamed tributary upstream of Vermont Route 58 in Irasburg
Irasburg	Main stem adjacent to Vermont Route 58 in Irasburg (also sampled in 2006)
Brighton Brook	Brighton Brook downstream of Gage Road in Irasburg
Lords Creek	Lords Creek upstream of Vermont Route 14 in Irasburg (also sampled in 2005-2006)
Upper Lords Creek	Lords Creek downstream of Creek Road in Albany
Griggs Pond	Main stem adjacent to Vermont Route 14 in Albany (also sampled in 2005-2006)
Lamphear Brook	Lamphear Brook downstream of Vermont Route 14 in Albany
McCleary Brook	McCleary Brook downstream of Vermont Route 14 in Albany
Shalney Brook	Shalney Brook downstream of Vermont Route 14 in Albany
Rogers Tributary	Rogers Branch upstream of Vermont Route 14 in Albany
Rogers Branch	Main stem downstream of Wylie Hill Road in Albany (also sampled in 2006)
Seaver Branch	Seaver Branch upstream of Vermont Route 14 in Craftsbury
Cass Brook	Cass Brook upstream of confluence with Black River in Craftsbury
Craftsbury	Main stem downstream of Craftsbury Town Garage in Craftsbury (also sampled in 2005-2006)
Whetstone Brook	Whetstone Brook upstream of South Craftsbury Road in Craftsbury
Whitney Brook	Whitney Brook upstream of South Albany Road in Craftsbury
Seaver Brook	Seaver Brook upstream of Allen Hill Road in Craftsbury

Smaller tributaries (7 sites):

Site name	Site description
Holbrook Bay North	Northern branch of unnamed tributary upstream of Beaver Cove Road in Newport Town
Holbrook Bay South	Southern branch of unnamed tributary upstream of Beaver Cove Road in Newport Town
Strawberry Acres	Unnamed tributary downstream of Fishing Access Road in Newport Town (also sampled in 2008-2009)
Upper Strawberry Acres	Unnamed tributary upstream of City Farm Road in Newport Town
Wishing Well	Unnamed tributary downstream of snowmobile bridge north of Lake Road in Newport City (also sampled in 2008-2009)
Upper Wishing Well	Unnamed tributary downstream of Vermont Route 105 in Newport City (also sampled in 2009)
Sunset Acres	Unnamed tributary downstream of North Derby Road in Derby (also sampled in 2008-2009)

Johns River (3 sites):

Site name	Site description
North Derby Road	Main stem downstream of North Derby Road in Derby (also sampled in 2006 and 2008-2009)
Johns River	Main stem beside old well house off Beebe Road in Derby (also sampled in 2005-2006 and 2008-2009)
Darling Hill	Unnamed tributary upstream of confluence with Johns River in Derby (also sampled in 2006 and 2008-2009)

DEC sites (3 sites):

Site name	Site description
Barton River	Main stem upstream of Coventry Station Road in Coventry (also sampled in 2005-2009)
Black River	Main stem upstream of Airport Road in Coventry (also sampled in 2005-2009)
Clyde River	Main stem upstream of Gardner Park Road in Newport City (also sampled in 2005-2009)

Appendix B. Water quality data collected at 33 sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. Bold or italicized fonts highlight concentrations greater than Vermont water quality standards (State of Vermont 2008b) or what might be considered elevated concentrations if no water quality standards apply: total phosphorus >20 :g/l (italics) or >35 :g/l (bold), total nitrogen >2 mg/l (italics) or >5 mg/l (bold), and turbidity >5 NTU (italics) or >10 NTU (bold).

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (:g/l)**	**Turbidity (NTU)**
Barton River	4/19/2010	0.39	**36**	-
Barton River	5/11/2010	0.28	*26*	1.22
Barton River	6/7/2010	0.86	-	-
Barton River	6/9/2010	0.42	**36.7**	4.12
Barton River	6/28/2010	0.48	**49.3**	*9.58*
Barton River	8/3/2010	0.66	**122**	**34.2**
Barton River	9/29/2010	0.36	*30*	3.57
Black River	4/19/2010	0.46	*29.3*	-
Black River	5/11/2010	0.43	*34.4*	2.47
Black River	6/7/2010	1.05	**127**	-
Black River	6/9/2010	0.57	**39.7**	*5.36*
Black River	6/28/2010	0.5	**43.5**	3.92
Black River	8/3/2010	0.37	*28.8*	3.97
Black River	9/29/2010	0.46	**36.1**	*5.59*
Brighton Brook	4/14/2010	0.51	*20.7*	1.62
Brighton Brook	5/11/2010	0.56	*25.6*	1.75
Brighton Brook	6/9/2010	0.54	*24.7*	1.43
Brighton Brook	6/28/2010	**5.53**	**450**	**48.2**
Brighton Brook	7/7/2010	0.67	*34.9*	3.23
Brighton Brook	8/3/2010	0.79	**97.3**	**17.7**
Brighton Brook	9/1/2010	0.66	*22.1*	2.1
Brighton Brook	9/29/2010	0.56	**49**	3.26
Cass Brook	4/14/2010	0.52	15	0.35
Cass Brook	5/11/2010	0.38	*24.2*	0.94
Cass Brook	6/9/2010	0.44	12.2	0.72
Cass Brook	6/28/2010	0.8	**118**	**14.4**
Cass Brook	7/7/2010	0.55	19.2	0.47
Cass Brook	8/3/2010	0.6	**54.6**	4.73
Cass Brook	9/1/2010	0.52	10.8	0.8
Cass Brook	9/29/2010	0.31	16.4	0.58

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (:g/l)**	**Turbidity (NTU)**
Clyde River	4/19/2010	0.41	16.1	-
Clyde River	5/11/2010	0.41	16.2	1.14
Clyde River	6/7/2010	0.48	*28.9*	-
Clyde River	6/9/2010	0.36	*22.5*	3.23
Clyde River	6/28/2010	0.5	**41.2**	*5.26*
Clyde River	8/3/2010	0.38	**35.3**	*7.5*
Clyde River	9/29/2010	0.66	*22.7*	1.78
Coventry Bridge	4/14/2010	0.41	16.9	1.44
Coventry Bridge	5/11/2010	0.37	*20.4*	1.46
Coventry Bridge	6/9/2010	0.48	**44**	*8.51*
Coventry Bridge	6/28/2010	1.48	**159**	**55.5**
Coventry Bridge	7/7/2010	0.31	*22.7*	1.89
Coventry Bridge	8/3/2010	1.62	**143**	**37.1**
Coventry Bridge	9/1/2010	0.3	*21.3*	2.96
Coventry Bridge	9/29/2010	0.43	**50.5**	*9.24*
Craftsbury	4/14/2010	0.78	9.14	1.02
Craftsbury	5/11/2010	0.63	11.4	0.5
Craftsbury	6/9/2010	0.51	11.9	1.05
Craftsbury	6/28/2010	0.72	**65.9**	**12**
Craftsbury	7/7/2010	0.8	16.9	0.87
Craftsbury	8/3/2010	1.52	**114**	**38**
Craftsbury	9/1/2010	0.67	9.38	0.59
Craftsbury	9/29/2010	0.41	15.1	1.42
Darling Hill	4/14/2010	1.87	17.2	0.6
Darling Hill	5/11/2010	1.81	15	0.39
Darling Hill	6/9/2010	*2.11*	*23*	0.82
Darling Hill	6/28/2010	*2.34*	**989**	**249**
Darling Hill	7/7/2010	*2.93*	*21.2*	1.14
Darling Hill	8/3/2010	1.38	**325**	**55**
Darling Hill	9/1/2010	*3.13*	*21.8*	0.95
Darling Hill	9/29/2010	1.25	**60.6**	3.68

Site	Date	Total nitrogen (mg/l)	Total phosphorus (:g/l)	Turbidity (NTU)
Griggs Pond	4/14/2010	0.52	*20.7*	1.55
Griggs Pond	5/11/2010	0.44	*22.1*	1.54
Griggs Pond	6/9/2010	0.48	**43.6**	*5.22*
Griggs Pond	6/28/2010	0.46	**38.9**	*8.14*
Griggs Pond	7/7/2010	0.36	*31.6*	4.17
Griggs Pond	8/3/2010	0.43	**153**	**57**
Griggs Pond	9/1/2010	0.32	*29.4*	4.95
Griggs Pond	9/29/2010	0.48	**46.7**	*8.58*
Holbrook Bay North	4/14/2010	0.29	-	0.85
Holbrook Bay North	5/11/2010	0.18	12.4	0.83
Holbrook Bay North	6/9/2010	0.23	*22.7*	2.45
Holbrook Bay North	6/28/2010	0.62	**109**	**29.5**
Holbrook Bay North	7/7/2010	0.42	*31*	3.64
Holbrook Bay North	7/12/2010	-	*22.4*	-
Holbrook Bay North	7/15/2010	-	**63.9**	-
Holbrook Bay North	8/3/2010	0.62	**91.4**	**15**
Holbrook Bay North	9/1/2010	0.38	**57.1**	*9.73*
Holbrook Bay North	9/29/2010	0.33	**35.4**	*7.03*
Holbrook Bay South	4/14/2010	0.26	*20.6*	2.04
Holbrook Bay South	5/11/2010	0.23	*20.3*	1.79
Holbrook Bay South	6/9/2010	0.43	**41.8**	*6.27*
Holbrook Bay South	6/28/2010	1.12	**381**	**106**
Holbrook Bay South	7/7/2010	1.43	**132**	**28**
Holbrook Bay South	7/12/2010	-	**96.2**	-
Holbrook Bay South	7/15/2010	-	**172**	-
Holbrook Bay South	8/3/2010	0.98	**197**	**49.8**
Holbrook Bay South	9/1/2010	1.2	**79.5**	**17.9**
Holbrook Bay South	9/29/2010	0.54	**53.8**	**11.5**
Irasburg	4/14/2010	0.45	*20.5*	1.73
Irasburg	5/11/2010	0.4	*20.3*	2.04
Irasburg	6/9/2010	0.46	**39.6**	*8.62*
Irasburg	6/28/2010	0.7	**98.5**	**13.4**
Irasburg	7/7/2010	-	*29.3*	3.41
Irasburg	8/3/2010	0.46	**104**	**36.4**
Irasburg	9/1/2010	0.32	*25.4*	3.02
Irasburg	9/29/2010	0.4	**42.1**	*7.2*

Site	Date	Total nitrogen (mg/l)	Total phosphorus (:g/l)	Turbidity (NTU)
Johns River	4/14/2010	*2.31*	15.2	0.74
Johns River	4/19/2010	1.62	15.9	-
Johns River	5/11/2010	*2.29*	12.9	1.07
Johns River	6/7/2010	1.36	**40**	-
Johns River	6/9/2010	*2.36*	17.2	0.95
Johns River	6/28/2010	*2.85*	**680**	**217**
Johns River	7/7/2010	*2.7*	18.4	2.17
Johns River	8/3/2010	1.6	**186**	**44**
Johns River	9/1/2010	*3.56*	18	0.56
Johns River	9/29/2010	1.8	**38.2**	3.39
Lamphear Brook	4/14/2010	0.17	5.12	<0.2
Lamphear Brook	5/11/2010	0.13	5.2	<0.2
Lamphear Brook	6/9/2010	0.17	6.74	0.25
Lamphear Brook	6/28/2010	0.41	**37.9**	*7.13*
Lamphear Brook	7/7/2010	0.28	7.3	<0.2
Lamphear Brook	8/3/2010	0.47	**37.5**	*5.09*
Lamphear Brook	9/1/2010	0.15	6.03	<0.2
Lamphear Brook	9/29/2010	0.23	11.3	0.37
Lords Creek	4/14/2010	0.2	11.6	0.97
Lords Creek	5/11/2010	0.17	11.6	0.92
Lords Creek	6/9/2010	0.27	15.7	1.43
Lords Creek	6/28/2010	1.34	**169**	**36.1**
Lords Creek	7/7/2010	0.26	18.2	1.71
Lords Creek	8/3/2010	1.03	**234**	**94.5**
Lords Creek	9/1/2010	0.69	*21*	1.64
Lords Creek	9/29/2010	0.42	**42.1**	**10.6**
McCleary Brook	4/14/2010	0.11	5.61	<0.2
McCleary Brook	5/11/2010	0.1	<5	<0.2
McCleary Brook	6/9/2010	0.13	5.26	<0.2
McCleary Brook	6/28/2010	0.33	*25.6*	3.48
McCleary Brook	7/7/2010	0.13	5.72	<0.2
McCleary Brook	8/3/2010	0.42	**36.7**	*6.03*
McCleary Brook	9/29/2010	0.14	9.7	0.31

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (:g/l)**	**Turbidity (NTU)**
North Derby Road	4/14/2010	*2.27*	*23.2*	1.3
North Derby Road	5/11/2010	1.96	18.6	1.17
North Derby Road	6/9/2010	*2*	**37.7**	3.31
North Derby Road	6/28/2010	*2.06*	**306**	**81.4**
North Derby Road	7/7/2010	*2.03*	**58**	*9.38*
North Derby Road	8/3/2010	1.94	**190**	**45.5**
North Derby Road	9/1/2010	*2.43*	**50.9**	1.85
North Derby Road	9/29/2010	1.68	**58.2**	*6.67*
Rogers Branch	4/14/2010	0.61	18.9	1.68
Rogers Branch	5/11/2010	0.47	17.6	1.22
Rogers Branch	6/9/2010	0.51	**38.2**	*7.94*
Rogers Branch	6/28/2010	0.52	**46.8**	**10.9**
Rogers Branch	7/7/2010	0.52	**44.3**	*7.59*
Rogers Branch	8/3/2010	0.6	**65.3**	**14.3**
Rogers Branch	9/1/2010	0.49	*31.7*	*7.16*
Rogers Branch	9/29/2010	0.54	**40**	*5.83*
Rogers Tributary	4/14/2010	0.14	7.61	<0.2
Rogers Tributary	5/11/2010	0.15	8.48	0.32
Rogers Tributary	6/9/2010	0.24	11.4	0.42
Rogers Tributary	6/28/2010	0.5	**42.5**	4.39
Rogers Tributary	8/3/2010	0.57	**46.5**	3.96
Rogers Tributary	9/29/2010	0.37	*20.5*	0.84
School Brook	4/14/2010	0.2	13.4	1.62
School Brook	5/11/2010	0.31	12.1	1.3
School Brook	6/9/2010	0.31	17.8	2.24
School Brook	6/28/2010	1.04	**145**	**79.4**
School Brook	7/7/2010	0.38	*21.3*	1.12
School Brook	8/3/2010	0.86	**99.1**	**35.8**
School Brook	9/1/2010	0.22	11.3	0.52
School Brook	9/29/2010	0.49	**38.4**	*6.73*
Seaver Brook	4/14/2010	0.51	8.16	0.58
Seaver Brook	5/11/2010	0.43	7.87	0.31
Seaver Brook	6/9/2010	0.34	9.15	0.56
Seaver Brook	6/28/2010	0.52	**37.4**	4.06
Seaver Brook	7/7/2010	0.37	12.9	1.38
Seaver Brook	8/3/2010	0.52	**44.8**	4.86
Seaver Brook	9/1/2010	0.41	11.5	1.48
Seaver Brook	9/29/2010	0.27	11.2	0.95

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (:g/l)**	**Turbidity (NTU)**
Seaver Branch	4/14/2010	0.14	9.79	0.3
Seaver Branch	5/11/2010	0.18	9.52	0.44
Seaver Branch	6/9/2010	0.23	12.2	0.77
Seaver Branch	6/28/2010	0.45	**47.6**	*7.98*
Seaver Branch	7/7/2010	0.31	15.9	0.22
Seaver Branch	8/3/2010	0.62	**56.9**	*6.24*
Seaver Branch	9/1/2010	0.24	8.43	<0.2
Seaver Branch	9/29/2010	0.33	*21.7*	1.06
Shalney Brook	4/14/2010	0.18	8.98	0.37
Shalney Brook	5/11/2010	0.36	8.28	0.49
Shalney Brook	6/9/2010	0.25	13.5	0.64
Shalney Brook	6/28/2010	0.61	**83.3**	**16**
Shalney Brook	7/7/2010	0.52	*33.9*	0.59
Shalney Brook	8/3/2010	0.82	**99**	**16**
Shalney Brook	9/1/2010	0.62	**70.9**	0.88
Shalney Brook	9/29/2010	0.42	**36.8**	2.84
Stony Brook	4/14/2010	1.26	*21.4*	0.69
Stony Brook	5/11/2010	1.05	**109**	**13**
Stony Brook	6/9/2010	1.12	*32.2*	2.13
Stony Brook	6/28/2010	1.1	**129**	**20.4**
Stony Brook	7/7/2010	1.61	16.7	1.12
Stony Brook	8/3/2010	1.22	**161**	**64**
Stony Brook	9/1/2010	1.67	12.9	0.57
Stony Brook	9/29/2010	1.25	*22.3*	1.26
Strawberry Acres	4/14/2010	0.35	16	1.04
Strawberry Acres	5/11/2010	0.24	16.1	0.73
Strawberry Acres	6/9/2010	0.45	**39.1**	*6.75*
Strawberry Acres	6/28/2010	1.81	**496**	**131**
Strawberry Acres	7/7/2010	0.55	**37.8**	*6.63*
Strawberry Acres	8/3/2010	1.13	**226**	**33**
Strawberry Acres	9/29/2010	0.27	*20.4*	1.98

Site	Date	Total nitrogen (mg/l)	Total phosphorus (:g/l)	Turbidity (NTU)
Sunset Acres	4/14/2010	*3.33*	12.3	0.6
Sunset Acres	5/11/2010	*3.41*	9.47	0.4
Sunset Acres	6/9/2010	*3.62*	12.9	0.94
Sunset Acres	6/28/2010	1.83	**510**	**170**
Sunset Acres	7/7/2010	**6.07**	13.2	0.67
Sunset Acres	8/3/2010	1.07	**121**	**27.4**
Sunset Acres	9/1/2010	**6.86**	12	0.53
Sunset Acres	9/29/2010	1.99	*23.7*	1.74
Upper Lords Creek	4/14/2010	0.22	11.2	0.62
Upper Lords Creek	5/11/2010	0.16	9.49	0.46
Upper Lords Creek	6/9/2010	0.29	17.7	0.81
Upper Lords Creek	6/28/2010	0.56	**72.1**	**18**
Upper Lords Creek	7/7/2010	0.3	*25.2*	2.04
Upper Lords Creek	8/3/2010	0.95	**218**	**73.5**
Upper Lords Creek	9/1/2010	0.29	16.9	1.2
Upper Lords Creek	9/29/2010	0.32	*26.3*	3.21
Upper Strawberry Acres	4/14/2010	0.32	17.8	0.47
Upper Strawberry Acres	5/11/2010	0.28	19	0.63
Upper Strawberry Acres	6/9/2010	0.42	**40.3**	1.68
Upper Strawberry Acres	6/28/2010	0.81	**175**	**16.6**
Upper Strawberry Acres	7/7/2010	0.61	**37.3**	1.48
Upper Strawberry Acres	8/3/2010	1.02	**226**	**13.5**
Upper Strawberry Acres	9/1/2010	0.41	*22.8*	0.28
Upper Strawberry Acres	9/29/2010	0.41	*27.4*	0.98
Upper Wishing Well	4/14/2010	0.29	*22.6*	0.92
Upper Wishing Well	5/11/2010	0.28	*20*	1.06
Upper Wishing Well	6/9/2010	0.53	**46.4**	2.21
Upper Wishing Well	6/28/2010	*2.33*	**755**	**31.2**
Upper Wishing Well	7/7/2010	0.73	**41.3**	1.98
Upper Wishing Well	8/3/2010	1.45	**488**	**99.6**
Upper Wishing Well	9/1/2010	0.41	*32.8*	4.41
Upper Wishing Well	9/29/2010	0.81	**126**	*6.92*

Site	Date	Total nitrogen (mg/l)	Total phosphorus (:g/l)	Turbidity (NTU)
Ware Brook	4/14/2010	1.22	13.4	0.52
Ware Brook	5/11/2010	1.03	10.3	0.67
Ware Brook	6/9/2010	1.1	13.6	0.68
Ware Brook	6/28/2010	0.85	**101**	**18.5**
Ware Brook	7/7/2010	1.63	14.1	1.59
Ware Brook	8/3/2010	0.77	**122**	**18.4**
Ware Brook	9/1/2010	*2*	13.1	1.53
Ware Brook	9/29/2010	1.17	19.2	1.31
Whetstone Brook	4/14/2010	0.77	10.6	0.43
Whetstone Brook	5/11/2010	0.69	12.4	0.93
Whetstone Brook	6/9/2010	0.53	13	0.9
Whetstone Brook	6/28/2010	1.14	**133**	**36.1**
Whetstone Brook	7/7/2010	-	*26.1*	0.8
Whetstone Brook	8/3/2010	1.53	**112**	**18.5**
Whetstone Brook	9/1/2010	0.47	11.8	0.36
Whetstone Brook	9/29/2010	0.37	10.4	0.26
Whitney Brook	4/14/2010	0.77	9.21	0.29
Whitney Brook	5/11/2010	0.65	10.6	0.36
Whitney Brook	6/9/2010	0.48	12.2	1.11
Whitney Brook	6/28/2010	0.78	**81.7**	**18.4**
Whitney Brook	7/7/2010	0.64	*30.1*	<0.2
Whitney Brook	8/3/2010	0.8	**77.2**	**16.3**
Whitney Brook	9/1/2010	0.43	6.78	<0.2
Whitney Brook	9/29/2010	0.3	9.41	<0.2
Wishing Well	4/14/2010	0.32	18.1	0.71
Wishing Well	5/11/2010	0.28	15.5	0.57
Wishing Well	6/9/2010	0.51	**35.3**	1.03
Wishing Well	6/28/2010	*2.44*	**774**	**42.2**
Wishing Well	7/7/2010	0.68	**40.6**	0.41
Wishing Well	8/3/2010	1.56	**979**	**498**
Wishing Well	9/1/2010	0.4	*28.3*	<0.2
Wishing Well	9/29/2010	0.74	**85**	4.05

Appendix C. Quality assurance data, including field blanks and field duplicates, collected from 33 sample sites along the Black River, Johns River, and four smaller tributaries of Lake Memphremagog during April-September 2010. Bold values indicate field blanks that exceeded detection limits (5 :g/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 (:g/l)**	**Turbidity (NTU)**
Holbrook Bay South	4/14/2010	<0.1	-	<0.2
McCleary Brook	4/14/2010	<0.1	-	<0.2
Stony Brook	4/14/2010	<0.1	-	<0.2
Black River	4/19/2010	<0.1	<5	-
Holbrook Bay South	5/11/2010	-	<5	-
McCleary Brook	5/11/2010	-	<5	-
Shalney Brook	5/11/2010	<0.1	<5	<0.2
Stony Brook	5/11/2010	-	<5	-
Sunset Acres	5/11/2010	<0.1	<5	<0.2
Ware Brook	5/11/2010	<0.1	<5	<0.2
Coventry Bridge	6/9/2010	<0.1	<5	<0.2
Holbrook Bay North	6/9/2010	<0.1	<5	<0.2
Rogers Tributary	6/9/2010	<0.1	<5	<0.2
Holbrook Bay South	6/28/2010	<0.1	<5	<0.2
McCleary Brook	6/28/2010	<0.1	<5	<0.2
Stony Brook	6/28/2010	<0.1	<5	<0.2
Irasburg	7/7/2010	<0.1	<5	<0.2
North Derby Road	7/7/2010	<0.1	<5	<0.2
Rogers Branch	7/7/2010	<0.1	<5	<0.2
Johns River	8/3/2010	<0.1	<5	<0.2
School Brook	8/3/2010	<0.1	<5	<0.2
Seaver Branch	8/3/2010	<0.1	<5	<0.2
Brighton Brook	9/1/2010	<0.1	<5	<0.2
Cass Brook	9/1/2010	<0.1	<5	<0.2
Darling Hill	9/1/2010	<0.1	<5	<0.2
School Brook	9/29/2010	<0.1	<5	<0.2
Seaver Branch	9/29/2010	<0.1	<5	<0.2
Strawberry Acres	9/29/2010	<0.1	<5	<0.2

Field duplicates:

Total phosphorus

Site	**Date**	**1st total phosphorus (:g/l)**	**2nd total phosphorus (:g/l)**	**Relative % difference**
Black River	4/19/2010	29.3	28.9	1
Holbrook Bay South	5/11/2010	20.3	20.7	2
McCleary Brook	5/11/2010	<5	<5	0
Shalney Brook	5/11/2010	8.28	8.36	1
Stony Brook	5/11/2010	109	116	6
Sunset Acres	5/11/2010	9.47	10.5	10
Ware Brook	5/11/2010	10.3	10.7	4
Coventry Bridge	6/9/2010	44	47.6	8
Holbrook Bay North	6/9/2010	22.7	17.6	25
Rogers Tributary	6/9/2010	11.4	11.7	3
Holbrook Bay South	6/28/2010	381	349	9
McCleary Brook	6/28/2010	25.6	25.2	2
Stony Brook	6/28/2010	129	124	4
Irasburg	**7/7/2010**	**29.3**	**43.3**	**39**
North Derby Road	7/7/2010	58	63.3	9
Rogers Branch	7/7/2010	44.3	44.3	0
Johns River	8/3/2010	186	178	4
School Brook	8/3/2010	99.1	99	0
Seaver Branch	8/3/2010	56.9	55.1	3
Brighton Brook	9/1/2010	22.1	23	4
Cass Brook	9/1/2010	10.8	11.7	8
Darling Hill	9/1/2010	21.8	28.7	27
School Brook	9/29/2010	38.4	38.2	1
Seaver Branch	9/29/2010	21.7	21.4	1
Strawberry Acres	9/29/2010	20.4	20.3	0

Total nitrogen

Site	Date	1st total nitrogen (mg/l)	2nd total nitrogen (mg/l)	Relative % difference
Holbrook Bay South	4/14/2010	0.26	0.28	7
McCleary Brook	4/14/2010	0.11	0.13	17
Stony Brook	4/14/2010	1.26	1.22	3
Black River	4/19/2010	0.46	0.48	4
Shalney Brook	5/11/2010	0.36	0.39	8
Sunset Acres	5/11/2010	3.41	3.38	1
Ware Brook	5/11/2010	1.03	1.03	0
Coventry Bridge	6/9/2010	0.48	0.49	2
Holbrook Bay North	6/9/2010	0.23	0.23	0
Rogers Tributary	6/9/2010	0.24	0.23	4
Holbrook Bay South	6/28/2010	1.12	1.11	1
McCleary Brook	6/28/2010	0.33	0.32	3
Stony Brook	6/28/2010	1.1	1.08	2
North Derby Road	7/7/2010	2.03	2.12	4
Rogers Branch	7/7/2010	0.52	0.5	4
Johns River	8/3/2010	1.6	1.65	3
School Brook	8/3/2010	0.86	0.85	1
Seaver Branch	8/3/2010	0.62	0.6	3
Brighton Brook	9/1/2010	0.66	0.65	2
Cass Brook	9/1/2010	0.52	0.53	2
Darling Hill	9/1/2010	3.13	3.18	2
School Brook	9/29/2010	0.49	0.47	4
Seaver Branch	9/29/2010	0.33	0.34	3
Strawberry Acres	9/29/2010	0.27	0.27	0

Turbidity

Site	**Date**	**1st turbidity (NTU)**	**2nd turbidity (NTU)**	**Relative % difference**
Holbrook Bay South	4/14/2010	2.04	1.97	3
McCleary Brook	4/14/2010	<0.2	<0.2	0
Stony Brook	4/14/2010	0.69	0.8	15
Shalney Brook	**5/11/2010**	**0.49**	**0.38**	**25**
Sunset Acres	5/11/2010	0.4	0.45	12
Ware Brook	**5/11/2010**	**0.67**	**0.52**	**25**
Coventry Bridge	6/9/2010	8.51	8.15	4
Holbrook Bay North	6/9/2010	2.45	2.5	2
Rogers Tributary	6/9/2010	0.42	0.45	7
Holbrook Bay South	6/28/2010	106	98.5	7
McCleary Brook	6/28/2010	3.48	3.33	4
Stony Brook	**6/28/2010**	**20.4**	**24.9**	**20**
Irasburg	7/7/2010	3.41	2.95	14
North Derby Road	7/7/2010	9.38	9.48	1
Rogers Branch	7/7/2010	7.59	7.26	4
Johns River	8/3/2010	44	45.1	2
School Brook	8/3/2010	35.8	36.1	1
Seaver Branch	8/3/2010	6.24	6.21	0
Brighton Brook	9/1/2010	2.1	1.8	15
Cass Brook	**9/1/2010**	**0.8**	**0.44**	**58**
Darling Hill	9/1/2010	0.95	0.86	10
School Brook	9/29/2010	6.73	6.34	6
Seaver Branch	9/29/2010	1.06	1.14	7
Strawberry Acres	9/29/2010	1.98	1.83	8

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 increased nutrients (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 forms of 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.

Class A waters – Designation given by the State of Vermont to all surface waters being managed as a public water supply or located above an elevation of 2,500 feet.

Class B waters – Designation given by the State of Vermont to all surface waters not being managed as a public water supply and located below an elevation of 2,500 feet.

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, increasing its productivity and eventually turning it into a wetland. Human activities often accelerate this process.

Flow – The volume of water that moves past a given location per unit of time (usually measured as cubic feet per second or cubic meters 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 amount of a physical or chemical substance, such as sediment or phosphorus, 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 comes 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.

Transpiration – The evaporative loss of water from a plant, especially during photosynthesis.

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.

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