Restoring Water Quality in the Lake Memphremagog Basin: Water Quality in the Four Vermont Tributaries

Final Report for the 2006 Nonpoint Source Pollution Reduction Project/LaRosa Analytical Partnership/Town of Charleston Supplemental Environmental Project

Photo by Jayson Benoit

Melissa Dyer and Fritz Gerhardt

7 March 2007

NorthWoods Stewardship Center

Mission

A multi-disciplinary organization founded in 1989, the NorthWoods Stewardship Center seeks to foster long-term stewardship of human and natural communities in the Northern Forest. By combining learning, teaching and doing in all of its programs, NorthWoods strives to help people understand and practice good stewardship of our region's human and natural communities.

Founded by Bill Manning as the Vermont Leadership Center, the organization began offering educational programs to local schools on its wooded site in the heart of Vermont's Northeast Kingdom. In 1995, the Vermont Leadership Center received its 501(c)(3) non-profit status and in doing so broadened its scope of service into three program areas: Education, Ecosystem Management and Conservation Service. In 2004, the Center changed its name to the NorthWoods Stewardship Center to better reflect its multidisciplinary programs as well as its multi-state service area. Today, NorthWoods is a dynamic organization that serves Northern Forest communities through environmental education, land management, conservation science, conservation service, and outdoor recreation programs.

NorthWoods is rooted in education, and NorthWoods' Education programs offer local and regional youth a wide array of hands-on learning experiences specifically designed to teach participants a land ethic and empower them with the knowledge and motivation necessary to take responsible action on behalf of themselves, their communities, and the natural world.

Through its Land Management offerings, NorthWoods is in a unique position to demonstrate and teach sustainable land management to landowners and land managers throughout the Northern Forest region.

Our Conservation Science efforts use research and monitoring to increase our understanding of humans and the natural environment in the Northern Forest by evaluating the health of Northern Forest ecosystems and assessing the impacts of local and regional human activities on these magnificent ecosystems.

NorthWoods' Northeast Kingdom Conservation Service Corps represents our steadfast commitment to the next generation of land stewards. The Kingdom Corps utilizes hands-on conservation work as a tool for teaching young people about the human and natural communities in which they live while working on projects that protect the environment, improve recreational opportunities, and ultimately strengthen our local communities.

Finally, through Outdoor Recreation, NorthWoods seeks to bring people in closer contact with the wonders of their natural environment while enjoying hikes through the woods, paddling down the Clyde River, or skiing or snowshoeing through the snowy woods.

Today NorthWoods Stewardship Center is poised to broaden our reach from local to regional communities while continuing the programs that we do best: learning stewardship through ecological research and monitoring; teaching stewardship through educational and recreational offerings for students of all ages; and doing stewardship through demonstration forestry, landowner assistance, and the Northeast Kingdom Conservation Service Corps. For further information on NorthWoods Stewardship Center, visit our website at www.northwoodscenter.org.

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fostering stewardship of human and natural communities

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Executive Summary

To assess water-quality problems in the Lake Memphremagog Basin, we have undertaken a multi-year monitoring and assessment program to identify water quality problems and their sources as the first step in developing restoration and mitigation plans to resolve those problems. In 2005, we conducted a Phase 1 Stream Geomorphic Assessment of the Clyde River and sampled water quality at 22 sites distributed throughout the watersheds of the four principal tributaries of Lake Memphremagog in Vermont. In 2006, we continued these monitoring and assessment programs to better assess water quality issues and pinpoint their sources in the Lake Memphremagog Basin. First, we conducted a Phase 2 Stream Geomorphic Assessment of the Clyde River to further identify and prioritize degraded stream sections. The results of this assessment will be presented in a forthcoming report. Second, we expanded our water quality sampling to include 38 sites distributed throughout the watersheds of the four principal tributaries of Lake Memphremagog in Vermont. The results of these analyses are detailed in this report. The goal of these analyses was to further identify and pinpoint the sources of phosphorus and other nutrients and sediments entering the Southern Basin of Lake Memphremagog. To accomplish these goals, we collected and submitted water samples from 38 sites to the LaRosa Analytical Laboratory in Waterbury for analysis of alkalinity, total phosphorus, total nitrogen, NO_x (nitrate + nitrite), chloride, and total suspended solids. In addition, we measured water temperature, pH, conductivity, and dissolved oxygen *in situ* during each site visit. We also measured water depth and velocity, so that we could calculate stream flows and instantaneous mass estimates to estimate the total amounts of nutrients and sediment being contributed by each tributary. Overall, the results from this second year of sampling indicate that all four tributaries are sending high levels of nutrients and sediments into Lake Memphremagog. As in 2005, water quality was generally best in the Clyde River, intermediate in the Barton and Black Rivers, and (not surprisingly, given the 2005 results) poorest in the John's River. Except in the John's River, water quality was generally better in the upper parts of the watersheds and along the smaller tributaries. The John's River continued to have the highest levels of nitrogen and phosphorus as well as high total suspended solids. The Black River had the highest levels of total suspended solids as well as high levels of phosphorus. In contrast, high nutrient levels were more localized in the Barton and Clyde Rivers. However, when flow measurements were incorporated into estimates of the total amounts of nutrients and sediments being delivered into Lake Memphremagog, the Clyde River actually contributed more phosphorus and nitrogen into Lake Memphremagog than did the other tributaries. This result is due primarily to the significantly greater flows occurring in this river. Collectively, these data continue to expand our knowledge about water quality problems and their sources in the Vermont tributaries of Lake Memphremagog, and, with them, we are beginning to develop and implement plans to maintain and enhance water quality in this watershed.

Introduction

Project Background

Water quality is important to both our human and natural communities. Surface waters - such as streams, rivers, lakes, and ponds - provide and support a great diversity of natural communities and organisms. Water is also essential for human life as well as most other forms of life. Both surface and ground waters provide drinking water, hydroelectric power, and disposal of treated wastewater; support agricultural and industrial production; and serve important flood control and water filtration functions. Furthermore, surface waters and aquatic organisms serve as important vectors of disease. Surface waters also provide an important source of recreation, whether for swimming, boating, fishing, hunting, nature watching, or other outdoor activities. Finally, because water is essential for supporting ecosystems, water quality serves as a valuable tool for measuring ecological health.

Throughout the world, water quality faces a number of important threats. These threats occur at a number of scales from local to global. At the regional and global scales, water quality is threatened by global climate change, atmospheric deposition (e.g. acid precipitation and sulfur and nitrogen deposition), and invasive species. At the more local and landscape scales, water quality is threatened by these factors as well as poor agricultural and forestry practices, urban and suburban development, and loss of wetlands and other shoreline habitats.

This project continues our efforts to assess and identify threats to water quality and to plan and implement protection and restoration projects in the Lake Memphremagog Basin (see Figure 1). The Lake Memphremagog Basin is located in the Northeast Kingdom of Vermont and the Eastern Townships of Quebec and is a tributary of the larger St. Francis Watershed, which ultimately flows into the St. Lawrence River and the Atlantic Ocean. Lake Memphremagog currently faces a number of imminent threats to water quality, including high sediment and nutrient loads, high phosphorus and mercury levels, excessive algal growth and eutrophication, and exotic species invasions (State of Vermont 2004a, Simoneau 2004). 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 high phosphorus levels, nutrient enrichment, and excessive algal growth (State of Vermont 2004a). The Southern Basin is fed by three major tributaries that lie entirely within Vermont (the Black, Barton, and Clyde Rivers) and one smaller tributary that straddles the Vermont-Quebec border (the John's River). All four tributaries have been identified as priority surface waters outside the scope of Clean Water Act Section 303(d). Lake Memphremagog and parts of two of its tributaries (the Clyde and John's Rivers) are listed by the State of Vermont as needing a TMDL due to high phosphorus levels, nutrient enrichment, excessive algal growth, elevated levels of mercury, altered flow regimes, and invasions of priority exotic species (Part A). All four tributaries are also listed as needing further assessment (Part C). All surface waters in the Lake Memphremagog Basin are Class B waters, except the watersheds feeding an unnamed reservoir in Derby, May Pond in Barton, Island Pond in Brighton, an unnamed tributary of the Black River, an unnamed tributary of the Clyde River, and Lightning Brook in

Brighton (all Class A2 waters), and all waters located above an elevation of 2,500 feet (Class A1 waters)(State of Vermont 2006).

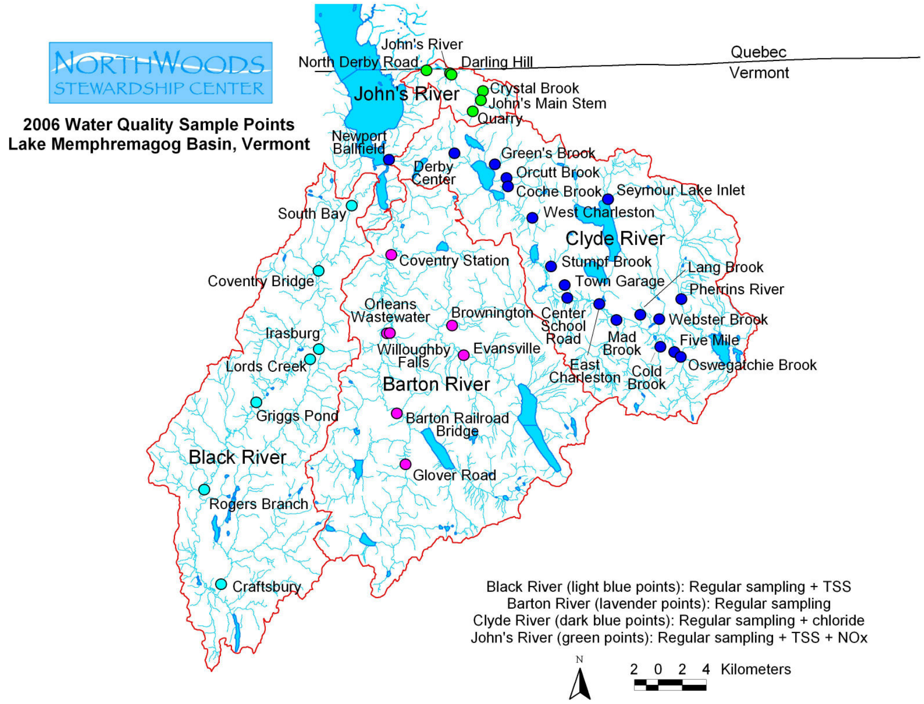

Figure 1. *Map of the Vermont portion of the Lake Memphremagog Basin and the four principal Vermont tributaries. During May-October 2006, we sampled water quality at 38 sites distributed throughout the watersheds of these four tributaries.*

In the Lake Memphremagog Basin, nonpoint source pollution originates from a number of EPA categories and subcategories of sources, including agriculture (non-irrigated crop production, specialty crop production, pastureland, all types of feedlots, and manure lagoons); silviculture (harvesting, restoration, residue management; forest management; and road construction and maintenance); construction (highways, roads, and bridges and land development); urban runoff (storm sewers, combined sewers, and surface runoff); resource extraction, exploration, and development (surface mining, mill tailings); land disposal (wastewater, landfills, onsite wastewater systems, hazardous waste, and septage disposal); hydromodification (channelization, dam construction, flow regulation and modification, bridge construction, removal of riparian vegetation, streambank modification and destabilization, and draining and filling of wetlands); and other sources (atmospheric deposition, waste storage and storage tank leaks, highway maintenance and runoff, spills, recreational activities, upstream impoundment, and salt storage sites).

In addition to impairing water quality in Lake Memphremagog and its tributaries, pollutants from these sources are also impairing the aesthetics, aquatic life, and recreational opportunities of the Lake Memphremagog Basin (see Figure 2). 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, and nature-viewing. Lake Memphremagog and the Clyde River 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. Water bodies in this basin also provide drinking water, hydroelectric power, and disposal of treated wastewater; and their associated wetlands serve important flood control and water filtration functions. These wetlands also support a number of rare species and significant natural communities, which contribute greatly to regional biodiversity.

Figure 2. *Murky water and algae near the mouth of the John's River. Excessive nutrient and sediment inputs are responsible for increasing algal growth and decreasing water quality.*

Project Goals

In 2005, we sampled water quality at 22 sites distributed throughout the watersheds of the four principal tributaries of Lake Memphremagog in Vermont. This first year of sampling indicated that water quality was generally best in the Clyde River, intermediate in the Barton and Black Rivers, and poorest in the John's River. Based on these results, we expanded the water quality sampling to better assess and identify the origins of phosphorus and other nutrient and sediment inputs into the Southern Basin of Lake Memphremagog. In addition, this study also allowed us to evaluate the overall water quality of the four principal tributaries of Lake Memphremagog in Vermont. To accomplish these goals, we sampled water chemistry monthly at 38 sites distributed throughout the watersheds of the four principal tributaries of Lake Memphremagog (the Barton, Black, Clyde, and John's Rivers). These 38 sites included one site near the mouth of each tributary and additional sites at the end of each major reach or each major branching of the river (see Figure 1). These 38 sites included 16 sites that were sampled in 2005. Twenty-two "new" sites were added in 2006 to help us better assess overall water quality conditions in these four tributaries and to better pinpoint the origins of the high nutrient and sediment levels observed in 2005. This distribution of sites allowed us to identify the major sources of nutrient and sediment inputs into the Southern Basin of Lake Memphremagog and to focus future restoration and protection efforts along the most degraded river reaches and sub-basins.

Study Area

As noted previously, the Southern Basin of Lake Memphremagog is fed by four principal tributaries in Vermont: the Barton, Black, Clyde, and John's Rivers.

The Barton River (Waterbody ID VT17-07/08) drains an area of 445 km^2. The Barton River flows from its headwaters in the towns of Barton and Glover to its mouth at the southern end of South Bay near the City of Newport. 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 has been identified as being a high priority for further assessment and monitoring (Part C; State of Vermont 2004a). Identified threats include elevated levels of sediments, nutrients, and *Escherichia coli* caused by agricultural runoff and by morphological instability in the upper watershed. Rapidly expanding populations of several priority invasive species [purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and Japanese knotweed (*Polygonum cuspidatum*)] occur throughout the watershed, although they are most abundant in the lower watershed, especially near the river's mouth at South Bay. In 2006, we sampled seven sites in the Barton River Watershed (see Figure 1 for a map of the study sites and Appendix A for complete list and description).

The Black River (Waterbody ID VT17-09/10) drains an area of 349 km^2. The Black River flows from its headwaters in the towns of Craftsbury and Greensboro to its mouth at South Bay near the City of Newport. The watershed includes one large tributary (Lord's Creek) and several small lakes and ponds. The Black River has been identified as being a high priority for further assessment and monitoring (Parts C, E, and F; State of Vermont 2004a). Identified threats include elevated levels of mercury in walleye (*Stizostedion vitrium*) downstream of Coventry Falls; elevated levels of sediments, nutrients, and *Escherichia coli* caused by agricultural runoff and by morphological instability in Lord's Creek; and water level fluctuations that impair aquatic habitat in Shadow Lake in Glover. In addition, several priority exotic species have invaded the Black River watershed. Lake Elligo is currently infested by Eurasian milfoil (*Myriophyllum spicatum*), but aggressive control efforts are currently underway, including biological control with weevils. Rapidly expanding populations of other priority species (purple loosestrife, common reed, and Japanese knotweed) occur throughout the watershed but are most abundant and widespread in the lower watershed, especially near the river's mouth at South Bay. In 2006, we sampled seven sites in the Black River Watershed.

The Clyde River (Waterbody ID VT17-04) drains an area of 373 km^2. The Clyde River flows from the river's headwaters in the Towns of Brighton and Morgan to its mouth at the City of Newport. The watershed includes several 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 has been identified as being a high priority for further assessment and monitoring (Parts C, E, and F; State of Vermont 2004a). Identified threats include elevated levels of mercury in walleye (*Stizostedion vitrium*) in the Lower Clyde River; elevated levels of sediments, nutrients, and *Escherichia coli* caused by agricultural runoff throughout the watershed; and flow regimes altered by hydroelectric and other dams and water withdrawal along the Clyde River and its tributaries. In addition, several priority exotic species have invaded the Clyde River watershed. Lakes Derby and Salem are currently infested by Eurasian milfoil, and control efforts are currently underway in Lake Derby (Ann Bove, personal communication). 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. In 2006, we sampled 18 sites in the Clyde River Watershed.

The John's River (Waterbody ID VT17-01) drains an area of approximately 29 km^2. It flows through the towns of Derby and Stanstead, Quebec and into Lake Memphremagog at Derby Bay, just south of the U.S.-Canada border. It is fed by three main tributaries, but there are no large lakes or ponds in the watershed. The John's River, especially below its confluence with Crystal Brook, is listed as a priority surface water for further assessment and monitoring (Part C, State of Vermont 2004a). Identified threats include elevated levels of sediments, nutrients, and *Escherichia coli* caused by agricultural runoff. In addition, Crystal Brook, which is one of the three main tributaries, is listed as an impaired surface water needing a TMDL due to excessive sediments and nutrients from agricultural runoff (Part A, State of Vermont 2004a). In 2006, we sampled six sites in the John's River Watershed.

Methods

We collected water samples at monthly intervals during May-October 2006. With the assistance of Dr. Jerry Divincenzo and Neil Kamman, we were able to have the samples analyzed by the LaRosa Analytical Laboratory in Waterbury, Vermont. Prior to sampling, we prepared a Quality Assurance Project Plan in conjunction with the Vermont Department of Environmental Conservation (Vermont DEC). Samples were collected in pre-labeled, sterilized bottles according to protocols established in conjunction with the LaRosa Laboratory. Chloride samples were filtered through 0.45 µm membrane filters prior to storage in sample bottles. Total nitrogen and NO_x were preserved with 0.1 ml concentrated sulfuric acid at the end of each sample day. All samples were stored in coolers from the time they were collected until they were delivered to the laboratory. During each sampling interval, we also collected four field blanks and four field duplicates for quality assurance analysis. All 46 samples (38 sites plus four duplicates and four blanks) were collected during a three-day period and delivered to the LaRosa Laboratory on the afternoon of the third day. This schedule ensured that LaRosa was able to process the samples in a timely manner. The LaRosa Laboratory analyzed the samples for alkalinity, total phosphorus, total nitrogen, chloride, NO_x (nitrate + nitrite), and total suspended solids.

During each site visit, we also measured water depth with a meter stick. Temperature, pH, and conductivity were measured with a Hanna combination pH and electroconductivity probe; and dissolved oxygen was measured with a YSI DO200 meter. We also measured water flow at each site by multiplying the cross-sectional area of the stream by its velocity (*sensu* Leopold 1994). Cross-sectional area was measured by multiplying the width of the water surface by the average of 10-20 depth measurements recorded at equally-spaced points across the channel. Surface velocity was measured by dividing the distance traveled by a float by the average of the times required for three floats (in this case, orange peels) to cover that distance. The three floats were placed roughly ¼, ½, and ¾ of the distance across the stream channel. Average surface velocity was then multiplied by 0.8 to estimate average velocity for the entire water column.

For several parameters, we estimated the actual amount of nutrients and suspended solids being carried by the water column at each site on each sampling date Referred to as “instantaneous mass estimates”, these estimates were calculated by multiplying nutrient concentrations by stream flow at the time of sampling.

Both field and laboratory data were entered into Microsoft Excel spreadsheets. All data sheets and analyses were archived at the NorthWoods Stewardship Center (backup electronic copies were stored off-site), and electronic and hard copies were submitted to the Vermont DEC.

Results

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

Water Depth

Water depth at the sample sites varied greatly throughout the year. Although water depth does not measure stream flow (for flow data, see the following section), it does show month-to-month fluctuations in water levels. In 2005, water depths in all tributaries and at most sites were high in spring, decreased through the summer, and were highest in October when heavy rains caused extensive but minor flooding (see Gerhardt 2006). In 2006, water depths were highest in May due to high precipitation levels in the preceding week and the already saturated soils following spring snowmelt (see Figure 3). As in 2005, water depth decreased during the summer and peaked again in October when there were again heavy precipitation events.

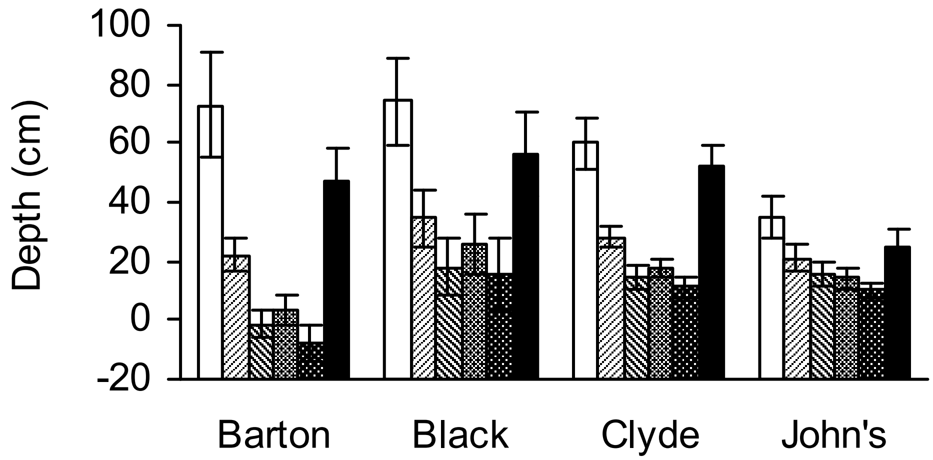

Figure 3. *Mean monthly water depths (±1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006. In this and all subsequent bar graphs, the individual bars for each watershed indicate the month of sampling from May through October.*

Flow

While water depth indicates relative water levels, flow measures the total volume of water passing through the channel at any given moment. Of the four principal Vermont tributaries, the Clyde River accounted for the highest flow levels entering Lake Memphremagog, nearly double that of either the Barton or Black Rivers (see Figure 4). The Barton and Black Rivers exhibited similar flow levels that were approximately half that of the Clyde River. Finally, of the four major tributaries, the John's River with its small watershed had the lowest levels of flow emptying into Lake Memphremagog.

Temperature

Temperature regulates biological and chemical processes, and many aquatic organisms are dependent on specific temperature ranges (Picotte & Boudette 2005). For example, brook trout (*Salvelinus fontinalis*) cannot survive temperatures exceeding 22^{o}C for an extended period of time. In 2006, temperatures ranged between 4.9 and 24.4^{o}C, similar to the range observed in 2005. Temperatures for all watersheds were lowest in May and October and peaked in July (see Figure 5). Unlike 2005, however, temperatures actually decreased in August probably due to a prolonged cold spell that occurred in the preceding two weeks. In 2006, temperatures exceeded 22^{o}C at 2 sites on the Clyde River in June and at 13 sites on the Barton, Black, and Clyde Rivers in July (see Figure 6). One Clyde River site (Newport Ballfield) exceeded 22^{o}C during both June and July. Temperatures never exceeded 22^{o}C in the John's River Watershed and along the smaller tributaries of the Clyde River, and many of these sites never exceeded 18^{o}C.

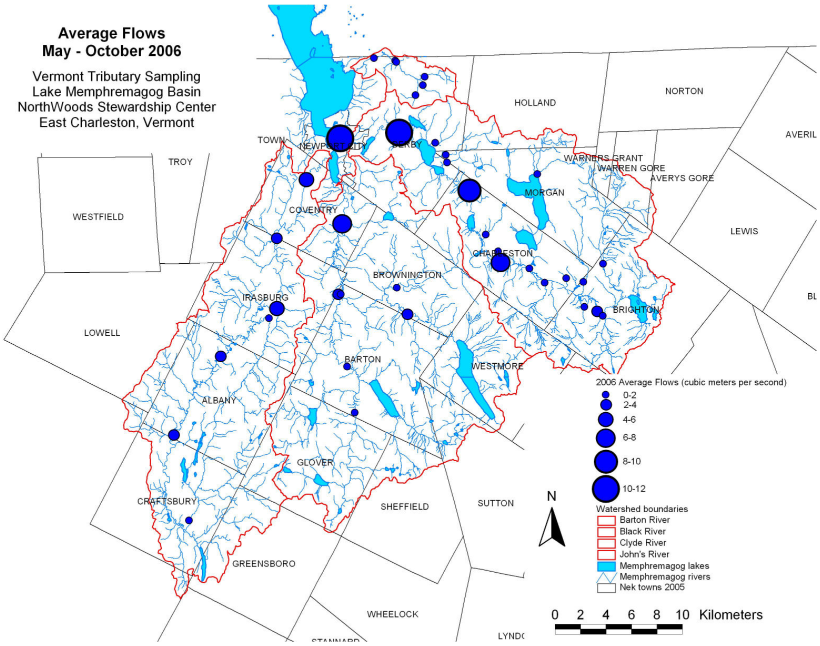

Figure 4. *Mean monthly flows observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

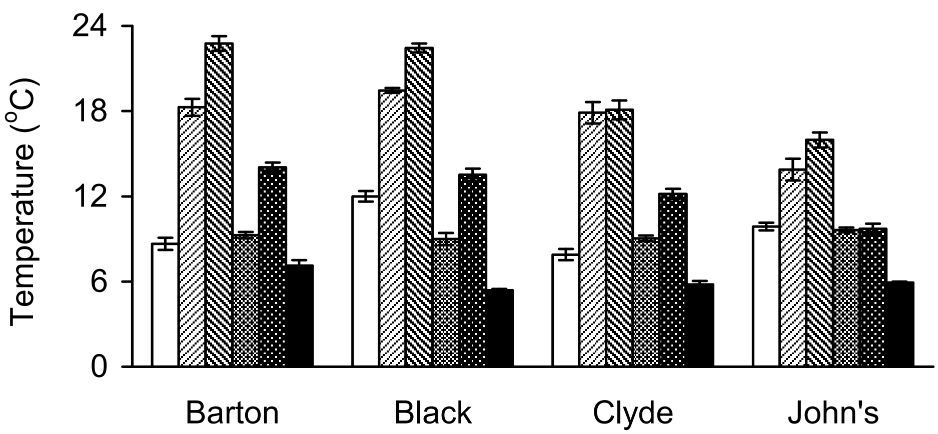

Figure 5. *Mean monthly water temperatures (±1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

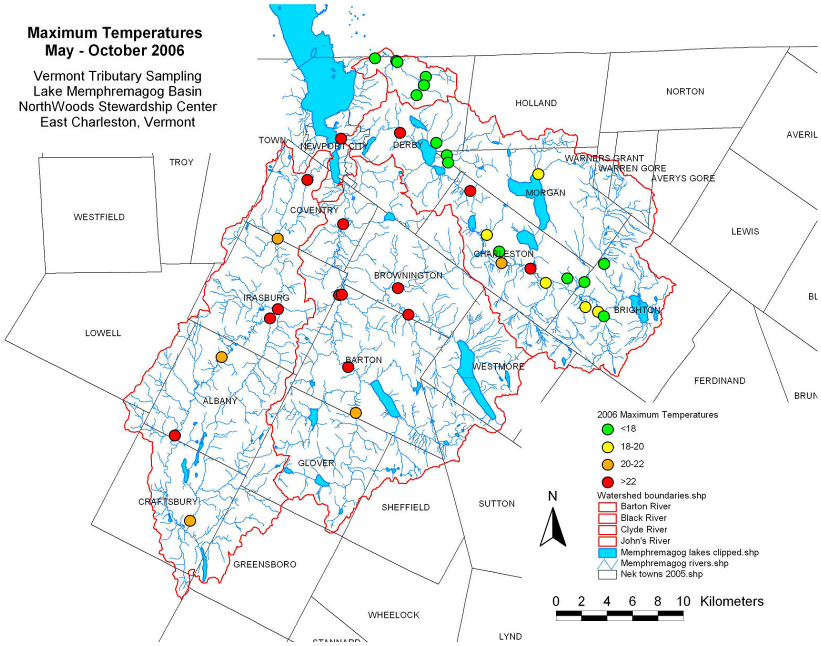

Figure 6. *Maximum water temperatures observed at 38 along the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Dissolved Oxygen

Oxygen is essential to the survival of most forms of plant and animal life. However, oxygen is not very soluble in water and exists there only in small quantities. Thus, although oxygen comprises about 21% of our atmosphere, it comprises less than 1% of surface waters. Oxygen enters water primarily through photosynthesis and turbulent water flow, which increases the amount of water coming into contact with the oxygen-rich air. In contrast, oxygen also dissipates out of surface waters through respiration and decomposition of dead plant and animal matter. Although algae add dissolved oxygen through photosynthesis, high rates of decomposition, following algal blooms depletes oxygen to levels too low to support most fish and other aquatic life. High temperatures also lower oxygen levels, as cold water holds more oxygen than warm water. According to Vermont water quality standards (State of Vermont 2006), cold-water fisheries require at least 7.0 mg/l of dissolved oxygen, and warm-water fisheries require at least 6.5 mg/l of oxygen. During the six month sampling period, all sample points had dissolved oxygen levels exceeding 7.0 mg/l, except the June sample from East Charleston on the Clyde River (6.88 mg/l). In addition, dissolved oxygen levels were generally highest in the spring and fall and lowest in July (see Figure 7). During the summer months, the John's River sites generally had higher dissolved oxygen levels than the other three tributaries, probably reflecting the higher water temperatures in these tributaries.

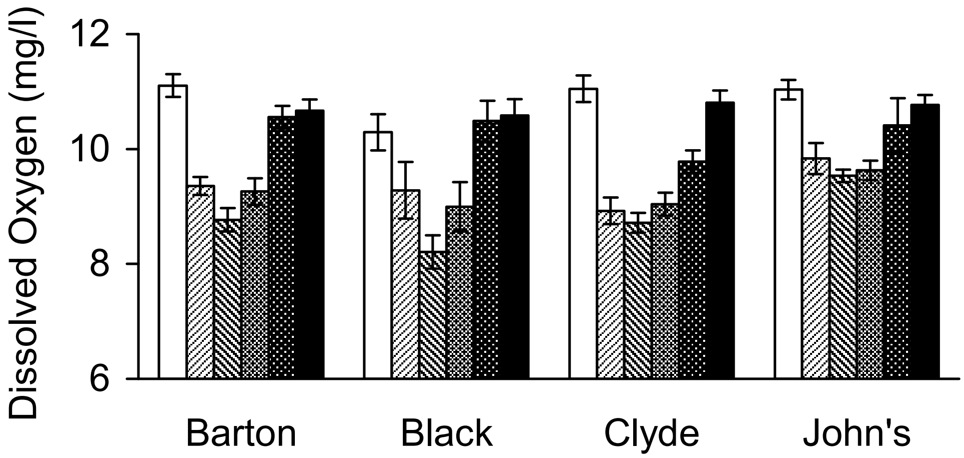

Figure 7. *Mean monthly dissolved oxygen values (± 1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May–October 2006.*

pH

pH measures the hydrogen ion concentration, or acidity, of water and is determined primarily by the underlying bedrock, atmospheric pollution, and rates of photosynthesis and respiration. pH is measured on a logarithmic scale from 0 (most acidic) to 14 (most alkaline). pH determines the solubility and biological availability of many materials, including nutrients, metals, and pollutants. Values between 6.5 and 8.5 are generally considered desirable for most aquatic life. The pH values measured in this study were similar to those observed in 2005 and ranged between 6.46 and 8.55. pH levels generally peaked during the summer months on all tributaries, except the John's River, which showed a general decline through the summer (see Figure 8). As in 2005, the Clyde River exhibited the lowest pH values, and the John's River had the highest pH values. Although most sites fell within the desired range, four sites on the Barton and Black Rivers exceeded 8.5 during June or July, and one site on the Clyde River (pH=6.46 on Lang Brook in July) measured slightly below 6.5 (see Figure 9).

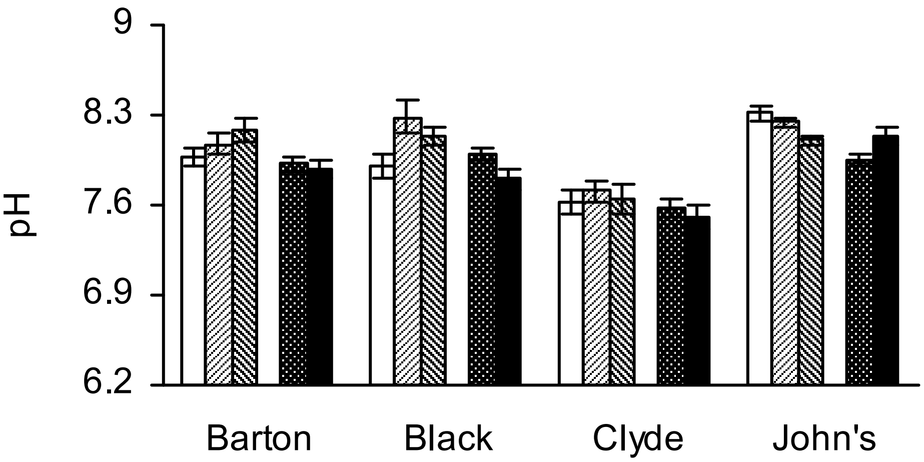

Figure 8. *Mean monthly pH values (± 1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006. August data were not collected due to a meter malfunction.*

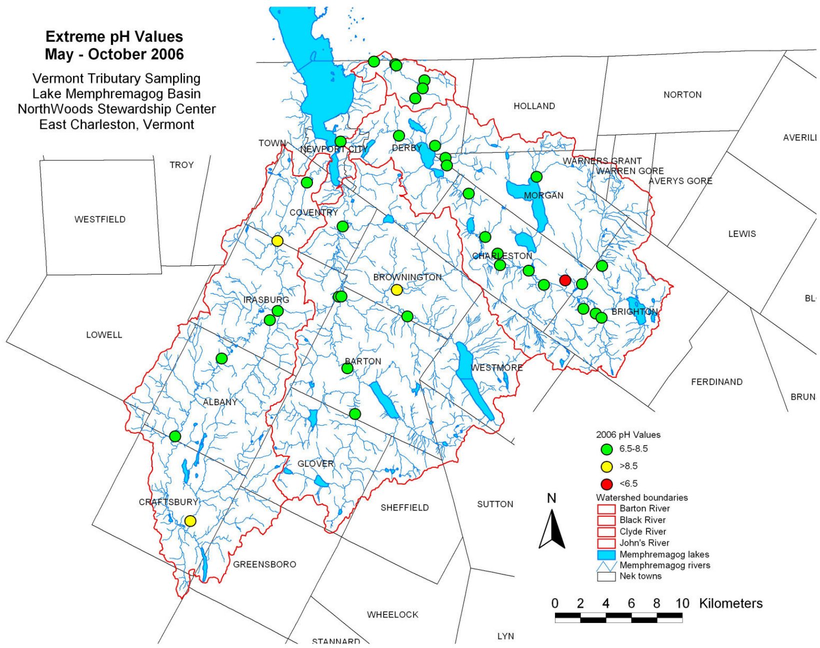

Figure 9. *Extreme pH values observed at each of 38 sample sites in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Alkalinity

Alkalinity is measured as the concentration of calcium carbonate ($CaCO_3$) dissolved in stream water. This parameter describes the ability of rivers and streams to neutralize acid inputs. The amount of $CaCO_3$ in a stream is determined by the composition of underlying bedrock and surficial deposits. Values less than 2.5 mg/L are considered chronically acidic, and those between 2.5 and 5.0 mg/l are likely to be sensitive to acidic inputs (Picotte & Boudette 2005). The 2006 results paralleled those obtained in 2005. In this study, alkalinities ranged between 5.9 and 194 mg/l (2005 values ranged between 8 and 173 mg/l). In all watersheds, alkalinity peaked during the drier months of summer, likely due to proportionately higher groundwater inputs then, and values were lowest during May and October, when precipitation levels were highest (see Figure 10). Overall the Clyde River watershed had the lowest alkalinity values, which likely reflects the larger amount of granitic bedrock in the watershed (see Figure 11). In contrast, the John's River generally exhibited the highest alkalinity values, probably due to the higher proportion of calcareous bedrock in the watershed. The Barton and Black Rivers, which also have higher proportions of calcareous bedrock, generally exhibited intermediate alkalinity values. These results suggest that the four Vermont tributaries are generally able to buffer acid inputs.

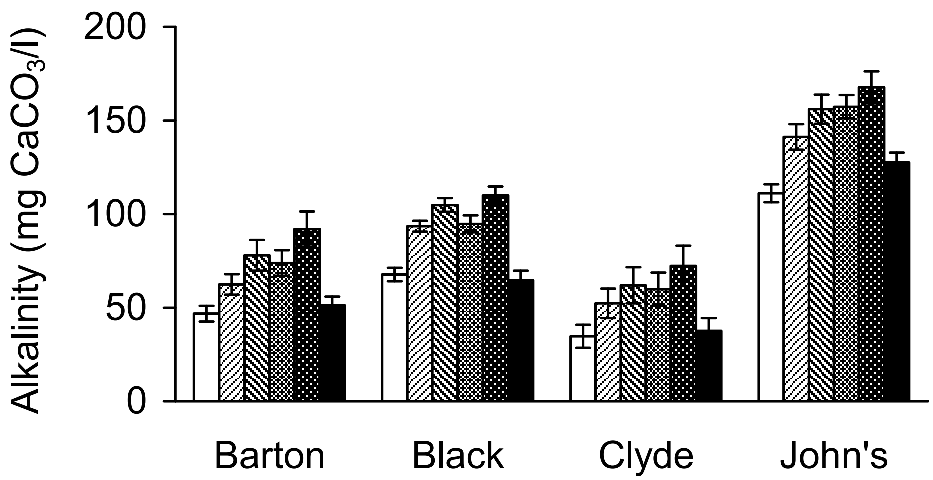

Figure 10. *Mean monthly alkalinity values (± 1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

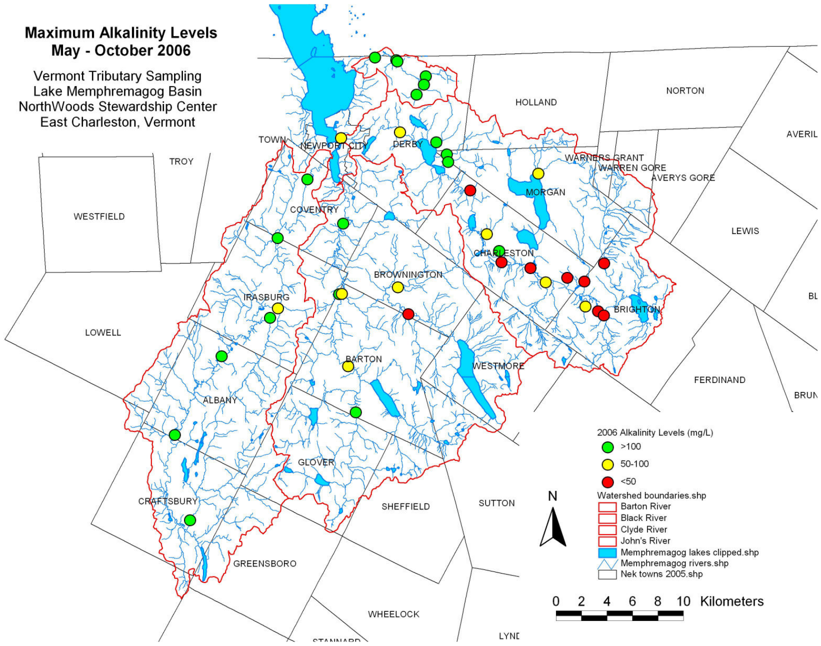

Figure 11. *Maximum alkalinity values observed at 38 sites along the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Conductivity

Conductivity measures the amount of dissolved ions in the water column. Conductivity is determined primarily by bedrock geology (especially the availability of carbonate minerals), watershed size (flowing water has more time to dissolve ions in large watersheds), sediment load, and inputs of wastewater and runoff from roads and agricultural fields. Conductivity is measured as microsiemens (µS) at a standardized temperature (25°C). In 2006, conductivities measured between 14 and 1535 µS. However, if data from a single site with exceedingly high values are excluded, then the range of conductivity is 14-465 µS, which is comparable to that observed in 2005 (19-485 µS). In all watersheds, conductivity peaked during the summer and then decreased again in October (see Figure 12). As in 2005, the John's River consistently had the highest values: Results greater than 300 µS were common at all but one site (see Figure 13). Conductivity values for the Barton and Black Rivers were generally intermediate with most sites exceeding 150 µS but never reaching 300 µS. Although the Clyde River had the lowest conductivity values [only four sites in the lower watershed (Newport Ballfield and Coche, Orcutt, and Greens Brooks] ever exceeded 150 µS), a single site in the Clyde River Watershed (Town Garage) had the highest values of any site, ranging from 100-1535 µS.

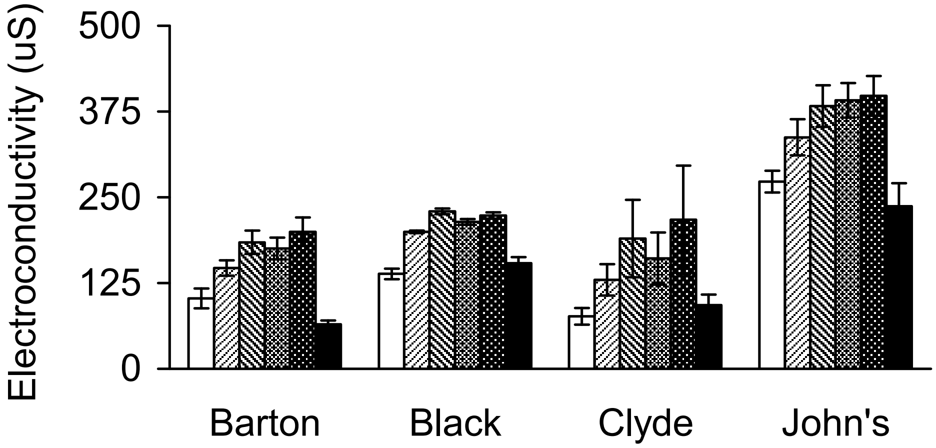

Figure 12. *Mean monthly conductivity values (± 1 SEM) observed at each of the 38 sample sites in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

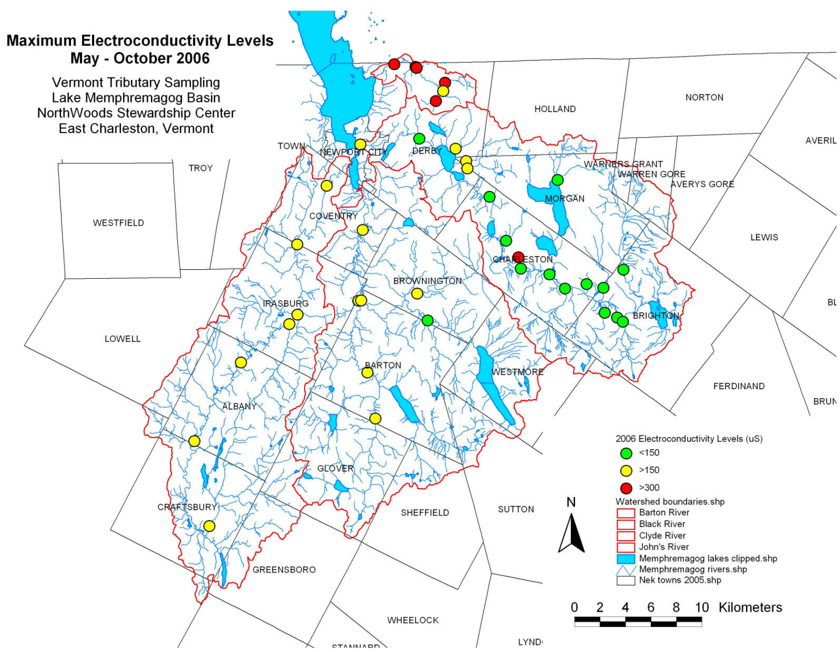

Figure 13. *Maximum conductivity values observed at 38 sites along the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Total Phosphorus

Total phosphorus measures the total amount of phosphorus in the water column. Phosphorus concentrations are important because phosphorus is typically the limiting nutrient in aquatic systems, and high phosphorus levels can lead to eutrophication, in which there is excessive algal and plant growth. Phosphorus originates from both the underlying bedrock as well as wastewater and agricultural runoff. 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 in organic matter. The values measured in this study ranged between 5.41 and 655 µg/l (in comparison, 2005 values ranged between <5 and 664 µg/l). During 2006, total phosphorus values were highest in May and October for all tributaries, except the John's River, where levels were highest during the summer months (see Figure 14). As in 2005, the highest total phosphorus values consistently occurred in the John's River, especially in the middle and lower parts of that watershed (see Figure 15). The Black River exhibited the next highest values with sites throughout the watershed exceeding 25 µg/l. The Barton River also had higher concentrations of phosphorus; however, levels exceeding 25 µg/l were infrequent and only occurred at three sites in the lower watershed. Finally, as in 2005, the Clyde River watershed generally exhibited the lowest phosphorus levels, especially in the tributaries of the upper watershed. Only two small tributaries (Coche Brook and Town Garage) exceeded 25 µg/l, although nine other sites exceeded 14 µg/l sometime during the season. However, because flow levels were highest in the Clyde River, the Clyde actually sends the most phosphorus into Lake Memphremagog, as measured by the instantaneous mass estimates (see Figure 16). In contrast, despite the high concentrations of total phosphorus in the John's River, the low flow levels there result in the John's River sending the lowest amounts of phosphorus into Lake Memphremagog. Like their concentrations, the instantaneous mass estimates of phosphorus flowing into Lake Memphremagog are intermediate for the Barton and Black Rivers.

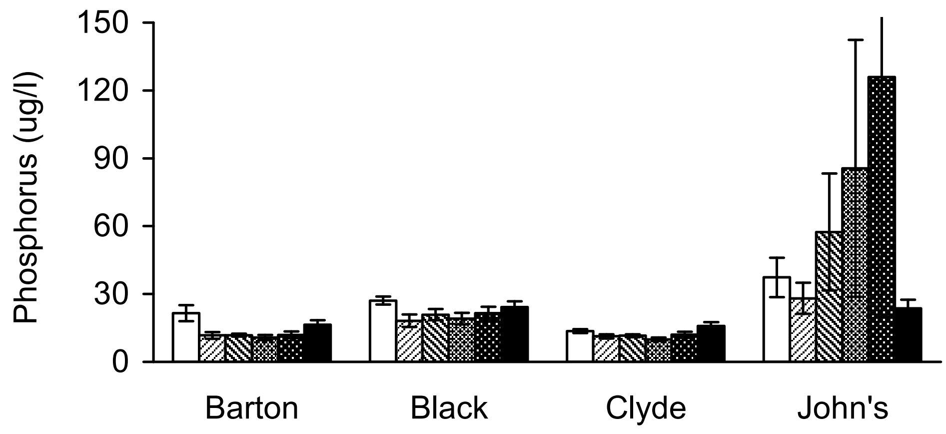

Figure 14. *Mean monthly total phosphorus values (± 1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

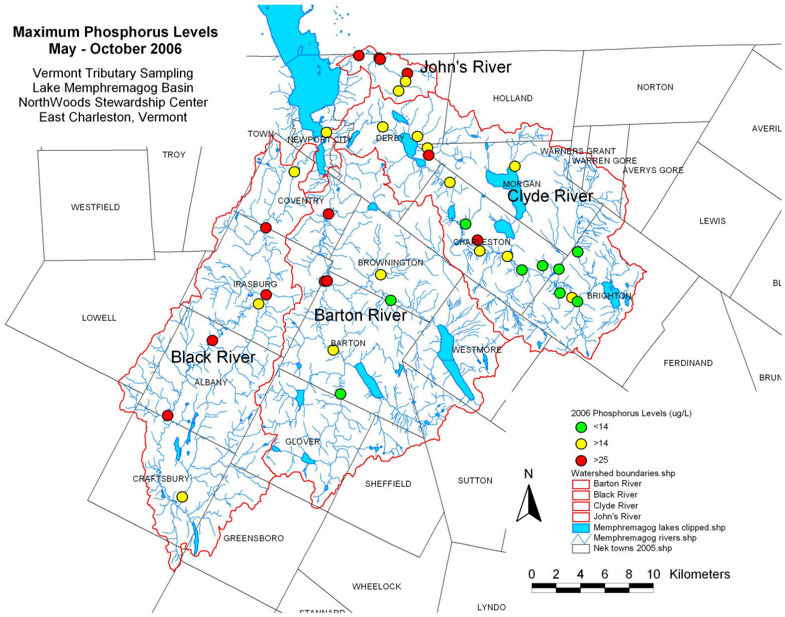

Figure 15. *Maximum total phosphorus values observed at 38 sites along the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

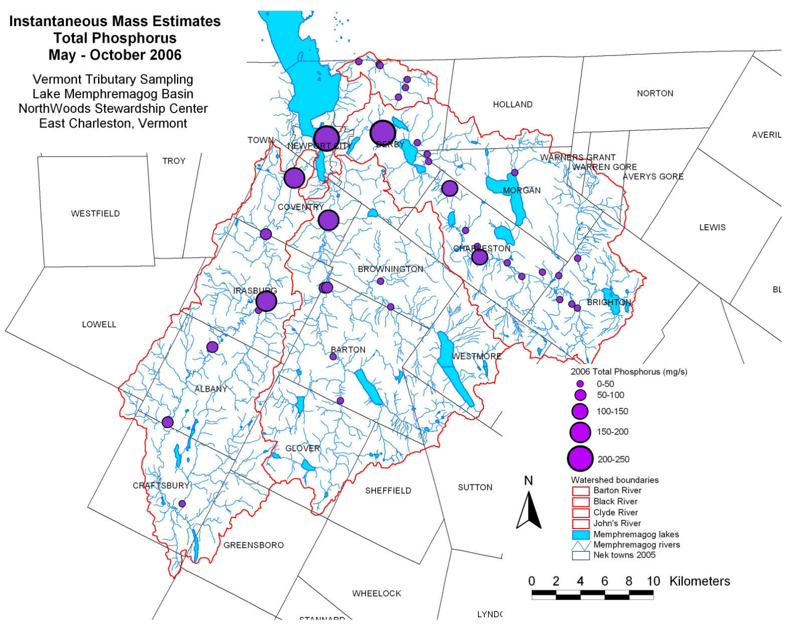

Figure 16. *Mean instantaneous mass estimates of total phosphorus observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Total Nitrogen

Total nitrogen measures the total amount of all forms of nitrogen in water, including nitrate (NO_3), nitrite (NO_2), ammonium (NH_4^+), as well as biologically unavailable nitrogen. Although typically not the limiting nutrient in aquatic systems, high levels of nitrogen can also lead to eutrophication. Most nitrogen originates from wastewater, agricultural runoff, and atmospheric deposition. The values measured in this study ranged between <0.1 and 6.17 mg/l (in 2005, values ranged between <0.1 and 6.06 mg/l). Values generally peaked during the summer and were lowest in the spring and fall (see Figure 17). Values were consistently highest in the John's River Watershed; otherwise, values were generally low in the other three tributaries. Of the 38 sample sites, four of the sites on the John's River exceeded 2 mg/l, and three of these sites exceeded 5 mg/l but only in September (see Figure 18). Like total phosphorus, when instantaneous mass estimates are calculated, the John's River did not contribute as much total nitrogen into Lake Memphremagog as the other three tributaries due to its small size (see Figure 19). Again, because of its greater flow, the Clyde River contributed the most total nitrogen into Lake Memphremagog followed by the Barton and Black Rivers.

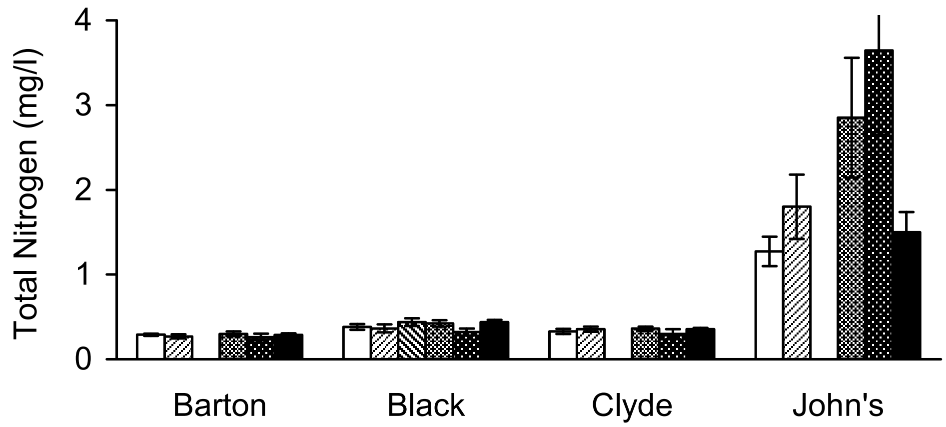

Figure 17. *Mean monthly total nitrogen values (± 1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

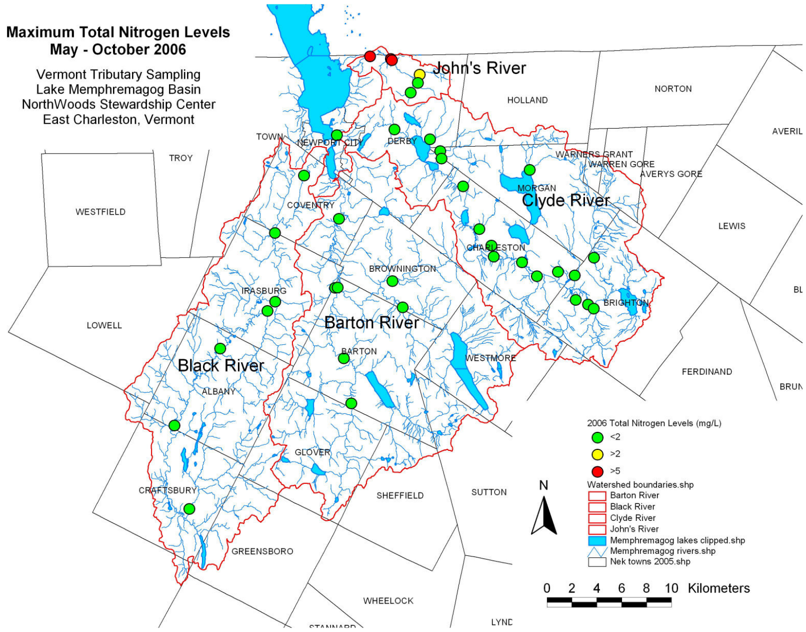

Figure 18. *Maximum total nitrogen values observed at 38 sites along the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

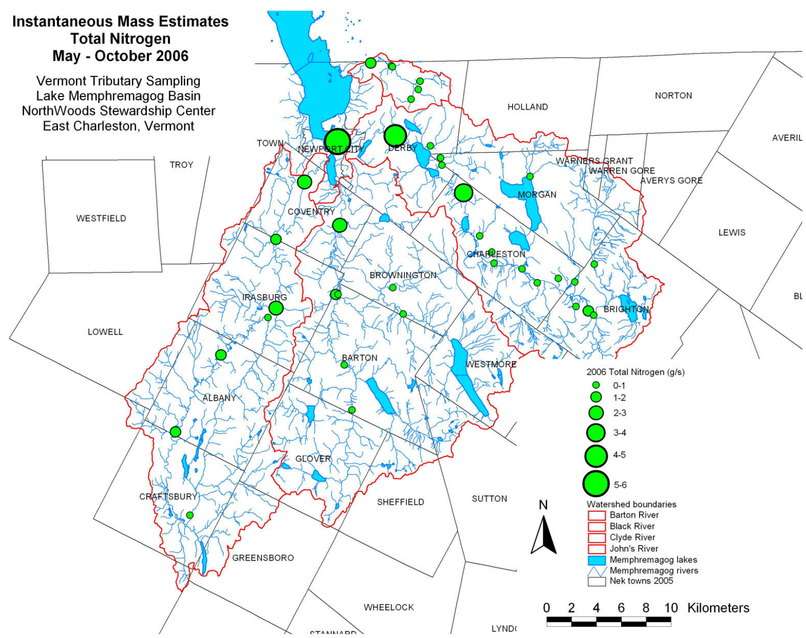

Figure 19. *Mean instantaneous mass estimates of total nitrogen observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

NO_x (Nitrate + Nitrite)

Nitrate and nitrite (collectively referred to as NO_x) are forms of nitrogen that are readily used by algae and other plants. The primary sources of NO_x are agricultural runoff, sewage, and atmospheric deposition from the burning of fossil fuels. Vermont state water quality standards (State of Vermont 2006) for NO_x are 5 mg/l in Class B waters and 2 mg/l in Class A(2) waters. Because we found elevated levels of total nitrogen on the John's River in 2005, we sampled NO_x at the John's River sites in 2006 to determine what proportion of the total nitrogen occurred in this form. In general, NO_x levels peaked during the summer and early fall, and samples from three sites exceeded 5 mg/l in September (see Figure 20). These sites are located in the lower watershed (see Figure 21): One site is located on a small tributary draining Darling Hill, and the other two sites lie downstream of this tributary on the main stem of the John's River. However, because the Darling Hill tributary has such low flow, this tributary makes a relatively small contribution of NO_x to the John's main stem (see Figure 22).

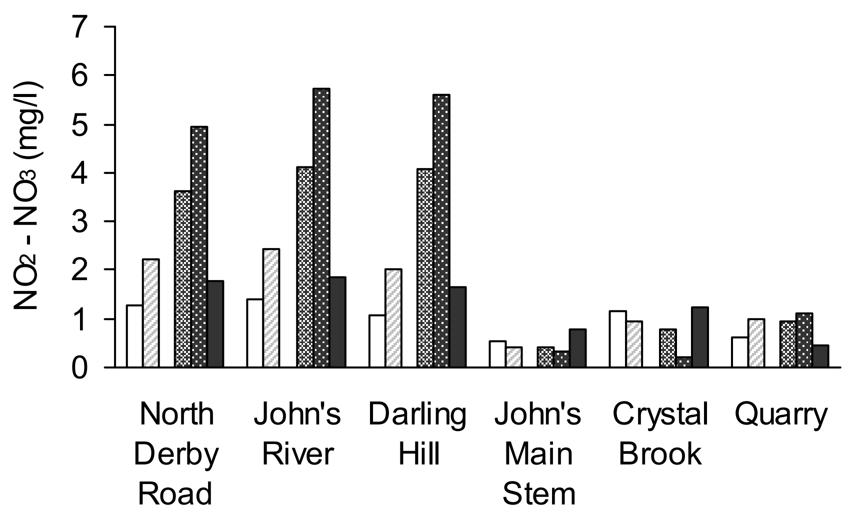

Figure 20. NO_x *values observed in each of the John's River sample sites during May-October 2006 (July values are missing).*

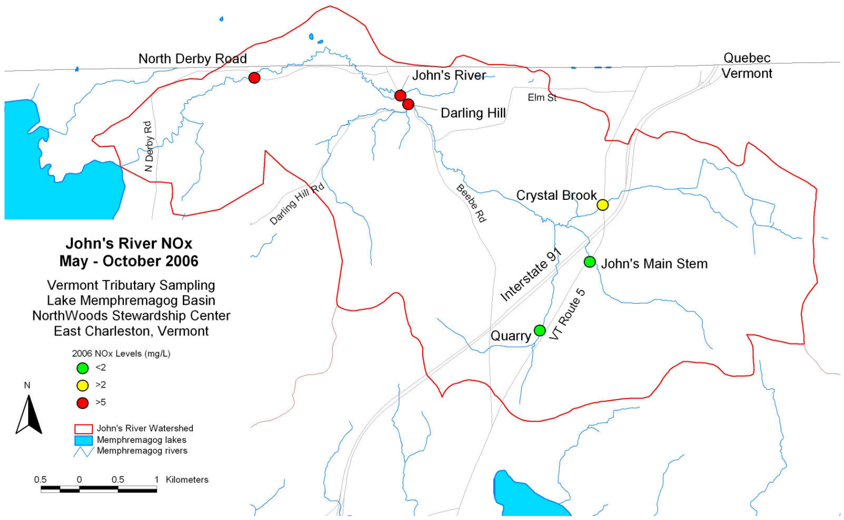

Figure 21. *Maximum NO_x values observed at six sites in the John's River Watershed during May-October 2006.*

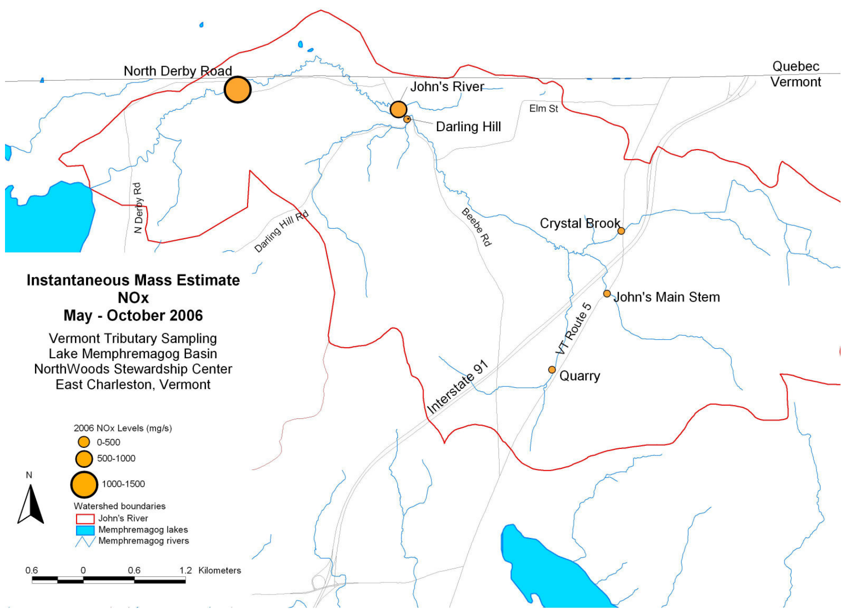

Figure 22. *Mean instantaneous mass estimates of NO_x observed in the John's River watershed during May-October 2006.*

Chloride

In 2006, we sampled chloride at 18 sites in the Clyde River Watershed. Chloride is a component of many salts, including sodium chloride (NaCl), calcium chloride ($CaCl_2$), potassium chloride (KCl), magnesium chloride ($MgCl_2$), and others. Salt enters streams naturally from the weathering and erosion of bedrock and soil, precipitation, and groundwater; however, elevated levels of salts arise from the application of road salt for deicing (NaCl) and dust control ($CaCl_2$). Although there are currently no water quality standards for chloride in Vermont, levels exceeding 210 mg/l are thought to impact aquatic life (Environment Canada 2001). Chloride levels generally peaked during the summer months, when flow levels were at their lowest, but only one site had chloride levels that exceeded 210 mg/l (see Figure 23). However, it is important to note that sampling did not occur during spring snowmelt and likely did not capture the resulting salt runoff. The one notable exception was the small tributary adjacent to the Charleston Town Garage, where chloride concentrations ranged between 9 and 434 mg/l. Although chloride levels were high at the Town Garage, they did not substantially increase chloride levels in the main stem of the Clyde River. Instantaneous mass estimates incorporating flow did show that the total amount of chloride in the water column did increase at the downstream sites (see Figure 24).

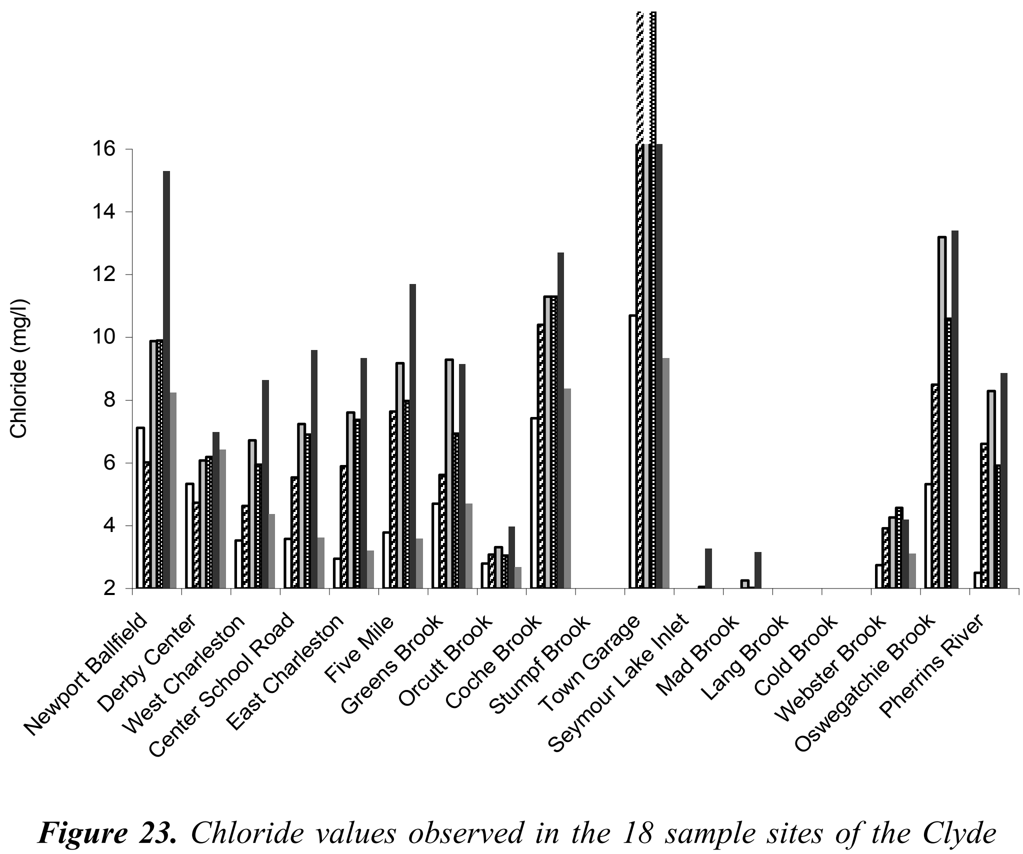

Figure 23. *Chloride values observed in the 18 sample sites of the Clyde River watershed during May – October 2006. Town Garage values are: May=10.7 mg/l, June=88.7 mg/l, July=286 mg/l, August=182 mg/l, September=434 mg/l, and October=9.4 mg/l.*

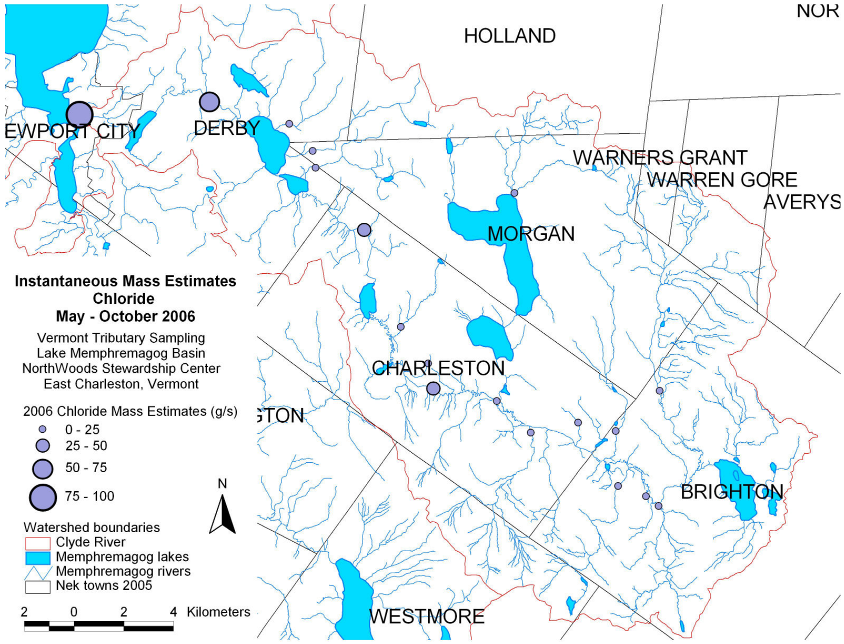

Figure 24. *Mean instantaneous mass estimates of chloride observed at 18 sites in the Clyde River Watershed during May-October 2006*

Total Suspended Solids

Total suspended solids (TSS) measures the total amount of dissolved and suspended material in the water column. Sediment load greatly affects the health of aquatic systems. High sediment loads lower water clarity and transport pollutants and nutrients, such as heavy metals and phosphorus. Sediments, when they settle out of the water column, also smother aquatic life and their habitats. Much of the sediment being transported in the water column originates from erosion associated with agriculture, forestry, urban and suburban development, and stream adjustment processes. In 2005, we sampled TSS levels on all four tributaries. TSS levels were generally lowest on the Clyde River, intermediate on the Barton and Black Rivers, and highest on the John's River. In 2006, we only sampled TSS on the Black and John's Rivers. Values ranged between <1 and 20.2 mg/l (in comparison, values ranged between <1 and 27.7 mg/l in 2005). For both tributaries, TSS levels were highest in May and were lower in the other months (see Figure 25). In 2006, the Black River had the highest TSS levels, as all sites exceeded 10 mg/l at least once (see Figure 26). Incorporating flow levels into instantaneous mass estimates indicated that the Black River contributed high levels of sediment into Lake Memphremagog, although the highest estimates were observed upstream at Irasburg, but some of this sediment must settle out of the water column before the river reaches South Bay (see Figure 27).

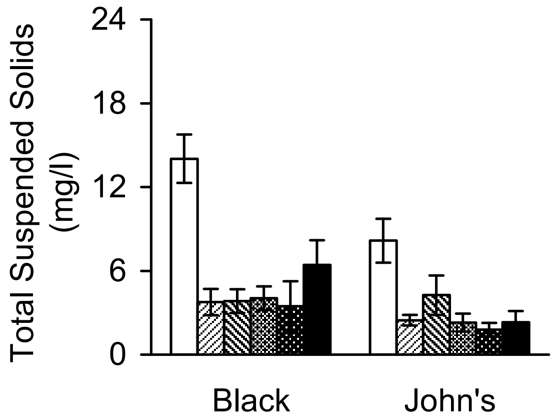

Figure 25. *Mean monthly total suspended solids values (± 1 SEM) observed in the Black and John's Rivers during May-October 2006.*

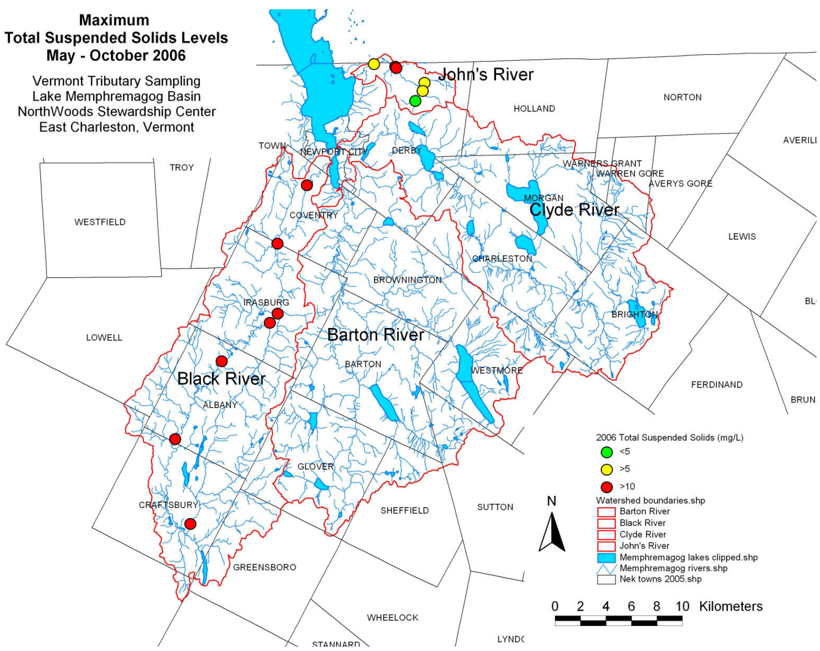

Figure 26. *Maximum total suspended solids values observed at 13 sites in the Black and John's River Watersheds during May-October 2006.*

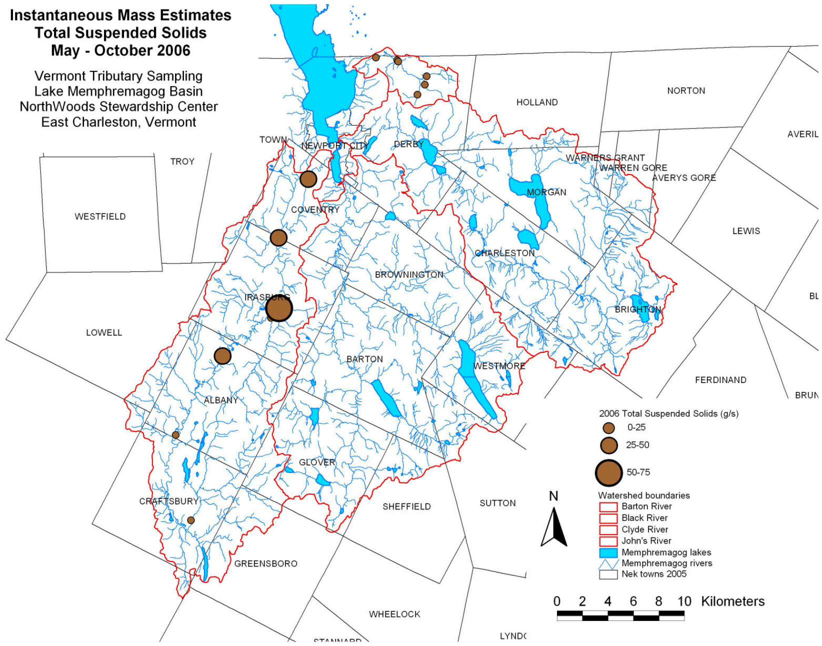

Figure 27. *Mean instantaneous mass estimates of total suspended solids at 13 sites in the Black and John's River Watersheds during May-October 2006.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with Neil Kamman of the Vermont DEC. As part of this plan, we collected four field blanks and four field duplicate samples each month. Blank sample containers were filled with only de-ionized water and, if done properly, would result in values that were below the detection limits (alkalinity <1 mg $CaCO_3$/l, total phosphorus <5 µg/l, total nitrogen <0.1 mg/l, NO_x <0.05 mg/l, chloride <2 mg/l, and total suspended solids <1 mg/l). Only one of the 89 blank samples (a total phosphorus blank) exceeded its detection limit, possibly due to field or laboratory contamination, accidental filling with stream water, or mislabeling. Likewise, all but one of the 93 pairs of duplicate samples resulted in similar values (>97% similarity).

Discussion and Implications

Overall Results

As in 2005, our 2006 results indicate that all four Vermont tributaries are sending high levels of sediment, nitrogen, and phosphorus into Lake Memphremagog. Again water quality was generally best in the Clyde River, which has the least agricultural and urban development; intermediate in the Barton and Black Rivers, probably reflecting their large agricultural land base; and worst in the John's River. In particular, total phosphorus, total nitrogen, and NO_X levels were all exceedingly high at one or more sites in the John's River Watershed, with nitrogen and phosphorus levels far exceeding those observed at any site in the other three tributaries. The Black River watershed, where agricultural development is most extensive, had the second-poorest water quality, with the highest levels of total suspended solids and high levels of nitrogen and phosphorus. In contrast, the Barton River generally had the lowest nitrogen levels, and the Clyde River generally had the lowest phosphorus levels. However, when flow measurements were incorporated into instantaneous mass estimates, the Clyde River sent substantially higher levels of both total nitrogen and total phosphorus into Lake Memphremagog, because flow levels there were nearly double those observed in the Barton and Black Rivers. Conversely, the John's River, which had the lowest flow levels, contributed the least total nitrogen and total phosphorus into Lake Memphremagog.

Individual Results

Water depth and flow at the sample sites varied greatly throughout the year. In this region, flows are generally greatest during spring snowmelt and secondarily during the fall, when precipitation levels often increase and plants are no longing transpiring water during photosynthesis. In contrast, flows are generally lowest during the summer months when there is less precipitation and more evaporation and plant transpiration. In 2006, water depth and flow generally reflected this pattern. The greatest water depths and flows were observed in May, progressively lessened during the summer months, and peaked again in October (see Figure 3). Of the four tributaries, the John's River accounted for the lowest flows into Lake Memphremagog, the Barton and Black Rivers had intermediate flows, and the Clyde River had the greatest flows, nearly double those of the Barton and Black Rivers (see Figure 4). The flow data also enabled us to calculate instantaneous mass estimates for several parameters each sample site. While concentrations describe one measure of water quality, instantaneous mass estimates allow us to quantify the actual amount of nitrogen, phosphorus, or sediment being carried by the river at any one time.

Water temperatures in this study ranged between 4.9 and 24.4^{o}C. In all four watersheds, temperatures were lowest in May and October and peaked in July (see Figure 5). Temperatures exceeded 22^{o}C at many sites, especially in the lower watersheds during July (see Figure 6). In contrast, temperatures at sites in the upper watersheds and along the smaller tributaries often remained below 22^{o}C, even in July. Interestingly, all sites on the John's River also remained below 22^{o}C throughout the summer. Thus, at many of these sites, temperature-sensitive species, such as brook trout, are unlikely to be able to survive. In contrast, these species are likely to survive in the upper watersheds and along many of the smaller rivers and streams (e.g. Webster and Oswegatchie Brooks and the John's and Pherrins Rivers), in which July temperatures never exceeded $<$22^{o}C. These results indicate that the main stem and larger tributaries of the Barton and Black Rivers are not likely to provide good habitat for cold-water species, at least during the summer months. Many sections of these rivers and streams no longer have intact riparian forests along their corridors. Restoring these riparian buffers would shield the water's surface from solar radiation and would help to lower stream temperatures overall. In contrast, the upper watersheds and smaller tributaries, which often retain their riparian forests, are likely to provide good habitat for cold-water species all year round. Although none of the John's River sites exceeded 22°C, other water quality issues in this watershed likely preclude this watershed from providing high-quality habitat currently.

In addition to its direct impacts on aquatic life, water temperature also affects the ability of water to retain dissolved oxygen. As illustrated in Figure 28, there is typically an inverse relationship between temperature and dissolved oxygen. This relationship is further illustrated by the fact that dissolved oxygen levels were generally highest in the spring and fall, when temperatures were lowest, and lowest in July, when temperatures were highest (see Figures 5 and 7). Furthermore, the John's River generally had higher dissolved oxygen levels than the other three tributaries, probably reflecting the lower water temperatures in this tributary. In this study, dissolved oxygen levels generally met the Vermont water quality standards (State of Vermont 2006) for cold-water fisheries (>7.0 mg/l) and warm-water fisheries (>6.5 mg/l). During the six months of this study, all sites had dissolved oxygen levels exceeding 7.0 mg/l, except the June sample from East Charleston on the Clyde River, which was 6.88 mg/l (this site also had water temperatures exceeding 22°C in July). Thus, dissolved oxygen levels in most of the watershed remained acceptable throughout the summer, although slow-flowing areas without adequate riparian buffers should be watched carefully in the future.

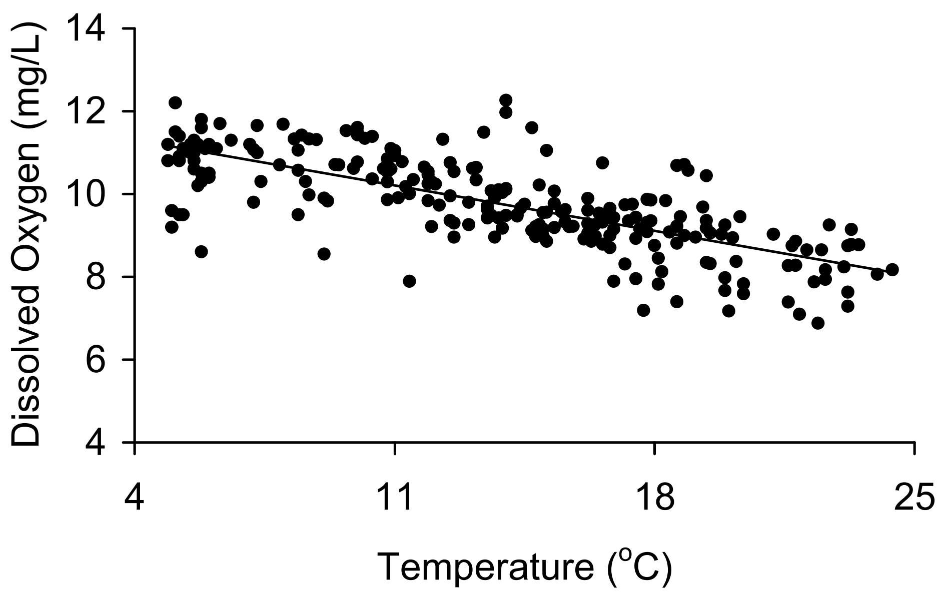

Figure 28. *Relationship between dissolved oxygen and water temperature in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Acidity (pH) was neutral to slightly alkaline at most sites in all watersheds and fell within the range preferred by most aquatic organisms (pH=6.5-8.5). The few exceptions were two sites on the Black River and one site on the Barton River, where the pH exceeded 8.5, and one site on the Clyde River, where the pH was below 6.5 (see Figure 9). The generally high pH values raise an interesting question: Why are the pH values of the surface waters so high when the pH values of the precipitation falling in this region are so low? Due to atmospheric pollution (primarily from coal-burning power plants and industries in the Ohio Valley and Midwest), the precipitation falling in the Lake Memphremagog Basin is highly acidic. For example, pH values of rainfall measured in East Charleston during 2005-2006 generally ranged between 3.9 and 4.9 (except during tropical storms, when pH levels were slightly higher). Despite the acidic nature of our precipitation, the pH of these surface waters was generally at levels healthy for aquatic life. As sulfur emissions continue to decline due to Clean Air Act regulations, this threat to water quality will likely be reduced in the future.

One explanation for this discrepancy is offered by another parameter that we measured. Alkalinity measures the ability of rivers and streams to neutralize acid inputs and is determined primarily by the underlying bedrock and surficial deposits. Because all values of alkalinity exceeded 5 mg/l (the value below which ecosystems are sensitive to acid inputs), the four tributaries of Lake Memphremagog are well buffered against acid inputs. The explanation is supported by the positive relationship between alkalinity and pH, especially at alkalinity values of less than 50 mg $CaCO_3$/l (see Figure 29). The reason for these differences in buffering capacity is likely determined by the underlying bedrock and surficial deposits. Specifically, the John's River has the highest buffering capacity due to the high proportion of carbonate-rich bedrock in its watershed (see Table 1); the Clyde River has the lowest buffering capacity, especially in the upper watershed, due to the high proportion of non-calcareous bedrock in its watershed.

Table 1. Percentages of carbonate-containing and non-calcareous bedrock in each Lake Memphremagog tributary watershed. Percentages were calculated by laying watershed boundaries over a bedrock geology G.I.S. layer obtained from the Vermont Center for Geographic Information.

Variable	% Carbonate-Containing Bedrock[1]	% Non-Calcareous Bedrock[2]
Barton River	74	26
Black River	76	23
Clyde River	53	46
John's River	99	1

[1] Carbonate-containing bedrock includes the Gile Mountain, Waits River, and Standing Pond Volcanics Formations.

[2] Non-calcareous bedrock includes the New Hampshire Series Plutons and the Missisquoi Formation.

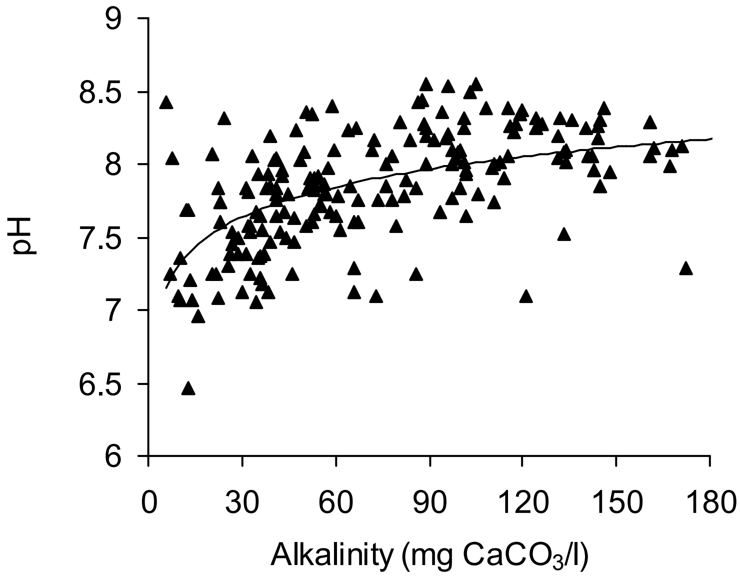

Figure 29. *Relationship between pH and alkalinity in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.*

Paralleling these patterns in pH and alkalinity, conductivity is also greatly impacted by the availability of carbonate minerals in bedrock or surface deposits. Values measured in this study ranged between 14 and 1535 µS, and values were lowest in spring and fall and peaked during summer months (see Figure 12). Values were generally highest in the John's River Watershed, intermediate throughout the Barton and Black River Watersheds, and least in the Clyde River Watershed, especially the upper watershed (see Figure 13). The one exception was the small tributary adjacent to the Charleston Town Garage, which consistently had the highest conductivity readings of any site in this study (100-1535 µS). Conductivity was also high throughout the John's River Watershed; where values often exceeded 300 µS at five of the six sites. Values in the upper part of the Clyde River Watershed were generally less than 100 µS. As with pH and alkalinity, these results indicate that dissolved ion concentrations were greater in areas underlain by the more calcium-rich Waits River and Gile Mountain Formations, and they were lower in areas underlain by calcium-poor bedrock, such as the New Hampshire Series Plutons. However, in addition to these geological inputs, human activities can also add dissolved ions into the water column primarily through runoff from agriculture and forestry and stormwater and wastewater from urban and suburban development.

Total phosphorus levels were high in all watersheds; however, individual sites differed in their levels. Our 2005 data from a single site on the John's River indicated a critical need to identify sources of phosphorus in that watershed. This year, our sampling was expanded to include six sites there with the expressed purpose of trying to better understand phosphorus inputs. All sites in the John's River Watershed, except the John's Main Stem, had high phosphorus levels. The Crystal Brook tributary (see Figure 30) had extremely high total phosphorus values that peaked at 655 µg/l in September, a value more than ten times that observed at any other site in this study. Even though Crystal Brook accounted for only one quarter of the flow in the John's River, all sites downstream of Crystal Brook also exhibited high phosphorus levels (see Figure 15). However, two other tributaries of the John's River (Quarry and Darling Hill) also had high phosphorus levels, so this problem is spread throughout the watershed. As in 2005, the Black River had the second highest phosphorus levels of the four tributaries, and these high values occurred throughout the watershed. In contrast, the Clyde and Barton Rivers had the lowest phosphorus levels during both years, although the lower watersheds of both rivers had higher levels than the upper watersheds. Although phosphorus concentrations were highest in the John's River, the other watersheds, especially the Clyde River but also the Black and Barton Rivers, likely contribute greater amounts of phosphorus into Lake Memphremagog (see Figure 16). In all four tributaries, phosphorus is likely arising primarily from agricultural runoff and secondarily from urban development and wastewater. As far as we know, the bedrock in this area is not a significant source of phosphorus. Because phosphorus is the main nutrient causing eutrophication of Lake Memphremagog, it is essential that we identify and eliminate its sources. Needed efforts to control phosphorus include eliminating point sources as well as reducing nonpoint sources by maintaining and enhancing riparian buffers that reduce erosion and filter runoff entering the rivers and streams.

Figure 30. *The presence of sewer fungus and foul-smelling water reflected the high phosphorus levels in Crystal Brook and made the use of latex gloves necessary during sampling.*

Total nitrogen levels were generally low in three of the four watersheds during both 2005 and 2006, although they were slightly higher in the Black than the Barton and Clyde Rivers (see Figure 17). As with total phosphorus, the John's River also had exceedingly high total nitrogen levels. In September, samples from three of the John's River sites exceeded 5 mg/l (see Figure 18). Although the concentration of total nitrogen within the John's River was extremely high, this river did not contribute as much total nitrogen to Lake Memphremagog as the Clyde River because of its lower flows (see Figure 19). Although typically not the limiting nutrient in many aquatic systems, high levels of nitrogen in combination with high levels of phosphorus can accelerate eutrophication. Local sources of nitrogen include agricultural and urban runoff, septic leakage, and wastewater discharge. Nitrogen also originates from dry and wet atmospheric deposition, mostly due to the burning of fossil fuels. Because the exceedingly high nitrogen levels are restricted to the John's River, the sources of these inputs are likely to be local, and there is a critical need to identify and remove these sources as soon as possible. In contrast, more broad-scale atmospheric inputs will require regional and national corrective actions in order to reduce their impacts on aquatic and terrestrial systems.

Nitrates and nitrites (NO_x) are two forms of nitrogen which are readily available for uptake and use by algae and aquatic plants. Because we observed high total nitrogen levels in the John's River in 2005, we assessed NO_x at the six John's River sites in order to determine the proportion of total nitrogen occurring in this form. For five of the six sites, NO_x constituted the bulk of the total nitrogen (compare Figures 20 and 31). Three of these sites - Darling Hill, John's River, and North Derby Road - exceeded the Vermont water quality standard for Class B waters (5 mg/l, State of Vermont 2006). Although the NO_x levels observed at Darling Hill were similar to those observed at the John's River and North Derby Road sites, its small size and correspondingly low flows suggest that this tributary is not the only source of NO_x and that there must be other sources of NO_x upstream of the John's River site but downstream of the sites on the other tributaries. At Crystal Brook, NO_x constituted a smaller fraction of the total nitrogen, especially in August and September, than at these other sites (compare Figures 20 and 31). In this tributary, the remaining nitrogen may occur as ammonia or bound in organic materials. Collectively, these results indicate that there is a critical need to better understand the sources of nitrogen in this watershed, especially upstream of the Darling Hill site and between the John's River site and the upstream sample points.

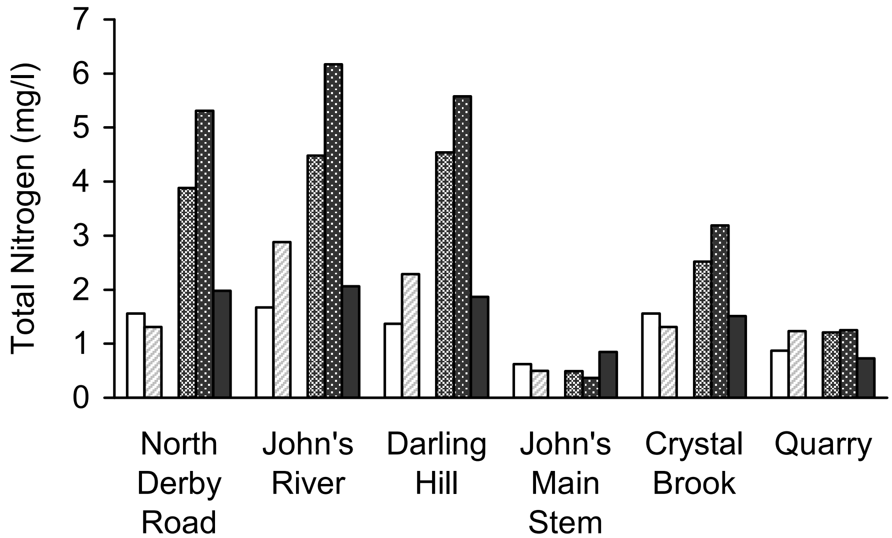

Figure 31. *Total nitrogen values observed at the six sites in the John's River Watershed during May-October 2006 (July values are missing).*

Chlorides have become elevated in many streams due to the application of road salts in both summer ($CaCl_2$ for dust control) and winter (NaCl for deicing). Although the environmental impacts of chloride are not well understood, there is concern that chronic toxicity will occur at concentrations as low as 210 mg/l (Environment Canada 1997, 2001). We only tested for chloride in the Clyde River Watershed, and samples from all but one site measured at or below 15 mg/l. The one exception was the small tributary adjacent to the Charleston Town Garage, where chloride levels ranged between 9 and 434 mg/l (see Figure 23). These levels increased throughout the summer as flows lessened, but concentrations exceeding 210 mg/l were only observed in July and September. Thus, efforts should be made to reduce salt runoff from the Charleston Town Garage, as well as other town garages where similar problems exist. Although chloride concentrations there were high, the small size of this tributary meant that the total contribution of chloride to the main stem was diluted by the larger flows encountered there. However, instantaneous mass estimates did indicate that there was an overall increase in the amount of chloride being carried in downstream sections of the main stem (see Figure 24).

Total suspended solids measures the total amount of dissolved and suspended material in the water column, which can greatly affect the health of aquatic systems. Suspended solids also serve as a vector for transporting other materials, such as phosphorus, toxins, and heavy metals. In 2005, we sampled all four Vermont tributaries for total suspended solids: Total suspended solids were highest in the John's River, intermediate in the Black and Barton Rivers, and least in the Clyde River. In 2006, we only sampled total suspended solids in the Black and John's Rivers. Unlike 2005, total suspended solids levels did not peak in June and July but rather were highest in May and then lower during the remainder of the year (see Figure 25). The high levels observed in May may have reflected the combination of high rainfall and bare, unvegetated soils (especially in agricultural fields) during that month. Also in contrast to 2005, levels in the Black River Watershed were higher than those observed in the John's River Watershed. Because these sediment levels are higher than desirable, there is a need to pinpoint the sources of these sediment inputs. Much of the sediment likely originates from erosion associated with agriculture, forestry, and urban and suburban development. High rainfall in combination with saturated or bare soils worsens these erosion problems. Stream adjustment processes, whether as a natural part of stream evolution or in response to past mismanagement of stream corridors, also increase erosion. These data further illustrate the need to properly manage riparian corridors to minimize erosion and reduce nutrient and sediment inputs.

Quality Assurance

This project was conducted in accordance with an approved Quality Assurance Project Plan developed in conjunction with the Vermont DEC. The results of the analyses of the blank and duplicate samples indicated that we were collecting replicable samples and that samples were generally not being contaminated during field or laboratory processing. There were two exceptions that warrant review. First, one of the blank samples exceeded its detection limit, possibly due to field or laboratory contamination, accidental filling with stream water, or mislabeling. Second, one of the 93 pairs of duplicate samples resulted in slightly dissimilar values. These two errors, both of which occurred during the initial May sampling, indicate that we need to take greater care in collecting and processing samples to ensure that there is no field contamination and that samples are being collected in a repeatable manner. In addition, there were a number of issues that resulted in the loss of data in either the field or laboratory (see Appendix C). The major problems were caused by equipment failure, inadequate acidification of nitrogen samples, and failure to measure flow distances. Discussions and corrective actions by field and laboratory personnel and the acquisition of a better pH and conductivity meter should preclude the recurrence of these problems in the future.

Education and Outreach

As part of this project, we incorporated the process and results of this study into several educational and outreach programs oriented towards the local community. Several groups from Sterling College, Green Mountain Audubon, and Kroka Expeditions joined us for one or more field days, in which we discussed and collaborated on field data collection. We also presented the results of this and other water quality studies at Sterling College, a public meeting hosted by Vermont DEC, and a Memphremagog Steering Committee meeting. Another presentation is currently scheduled as part of the Osher Lifelong Learning Institute in Newport, Vermont, and we are actively discussing ways to incorporate these studies into curricula for local schools. Furthermore, we provided this information to the local and regional community, including various lake associations and the general public, through a number of formal and informal consultations. We also continued to develop collaborative relationships with the Water Quality Division of the Vermont DEC (including the LaRosa Analytical Laboratory, the River Management Section, the Lakes & Ponds Management/Protection Section, and the Watershed

Planning Section), the Silvia O. Conte National Fish and Wildlife Refuge Nulhegan Basin Division, the Biological Sciences Department at Dartmouth College, and other partners working in the Lake Memphremagog Basin (Quebec Ministère du Développement durable, de l'Environnement et des Parcs; MRC de Memphrémagog; Villes des Sherbrooke et Magog; and Memphremagog Conservation, Inc.).

Recommendations and Future Plans

Overall, the results from this second year of sampling indicated that water quality was ranked from best to worst as follows: Clyde River, Barton River, Black River, and John's River. In the Barton and Clyde Rivers, water quality was generally better in the upper than the lower watershed. In contrast, water quality was poor throughout the Black and John's River Watersheds. For the John's River, the additional sites sampled in 2006 helped us to better understand the phosphorus and nitrogen problems in this watershed. It is now clear that much of the phosphorus originates from Crystal Brook, and efforts are proposed to correct a known point source of phosphorus in 2007. In contrast, the nitrogen problem remains less well understood and will require additional sampling to pinpoint the sources of these problems, so that we can develop and implement effective restoration and protection projects.

In 2007, we propose to continue assessing and identifying threats to water quality in the Lake Memphremagog Basin. This year's efforts will include three components. First, in collaboration with Dartmouth College and the Silvia O. Conte National Fish and Wildlife Refuge, we will continue to collect continuous temperature data in the Upper Clyde and Nulhegan Watersheds. Second, we will continue the Phase 1 and 2 Stream Geomorphic Assessment of the Clyde River, and we will begin Phase 1 and 2 Stream Geomorphic Assessments of the John's and Barton Rivers in collaboration with Lake Region Union High School. Third, we will continue sampling water quality throughout the watersheds of the four Vermont tributaries of Lake Memphremagog. This sampling will include additional sites on the John's River and its tributaries to better identify and assess the sources of nitrogen in this watershed. We will also analyze samples from all sites in the John's River Watershed for both ammonium (NH_4) and NO_x to better identify the sources of nitrogen in this watershed. In addition, we will sample turbidity, rather than total dissolved solids (TSS), in the John's and Black River Watersheds, since this is the parameter used to assess compliance with Vermont water quality standards (State of Vermont 2006). Finally, we will reduce the number of sites sampled in the Clyde River Watershed and eliminate analyses of chloride. The goal of these projects will be to continue increasing our knowledge of and identifying sources of stream erosion, sedimentation, and nutrient enrichment, so that we can prioritize and implement on-the-ground protection and restoration projects that will maintain and enhance water quality in the Lake Memphremagog Basin. Finally, we will continue our education and outreach efforts to raise public awareness about threats to water quality in the Lake Memphremagog Basin and to include the public in efforts to both prevent further degradation and improve water quality in this important region.

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Appendix A. Description of the 38 sites sampled in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.

Barton River (seven sites):
Main stem downstream of Coventry Station Road in Coventry
Willoughby River at Willoughby Falls Wildlife Management Area in Orleans
Main stem upstream of Wastewater Treatment Plant in Orleans
Brownington Brook upstream of Schoolhouse Road in Brownington
Willoughby River upstream of Vermont Route 58 in Brownington
Main stem upstream of U.S. Highway 5 in Barton
Main stem at Glover Road Fishing Access in Barton

Black River (seven sites):
Main stem adjacent to U.S. Highway 5 at South Bay Wildlife Management Area in Coventry
Main stem downstream of Coventry Covered Bridge (and upstream of USGS gauging station)
Main stem below village of Irasburg in Irasburg
Lord's Creek downstream of Creek Road in Irasburg
Main stem near Griggs Pond in Albany
Main stem downstream of Wylie Hill Road in Albany
Main stem downstream of Craftsbury Town Garage

Clyde River (eighteen sites):
Main stem at Newport Ballfield in Derby (downstream of wastewater treatment plant)
Main stem downstream of Vermont Route 105 in Derby
Greens Brook upstream of Dumas Road in Derby
Orcutt Brook upstream of Dumas Road in Derby
Coche Brook downstream of Fontaine Road in Derby
Main stem downstream of Durgin Road in Charleston
Stumpf Brook upstream of Vermont Route 105 in Charleston
Unnamed tributary adjacent to Charleston Town Garage
Main stem downstream of Center School Road in Charleston
Seymour Lake Inlet (Sucker Brook) upstream of Vermont Route 111 in Morgan
Main stem upstream of Twin Bridges Road in Charleston
Mad Brook near confluence with Clyde River in Charleston
Lang Brook at NorthWoods Stewardship Center in Charleston
Webster Brook downstream of Dollof Mountain Road in Brighton
Cold Brook upstream of Vermont Route 105 in Brighton
Main stem downstream of Five Mile Square Road in Brighton (downstream of wastewater treatment plant)
Oswegatchie Brook upstream of Vermont Route 105 in Brighton
Pherrins River upstream of Vermont Route 105 in Brighton

John's River (six sites):
Unnamed tributary downstream of U.S. Highway 5 in Derby
Main stem upstream of U.S. Highway 5 in Derby
Crystal Brook downstream of U.S. Highway 5 in Derby
Unnamed tributary downstream of Darling Hill Road in Derby
Main Stem downstream of Beebe Plain Road in Derby
Main stem downstream of North Derby Road in Derby

Appendix B. Raw data collected at 38 sites in the watersheds of the four Vermont tributaries of Lake Memphremagog during May-October 2006. Parameters are: T = temperature, EC = conductivity, DO = dissolved oxygen, TN = total nitrogen, TP = total phosphorus.

Barton River:

Site	Month	Depth (cm)	Flow (m^3/s)	T (^oC)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3/l$)	TN (mg/l)	TP (µg/l)
Barton Railroad Bridge	5/25/06	35	-99	9.4	8.08	124	10.71	49.7	0.27	20.6
Barton Railroad Bridge	6/21/06	9	3.10	20.1	8.1	154	8.94	59.5	0.28	11.2
Barton Railroad Bridge	7/26/06	-9	1.29	**22.7**	8.05	203	9.25	78		11.1
Barton Railroad Bridge	8/23/06	18	1.76	19.3		181	9.68	74.3	0.34	11.8
Barton Railroad Bridge	9/27/06	-14	0.42	14.7	7.77	233	11.6	97.4	0.42	19.5
Barton Railroad Bridge	10/25/06	22	5.37	8.4	7.92	71	10.57	54.4	0.23	13.6
Brownington	5/23/06	30	1.37	7.3	7.83	71	11	35	0.3	14.6
Brownington	6/22/06	9	0.24	16.2	7.85	153	9.89	76.3	0.2	9.44
Brownington	7/26/06	10.2	0.24	**23.3**	**8.54**	184	9.14	96.3		11.4
Brownington	8/23/06	13	0.24	18.3		172	9.84	85.4	0.26	9.43
Brownington	9/27/06	9.2	0.13	13.1	8.08	175	10.62	99.6	0.16	10.2
Brownington	10/25/06	37	2.04	5.2	7.79	48	10.8	40.9	0.37	12.7
Coventry Station	5/23/06	142	20.37	9.4	7.83	120	0	49	0.33	**31.2**
Coventry Station	6/21/06	40	5.93	18.6	7.85	157	9.22	64.6	0.34	19.9
Coventry Station	7/26/06	-13	1.88	**22.5**	7.78	205	8.65	82		14.2
Coventry Station	8/23/06	-3	2.73	18.2		197	8.12	78.8	0.32	14.4
Coventry Station	9/27/06	-39	0.76	13.8	7.65	226	10.1	102	0.29	14.6
Coventry Station	10/25/06	85	9.90	7.1	7.71	70	11.2	55.2	0.34	**27.4**
Evansville	5/23/06	52	6.46	7.3	7.69	80	11.65	34.4	0.25	10.5
Evansville	6/22/06	33	2.20	16.2	7.85	96	9.61	39	0.2	7.91
Evansville	7/26/06	16	1.33	**24.4**	8.03	104	8.17	40.1		13.5
Evansville	8/23/06	13.4	0.99	19.5		101	9.06	41.4	0.24	9.25
Evansville	9/27/06	-2.5	0.41	15.3	7.92	103	10.07	43.2	0.16	9.56
Evansville	10/25/06	38.5	4.90	7.2	7.64	47	9.8	36	0.24	13.4
Glover Road	5/25/06	31	2.59	8.4	8.24	149	11.06	65.8	0.24	12.6
Glover Road	6/21/06	15	1.43	17.9	8.29	177	9.85	80.8	0.33	11.3
Glover Road	7/26/06	-6	0.76	20.3	8.31	222	9.45	101		9.76
Glover Road	8/23/06	-3	0.87	17.8		220	9.87	95.4	0.33	7.43
Glover Road	9/27/06	-4.5	0.80	14.9	8.06	236	10.22	115	0.3	7.93
Glover Road	10/25/06	6.5	2.05	7.4	8.16	84	10.3	72.1	0.28	12
Orleans Wastewater	5/23/06	121	9.81	10.3	8.07	131	0	52.3	0.34	**34.4**
Orleans Wastewater	6/21/06	38	4.22	19.1	8.25	173	8.96	66.3	0.31	12.5
Orleans Wastewater	7/26/06	8	2.18	**22.1**	8.19	227	8.65	89		10.2
Orleans Wastewater	8/23/06	6	1.57	18.4		214	9.08	82.4	0.41	15.1
Orleans Wastewater	9/27/06	-7	0.78	13.2	7.97	262	10.63	110	0.35	11
Orleans Wastewater	10/25/06	73	4.95	7.9	7.97	79	10.7	57.6	0.26	18.8

Site	Month	Depth (cm)	Flow (m^3/s)	T (^oC)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)
Willoughby Falls	5/23/06	99	6.79	8.5	8.04	43	0	41.2	0.29	**26.7**
Willoughby Falls	6/21/06	9	1.99	19.8	8.35	119	9.03	50.4	0.23	9.8
Willoughby Falls	7/26/06	-16	0.31	**24**	8.4	146	8.06	59		12.6
Willoughby Falls	8/23/06	-20	0.12	19.4		142	9.17	59.5	0.19	8.16
Willoughby Falls	9/27/06	2.5	0.38	13.2	8	164	10.64	76.4	0.15	10.6
Willoughby Falls	10/25/06	69	5.38	6.6	7.96	54	11.3	42.6	0.29	17.1

Black River:

Site	Month	T (^oC)	Depth (cm)	Flow (m^3/s)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	TSS (mg/l)
Coventry Bridge	5/25/06	11.8	53	8.00	8.03	113	10.65	60.7	0.38	**34.3**	**20.2**
Coventry Bridge	6/22/06	19.4	28	2.48	**8.55**	203	10.44	88.9	0.3	16.6	2.5
Coventry Bridge	7/27/06	21.8	21.9	1.42	8.25	234	8.86	101	0.36	19.5	2.8
Coventry Bridge	8/24/06	16.6	25.8	1.75		208	9.32	87.1	0.38	18.4	3.11
Coventry Bridge	9/28/06	12	17	0.59	7.96	223	10.29	102	0.25	16.8	1.12
Coventry Bridge	10/26/06	5.5	44	5.28	7.86	142	11.1	56.1	0.44	**30**	**15.4**
Craftsbury	5/25/06	12.5	35	2.62	8.25	176	10.76	85.7		23.1	**13.9**
Craftsbury	6/22/06	18.9	17	0.94	**8.55**	204	10.57	105	0.54	9.17	1
Craftsbury	7/27/06	21.2	7.3	0.72	8.37	242	9.03	120	0.6	11.6	1.35
Craftsbury	8/24/06	17.2	8.6	0.53		232	9.74	111	0.52	8.85	1.6
Craftsbury	9/28/06	14	1	0.23	8.04	245	11.97	131	0.45	10.6	1
Craftsbury	10/26/06	5.2	30	1.86	8.16	188	10.9	83.9	0.48	12.4	2.59
Griggs Pond	5/25/06	12.6	147	7.78	7.65	132	9.3	64	0.4	**28.6**	**16.2**
Griggs Pond	6/22/06	19.4	84	2.01	8	197	8.35	89	0.39	22.4	4.3
Griggs Pond	7/27/06	21.9	66.7	0.91	8	218	7.1	97.5	0.38	22.8	4.3
Griggs Pond	8/24/06	17.5	82	1.30		202	7.95	86.5	0.4	21.6	3.67
Griggs Pond	9/28/06	13.5	86.5	0.42	8.02	210	9.42	101	0.24	21.1	2.1
Griggs Pond	10/26/06	5.3	137	4.59	7.58	126	9.5	50.6	0.42	**27.5**	8.78
Irasburg	5/25/06	11.5	52	15.62	7.84	131	10.35	60.5	0.46	**31**	**18.2**
Irasburg	6/22/06	19.9	8	2.44	8.27	196	9.25	88.2	0.38	22.3	4.8
Irasburg	7/27/06	**22.6**	5.5	2.01	8.21	217	8.17	96	0.4	23	4.8
Irasburg	8/24/06	17.9	10.7	4.00		205	9.35	86	0.42	**25**	7
Irasburg	9/28/06	13.6	3.5	1.36	8.04	210	10.08	98.4	0.25	21.3	3.03
Irasburg	10/26/06	5.6	40	8.06	7.73	137	11	54.9	0.44	**28**	7.72
Lords Creek	5/25/06	10.9	64	1.77	8.06	141	11.1	72.9	0.22	23	**11.3**
Lords Creek	6/22/06	18.8	34	0.27	8.49	192	10.71	103	0.14	8.46	1
Lords Creek	7/27/06	**23.3**	-8	0.11	8.26	219	8.78	116	0.26	14.9	1.9
Lords Creek	8/24/06	16.6	34	0.36		219	10.75	111	0.24	11.4	1.8
Lords Creek	9/28/06	13.4	14.5	0.10	8.25	216	11.49	124	0.21	22.7	1.12
Lords Creek	10/26/06	5.2	55	1.20	7.89	178	10.9	82.6	0.29	16.8	2.4

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	TSS (mg/l)
Rogers Branch	5/25/06	13.7	61	6.53	7.57	151	8.96	71.5	0.42	21.5	6.8
Rogers Branch	6/22/06	19.9	18	2.64	7.67	201	7.67	93.7	0.42	28.1	8
Rogers Branch	7/27/06	23.2	1.4	0.80	7.8	232	7.29	106	0.54	32.4	8.1
Rogers Branch	8/24/06	18.6	4	1.35		222	7.4	97.8	0.5	27.8	7.12
Rogers Branch	9/28/06	15.6	-9	0.49	7.74	228	9.62	111	0.45	36.4	14.1
Rogers Branch	10/26/06	5.2	28	3.70	7.6	163	9.5	67	0.49	25.1	2.95
South Bay	5/25/06	11	108	16.71	7.93	125	10.93	58.6	0.42	28.1	11.6
South Bay	6/22/06	19.9	53	4.70	8.43	205	7.98	86.7	0.38	20.1	4.7
South Bay	7/27/06	23.1	30.1	2.80	8.09	244	8.24	97.3	0.52	21.8	3.64
South Bay	8/24/06	18.1	13.8	1.12		211	8.45	83.7	0.5	20.7	3.89
South Bay	9/28/06	12.6	-5	1.45	7.93	232	10.54	102	0.4	21.4	1.77
South Bay	10/26/06	5.7	60	8.17	7.79	144	11.2	56.8	0.5	29.7	5.08

Clyde River:

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µS)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	Chloride (mg/l)
Center School Road	5/23/06	8.5	135	21.91	7.25	53		22.2	0.28	11.9	3.58
Center School Road	6/20/06	21.6	38	6.51	7.25	84	7.39	32.4	0.28	14.5	5.54
Center School Road	7/25/06	20.4	-9	2.93	7.38	104	7.83	37		13.8	7.24
Center School Road	8/22/06	18.1	-1	2.25		96	7.82	36.9	0.27	11	6.9
Center School Road	9/26/06	13	-38	1.01	7.47	113	9.26	46.5	0.23	12.2	9.6
Center School Road	10/24/06	5.8	104	13.19	7.08	58	8.6	22.4	0.3	15.3	3.62
Coche Brook	5/24/06	8.9	32	0.72	8.31	176	11.31	86	0.49	17.4	7.42
Coche Brook	6/20/06	17.6	25	0.24	8.34	255	9.16	119	0.64	11.4	10.4
Coche Brook	7/25/06	17.8	22.4	0.14	8.32	278	9.31	132		12.7	11.3
Coche Brook	8/22/06	16.9	23	0.13		276	9.15	128	0.52	11	11.3
Coche Brook	9/26/06	10.8	18.5	0.05	8.06	284	9.86	141	0.53	8.74	12.7
Coche Brook	10/24/06	5.6	30	0.66	8.16	214	11.3	91.8	0.49	35.1	8.36
Cold Brook	5/23/06	6.3	36	1.22	7.78	41		24.4	0.27	9.25	2
Cold Brook	6/20/06	18	19	0.37	8.04	81	8.76	40.9	0.24	8.02	2
Cold Brook	7/25/06	16.9	19.9	0.19	7.91	104	9.43	51.6		7.21	2
Cold Brook	8/22/06	15.1	19.5	0.43		84	11.05	42.4	0.27	5.79	2
Cold Brook	9/26/06	10.9	14	0.16	7.86	95	10.6	53.1	0.1	6.99	2
Cold Brook	10/24/06	5.1	35	0.99	7.6	49	12.2	23.1	0.34	11.1	2
Derby Center	5/23/06	11.1	79	25.94	7.74	91	9.91	39	0.37	16.4	5.33
Derby Center	6/20/06	21.7	39	8.13	7.93	96		38.7	0.37	16.2	4.73
Derby Center	7/25/06	23.5	34.4	3.90	8.23	115	8.77	47.3		12.7	6.08
Derby Center	8/22/06	21.6	11	2.74		117	8.27	48.1	0.43	10.6	6.19
Derby Center	9/26/06	14.8	18.7	2.02	7.6	121	9.21	52.3	0.41	13.4	6.98
Derby Center	10/24/06	8.4	85	25.38	7.63	124	9.5	46.8	0.36	21.2	6.43

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µS)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	Chloride (mg/l)
East Charleston	5/23/06	8.3	85	-99	7.05	41		16.3	0.28	15.1	2.95
East Charleston	6/20/06	22.4	14	3.67	7.13	81	6.88	29.9	0.31	20.1	5.9
East Charleston	7/25/06	20	-27	1.64	7.37	98	7.17	36.1		15.5	7.61
East Charleston	8/22/06	17.7	4	3.29		95	7.19	36.6	0.25	13.5	7.37
East Charleston	9/26/06	12.6	32	2.15	7.24	114	8.96	46.4	0.17	15.7	9.34
East Charleston	10/24/06	5	70	-99	6.96	49	9.6	16.3	0.33	16.5	3.2
Five Mile	5/23/06	7.2	78	8.01	7.12	35		12.7	0.26	12.3	3.78
Five Mile	6/20/06	18.8	41	2.62	7.38	78	9	26.4	0.36	15.3	7.64
Five Mile	7/25/06	17.2	18.2	1.15	7.38	93	8.31	31.1		15.9	9.18
Five Mile	8/22/06	16.3	21	1.26		87	8.86	30	0.28	13.7	7.98
Five Mile	9/26/06	12.3	9	0.54	7.67	111	11.32	43.6	0.16	14	11.7
Five Mile	10/24/06	6	61	6.59	7.07	42	10.4	13.8	0.28	15.1	3.58
Greens Brook	5/24/06	8.3	35	1.07	8.23	181	11.33	88.8	0.62	16.3	4.7
Greens Brook	6/21/06	13.2	22	0.36	8.22	242	10.34	117	0.66	11	5.62
Greens Brook	7/25/06	16.5	12.8	0.13	8.18	291	9.54	144		12.1	9.29
Greens Brook	8/22/06	15.5	17	0.13		270	9.57	135	0.55	9.56	6.94
Greens Brook	9/26/06	10.8	7	0.05	7.95	277	10.29	148	0.34	8.11	9.15
Greens Brook	10/24/06	5.8	31.5	0.60	8.09	222	10.3	100	0.5	10.8	4.7
Lang Brook	5/23/06	6.2	39	0.33	7.1	14		5.9	0.24	7.98	2
Lang Brook	6/20/06	13.9	25	0.07	7.1	27	10.04	9.6	0.19	6.15	2
Lang Brook	7/25/06	14.9	19	0.01	6.46	43	9.26	13		8.72	2
Lang Brook	8/22/06	14	27	0.07		34	9.48	14.6	0.31	7.41	2
Lang Brook	9/26/06	10.4	24	0.02	7.24	37	10.36	20.6	0.15	8.71	2
Lang Brook	10/24/06	6.3	35	0.36	7.25	23	11.7	7.2	0.29	10.9	2
Mad Brook	5/23/06	6.5	34	-99	7.65	63		33.1	0.1	12	2
Mad Brook	6/20/06	18.7	37	0.34	7.66	109	9.45	53	0.31	6.18	2
Mad Brook	7/25/06	16.4	8	-99	7.49	131	8.98	44.2		8.24	2.26
Mad Brook	8/22/06	15.1	40	0.30		124	9.56	58.9	0.28	5.41	2.02
Mad Brook	9/26/06	12	18	0.20	7.29	133	9.21	65.8	0.1	7.5	3.16
Mad Brook	10/24/06	5.2	98	1.12	7.55	78	11.4	36.4	0.33	11	2
Newport Ballfield	5/25/06	11.3	151	29.22	8.01	103	10.18	41	0.43	19.7	7.12
Newport Ballfield	6/20/06	22.3	69	12.90	7.84	100	7.88	41.2	0.38	15	6.02
Newport Ballfield	7/25/06	23.2	43.6	4.68	7.91	146	7.63	53.3		15.9	9.88
Newport Ballfield	8/22/06	21.8	53	3.97		144	8.28	54.7	0.57	19.8	9.9
Newport Ballfield	9/26/06	15.1	19.4	0.00	7.55	172	8.86	61.8	1.17	23.9	15.3
Newport Ballfield	10/24/06	8.6	75	20.31	7.84	141	10.3	51.3	0.4	18.5	8.24

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µS)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	Chloride (mg/l)
Orcutt Brook	5/24/06	8.5	29	0.50	8.34	175	11.42	87.8	0.51	13.8	2.8
Orcutt Brook	6/21/06	14	20	0.31	8.38	214	10.11	108	0.51	14.1	3.08
Orcutt Brook	7/25/06	17.5	17.9	0.20	8.32	242	9.44	124		10.8	3.32
Orcutt Brook	8/22/06	15.6	25.5	0.40		237	9.32	119	0.51	9.03	3.05
Orcutt Brook	9/26/06	10.8	16.9	0.11	8.05	253	10.7	142	0.45	8.06	3.97
Orcutt Brook	10/24/06	5.5	34	0.44	8.18	211	11.2	95.5	0.47	12.8	2.68
Oswegatchie Brook	5/23/06	6.1	83	0.72	7.36	55		20.3	0.26	13.5	5.32
Oswegatchie Brook	6/20/06	16.2	26	0.67	7.39	86	9.28	29	0.26	9.93	8.5
Oswegatchie Brook	7/25/06	13.6	13.3	0.42	7.36	111	9.48	35.2		11	13.2
Oswegatchie Brook	8/22/06	14.3	17	0.52		99	9.47	33.3	0.29	8.47	10.6
Oswegatchie Brook	9/26/06	11.9	13.2	0.26	7.18	107	9.84	36.6	0.21	10.5	13.4
Oswegatchie Brook	10/24/06	5.3	67	0.45	7.24	65	11.1	22	0.23	9.77	
Pherrins River	5/23/06	6.1	62	3.70	7.1	25		10	0.24	9.02	2.5
Pherrins River	6/20/06	15.6	31	1.02	7.45	76	9.32	27	0.24	7.25	6.61
Pherrins River	7/25/06	15.3	23.7	0.46	7.22	106	9.19	35.6		10.9	8.29
Pherrins River	8/22/06	13.5	25.6	0.59		79	9.71	30.7	0.24	7.18	5.92
Pherrins River	9/26/06	11.9	17.5	0.41	7.47	97	10.54	39.3	0.17	9.75	8.86
Pherrins River	10/24/06	4.9	54	3.72	7.07	24	11.2	10	0.28	12.3	2
Seymour Lake Inlet	5/24/06	7.2	32	0.73	7.67	69	11.07	32.9	0.3	14.2	2
Seymour Lake Inlet	6/21/06	13	10	0.44	7.76	120	9.8	73.5	0.3	10.4	2
Seymour Lake Inlet	7/25/06	18.6	-1.5	0.30	7.82	115	8.81	53.1		10.8	2
Seymour Lake Inlet	8/22/06	16.1	-3	0.26		102	8.91	50.3	0.31	8.06	2.05
Seymour Lake Inlet	9/26/06	11.9	-7	0.00	7.6	128	10.25	66.2	0.21	8.82	3.26
Seymour Lake Inlet	10/24/06	5.5	17.5	1.07	7.54	77	11	32.5	0.31	12.6	2
Stumpf Brook	5/24/06	8	42	0.37	7.83	65	11.68	35.2	0.24	9.78	2
Stumpf Brook	6/20/06	19.5	29	0.21	7.8	108	8.32	56.5	0.28	7.09	2
Stumpf Brook	7/25/06	17.8	24.5	0.08	7.75	127	9.09	67.5		8.7	2
Stumpf Brook	8/22/06	16.4	6.3	0.04		120	9.26	63.6	0.3	8.31	2
Stumpf Brook	9/26/06	11.4	14	0.02	7.58	132	10.01	79.6	0.17	7.26	2
Stumpf Brook	10/24/06	5.1	38	0.43	7.67	72	11.5	34.6	0.3	12.2	2

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µS)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	TP (µg/l)	Chloride (mg/l)
Town Garage	5/24/06	7.4	18	0.13	7.68	100		31.2	0.38	19.9	10.7
Town Garage	6/20/06	16.8	5	0.00	7.76	430	8.7	78	0.34	6.44	**88.7**
Town Garage	7/25/06	16.9	5.7	0.00	7.52	1109	7.89	133		8.06	**286**
Town Garage	8/22/06	15	-1	0.00		748	8.98	118	0.36	7.96	**182**
Town Garage	9/26/06	11.4	-2	0.00	7.29	1535	7.89	172	0.17	**26.9**	**434**
Town Garage	10/24/06	5.6	15.5	0.08	7.58	108	10.8	32.3	0.45	**27**	9.34
Webster Brook	5/23/06	6.2	36	0.95	7.3	33		12.3	0.35	10.9	2.74
Webster Brook	6/20/06	16.8	24	0.46	7.49	73	9	29	0.47	11.1	3.92
Webster Brook	7/25/06	16.6	21.8	0.21	7.12	101	8.79	38.5		13.6	4.26
Webster Brook	8/22/06	13.8	13.2	0.14		88	9.42	40.2	0.43	11.2	4.57
Webster Brook	9/26/06	12.2	23	0.16	7.54	89	9.73	42	0.35	11.8	4.19
Webster Brook	10/24/06	4.9	39	1.49	7.2	43	10.8	13.4	0.37	13.1	3.11
West Charleston	5/24/06	10	72	28.67	7.76	57	11.49	25.9	0.31	15.9	3.53
West Charleston	6/20/06	21.8	35	6.59	7.81	77	8.28	31.9	0.26	12.8	4.63
West Charleston	7/25/06	**22.6**	17.7	2.83	7.83	103	7.94	37.6		11.5	6.72
West Charleston	8/22/06	20.2	18	3.00		95	8.37	37.4	0.32	11.7	5.95
West Charleston	9/26/06	15	2.6	4.01	7.79	112	9.15	44.6	0.26	13.5	8.64
West Charleston	10/24/06	5.8	58	10.30	7.53	70	11.6	26.9	0.34	21.5	4.37

John's River:

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	NO_x (mg/l)	TP (µg/l)	TSS (mg/l)
Crystal Brook	5/24/06	8.7	26	0.32	8.36	284	11.33	124	1.56	1.17	**75.3**	9.38
Crystal Brook	6/21/06	11.9	15	0.27	8.25	323	10.46	140	1.31	0.96	**52.8**	2.3
Crystal Brook	7/26/06	14.3	10	0.08	8.11	364	9.5	162			**180**	9.43
Crystal Brook	8/23/06	12.5	11	0.06		390	9.36	166	2.52	0.8	**366**	5.05
Crystal Brook	9/27/06	9.1	8.3	0.02	7.78	408	8.55	186	3.19	0.2	**655**	3.73
Crystal Brook	10/25/06	5.9	19.5	0.35	8.3	346	11.1	145	1.51	1.23	**29.1**	1.04
Darling Hill	5/24/06	10.7	16	0.08	8.19	291	10.61	94.2	1.37	1.08	**37.1**	**14**
Darling Hill	6/21/06	15.8	10	0.04	8.19	325	9.22	131	2.29	2.01	20.1	1.41
Darling Hill	7/26/06	16.6	7.3	0.03	8.01	356	9.5	134			22.5	1.7
Darling Hill	8/23/06	13.7	9	0.03		387	9.91	138	4.54	4.06	16.8	1.22
Darling Hill	9/27/06	10	5.1	0.01	7.96	374	11.61	143	**5.58**	**5.6**	12.4	1
Darling Hill	10/25/06	5.7	13	0.06	8	147	10.2	111	1.87	1.63	21.6	1.33

Site	Month	T (°C)	Depth (cm)	Flow (m^3/s)	pH	EC (µs)	DO (mg/l)	Alkalinity (mg $CaCO_3$/l)	TN (mg/l)	NO_x (mg/l)	TP (µg/l)	TSS (mg/l)
Johns Main Stem	5/24/06	9.7	26	0.35	8.38	197	11.53	99.7	0.62	0.54	**14.4**	**5.3**
Johns Main Stem	6/21/06	11.2	11	0.16	8.27	227	10.78	118	0.5	0.4	9.33	2.57
Johns Main Stem	7/26/06	14.5	6.5	0.06	8.09	258	9.75	134			9.94	1.78
Johns Main Stem	8/23/06	12.5	1	0.02		273	9.95	140	0.49	0.4	7.12	1
Johns Main Stem	9/27/06	9.1	0.5	0.02	7.85	266	9.9	145	0.37	0.32	9.49	1
Johns Main Stem	10/25/06	6.2	8.5	0.10	8.27	267	11.1	126	0.85	0.78	9.87	1
Johns River	5/24/06	10	51	0.72	8.43	279	10.77	115	1.67	1.39	**38.7**	**10.1**
Johns River	6/21/06	14.4	30	0.19	8.38	365	9.66	146	**2.88**	**2.41**	**38.3**	3.2
Johns River	7/26/06	16.8	22	0.15	8.29	424	9.65	161			**50.9**	3.05
Johns River	8/23/06	14	17.7	0.08		430	10.13	161	**4.48**	**4.13**	**49.3**	1.5
Johns River	9/27/06	10.4	16.5	0.06	8.13	445	11.39	171	**6.17**	**5.72**	**20.9**	1.27
Johns River	10/25/06	6	35	0.34	8.3	175	11.2	136	**2.06**	1.86	**26.3**	2.64
North Derby Road	5/24/06	10.2	62	1.20	8.44	278	11.34	113	1.55	1.28	**38.9**	**7.13**
North Derby Road	6/21/06	15.3	38	0.69	8.26	365	9.77	144	**2.59**	**2.21**	**34.9**	3.8
North Derby Road	7/26/06	17.4	28.5	0.40	8.06	430	9.75	161			**62**	**7.8**
North Derby Road	8/23/06	14.9	27.5	0.49		427	9.25	163	**3.88**	**3.61**	**60.4**	3.25
North Derby Road	9/27/06	11	13.5	0.18	7.98	442	11.05	167	**5.31**	**4.93**	**44.9**	2.79
North Derby Road	10/25/06	6	49	0.89	8.08	177	10.5	133	1.98	1.78	**37.1**	**6.17**
Quarry	5/24/06	9.9	28	0.10	8.09	309	10.62	121	0.87	0.62	**19.8**	3.06
Quarry	6/21/06	14.7	22	0.06	8.1	419	9.12	168	1.23	1	13.1	1.5
Quarry	7/26/06	16.2	19	0.06	8.05	465	9.05	184			**18.9**	1.8
Quarry	8/23/06	13.9	18.4	0.04		441	9.17	176	1.21	0.93	13.8	1.71
Quarry	9/27/06	8.7	16.6	0.04	7.99	451	9.98	194	1.25	1.12	13.1	1
Quarry	10/25/06	5.8	21	0.06	7.91	310	10.5	114	0.73	0.45	**17.9**	1.68

Bold font highlights values greater than Vermont water quality standards (State of Vermont 2006) or arbitrary values if no standards apply:

pH < 6.5 or > 8.5
Total phosphorus > 14µg/l (yellow, standard for Lake Memphremagog) or >25 µg/l (red, standard for South Bay)
Total nitrogen >2 mg/l (yellow) or >5 mg/l (red)
NO_x >2 mg/l (yellow, standard for Class A waters) or >5 mg/l (red, standard for Class B waters)
Chloride >50 mg/l (arbitrary value - no standard set)
Total suspended solids > 5 mg/l (yellow) or > 10 mg/l (red)

Appendix C. Description of missing data, including month, site, and reason data are missing.

Variable	Month(s)	Site(s)	Reason
LaRosa Data			
Total nitrogen	May	CRA	Missing sample
	July	All Barton, Clyde, and John's River sites	Samples were underacidified
NO_x	July	All John's River sites	Samples were underacidified
Field Data			
pH	August	All sites	pH meter broke during survey
Dissolved oxygen	May	10 Clyde River sites, WFA, ORL, COV	Torn probe membrane
Flow	May	ECH	Site flooded
	May	MB1, BRR	No distance recorded
	July	MB1	No distance recorded
	October	ECH	Site flooded

Appendix D. Glossary

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

Algal bloom – Occurs when algae grow in extremely high densities. Blooms often occur when there are excessive nutrients (particularly phosphorus and nitrogen) in the water column. When these algae die, decomposition consumes a lot of oxygen and can result in levels too low to support many forms of aquatic life.

Basin – See Watershed.

Calcareous – Rock or soil that contains large amounts of calcium carbonate ($CaCO_3$), the main chemical responsible for buffering acid inputs.

Carbonate materials – Generally refers to rock or soils that contain calcium carbonate.

Class A(1) waters – Designation given by the State of Vermont to all waters located above 2,500 feet elevation not being managed as a public water supply.

Class A(2) waters – Designation given by the State of Vermont to all waters being managed as a public water supply.

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

Conductivity – Measured in microsiemens (μS), conductivity measures the amount of dissolved ions in the water column and is based on the ability of water to conduct an electrical charge.

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

Eutrophication – The aging of a lake, marked by increased nutrient inputs, increased sedimentation, and increased productivity (i.e. algal growth). Eutrophication occurs naturally, but human activities often accelerate the process.

Flow – The volume of water passing a given point per unit of time.

Ions – Charged particles, either positive (cations) or negative (anions).

Invasive species – Plants and animals that have been introduced by humans into an area where they did not occur previously and that have established populations that significantly impact the natural communities in which they occur.

Limiting nutrient – A nutrient that is in short supply and that limits growth of plants or animals in an ecosystem.

Mean (average) – A number describing the central tendency of a group of numbers and derived by adding all of the numbers in that group and dividing by the number of data points.

Microgram (µg) – A unit of weight measurement equaling one millionth of a gram. Nutrient and sediment concentrations are often expressed as either mg/l or µg/l.

Nonpoint Source Pollution – Pollution that does not originate from a single location or source (for example, a drainage pipe) but rather from many sources spread out across the landscape (for example, runoff from agricultural fields).

Nutrient – A chemical compound that sustains growth of an organism. While nutrients are essential to sustaining natural communities, too much of any one nutrient can upset the balance of an ecosystem.

Organic – A chemical compound that contains carbon and that generally originates in living organisms.

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

Respiration – The process of converting sugar and oxygen into carbon dioxide, water, and energy.

Riparian buffer – A strip of vegetation growing along a waterbody which serves to reduce erosion, filter sediment and pollutants, and enhance aquatic biodiversity.

Solubility – The extent to which a material can dissolve in water.

Standard error of the mean (SEM) – A statistic that uses the variability of a group of data points to describe the precision of the estimate of the mean for that group.

Suspended solids – Particles that are carried in the water column, including eroded materials and decomposed organic matter. Large amounts of suspended solids can be detrimental to water quality and clarity.

Tributary – A body of water, such as a 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 while still meeting water quality standards.

Watershed (or basin) – A region drained by all of the rivers and streams flowing into a lake, river, or ocean. The relative size of a watershed and the human alterations to that watershed greatly affect the quality of the water in the waterbody into which it drains.

NorthWoods Stewardship Center

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