Restoring Water Quality in the Lake Memphremagog Basin:

2011 Black River Water Quality Report

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

by

Fritz Gerhardt, Ph.D.

14 February 2012

Memphremagog Watershed Association

The Memphremagog Watershed Association (MWA), founded in 2007, is a nonprofit organization dedicated to the preservation of the environment and natural beauty of the Lake Memphremagog Basin. The Memphremagog Watershed Association achieves this mission through public education, water quality monitoring, shoreline cleanup and renaturalization, and protection of local wildlife.

Memphrémagog Conservation Inc.

Memphremagog Conservation Inc. (MCI) is a not-for-profit organization dedicated to environmental conservation and preserving the natural beauty of Lake Memphremagog and its watershed since 1967. To this end, MCI monitors water quality in the lake and its tributaries; promotes shoreline re-naturalization; actively works toward the protection of area plants and wildlife; lobbies local, provincial, and federal governments to adopt regulations that protect and improve the quality of life in and around the lake; and informs the public about issues affecting the environment and natural beauty of Lake Memphremagog.

Beck Pond LLC

Beck Pond LLC partners with public and private organizations to conduct scientific research that guides on-the-ground conservation in northern New England and adjacent Canada. Founded in 2009, Beck Pond LLC is a limited liability company organized in the state of Vermont and owned and operated by Dr. Fritz Gerhardt. Dr. Gerhardt has been working as a conservation scientist since 1987 and is dedicated to conducting scientific research that not only increases our understanding of the natural environment but also informs on-the-ground conservation. Among other projects, he has conducted scientific studies to assess the impacts of historical land uses on forest plant communities; to assess the impacts of invasive plants on grasslands and forests; to protect and improve water quality in the Lake Memphremagog and White River watersheds; to protect and restore floodplain forests and wetlands along the Upper Connecticut River and tributaries to Lake Memphremagog; and to identify and protect wildlife habitat linkages across northern New England and eastern Canada.

Cover. *In 2011, extensive flooding occurred frequently along the Vermont tributaries of Lake Memphremagog as seen in Coventry, Vermont on 12 April 2011. Clearing floodplains for agriculture and other land uses greatly reduces their ability to store excess floodwaters and to filter nutrients and sediment from those floodwaters.*

Restoring Water Quality in the Lake Memphremagog Basin:

2011 Black River Water Quality Report

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

Fritz Gerhardt, Ph.D.

Beck Pond LLC
394 Beck Pond Road
Newark, VT 05871
fgerhardt@newarkvt.net

Acknowledgments

This project would not have been possible without the support of many individuals and organizations. Gisèle Benoit, 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. Neil Kamman, Jim Kellogg, and Jerry Divincenzo enabled establishment of the Analytical Services Partnership to fund analyses of the water samples at the LaRosa Analytical Laboratory. Dan McAvinney and Alison Farnsworth provided valuable administrative and logistical support in terms of analyzing the water samples at the LaRosa Analytical Laboratory. Don Hendrich and King Boyd of the Memphremagog Watershed Association helped collect water samples on several dates. Numerous landowners graciously gave us permission to sample water quality on their properties. Memphrémagog Conservation Inc. and the Vermont Agency of Natural Resources provided financial support for this project. The assistance and support of all of these individuals and organizations are greatly appreciated.

Table of Contents

List of Figures

Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially the high phosphorus and turbidity levels and more frequent and widespread occurrences of algal and cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, previous studies have focused on identifying and assessing the nutrient and sediment sources along the Vermont tributaries of the lake. These studies have identified the Black River as being the largest source of phosphorus and sediment flowing into Lake Memphremagog.

2. The goal of our 2011 sampling program was to further pinpoint and assess potential sources of phosphorus, nitrogen, and sediment in the Black River watershed, especially along the main stem between Craftsbury and Albany villages and four tributaries where high phosphorus levels were measured previously. To accomplish this goal, we collected and analyzed water samples for total phosphorus, total nitrogen, and turbidity on seven dates at 27 sites distributed throughout the Black River watershed.

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. The seven sample dates included two low flows (which were very informative for identifying point sources of pollution), one moderate flow, two dates on which rain fell while we were sampling (which helped pinpoint nonpoint sources of pollution), a 10-year flood event in April, and a 50-year flood event in August. Along the main stem of the Black River, phosphorus and turbidity levels increased dramatically just downstream of Craftsbury village and continued to increase from there downstream to Albany village and again downstream of Irasburg village. Along the four tributaries, we were able to pinpoint phosphorus and turbidity sources along Shalney Branch and Stony Brook, two of the tributaries with the highest phosphorus levels in the watershed. In addition, we identified one possible source area for the high phosphorus and turbidity levels measured in Brighton Brook. Finally, we identified three tributaries where nitrogen levels were somewhat elevated (Brighton, Ware, and Stony Brooks).

4. Collectively, these data greatly increased our understanding of water quality problems and their sources along the Vermont tributaries of Lake Memphremagog. Additional analyses and studies will be undertaken to further pinpoint the sources of the elevated phosphorus and turbidity levels in the Black River and the other tributaries of Lake Memphremagog. In the meantime, we have initiated discussions with several landowners to solicit their interest in undertaking protection and restoration projects

to reduce nutrient and sediment inputs in those areas where specific problems were identified by 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 occurrence of cyanobacterial (blue-green algal) blooms, especially during the past several years (Figure 2).

Figure 1. *Turbid water and algae near the mouth of the Johns River in 2006. Excessive nutrients and sediment 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 levels 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 elevated phosphorus levels, 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 Quebec and Vermont. Since 2004, the Steering Committee has coordinated water quality monitoring efforts on both sides of the Quebec/Vermont border. The overall goal of these efforts has been to identify 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 at 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 Quebec tributaries of 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 Vermont tributaries of Lake Memphremagog. During 2004-2005, MCI and the Regroupement des Associations pour la Protection de l'Environnement des Lacs (RAPPEL) completed comprehensive habitat assessments along the littoral zones of Lake Memphremagog in both Quebec and Vermont. Finally, in partnership with the Vermont DEC, the NorthWoods Stewardship Center has completed stream geomorphic assessments along all four major Vermont tributaries of Lake Memphremagog.

Although 73% of Lake Memphremagog is located in Quebec, 71% of the watershed lies in Vermont. Thus, previous monitoring efforts have focused on assessing water quality conditions and identifying nutrient and sediment sources along the four principal Vermont tributaries of Lake Memphremagog. Sampling efforts in 2005 and 2006 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 installed in the summer of 2009. Replacing the failed manure lagoon and curtailing 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 on 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.

In 2010, we refocused our efforts on identifying and assessing threats to water quality in the watershed of the Black River. The Black River has been targeted as a high priority for assessment due to the elevated phosphorus and sediment levels 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). 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 main stem of the Black River, phosphorus and turbidity levels were highest between the villages of Craftsbury and Albany and again downstream of Irasburg village. Phosphorus and sediment levels were also high along four tributaries of the Black River: Shalney Branch, Brighton Brook, Lords Creek, and Stony Brook.

Study Goals

In 2011, we continued these 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, Memphremagog Conservation Inc., Orleans County Natural Resources Conservation District, Vermont DEC, and Beck Pond LLC again partnered to sample water quality along the Black River. The goal of this year's project was to further assess and identify the sources of water quality problems along the main stem and several tributaries of the Black River, where high phosphorus and sediment levels had been measured previously. To accomplish this goal, we measured water quality at 27 sites distributed throughout the Black River watershed, including ten sites along the main stem and 17 sites along six tributaries of the Black River. This distribution of sites allowed us to identify and assess possible nutrient and sediment sources 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).

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.

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). 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.

The Johns River (Waterbody ID VT17-01) drains an area of approximately 29 km^2 in the towns of Derby, Vermont and Stanstead, Quebec. The Johns River is fed by Crystal Brook and several smaller tributaries and flows into Lake Memphremagog at Derby Bay, just south of the Quebec/Vermont border. There are no large lakes or ponds in the watershed. The Johns River is 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 addition to these four large 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), although high sediment and nutrient levels have been measured in several of these (Gerhardt 2009, 2010).

Methods

To better pinpoint possible nutrient and sediment sources in the Black River watershed, we sampled water quality at 27 sites distributed throughout the watershed, including ten sites along the main stem and 17 sites along six of the larger tributaries (Figure 3; see Appendix A for descriptions of all sites). In addition to five sites along the main stem that had been sampled previously (Coventry Bridge, Irasburg, Griggs Pond, Rogers Branch, and Craftsbury), we added five sites along the main stem between Craftsbury and Albany villages, where we had detected a substantial increase in phosphorus and sediment levels previously (Cemetery Road, Mud Pond, Post Road, North Craftsbury Road, and Tanner Road). Along the major tributaries of the Black River, we expanded our sampling along four tributaries where we had detected high phosphorus and sediment levels previously (Stony Brook, Brighton Brook, Lords Creek, and Shalney Branch). In addition to the sites sampled previously near the mouths of these tributaries, we added 1-3 additional sites further upstream to better pinpoint nutrient and sediment sources along these tributaries. We also resampled several other tributaries that either had exhibited elevated nutrient or sediment levels in 2010 (Ware, School, and Whetstone Brooks) or that drained the eastern slopes of Lowell Mountain, where a large industrial wind farm is being developed (Rogers and Seaver Branches). Finally, the Vermont DEC continued sampling water quality at four sites near the mouths of the four major tributaries of Lake Memphremagog (Barton, Black, Clyde, and Johns Rivers), which have been sampled every year since 2005.

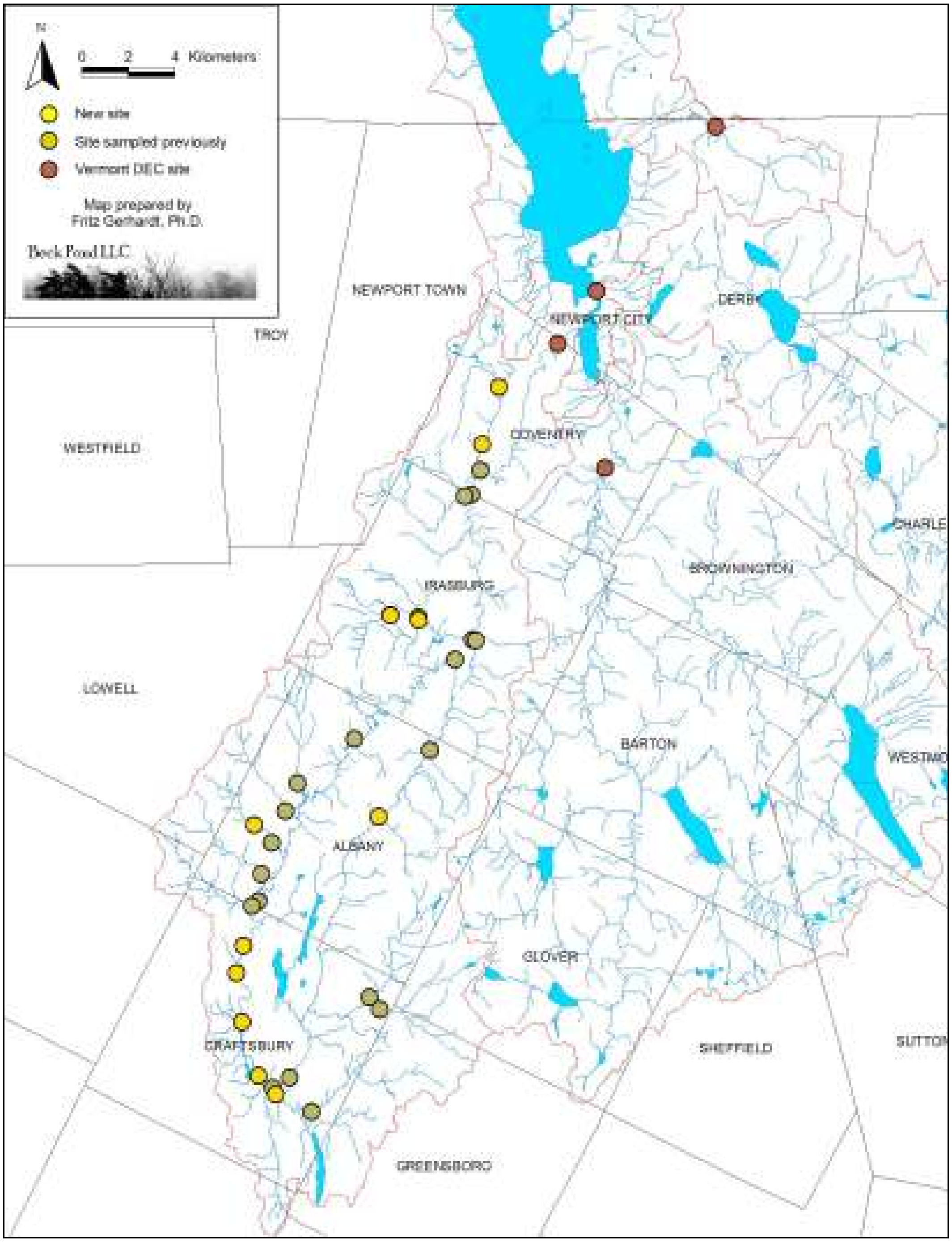


Figure 3. *Locations of the 31 sites sampled along the Black River and its tributaries and the four major tributaries of Lake Memphremagog during April-October 2011.*

To accomplish the goals of this study, we sampled water quality at 27 sites on seven dates during 12 April-12 October 2011 (the four DEC-maintained sites were also sampled on additional dates and for a longer sampling season). Since we were able to capture two high-flow events during our regularly-scheduled sample dates, we did not add additional sample dates beyond these regularly-scheduled dates. However, due to flooding of the LaRosa Analytical Laboratory caused by Tropical Storm Irene, we postponed our last sample date from late September until early October, and we did not collect an eighth round of water quality samples as originally planned. In addition, the Alderbrook site on Stony Brook was not sampled on the first date (12 April), and the Rogers Tributary site on Rogers Branch was not sampled on 2 August, when no water was flowing in this tributary.

On each sample date, we collected water samples from each site to be analyzed for total phosphorus, total nitrogen, and turbidity. Samples were collected in pre-labeled, sterilized bottles according to protocols established in conjunction with the Vermont DEC and the LaRosa Analytical Laboratory (State of Vermont 2000, 2006). We collected grab samples with either a dip sampler. Before collecting the samples, we rinsed the total nitrogen and turbidity bottles and the dip sampler with sample water three times. All samples were collected on a single day, stored in coolers, and delivered to the LaRosa Analytical Laboratory the next morning. This schedule ensured that the laboratory was able to process the samples in a timely manner. Unfortunately, due to the flooding of the LaRosa Laboratory, the samples collected on 29 August were not analyzed until early October (4 October for turbidity, 6 October for total nitrogen, and 19 October for total phosphorus). Since the hold times for all of these samples (four days for turbidity and 28 days for phosphorus and nitrogen) were exceeded, we discarded the turbidity and total nitrogen data but do present the total phosphorus data. Although these data were less likely to be impacted by the excessive hold times, they are presented cautiously and only to provide a better assessment of phosphorus levels at the highest stream flows.

On each sample date, we measured water depth with a meter stick at eight sites in the Black River watershed, including three sites along the main stem and five sites along the tributaries. In addition, the U.S. Geologic Survey maintained gauge stations that measured water depths and stream flows on the Barton, Black, and Clyde Rivers; and the Vermont DEC maintained a seasonal gauge station that measured water depth on the Johns River. For the latter, we were able to create a continuous record of stream flows for the entire sampling season based on a rating curve developed from the water depths recorded by a YSI 600 LS vented sonde (YSI, Yellow Springs, Ohio) and stream flows measured with a SonTek Acoustic Doppler Flowtracker (SonTek, San Diego, California). When combined with the phosphorus and nitrogen concentrations, these stream 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. Blank sample containers were rinsed and filled only with de-ionized water and, if done properly, should result in values below the detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.2 NTU for turbidity). Field duplicates required collecting a second sample at the same time and place as the original sample. When done properly, the mean relative percent difference among all of the pairs of duplicate samples should be less than 30% for total phosphorus, 20% for total nitrogen, and 15% for turbidity.

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 approximate stream flows at our sample sites, we relied on stream flow measurements from two gauges, one maintained by the U.S. Geological Survey on the Black River and one maintained seasonally by the Vermont DEC on the Johns River. The 2011 sampling season was characterized by prolonged spring flooding and several extreme high-flow events that punctuated the otherwise typical seasonal flow patterns (Figure 4). Peak spring flows occurred throughout March and April following snowmelt but recurred again in May following numerous heavy rains. The highest flows occurred during 11-14 April and 27-29 April, both of which represented 10-year flood events. Flows declined thereafter and were seasonally low throughout June, July, and early August, although flows did increase occasionally following heavy but localized rains, especially on the smaller tributaries. At the end of August, the torrential rains associated with the remnants of Tropical Storm Irene caused extremely high flows and widespread flooding, as the rivers exceeded levels representing a 50-year flood event.

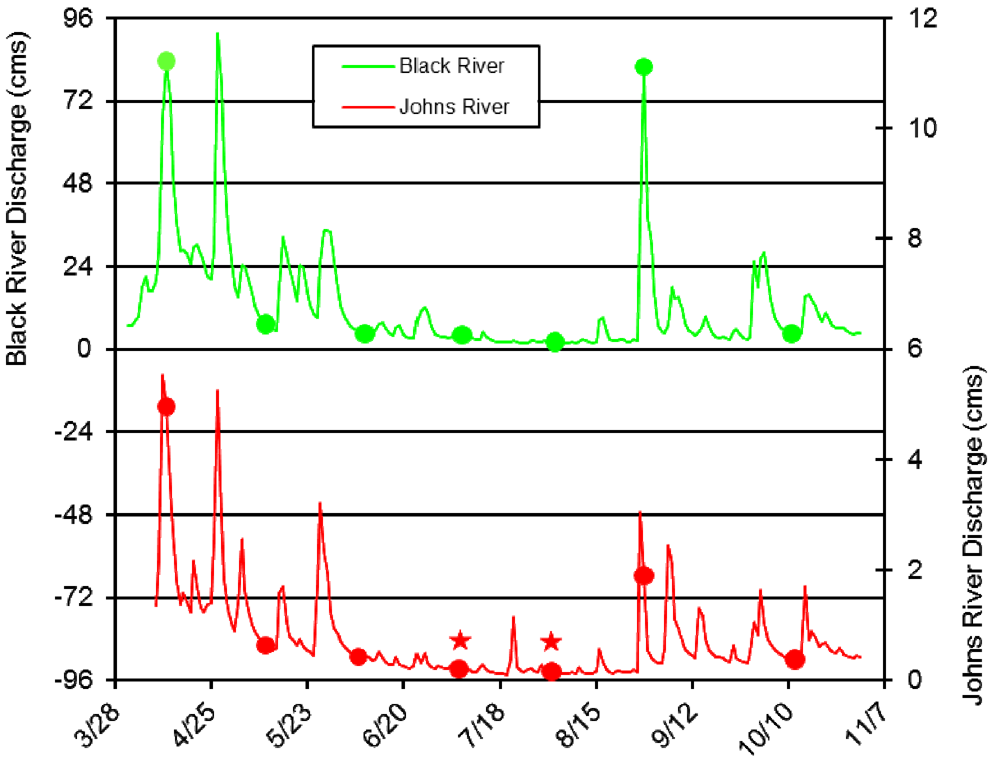


Figure 4. *Stream flows along the Black River (top) and Johns River (bottom) during April-October 2011. The seven dates on which water samples were collected are indicated by the circles. Stream flows for the Black River were measured by the U.S. Geological Survey [USGS station 04296000 (Black River at Coventry, VT)]; stream flows for the Johns River were measured by the Vermont DEC.*

Our sample dates captured this extreme variation in stream flow in 2011 (Figure 4). We collected water samples during the high flows associated with both the spring snowmelt (12 April) and immediately following the passage of Tropical Storm Irene (29 August). We also collected water samples during more moderate flows on three dates in late spring, early summer, and late autumn (11 May, 7 June, and 12 October). Finally, we captured generally low flows on two dates in mid-summer (6 July and 2 August), although both dates included some sites with higher flows due to localized but heavy rains. Collecting water samples across this range of stream flows greatly enhanced our ability to identify and assess water quality problems. Low flows are especially informative for identifying and assessing nutrient and sediment inputs originating from point and groundwater sources. In contrast, high flows are more informative for identifying and assessing nutrient and sediment inputs originating from nonpoint sources, which typically generate the majority of the sediment and nutrient pollution exported from these watersheds.

Total Phosphorus

Total phosphorus measures the concentration of all forms of phosphorus in the water column, including dissolved phosphorus, phosphorus attached to suspended sediments, and phosphorus incorporated into organic matter. Phosphorus is typically the limiting nutrient and regulates the amount of aquatic life in northern freshwater 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 7.70-406 µg/l. Total phosphorus concentrations showed no marked seasonal pattern (Figure 5). Instead, the highest phosphorus levels were observed on the two sample dates with the highest stream flows (12 April and 29 August). Total phosphorus concentrations were also somewhat higher on the two dates when localized but heavy rains fell in portions of the Black River watershed (6 July and 2 August).

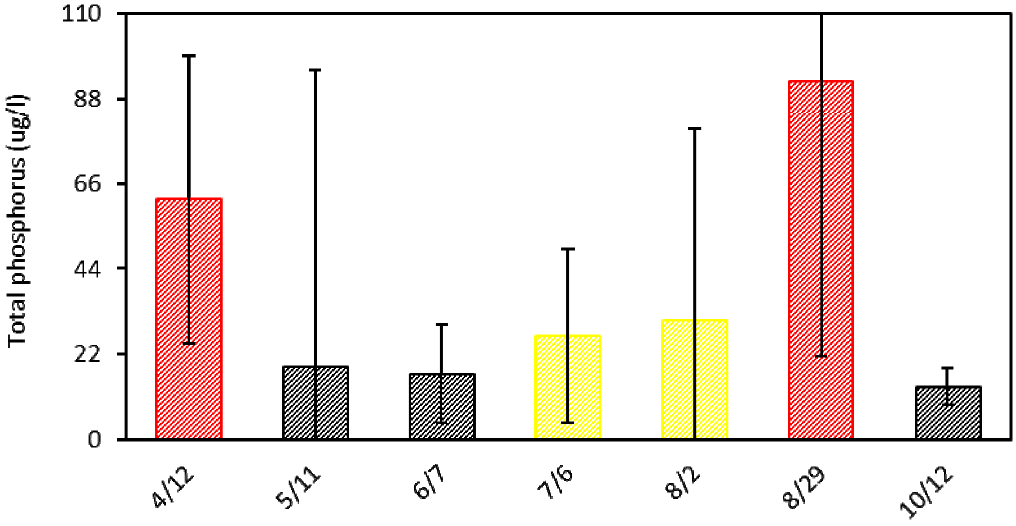


Figure 5. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 27 sites along the Black River and its tributaries during April-October 2011. Red hatching indicates the two high-flow events, and the yellow hatching indicates the two dates on which heavy but localized rains fell during the sampling.*

Total phosphorus concentrations were generally high (median values >20 µg/l) along much of the length of the main stem and the four major tributaries of the Black River (Stony Brook, Brighton Brook, Lords Creek, and Shalney Branch)(Figures 6-7). The main stem and all four tributaries drained areas of diverse land uses, including large areas of agriculture (Shalney Branch, Brighton Brook, and Lords Creek) and large areas of agriculture and gravel mining (Stony Brook).

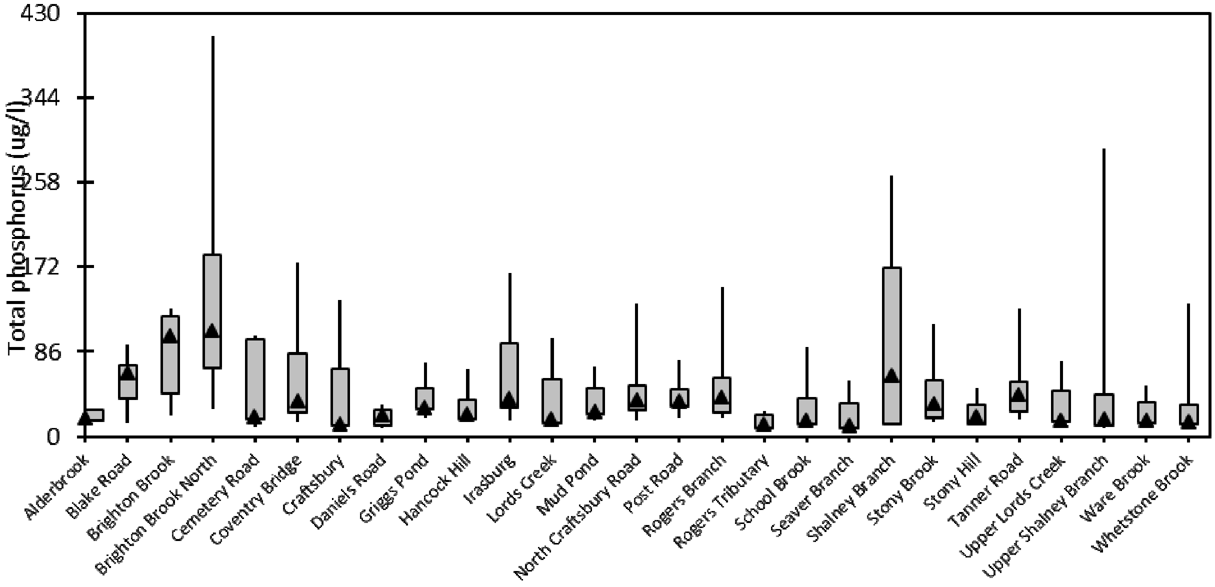


Figure 6. *Total phosphorus concentrations at 27 sites along the Black River and its tributaries during April-October 2011. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

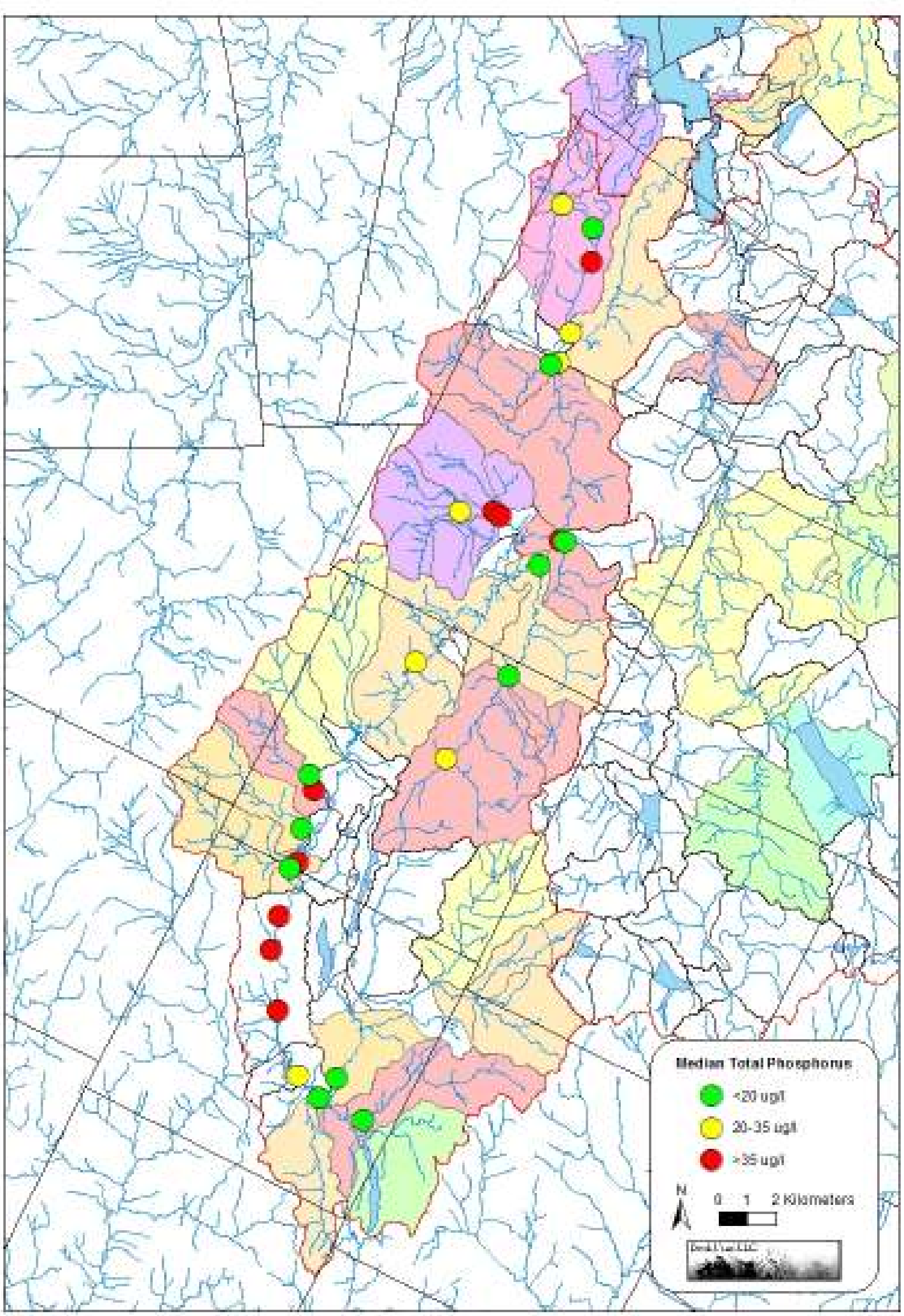


Figure 7. *Median total phosphorus concentrations at 27 sites along the Black River and its tributaries during April-October 2011.*

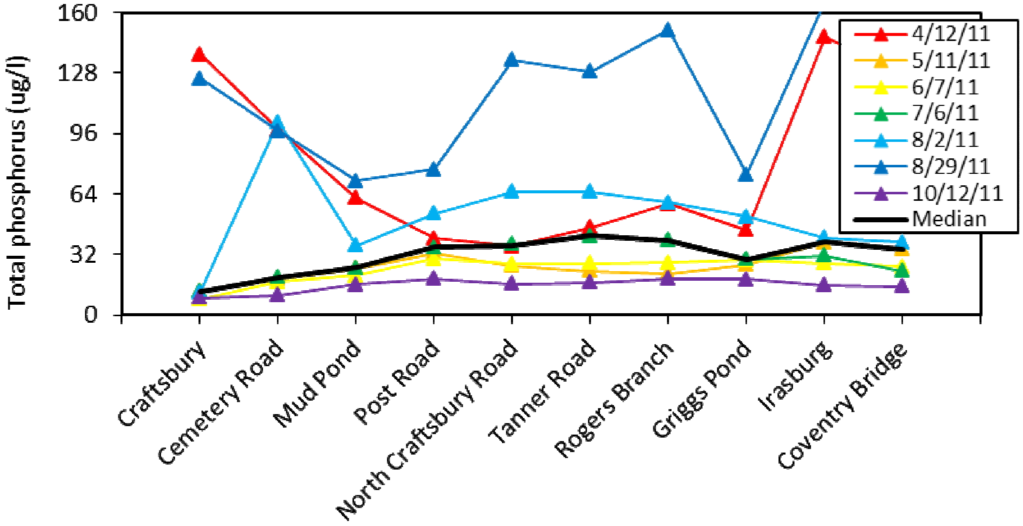


Figure 8. *Total phosphorus "profile" along the main stem of the Black River from Craftsbury downstream to Coventry Bridge during April-October 2011.*

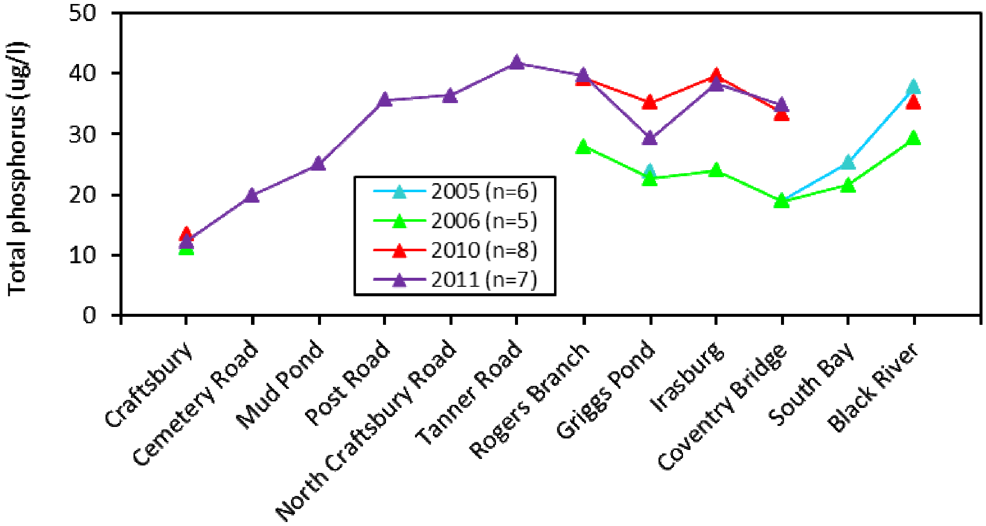


Figure 9. *Median total phosphorus "profile" along the main stem of the Black River from Craftsbury downstream to its mouth during 2005-2011. The sample size (n) is the number of dates sampled each year.*

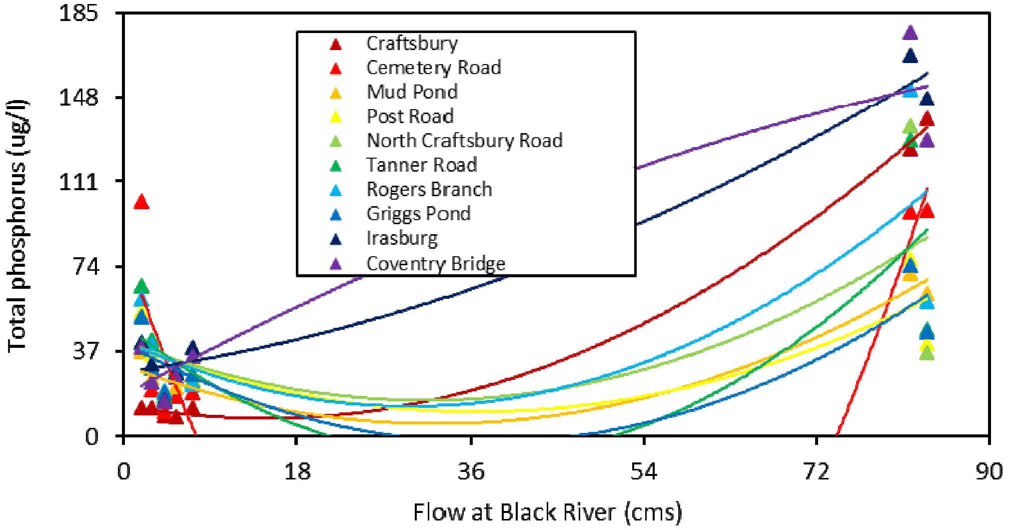


Figure 10. *Total phosphorus concentrations in relation to stream flow along the main stem of the Black River during April-October 2011. The regression lines indicate the polynomial relationships between the two parameters.*

Along Stony Brook, total phosphorus concentrations were relatively low at the two upstream sites, peaked sharply at Blake Road, and declined farther downstream (Figure 11). This pattern was evident on most but not all dates. Thus, most of the phosphorus in this tributary likely originated somewhere between the Blake Road and Alderbrook sites. Like the main stem, total phosphorus concentrations in Stony Brook generally increased with increasing stream flows, as would be expected if the phosphorus was originating from nonpoint sources (Figure 12). Although, much of this stretch of Stony Brook flows through alder swamps and beaver ponds, on-the-ground reconnaissance identified an area upstream of Nadeau Road where the landowner was constructing dams and ditches with no erosion control measures. These activities appeared to be the likely source of much of the sediment and phosphorus entering this stream. Consequently, personnel from the Vermont DEC initiated discussions with the landowner in order to address these issues.

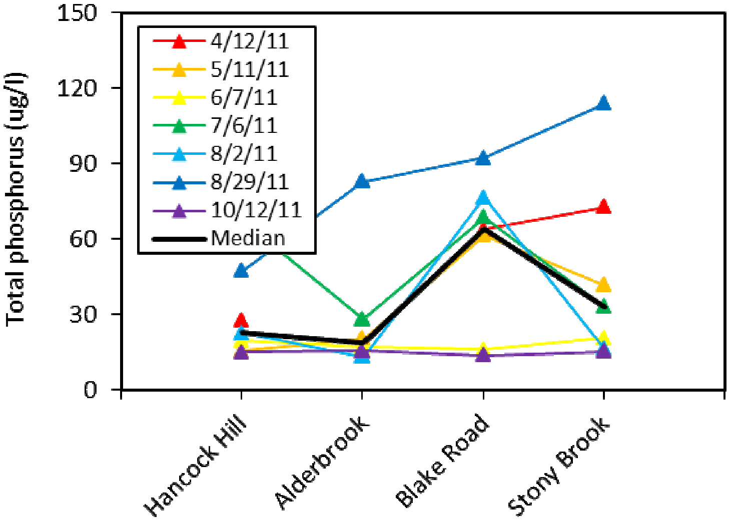


Figure 11. *Total phosphorus "profile" along Stony Brook from Hancock Hill downstream to Stony Brook in Coventry, Vermont during April-October 2011.*

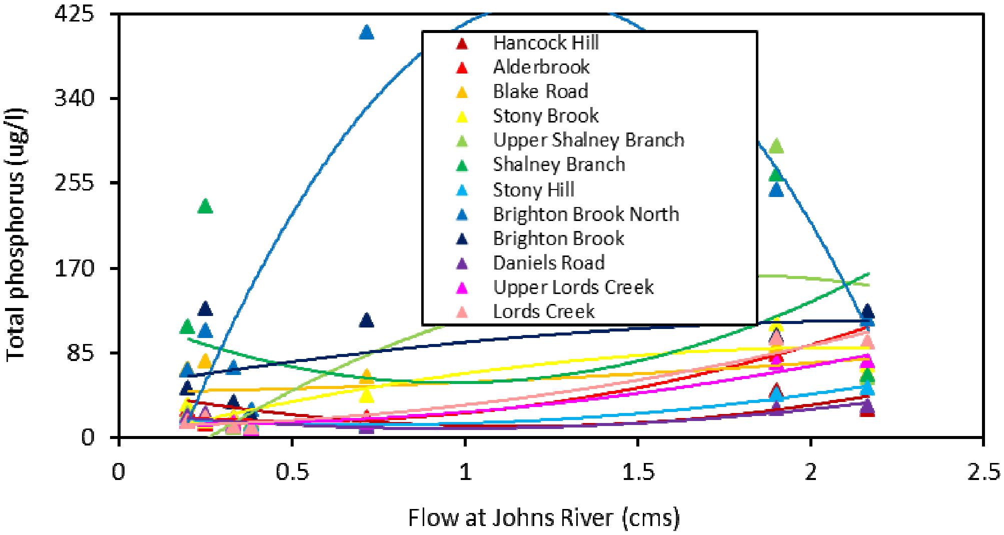


Figure 12. *Total phosphorus concentrations in relation to stream flow along four tributaries of the Black River during April-October 2011. The regression lines indicate the polynomial relationships between the two parameters.*

Along Lords Creek, total phosphorus concentrations generally declined from the upstream to downstream sites (Figure 13). However, during the two high-flow events (12 April and 29 August), total phosphorus concentrations increased dramatically from the upstream to downstream sites. In addition, total phosphorus concentrations at all three sites along this tributary generally increased with increasing stream flows (Figure 12). Collectively, these data suggested that the phosphorus in this stream likely originated from nonpoint sources of surface runoff. Given the land uses in this watershed, these sources were most likely associated with the many agricultural fields, especially pastures, located along this tributary, including several areas where livestock had direct access to the stream channel (Figure 14). Discussions with several of these landowners have been initiated by personnel from the Vermont DEC and Vermont Association of Conservation Districts.

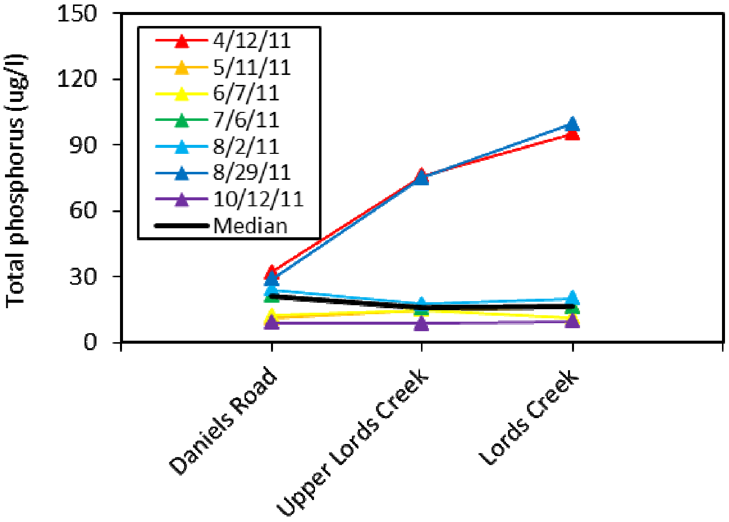


Figure 13. *Total phosphorus "profile" along Lords Creek from Daniels Road downstream to Lords Creek in Albany and Irasburg, Vermont during April-October 2011.*

Along Brighton Brook, total phosphorus concentrations were generally low at the Stony Hill site located at the upper end of Brighton Brook itself (Figure 15). In contrast, total phosphorus concentrations were extremely high at the Brighton Brook North site, which was located on a small tributary that entered Brighton Brook from the north, and they were also quite high along Brighton Brook downstream of its confluence with this northern tributary. Total phosphorus concentrations at all three sites generally increased with increasing stream flows, as would be expected if the phosphorus was originating from nonpoint sources. However, the highest levels of total phosphorus at the Brighton Brook North and Brighton Brook sites were measured on one low-flow date (11 May). Based on these data, it seems likely that the high phosphorus levels in this tributary were originating in surface runoff from the many, large corn and hay fields that drained into the small northern tributary of Brighton Brook (Figure 16). Possible sources of phosphorus included synthetic fertilizers and manure being applied to the corn and hay fields in this area. If this pattern is confirmed by future sampling, we recommend initiating discussions with the landowner(s) to identify and implement practices that will reduce runoff from these fields.

Figure 14. *Cattle directly accessing the stream channel near Irasburg, Vermont likely contributed to the high phosphorus levels measured in Lords Creek (photographed on 29 September 2010).*

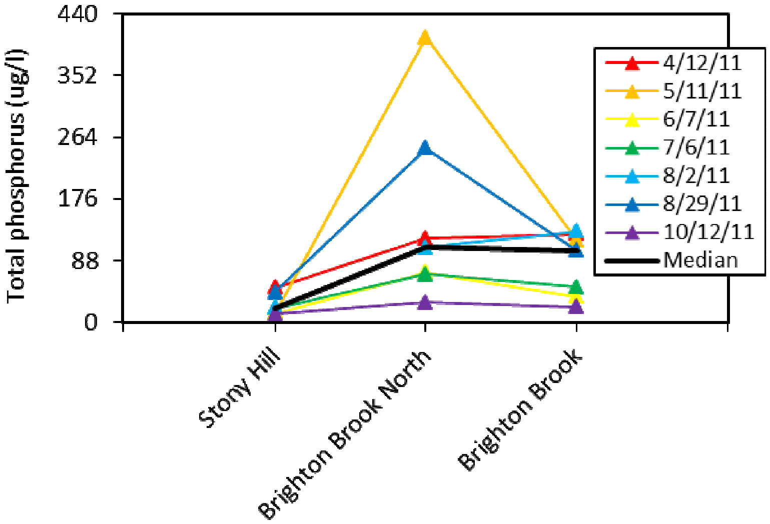


Figure 15. *Total phosphorus "profile" along Brighton Brook from Stony Hill downstream to Brighton Brook in Irasburg, Vermont during April-October 2011.*

Figure 16. *The large area of agricultural fields near Irasburg, Vermont likely contributed to the high phosphorus levels measured in the small northern tributary of Brighton Brook (photographed on 11 May 2011).*

Along Shalney Branch, total phosphorus concentrations increased dramatically between the upstream and downstream sites; however, this pattern was not entirely consistent among sample dates (Figure 17). In addition, total phosphorus concentrations generally increased with increasing stream flow at the upstream site but decreased with increasing stream flow at all but the highest flows at the downstream site. Thus, the principal phosphorus source(s) along this tributary was likely located somewhere between these two sites. This stretch included both the developed lands associated with the village of Albany as well as agricultural fields and infrastructure, including a cattle crossing, barnyard, and manure lagoon. On-the-ground reconnaissance suggested that one likely source of phosphorus in this area was barnyard runoff flowing down a cattle path and into the stream (Figure 18). We have already met with the owners of this property, and it is our understanding that they intend to undertake a barnyard improvement project to divert drainage from the stream and to install a bridge so that cattle will no longer enter the stream while moving to pasture. We will continue to work with and encourage this landowner to undertake these and other agricultural improvement and conservation projects to improve water quality in this tributary of the Black River.

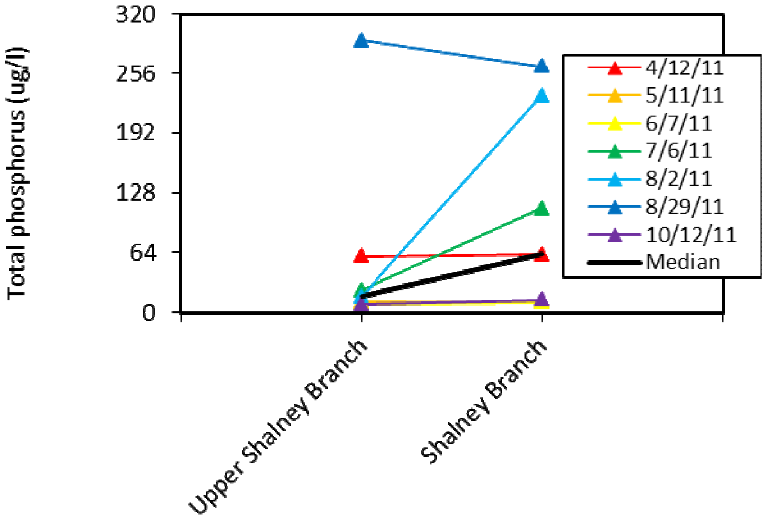


Figure 17. *Total phosphorus "profile" along Shalney Branch from Upper Shalney Branch downstream to Shalney Branch in Albany, Vermont during April-October 2011.*

Figure 18. *The cattle path leading down to Shalney Branch in Albany, Vermont may contribute to the high phosphorus levels measured in this tributary (photographed on 8 September 2011).*

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 (N). Total nitrogen measures the concentration of all forms of nitrogen in the water column. In Vermont, most nitrogen in surface waters originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

Total nitrogen concentrations in this study ranged between 0.13-3.89 mg/l. Total nitrogen concentrations showed no marked seasonal trend, and the highest levels were measured following heavy but localized rains on 2 August (Figure 19). These higher levels may have incorporated both dissolved forms of nitrogen as well as higher inputs of particulate nitrogen transported by surface runoff.

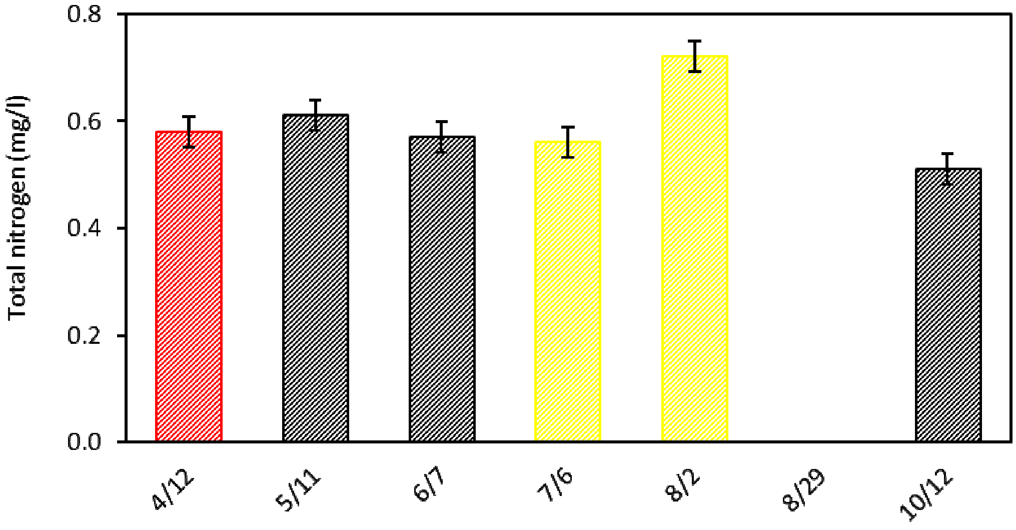


Figure 19. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 27 sites along the Black River and its tributaries during April-October 2011. Total nitrogen samples from 29 August were not analyzed due to flooding of the LaRosa Laboratory. Red hatching indicates the two high-flow events, and the yellow hatching indicates the two dates on which heavy but localized rains fell during the sampling.*

In general, median total nitrogen concentrations were relatively low (i.e. <1 mg/l) at most sites; however, they did exceed 1 mg/l along two tributaries (Stony and Ware Brooks) located in the town of Coventry (Figures 20-21). Total nitrogen concentrations along these two tributaries were negatively related to stream flow (Figure 22), and these negative relationships suggested that the nitrogen inputs in these two streams were derived from groundwater or point sources, rather than nonpoint sources such as agricultural or urban runoff. Thus, the high nitrogen levels in these two tributaries may have a similar origin to those measured in the Johns River watershed (Gerhardt 2009, 2010). That is, much of the nitrogen in these two tributaries may originate in groundwater that contains nitrogen applied as manure and/or synthetic fertilizers to cornfields located on coarse sand and gravel deposits.

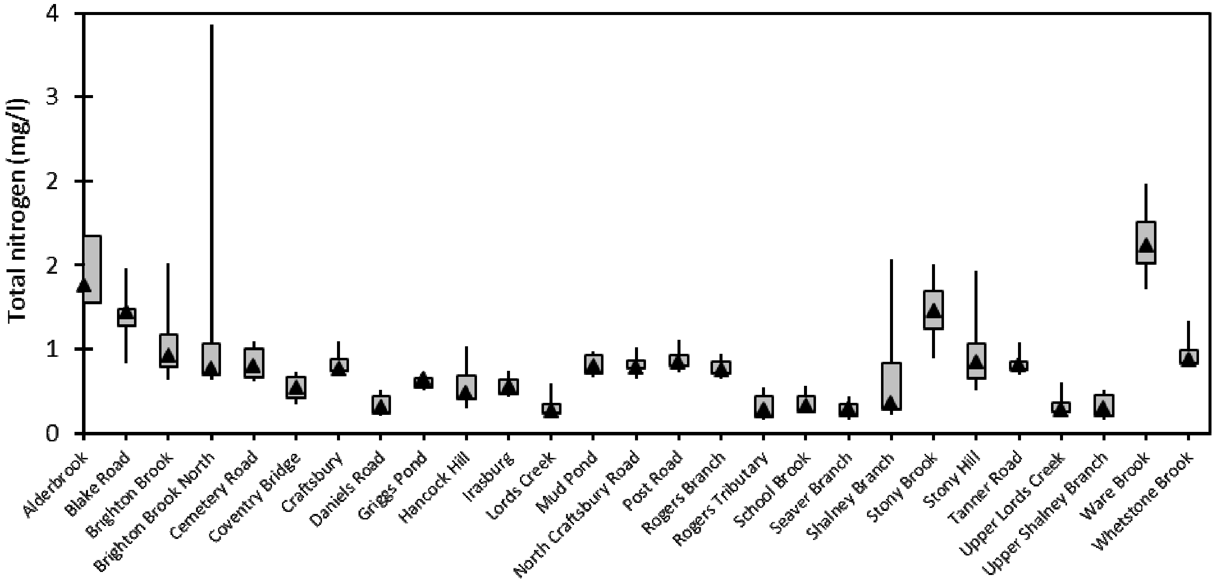


***Figure 20.** Total nitrogen concentrations at 27 sites along the Black River and its tributaries during April-October 2011. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

Total nitrogen concentrations were also very high (3.89 mg/l) at one other site (Brighton Brook North) and moderately high (1.62 mg/l) at a site farther downstream (Brighton Brook) on 11 May. As noted previously, this was the same date on which total phosphorus levels peaked at these two sites. Thus, these high nitrogen levels may also have been caused by runoff of recently-applied fertilizer and/or manure from the many large corn and hay fields drained by this small tributary (Figure 16). Total nitrogen concentrations were moderately high (>1 mg/l) on a single date at three other sites (Stony Hill, Shalney Branch, and Whetstone Brook).

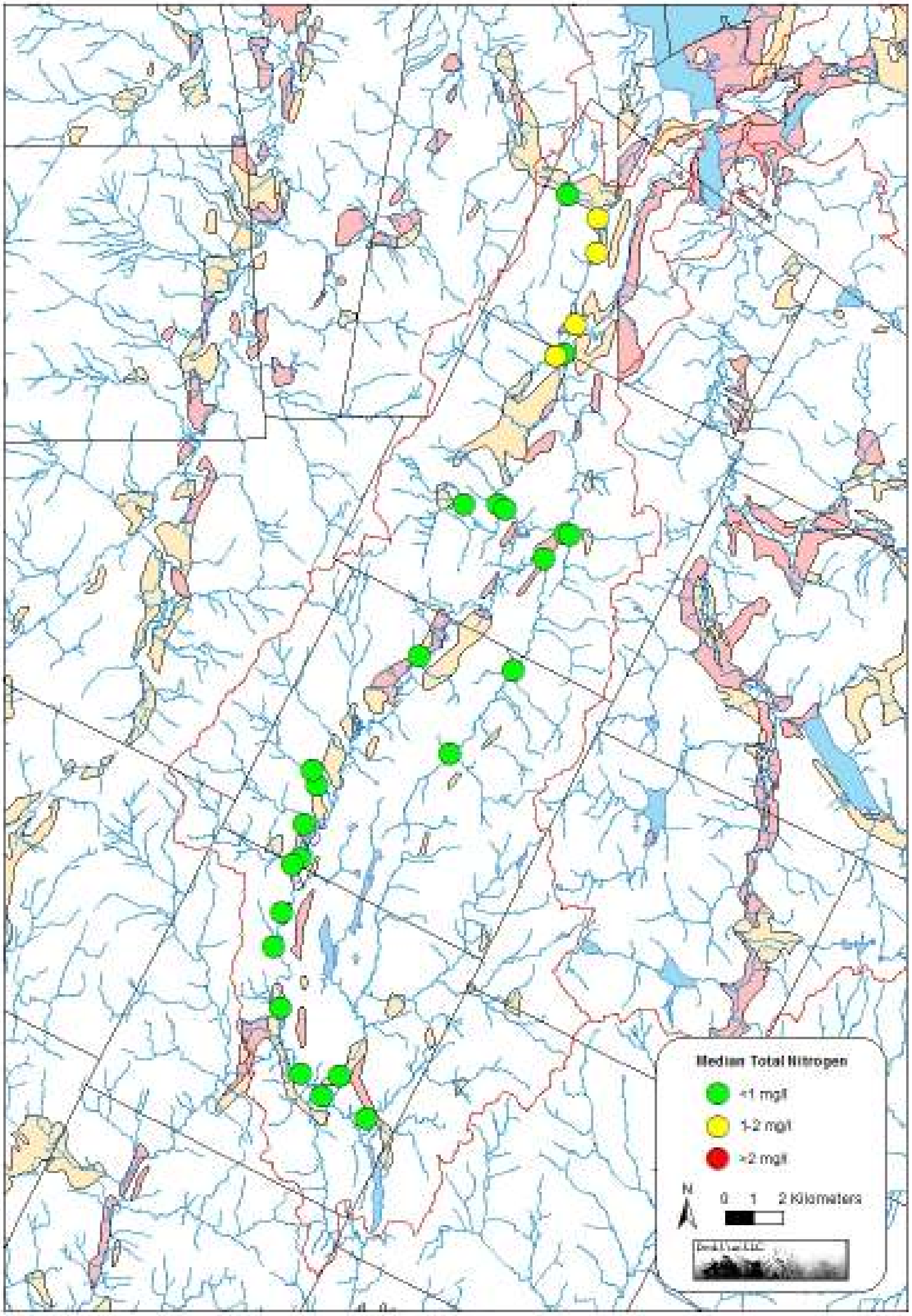


Figure 21. *Median total nitrogen concentrations at 27 sites along the Black River and its tributaries during April-October 2011. The locations of surficial sand and gravel deposits are shaded yellow and orange.*

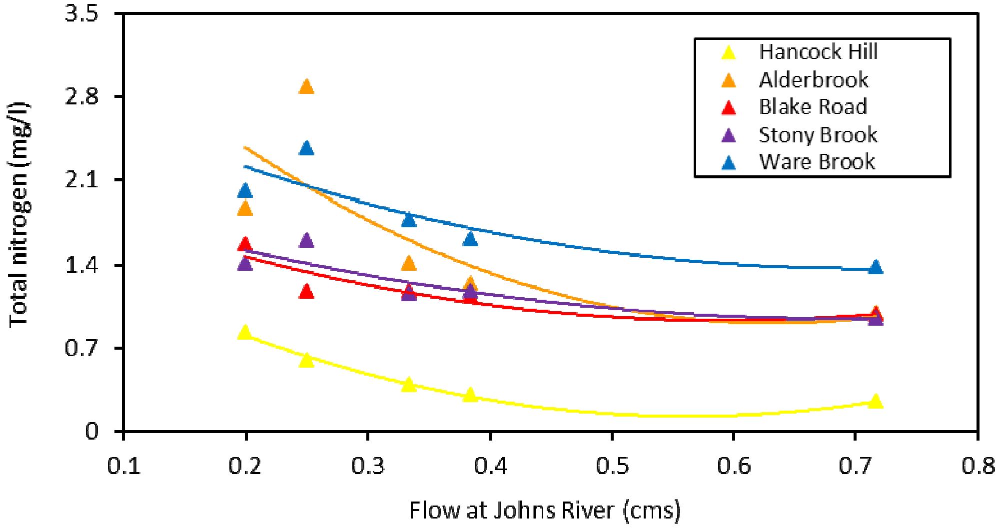


Figure 22. *Total nitrogen concentrations in relation to stream flow along two tributaries with high nitrogen levels in the Black River watershed during April-October 2011. The regression lines indicate the polynomial relationships between the two parameters.*

As with the Johns River watershed, the high nitrogen levels in the Black River watershed may not be reaching levels that are harmful to the aquatic communities. Although high, the nitrogen levels in two Black River tributaries were lower than those observed in the Johns River watershed (Gerhardt 2009, 2010). Based on recent biological assessments of the Johns River and its tributaries, even the higher nitrogen levels measured there did not appear to be harming the aquatic communities in those streams. Thus, we recommend continuing to monitor total nitrogen levels in these two tributaries while working with landowners to reduce the amounts of nitrogen being lost from agricultural fields and into both groundwater and surface waters.

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 can 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 channel adjustment processes. However, turbidity is also affected by natural biological and chemical processes and by the presence of chemical pollutants. Turbidity is measured as the light-scattering properties of dissolved and suspended materials in Nephelometric Turbidity Units (NTU).

Turbidity levels in this study ranged between 0.33-75.4 NTU. Like total phosphorus, turbidity levels showed no marked seasonal pattern and were highest on the sample dates with either the highest flows (12 April) or on which there were heavy but localized rains (2 August and 6 July)(Figure 23).

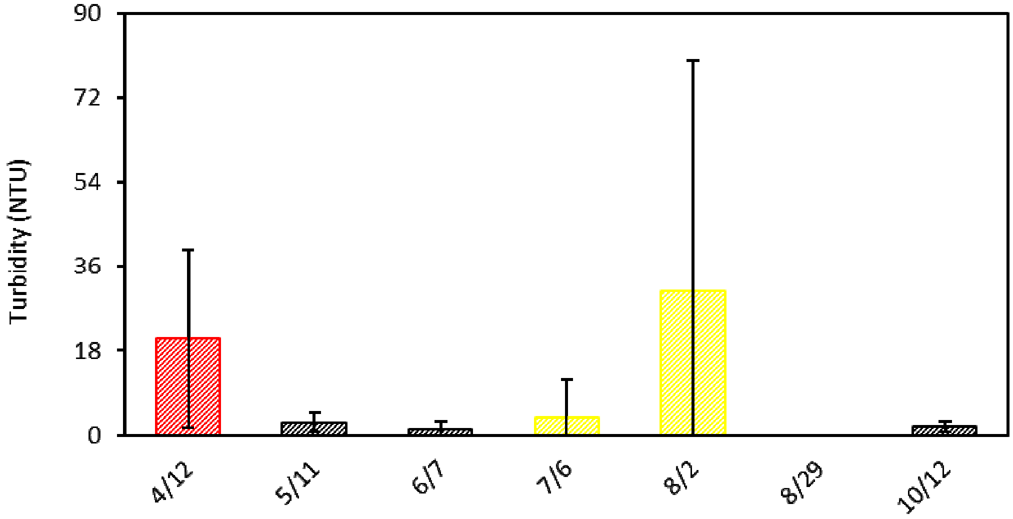


Figure 23. *Median turbidity levels (±1 SD) measured on each sample date at 27 sites along the Black River and its tributaries during April-October 2011. Red hatching indicates the two high-flow events, and the yellow hatching indicates the two dates on which heavy but localized rains fell during the sampling. Turbidity samples from 29 August were not analyzed due to flooding of the LaRosa Laboratory.*

Turbidity levels were generally high at the same sites as total phosphorus levels (Figures 24-25). The highest turbidity levels were observed at the downstream-most site on Shalney Branch (median = 16.6 NTU) and the Blake Road site on Stony Brook (median = 11.9 NTU). Along Shalney Branch, turbidity levels were markedly higher at the downstream than the upstream site (Figure 26). Likewise, turbidity levels peaked sharply at the Blake Road site on Stony Brook and were markedly lower both upstream and downstream of that site (Figure 26). At these two sites, turbidity levels generally decreased with increasing stream flows at the lower flow levels (Figure 27). This negative relationship with flow suggested that these high turbidity levels may have been caused by point sources, rather than nonpoint sources (e.g. barnyard runoff at Shalney Branch and construction of instream ditches and dams at Stony Brook).

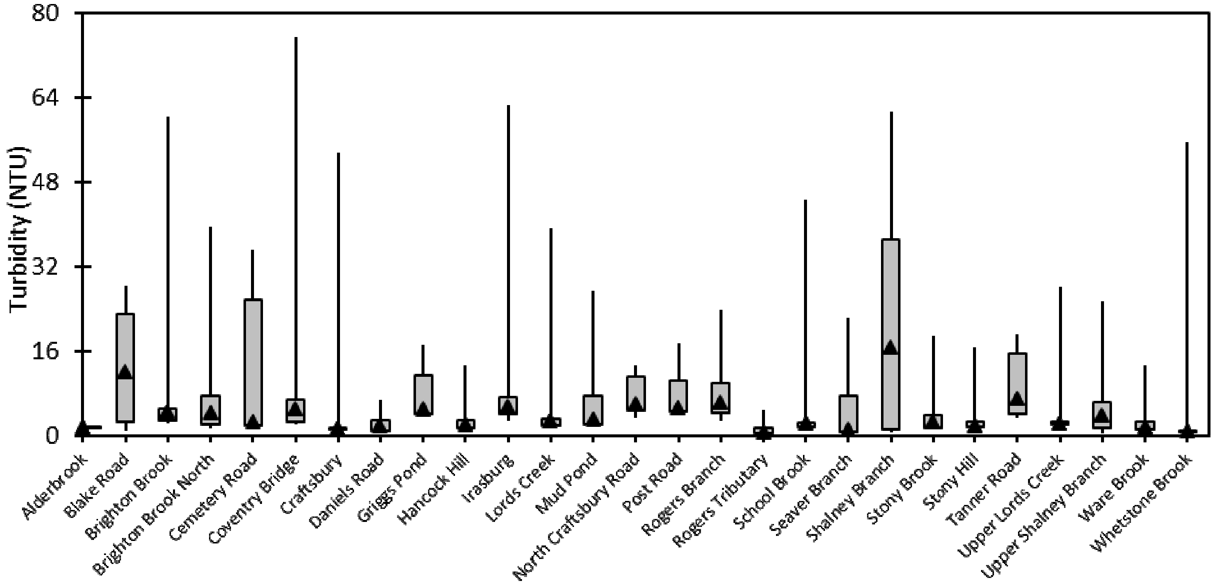


Figure 24. *Turbidity levels at 27 sites along the Black River and its tributaries during April-October 2011. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line).*

Median turbidity levels were moderately high (>5 NTU) at six other sites, all located along the main stem of the Black River (Post Road, North Craftsbury Road, Tanner Road, Rogers Branch, Irasburg, and Coventry Bridge). Turbidity levels generally increased from Craftsbury downstream to Tanner Road and Rogers Branch and then again from Irasburg downstream to Coventry Bridge (Figure 28). These two areas were the same areas that exhibited higher total phosphorus levels as well, and both areas drained large areas of agriculture located on the floodplain immediately adjacent to the river channel. Turbidity levels at these sites generally increased with increasing stream flows at all but the lowest flows, especially at the upstream-most sites (Figure 27). This overall positive relationship suggested that much of the dissolved and suspended materials were likely carried into the rivers and streams in surface runoff from nonpoint sources, especially following heavy rains.

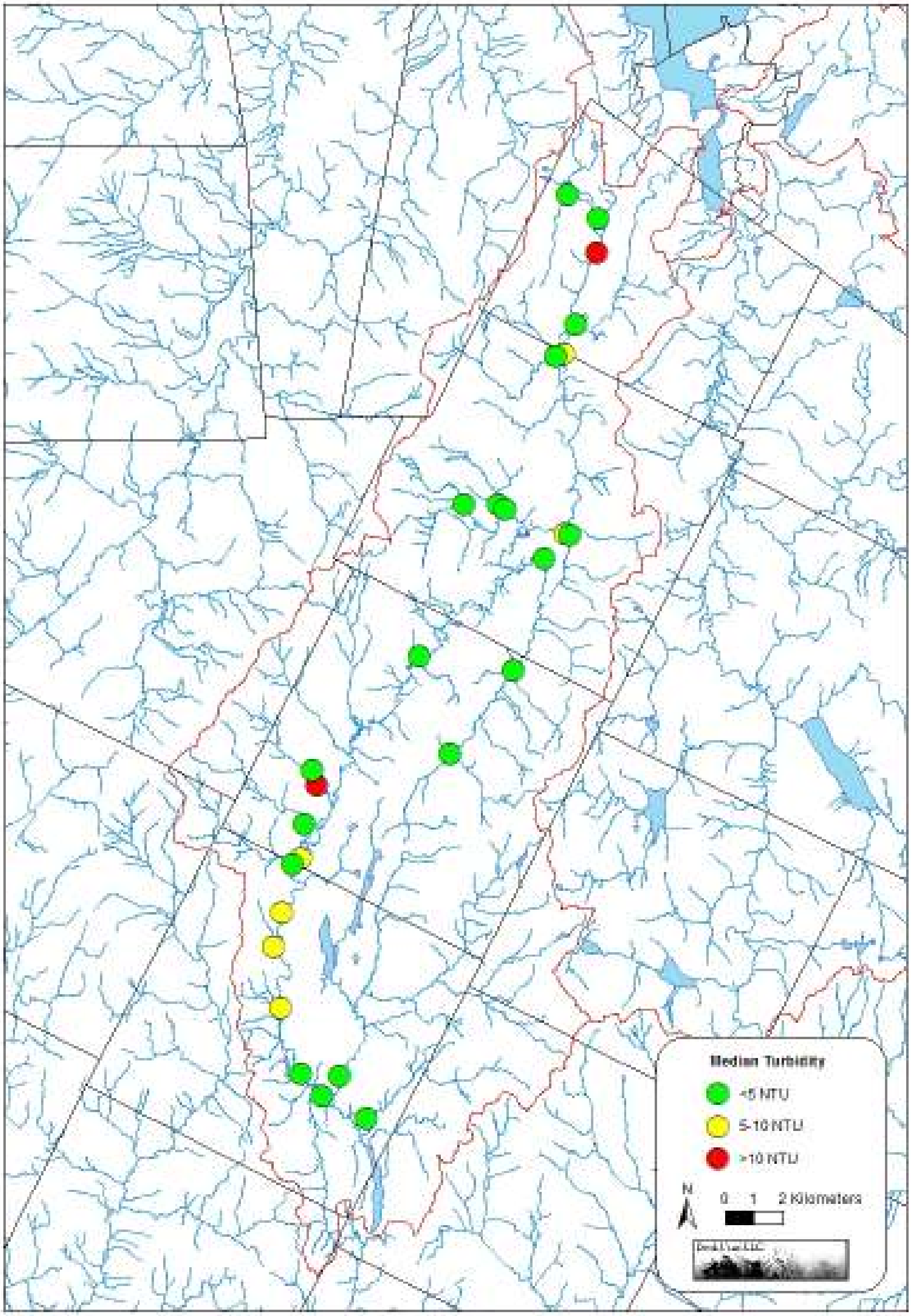
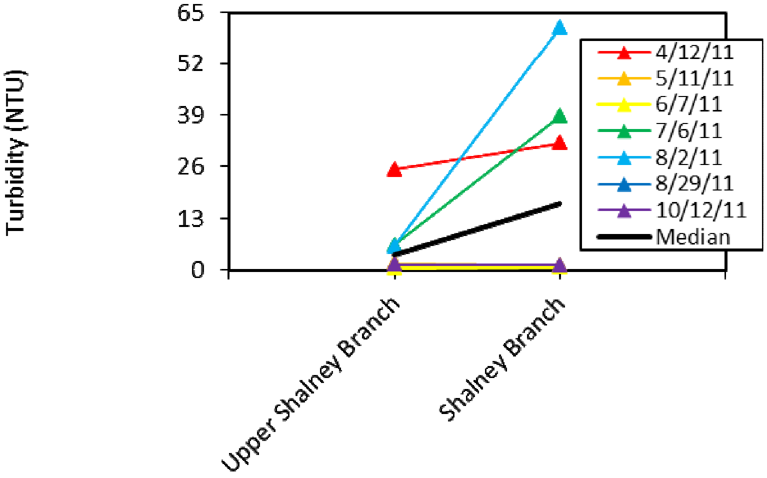


Figure 25. *Median turbidity levels at 27 sites along the Black River and its tributaries during April-October 2011.*



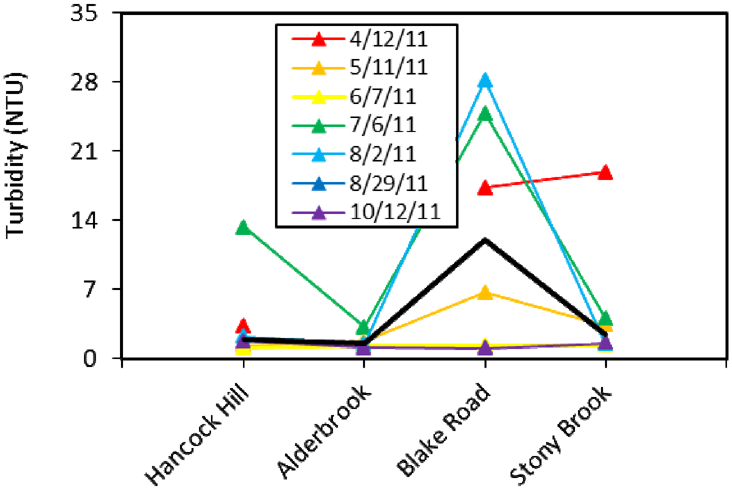


Figure 26. *Turbidity "profiles" along Shalney Branch (top) and Stony Brook (bottom) during April-October 2011.*

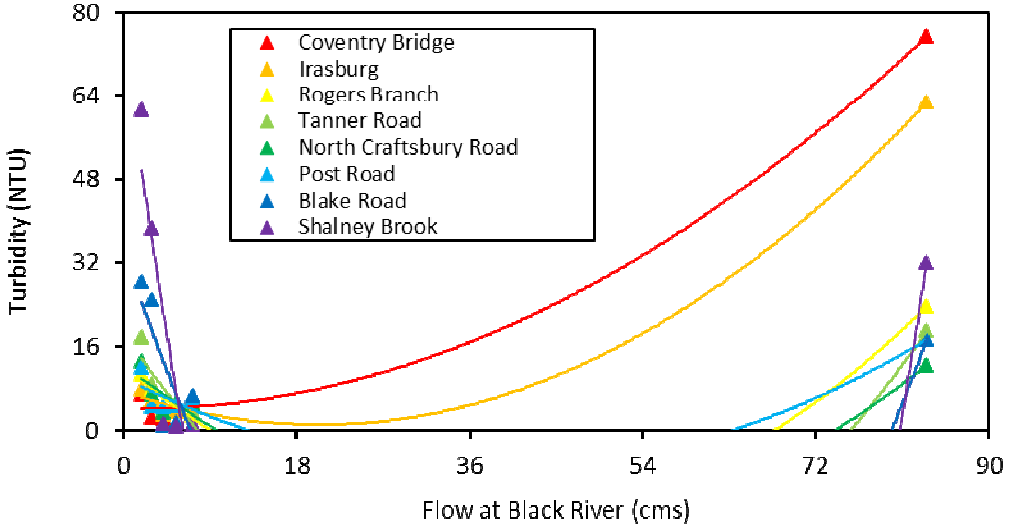


Figure 27. *Turbidity levels in relation to stream flow at six sites along the main stem of the Black and two sites along two tributaries of the Black River during April-October 2011. The regression lines indicate the polynomial relationships between the two parameters.*

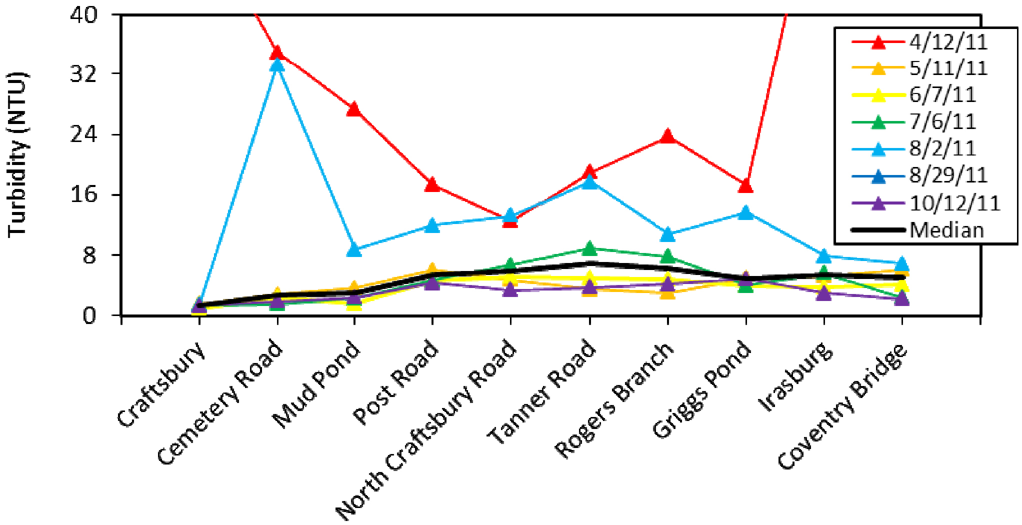


Figure 28. *Turbidity "profile" along the main stem of the Black River from Craftsbury downstream to Coventry Bridge during April-October 2011.*

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). The field blanks, which indicate possible contamination during the sampling process, generally measured below the detection limits for two of the three parameters. For both total phosphorus and total nitrogen, only one the 20 field blanks exceeded the detection limit (5 µg/l for total phosphorus and 0.1 mg/l for total nitrogen). However, as in past years, the field blanks for turbidity were more problematic, as seven of the 20 blanks exceeded the detection limit (0.2 NTU for turbidity). Similarly, the mean relative percent differences between duplicate samples were well within the prescribed differences for two of the three parameters [total phosphorus = 8% (prescribed difference <30%) and total nitrogen = 5% (prescribed difference <20%)], and only one of the 21 pairs of duplicate samples exceeded the prescribed differences for both total phosphorus and total nitrogen. Although the mean relative percent difference between the duplicate turbidity samples was below the prescribed difference [turbidity = 11% (prescribed difference <15%)], four of the 21 pairs of turbidity samples differed by >15%. Thus, the quality assurance samples, including both field blanks and field duplicates, indicated that the water samples were generally being collected in a repeatable manner and were generally not being contaminated during collection or processing.

Unfortunately, due to the flooding of the LaRosa Laboratory, the samples collected on 29 August were not analyzed until early October (4 October for turbidity, 6 October for total nitrogen, and 19 October for total phosphorus). Since the hold times for all of these samples (four days for turbidity and 28 days for phosphorus and nitrogen) were exceeded, we discarded the turbidity and total nitrogen data but do present the total phosphorus data. Although the phosphorus data were less likely to be impacted by the excessive hold times, they are presented cautiously and only to provide a better assessment of phosphorus levels at the highest stream flows.

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 implemented to reduce the amounts of nutrients and sediments being exported into the lake. These efforts should target areas where nutrient and sediment sources are not yet clearly identified or where information on nutrient and sediment sources is lacking. In this regard, additional sampling should be undertaken along the main stem and two of the tributaries of the Black River. Along the main stem, additional sampling should be focused between Craftsbury and Albany and between Irasburg and Coventry, as these were the two areas where phosphorus levels increased most dramatically (Figures 8-9). Additional sampling should also be undertaken along Brighton Brook and Lords Creek, where nutrient and sediment sources remain less well understood. In addition, on-the-ground field surveys should be undertaken along the main stem and these two tributaries to identify potential point and nonpoint sources of phosphorus and sediment inputs. Similar efforts should be initiated along the northern half of the Barton River watershed as well, as the source(s) of the high phosphorus and turbidity levels in this tributary also remain unclear.

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

Finally, we propose to undertake more comprehensive analyses of all of the water quality data collected to date throughout the watersheds of the Vermont tributaries of Lake Memphremagog. These spatial and statistical analyses will use existing water quality and stream geomorphic assessment data to identify and prioritize areas within the Vermont portion of the basin that export the largest amounts of nutrients and sediment into Lake Memphremagog. These analyses will prioritize areas for implementation of protection and restoration projects that will most effectively reduce phosphorus and sediment inputs into the surface waters of the Lake Memphremagog Basin.

Protection and Restoration Projects

Based on the results of the 2010 and 2011 water quality sampling, we identified several on-the-ground protection and/or restoration projects that can be implemented immediately to reduce nutrient and sediment inputs in the Lake Memphremagog Basin. Specifically, confirmed that the high phosphorus and sediment levels in Shalney Branch were originating between Vermont Route 14 and New Street in Albany village. Field observations indicated that a number of opportunities existed to improve practices on a large dairy farm there to improve water quality in Shalney Branch. We have already begun discussions with the landowners about these management projects and practices that would best reduce phosphorus and sediment runoff from that farm. The water quality data and on-the-ground field observations also identified an area along Stony Brook where the landowner was building ditches and dams with no erosion or sedimentation control practices. Discussions with this landowner are ongoing, and we will continue to monitor this situation to ensure that these activities cease or, at least, no longer impact water quality in Stony Brook.

During our sampling, we also observed cattle grazing directly in several tributaries of Lake Memphremagog, including Shalney Branch and multiple locations on Lords Creek (Figure 14). In these areas, we 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. We have already initiated discussions with two landowners along Lords Creek, and we will continue to pursue these discussions in order to identify the appropriate conservation strategies for these areas. Such projects could be funded by existing federal cost-share or other programs (e.g. Conservation Reserve Enhancement Program, Trees for Streams Memphremagog, River Corridor Easements).

Finally, we will continue our efforts to identify, prioritize, and implement additional wetland, floodplain forest, and riparian buffer restoration projects in the Vermont portion of the Lake Memphremagog Basin. We will use data from stream geomorphic assessments, wetland assessments, aerial photos, and soil and other maps to identify and prioritize potential restoration sites in the basin. These efforts will continue to target areas in the Black River watershed but will also target areas in the watersheds of the other Vermont tributaries of Lake Memphremagog. In these areas, resources will be targeted towards those protection and restoration projects that will lead to the greatest improvements in water quality in the Lake Memphremagog Basin. As part of these efforts, we will continue to inform and encourage landowners to participate in various floodplain and wetlands conservation and restoration programs, including Trees for Streams Memphremagog, the Conservation Reserve Enhancement Program, the Wetlands Reserve Program, River Corridor Easements, and other conservation programs offering opportunities to protect and improve water quality.

Education and Outreach

As an integral part of this project, we continued our efforts to educate local communities and stakeholders about water quality issues and efforts to protect and improve water quality in the Lake Memphremagog. First, several individuals from the local community volunteered to collect and process water samples, and their efforts and their interactions with the salaried employees, paid consultants, and other volunteers working on this project furthered the education and outreach objectives of this project. Second, Ben Copans, Watershed Coordinator for the Vermont DEC, presented the results of this and earlier studies at a public meeting of the Memphremagog Watershed Association held in Irasburg Vermont. Finally, 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. 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 Natural Resources Conservation Service, Orleans County Natural Resources Conservation District, Vermont Association of Conservation Districts, and Vermont DEC. Finally, we continued to develop collaborative relationships with other agencies and organizations working to protect and improve water quality in the Lake Memphremagog Basin, including the Quebec Ministère du Développement durable, de l'Environnement et des Parcs; Municipalités régionales de comté de Memphrémagog; cities of Newport, Sherbrooke, and Magog; and the NorthWoods Stewardship Center.

Bibliography

Dyer, M. and F. Gerhardt. 2007. *Restoring Water Quality in the Lake Memphremagog Basin: Water Quality in the Four Vermont Tributaries*. NorthWoods Stewardship Center, East Charleston, Vermont.

Gerhardt, F. 2006. *Restoring Water Quality in the Lake Memphremagog Basin: Water Quality in the Four Vermont Tributaries.* NorthWoods Stewardship Center, East Charleston, Vermont.

Gerhardt, F. 2009. *Restoring Water Quality in the Lake Memphremagog Basin: Nutrient and Sediment Sources along the Johns River and Seven Smaller Tributaries*. Memphremagog Watershed Association, Newport, Vermont.

Gerhardt, F. 2010. *Restoring Water Quality in the Lake Memphremagog Basin: Phosphorus and Nitrogen Levels along the Johns River and Seven Smaller Tributaries*. Beck Pond LLC, Newark, Vermont.

Gerhardt, F. 2011. *Restoring Water Quality in the Lake Memphremagog Basin: Black River Protection and Restoration Project*. Memphremagog Watershed Association, Derby, VT and Beck Pond LLC, Newark, VT

Picotte, A. and L. Boudette. 2005. *Vermont Volunteer Surface Water Monitoring Guide*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

Quebec/Vermont Steering Committee. 2008. *The Water Quality of Lake Memphremagog: Results of the Joint Quebec-Vermont Water Quality Monitoring Initiative and Recommendations for Strategy Development*. Quebec/Vermont Steering Committee on Lake Memphremagog, Newport, Vermont and Magog, Quebec.

SMi. 2009. Modélisation du transport du phosphore sur l'ensemble du bassin versant du lac Memphrémagog. SMi Aménatech, Sherbrooke, Quebec.

State of Vermont. 2000. *A Guide to Analytical Laboratory Services*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

State of Vermont. 2006. *Water Quality Division Field Methods Manual*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

State of Vermont. 2008a. *List of Priority Surface Waters outside the Scope of Clean Water Act Section 303(d)*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

State of Vermont. 2008b. *Vermont Water Quality Standards*. Vermont Water Resources Board, Montpelier, Vermont.

Appendix A. Descriptions of the 27 sites sampled along the Black River and its tributaries during April-October 2011 (locations are mapped in Figure 3).

Main Stem of the Black River (10 sites):

Site name	Site description
Coventry Bridge	Main stem downstream of Back Coventry Road in Irasburg (also sampled in 2005-2006 and 2010)
Irasburg	Main stem adjacent to Vermont Route 58 in Irasburg (also sampled in 2006 and 2010)
Griggs Pond	Main stem adjacent to Vermont Route 14 in Albany (also sampled in 2005-2006 and 2010)
Rogers Branch	Main stem downstream of Wylie Hill Road in Albany (also sampled in 2006 and 2010)
Tanner Road	Main stem upstream of Tanner Road in Craftsbury
North Craftsbury Road	Main stem upstream of North Craftsbury Road in Craftsbury
Post Road	Main stem downstream of Post Road in Craftsbury
Mud Pond	Main stem downstream of Black River Road in Craftsbury
Cemetery Road	Main stem downstream of Cemetery Road in Craftsbury
Craftsbury	Main stem downstream of Craftsbury Town Garage in Craftsbury (also sampled in 2005-2006 and 2010)

Tributaries of the Black River (17 sites):

Site name	Site description
Stony Brook	Stony Brook upstream of confluence with Black River in Coventry (also sampled in 2010)
Blake Road	Stony Brook downstream of Vermont Route 14 and Blake Road in Coventry
Alderbrook	Stony Brook upstream of Nadeau Road in Coventry
Hancock Hill	Stony Brook upstream of Hancock Hill Road in Coventry
Ware Brook	Ware Brook upstream of Chilafoux Road in Irasburg (also sampled in 2010)
School Brook	Unnamed tributary upstream of Vermont Route 58 in Irasburg (also sampled in 2010)
Brighton Brook	Brighton Brook downstream of Gage Road in Irasburg (also sampled in 2010)

Site name	Site description
Brighton Brook North	Unnamed tributary to Brighton Brook upstream of Vermont Route 58 in Irasburg
Stony Hill	Brighton Brook upstream of Vermont Route 58 in Irasburg
Lords Creek	Lords Creek upstream of Vermont Route 14 in Irasburg (also sampled in 2005-2006 and 2010)
Upper Lords Creek	Lords Creek downstream of Creek Road in Albany (also sampled in 2010)
Daniels Road	Lords Creek upstream of Daniels Road in Albany
Shalney Branch	Shalney Branch downstream of Vermont Route 14 in Albany (also sampled in 2010)
Upper Shalney Branch	Shalney Branch upstream of Old Street in Albany
Rogers Tributary	Rogers Branch upstream of Vermont Route 14 in Albany (also sampled in 2010)
Seaver Branch	Seaver Branch upstream of Vermont Route 14 in Craftsbury (also sampled in 2010)
Whetstone Brook	Whetstone Brook upstream of South Craftsbury Road in Craftsbury (also sampled in 2010)

Appendix B. Water quality data collected at 27 sites along the Black River and its tributaries during April-October 2011. 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 µg/l (italics) or >35 µg/l (bold), total nitrogen >1 mg/l (italics) or >2 mg/l (bold), and turbidity >5 NTU (italics) or >10 NTU (bold). Only the total phosphorus data are presented for the August 29th sample date, and these data should be interpreted cautiously since the hold times for these samples were exceeded due to flooding of the LaRosa Laboratory.

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Alderbrook	5/11/2011	0.99	*20.3*	1.77
Alderbrook	6/7/2011	*1.41*	17	1.37
Alderbrook	7/6/2011	*1.87*	*28.2*	3.2
Alderbrook	8/2/2011	**2.88**	13.1	1.54
Alderbrook	8/29/2011		**83**	
Alderbrook	10/12/2011	*1.24*	15.5	1.1
Blake Road	4/12/2011	0.67	**63.9**	**17.3**
Blake Road	5/11/2011	0.98	**61.5**	*6.67*
Blake Road	6/7/2011	*1.18*	15.9	1.32
Blake Road	7/6/2011	*1.57*	**68.6**	**24.8**
Blake Road	8/2/2011	*1.18*	**76.6**	**28.2**
Blake Road	8/29/2011		**92.4**	
Blake Road	10/12/2011	*1.13*	13.7	1.04
Brighton Brook	4/12/2011	0.99	**126**	4.15
Brighton Brook	5/11/2011	*1.62*	**117**	*5.26*
Brighton Brook	6/7/2011	0.6	**36.1**	2.37
Brighton Brook	7/6/2011	0.72	**50.1**	4.68
Brighton Brook	8/2/2011	0.76	**129**	**60.3**
Brighton Brook	8/29/2011		**102**	
Brighton Brook	10/12/2011	0.51	*21.5*	2.48
Brighton Brook North	4/12/2011	0.91	**119**	4.82
Brighton Brook North	5/11/2011	**3.89**	**406**	*8.39*
Brighton Brook North	6/7/2011	0.57	**70.5**	1.72
Brighton Brook North	7/6/2011	0.56	**68**	3.73
Brighton Brook North	8/2/2011	0.67	**107**	**39.5**
Brighton Brook North	8/29/2011		**248**	
Brighton Brook North	10/12/2011	0.51	*27.9*	1.54

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Cemetery Road	4/12/2011	0.83	**97.9**	**35**
Cemetery Road	5/11/2011	0.73	19	2.77
Cemetery Road	6/7/2011	0.55	17.4	2.46
Cemetery Road	7/6/2011	0.53	19.9	1.47
Cemetery Road	8/2/2011	0.88	**102**	**33.2**
Cemetery Road	8/29/2011		**97.3**	
Cemetery Road	10/12/2011	0.5	10.3	1.85
Coventry Bridge	4/12/2011	0.58	**129**	**75.4**
Coventry Bridge	5/11/2011	0.56	*34.8*	*6.1*
Coventry Bridge	6/7/2011	0.45	*25.7*	4
Coventry Bridge	7/6/2011	0.32	*23.3*	2.34
Coventry Bridge	8/2/2011	0.42	**38.4**	*6.85*
Coventry Bridge	8/29/2011		**176**	
Coventry Bridge	10/12/2011	0.28	15.1	2.16
Craftsbury	4/12/2011	0.88	**138**	**53.6**
Craftsbury	5/11/2011	0.73	12.3	1.46
Craftsbury	6/7/2011	0.62	8.35	0.92
Craftsbury	7/6/2011	0.59	12.5	1.31
Craftsbury	8/2/2011	0.6	12	1.33
Craftsbury	8/29/2011		**125**	
Craftsbury	10/12/2011	0.58	9.14	1.25
Daniels Road	4/12/2011	0.39	*32.2*	*6.79*
Daniels Road	5/11/2011	0.19	11	1.29
Daniels Road	6/7/2011	0.23	12.4	0.85
Daniels Road	7/6/2011	0.27	*21.3*	2.28
Daniels Road	8/2/2011	0.41	*24.3*	2.99
Daniels Road	8/29/2011		*29*	
Daniels Road	10/12/2011	0.17	8.94	0.91
Griggs Pond	4/12/2011	0.56	**45**	**17.2**
Griggs Pond	5/11/2011	0.53	*26.6*	4.88
Griggs Pond	6/7/2011	0.52	*29*	3.91
Griggs Pond	7/6/2011	0.41	*29.3*	3.95
Griggs Pond	8/2/2011	0.51	**52.1**	**13.6**
Griggs Pond	8/29/2011		**74.2**	
Griggs Pond	10/12/2011	0.42	18.8	4.76

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Hancock Hill	4/12/2011	0.39	*27.5*	3.26
Hancock Hill	5/11/2011	0.25	15.4	1.35
Hancock Hill	6/7/2011	0.39	19.5	1.09
Hancock Hill	7/6/2011	0.83	**67.7**	**13.3**
Hancock Hill	8/2/2011	0.6	*22.7*	2.22
Hancock Hill	8/29/2011		**47.4**	
Hancock Hill	10/12/2011	0.31	15.1	1.77
Irasburg	4/12/2011	0.53	**147**	**62.6**
Irasburg	5/11/2011	0.6	**38.3**	*5.2*
Irasburg	6/7/2011	0.48	*27.3*	3.75
Irasburg	7/6/2011	0.37	*31.2*	*5.55*
Irasburg	8/2/2011	0.41	**40.9**	*7.84*
Irasburg	8/29/2011		**166**	
Irasburg	10/12/2011	0.36	15.7	2.93
Lords Creek	4/12/2011	0.47	**95.3**	**39.2**
Lords Creek	5/11/2011	0.2	16.4	3.21
Lords Creek	6/7/2011	0.2	11.5	1.82
Lords Creek	7/6/2011	0.22	16.2	1.46
Lords Creek	8/2/2011	0.31	*20.2*	3.25
Lords Creek	8/29/2011		**99.6**	
Lords Creek	10/12/2011	0.16	9.76	2.42
Mud Pond	4/12/2011	0.78	**61.9**	**27.3**
Mud Pond	5/11/2011	0.7	*24.5*	3.61
Mud Pond	6/7/2011	0.59	*20.9*	1.59
Mud Pond	7/6/2011	0.56	*25*	2.26
Mud Pond	8/2/2011	0.75	**36.8**	*8.74*
Mud Pond	8/29/2011		**71**	
Mud Pond	10/12/2011	0.54	16.1	2.31
North Craftsbury Road	4/12/2011	0.62	**36.4**	**12.5**
North Craftsbury Road	5/11/2011	0.71	*26*	4.75
North Craftsbury Road	6/7/2011	0.63	*27.1*	*5.15*
North Craftsbury Road	7/6/2011	0.63	**37.4**	*6.7*
North Craftsbury Road	8/2/2011	0.81	**65.2**	**13.2**
North Craftsbury Road	8/29/2011		**135**	
North Craftsbury Road	10/12/2011	0.52	16.5	3.37

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Post Road	4/12/2011	0.71	**40.4**	**17.3**
Post Road	5/11/2011	0.75	*32.6*	*5.98*
Post Road	6/7/2011	0.64	*29.8*	4.6
Post Road	7/6/2011	0.65	**35.6**	4.62
Post Road	8/2/2011	0.89	**53.8**	**11.9**
Post Road	8/29/2011		**76.9**	
Post Road	10/12/2011	0.58	19.3	4.28
Rogers Branch	4/12/2011	0.76	**58.7**	**23.7**
Rogers Branch	5/11/2011	0.61	*22*	3
Rogers Branch	6/7/2011	0.59	*27.5*	4.7
Rogers Branch	7/6/2011	0.56	**39.6**	*7.75*
Rogers Branch	8/2/2011	0.71	**59.5**	**10.7**
Rogers Branch	8/29/2011		**151**	
Rogers Branch	10/12/2011	0.53	19.3	4.14
Rogers Tributary	4/12/2011	0.36	*25.7*	4.72
Rogers Tributary	5/11/2011	0.13	7.76	0.53
Rogers Tributary	6/7/2011	0.23	8.34	0.67
Rogers Tributary	7/6/2011	0.44	15	1.48
Rogers Tributary	8/29/2011		*24.2*	
Rogers Tributary	10/12/2011	0.16	7.7	0.55
School Brook	4/12/2011	0.45	**90.9**	**44.6**
School Brook	5/11/2011	0.21	14.2	2.25
School Brook	6/7/2011	0.26	11.5	1.33
School Brook	7/6/2011	0.35	15.6	1.44
School Brook	8/2/2011		16	2.14
School Brook	8/29/2011		**60.8**	
School Brook	10/12/2011	0.2	10.4	2.33
Seaver Branch	4/12/2011	0.28	**56**	**22.3**
Seaver Branch	5/11/2011	0.13	9.35	0.96
Seaver Branch	6/7/2011	0.19	7.98	0.57
Seaver Branch	7/6/2011	0.36	*26.7*	*7.58*
Seaver Branch	8/2/2011	0.29	10.3	<0.2
Seaver Branch	8/29/2011		**39**	
Seaver Branch	10/12/2011	0.16	7.78	0.74

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Shalney Branch	4/12/2011	0.32	**61.8**	**31.9**
Shalney Branch	5/11/2011	0.19	10.5	1.19
Shalney Branch	6/7/2011	0.25	10.9	0.76
Shalney Branch	7/6/2011	0.79	**111**	**38.6**
Shalney Branch	8/2/2011	*1.65*	**232**	**61.2**
Shalney Branch	8/29/2011		**264**	
Shalney Branch	10/12/2011	0.22	13.1	1.11
Stony Brook	4/12/2011	0.72	**72.6**	**18.9**
Stony Brook	5/11/2011	0.95	**41.8**	3.42
Stony Brook	6/7/2011	*1.15*	*20.7*	1.3
Stony Brook	7/6/2011	*1.41*	*33*	4.1
Stony Brook	8/2/2011	*1.61*	16.3	1.5
Stony Brook	8/29/2011		**114**	
Stony Brook	10/12/2011	*1.18*	15.3	1.55
Stony Hill	4/12/2011	0.42	**49.3**	**16.6**
Stony Hill	5/11/2011	0.48	12.7	1.63
Stony Hill	6/7/2011	0.64	12.3	1.28
Stony Hill	7/6/2011	0.89	*20.1*	1.69
Stony Hill	8/2/2011	*1.54*	*20.6*	2.81
Stony Hill	8/29/2011		**42.8**	
Stony Hill	10/12/2011	0.72	11.8	1.73
Tanner Road	4/12/2011	0.69	**46.3**	**19**
Tanner Road	5/11/2011	0.68	*23.2*	3.46
Tanner Road	6/7/2011	0.62	*27.4*	4.89
Tanner Road	7/6/2011	0.61	**41.7**	*8.85*
Tanner Road	8/2/2011	0.86	**65.1**	**17.7**
Tanner Road	8/29/2011		**129**	
Tanner Road	10/12/2011	0.56	17.2	3.7
Upper Lords Creek	4/12/2011	0.49	**76.1**	**28**
Upper Lords Creek	5/11/2011	0.21	15	2.28
Upper Lords Creek	6/7/2011	0.21	14.8	2.28
Upper Lords Creek	7/6/2011	0.25	15.7	1.72
Upper Lords Creek	8/2/2011	0.31	17.6	2.76
Upper Lords Creek	8/29/2011		**75.1**	
Upper Lords Creek	10/12/2011	0.17	8.86	2.05

Site	**Date**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Upper Shalney Branch	4/12/2011	0.26	**60**	**25.3**
Upper Shalney Branch	5/11/2011	0.16	11.6	1.61
Upper Shalney Branch	6/7/2011	0.23	9.34	0.57
Upper Shalney Branch	7/6/2011	0.41	*24*	*6.24*
Upper Shalney Branch	8/2/2011	0.4	16.9	*6*
Upper Shalney Branch	8/29/2011		**292**	
Upper Shalney Branch	10/12/2011	0.13	8.43	1.28
Ware Brook	4/12/2011		**52**	**13.2**
Ware Brook	5/11/2011	*1.38*	14.5	1.17
Ware Brook	6/7/2011	*1.78*	15.9	1.04
Ware Brook	7/6/2011	**2.01**	*22.4*	3.02
Ware Brook	8/2/2011	**2.37**	13.5	1.72
Ware Brook	8/29/2011		**46.4**	
Ware Brook	10/12/2011	*1.62*	12.1	1.52
Whetstone Brook	4/12/2011	*1.07*	**134**	**55.4**
Whetstone Brook	5/11/2011	0.82	14.4	1.14
Whetstone Brook	6/7/2011	0.68	11.7	0.69
Whetstone Brook	7/6/2011	0.67	14.2	0.75
Whetstone Brook	8/2/2011	0.72	*21.2*	0.33
Whetstone Brook	8/29/2011		**41.8**	
Whetstone Brook	10/12/2011	0.63	8.96	0.78

Appendix C. Quality assurance data, including field blanks and field duplicates, collected from 27 sample sites along the Black River and its tributaries during April-October 2011. Bold values indicate field blanks that exceeded detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.2 NTU for turbidity) or field duplicates that differed by >30% for total phosphorus, >20% for total nitrogen, and >15% for turbidity.

Field blanks:

Site	Date	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
Griggs Pond	4/12/2011	< 0.1	< 5	< 0.2
Hancock Hill	4/12/2011	**0.15**	< 5	**0.3**
Mud Pond	4/12/2011	< 0.1	< 5	**0.23**
Upper Shalney Branch	5/11/2011	< 0.1	< 5	< 0.2
Whetstone Brook	5/11/2011	< 0.1	< 5	< 0.2
Blake Road	6/7/2011	< 0.1	< 5	< 0.2
Cemetery Road	6/7/2011	< 0.1	< 5	< 0.2
Shalney Branch	6/7/2011	< 0.1	< 5	**0.32**
Craftsbury	7/6/2011	< 0.1	< 5	< 0.2
Shalney Branch	7/6/2011	< 0.1	< 5	**0.3**
Ware Brook	7/6/2011	< 0.1	< 5	**0.21**
Brighton Brook North	8/2/2011	< 0.1	< 5	< 0.2
Rogers Branch	8/2/2011	< 0.1	< 5	< 0.2
Upper Lords Creek	8/2/2011	< 0.1	< 5	< 0.2
Lords Creek	8/29/2011	< 0.1	< 5	< 0.2
Seaver Branch	8/29/2011	< 0.1	**5.42**	< 0.2
Stony Hill	8/29/2011	< 0.1	< 5	< 0.2
Craftsbury	10/12/2011	< 0.1	< 5	< 0.2
Shalney Branch	10/12/2011	< 0.1	< 5	**0.66**
Ware Brook	10/12/2011	< 0.1	< 5	**0.63**

Field duplicates:

Total phosphorus

Site	Date	1st total phosphorus (µg/l)	2nd total phosphorus (µg/l)	Relative % difference
Griggs Pond	**4/12/2011**	**45**	**67.9**	**41**
Hancock Hill	4/12/2011	27.5	30	9
Mud Pond	4/12/2011	61.9	63.5	3
Stony Brook	5/11/2011	41.8	43	3
Upper Shalney Branch	5/11/2011	11.6	11.4	2
Whetstone Brook	5/11/2011	14.4	13.9	4
Blake Road	6/7/2011	15.9	16.1	1
Cemetery Road	6/7/2011	17.4	17.3	1
Shalney Branch	6/7/2011	10.9	10.1	8
Craftsbury	7/6/2011	12.5	13.8	10
Shalney Branch	7/6/2011	111	113	2
Ware Brook	7/6/2011	22.4	24.2	8
Brighton Brook North	8/2/2011	107	112	5
Rogers Branch	8/2/2011	59.5	51.4	15
Upper Lords Creek	8/2/2011	17.6	17.3	2
Lords Creek	8/29/2011	99.6	111	11
Seaver Branch	8/29/2011	39	37.5	4
Stony Hill	8/29/2011	42.8	53.5	22
Craftsbury	10/12/2011	9.14	9.02	1
Shalney Branch	10/12/2011	13.1	12.1	8
Ware Brook	10/12/2011	12.1	11.9	2

Total nitrogen

Site	**Date**	**1st total nitrogen (mg/l)**	**2nd total nitrogen (mg/l)**	**Relative % difference**
Griggs Pond	4/12/2011	0.56	0.56	0
Hancock Hill	4/12/2011	0.39	0.38	3
Mud Pond	4/12/2011	0.78	0.77	1
Stony Brook	5/11/2011	0.95	0.96	1
Upper Shalney Branch	5/11/2011	0.16	0.14	13
Whetstone Brook	5/11/2011	0.82	0.85	4
Blake Road	6/7/2011	1.18	1.15	3
Cemetery Road	6/7/2011	0.55	0.56	2
Shalney Branch	6/7/2011	0.25	0.26	4
Craftsbury	7/6/2011	0.59	0.59	0
Shalney Branch	7/6/2011	0.79	0.76	4
Ware Brook	7/6/2011	2.01	2.05	2
Brighton Brook North	8/2/2011	0.67	0.69	3
Rogers Branch	8/2/2011	0.71	0.7	1
Upper Lords Creek	8/2/2011	0.31	0.29	7
Craftsbury	10/12/2011	0.58	0.64	10
Shalney Branch	**10/12/2011**	**0.22**	**0.16**	**32**
Ware Brook	10/12/2011	1.62	1.66	2

Turbidity

Site	**Date**	**1st turbidity (NTU)**	**2nd turbidity (NTU)**	**Relative % difference**
Griggs Pond	4/12/2011	17.2	18.2	6
Hancock Hill	4/12/2011	3.26	3.35	3
Mud Pond	4/12/2011	27.3	29.1	6
Stony Brook	5/11/2011	3.42	3.44	1
Upper Shalney Branch	5/11/2011	1.61	1.63	1
Whetstone Brook	5/11/2011	1.14	1.28	12
Blake Road	**6/7/2011**	**1.32**	**1.06**	**22**
Cemetery Road	**6/7/2011**	**2.46**	**1.74**	**34**
Shalney Branch	6/7/2011	0.76	0.66	14
Craftsbury	7/6/2011	1.31	1.34	2
Shalney Branch	7/6/2011	38.6	39.6	3
Ware Brook	7/6/2011	3.02	3.07	2
Brighton Brook North	8/2/2011	39.5	40.1	2
Rogers Branch	8/2/2011	10.7	11	3
Upper Lords Creek	8/2/2011	2.76	2.74	1
Craftsbury	10/12/2011	1.25	1.43	13
Shalney Branch	10/12/2011	0.66	0.66	0
Ware Brook	**10/12/2011**	**1.52**	**1.78**	**16**

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

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

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

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

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

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

Load – The total amount of a physical or chemical substance, such as sediment or 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.

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.

Memphremagog Watershed Association
P. O. Box 1071
Derby, VT 05829
www.lakememphremagog.org

Memphrémagog Conservation Inc.
C. P. 70
Magog, QC J1X 3W7
www.memphremagog.org

Beck Pond LLC
394 Beck Pond Road
Newark, VT 05871
fgerhardt@newarkvt.net