Restoring Water Quality in the Lake Memphremagog Basin: Nutrient and Sediment Sources along the Johns River and Seven Smaller Tributaries

Final Report for the 2008 LaRosa Analytical Partnership

Fritz Gerhardt, Ph.D.

15 February 2009

Memphremagog Watershed Association

Memphremagog Watershed Association

Mission

Covering Lake Memphremagog, Clyde, Barton, Black, and Johns Rivers

The Memphremagog Watershed Association, founded in 2007, is a non-profit organization dedicated to the preservation of the environment and natural beauty of the Lake Memphremagog watershed to ensure its protection for generations to come.

The Memphremagog Watershed Association accomplishes this mission through public education, water quality monitoring, and clean-up and re-naturalization of shoreline and river banks to protect area plants and wildlife.

Objectives:

- To promote the ecological awareness of people who live in, work in, and visit the Memphremagog watershed and enjoy all that it offers.
- To inform and educate the public and promote participation in the preservation of the environment and natural beauty of the watershed.
- To work with other area lake associations; local, state and federal governments; and businesses to develop guidelines and policies that protect and improve the quality of life in and around the watershed.
- To participate in the monitoring of the water quality of the lake and its tributaries, clean-up and re-naturalize the shoreline and river banks and protect area plants and wildlife.

Cover. *Southern basin of Lake Memphremagog looking north from the Newport, Vermont waterfront on 8 October 2008.*

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Fritz Gerhardt, Ph.D.

Memphremagog Watershed Association
P. O. Box 1071
Derby, VT 05829
memphremagogwatershed@gmail.com

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Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially in light of the high phosphorus and sediment levels observed there and the more frequent and widespread occurrences of cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, previous projects have focused on identifying the sources of these nutrients and sediments along the four principal Vermont tributaries. These studies have identified the Johns River as having extremely high phosphorus and nitrogen levels, which were evident in the abundant algal and plant growth at the river's mouth. In addition, no sampling has occurred along the many smaller tributaries that flow directly into Lake Memphremagog.
2. In 2008, volunteers from the Memphremagog Watershed Association sampled water quality at 20 sites distributed throughout the watersheds of the Johns River and seven smaller tributaries of Lake Memphremagog. The goal of these efforts was to further assess and pinpoint the sources of phosphorus, nitrogen, and sediment flowing into the Southern Basin of Lake Memphremagog. To accomplish this goal, we collected and analyzed water samples for total phosphorus, total nitrogen, and turbidity. In addition, we measured water depths at each site and stream flows at one site on the Johns River.
3. Through this sampling, we identified a number of areas where phosphorus, nitrogen, and turbidity levels were potentially problematic. Phosphorus levels were high along five of the smaller tributaries as well as the downstream section of the Johns River. In contrast, phosphorus levels in the upper watershed of the Johns River were dramatically lower than those measured in 2006, no doubt due to the replacement of a failing manure lagoon previously located alongside Crystal Brook. As in previous years, nitrogen levels were extremely high at numerous sites throughout the Johns River and adjacent watersheds, and turbidity levels were high along two smaller tributaries.
4. Collectively, these data greatly increase our knowledge about water quality problems and their sources along the Vermont tributaries of Lake Memphremagog. However, additional studies are needed to 1) identify the source(s) of the elevated phosphorus levels in downstream sections of the Johns River and the smaller tributaries, 2) verify that past remediation efforts continue to reduce phosphorus levels in Crystal Brook and the Johns River, 3) identify specific locations within the Johns River and adjacent watersheds where nitrogen is entering surface waters, and 4) evaluate whether nitrogen levels in these streams exceed Vermont water quality standards. In the meantime, initial remediation efforts can be undertaken in several areas where specific problems were identified in this study.

Introduction

Lake Memphremagog straddles the United States / Canadian border between the Northeast Kingdom of Vermont and the Eastern Townships of Quebec. Lake Memphremagog and its tributaries are a highly-valued resource that provides important ecological, economic, and aesthetic benefits to the residents of Vermont and Quebec. Over the past decade, there has been increasing interest in protecting and improving water quality in Lake Memphremagog and its tributaries. This interest has been spurred by concerns that water quality in Lake Memphremagog has been declining and may now be impaired by excessive nutrient and sediment levels, more frequent and widespread algal blooms, and eutrophication (see Figure 1). This concern has been further exacerbated by the increasing incidence of cyanobacterial (blue-green algae) blooms, especially during the past several years (see Figure 2).

Figure 1. *Murky water and algae near the mouth of the Johns River in 2006. Excessive nutrient and sediment inputs are responsible for increasing plant and algal growth and decreasing water quality.*

Figure 2. *Cyanobacterial bloom along the north shore of Derby Bay near North Derby, Vermont on 23 September 2008 (photo courtesy of Karen Lippens).*

Lake Memphremagog and its tributaries are highly-valued resources supporting a wide variety of recreational opportunities, economic benefits, and ecological functions. Water bodies in the basin are used extensively for boating, swimming, fishing, hunting, nature-viewing, and other outdoor activities. 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. Lake Memphremagog and other water bodies in the basin also serve as public water supplies, provide hydroelectric power and disposal of treated wastewater, and support agricultural and industrial production. The floodplains and the many wetlands along the lake and in surrounding watersheds also serve important flood control and water filtration functions. Finally, the surface waters and associated habitats support a number of rare species and significant natural communities, which contribute greatly to regional biodiversity.

Lake Memphremagog currently faces a number of imminent threats, including high sediment and nutrient levels, high mercury concentrations, excessive algal growth, eutrophication, and exotic species invasions (State of Vermont 2008, 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 nutrient enrichment and excessive algal growth (Part A, State of Vermont 2008). All four of the main tributaries have been identified as priority surface waters outside the scope of Clean Water Act Section 303(d) and are listed as needing further assessment (Part C, State of Vermont 2008). The Johns 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 2008). Identified threats include elevated concentrations of sediments, nutrients, and *Escherichia coli* caused by agricultural runoff. In addition, Crystal Brook, one of the main tributaries of the Johns River, is listed as an impaired surface water needing a TMDL due to excessive sediments and nutrients from agricultural runoff (Part A, State of Vermont 2008).

Efforts to assess these threats and to protect and improve water quality in the Lake Memphremagog Basin are coordinated by the Quebec/Vermont Steering Committee on Lake Memphremagog, an international partnership of federal, provincial, state, municipal, and non-governmental stakeholders from Vermont and Quebec. Since 2004, the Steering Committee has coordinated water quality monitoring efforts on both sides of the border. The overall goal of these efforts has been to identify and support projects that protect and improve water quality in the Lake Memphremagog Basin. Specifically, monitoring efforts have been established to document water quality conditions in the Lake Memphremagog Basin, to assess compliance with applicable water quality standards, and to determine whether a comprehensive pollution control plan needs to be developed for the Vermont waters.

Past monitoring efforts have been funded and/or implemented by a variety of governmental agencies and non-governmental organizations (Quebec/Vermont Steering Committee 2008). The Quebec Ministère du Développement durable, de l'Environnement et des Parcs and Memphrémagog Conservation Inc. (MCI) have been monitoring water quality in the open waters of Lake Memphremagog in Quebec since 1996. The Vermont Department of Environmental Conservation (DEC) has been monitoring water quality in the open waters of the lake in Vermont since 2005. Since 1999, the MRC de Memphrémagog has been monitoring water quality conditions in the tributaries draining the Quebec portion of the Lake Memphremagog Basin. Since 2005, the NorthWoods Stewardship Center and the Memphremagog Watershed Association have partnered with the Vermont DEC to monitor water quality in the tributaries draining the Vermont portion of the basin. During 2004-2005, MCI also completed comprehensive assessments of littoral habitat quality in both Quebec and Vermont.

Although 73 percent of the lake is located in Quebec, 71 percent of the watershed is located in Vermont. Because most of the lake's watershed lies in Vermont, previous monitoring efforts have focused on assessing water quality conditions and identifying possible sources of nutrients and sediments in the watersheds of the four principal Vermont tributaries. The monitoring in 2005 and 2006 identified a number of water quality issues in the watersheds of all four of these tributaries (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008). In particular, water quality was poorest in the Johns River watershed, which suffered from extremely high levels of phosphorus, nitrogen, and sediment. The Black River watershed, where agricultural development was most extensive, had the second poorest water quality, and high levels of phosphorus and sediment occurred at many sites, especially during high flows. The Barton River watershed, which also had extensive areas of agriculture, occasionally exhibited high levels of phosphorus and sediment at some sites. Finally, the Clyde River, especially the upper watershed, exhibited relatively low levels of nutrients and sediment.

Study Goals

This project continues efforts to assess and identify threats to water quality and to plan and implement protection and restoration projects in the Vermont portion of the Lake Memphremagog Basin. As noted previously, earlier studies had determined that water quality conditions were poorest in the Johns River watershed, which had extremely high phosphorus and nitrogen concentrations and which were evident in the abundant algal and plant growth at the river's mouth (see Figure 1). In addition, the Vermont portion of Lake Memphremagog is fed by a number of smaller tributaries that flow directly into the lake but that have not been sampled previously. Although small, these tributaries drain some of the most developed and densely populated areas in the Vermont portion of the Lake Memphremagog Basin. Thus, the overall goals of this project were to assess water quality conditions in the watersheds of the Johns River and seven smaller tributaries and to identify the source(s) of any problems, so that we can develop and implement protection and restoration projects to reduce nutrient and sediment inputs flowing into Lake Memphremagog. The specific goals of this project were the following:

1) To assess water quality conditions in seven smaller tributaries of Lake Memphremagog,
2) To identify additional source(s) of elevated phosphorus levels in the Johns River and its tributaries,
3) To determine whether the replacement of a failing manure lagoon along Crystal Brook effectively reduced phosphorus levels in the Johns River,
4) To determine the source(s) of the extremely high nitrogen levels observed in the Johns River watershed,
5) To evaluate whether nitrogen levels in the Johns River and adjacent tributaries exceed Vermont water quality standards.

The distribution of sample sites in the watersheds of the Johns River and the seven smaller tributaries allowed us to address these goals and to focus future restoration and protection efforts along the most degraded rivers and streams.

Study Area

The Lake Memphremagog Basin is located in the Northeast Kingdom of Vermont and the Eastern Townships of Quebec and is a tributary of the St. Francis River, which flows into the St. Lawrence River. As noted previously, the Southern Basin of Lake Memphremagog is fed by three major tributaries that lie entirely within Vermont (the Black, Barton, and Clyde Rivers) and one smaller tributary that straddles the Vermont / Quebec border (the Johns River). The Johns River drains an area of approximately 29 km^2 in the towns of Derby, Vermont and Stanstead, Quebec and flows into Lake Memphremagog at Derby Bay, just south of the U.S. / Canadian border. The Johns River is fed by three smaller tributaries, but there are no lakes or ponds in the watershed. In addition to the four main tributaries, numerous smaller tributaries flow directly into Lake Memphremagog.

In this project, we sampled water quality at 20 sites located throughout the watersheds of the Johns River and seven smaller tributaries of Lake Memphremagog (see Figure 3 for a map and Appendix A for descriptions of all sites). In the Johns River watershed, we sampled water quality at 13 sites. One site (Johns River) was sampled in both 2005 and 2006, and four sites were sampled in 2006 (North Derby Road, Darling Hill, Crystal Brook, and Quarry). To better understand the high nitrogen and phosphorus levels observed in this watershed previously, we added eight additional sites along the main stem (Confluence and Elm Street), the Darling Hill tributary (Middle Darling Hill, Upper Darling Hill, and Darling Tributary), Crystal Brook (Silage Seep), and another small tributary (Horse Farm). The sites along the seven smaller tributaries were all new sites that had not been sampled previously. Three sites were located on the western side of the lake (Holbrook Bay, Strawberry Acres, and Wishing Well), and four sites were located on the eastern side of the lake (East Side, Lindsay Beach, Sunset Acres, and Eagle Point).

Methods

We collected water quality samples at biweekly intervals during June-October 2008. Samples were collected in pre-labeled, sterilized bottles according to protocols established in conjunction with the Vermont DEC and the LaRosa Analytical Laboratory (State of Vermont 2000, 2006a). We collected grab samples either by hand (seven smaller tributaries) or with a dip sampler (Johns River)(see Figure 4). Before collecting the samples, we rinsed the total nitrogen and turbidity sample bottles and the dip sampler with sample water three times. Based on the Quality Assurance Project Plan (see following paragraph), we also collected three field blanks and three field duplicates on each sample date for quality assurance analyses. All 26 samples (20 sites plus three blanks and three duplicates) were collected in a single day, stored in coolers, and delivered to the LaRosa Laboratory by courier the next morning. This schedule ensured that the LaRosa Laboratory was able to process the samples in a timely manner. Water samples were analyzed for total phosphorus, total nitrogen, and turbidity.

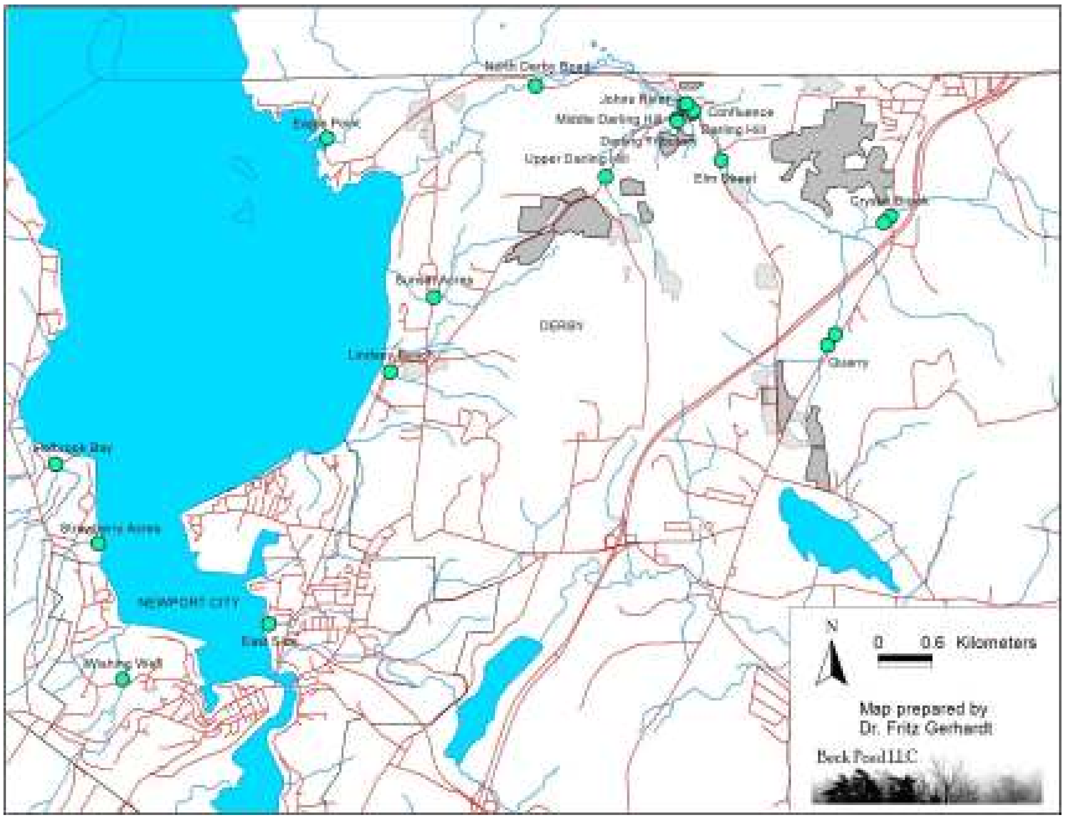

Figure 3. *Locations of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

On each sample date, we measured water depth at each site with a meter stick. We also measured stream flow near the Johns River site with a SonTek Acoustic Doppler Flowtracker. In order to develop a continuous record of stream flow, we also placed a depth gauge near the Johns River site. Using the flow and depth measurements, we were able to develop a rating curve that allowed us to estimate flow levels at each sample site for the entire sampling season. These flow measurements, when combined with the phosphorus and nitrogen concentrations, allowed us to calculate daily phosphorus and nitrogen loads for each sample site. Using the flow data from the Johns River site, we were able to calculate flow levels and phosphorus and nitrogen loads. While concentrations describe one measure of water quality, load calculations allow us to estimate the actual amount of nitrogen and phosphorus being carried downstream into Lake Memphremagog.

Figure 4. *Don and Sarah Chapdelaine collecting water samples with a dip sampler at the Darling Hill site near Beebe Plain, Vermont on 17 July 2008.*

Prior to sampling, we prepared a Quality Assurance Project Plan in conjunction with the Vermont DEC. As part of this plan, we collected three field blanks and three field duplicates on each sample date. Blank sample containers were rinsed and filled with de-ionized water only and, if done properly, should result in values below detection limits (total phosphorus <5 µg/l, total nitrogen <0.1 mg/l, and turbidity <0.2 NTU). Field duplicates involved collecting a second sample at the same time and place as the original sample. When done properly, the values for the two samples should differ by ≤15% (turbidity), ≤20% (total nitrogen), and ≤30% (total phosphorus).

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

Results

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

Water Depth and Flow

Stream flow measures the volume of water passing a specific location per unit of time and is a function of water volume and velocity. Stream flow impacts both water quality and aquatic and riparian habitats. Fast-moving streams are more turbulent and better aerated than slow-moving streams. High flows also dilute dissolved and suspended pollutants but, at the same time, also typically carry more sediment and attached nutrients. Stream flow is very dynamic and changes frequently in response to precipitation events, drought, and seasons of the year.

Although water depth does not measure stream flow directly, it does provide an indirect measure of stream flows among sample dates. Water depths at the sample sites varied greatly during the 2008 sampling season (see Figure 5). Water depths were greatest on 4 June and 13 August and were relatively low on all of the other sample dates.

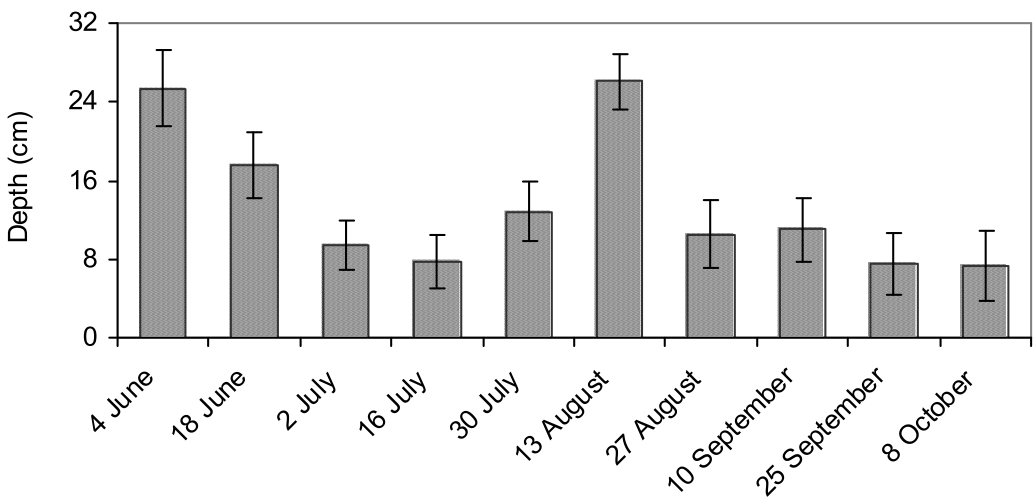

Figure 5. *Median water depths (±1 SEM) observed on each sample date at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

A more complete record of water depths was provided by the depth gauge installed near the Johns River site. This gauge recorded water depths every 20 minutes from 30 July until 19 November (see Figure 6). Water depths peaked in early August, decreased steadily through the autumn, and increased again slightly in late October and early November. Water depths spiked on numerous occasions, especially following the numerous heavy rains in early August but also occasionally throughout late autumn (although maximum depths were not as great as those recorded in early August).

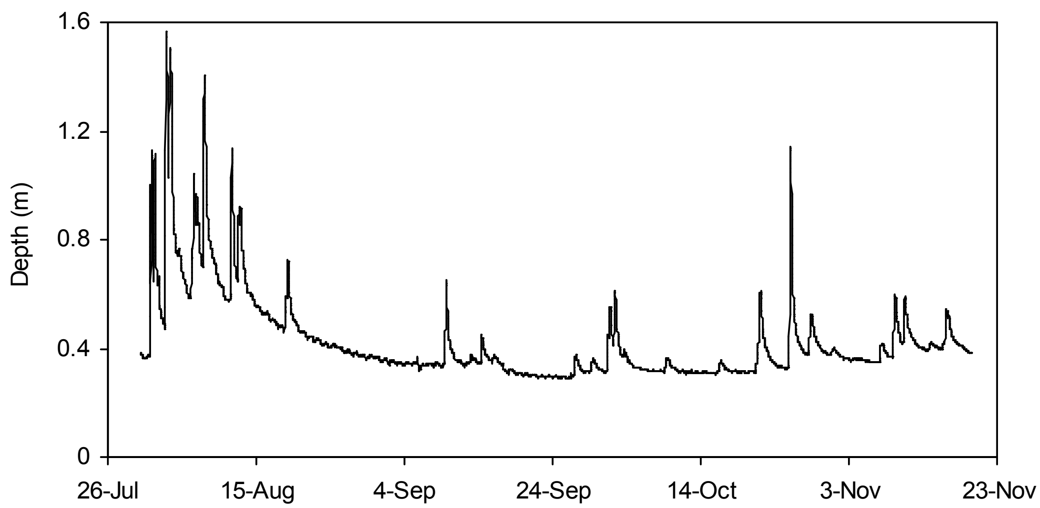

Figure 6. *Water depths recorded by the depth gauge installed near the Johns River site during July-November 2008.*

While water depth indicates relative water levels, flow measures the total volume of water passing through the channel at any given time. We were able to measure stream flows near the Johns River site on all but the first sample date. As with water depth, peak flows occurred on 13 August and were generally low on all other sample dates (see Figure 7). Unfortunately, we did not have the equipment to measure flow on the first sample date (4 June), the other sample date on which we measured the greatest water depths. However, we were able to use the rating curve to estimate stream flow on that date, which ultimately had more than twice the flow as 13 August.

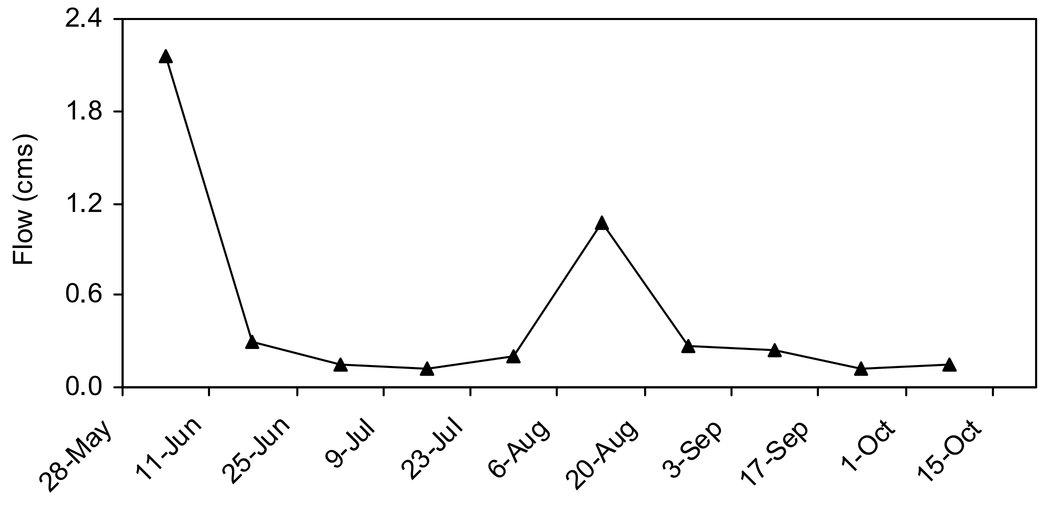

Figure 7. *Stream flows observed on each sample date near the Johns River site during June-October 2008. The value for 4 June was not measured in the field but was back-calculated from the rating curve.*

Total Phosphorus

Total phosphorus measures the concentration of all forms of phosphorus in the water column, including dissolved phosphorus, phosphorus attached to suspended sediments, and phosphorus incorporated into organic matter. Phosphorus is typically the limiting nutrient in aquatic ecosystems. Consequently, high phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to die-offs of aquatic life. In Vermont, most phosphorus originates from soils, wastewater, lawn and garden fertilizers, and agricultural runoff.

Total phosphorus concentrations in this study ranged between 8-575 µg/l. Total phosphorus concentrations were highest on the first sample date (4 June) and peaked again on 13 August and were lowest in late autumn (see Figure 8). Median total phosphorus concentrations exceeded 35 µg/l (what might be considered a baseline level) along five of the smaller tributaries but only the downstream-most site on the Johns River (see Figures 9-10). Median phosphorus concentrations exceeded 20 µg/l at seven other sites in the Johns River watershed as well as one other smaller tributary.

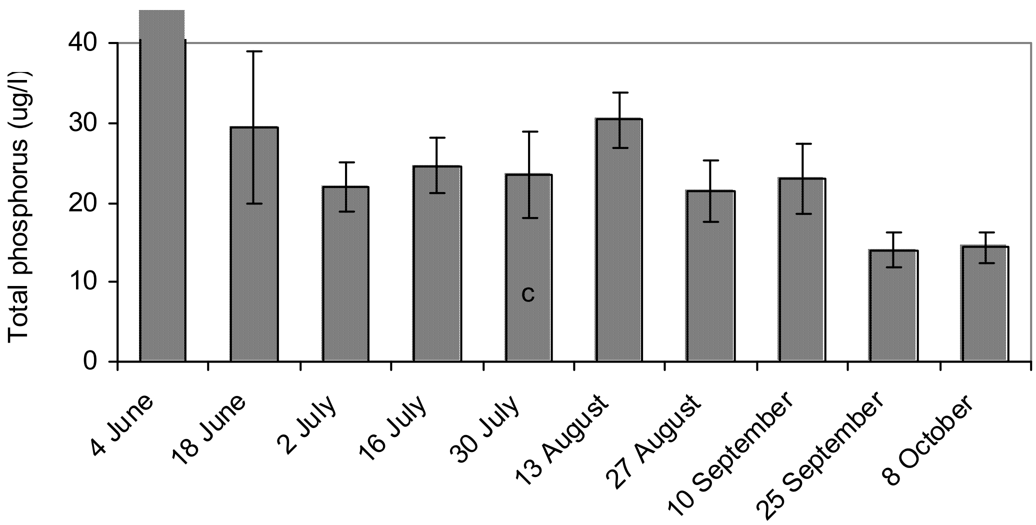

Figure 8. *Median total phosphorus concentrations (±1 SEM) observed on each sample date at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

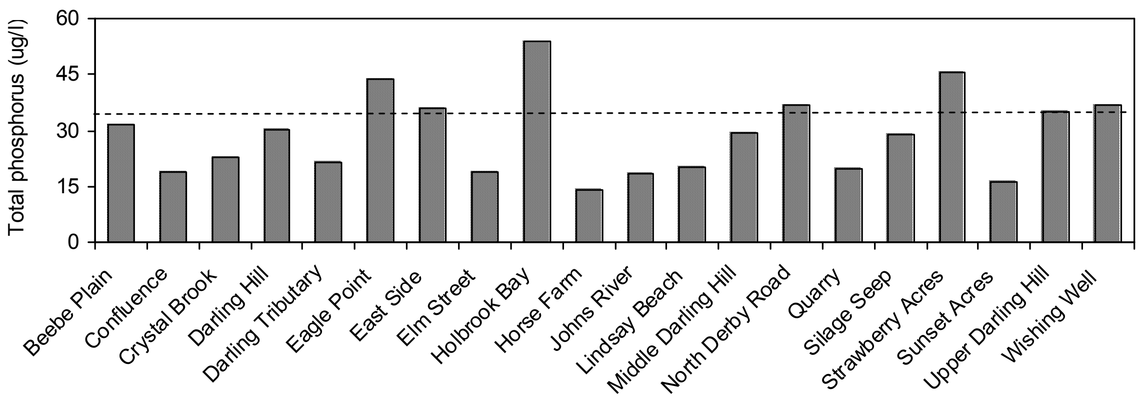

Figure 9. *Median total phosphorus concentrations observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008. The horizontal line indicates baseline phosphorus levels (35 μg/l).*

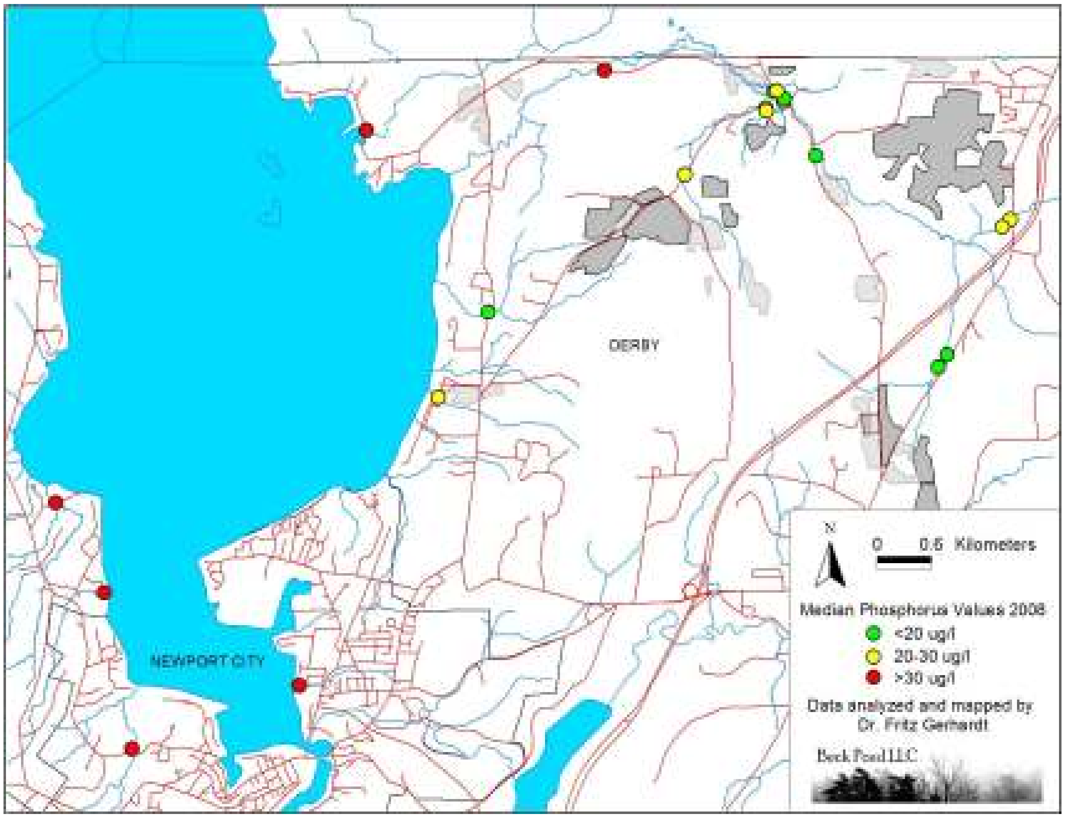

Figure 10. *Map of median total phosphorus concentrations observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Total phosphorus concentrations generally increased with increasing water depth and stream flow (see Figure 11). The one exception to this pattern was Eagle Point, where phosphorus concentrations decreased with increasing flows. One interesting change from previous years was that phosphorus concentrations in Crystal Brook increased with increasing flows in 2008, although they had decreased with increasing flows in 2006.

In following the phosphorus profile downstream from Crystal Brook, it is evident that phosphorus concentrations increased slightly immediately downstream of Crystal Brook, decreased again between there and Elm Street, and then increased rather dramatically between Johns River and North Derby Road (see Figure 12). This pattern was consistent across all sample dates, except the two dates with the highest flows (4 June and 13 August) when concentrations consistently increased all the way downstream.

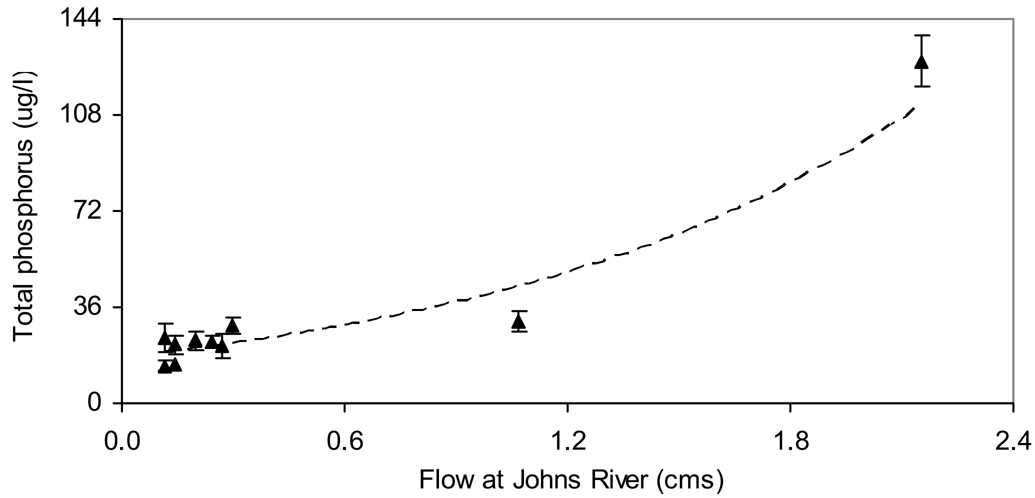

Figure 11. *Median total phosphorus concentrations (±1 SEM) in relation to stream flow at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

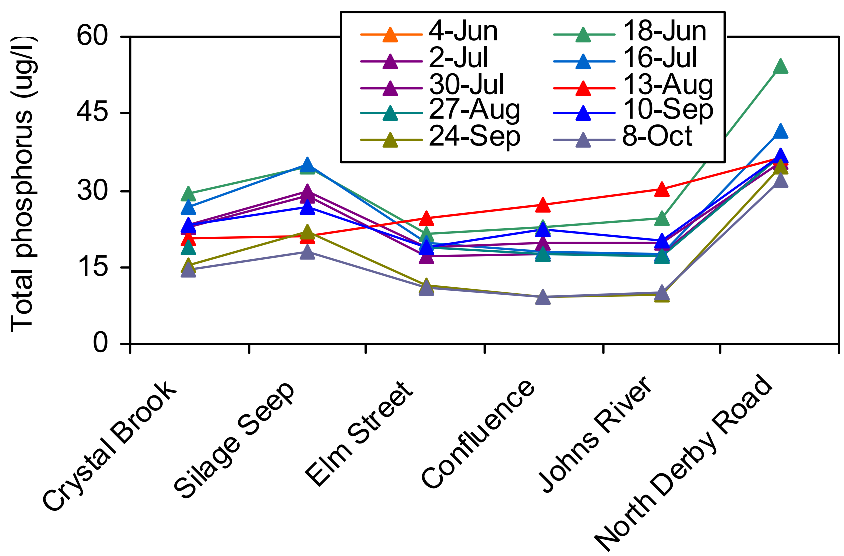

Figure 12. *Total phosphorus profile from Crystal Brook downstream to North Derby Road along the Johns River during June-October 2008.*

Using the stream flow measurements from the Johns River site, we were able to estimate daily phosphorus loads for each sample site. Based on these load calculations, it is evident that phosphorus loads largely paralleled the profile of phosphorus concentrations presented previously (see Figure 13).

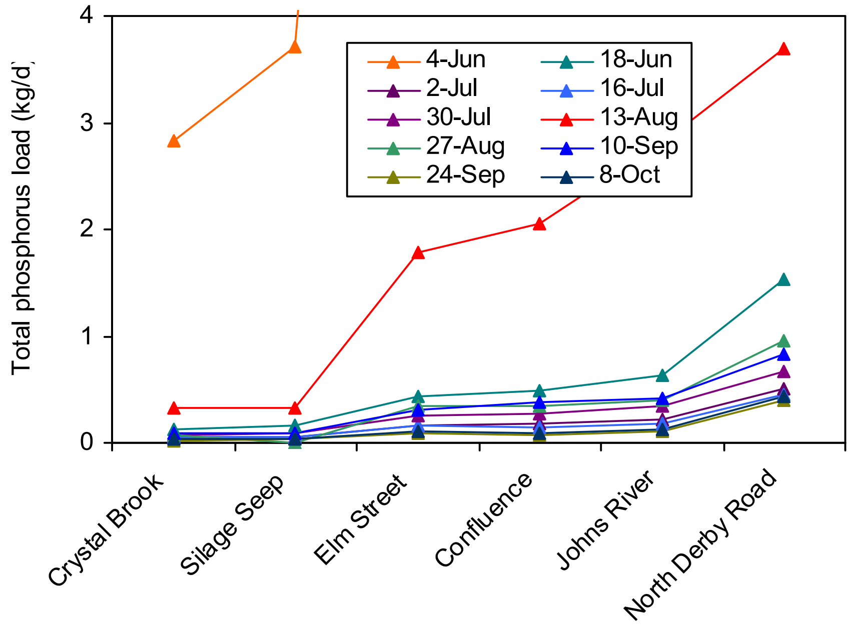

Figure 13. *Daily phosphorus load profile from Crystal Brook downstream to North Derby Road along the Johns River during June-October 2008.*

Although the seven smaller tributaries were not sampled in previous years, we did measure phosphorus concentrations along the Johns River during 2005 (one site) and 2006 (six sites, although only five were resampled in 2008). During 2005-2008, phosphorus concentrations changed dramatically, especially at the upstream sites (see Figure 14). In particular, median phosphorus concentrations declined to <20% of their 2006 concentrations at the Crystal Brook site and <50% of their 2006 concentrations at the Johns River site. Unfortunately, a similar decline in phosphorus concentrations was not observed at the downstream-most site (North Derby Road), where median phosphorus concentrations in 2008 were still 88% of those observed in 2006.

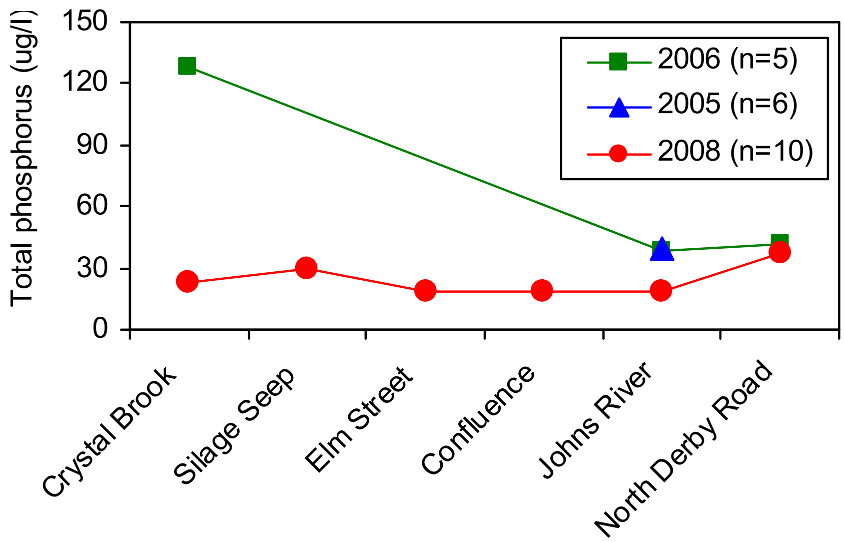

Figure 14. *Median total phosphorus concentrations from Crystal Brook downstream to North Derby Road along the Johns River during 2005-2008.*

Total Nitrogen

Total nitrogen measures the total amount of all forms of nitrogen in the water, including nitrate (NO_3), nitrite (NO_2), and ammonium (NH_4^+), as well as biologically unavailable nitrogen. Although typically not the limiting nutrient in aquatic systems, high concentrations of nitrogen can exacerbate algal blooms and eutrophication. In Vermont, most nitrogen inputs originate from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

Total nitrogen concentrations in this study ranged between 0.19-11.10 mg/l. Total nitrogen concentrations peaked in mid-July and again in late September (see Figure 15). Median concentrations consistently exceeded 5 mg/l at two sites (Upper Darling Hill and Sunset Acres) and 2 mg/l at seven other sites on the Johns River (see Figures 16-17).

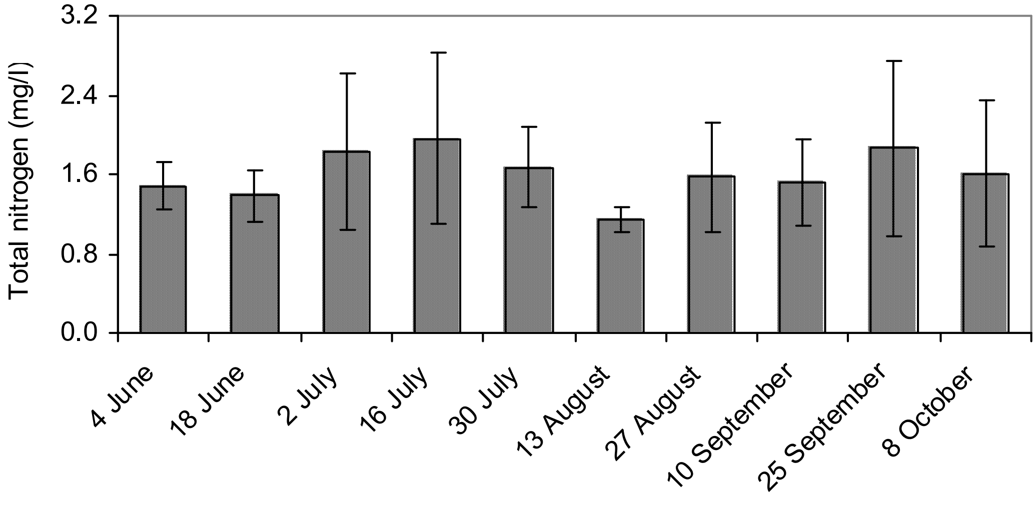

Figure 15. *Median total nitrogen concentrations (±1 SEM) observed on each sample date at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

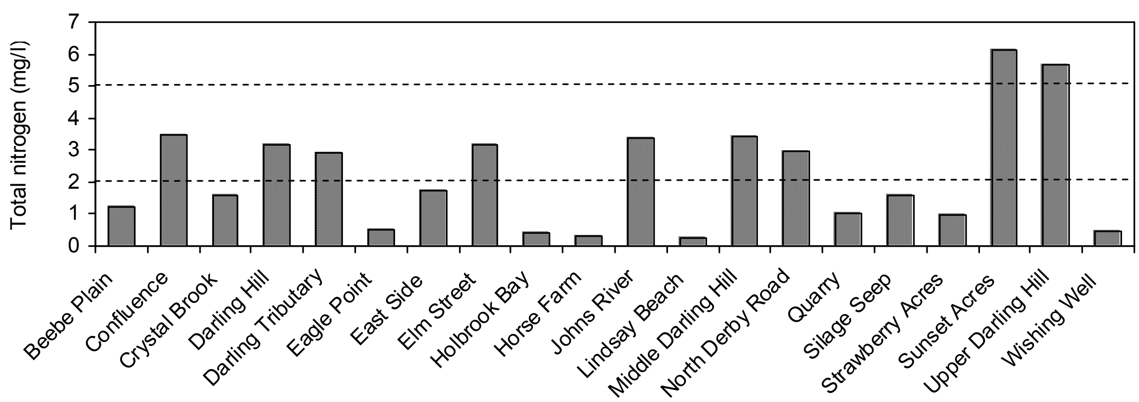

Figure 16. *Median total nitrogen concentrations observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008. The horizontal lines indicate higher nitrogen levels (2 and 5 mg/l).*

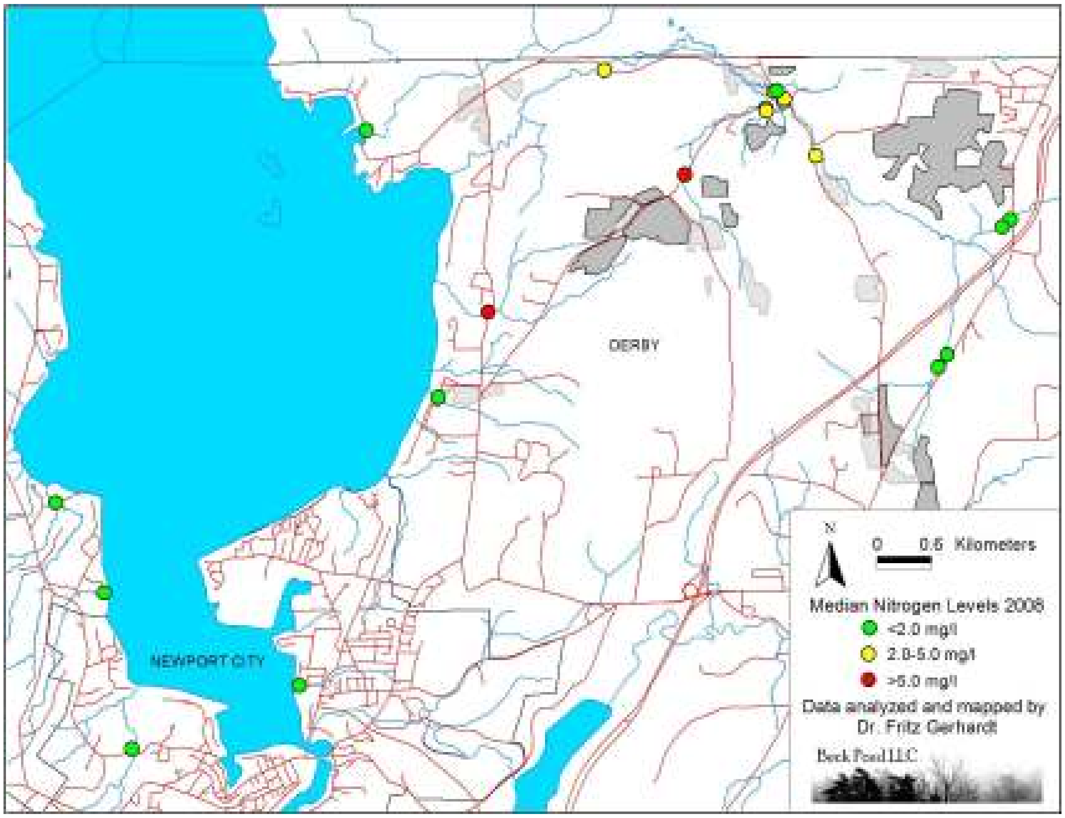

Figure 17. *Map of median total nitrogen concentrations observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

In contrast to phosphorus, total nitrogen concentrations generally decreased with increasing water depth and stream flow (see Figure 18). Interestingly, nitrogen concentrations were more variable at lower flows (as indicated by the longer SEM bars), probably due to the very high nitrogen concentrations observed at several sites during low flows.

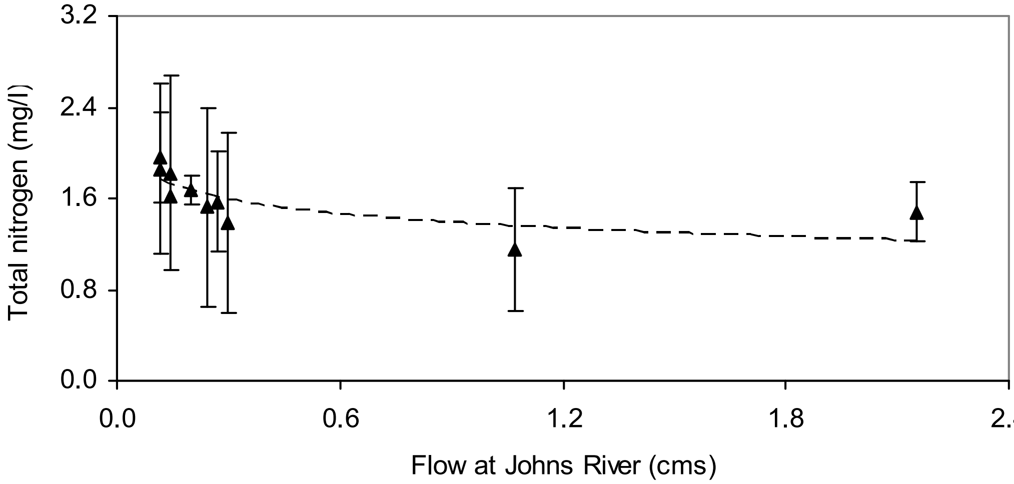

Figure 18. *Median total nitrogen concentrations (±1 SEM) in relation to stream flow at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Using the nitrogen concentration data, we developed nitrogen concentration profiles downstream from Crystal Brook and Upper Darling Hill to determine where the majority of the nitrogen was entering these surface waters. Based on these profiles, it is evident that nitrogen concentrations increased dramatically between Silage Seep and Elm Street and remained high from there downstream to the mouth of the Johns River (see Figure 19). In contrast, nitrogen concentrations decreased between Upper Darling Hill and Middle Darling Hill but remained fairly constant from there downstream to the mouth of the Johns River (see Figure 20).

Using the stream flow measurements from the Johns River site, we were able to estimate daily nitrogen loads for each sample site. Based on these calculations, we developed nitrogen load profiles downstream from Crystal Brook and Upper Darling Hill to identify the source areas for nitrogen inputs. Based on these profiles, it is evident that nitrogen loads increased dramatically between Silage Seep and Elm Street, continued to climb slightly downstream to Johns River, and then plateaued from there downstream to North Derby Road (see Figure 21). In contrast, nitrogen loads along the Darling Hill tributary were an order of magnitude lower than those along the main stem and increased only slightly between Upper Darling Hill and the confluence with the Johns River (see Figure 22).

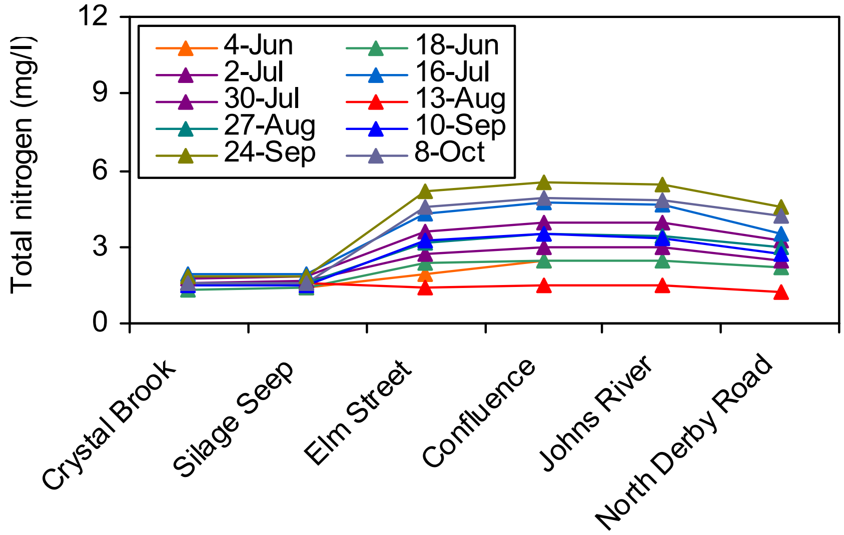

Figure 19. *Median total nitrogen profile from Crystal Brook downstream to North Derby Road along the Johns River during June-October 2008.*

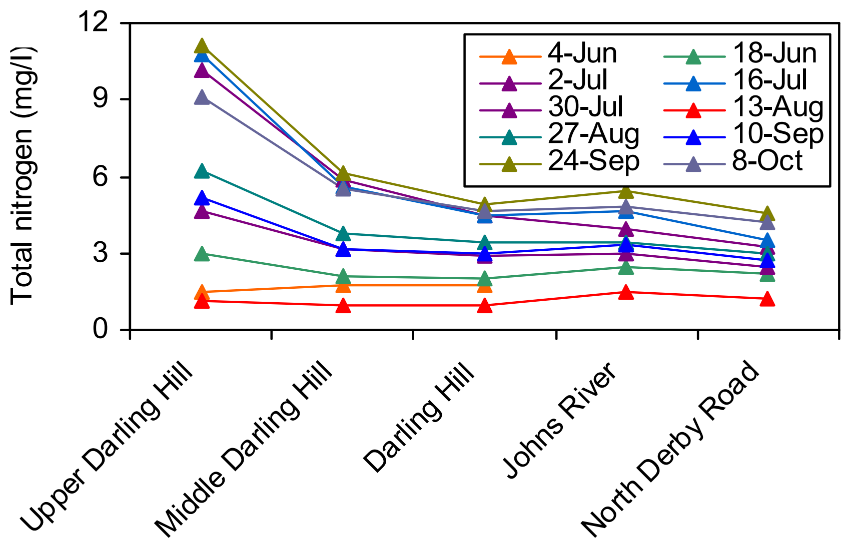

Figure 20. *Median total nitrogen profile from Upper Darling Hill downstream to North Derby Road along the Johns River during June-October 2008.*

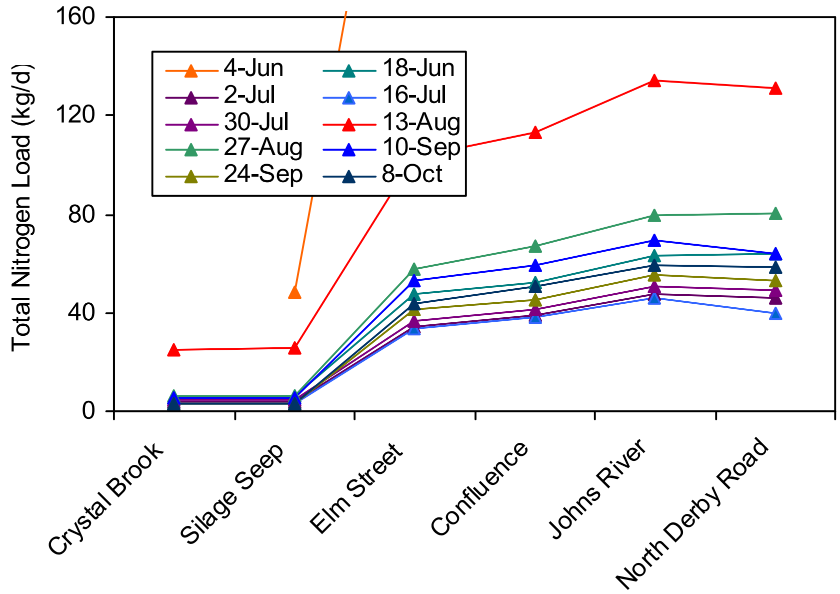

Figure 21. *Daily nitrogen load profile from Crystal Brook downstream to North Derby Road along the Johns River during 2008.*

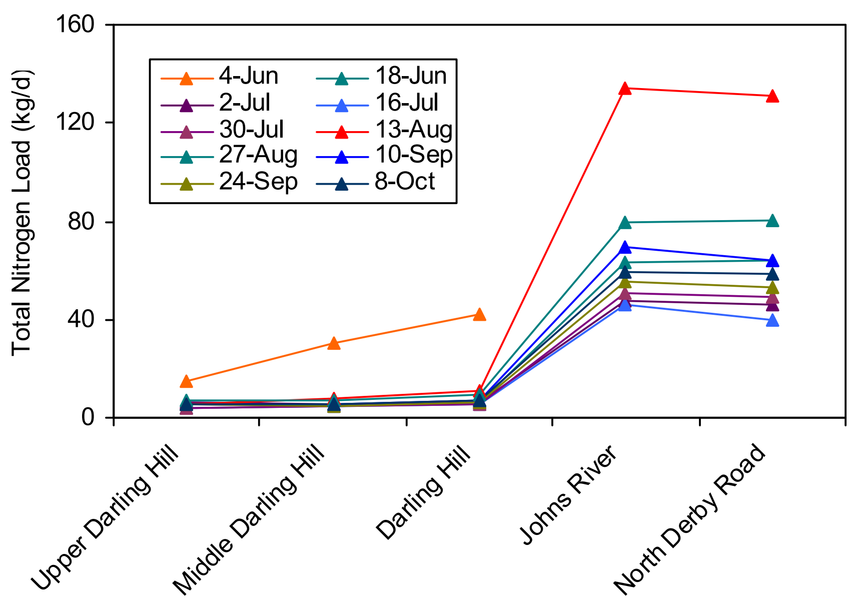

Figure 22. *Daily nitrogen load profile from Upper Darling Hill downstream to North Derby Road along the Johns River during 2008.*

Turbidity

Turbidity measures the total amount of dissolved and suspended material in the water column. Turbidity greatly affects the health of aquatic systems, as more turbid waters are less clear and transport more pollutants, nutrients, and sediments. Sediments that settle out of the water column also smother aquatic life and their habitats. Much of the nutrients and sediment being transported in the water column originates from erosion associated with agriculture, forestry, urban and suburban development, and stream adjustment processes. Turbidity is measured as the light-scattering properties of suspended materials in Nephelometric Turbidity Units (NTU).

Unfortunately, our quality assurance tests indicated that there were serious problems with the turbidity sampling at our sites (see following section). Thus, we have limited our analyses and discussion to the most basic results that allowed us to identify possible problem areas for future assessment. Turbidity levels in this study ranged between <0.2-51.8 NTU. Like total phosphorus, turbidity levels were highest early in the sampling season (18 June) and again on 13 August and were lowest in late autumn (see Figure 23). Median turbidity levels exceeded 10 NTU at one site (Holbrook Bay) and 5 NTU at another site (East Side)(the State of Vermont water quality standard for most Class A and Class B streams, respectively)(see Figures 24-25).

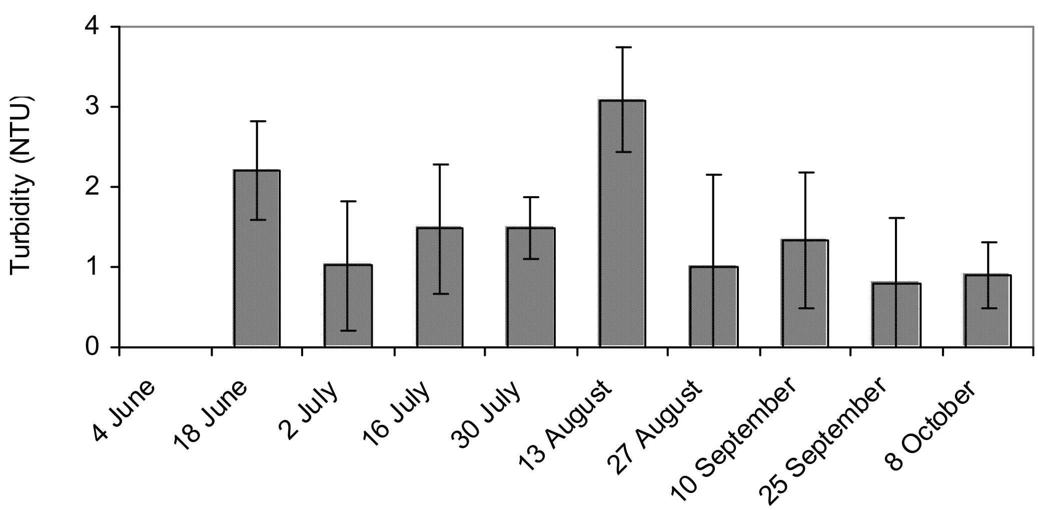

Figure 23. *Median turbidity levels (±1 SEM) observed on each sample date at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

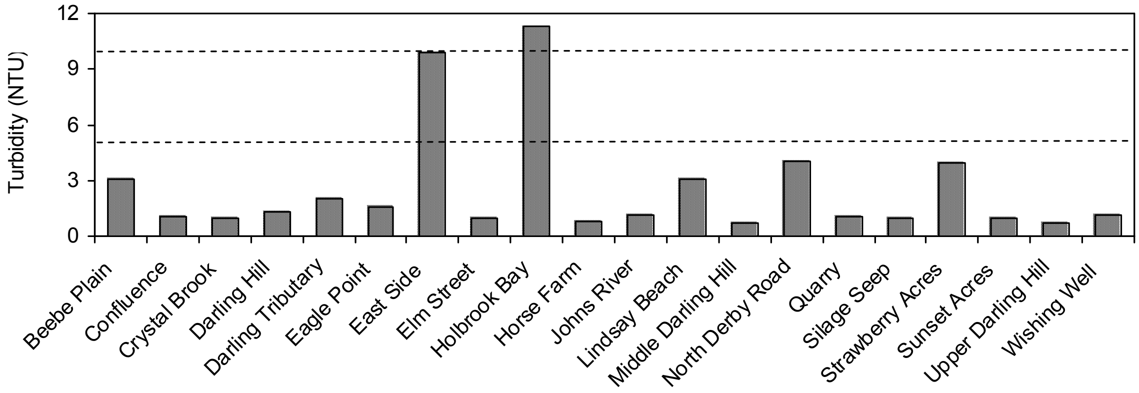

Figure 24. *Median turbidity levels observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008. The horizontal lines indicate water quality standards for class B and A streams (5 and 10 NTU).*

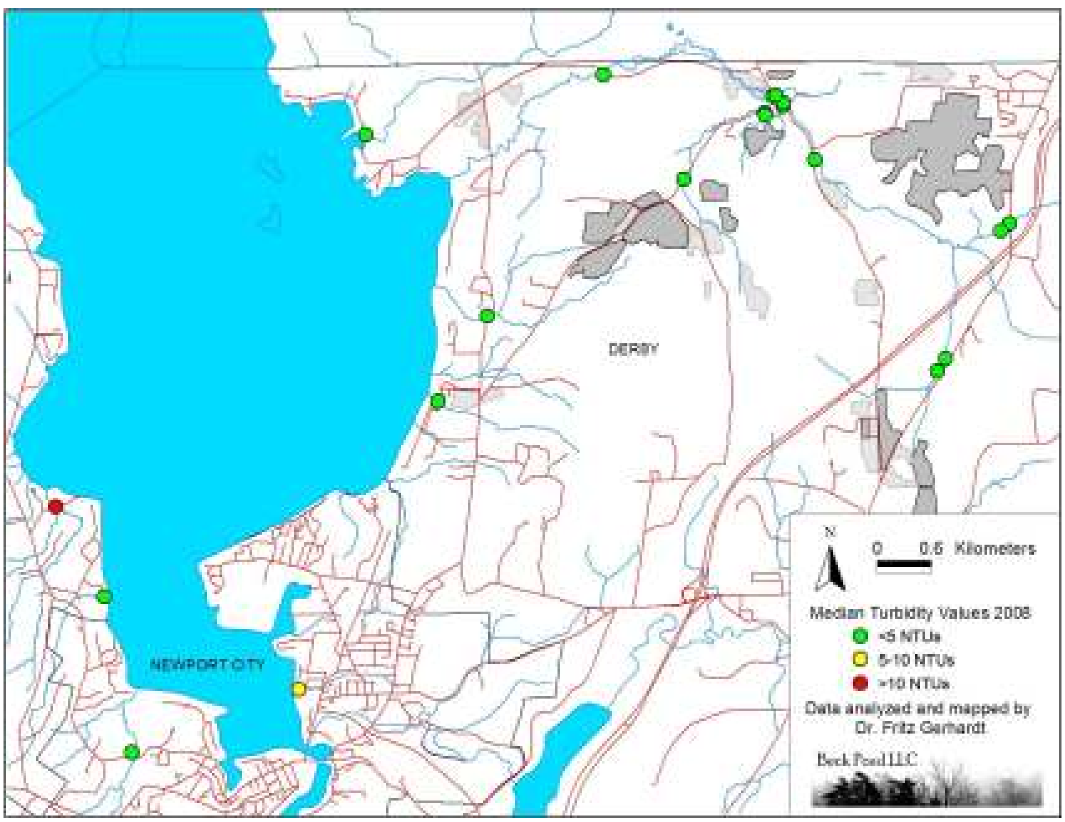

Figure 25. *Map of median turbidity levels observed at each of 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Like total phosphorus, turbidity levels generally increased with increasing water depth and stream flow (see Figure 26).

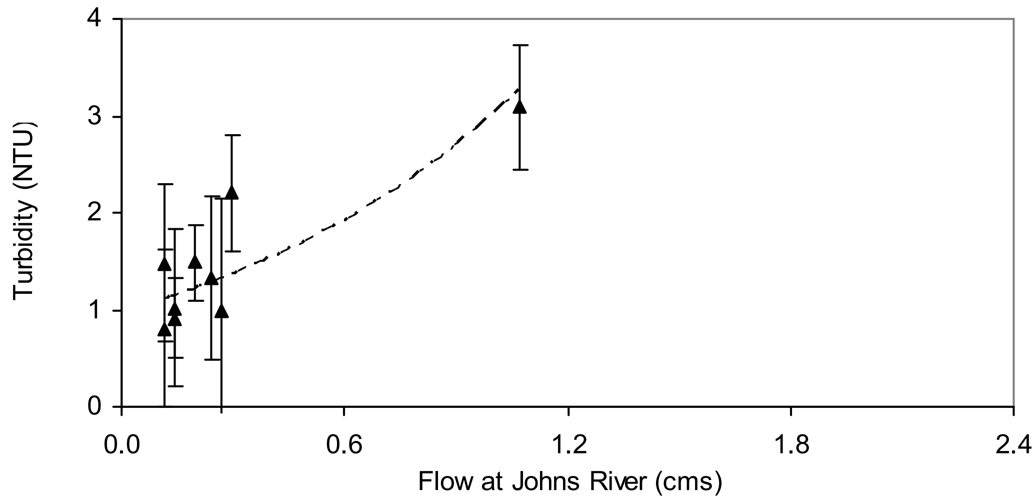

Figure 26. *Median turbidity levels (±1 SEM) in relation to stream flow at 20 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with the Vermont DEC (see Methods). Our sampling generally met the quality assurance standards for total phosphorus and total nitrogen (quality assurance data are presented in Appendix C). All 29 phosphorus blanks were below the detection limit (5 µg/l), and only one of the 29 nitrogen blanks (0.17 mg/l) exceeded its detection limit (0.1 mg/l). Likewise, only one of the 29 pairs of nitrogen samples differed by >20%, and two of the 30 pairs of phosphorus samples differed by >30%. In contrast, we had many problems with both the blank and duplicate turbidity samples. Seven of the 29 turbidity blanks (range = 0.25-0.52 NTU) exceeded the detection limit (0.2 NTU), and 12 of 29 pairs of turbidity samples differed by >15%. Because of these problems, we limited our presentation and discussion of the turbidity results to the most basic analyses, emphasizing those values that greatly exceeded the detection limits (e.g. >1 NTU). The reason(s) for the problems with the turbidity samples remain unclear and will require additional discussion and analyses to resolve satisfactorily.

Discussion

As in 2005 and 2006, the 2008 results indicated that the Johns River continued to send high levels of nitrogen and phosphorus into Lake Memphremagog. The results for the seven smaller tributaries suggested that all but one of these tributaries (Lindsay Beach) were also sending high concentrations of sediments and/or nutrients into Lake Memphremagog. Specifically, the Johns River, the four tributaries located in or near Newport City, and the Eagle Point tributary were all sending high levels of phosphorus into Lake Memphremagog. In addition, the Johns River and the Sunset Acres tributary were also sending high levels of nitrogen into Lake Memphremagog. Finally, two of the smaller tributaries (Holbrook Bay and East Side) exhibited high turbidity levels that warrant further investigation.

Water Depth and Stream Flow

Water depths and stream flows at the sample sites varied greatly throughout the sampling season. In this region, flows are generally greatest during spring snowmelt and secondarily during the autumn, when precipitation levels generally increase and plants no longer transpire water during photosynthesis. In contrast, stream flows are generally lowest during the summer months when there is less precipitation and more evaporation and transpiration. In 2008, water depths and stream flows generally followed this pattern, although we did not start sampling until early June, well after the snowpack had melted. In our sampling, water depths and flows were greatest in early June, progressively lessened during the summer months, peaked again in early August following heavy rains, and then decreased again through early autumn (see Figure 5). Based on the depth gauge data, water depths and flows increased slightly during the remainder of October and into November (see Figure 6). Compared to 2005 and 2006, water depths in 2008 were relatively low, except in early June and early August. In addition, seasonal patterns of flow differed among the three years. In 2005, water depths were generally high in the spring, decreased through the summer, and were highest in October when heavy rains caused extensive but minor flooding (Gerhardt 2006). In 2006, water depths were highest in May due to heavy rains that fell on the already saturated soils following spring snowmelt (Dyer and Gerhardt 2007).

Total Phosphorus

As expected, total phosphorus concentrations increased with increasing water depths and stream flows (see Figure 14). This positive relationship is fairly typical of streams where most phosphorus inputs arise from nonpoint sources, such as agricultural and urban runoff. This positive relationship contrasts sharply with the negative relationship between phosphorus levels and stream flows observed in 2006 (Dyer and Gerhardt 2007). Such negative relationships generally indicate groundwater or point sources of nutrient inputs, and this change probably reflects the replacement of the failing manure lagoon and the elimination of this "point source" of phosphorus inputs into Crystal Brook. One site (Eagle Point) did show a negative relationship (phosphorus concentrations decreased with increasing flows). This site is bordered by hayfields, which are heavily manured, but the negative relationship suggests that there might be another point source of phosphorus in this watershed.

In 2008, the highest phosphorus levels occurred on five of the seven smaller tributaries (see Figures 9-10). Interestingly, these high phosphorus levels were not located in areas dominated by active agricultural fields but, rather, were located in areas with more urban and suburban development (see Table 1). Thus, one possible source of phosphorus inputs in these areas is phosphorus fertilizers being applied to lawns and gardens as well as runoff from roads. In the Lake Champlain Basin, lawns exported three times more phosphorus per acre, on average, than did agricultural lands (State of Vermont 2002).

Table 1. Percentages of watersheds in different land uses and land cover types, including wetlands, urban and suburban development, forests, and agriculture. Data were compiled from the U.S. Geological Survey's *2001 National Land Cover Dataset - Vermont* available from the Vermont Center for Geographic Information (www.vcgi.org). Eagle Point was not included in this analysis, because much of its watershed lies in Quebec.

	Median phosphorus conc. (µg/l)	% wetland	% urban and suburban	% forest	% agri-culture	% roads
North Derby Road	**36.7**	**4.4**	2.5	**57.3**	**27.2**	6.3
Sunset Acres	16.2	0.0	13.1	**52.6**	**26.3**	4.3
Lindsay Beach	20.1	0.0	**22.8**	**55.8**	12.4	3.2
East Side	**36.0**	**3.9**	**51.2**	5.4	7.0	**27.7**
Wishing Well	**36.8**	0.5	7.5	33.5	**41.9**	**12.9**
Strawberry Acres	**45.7**	0.0	13.1	**52.6**	**26.3**	4.3
Holbrook Bay	**53.7**	1.5	3.1	**65.7**	13.3	4.9

In contrast to 2005 and 2006, median phosphorus concentrations in the Johns River watershed exceeded 35 µg only at the downstream-most site, although they did exceed 20 µg/l at seven other sites throughout the watershed (see Figure 10). In 2006, actual phosphorus concentrations (not median values) exceeded 35 µg/l at Crystal Brook on all six sample dates, at Johns River on 4 of 6 sample dates, and at North Derby Road on 5 of 6 sample dates. In contrast, in 2008, phosphorus concentrations at Crystal Brook and Johns River exceeded 35 µg/l on only 1 of 10 sample dates, although they still exceeded 35 µg/l at North Derby Road on 8 of 10 sample dates. In 2006, phosphorus concentrations at Crystal Brook ranged between 29-655 µg/l. In contrast, in 2008, phosphorus concentrations at the same location ranged between 14-87 µg/l. This dramatic drop in phosphorus levels along Crystal Brook was no doubt due to the replacement of a failing manure lagoon previously located immediately alongside Crystal Brook. It is encouraging to note that not only did the median phosphorus concentration at Crystal Brook in 2008 decrease to 18% of the 2006 value but that the median phosphorus concentration further downstream at Johns River also decreased to 48% of the 2006 value (see Figure 14).

Unfortunately, a similar decrease was not observed at the North Derby Road site, where the median phosphorus concentration in 2008 was still 88% of the 2006 value. This absence of a significant drop in phosphorus levels at North Derby Road was disheartening, especially since this site represented the downstream-most site before the river enters Lake Memphremagog. Thus, the high levels observed at this site indicated that the Johns River was still sending significant amounts of phosphorus into Lake Memphremagog. There are several possible explanations for the high levels observed there. First, runoff from the granite operations in Beebe Plain may carry a lot of phosphorus attached to sediment into the Johns River (see Figure 27). Second, as noted by Dyer (2008), there was abundant beaver activity upstream of the North Derby Road site, and this activity may release large amounts of phosphorus and sediment into the Johns River. Third, increased agricultural activity was observed in this area in 2008, including cattle grazing that was causing significant streambank erosion in an unfenced pasture downstream of the Johns River site (see Figure 28). Finally, residual phosphorus and sediments from Crystal Brook may not have completely flushed out of the downstream sections of the river at this time. Additional sampling will be needed to assess this issue further and to identify the source(s) of the high phosphorus levels observed in this section of the Johns River.

Total Nitrogen

Unlike the other Vermont tributaries of Lake Memphremagog, total nitrogen concentrations were extremely high along the Johns River in both 2005 and 2006 (Gerhardt 2006, Dyer and Gerhardt 2007). These high nitrogen levels were part of the rationale for focusing this study on the Johns River watershed. The inclusion of the seven smaller tributaries allowed us to narrow the focus of our nitrogen studies to the northeast quadrant of the study area, including much of the Johns River watershed as well as the watershed drained by the Sunset Acres tributary (see Figure 17). Although typically not the limiting nutrient in aquatic systems, high nitrogen levels, especially in combination with high phosphorus levels, can increase the incidence and toxicity of algal and cyanobacterial blooms and can accelerate eutrophication. Because the high nitrogen levels were restricted to the Johns River and Sunset Acres watersheds, the source(s) of these inputs are likely to be local, and there is a critical need to identify and mitigate these sources as soon as possible.

Figure 27. *One possible source of the high phosphorus levels observed at the North Derby Road site was runoff from the granite operations in Beebe Plain, Quebec photographed on 8 October 2008.*

Figure 28. *Another possible source of the high phosphorus levels observed at the North Derby Road site was cattle grazing and streambank erosion in the Johns River near Beebe Plain, Vermont photographed on 20 August 2008 (photo courtesy of Melissa Dyer).*

In contrast to phosphorus and turbidity, nitrogen levels showed a negative relationship with stream flow (see Figure 18). That is, nitrogen concentrations increased as water depths decreased, especially at the sites exhibiting the highest nitrogen concentrations (Upper Darling Hill and Sunset Acres). This negative relationship suggests that the nitrogen inputs were not derived from nonpoint sources, such as agricultural and urban runoff, but rather were derived from groundwater or point sources. Based on past sampling, we originally suspected that the nitrogen in the Johns River might be coming from failing septic systems, especially near the confluence of the Johns River and the Darling Hill tributary. Although several homes in this area may have failing septic systems (Don Chapdelaine, personal communication), the results of this year's sampling suggest that nitrogen inputs are more widely distributed in this area, including upstream of Elm Street in Derby Line as well as along the ridge dividing the Darling Hill and Sunset Acres tributaries (see Figure 17). Based on these additional analyses, we now suspect that the nitrogen is coming from manure and nitrogen fertilizers leaching into the groundwater from cornfields located on sand and gravel deposits (see Figures 29-30). Additional analyses showed that nitrogen loads in these watersheds were correlated with the amount of area planted in corn in 2008 (see Figure 31). Ultimately, we will only be able to confirm this hypothesis with additional surface water and groundwater sampling.

Figure 29. *One possible source of the high nitrogen levels observed in the Johns River and adjacent tributaries was manure and synthetic fertilizers that were applied to cornfields such as this one overlooking Echo Lake in East Charleston, Vermont on 20 August 2007.*

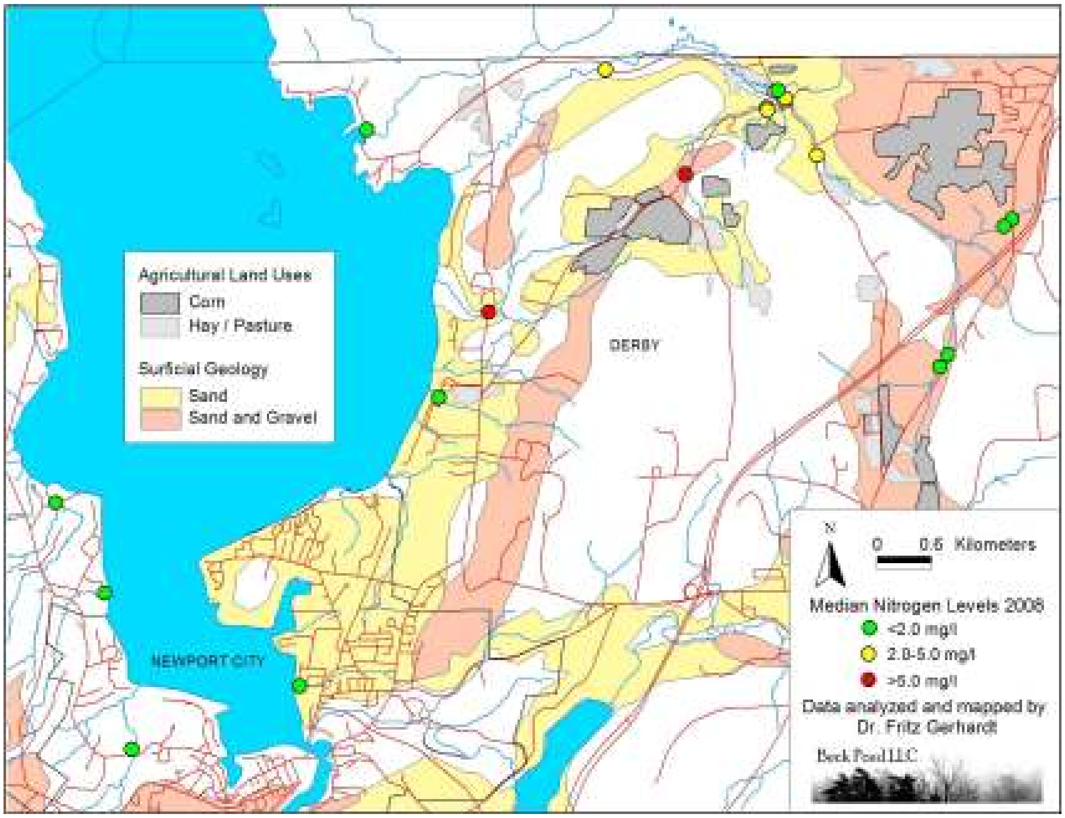

Figure 30. *Map of median total nitrogen concentrations in relation to locations of active agricultural fields and sand and gravel deposits along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Turbidity

Unfortunately, the quality assurance tests indicated that our turbidity sampling was compromised in some fashion. We had high numbers of failed tests for both the field blanks, which tested for field contamination, and the field duplicates, which measured the repeatability of the sampling (see Appendix C). Thus, we were limited in our ability to make any major conclusions about the turbidity results or their implications for our understanding of water quality issues along the Johns River and the seven smaller tributaries. What we can say is that there were two sites (East Side and Holbrook Bay) where turbidity levels greatly exceeded those observed at any other sites or measured by the field blanks (see Figure 24 and Appendix C). Thus, we are confident that these two tributaries require additional assessment to evaluate possible sediment sources or other impairments to water clarity. In these two watersheds, sediments may originate from runoff associated with agricultural lands or urban and suburban development. The East Side site, in particular, was located in an area with a large amount of urban and suburban development (see Table 1). In addition, there were several very active beavers along the Holbrook Bay tributary (King Boyd, personal communication), and these beavers may be responsible for disturbing in-stream sediments in this watershed. Thus, future sampling should be undertaken in these two watersheds to verify these high turbidity levels and to identify their source(s), so that they can be reduced or eliminated in the near future.

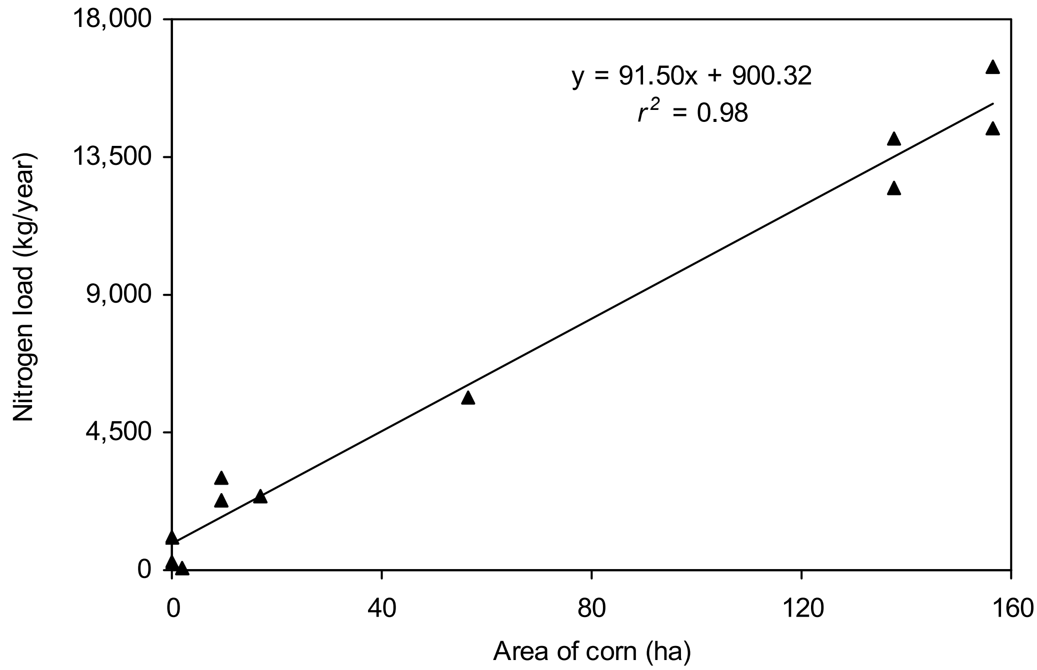

Figure 31. *Relationship between nitrogen load and amount of land planted in corn in the watersheds of the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan approved by the Vermont DEC. The field blanks and field duplicates indicated that the phosphorus and nitrogen samples were being collected in a repeatable manner and were not being contaminated during field or laboratory processing. In contrast, the quality assurance tests for turbidity indicated that there were serious problems with the collection and processing of the turbidity samples. Seven of the 29 field blanks exceeded the detection limit, and 12 of the 29 pairs of field duplicates differed by >15% (see Appendix C). However, we were unable to identify the source(s) of these problems. They may have arisen due to field or laboratory contamination, accidental filling of sample vials with stream water, mislabeling, or some other cause. Despite repeated discussions about sampling protocols and the utmost diligence on the part of field and laboratory personnel, we were unable to eliminate these problems. Due to the large numbers of problems with the turbidity quality assurance tests and our inability to identify the source(s) of these problems, we will need to reconsider our methods for sampling water clarity and sediments in the future. For example, we might consider measuring total suspended solids, rather than turbidity, at least on those streams where the turbidity samples suggested that there were problems with water clarity.

Education and Outreach

As part of this project, we incorporated the process and results of this study into several educational and outreach programs. Numerous individuals from the local community volunteered their time to help with the collection and processing of water quality samples. In addition, Sterling College's Watershed Ecosystem Analysis class spent a field day learning about water quality issues in the Lake Memphremagog Basin. In the future, we plan to present the results of this and other water quality studies at one or more public meetings hosted by the Memphremagog Watershed Association and the Vermont DEC and to the Quebec/Vermont Steering Committee on Lake Memphremagog. Furthermore, we have discussed the results of this study and their implications with staff from the Orleans County office of the Natural Resources Conservation Service, the Orleans County Natural Resources Conservation District, the Vermont DEC, the Vermont Geological Survey, and the Vermont Agency of Agriculture. We have also continued to develop collaborative relationships with other agencies and organizations working to protect and improve water quality in the Lake Memphremagog Basin, including the Water Quality Division of the Vermont DEC (Lakes & Ponds Management/Protection Section, Watershed Planning Section, Biomonitoring and Aquatic Studies Section, River Management Section, and LaRosa Analytical Laboratory); Quebec Ministère du Développement durable, de l'Environnement et des Parcs; MRC de Memphrémagog; cities of Newport, Sherbrooke, and Magog; Memphrémagog Conservation Inc.; and the NorthWoods Stewardship Center.

Recommendations

Monitoring and Assessment Studies

During 2005-2006, we assessed and ranked the four principal Vermont tributaries of Lake Memphremagog according to the amounts of phosphorus, nitrogen, and sediment that they were sending into the lake (Johns River > Black River > Barton River > Clyde River). Although smaller, the Johns River exhibited far higher phosphorus and nitrogen levels than the other three tributaries. Thus, we sampled additional sites along the Johns River in 2006 and 2008 to better understand the phosphorus and nitrogen problems in this watershed. It is now clear that much of the phosphorus originated from a failing manure lagoon located alongside Crystal Brook, and the results of this year's sampling suggest that relocating this lagoon has dramatically reduced phosphorus inputs into the Johns River. Although phosphorus levels decreased dramatically in the upper watershed of the Johns River, they remained high further downstream and were also high along five of the seven smaller tributaries.

In contrast, the nitrogen problem remains less well understood and will require additional studies to pinpoint the source(s) of these inputs. High nitrogen levels, especially when combined with high phosphorus and iron levels, can dramatically increase the incidence and toxicity of algal and cyanobacterial blooms. In the past year, we have narrowed the focus to one possible mechanism whereby nitrogen enters these rivers: leaching of nitrogen from manure and synthetic fertilizers into groundwater. Thus, there remains a critical need to continue sampling surface waters - in conjunction with targeted groundwater sampling – in order to develop a comprehensive understanding of nitrogen and phosphorus dynamics in these watersheds and to identify and prioritize projects and management practices that reduce phosphorus, nitrogen, and sediment inputs into Lake Memphremagog.

Specifically, we recommend that projects be implemented immediately to address the following goals:

1) To identify the source(s) of elevated phosphorus levels in downstream sections of the Johns River and five of the smaller tributaries (Holbrook Bay, Strawberry Acres, Wishing Well, East Side, and Eagle Point),
2) To verify that past remediation efforts have effectively reduced phosphorus levels in Crystal Brook and the Johns River,
3) To verify that the nitrogen in the Johns River and adjacent tributaries is coming from manure and synthetic fertilizers being applied to cornfields on sand and gravel deposits and to identify specific locations where nitrogen is entering these streams from ground water sources,
4) To evaluate whether nitrogen levels in the Johns River and adjacent tributaries exceed Vermont water quality standards,
5) To identify the magnitude of nitrogen reductions needed to meet water quality standards and to identify management practices or projects that will achieve these reductions.
6) To further assess and identify the source(s) of the high turbidity levels in the East Side and Holbrook Bay tributaries.

To address these goals, we recommend continuing the partnerships that have been established thus far to achieve these goals and to develop projects and practices that will reduce nutrient and sediment inputs in the coming years. These goals will require additional surface water sampling and assessments throughout the watersheds of the Johns River and the smaller tributaries (see Figure 32). Specifically, we recommend resampling 7 of the 13 sites sampled in 2008 in the Johns River watershed (North Derby Road, Johns River, Darling Hill, Upper Darling Hill, Confluence, Elm Street, and Crystal Brook). We also recommend relocating one site (Silage Seep) further downstream to better sample groundwater entering Crystal Brook from a silage storage area. In addition, we recommend adding four new sites to better pinpoint sources of nitrogen and phosphorus inputs, including one site to identify phosphorus sources between North Derby Road and Johns River, one site to assess phosphorus and nitrogen inputs upstream of Crystal Brook, and two sites to identify nitrogen sources upstream of Quarry. On the smaller tributaries, we recommend resampling all seven sites again; however, we recommend relocating one site (Eagle Point) further upstream to avoid issues with back flows from Lake Memphremagog. We also recommend adding an additional site further upstream from the Wishing Well site and another site on a small tributary located in the Lakemont section of Newport.

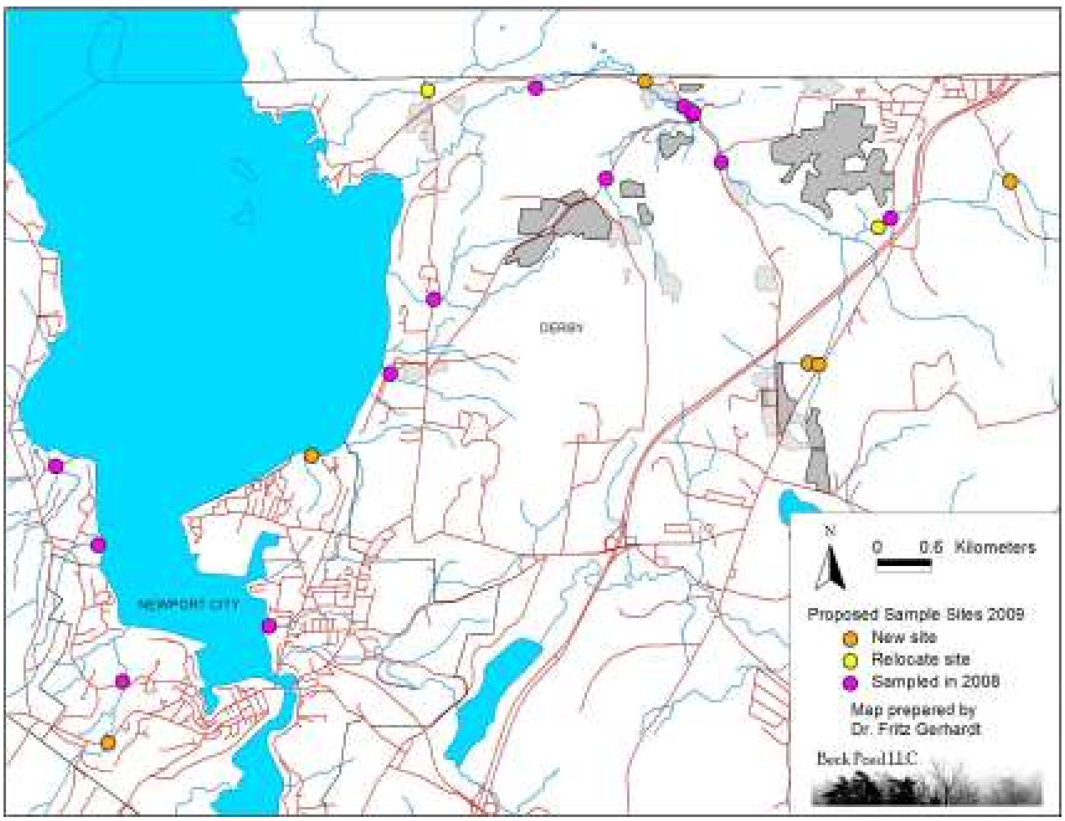

Figure 32. *Locations of proposed sample sites in the watersheds of the Johns River and eight smaller tributaries of Lake Memphremagog.*

At all sites, we recommend sampling total phosphorus and total nitrogen. Given the quality assurance problems with the turbidity samples, we wonder if it might be better to sample total suspended solids, rather than turbidity, at the two sites where we measured high turbidity levels (East Side and Holbrook Bay). Unfortunately, turbidity is the parameter used to determine whether rivers and streams meet Vermont water quality standards (State of Vermont 2006b); however, measuring total suspended solids would allow us to calculate sediment loads and would be comparable to data collected by other organizations (e.g. MRC de Memphrémagog). At the Johns River and Sunset Acres sites, we also recommend sampling for NO_x, iron, and atrazine (a pesticide commonly used on corn in this area). In these areas, we suspect that nitrogen is leaching into the groundwater from manure and synthetic fertilizers, and there is a distinct possibility that pesticides may also be leaching into the groundwater. Sampling NO_x will allow us to better identify the sources of nitrogen in this watershed and to determine whether these streams meet Vermont water quality standards, which are based on NO_x concentrations. In addition, we recommend sampling for iron at these sites, as we have noticed considerable precipitate on streambed cobbles and boulders (see Figure 33). High iron levels, when combined with high phosphorus and nitrogen levels, are known to increase the frequency and toxicity of cyanobacterial blooms. As was done in 2008, we recommend sampling all sites at biweekly intervals during May-September.

Figure 33. *Iron deposits on streambed of Crystal Brook near Derby Line, Vermont on 2 July 2008.*

In addition to surface water sampling, we highly recommend implementing a parallel effort to sample groundwater, especially in areas where we suspect nitrogen is leaching into the groundwater. We have already met with and established an informal partnership with personnel from the Vermont Geological Survey and the Vermont Agency of Agriculture. Based on these discussions, we have identified several preliminary steps that can be undertaken towards identifying the source(s) of nitrogen inputs into surface waters: 1) delineate likely groundwater nitrogen source areas, 2) identify and prioritize groundwater wells for sampling in priority areas, 3) review well logs for groundwater wells in these priority areas to better map the surficial geology, and 4) coordinate surface and groundwater sampling to ensure complementarity. As with all of these recommendations, we will need to identify and procure funding and other resources to support both the surface water and groundwater sampling.

To further evaluate the impacts of the high nitrogen and phosphorus levels on aquatic communities, we recommend that aquatic habitat characteristics be evaluated by the Biomonitoring and Aquatic Studies Section (BASS) of the Vermont DEC. Such biomonitoring would allow us to evaluate the impacts of the high nitrogen and phosphorus levels on the aquatic communities as well as to determine whether aquatic communities in Crystal Brook have started to recover following the reduction of phosphorus inputs there. Specifically, we recommend that BASS scientists resample their two long-term monitoring sites on Crystal Brook and add new sites along the Johns River (perhaps near the Elm Street or Johns River sites) and the Darling Hill and Sunset Acres tributaries.

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 prevent further degradation and to improve water quality in this watershed. Ultimately, the goal of all of these recommendations is to continue increasing our knowledge about and identifying sources of stream erosion, sedimentation, and nutrient enrichment in these watersheds, so that we can prioritize and implement on-the-ground protection and restoration projects that protect and improve water quality in the Lake Memphremagog Basin.

Protection and Restoration Projects

Although additional studies are still needed, our results do suggest several protection and restoration projects and practices that can be implemented immediately to improve water quality along these tributaries. First, whether or not it is the source of the high phosphorus levels in the downstream section of the Johns River, we recommend fencing the revived pasture along North Derby Road to prevent cattle from entering the stream and eroding the streambanks and stream channel (see Figure 28). In addition, we recommend planting streamside buffers on this reach to reduce erosion, filter out pollutants, shade the stream channel, and reduce water temperatures. Such projects could be funded by cost-share programs, such as the Conservation Reserve Enhancement Program administered by the Farm Services Agency. Although we still do not have conclusive proof that the high nitrogen levels in the Johns River and adjacent tributaries are originating from manure and synthetic fertilizers, we should continue developing partnerships with the Orleans County office of the Natural Resources Conservation Service, the Orleans County Natural Resources Conservation District, and local farmers to further evaluate this scenario and to begin adopting management practices that reduce the amount of nitrogen being lost to leaching. This reduction would benefit both water quality and the farmers, who are paying the costs for the nitrogen fertilizers that are leaching into the groundwater.

In urban and suburban areas, there are also a number of practices and projects that can be adopted immediately to reduce nutrient and sediment inputs into rivers and streams. One immediate step would be to plant buffers along streams to filter nutrients and sediments from stormwater and other runoff. These buffers would also shade the streams and reduce water temperatures. In addition, property owners should be encouraged to use rain barrels and to plant rain gardens to reduce stormwater runoff, especially in residential areas. Property owners should also be encouraged to use fewer synthetic fertilizers on their lawns and gardens, especially those located near or bordering rivers and streams. Thus, these property owners will need the tools and information necessary to maintain healthy lawns and gardens without the use of synthetic fertilizers. All of these efforts would be facilitated by educational and outreach programs as well as demonstration projects. The Memphremagog Watershed Association is ideally situated to coordinate and implement any such workshops and demonstration projects.

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Appendix A. Description of the 20 sample sites located along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008 (locations are mapped in Figure 3).

Smaller tributaries (7 sites):

Holbrook Bay	Unnamed tributary downstream of Beaver Cove Road in Newport Town
Strawberry Acres	Unnamed tributary downstream of Fishing Access Road in Newport Town
Wishing Well	Unnamed tributary downstream of snowmobile bridge north of Lake Road in Newport City
East Side	Unnamed tributary south of Landing Street boat launch in Newport City
Lindsay Beach	Unnamed tributary along bike path off north end of Lindsay Road Extension in Derby
Sunset Acres	Unnamed tributary downstream of North Derby Road in Derby
Eagle Point	Unnamed tributary upstream of Eagle Point Road in Derby

Johns River (13 sites):

North Derby Road	Main stem downstream of North Derby Road in Derby (also sampled in 2006)
Johns River	Main stem beside old well house off Beebe Road in Derby (also sampled in 2005 and 2006)
Beebe Plain	Unnamed tributary downstream of Beebe Road in Derby
Darling Hill	Unnamed tributary upstream of confluence with Johns River in Derby (also sampled in 2006)
Darling Tributary	Unnamed tributary upstream of confluence with Darling Hill tributary in Derby
Middle Darling Hill	Unnamed tributary upstream of Darling Hill Road (middle crossing) in Derby
Upper Darling Hill	Unnamed tributary upstream of Darling Hill Road (upper crossing) in Derby
Confluence	Main stem downstream of Beebe Road in Derby
Elm Street	Main stem downstream of snowmobile bridge along Beebe Road in Derby
Silage Seep	Crystal Brook downstream of U.S. Highway 5 and snowmobile crossing in Derby
Crystal Brook	Crystal Brook downstream between U.S. Highway 5 and snowmobile crossing in Derby (also sampled in 2006)

Horse Farm	Unnamed tributary across U.S. Highway 5 from Bernier's Garage in Derby
Quarry	Unnamed tributary across U.S. Highway 5 from Bernier's Garage in Derby (also sampled in 2006)

Appendix B. Water quality data collected at 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008. Colored fonts highlight concentrations greater than Vermont water quality standards (State of Vermont 2006) or arbitrary concentrations if no water quality standards apply: total phosphorus >20 µg/l (italics) or >35 µg/l (bold), total nitrogen >2 mg/l (italics) or >5 mg/l (bold), and turbidity >5 mg/l (italics) or >10 mg/l (bold).

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
Beebe Plain	6/4/2008	35.56	*3.73*	**575.0**	-
Beebe Plain	6/18/2008	16.51	0.69	**41.8**	2.57
Beebe Plain	7/2/2008	16.51	0.43		*7.12*
Beebe Plain	7/16/2008	15.49	0.43	*28.3*	4.74
Beebe Plain	7/30/2008	15.75	0.55	*32.5*	4.46
Beebe Plain	8/13/2008	-	1.15	**40.9**	1.78
Beebe Plain	8/27/2008	17.27	1.57	*30.7*	3.09
Beebe Plain	9/10/2008	17.78	1.29	*33.7*	3.91
Beebe Plain	9/24/2008	15.24	1.29	16.3	1.62
Beebe Plain	10/8/2008	18.80	1.33	14.8	1.26
Confluence	6/4/2008	36.83	*2.43*	**174.0**	-
Confluence	6/18/2008	7.87	*2.48*	*22.6*	2.20
Confluence	7/2/2008	2.79	*3.92*	17.3	0.88
Confluence	7/16/2008	0.00	*4.72*	18.0	1.05
Confluence	7/30/2008	4.06	*2.96*	19.7	1.47
Confluence	8/13/2008	29.85	1.50	*27.1*	3.39
Confluence	8/27/2008	6.10	*3.50*	17.4	0.89
Confluence	9/10/2008	4.57	*3.49*	*22.3*	2.44
Confluence	9/24/2008	0.00	**5.49**	9.4	0.64
Confluence	10/8/2008	1.52	*4.93*	9.3	0.75
Crystal Brook	6/4/2008	11.94	-	**87.3**	*7.38*
Crystal Brook	6/18/2008	10.16	1.32	*29.4*	1.14
Crystal Brook	7/2/2008	5.33	1.72	*22.7*	0.98
Crystal Brook	7/16/2008	12.95	1.92	*26.7*	1.33
Crystal Brook	7/30/2008	16.00	1.62	*23.1*	-
Crystal Brook	8/13/2008	22.86	1.58	*20.7*	1.05
Crystal Brook	8/27/2008	10.92	1.55	18.9	0.45
Crystal Brook	9/10/2008	13.72	1.47	*23.0*	1.34
Crystal Brook	9/24/2008	13.97	1.87	15.2	0.52
Crystal Brook	10/8/2008	14.22	1.60	14.4	0.89

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
Darling Hill	6/4/2008	18.54	1.75	**256.0**	
Darling Hill	6/18/2008	3.30	1.99	*31.0*	1.76
Darling Hill	7/2/2008	-3.05	*4.46*	*21.9*	1.05
Darling Hill	7/16/2008	2.54	*4.50*	*33.9*	1.63
Darling Hill	7/30/2008	2.29	*2.86*	*29.4*	1.80
Darling Hill	8/13/2008	19.05	0.97	**41.8**	3.66
Darling Hill	8/27/2008	0.00	*3.40*	*21.8*	1.02
Darling Hill	9/10/2008	2.03	*2.94*	*32.6*	1.32
Darling Hill	9/24/2008	0.64	*4.93*	12.9	0.81
Darling Hill	10/8/2008	0.76	*4.64*	14.8	0.54
Darling Tributary	6/4/2008	44.45	1.27	**73.4**	-
Darling Tributary	6/18/2008	17.78	*2.52*	*24.5*	3.27
Darling Tributary	7/2/2008	12.70	*2.96*	*21.6*	3.04
Darling Tributary	7/16/2008	11.43	*2.98*	*20.3*	1.65
Darling Tributary	7/30/2008	-	*2.35*	*23.5*	2.62
Darling Tributary	8/13/2008	-	1.36	*27.6*	**11.50**
Darling Tributary	8/27/2008	1.78	*2.89*	*21.4*	2.05
Darling Tributary	9/10/2008	18.29	*2.96*	16.6	1.00
Darling Tributary	9/24/2008	13.97	*3.53*	14.0	1.74
Darling Tributary	10/8/2008	15.24	*3.27*	11.7	1.12
Eagle Point	6/4/2008	45.72	0.46	*33.1*	-
Eagle Point	6/18/2008	41.91	0.50	**45.2**	3.09
Eagle Point	7/2/2008	22.86	0.59	**41.6**	1.19
Eagle Point	8/13/2008	35.56	0.52	**43.8**	1.05
Eagle Point	8/27/2008	19.05	0.52	**41.4**	1.32
Eagle Point	9/10/2008	-	0.74	**53.3**	1.84
Eagle Point	10/8/2008	45.40	0.80	**73.5**	2.23
East Side	6/4/2008	25.40	1.41	**48.1**	-
East Side	6/18/2008	25.65	1.57	**44.9**	**21.10**
East Side	7/2/2008	16.00	1.72	**36.0**	**11.90**
East Side	7/16/2008	21.59	1.73	*31.7*	**31.40**
East Side	7/30/2008	33.66	1.45	**41.0**	*7.84*
East Side	8/13/2008	50.80	-	-	-
East Side	8/27/2008	26.99	1.77	*29.9*	4.58
East Side	9/10/2008	22.86	1.77	*25.9*	4.45
East Side	9/24/2008	20.96	*2.02*	**70.7**	**51.80**
East Side	10/8/2008	28.89	1.69	17.2	3.58

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Elm Street	6/4/2008	13.21	1.96	**115.0**	*5.84*
Elm Street	6/18/2008	12.19	*2.36*	*21.4*	1.82
Elm Street	7/2/2008	19.30	*3.57*	17.2	0.69
Elm Street	7/16/2008	36.83	*4.30*	19.5	1.09
Elm Street	7/30/2008	19.81	*2.70*	19.0	0.72
Elm Street	8/13/2008	20.32	1.42	*24.5*	3.23
Elm Street	8/27/2008	60.45	*3.12*	18.7	-
Elm Street	9/10/2008	17.27	*3.25*	19.0	0.94
Elm Street	9/24/2008	7.62	**5.15**	11.3	0.80
Elm Street	10/8/2008	17.27	*4.57*	10.9	0.99
Holbrook Bay	6/4/2008	49.02	0.39	**62.5**	-
Holbrook Bay	6/18/2008	38.10	0.43	**49.1**	**11.30**
Holbrook Bay	7/2/2008	16.51	0.45	**58.2**	**13.40**
Holbrook Bay	7/16/2008	-5.08	0.57	**72.4**	**14.70**
Holbrook Bay	7/30/2008	33.02	0.43	**40.0**	*5.06*
Holbrook Bay	8/13/2008	35.56	0.36	*32.0*	*5.70*
Holbrook Bay	8/27/2008	15.24	0.49	**81.6**	**21.50**
Holbrook Bay	9/10/2008	15.24	0.76	**87.6**	**16.20**
Holbrook Bay	9/24/2008	7.62	0.38	**40.8**	**10.90**
Holbrook Bay	10/8/2008	5.08	0.35	**38.0**	*7.50*
Horse Farm	6/4/2008	15.24	0.48	*21.6*	-
Horse Farm	6/18/2008	10.67	0.31	17.5	1.68
Horse Farm	7/2/2008	10.41	0.32	14.1	0.99
Horse Farm	7/16/2008	10.16	0.40	14.5	1.04
Horse Farm	7/30/2008	10.92	0.29	14.7	0.67
Horse Farm	8/13/2008	22.86	0.32	11.4	0.44
Horse Farm	8/27/2008	14.48	0.27	11.2	0.53
Horse Farm	9/10/2008	11.94	0.32	14.1	0.52
Horse Farm	9/24/2008	10.16	0.37	11.4	0.81
Horse Farm	10/8/2008	9.65	0.37	14.3	2.55

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**Total phosphorus (µg/l)**	**Turbidity (NTU)**
Johns River	6/4/2008	49.53	-	**204.0**	-
Johns River	6/18/2008	20.32	*2.42*	*24.7*	2.33
Johns River	7/2/2008	15.24	*3.90*	17.7	1.15
Johns River	7/16/2008	14.22	*4.61*	17.3	1.13
Johns River	7/30/2008	16.51	*2.95*	19.5	0.96
Johns River	8/13/2008	35.56	1.45	*30.4*	3.68
Johns River	8/27/2008	15.75	*3.39*	17.2	1.02
Johns River	9/10/2008	19.81	*3.36*	*20.0*	1.11
Johns River	9/24/2008	13.97	**5.47**	9.8	0.68
Johns River	10/8/2008	15.24	*4.86*	10.0	0.93
Lindsay Beach	6/4/2008	16.51	0.29	*21.2*	-
Lindsay Beach	6/18/2008	11.68	0.28	*21.0*	3.44
Lindsay Beach	7/2/2008	8.64	0.31	16.4	3.07
Lindsay Beach	7/16/2008	10.16	0.26	17.5	3.06
Lindsay Beach	7/30/2008	23.18	0.36	*21.3*	4.00
Lindsay Beach	8/13/2008	12.70	0.30	*23.6*	*8.22*
Lindsay Beach	8/27/2008	-12.07	0.21	19.9	2.78
Lindsay Beach	9/10/2008	-6.99	0.24	*20.2*	3.08
Lindsay Beach	9/24/2008	-6.99	0.19	11.3	2.55
Lindsay Beach	10/8/2008	-6.03	0.23	12.9	2.59
Middle Darling	6/4/2008	39.62	1.78	**258.0**	-
Middle Darling Hill	6/18/2008	16.51	*2.07*	*34.6*	1.20
Middle Darling Hill	7/2/2008	12.19	**5.87**	*21.7*	0.62
Middle Darling Hill	7/16/2008	12.70	**5.63**	*26.3*	0.73
Middle Darling Hill	7/30/2008	9.14	*3.14*	*32.6*	1.03
Middle Darling Hill	8/13/2008	-	1.00	**41.5**	3.57
Middle Darling Hill	8/27/2008	16.76	*3.73*	*22.3*	0.34
Middle Darling Hill	9/10/2008	4.06	*3.16*	**37.2**	1.16
Middle Darling Hill	9/24/2008	-99.00	**6.14**	14.5	0.64
Middle Darling Hill	10/8/2008	0.76	**5.48**	14.8	0.30

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
North Derby Road	6/4/2008	31.75	-	**128.0**	-
North Derby Road	6/18/2008	-2.54	*2.17*	**54.5**	*6.90*
North Derby Road	7/2/2008	-16.51	*3.24*	**37.0**	3.98
North Derby Road	7/16/2008	-17.78	*3.46*	**41.7**	*7.25*
North Derby Road	7/30/2008	-7.62	*2.49*	**35.3**	4.32
North Derby Road	8/13/2008	29.21	1.23	**36.5**	4.03
North Derby Road	8/27/2008	-15.24	*2.97*	**36.8**	3.77
North Derby Road	9/10/2008	-17.78	*2.68*	**36.6**	4.08
North Derby Road	9/24/2008	-20.32	*4.54*	*34.8*	3.21
North Derby Road	10/8/2008	-22.86	*4.20*	*31.8*	3.33
Quarry	6/4/2008	28.45	0.92	**37.6**	-
Quarry	6/18/2008	17.78	0.81	*20.1*	1.42
Quarry	7/2/2008	15.49	1.07	*22.7*	3.88
Quarry	7/16/2008	12.70	0.98	17.0	1.85
Quarry	7/30/2008	16.00	0.89	19.7	0.93
Quarry	8/13/2008	34.93	0.74	*20.8*	1.47
Quarry	8/27/2008	20.32	1.44	19.3	0.75
Quarry	9/10/2008	19.81	1.18	18.5	1.01
Quarry	9/24/2008	20.32	1.46	11.3	0.75
Quarry	10/8/2008	16.76	1.12	11.2	0.72
Silage Seep	6/4/2008	-	1.37	**114.0**	-
Silage Seep	6/18/2008	-	1.39	*34.8*	2.04
Silage Seep	7/2/2008	-	1.82	*29.1*	0.88
Silage Seep	7/16/2008	-	1.96	**35.1**	0.95
Silage Seep	7/30/2008	-	1.63	*29.8*	1.20
Silage Seep	8/13/2008	-	1.58	*20.9*	1.91
Silage Seep	8/27/2008	-	1.57	-	0.63
Silage Seep	9/10/2008	-	1.52	*26.6*	1.63
Silage Seep	9/24/2008	-	1.86	*22.1*	0.31
Silage Seep	10/8/2008	-	1.61	17.9	0.70

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
Strawberry Acres	6/4/2008	25.40	1.20	**102.0**	-
Strawberry Acres	6/18/2008	29.21	1.35	**103.0**	*5.49*
Strawberry Acres	7/2/2008	7.62	1.09	**50.9**	*8.17*
Strawberry Acres	7/16/2008	1.27	0.46	**38.3**	3.93
Strawberry Acres	7/30/2008	12.70	1.67	**108.0**	*5.31*
Strawberry Acres	8/13/2008	14.61	1.44	**76.4**	2.94
Strawberry Acres	8/27/2008	0.00	0.46	**40.5**	3.70
Strawberry Acres	9/10/2008	3.81	0.90	**35.7**	3.28
Strawberry Acres	9/24/2008	-5.08	0.27	*25.1*	**11.80**
Strawberry Acres	10/8/2008	2.54	0.27	*21.3*	2.66
Sunset Acres	6/4/2008	15.24	*2.82*	**195.0**	-
Sunset Acres	6/18/2008	41.91	*3.30*	18.4	1.46
Sunset Acres	7/2/2008	0.00	**7.90**	15.4	0.98
Sunset Acres	7/16/2008	-2.54	**8.90**	15.0	1.09
Sunset Acres	7/30/2008	2.86	**5.21**	17.0	1.13
Sunset Acres	8/13/2008	21.59	1.65	*26.2*	2.52
Sunset Acres	8/27/2008	-10.16	**6.84**	17.2	0.60
Sunset Acres	9/10/2008	-5.08	**5.46**	13.8	0.70
Sunset Acres	9/24/2008	-8.26	**8.46**	7.9	0.56
Sunset Acres	10/8/2008	-11.43	**7.47**	9.5	0.49
Upper Darling Hill	6/4/2008	3.56	1.48	**152.0**	**23.80**
Upper Darling Hill	6/18/2008	0.25	*2.99*	**39.3**	2.21
Upper Darling Hill	7/2/2008	0.25	**10.20**	*23.8*	0.69
Upper Darling Hill	7/16/2008	2.79	**10.80**	*24.6*	0.48
Upper Darling Hill	7/30/2008	-	*4.63*	**37.8**	1.50
Upper Darling Hill	8/13/2008	2.29	1.18	**39.3**	1.38
Upper Darling Hill	8/27/2008	17.78	**6.19**	*32.0*	-
Upper Darling Hill	9/10/2008	3.30	**5.17**	**50.8**	1.32
Upper Darling Hill	9/24/2008	1.27	**11.10**	18.5	0.31
Upper Darling Hill	10/8/2008	2.03	**9.12**	17.7	0.20

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
Wishing Well	6/4/2008	24.13	*2.06*	**326.0**	-
Wishing Well	6/18/2008	17.78	1.11	**173.0**	4.48
Wishing Well	7/2/2008	7.62	0.43	**37.9**	0.98
Wishing Well	7/16/2008	12.70	0.47	**35.6**	1.93
Wishing Well	7/30/2008	12.70	0.64	**61.0**	1.79
Wishing Well	8/13/2008	15.24	0.48	**44.5**	0.92
Wishing Well	8/27/2008	10.16	0.44	*34.3*	1.11
Wishing Well	9/10/2008	10.16	0.46	*31.3*	1.66
Wishing Well	9/24/2008	10.16	0.42	*22.6*	1.08
Wishing Well	10/8/2008	10.16	0.32	18.1	0.74

Appendix C. Quality assurance data, including field blanks and field duplicates, from 20 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during June-October 2008. Bold values indicate field blanks that exceeded detection limits (total phosphorus >5 µg/l, total nitrogen >0.1 mg/l, and turbidity >0.2 NTU) or field duplicates that differed by >15% (turbidity), >20% (total nitrogen), and >30% (total phosphorus).

Field Blanks:

Date	Site	Total nitrogen (mg/l)	Total phosphorus (µg/l)	Turbidity (NTU)
6/4/2008	Holbrook Bay	<0.1	<5	-
6/4/2008	North Derby Road	<0.1	<5	**0.52**
6/4/2008	Middle Darling Hill	<0.1	<5	**0.48**
6/18/2008	Strawberry Acres	<0.1	<5	<0.2
6/18/2008	Johns River	<0.1	<5	<0.2
6/18/2008	Confluence	<0.1	<5	<0.2
7/2/2008	Eagle Point	<0.1	<5	**0.36**
7/2/2008	Upper Darling Hill	<0.1	<5	<0.2
7/2/2008	Beebe Plain	<0.1	<5	<0.2
7/16/2008	Sunset Acres	<0.1	<5	**0.33**
7/16/2008	Darling Hill	<0.1	<5	<0.2
7/16/2008	Elm Street	<0.1	<5	<0.2
7/30/2008	Wishing Well	<0.1	<5	**0.36**
7/30/2008	Crystal Brook	<0.1	<5	<0.2
8/13/2008	Lindsay Beach	<0.1	<5	**0.3**
8/13/2008	Horse Farm	<0.1	<5	<0.2
8/13/2008	Silage Seep	**0.17**	<5	**0.25**
8/27/2008	Holbrook Bay	<0.1	<5	<0.2
8/27/2008	North Derby Road	<0.1	<5	<0.2
8/27/2008	Quarry	<0.1	<5	<0.2
9/10/2008	East Side	<0.1	<5	<0.2
9/10/2008	Beebe Plain	<0.1	<5	<0.2
9/10/2008	Middle Darling Hill	<0.1	<5	<0.2
9/24/2008	Wishing Well	<0.1	<5	<0.2
9/24/2008	Johns River	<0.1	<5	<0.2
9/24/2008	Upper Darling Hill	<0.1	<5	<0.2
10/8/2008	Confluence	<0.1	<5	<0.2
10/8/2008	Darling Hill	<0.1	<5	<0.2
10/8/2008	Sunset Acres	<0.1	<5	**0.27**

Field Duplicates:

Total Phosphorus

Date	Site	1st total phosphorus (µg/l)	2nd total phosphorus (µg/l)	Relative % difference
6/4/2008	Holbrook Bay	**62.5**	**104**	**50**
6/4/2008	North Derby Road	128	106	19
6/4/2008	Middle Darling Hill	258	298	14
6/18/2008	Strawberry Acres	103	104	1
6/18/2008	Johns River	24.7	24	3
6/18/2008	Confluence	22.6	23.2	3
7/2/2008	Eagle Point	41.6	42.4	2
7/2/2008	Beebe Plain	26.6	25	6
7/2/2008	Upper Darling Hill	23.8	23	3
7/16/2008	Sunset Acres	15	15	0
7/16/2008	Darling Hill	33.9	30.4	11
7/16/2008	Elm Street	19.5	20	3
7/30/2008	Wishing Well	61	60.4	1
7/30/2008	Darling Tributary	23.5	23.8	1
7/30/2008	Crystal Brook	23.1	23	0
8/13/2008	Lindsay Beach	23.6	22.7	4
8/13/2008	Horse Farm	11.4	9.5	18
8/13/2008	Silage Seep	20.9	20.4	2
8/27/2008	Holbrook Bay	79.7	81.6	2
8/27/2008	North Derby Road	36.8	37.4	2
8/27/2008	Quarry	17.9	19.3	8
9/10/2008	East Side	25.9	25.1	3
9/10/2008	Beebe Plain	**33.7**	**23.5**	**36**
9/10/2008	Middle Darling Hill	37.2	35.8	4
9/24/2008	Wishing Well	22.6	23.4	3
9/24/2008	Johns River	9.8	9.6	2
9/24/2008	Upper Darling Hill	18.5	18.4	1
10/8/2008	Darling Hill	14.8	19	25
10/8/2008	Sunset Acres	9.5	8.2	15
10/8/2008	Confluence	9.3	9.1	2

Total Nitrogen

Date	Site	1st total nitrogen (mg/l)	2nd total nitrogen (mg/l)	Relative % difference
6/4/2008	Holbrook Bay	**0.39**	**0.5**	**25**
6/4/2008	North Derby Road	-	-	-
6/4/2008	Middle Darling Hill	1.78	1.89	6
6/18/2008	Strawberry Acres	1.35	1.38	2
6/18/2008	Johns River	2.42	2.52	4
6/18/2008	Confluence	2.48	2.53	2
7/2/2008	Eagle Point	0.59	0.57	3
7/2/2008	Beebe Plain	0.43	0.45	5
7/2/2008	Upper Darling Hill	10.2	9.74	5
7/16/2008	Sunset Acres	8.9	8.8	1
7/16/2008	Darling Hill	4.5	4.48	0
7/16/2008	Elm Street	4.3	4.28	0
7/30/2008	Wishing Well	0.64	0.65	2
7/30/2008	Darling Tributary	2.35	2.32	1
7/30/2008	Crystal Brook	1.62	1.62	0
8/13/2008	Lindsay Beach	0.3	0.3	0
8/13/2008	Horse Farm	0.32	0.33	3
8/13/2008	Silage Seep	1.58	1.59	1
8/27/2008	Holbrook Bay	0.47	0.49	4
8/27/2008	North Derby Road	2.97	2.98	0
8/27/2008	Quarry	1.37	1.44	5
9/10/2008	East Side	1.77	1.82	3
9/10/2008	Beebe Plain	1.29	1.34	4
9/10/2008	Middle Darling Hill	3.16	3.14	1
9/24/2008	Wishing Well	0.42	0.41	2
9/24/2008	Johns River	5.47	5.41	1
9/24/2008	Upper Darling Hill	11.1	10.8	3
10/8/2008	Darling Hill	4.64	4.61	1
10/8/2008	Sunset Acres	7.47	7.52	1
10/8/2008	Confluence	4.93	5.18	5

Turbidity

Date	Site	1st turbidity (NTU)	2nd turbidity (NTU)	Relative % difference
6/4/2008	Holbrook Bay	-	2.01	-
6/4/2008	North Derby Road	**14.2**	**37.7**	**91**
6/4/2008	Middle Darling Hill	**6.04**	**59.1**	**163**
6/18/2008	Strawberry Acres	**5.49**	**4.62**	**17**
6/18/2008	Johns River	**2.33**	**1.66**	**34**
6/18/2008	Confluence	**2.2**	**1.68**	**27**
7/2/2008	Eagle Point	1.19	1.18	1
7/2/2008	Beebe Plain	7.12	7.06	1
7/2/2008	Upper Darling Hill	**0.69**	**0.27**	**88**
7/16/2008	Sunset Acres	**1.09**	**1.42**	**26**
7/16/2008	Darling Hill	**1.63**	**1.09**	**40**
7/16/2008	Elm Street	1.09	1.05	4
7/30/2008	Wishing Well	1.79	1.91	6
7/30/2008	Darling Tributary	2.62	2.97	13
7/30/2008	Crystal Brook	0.76	0.85	11
8/13/2008	Lindsay Beach	**8.22**	**5.16**	**46**
8/13/2008	Horse Farm	**0.44**	**0.72**	**48**
8/13/2008	Silage Seep	1.91	1.97	3
8/27/2008	Holbrook Bay	21.7	21.5	1
8/27/2008	North Derby Road	3.77	3.65	3
8/27/2008	Quarry	0.79	0.75	5
9/10/2008	East Side	4.45	4.27	4
9/10/2008	Beebe Plain	**3.91**	**1.34**	**98**
9/10/2008	Middle Darling Hill	1.16	1.08	7
9/24/2008	Wishing Well	1.08	1.07	1
9/24/2008	Johns River	0.68	0.63	8
9/24/2008	Upper Darling Hill	0.31	0.32	3
10/8/2008	Darling Hill	0.54	0.58	7
10/8/2008	Sunset Acres	0.49	0.45	9
10/8/2008	Confluence	**0.75**	**0.94**	**22**

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

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

Algal bloom – A population explosion of algae usually in response to increased nutrients (particularly phosphorus and nitrogen), warm water temperatures, and long periods of sunlight. When these algae die, decomposition can result in oxygen levels that are too low to support many forms of aquatic life.

Basin – A region or area bounded peripherally by a divide and draining into a particular water course or water body. The relative size of a basin and the human alterations to that basin greatly affect water quality in the water body into which it drains.

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

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

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

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

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

Flow – The volume of water that moves past a given point per unit of time.

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

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

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

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

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

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

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

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

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

Respiration – The biological process by which organisms convert sugar and oxygen into carbon dioxide, water, and energy.

Standard error of the mean (SEM) – A statistic that measures the variability of a group of data and describes the precision of the estimate of the mean for that group.

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

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

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

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

Watershed – See basin.

Covering Lake Memphremagog, Clyde, Barton, Black, and Johns Rivers

Memphremagog Watershed Association
P. O. Box 1071
Derby, VT 05829
memphremagogwatershed@gmail.com