Restoring Water Quality in the Lake Memphremagog Basin:
Phosphorus and Nitrogen Levels along
the Johns River and Seven Smaller Tributaries

Prepared for Memphrémagog Conservation Inc., the Memphremagog Watershed Association, and the Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

27 February 2010

Beck Pond LLC

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Beck Pond LLC is owned and operated by Dr. Fritz Gerhardt. Dr. Gerhardt has been working as an ecologist and conservation scientist since 1987 and has a wealth of experience applying ecological research to the conservation and restoration of the natural environment. He completed his B.A. in Religious Studies at Grinnell College, his M.F.S. in Forest Ecology at Harvard University, and his Ph.D. in Community Ecology at the University of Colorado. He has worked for the U.S. Fish and Wildlife Service in Alaska and the Vermont Institute of Natural Science and NorthWoods Stewardship Center in Vermont. Dr. Gerhardt also has extensive teaching experience as a Visiting Instructor at Middlebury College; Teaching Assistant at Harvard University, Dartmouth College, Oregon Institute of Marine Biology, and the University of Colorado; and an instructor teaching secondary school teachers how to incorporate science into their classrooms. He has worked in a variety of terrestrial and aquatic ecosystems, including eastern deciduous forest in northern New England, arctic tundra and boreal forest in Alaska, and annual grassland in California.

Please feel free to contact us if you would like to discuss possible conservation projects.

Cover. *Southern basin of Lake Memphremagog as viewed from the cornfields along Darling Hill Road near Beebe Plain, Vermont on 3 June 2009. These cornfields are one possible source for the high nitrogen levels observed in the surface waters of the Lake Memphremagog Basin.*

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Executive Summary

1. Over the past decade, there has been increasing concern about water quality conditions in Lake Memphremagog, especially the high phosphorus and turbidity levels and more frequent and widespread occurrences of algal and cyanobacterial blooms. Because most of the lake's watershed lies in Vermont, previous projects have focused on identifying the sources of nutrients and sediments along the four principal Vermont tributaries. These studies have identified the Johns River and several of the smaller tributaries as potential sources of high phosphorus and nitrogen levels.

2. In 2009, we sampled water quality at 27 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 NO_x (nitrite plus nitrate). In addition, we measured water depths at several sites and stream flow at one site on the Johns River.

3. Through this sampling, we identified a number of areas that were potential sources of high phosphorus and nitrogen levels. Phosphorus levels were highest along five of the smaller tributaries, the downstream-most section of the Johns River, and the Darling Hill tributary. In contrast, phosphorus levels along Crystal Brook and the middle section of the Johns River were dramatically lower than those measured in 2005 and 2006, no doubt due to the replacement of a failed manure lagoon along Crystal Brook. Although slightly lower than in previous years, nitrogen and NO_x levels remained high at numerous sites throughout the Johns River and adjacent watersheds. The 2009 sampling allowed us to narrow the search for the source(s) of this nitrogen to three areas and to confirm that the nitrogen was indeed originating from groundwater surfacing from springs or seeps in two of these areas.

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 five of the smaller tributaries and 2) identify the pathway(s) by which nitrogen is entering the groundwater flowing into the Johns River and the Sunset Acres tributary. In the meantime, remediation efforts can be initiated to reduce phosphorus and nitrogen inputs in several of the areas where specific problems were identified in this study.

Introduction

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

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

Figure 2. *Cyanobacterial bloom along the north shore of Derby Bay on 23 September 2008 (photo courtesy of Karen Lippens). Cyanobacterial blooms are exacerbated by nutrient and sediment inputs and suggest that water quality is declining in Lake Memphremagog.*

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 recreational activities. Lake Memphremagog and the Clyde River (one of the major Vermont tributaries of Lake Memphremagog) are important links in the Northern Forest Canoe Trail, which extends 1,191 km from Old Forge, New York through Vermont, Quebec, and New Hampshire to Fort Kent, Maine. Lake Memphremagog and other water bodies in the basin also serve as public water supplies, provide hydroelectric power and disposal of treated wastewater, and support agricultural and industrial production. The floodplains and the many wetlands along the lake and in the surrounding watersheds also serve important flood control and water filtration functions. In addition, 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, Quebec/Vermont Steering Committee 2008). The Southern Basin, which lies primarily in Vermont and is the shallowest section of Lake Memphremagog, is listed by the State of Vermont as an impaired surface water needing a Total Maximum Daily Load (TMDL) due to nutrient enrichment and excessive algal growth (Part A, State of Vermont 2008). 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 Quebec/Vermont 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). Crystal Brook, which is a tributary of the Johns River, is listed by the State of Vermont as needing a TMDL due to high nutrient and sediment levels from agricultural runoff (Part A, State of Vermont 2008). The Johns River is listed as needing further assessment due to elevated nitrogen levels (Part C, State of Vermont 2008). In addition, the three larger tributaries, as well as several lakes and ponds in the watershed, are listed as needing further assessment due to elevated mercury, *Escherichia coli*, and toxin levels (Part C, State of Vermont 2008).

Efforts to assess these various threats and to protect and improve water quality in the Lake Memphremagog Basin are coordinated by the Quebec/Vermont Steering Committee on Lake Memphremagog, an international partnership of governmental and non-governmental stakeholders from Vermont and Quebec. Since 2004, the Steering Committee has coordinated water quality monitoring efforts on both sides of the Quebec/Vermont border. The overall goal of these efforts has been to identify and support projects that protect and improve water quality in the Lake Memphremagog Basin. Specifically, monitoring efforts have focused on documenting water quality conditions throughout the watershed, assessing compliance with applicable water quality standards, determining whether a comprehensive pollution control plan was needed for the Vermont waters, and identifying on-the-ground projects that protect and improve water quality in the basin.

Past monitoring and assessment efforts have been undertaken by both governmental agencies and non-governmental organizations (Quebec/Vermont Steering Committee 2008). The Quebec Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP) and Memphrémagog Conservation Inc. (MCI) have been monitoring water quality in the open waters of Lake Memphremagog in Quebec since 1996. The Vermont Department of Environmental Conservation (DEC) has been monitoring water quality in the open waters of the lake in Vermont since 2005. Since 1999, the MRC de Memphrémagog has been monitoring water quality in the tributaries draining the Quebec portion of the Lake Memphremagog Basin. Since 2005, the NorthWoods Stewardship Center, Memphremagog Watershed Association, and Beck Pond LLC have been partnering with the Vermont DEC to monitor water quality in the tributaries draining the Vermont portion of the basin. During 2004-2005, MCI and the Regroupement des Associations pour la Protection de l'Environnement des Lacs (RAPPEL) completed comprehensive assessments of habitat quality of the littoral zones of Lake Memphremagog in both Quebec and Vermont. Finally, in partnership with the Vermont DEC, the NorthWoods Stewardship Center has completed stream geomorphic assessments along all four major Vermont tributaries of Lake Memphremagog.

Although 73 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 nutrient and sediment sources along the four principal Vermont tributaries. Monitoring efforts in 2005 and 2006 identified a number of water quality issues in the watersheds of all four of these tributaries (Gerhardt 2006, Dyer and Gerhardt 2007, Quebec/Vermont Steering Committee 2008). Specifically, these efforts indicated that water quality conditions were poorest in the Johns River watershed, which suffered from extremely high phosphorus and nitrogen levels. The Black River watershed, where agricultural development was most extensive, had the second poorest water quality, as high phosphorus and sediment levels occurred at many sites, especially during high-flow events. The Barton River watershed, which also had extensive areas of agriculture, occasionally exhibited high phosphorus and sediment levels, especially at the downstream sites. Finally, the Clyde River, especially the upper watershed, exhibited relatively low nutrient and sediment levels. In addition, sampling in 2008 indicated that several of the smaller tributaries that flow directly into Lake Memphremagog also suffered from high phosphorus, nitrogen, and turbidity levels (Gerhardt 2009).

Although smaller than the other major Vermont tributaries, the Johns River exhibited far higher phosphorus and nitrogen levels during 2005-2008 and may be one of the few surface waters in Vermont that has exceeded water quality standards for nitrate. This combination of high nitrogen and high phosphorus levels has the potential to dramatically increase the frequency and toxicity of algal and cyanobacterial blooms in Lake Memphremagog. Through our prior sampling, we identified an area of possible nitrogen sources along the middle section of the main stem of the Johns River and the Darling Hill and Sunset Acres tributaries (Gerhardt 2009). In addition, we narrowed our focus on one possible mechanism whereby nitrogen enters these rivers and streams: leaching of nitrogen into groundwater from manure and chemical fertilizers being applied to cornfields located atop porous sand and gravel deposits. In addition, although phosphorus levels had decreased dramatically in the upper watershed of the Johns River, they remained high further downstream as well as along several of the smaller tributaries flowing directly into Lake Memphremagog. Thus, additional sampling was needed to develop a comprehensive understanding of nitrogen and phosphorus dynamics in these watersheds and to identify and prioritize projects and practices to reduce phosphorus, nutrient, and sediment inputs into Lake Memphremagog.

Study Goals

This project continues our efforts to assess and identify threats to water quality and to plan and implement protection and restoration projects along the Vermont tributaries of Lake Memphremagog. 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 (Figure 1). In addition, several of the smaller tributaries that flow directly into Lake Memphremagog had also exhibited high phosphorus, nitrogen, and turbidity levels in 2008. Although small, these tributaries drain some of the most highly developed and densely populated areas in the Vermont portion of the Lake Memphremagog Basin. Thus, the overall goals of this project were to continue our efforts to assess water quality conditions in the watersheds of the Johns River and the seven smaller tributaries and to further identify the source(s) of any water quality problems, so that we can develop and implement protection and restoration projects to reduce nutrient and sediment inputs into Lake Memphremagog. The specific goals of this year’s sampling were five-fold:

1) To further evaluate water quality conditions in seven smaller tributaries of Lake Memphremagog, especially where high nutrient and turbidity levels were observed in 2008,

2) To identify the source(s) of the elevated phosphorus levels in the downstream-most section of the Johns River,

3) To further verify that past remediation efforts have effectively reduced phosphorus levels flowing out of Crystal Brook,

4) To identify specific locations within the Johns River and adjacent watersheds where nitrogen is entering the surface waters,

5) To evaluate whether nitrogen levels in the Johns River and adjacent tributaries exceed State of Vermont water quality standards,

To accomplish these goals, we resampled 14 sites that were sampled in previous years along the Johns River and the seven smaller tributaries plus 13 new sites in order to better pinpoint nitrogen and phosphorus sources in these watersheds. The geographic distribution of these sample sites allowed us to address these five goals and to focus future protection and restoration 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 watershed of the St. Francis River, which flows into the St. Lawrence River. As noted previously, the Southern Basin of Lake Memphremagog is fed by three major tributaries that lie entirely within Vermont (the Black, Barton, and Clyde Rivers) and one smaller tributary that straddles the Quebec/Vermont 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 Quebec/Vermont border (Figure 3). The Johns River is fed by Crystal Brook and several other, smaller tributaries. In addition to the four major tributaries, numerous smaller tributaries flow from the eastern and western shores directly into Lake Memphremagog.

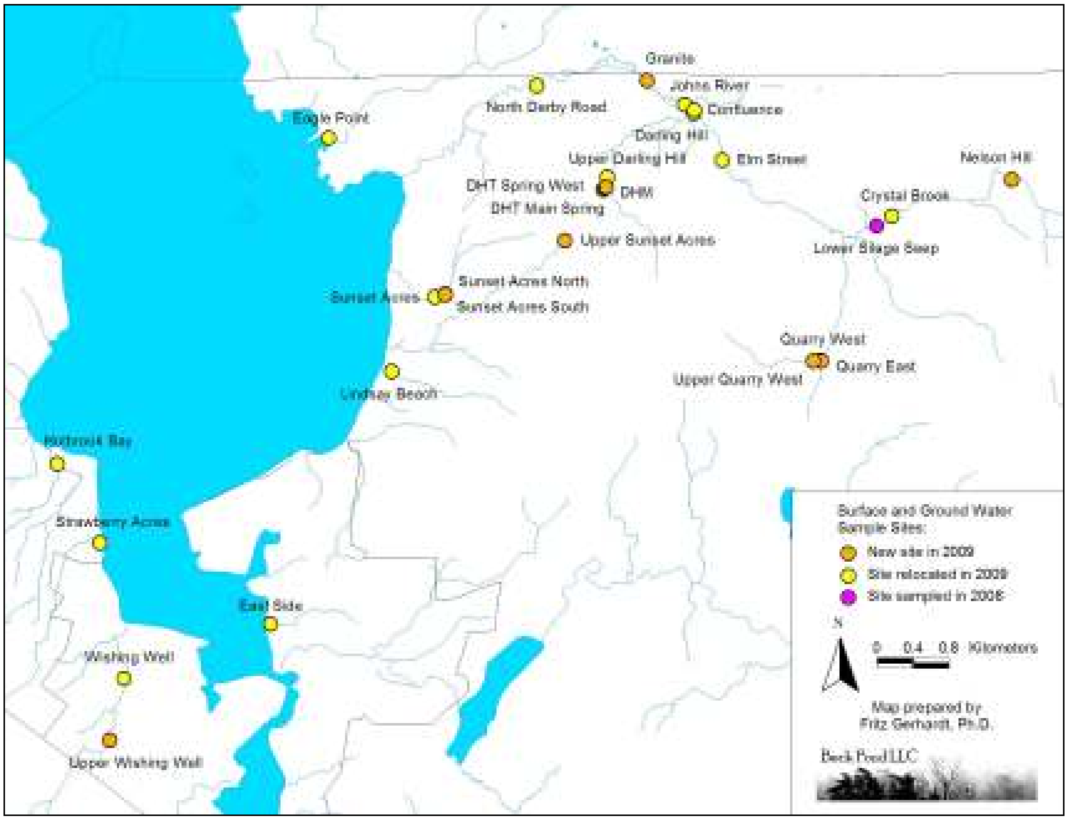

Figure 3. *Locations of 27 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009.*

In this project, we sampled water quality at 27 sites distributed throughout the watersheds of the Johns River and seven smaller tributaries of Lake Memphremagog (Figure 3; see Appendix A for descriptions of all sites). In the Johns River watershed, we sampled water quality at 16 sites, seven of which had been sampled in previous years. One site (Johns River) was previously sampled in 2005, 2006, and 2008; three sites (North Derby Road, Darling Hill, and Crystal Brook) were sampled in 2006 and 2008; and three other sites (Confluence, Elm Street, and Upper Darling Hill) were sampled in 2008. To better understand the high nitrogen and phosphorus levels previously observed in this watershed, we added nine additional sites along the main stem (Granite), Crystal Brook (Lower Silage Seep and Nelson Hill), the Darling Hill tributary (DHT, DHM Main Spring, and DHM Spring West), and another small tributary (Quarry East, Quarry West, and Upper Quarry West). Along the seven smaller tributaries, seven of the 11 sites were sampled previously in 2008. One new site was added along the Wishing Well tributary, and three new sites were added along the Sunset Acres tributary. Four of the sites along the smaller tributaries were located on the western side of the lake (Holbrook Bay, Strawberry Acres, Wishing Well, and Upper Wishing Well), and seven sites were located on the eastern side of the lake (East Side, Lindsay Beach, Sunset Acres, Sunset Acres North, Sunset Acres South, Upper Sunset Acres, and Eagle Point).

During April-October 2009, we sampled each site at biweekly intervals, although not all sites were sampled on all sample dates (see Appendix A for list of dates on which each site was sampled). Only 13 sites, primarily those located in the Johns River watershed and along the Sunset Acres tributary, were sampled on all 14 dates during the sampling season (22 April-21 October 2009). Seven of the sites along the seven smaller tributaries were sampled on nine dates (1 July-21 October 2009). Another five sites were added as the season progressed in order to better identify phosphorus and nitrogen sources within specific watersheds (initial sample dates ranged between 3 June and 9 September but all were sampled through 21 October 2009). Finally, two sites were dropped during the course of the season due to either loss of permission to access the site or beavers (*Castor canadensis* L.) repeatedly blocking stream flow through a culvert.

Methods

To accomplish the goals of this study, we collected water samples at biweekly intervals during April-October 2009. 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). Before collecting the samples, we rinsed the total nitrogen, NO_x, and metals sample bottles and the dip sampler with sample water three times. Based on the Quality Assurance Project Plan (see following paragraph), we also collected 2-3 field blanks and 2-3 field duplicates on each sample date for quality assurance analyses. All samples were collected in a single day, stored in coolers, and delivered to the LaRosa Analytical Laboratory the next morning. This schedule ensured that the laboratory was able to process the samples in a timely manner. Water samples were analyzed for total phosphorus, total nitrogen, nitrite plus nitrate (NO_x), and a target list of analyte metals (the results of the latter tests are not presented in this report, as they will be analyzed separately to identify groundwater inputs). Total phosphorus and total nitrogen were sampled at all sites, but NO_x was only sampled at sites in the Johns River watershed and along the Sunset Acres tributary.

On each sample date, we measured water depth with a meter stick at seven sites along the smaller tributaries and five sites in the Johns River watershed. We also measured stream flow on each sample date near the Johns River site with a SonTek Acoustic Doppler Flowtracker (SonTek, San Diego, CA). In order to develop a continuous record of stream flow, we also placed a water level data logger (YSI 600 LS vented sonde; YSI, Yellow Springs, Ohio) near the Johns River site. Using the stream flow and water depth measurements, we were developed a rating curve that will allow us to estimate flow levels for the entire sampling season. These flow measurements, when combined with the phosphorus and nitrogen concentrations, will ultimately allow us to calculate daily phosphorus and nitrogen loads for each sample site (not presented in this report).

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 only with de-ionized water and, if done properly, should result in values below the detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.05 mg/l for NO_x). Field duplicates involved collecting a second sample at the same time and place as the original sample. When done properly, the mean relative difference between the duplicate samples should be less than 30% for total phosphorus, 20% for total nitrogen, and 10% for NO_x.

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

Results and Discussion

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

Water Depth and Stream Flow

Stream flow measures the volume of water passing a specific location per unit of time and is a function of the area of the stream cross-section and water velocity. Stream flow affects both water quality and the quality of aquatic and riparian habitats. For example, fast-moving streams are more turbulent and better aerated than slow-moving streams. High flows also dilute dissolved and suspended pollutants but, at the same time, also typically carry more sediment and nutrients. Stream flow is extremely dynamic and changes frequently in response to changes in temperature, precipitation, and season.

Although water depth does not measure stream flow directly, it does provide an indirect measure of stream flows among sample dates. In contrast to previous years, water depths were generally low throughout the 2009 sampling season, even early in the season when snowmelt and spring thaw typically result in high water levels and despite frequent, heavy rains during June and July (Figure 4). Water depths were high on only one scheduled sample date (7 October). We did record high water levels on two other dates when we were working in the area on other projects, and we did collect total phosphorus samples at the Johns River site on those two dates (15 June and 31 July).

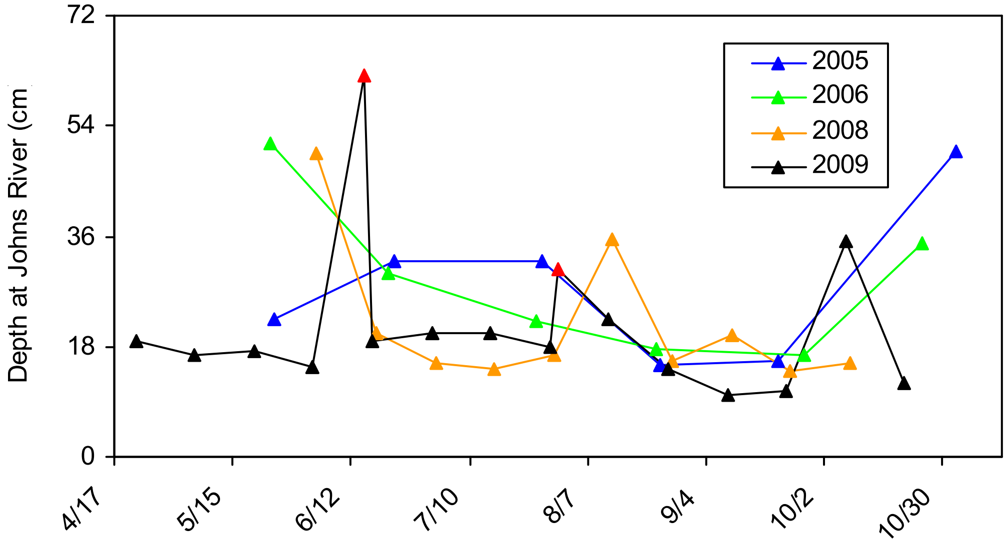

Figure 4. *Water depths measured on each sample date at the Johns River site during April-October 2009. Water depths measured at the same site during 2005-2008 are included for comparative purposes. The red triangles on the 2009 line represent two high-flow events that occurred outside of the regular sampling dates.*

Although water depth provides a good indicator of relative water levels, stream flow measures the actual volume of water passing through the channel at any given time. During 2009, we measured stream flows near the Johns River site on 13 occasions, including all but the first three sample dates. As with water depth, peak flows occurred on 15 June, 31 July, and 7 October. Although generally low on all other dates, stream flows did show a slight increase through June and July and then a decline thereafter (Figure 5).

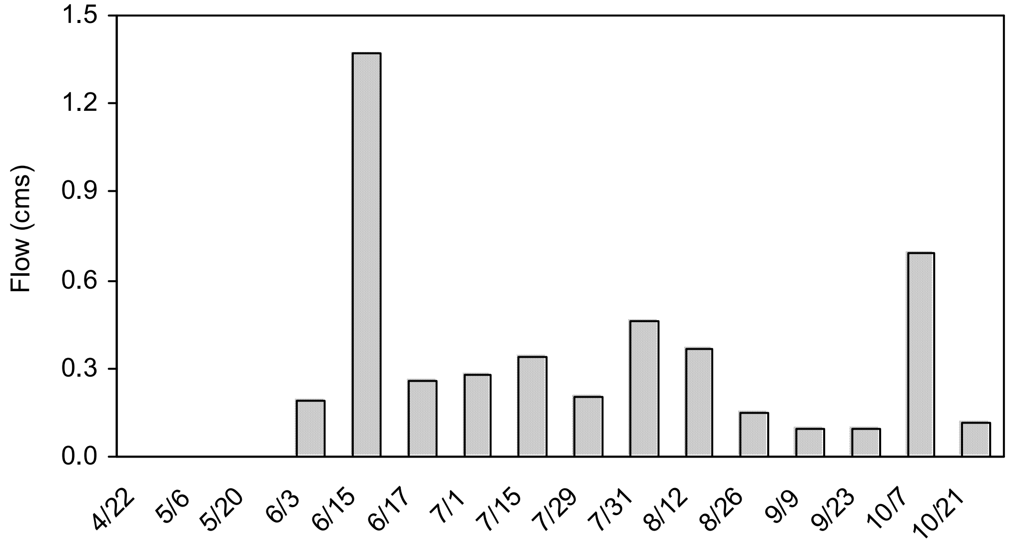

Figure 5. *Stream flows measured on each sample date near the Johns River site during April-October 2009. Stream flows were not measured on the first three sample dates.*

A more complete record of water depths was provided by the water level data logger installed near the Johns River site. This data logger recorded water depths every 20 minutes during 13 May-3 November 2009 (Figure 6). Although baseline water levels were low throughout the season, water depths did peak on numerous dates during June and July and, to a lesser extent, in May, late September, and October. These spikes in water depths typically followed heavy rains, which occurred frequently in late June, July, late September, and early October (Figure 7). However, even after those heavy rains and high-flow events, water levels quickly dropped back to baseline levels.

Seasonal patterns of water depth and stream flow have varied dramatically among years during 2005-2009. In 2005, water depths were generally high in the spring, decreased through the summer, and were highest in October, when heavy rains caused widespread but minor flooding (Gerhardt 2006). In 2006, water depths were highest in May when heavy rains fell on soils already saturated by spring snowmelt (Dyer and Gerhardt 2007). In 2008, water depths and stream flows were relatively low throughout summer and fall, except following heavy rains in early June and early August (Gerhardt 2009). Finally, in 2009, water depths and stream flows were generally low throughout the sampling season, except following heavy rains on numerous dates during June and July and, to a lesser extent, in May, late September, and October (Figure 7).

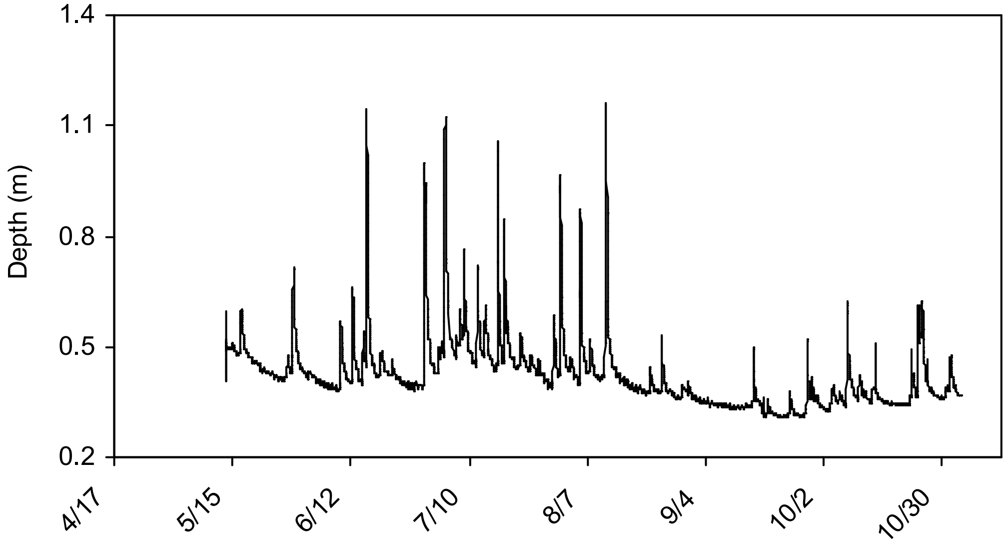

Figure 6. *Water depths recorded by the water level data logger installed near the Johns River site during April-November 2009.*

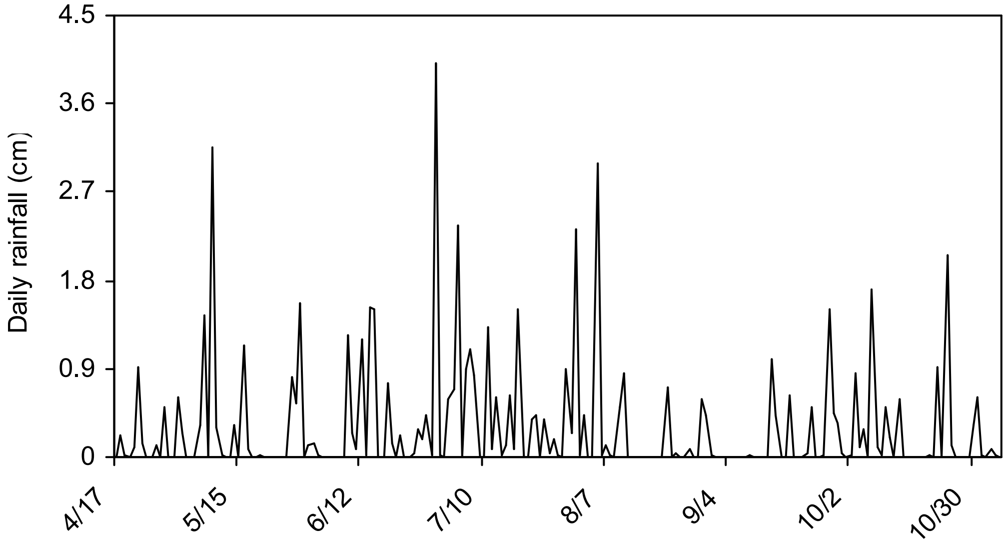

Figure 7. *Daily rainfall amounts measured at an automated weather station along Darling Hill Road (KVTNEWPO4, MADIS ID C5191) in Derby, Vermont during April-November 2009.*

This annual variation in stream flow patterns reflects the dynamic nature of stream flow and its sensitivity to both short- and long-term changes in temperature and precipitation patterns. In this region, stream flows are generally greatest following spring snowmelt and secondarily during the autumn, when lower temperatures decrease evaporation rates and plants no longer photosynthesize and transpire water. In contrast, stream flows are generally lowest during late summer even though precipitation levels are typically higher then (often in the form of heavy downpours during thunderstorms) but so are evaporation and transpiration rates. Along the Johns River, this pattern was most evident in 2006 and least evident in 2009 (Figure 4). In 2009, little snow fell in late winter, and the spring thaw and snowmelt began earlier and was more gradual than in other years. In addition, precipitation levels were very low during May and again in August, and water levels remained low throughout those months. In contrast, precipitation levels were extremely high during June and July, but, even then, flow levels quickly returned to baseline levels, presumably due to less groundwater and other inputs, which were depleted by the dry spring and lack of snowmelt.

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 and regulates the amount of aquatic life growing in those systems. Consequently, high phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to oxygen depletion and mortality of aquatic life. In Vermont, most phosphorus originates from soil erosion, wastewater, and synthetic fertilizers applied to lawns and agricultural fields.

Total phosphorus concentrations in this study ranged between 8.5-762 µg/l. Total phosphorus concentrations showed no obvious seasonal pattern and were fairly uniform throughout the sampling season, except they were both lowest and highest on the two October sample dates (Figure 8). This lack of seasonal pattern may reflect the generally low flows observed throughout the sampling season and the consequent lack of surface runoff carrying sediment and nutrients. October 7th was the only high-flow event sampled at all sites, and both median and individual phosphorus levels were an order of magnitude greater on this than other dates.

Moderate and high phosphorus levels were measured at several sites along the Johns River and the seven smaller tributaries. Median total phosphorus concentrations at individual sites ranged between 9.1-74.8 mg/l. Median total phosphorus concentrations exceeded 35 µg/l [what might be considered a baseline level in this watershed (Ben Copans, personal communication)] at six sites along five of the smaller tributaries and the upstream-most site along the Darling Hill tributary (Figures 9-10). Median phosphorus concentrations exceeded 20 µg/l at seven other sites in the Johns River watershed and along the Sunset Acres tributary, including one site that had exceeded 35 µg/l in 2008 (North Derby Road).

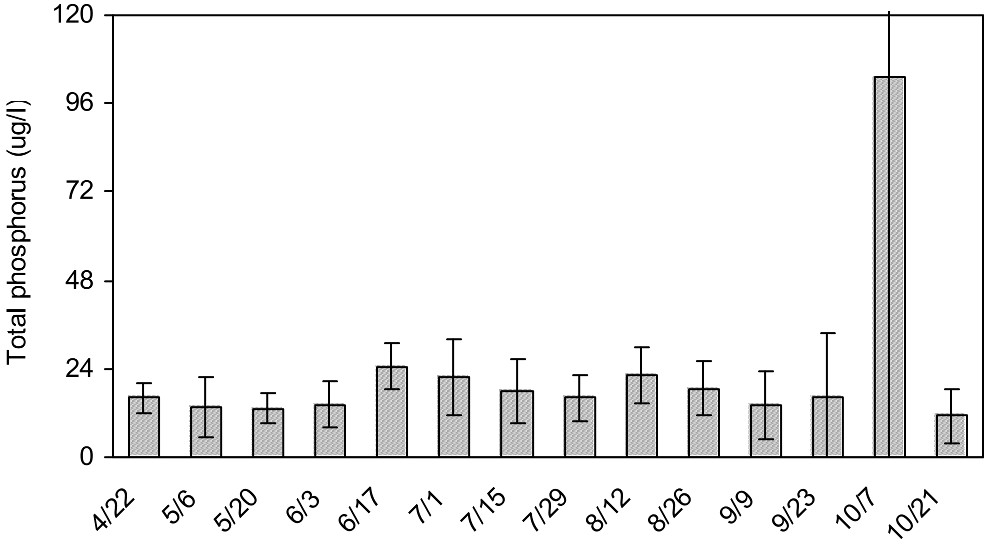

Figure 8. *Median total phosphorus concentrations (±1 SD) measured on each sample date at 13 sites along the Johns River and the Sunset Acres tributary during April-October 2009. These values include only those 13 sites sampled on all 14 sample dates.*

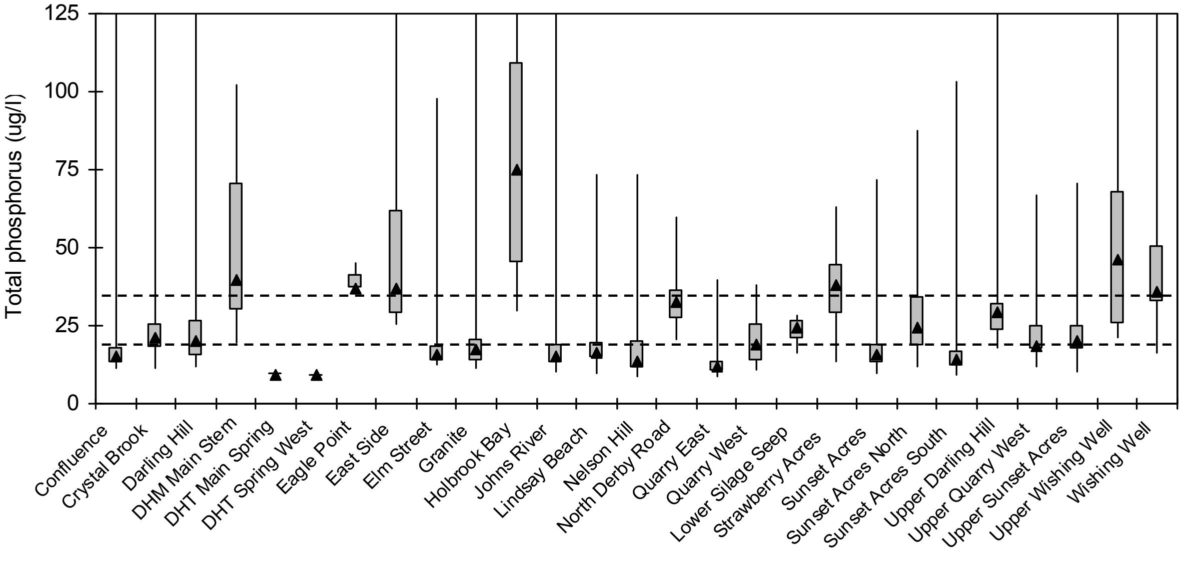

Figure 9. *Median total phosphorus concentrations measured at the 27 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line). The horizontal lines indicate what might be considered baseline phosphorus levels (20 and 35 µg/l).*

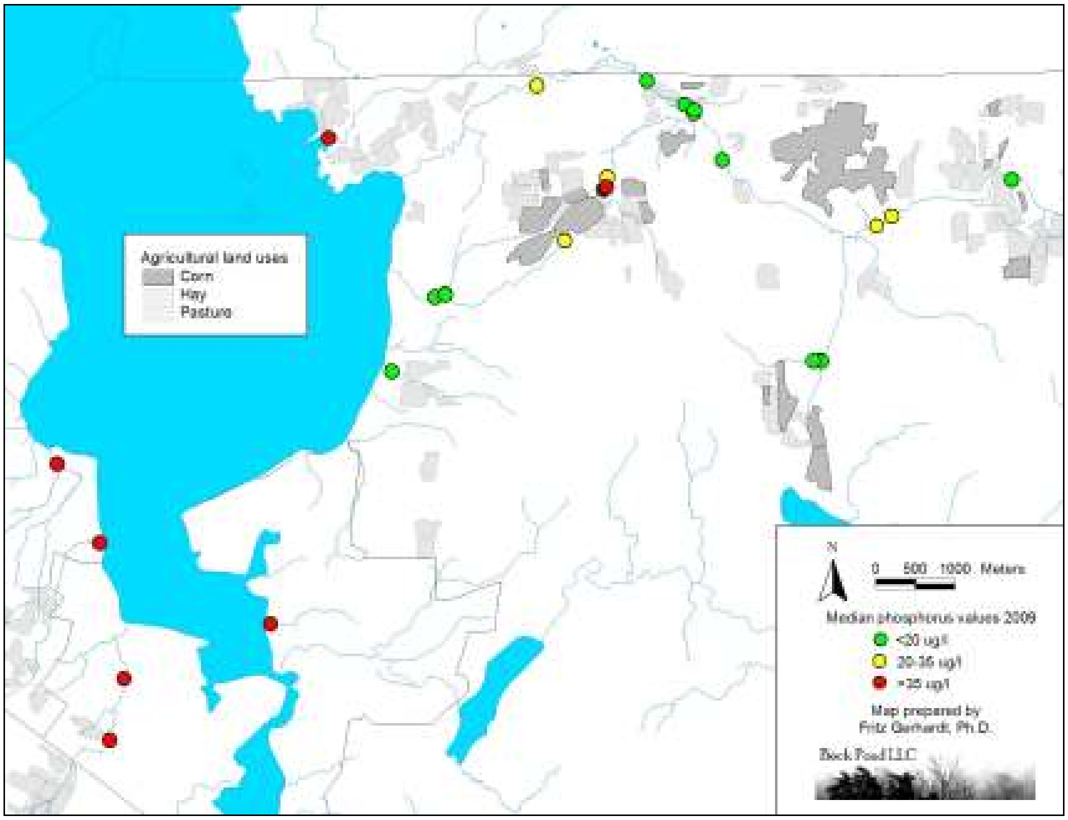

Figure 10. *Median total phosphorus concentrations and the locations of active agricultural fields along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009.*

Total phosphorus concentrations generally increased with increasing water depth, even when the single high-flow event was excluded from the analyses (Figure 11). This pattern was even more pronounced at two of the sites that had higher median phosphorus concentrations (Figure 12; Wishing Well and Upper Wishing Well). This positive relationship is fairly typical of rivers and streams in which most of the phosphorus originates from nonpoint sources, such as agricultural and urban and suburban runoff. This overall positive relationship contrasts sharply with the negative relationship between phosphorus levels and water depth observed in 2006, when much of the phosphorus likely originated from the failed manure lagoon along Crystal Brook (Dyer and Gerhardt 2007). Indeed, the relationship at the Crystal Brook site in both 2008 and 2009 closely approximated the overall positive relationship observed across all sites (Figure 12). No doubt this change reflects the elimination of the phosphorus inputs from the failed manure lagoon along Crystal Brook.

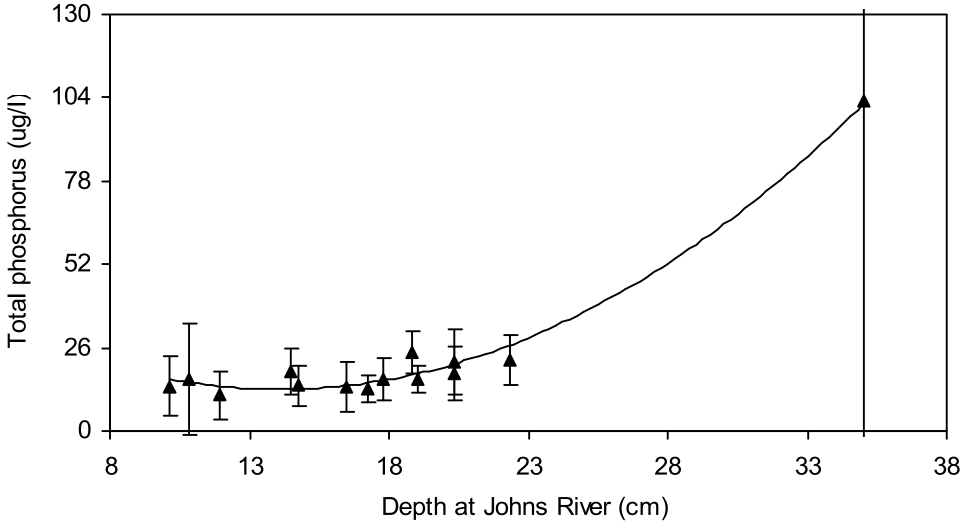

Figure 11. *Median total phosphorus concentrations (±1 SD) in relation to water depth at the 13 sites sampled on all 14 sample dates along the Johns River and the Sunset Acres tributary during April-October 2009. The regression line indicates the polynomial relationship between the two parameters.*

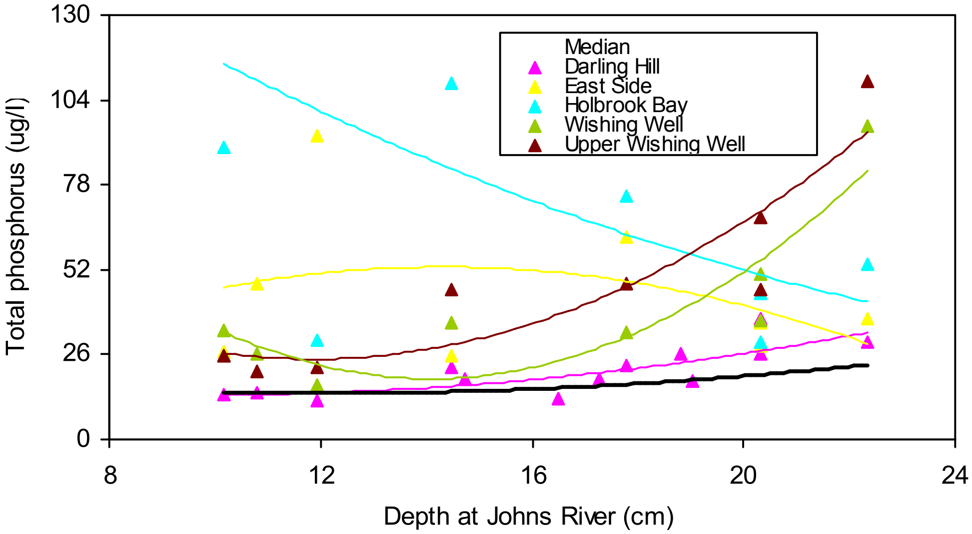

Figure 12. *Total phosphorus concentrations in relation to water depth at selected sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. The regression lines indicate the polynomial relationships between the two parameters; the solid black line represents the polynomial relationship including all 13 sites sampled on all 14 sample dates.*

In contrast, several sites showed different relationships between total phosphorus concentrations and water depth. The site with the highest median phosphorus concentration (Holbrook Bay) showed a negative relationship between phosphorus concentration and water depth (Figure 12). Such negative relationships suggest that the phosphorus originated from groundwater or point sources, rather than nonpoint sources. A second site (Eagle Point) showed a similar negative relationship in 2008 but was sampled on only three dates in 2009. The streams at both of these sites drain large areas of pastures and hayfields, which were heavily manured during the summer, but the negative relationship suggests that there might be other sources of phosphorus in these two watersheds. In addition, two sites (Darling Hill and East Side), one of which also had higher phosphorus levels, showed curvilinear relationships between phosphorus concentrations and water depth. That is, at these two sites, phosphorus concentrations decreased with increasing water depth during low flows (e.g. water depth <15 cm at the Johns River site) but increased with increasing water depth during high flows (e.g. >15 cm). This relationship suggested that there may be a combination of point and nonpoint source inputs in the areas drained by these two sites.

As in 2008, the highest phosphorus levels occurred along five of the seven smaller tributaries, including the four tributaries located at the southern end of the lake in Newport City and Newport Town (Figure 13). These areas were dominated by either urban development (East Side), a mix of suburban development and agricultural fields (Wishing Well, Upper Wishing Well, Strawberry Acres, and Holbrook Bay), or agricultural fields and wetlands (Eagle Point). In the urban and suburban areas, likely sources of phosphorus included phosphorus fertilizers being applied to lawns and gardens as well as runoff from paved surfaces and gravel roads. In the Lake Champlain Basin, lawns exported three times more phosphorus per acre on average than did agricultural lands (State of Vermont 2002). Many hayfields and pastures also occurred in these areas, especially near the Holbrook Bay, Upper Wishing Well, and Eagle Point sites; and these fields and pastures may be sources of additional phosphorus inputs. In the case of the Wishing Well tributary, phosphorus levels were higher at the upper site, which was located closer to a large area of active pastures and hayfields (Figure 14). Finally, the large wetland complex upstream of the Eagle Point site may capture and retain much of the sediment and phosphorus flowing downstream but release some of the particulate and dissolved phosphorus during the summer growing season, especially during low flows (Figure 15).

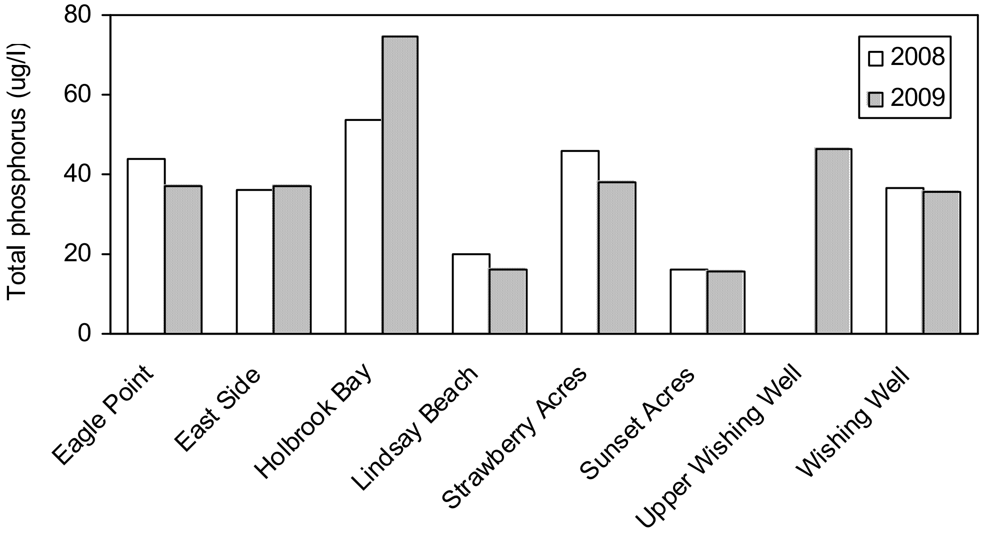

Figure 13. *Median total phosphorus concentrations measured at the eight sites along the seven smaller tributaries of Lake Memphremagog during 2008 and 2009. The horizontal lines indicate what might be considered baseline phosphorus levels (20 and 35 μg/l).*

Figure 14. *Possible sources of phosphorus include surface runoff from the pastures and hayfields in the upper watershed of the Wishing Well tributary (photographed on 16 November 2009).*

Figure 15. *Wetlands located near the mouth of the Eagle Point tributary (a.k.a. Hall's Brook) may trap and retain sediment and phosphorus during high-flow events but may release phosphorus during summer low flows (photographed on 20 May 2009).*

In the Johns River watershed, median phosphorus levels exceeded 20 µg/l at six sites and 35 µg/l at one site (Figures 9-10). These higher phosphorus levels were concentrated in three areas: the upper section of the Darling Hill tributary, Crystal Brook, and the downstream-most section of the main stem. The higher phosphorus levels in the Darling Hill tributary were most pronounced in the upper watershed. Following the phosphorus "profile" up the Darling Hill tributary, phosphorus levels were consistently higher upstream and far surpassed the levels observed flowing from the two groundwater springs in that watershed (Figure 16). Thus, the high phosphorus levels in this tributary likely originated in the upper part of this watershed, which is mostly agricultural and forest land. Possible sources for this phosphorus included overflow from a manure lagoon located immediately uphill of this stream, surface runoff from nearby cornfields, and/or cattle grazing directly in the stream (Figure 17).

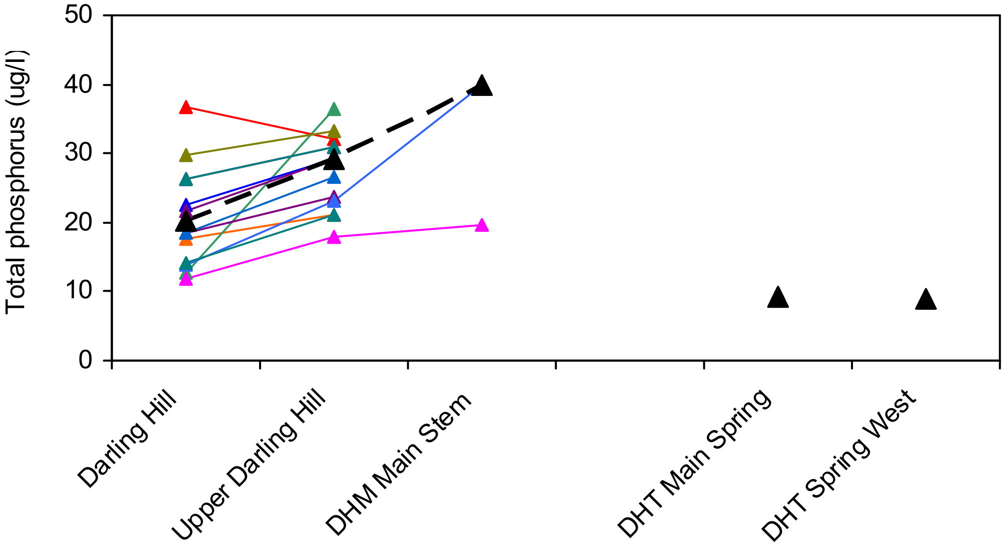

Figure 16. *Total phosphorus "profile" along the Darling Hill tributary from DHM Main Stem downstream to Darling Hill and from two groundwater springs along this tributary during April-October 2009. The dashed black line and large black triangles indicate the median value across all sample dates at each site.*

Following the phosphorus "profile" downstream along Crystal Brook and the main stem of the Johns River, phosphorus concentrations rose dramatically downstream of Nelson Hill, increased slightly between Crystal Brook and Lower Silage Seep, decreased from there to Elm Street, and remained relatively low until increasing dramatically between Granite and North Derby Road (Figure 18). This pattern was consistent across all but a few sample dates, primarily those during moderate and high-flow events. The decrease between Lower Silage Seep and Elm Street may reflect dilution by water flowing in from other tributaries of the Johns River, all of which exhibited relatively low phosphorus concentrations (e.g. the Quarry East and Quarry West sites).

Figure 17. *Possible sources for the high phosphorus levels observed in the upper section of the Darling Hill tributary include surface runoff and erosion from cattle grazing in the stream and a manure lagoon that occasionally overflowed uphill of this tributary (photographed on 30 July 2009).*

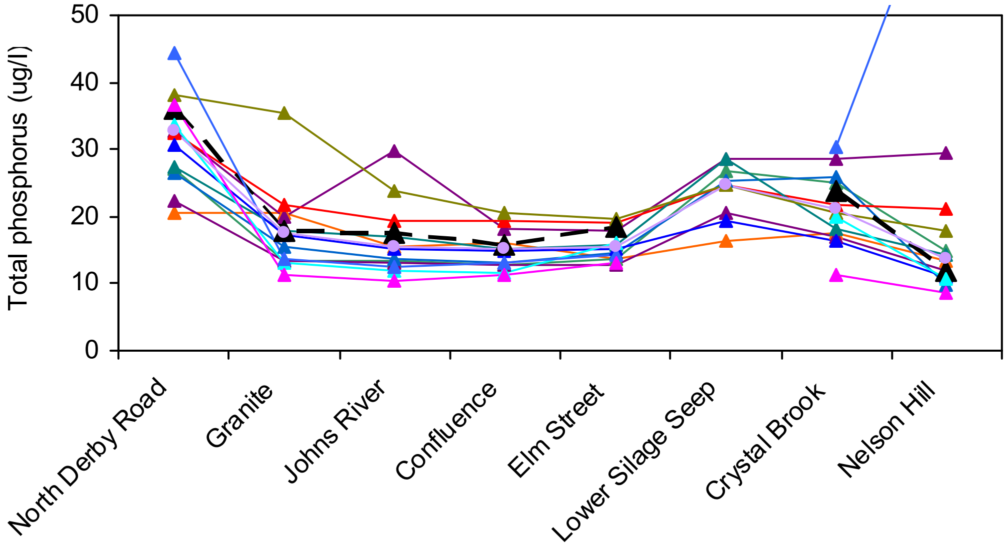

Figure 18. *Total phosphorus "profile" along Crystal Brook and the main stem of the Johns River from Nelson Hill downstream to North Derby Road during April-October 2009. The dashed black line and large black triangles indicate the median value across all sample dates at each site.*

Along Crystal Brook, the higher phosphorus levels were most pronounced at the Crystal Brook and Lower Silage Seep sites. These relatively high levels may be the legacy of the failed manure lagoon, which was replaced in the summer of 2007, and runoff from a silage storage area, which was captured by a drainage system starting in the summer of 2009. Although still elevated, the median phosphorus concentration at the Crystal Brook site has declined to <20% of its 2006 value (Table 1, Figure 19). Prior to the replacement of the failed manure lagoon, total phosphorus concentrations exceeded 35 µg/l at Crystal Brook on all six sample dates in 2006 (Dyer and Gerhardt 2007). Following the replacement of the manure lagoon, phosphorus concentrations at Crystal Brook exceeded 35 µg/l on only one of 10 dates in 2008 (Gerhardt 2009) and one of 14 dates in 2009 (this study). Thus, replacing the failed manure lagoon and curtailing the runoff from the silage storage area have dramatically improved water quality conditions and will hopefully improve the health of the aquatic communities in Crystal Brook and further downstream. Indeed, we observed caddisfly larvae (Order Trichoptera), an extremely sensitive indicator of pollution, in Crystal Brook for the first time in 2009, and, as in 2008, we observed no evidence of sewage fungus, a microbial indicator of extremely poor water quality.

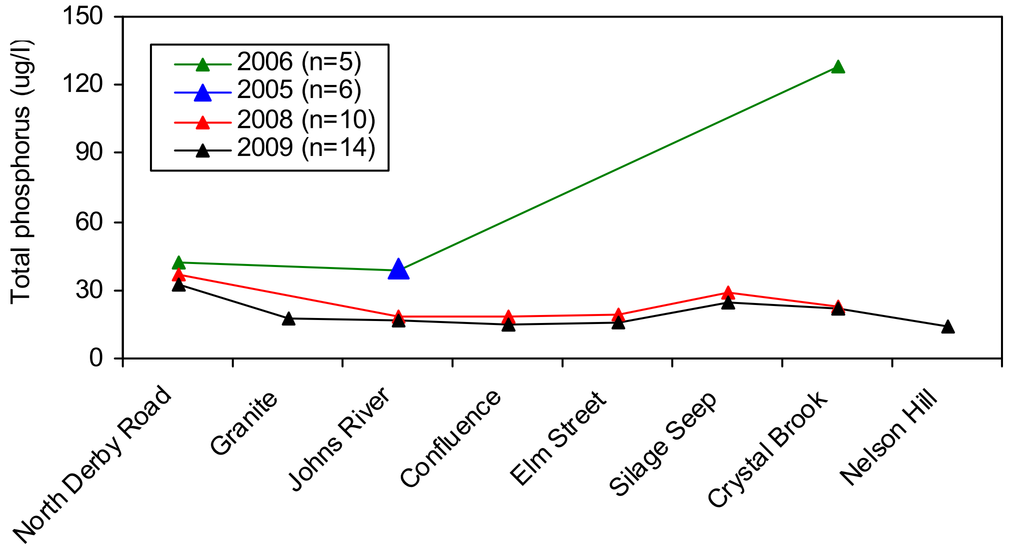

Figure 19. *Median total phosphorus "profile" along Crystal Brook and the main stem of the Johns River from Nelson Hill downstream to North Derby Road during 2005-2008. The sample size (n) is the number of dates sampled in each year.*

Table 1. Median and percent reduction in total phosphorus concentrations at three sites along the Johns River and Crystal Brook during 2006-2009. Values in parentheses are the range measured at each site in each year.

	2006	2008		2009	
	Median (µg/l)	Median (µg/l)	% of 2006 Value	Median (µg/l)	% of 2006 Value
Crystal Brook	127.7 (29-655)	22.9 (14-87)	18	21.6 (11-214)	17
Johns River	38.5 (21-51)	18.6 (10-204)	48	16.9 (10-376)	44
North Derby Road	41.9 (35-62)	36.7 (32-128)	88	32.4 (20-60)	77

This improvement in water quality was also observed further downstream at the Johns River site, which has been sampled since 2005 (Table 1, Figure 19). In 2005, median phosphorus concentrations at the Johns River site were 39.8 µg/l (range = 17-82 µg/l), and total phosphorus concentrations exceeded 35 µg/l on three of six sample dates in 2005 and four of six dates in 2006. However, following replacement of the manure lagoon in 2007, total phosphorus concentrations at the Johns River site exceeded 35 µg/l on only one of ten dates in 2008 and one of 14 dates in 2009. Thus, median phosphorus concentrations at the Johns River site have declined to <50% of their 2005 and 2006 values. Although the failed manure lagoon was located more than 4 km upstream of the Johns River site and although numerous other tributaries entered the Johns River between the Crystal Brook and Johns River sites, there was still a dramatic reduction in phosphorus levels at the Johns River site.

Interestingly, these reductions were most apparent at low stream flows (Figure 20). At low flows (water depths <24 cm), phosphorus concentrations at the Johns River site were lower in 2008-2009 than in 2005-2006. In contrast, at moderate and high flows (water depths >24 cm), results were more mixed, and phosphorus concentrations were actually higher in 2008-2009 than in 2005-2006. In part, these contrasting results may reflect the limited number of samples collected during high-flow events (1-3 times per year) and the importance of the timing of sampling relative to the timing of precipitation in determining phosphorus levels. However, these results were also consistent with reduced phosphorus inputs from the failed manure lagoon along Crystal Brook, which represented a majority of the phosphorus inputs at low flows, and the increased importance of nonpoint sources, such as surface runoff from urban, suburban, and agricultural land uses. Thus, these data were consistent with the notion that past remediation efforts have effectively reduced phosphorus levels in Crystal Brook and the upper reaches of the Johns River.

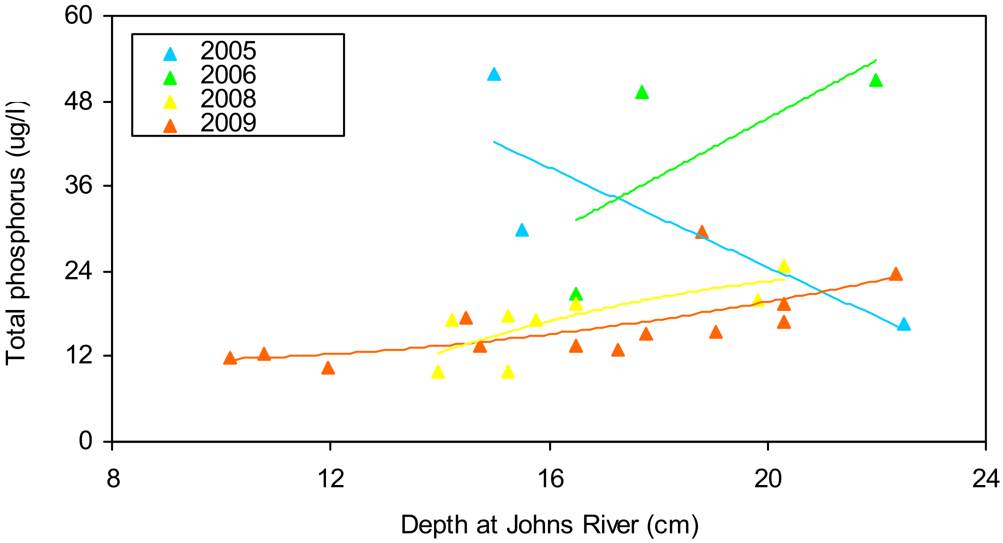

***Figure 20.** Total phosphorus concentrations in relation to water depth at the Johns River site during 2005-2009. The regression lines indicate the polynomial relationships between the two parameters.*

Unfortunately, similar reductions in phosphorus concentrations were not measured at the downstream-most site (North Derby Road), even though it was located only 3 km further downstream of the Johns River site and although there were few additional tributary inputs between the two sites. In contrast to the Crystal Brook and Johns River sites, median phosphorus concentrations at North Derby Road declined to only 88% of their 2006 values in 2008 and 77% of their 2006 values in 2009 (Table 1, Figure 19). Total phosphorus concentrations at the North Derby Road site exceeded 35 µg/l on five of six sample dates in 2006, eight of ten dates in 2008, and five of 14 dates in 2009. Thus, although declining somewhat, the high phosphorus levels at North Derby Road suggested that the Johns River was still sending significant amounts of phosphorus into Lake Memphremagog.

There are several possible explanations for why phosphorus levels remained relatively high at the North Derby Road site. First, runoff from the granite operations in Beebe Plain may transport sediment and attached phosphorus into the Johns River; however, much of this runoff was captured by settling ponds. Second, as noted by Dyer (2008), the abundant beaver activity in the wetlands upstream of the North Derby Road site may disturb instream and streambank sediments and release large amounts of phosphorus into the river. Third, sediment and phosphorus from the Johns River and Crystal Brook may have accumulated in these wetlands in the past, and the residual phosphorus may not have completely flushed out of the downstream sections of the river at this time. Finally, by adding a sample site upstream of these wetlands (Granite), we were able to eliminate the grazing and associated streambank erosion in an unfenced pasture between the Johns River and Granite sites as the primary source of the high phosphorus levels at North Derby Road.

All three of the proposed hypotheses were supported by the water quality data to varying degrees. At low flows, phosphorus levels were higher at the North Derby Road site than the Granite and Johns River sites and showed a negative relationship with water depth (Figure 21). In contrast, at high flows, phosphorus levels were still higher at the North Derby Road site than the Granite and Johns River sites but showed a positive relationship with water depth. Such patterns suggest that, at low flows, phosphorus was originating from either a point source, such as the settling ponds, or was being released from sediments by beaver activity or decomposition of organic matter in the wetlands. In all three scenarios, the majority of the phosphorus at high flows would have originated from surface runoff and nonpoint sources. One other line of evidence supported the third hypothesis. Phosphorus levels at North Derby Road (but not Granite) increased throughout the growing season (Figure 22), as would be expected if phosphorus was being released through decomposition of organic matter in the wetlands. If this third hypothesis is correct, we may expect to see further declines in phosphorus levels at the North Derby Road site now that phosphorus levels have declined in upstream areas of the watershed.

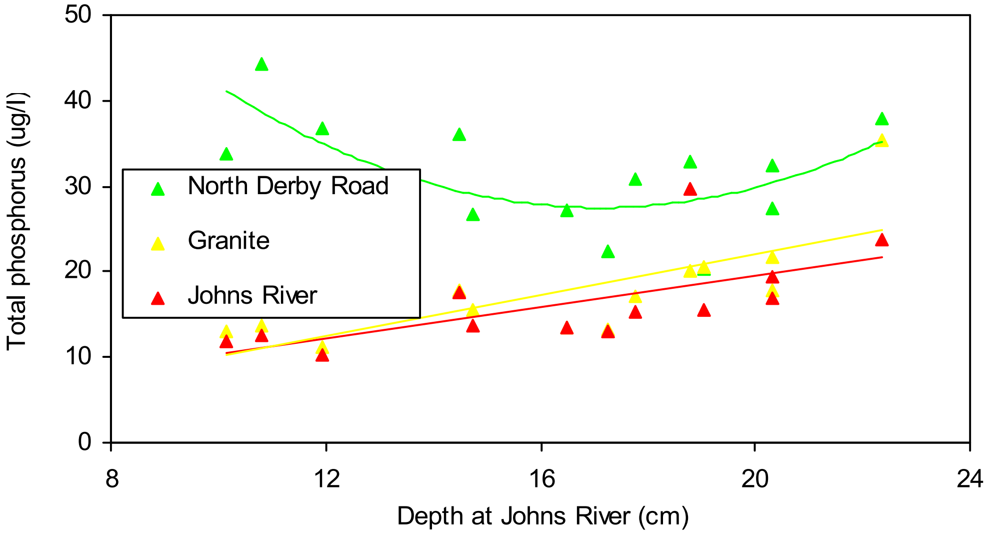

Figure 21. *Total phosphorus concentrations in relation to water depth at the North Derby Road, Granite, and Johns River sites during April-October 2009. The regression lines indicate the polynomial (North Derby Road) and linear (Granite and Johns River) relationships between the two parameters.*

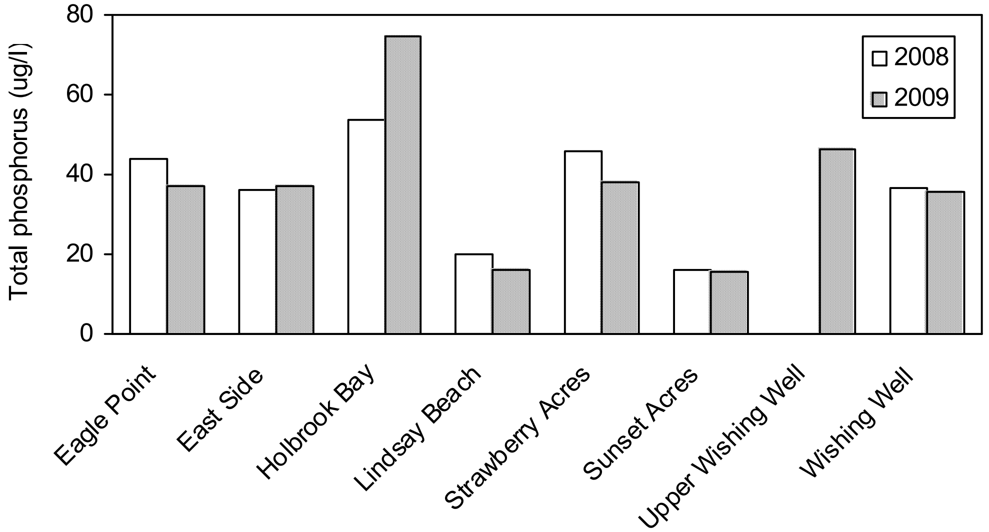

Figure 22. *Total phosphorus concentrations in relation to sample date at the Eagle Point, North Derby Road, and Granite sites during April-September 2009. The regression lines indicate the linear relationships between the two parameters, and the dashed black line and large black triangles indicate the median value across the 13 sites sampled on all 14 sample dates.*

Because we sampled only one high-flow event during 2009, we were unable to calculate accurate and precise phosphorus loads for each site. However, we were able to calculate flow-weighted averages that present a more complete picture of the amounts of phosphorus being transported past each site. Unlike median values, flow-weighted averages emphasize the phosphorus concentrations measured during high-flow events, since they represent a larger proportion of the total volume of water flowing past each site during the sampling season. In addition, these high-flow events likely carry the majority of the phosphorus load during each year (State of Vermont 2002). Flow-weighted averages were calculated for each site by multiplying stream flow and phosphorus concentration on each sample date, summing the resulting products across all sample dates, and then dividing the sum by the sum of stream flows measured on all sample dates. However, we caution that these flow-weighted averages are preliminary; are heavily weighted towards the measurements obtained during the single high-flow event; and are no doubt influenced by the timing of sampling at each site relative to the timing of rainfall that day.

The median and flow-weighted average phosphorus values at many sites generally paralleled each other (Figure 23). However, at several sites, the median and flow-weighted averages presented different perspectives on the phosphorus dynamics at those sites. The biggest difference occurred at the Darling Hill site, which had a moderate median phosphorus concentration (20.1 µg/l) but the highest flow-weighted average phosphorus value. Thus, both the upstream and downstream sections of the Darling Hill tributary may harbor significant sources of phosphorus flowing into Lake Memphremagog. Other sites exhibiting different median and flow-weighted average phosphorus values included Johns River (flow-weighted average indicated higher phosphorus levels than did the median) and North Derby Road, Eagle Point, Strawberry Acres, and Holbrook Bay (flow-weighted averages indicated lower phosphorus levels than did the medians). Of the latter, all sites, except possibly Strawberry Acres, may have been influenced by the presence of wetlands that impacted the phosphorus dynamics at those sites.

Total Nitrogen

Total nitrogen measures the total amount of all forms of nitrogen in the water column, including nitrite (NO_2), nitrate (NO_3), 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 and lead to more frequent and more toxic cyanobacterial blooms. In Vermont, most nitrogen originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

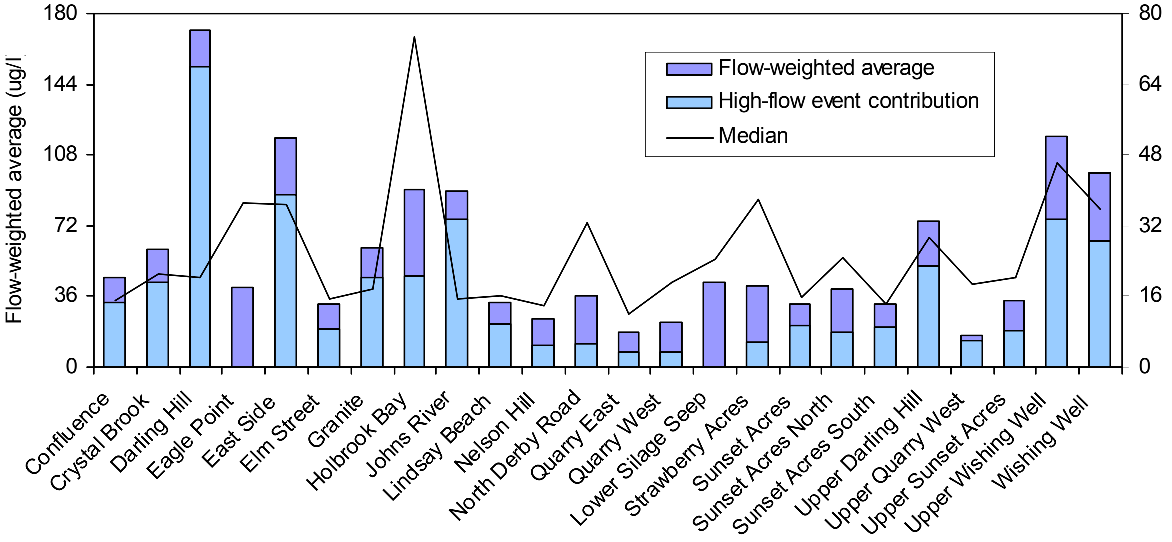

Figure 23. *Flow-weighted average phosphorus levels, the phosphorus contribution of the single high-flow event, and median phosphorus values at 24 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009.*

Total nitrogen concentrations in 2009 ranged between 0.14-18.80 mg/l and showed no consistent seasonal pattern (Figure 24).

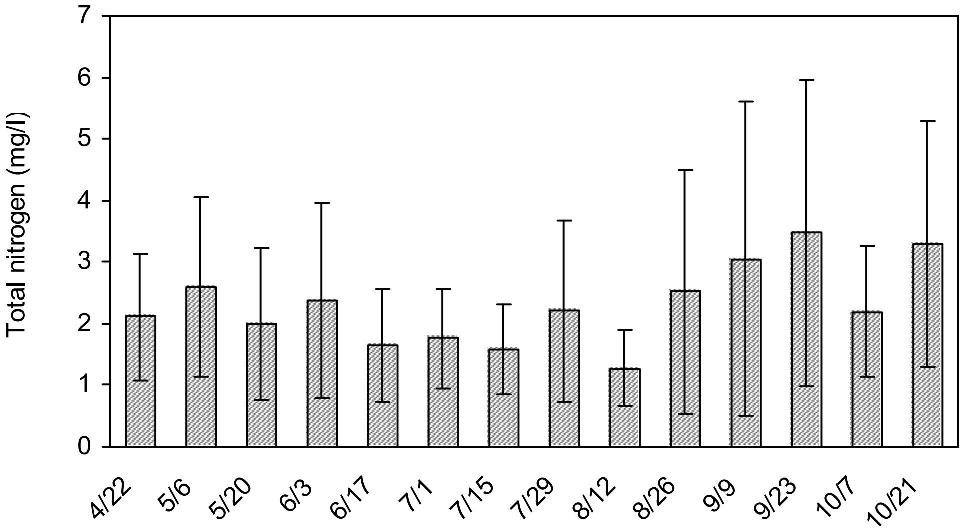

Figure 24. *Median total nitrogen concentrations (±1 SD) measured on each sample date at 13 sites along the Johns River and the Sunset Acres tributary during April-October 2009. These values include only those 13 sites sampled on all 14 sample dates.*

Moderate to extremely high nitrogen levels were measured at several sites along the Johns River and adjacent tributaries (Figures 25-26). Median total nitrogen concentrations at individual sites ranged between 0.27-15.30 mg/l. Median concentrations exceeded 5 mg/l at three sites, two of which were groundwater springs located along the Darling Hill tributary (DHT Main Spring, DHT Spring West, and Sunset Acres South), and 2 mg/l at eight other sites.

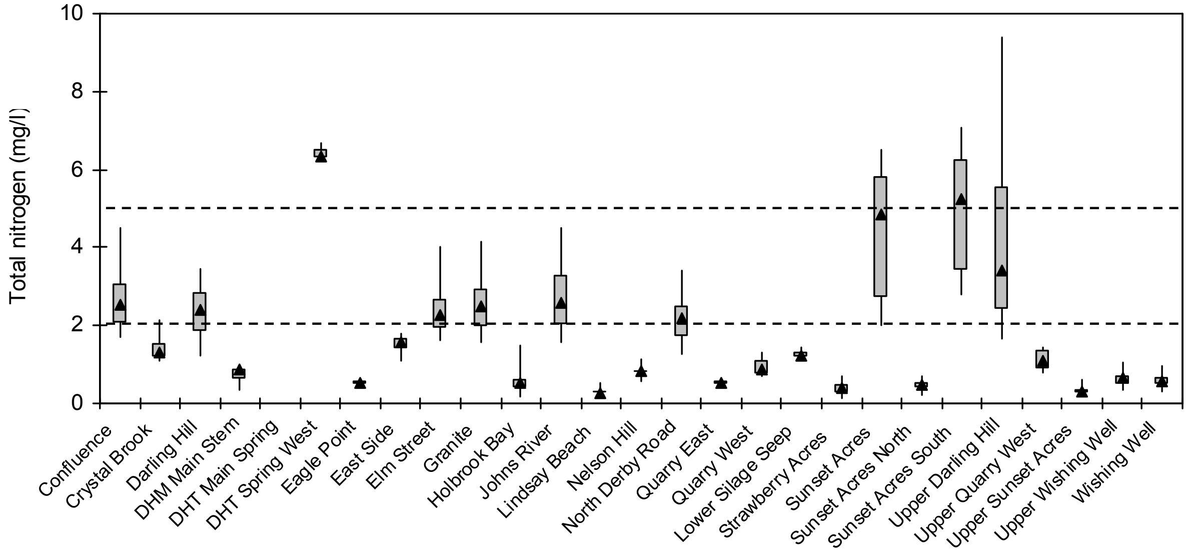

Figure 25. *Median total nitrogen concentrations measured at 27 sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum values (line). The horizontal lines indicate the thresholds for what might be considered high nitrogen levels based on the State of Vermont water quality standards for nitrate (2 and 5 mg/l). Note that the values for the DHT Main Spring site exceed the range encompassed by this figure.*

In contrast to phosphorus, total nitrogen concentrations generally decreased with increasing water depth (Figure 27). This negative relationship was not consistent among all sites (Figure 28). Three of the sites with the highest nitrogen levels (Upper Darling Hill, Sunset Acres, and Sunset Acres South) exhibited even sharper declines in relation to water depth. As in 2008, these negative relationships suggested that the nitrogen inputs were derived from groundwater or point sources, rather than nonpoint sources such as agricultural or urban runoff. In contrast, many of the sites with relatively low nitrogen levels showed no relationship with water depth (Quarry East and Strawberry Acres) or actually increased with increasing water depth (Sunset Acres North, Upper Sunset Acres, Lindsay Beach, Wishing Well, and Upper Wishing Well). At these sites, especially those exhibiting positive relationships, these results suggest that the nitrogen inputs may be derived from nonpoint sources, such as agricultural or urban runoff, rather than groundwater or point sources. Interestingly, nitrogen concentrations were more variable at lower stream flows (as indicated by the larger standard deviations), probably due to the very high nitrogen concentrations measured at several sites during lower flow events.

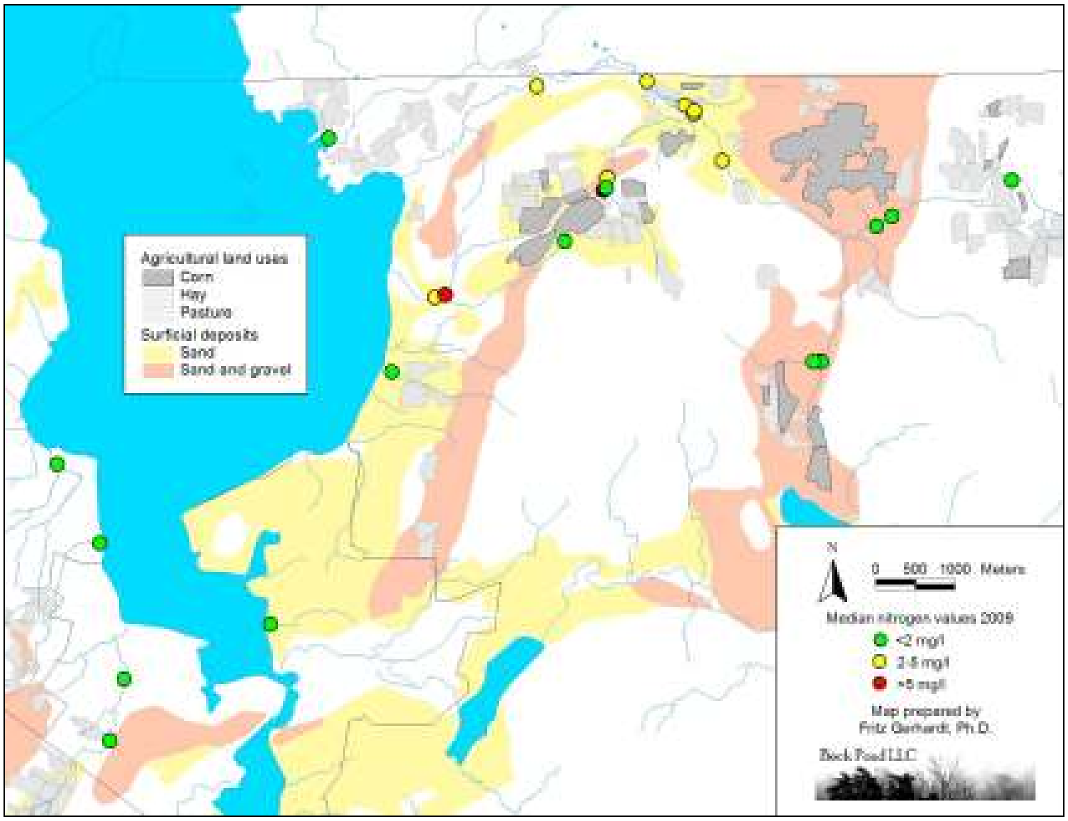

Figure 26. *Median total nitrogen concentrations and the locations of active agricultural fields and sand and gravel deposits along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009.*

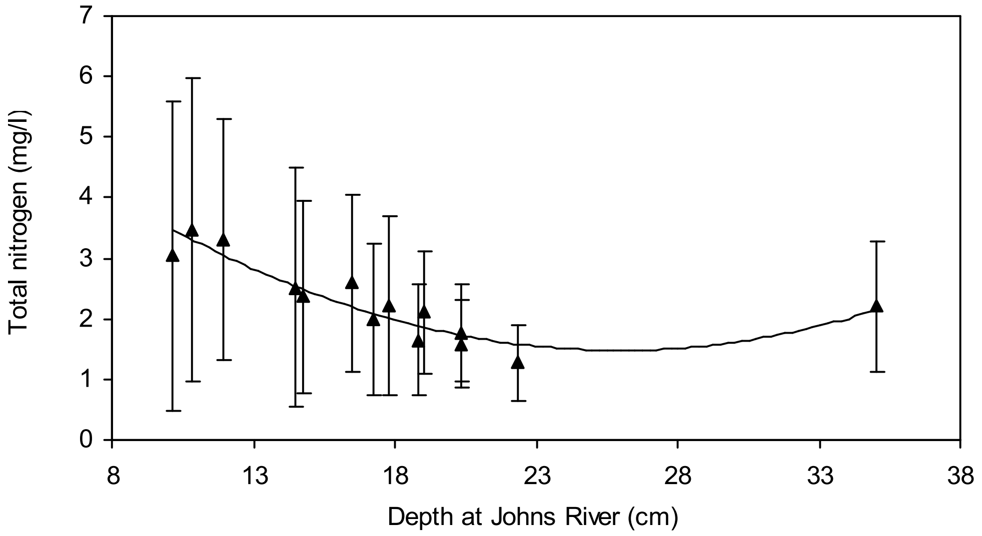

Figure 27. *Median total nitrogen concentrations (±1 SD) in relation to water depth at the 13 sites sampled on all 14 sample dates along the Johns River and the Sunset Acres tributary during April-October 2009. The regression line indicates the polynomial relationship between the two parameters.*

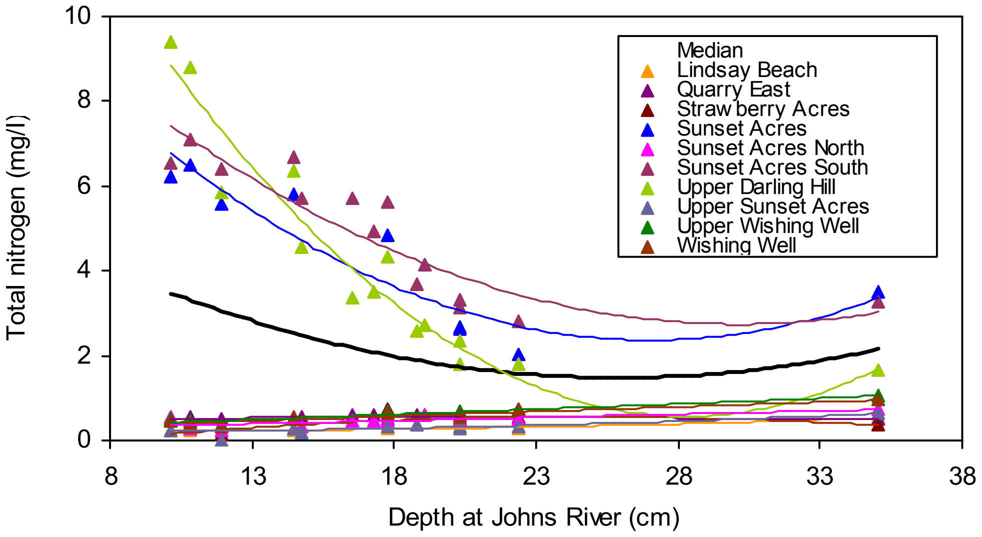

Figure 28. *Total nitrogen concentrations in relation to water depth at selected sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. The regression lines indicate the polynomial relationships between the two parameters; the solid black line represents the polynomial relationship including all 13 sites sampled on all 14 sample dates.*

Based on the data collected during 2005-2009, we identified three possible source areas for the nitrogen entering these rivers and streams and confirmed that the nitrogen was originating from groundwater in two of those areas. These three areas included the middle section of the main stem of the Johns River, the upper section of the Darling Hill tributary, and the south branch of the Sunset Acres tributary (Figure 29). As in 2008, total nitrogen concentrations increased dramatically between the Lower Silage Seep and Elm Street sites and remained high from there downstream to the mouth of the Johns River (Figure 30). Unfortunately, we were unable to survey this section of the Johns River to identify possible nitrogen and groundwater inputs; however, it seems likely that the nitrogen is entering the surface waters somewhere in this stretch of the Johns River and Crystal Brook, since our sampling indicated that the other two upstream tributaries of the Johns River exhibited relatively low nitrogen levels.

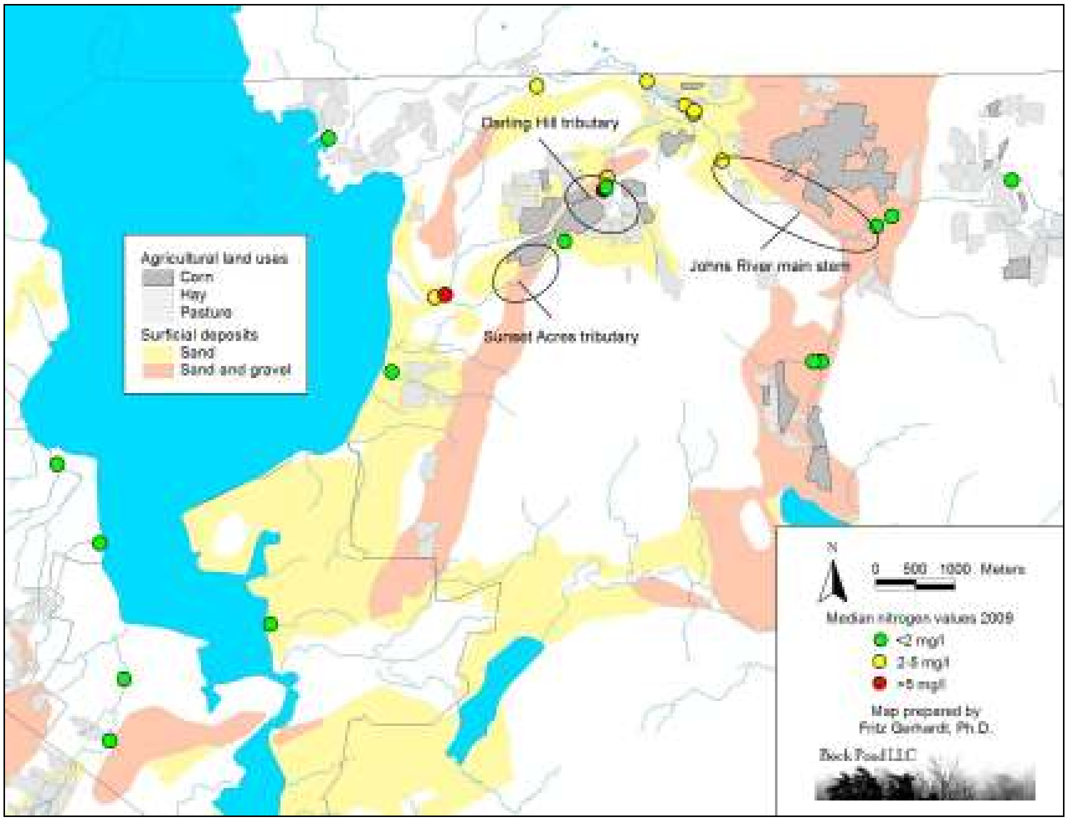

Figure 29. *Three areas where nitrogen may be entering the surface waters of the Johns River and adjacent tributaries of Lake Memphremagog.*

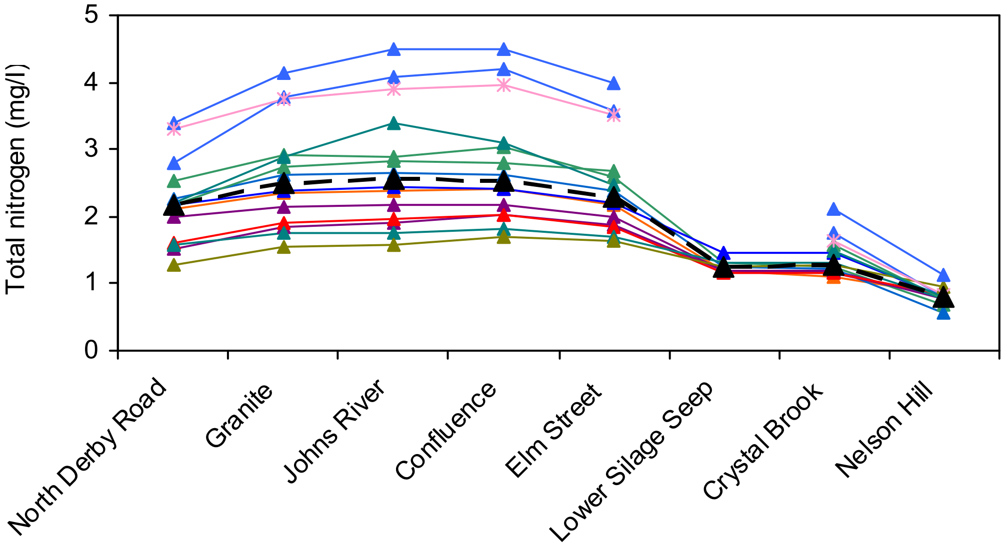

Figure 30. *Total nitrogen "profile" along Crystal Brook and the main stem of the Johns River from Nelson Hill downstream to North Derby Road during April-October 2009. The dashed black line and large black triangles indicate the median value across all sample dates at each site.*

On the south branch of the Sunset Acres tributary, nitrogen concentrations increased dramatically between the uppermost site (Upper Sunset Acres) and Sunset Acres South and remained high from there downstream to the Sunset Acres site (Figure 31). In contrast, nitrogen concentrations were very low on the north branch of this tributary (sampled at Sunset Acres North). We were able to survey the south branch from the Sunset Acres South site upstream to just downstream of the Upper Sunset Acres site, and we identified an area containing numerous groundwater seeps and springs that may be the source of the high nitrogen levels in this tributary. These springs and seeps were located just downhill from a large cornfield located on a large area of sand and gravel deposits (see cover photograph, Figure 29). We did sample the water flowing out of one of these seeps, and nitrate levels were elevated (9.49 mg/l).

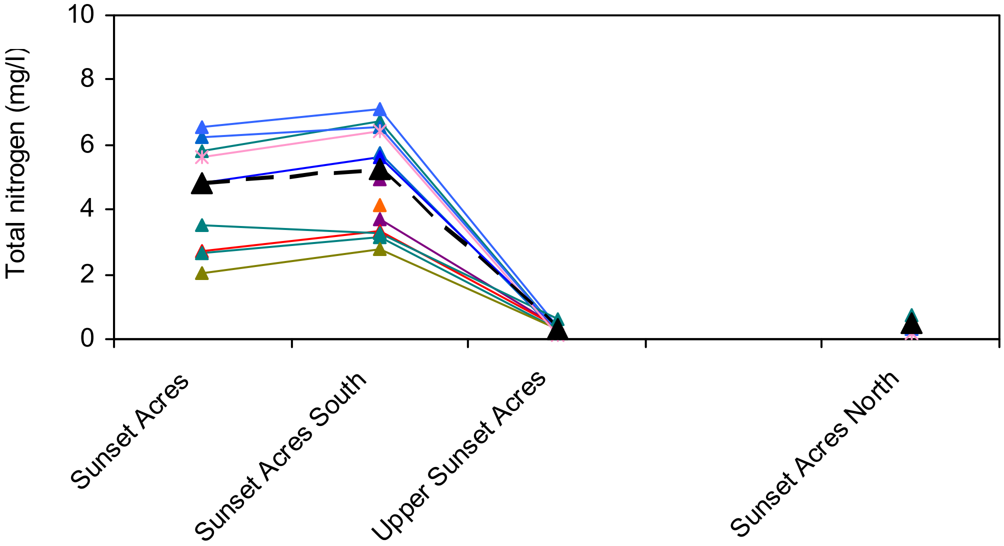

Figure 31. *Total nitrogen "profile" along the south branch of the Sunset Acres tributary from Upper Sunset Acres downstream to Sunset Acres and along the north branch of this tributary during April-October 2009. The dashed black line and large black triangles indicate the median value across all sample dates at each site.*

Finally, along the Darling Hill tributary, nitrogen concentrations increased dramatically below the uppermost site (DHM Main Stem) and then decreased downstream from the Upper Darling Hill to the Darling Hill sites, especially at low flows (Figure 32). Like the Sunset Acres tributary, we were able to survey this tributary upstream of the Upper Darling Hill site and located two groundwater springs (Figure 33; DHT Main Spring and DHT Spring West). The groundwater flowing out of these two springs exhibited extremely high nitrogen levels and caused nitrogen levels to rise dramatically where the water flowing from these springs entered the Darling Hill tributary just downstream of the DHM Main Stem site. Thus, this year's sampling allowed us to confirm that the nitrogen along the Darling Hill tributary was, in fact, originating from groundwater surfacing in this area, which was located downhill of a large cornfield located on sand and gravel deposits.

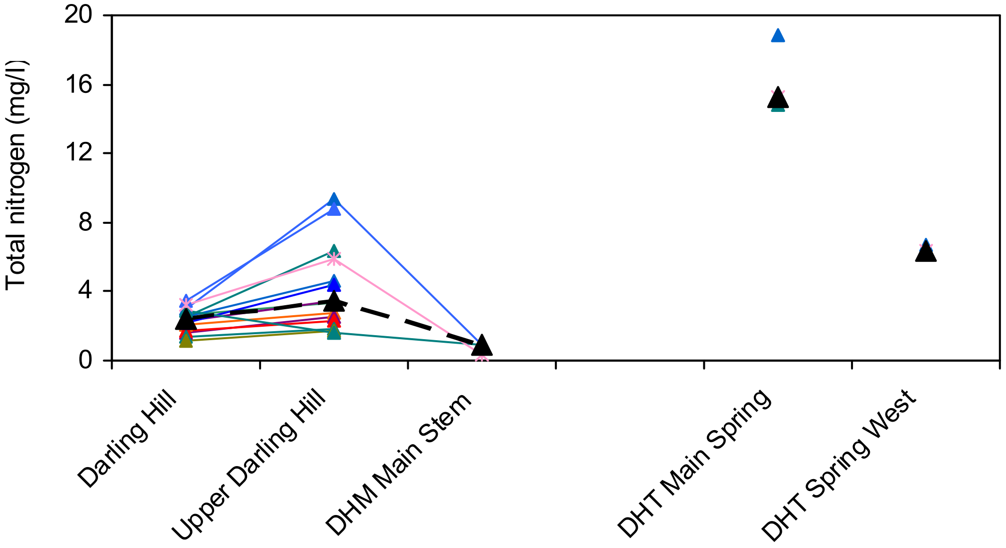

Figure 32. *Total nitrogen "profile" along the Darling Hill tributary from DHM Main Stem downstream to Darling Hill and from two groundwater springs along this tributary during April-October 2009. The dashed black line and large black triangles indicate the median value across all sample dates at each site.*

Interestingly, median nitrogen concentrations at most sample sites were lower in 2009 than in previous years, especially at low and moderate flows (Figure 34). At the 14 sites sampled in both 2008 and 2009, median total nitrogen values were lower in 2009 than in 2008 at ten sites (two sites showed no change and nitrogen levels actually increased at two other sites). In the areas with high total nitrogen concentrations (i.e. >2 mg/l), median nitrogen levels decreased 10-40% between 2008 and 2009. Median values at the two sites that exceeded 5 mg/l in 2008 (Sunset Acres and Upper Darling Hill) showed the largest absolute decreases in median nitrogen values (1.32 and 2.26 mg/l, respectively) and were less than 5 mg/l in 2009. In addition, total nitrogen levels at the Johns River site (the only site sampled all four years during 2005-2009) were lower in 2009 than they were in 2008 and lower in both 2008 and 2009 than they were in 2005 and 2006 (Figure 35).

Figure 33. *One source of the high nitrogen levels observed in the Johns River and the Darling Hill and Sunset Acres tributaries was groundwater flowing from springs such as this disused drinking water well near Beebe Plain, Vermont (photographed on 27 July 2009).*

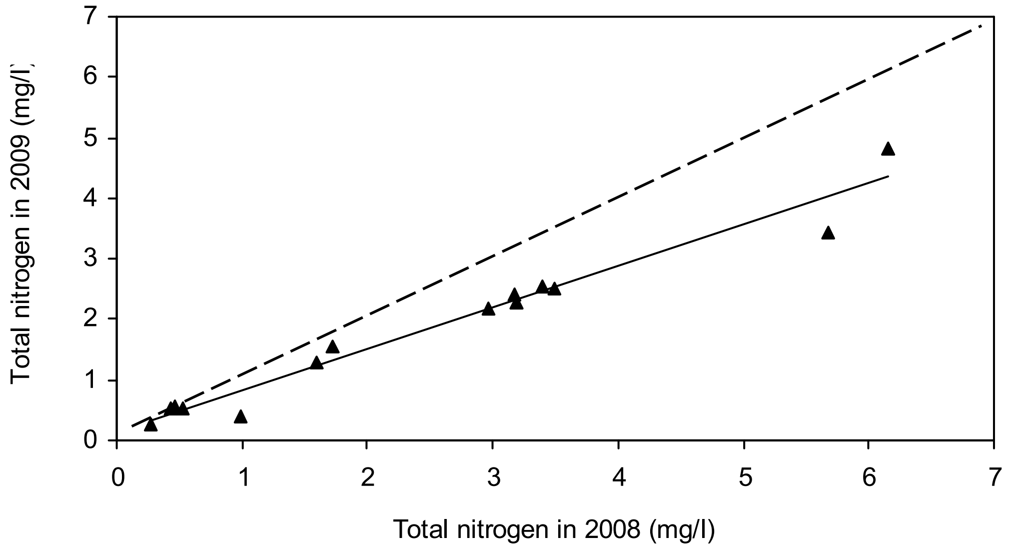

Figure 34. *Median total nitrogen concentrations in 2008 and 2009 at 14 sites sampled in both years along the Johns River and seven smaller tributaries of Lake Memphremagog. The dashed line indicates the expected relationship if the 2008 and 2009 values were identical; the solid regression line indicates the linear relationship between the two parameters.*

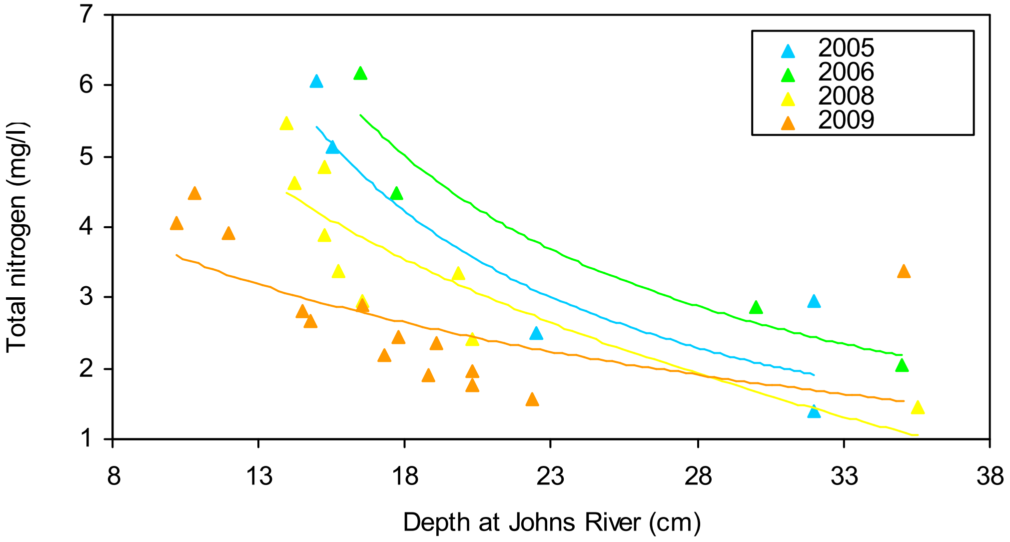

Figure 35. *Total nitrogen concentrations in relation to water depth at the Johns River site during 2005-2009. The regression lines indicate the polynomial relationships between the two parameters in each year.*

Although nitrogen levels were clearly lower in 2009 than in previous years, we do not know the cause(s) of these lower levels or their ramifications. On one hand, these lower levels may reflect decreased levels of nitrogen entering the groundwater and surface waters due to better nutrient management practices in the area (e.g. lower nitrogen fertilizer application rates). On the other hand, these lower levels may reflect some other, more "global" factor (e.g. the atypical precipitation patterns during the last two years), especially given that the declines in median nitrogen levels were so widespread. Ultimately, identifying the cause(s) of these decreases in nitrogen levels will require that we understand the underlying groundwater and nitrogen dynamics (e.g. residence times, flow rates and directions) as well as historical and current management practices in the area.

NO_2 - NO_3

Nitrogen, which is an essential plant nutrient, occurs in many forms in nature, including nitrogen gas (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), ammonium (NH_4), and particulate nitrogen. Total nitrogen measures the concentration of all forms of nitrogen in the water column. In contrast, NO_x measures only the concentration of nitrite plus nitrate (NO_2 - NO_3). Nitrate is the most soluble form of nitrogen and the form that is most readily used by plants. Nitrate in surface waters typically originates from animal manure, sewage, fertilizer, and atmospheric deposition. High concentrations of nitrate in surface waters increase the likelihood of algal blooms, increase the frequency and toxicity of cyanobacterial blooms, and alter aquatic plant and animal communities.

In 2009, NO_x was only sampled at 19 sites in the watersheds of the Johns River and the Sunset Acres tributary. In general, NO_x patterns paralleled those exhibited by total nitrogen. In 2009, NO_x concentrations ranged between 0.07-14.30 mg/l and, like total nitrogen, exhibited no consistent seasonal pattern (Figure 36).

Median NO_x concentrations at individual sites ranged between 0.13-13.40 mg/l. As expected, the sites with the highest total nitrogen levels also had the highest NO_x levels (Figures 37-38). Like total nitrogen, median NO_x concentrations exceeded 5 mg/l at three sites, two of which were groundwater springs located along the Darling Hill tributary (DHT Main Spring, DHT Spring West, and Sunset Acres South). In addition, median NO_x concentrations exceeded 2 mg/l at six other sites in the watersheds of the Johns River and the Sunset Acres tributary. Based on these data and the total nitrogen data collected in 2008 and 2009, it seems likely that nitrogen levels in several reaches of the Johns River and adjacent tributaries exceed Vermont water quality standards ("Not to exceed 5.0 mg/l as [nitrate] at flows exceeding low median monthly flows, in Class B waters"; State of Vermont 2006b).

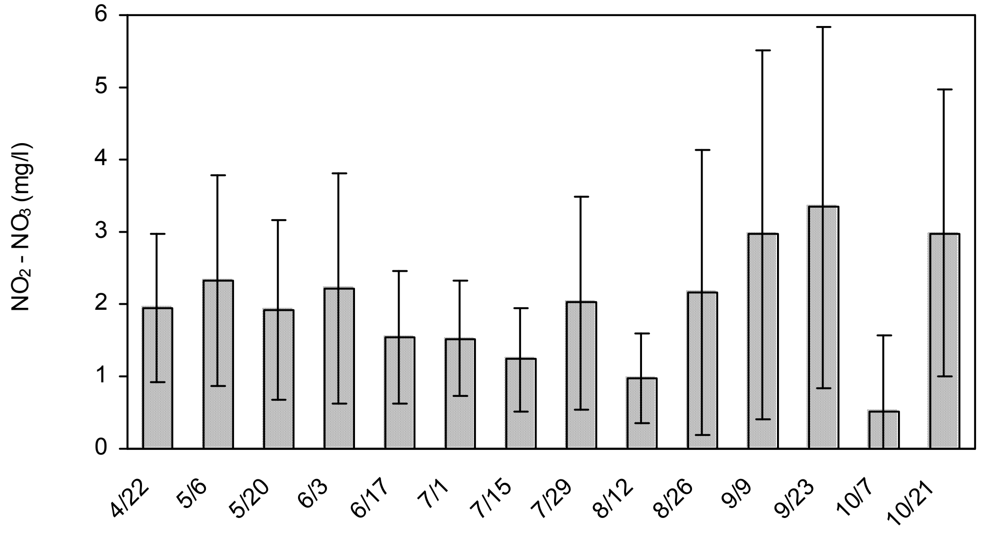

Figure 36. *Median NO_x concentrations (±1 SD) measured on each sample date at 13 sites along the Johns River and the Sunset Acres tributary during April-October 2009. These values include only those 13 sites sampled on all 14 sample dates.*

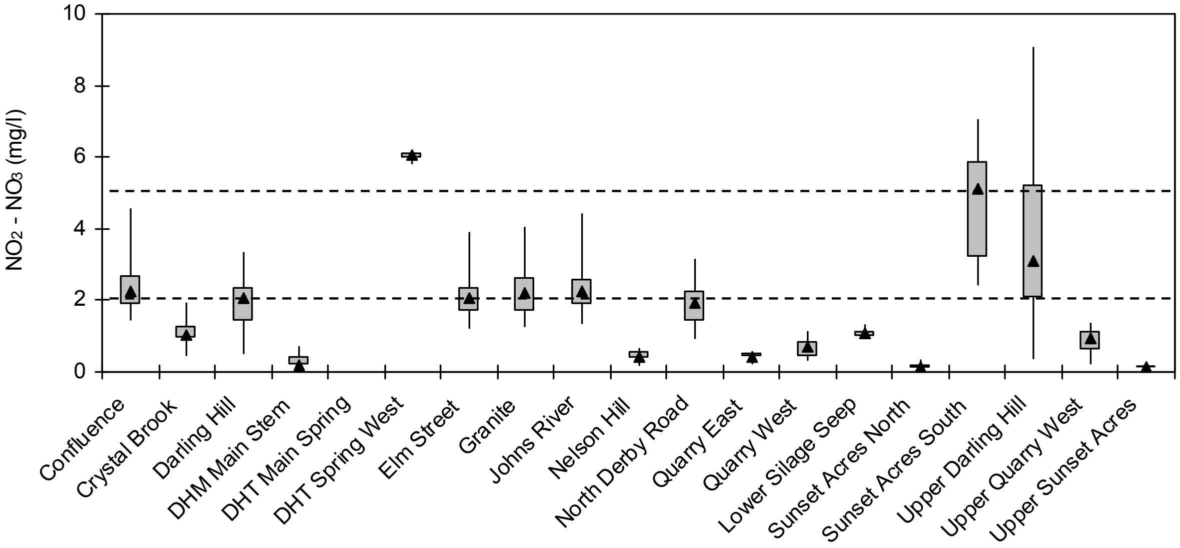

Figure 37. *Median NO_x concentrations measured at 19 sites along the Johns River and the Sunset Acres tributary during April-October 2009. Values are the median (triangle), 1^{st} and 3^{rd} quartiles (rectangle), and minimum and maximum values (line). The horizontal lines indicate State of Vermont water quality standards for nitrate in Class A and B waters (2 and 5 mg/l, respectively). Note that the values for the DHT Main Spring site exceed the range*

encompassed by this figure.

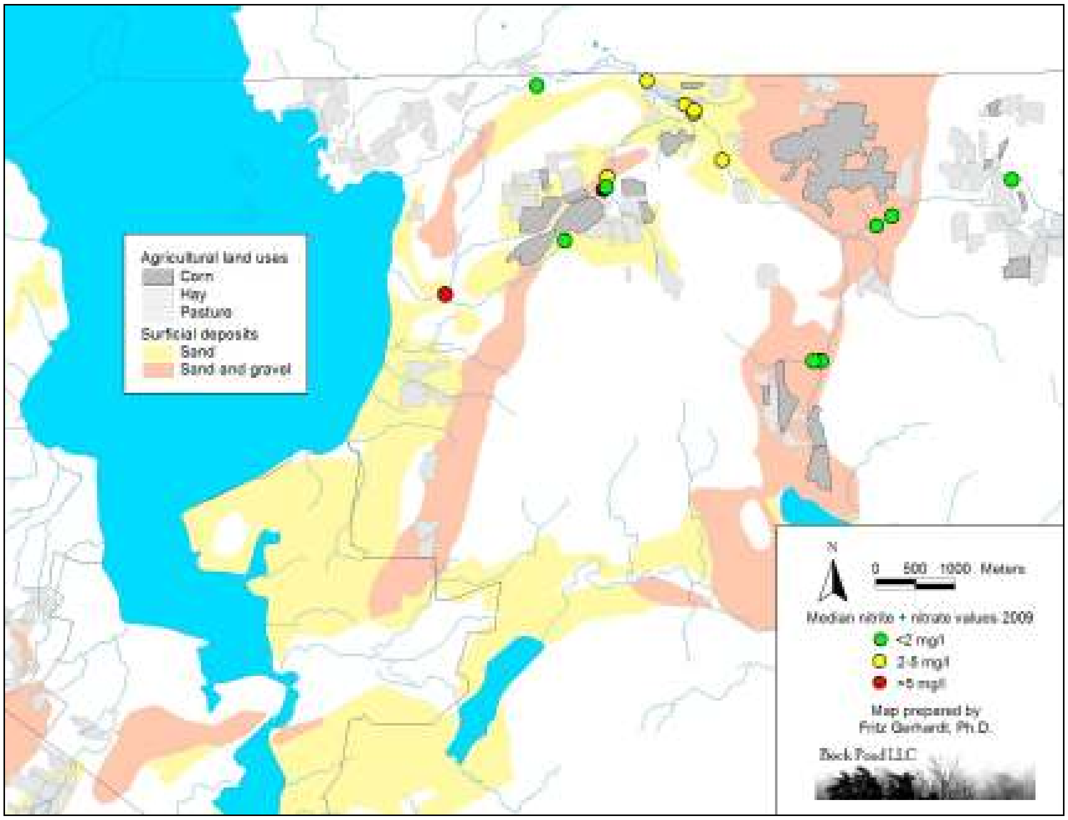

Figure 38. *Median NO_x concentrations measured at 19 sites and the locations of active agricultural fields and sand and gravel deposits along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009.*

Like total nitrogen, NO_x concentrations generally decreased with increasing water depth (Figure 39). Likewise, this relationship was not consistent among all sites (Figure 40). In particular, two of the sites with the highest nitrogen levels showed the sharpest declines in NO_x concentrations in relation to water depth (Upper Darling Hill and Sunset Acres South). In contrast, several of the sites with relatively low nitrogen levels showed no relationship with water depth (Nelson Hill, Quarry East, Sunset Acres North, and Upper Sunset Acres). However, unlike total nitrogen, no sites showed positive relationships with water depth. Like total nitrogen, NO_x concentrations were more variable at lower stream flows (as indicated by the larger standard deviations), probably due to the very high NO_x concentrations measured at several sites during low flow events.

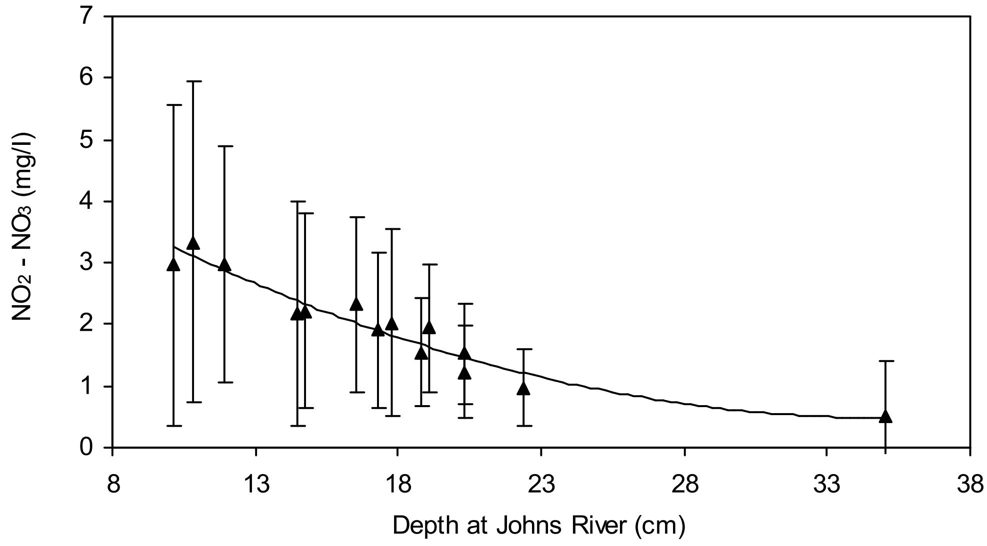

Figure 39. *Median NO_x concentrations (±1 SD) in relation to water depth at the 13 sites sampled on all 14 sample dates along the Johns River and the Sunset Acres tributary during April-October 2009. The regression line indicates the polynomial relationship between the two parameters.*

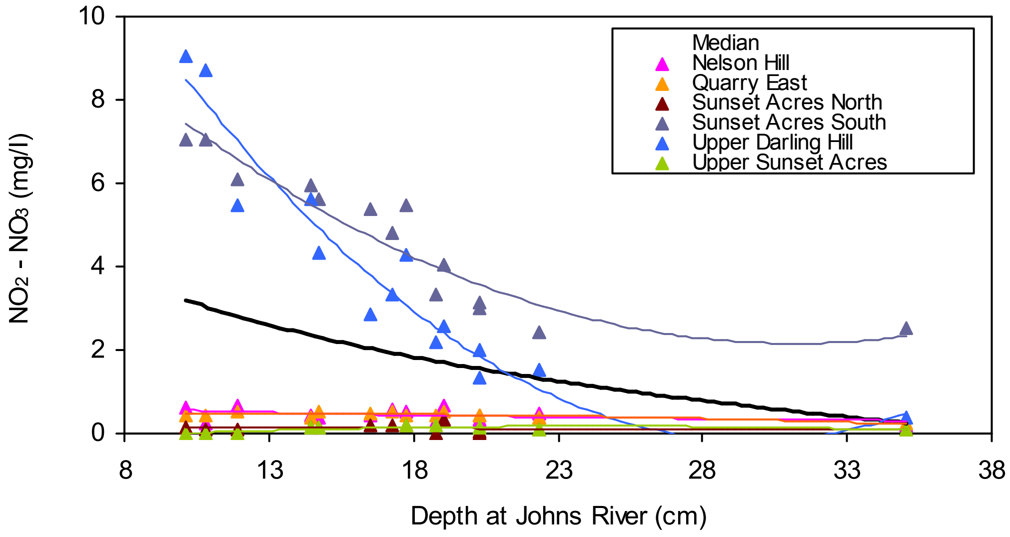

Figure 40. *NO_x concentrations in relation to water depth at selected sites along the Johns River and the Sunset Acres tributary during April-October 2009. The regression lines indicate the polynomial relationships between the two parameters; the solid black line represents the polynomial relationship including all 13 sites sampled on all 14 sample dates.*

In addition to evaluating NO_x concentrations, we also calculated the proportion of the total nitrogen that occurred in the form of NO_x at each site on each sample date. Across all sites and all sample dates, NO_x represented 13-100% of the total nitrogen. On individual sample dates, NO_x represented 19-100% of the total nitrogen, but, at individual sites, NO_x represented 33-98% of the total nitrogen (Figure 41). Interestingly, the sites with the highest total nitrogen concentrations (e.g. median values >2 mg/l) also had the highest percentages of that nitrogen occurring in the form of NO_x. In contrast, five of the six sites with the lowest total nitrogen concentrations (<1 mg/l) also had the lowest percentages of that nitrogen occurring in the form of NO_x (Sunset Acres North, Upper Sunset Acres, DHM Main Stem, Quarry West, and Nelson Hill). These results suggest that nitrate is the form of nitrogen that primarily responsible for the high nitrogen levels observed at many sites. In addition, across all sites, the proportion of nitrogen occurring as NO_x decreased with increasing stream flow (Figure 42). One possible explanation for this pattern is that, during high-flow events, runoff carried more dissolved and particulate nitrogen into the rivers and streams, and these forms of nitrogen contributed a higher proportion of the total nitrogen during these events.

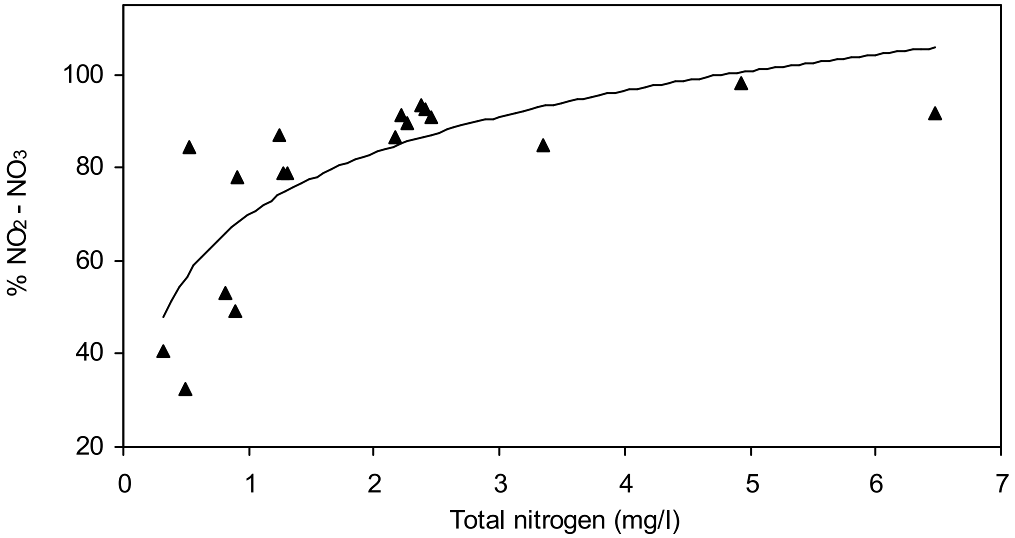

Figure 41. *Proportion of total nitrogen occurring in the form of NO_x in relation to median total nitrogen concentration at each site along the Johns River and the Sunset Acres tributary during April-October 2009. The regression line indicates the polynomial relationship between the two parameters.*

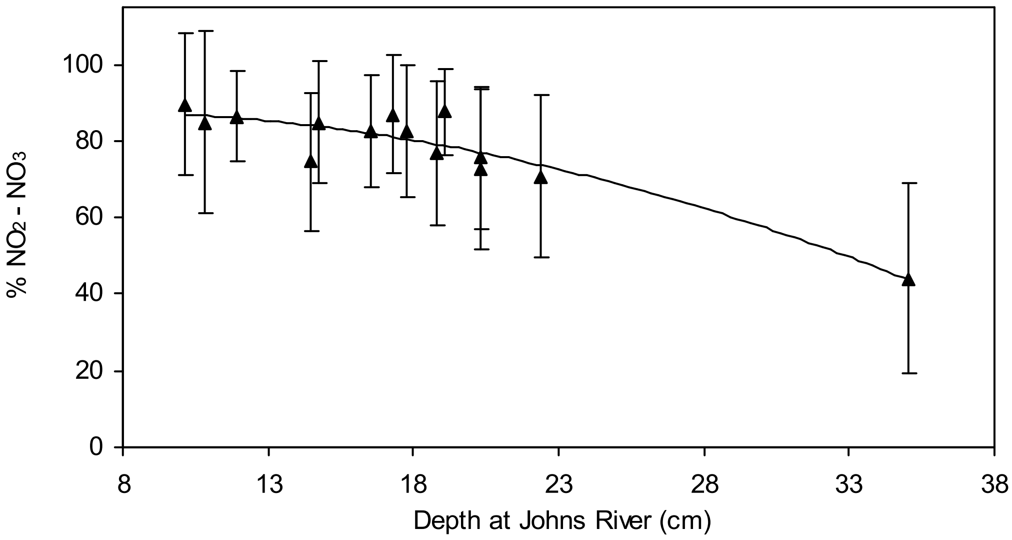

Figure 42. *Proportion of total nitrogen occurring in the form of* NO_x *in relation to water depth at 16 sites along the Johns River and the Sunset Acres tributary during April-October 2009. The regression line indicates the polynomial relationship between the two parameters.*

Quality Assurance

This project was conducted in accordance with a Quality Assurance Project Plan developed in conjunction with the Vermont DEC (see Methods). Our sampling generally met the quality assurance standards for all three parameters (quality assurance data are presented in Appendix C). All of the blank samples for all three parameters were below the detection limits (<5 µg/l for total phosphorus, <0.1 mg/l for total nitrogen, and <0.05 mg/l for NO_x). Similarly, the mean relative percent differences for all three parameters were well within their prescribed differences: total phosphorus = 6%, total nitrogen = 2%, and NO_x = 1% (prescribed differences were <30% for total phosphorus, <20% for total nitrogen, and <10% for NO_x). Only one of the 37 pairs of total phosphorus samples differed by >30%: This pair of samples, which differed by 44%, were collected two days after an extreme high-flow event, which may have created more heterogeneous nutrient concentrations in the water column. In addition, one of the 27 pairs of NO_x samples differed by >10%: This pair of samples, which differed by 14%, were collected on the same date as the errant pair of phosphorus samples. Thus, the quality assurance samples, including both field blanks and field duplicates, indicated that the water samples were being collected in a repeatable manner and were not being contaminated during collection or processing.

Although technically not a quality assurance issue, our sampling was biased towards low flow events during 2009, despite our biweekly sampling schedule and the frequent, heavy rains that occurred throughout June and July. Water samples from all but two of the 14 sample dates were collected at low to extremely low flow levels, even those collected in April and May, when snowmelt typically results in high flows, and in June and July, when the frequent, heavy rains occurred. Thus, our data were biased towards describing the nutrient dynamics characteristic of low stream flows. For nitrogen, this bias may actually have been beneficial, as the highest concentrations were observed during the lowest flows, presumably due to their origin in groundwater inputs, which would have been diluted at higher flows. In contrast, for phosphorus, the lack of high-flow events was more problematic, as much of the phosphorus in these rivers and streams likely arises from surface runoff and nonpoint sources, which are accentuated during high-flow events. Consequently, we were unable to accurately calculate the actual loads of phosphorus and nitrogen being transported into Lake Memphremagog. Ultimately, we will need to calculate these loads in order to identify the areas where reductions are needed in order to reduce nutrient levels in Lake Memphremagog. However, the low flows were informative in suggesting that the high phosphorus levels at North Derby Road (and possibly Eagle Point and Holbrook Bay) may be arising from decomposition of organic matter in wetlands along those tributaries.

Summary of Results

The data presented in this report build upon the data collected in previous years. In During 2005-2006, we assessed and ranked the four principal Vermont tributaries of Lake Memphremagog according to the levels of phosphorus, nitrogen, and sediment measured in those watersheds (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 and adjacent tributaries in 2006, 2008, and 2009 to better understand the phosphorus and nitrogen problems in that watershed. In conjunction with the Memphremagog Watershed Association, we also began sampling nutrient and sediment levels in seven smaller tributaries that flow directly into Lake Memphremagog.

As in previous years, the 2009 results indicated that the Johns River and the seven smaller tributaries continued to send high levels of nitrogen and phosphorus into Lake Memphremagog. Specifically, the downstream-most section of the Johns River, the Darling Hill and Eagle Point tributaries, and the four smaller tributaries located in or near Newport City all exhibited high phosphorus levels. In many of these tributaries, phosphorus levels increased with increasing stream flows as would be expected from nonpoint source runoff from urban, suburban, and agricultural lands. A few sites, however, showed different relationships with stream flow, and the phosphorus at those sites may instead be originating from groundwater or point sources. At Eagle Point and North Derby Road, much of the phosphorus may be originating from wetlands, which had previously trapped and retained sediments and phosphorus from upstream sources. The source of the high phosphorus levels on the Holbrook Bay tributary, however, remained enigmatic, and possible sources include beaver activity, grazing, and suburban development in that watershed. Because Lake Memphremagog is currently impaired by high phosphorus levels, there remains a critical research need to identify the sources of the high phosphorus levels flowing out of these tributaries into Lake Memphremagog. In contrast, phosphorus levels have decreased dramatically along Crystal Brook and the middle section of the Johns River, and, pending the outcome of biological assessments, it seems probable that Crystal Brook could be delisted from the Vermont list of impaired waters (State of Vermont 2008).

The Johns River and one of the seven smaller tributaries (Sunset Acres) also exhibited very high nitrogen levels. The majority (>85%) of this nitrogen occurred in the form of nitrate and/or nitrite, especially at those sites exhibiting the highest nitrogen levels. In contrast to phosphorus, nitrogen levels, especially at those sites with the highest nitrogen levels, showed a negative relationship with stream flow. This result was consistent with our hypothesis that the nitrogen was originating from groundwater that was being contaminated by nitrogen leaching from cornfields located on porous sand and gravel deposits. In 2009, we were able to confirm that the nitrogen in the Darling Hill and Sunset Acres tributaries was originating from groundwater seeps and springs. Interestingly, nitrogen levels at the Johns River and other sites were lower in 2009 than in previous years; however, we do not know the reason(s) for this decline and whether or not levels will continue to decline in the future. Due to the extremely high nitrogen levels observed in these watersheds, future efforts should focus on monitoring long-term trends in nitrogen levels, evaluating the potential impacts of these high levels, better understanding the nitrogen and groundwater dynamics in these watersheds, and identifying and mitigating possible nitrogen sources.

Recommendations

Monitoring and Assessment Studies

Phosphorus

Based on this and previous studies, we have identified several areas along the Johns River and the seven smaller tributaries where phosphorus levels were problematic. In the Johns River watershed, these areas included the downstream-most section of the Johns River, the Darling Hill tributary, and Crystal Brook. As noted previously, we now hypothesize that the high phosphorus levels in the downstream section of the Johns River (between Johns River and North Derby Road) are originating from residual phosphorus being released from the wetlands there. Evaluating this hypothesis would require additional surface water sampling upstream and downstream of the wetlands, especially at different flow levels; however, even such additional sampling may not be sufficient to confirm or reject this hypothesis. Thus, the primary benefit of additional sampling in this area may be to eliminate other possible phosphorus sources (e.g. runoff from the granite operations in Beebe Plain and cattle grazing in the pasture upstream of the Granite site). We have also identified several possible phosphorus sources along the upper section of the Darling Hill tributary; however, at this point, it seems unlikely that additional surface water sampling would be sufficient to further pinpoint the exact source(s) of this phosphorus. Instead, we recommend undertaking remediation efforts that will eliminate or minimize phosphorus inputs from these sources (see following section). Finally, the results from the 2008 and 2009 sampling confirmed that past remediation efforts have reduced phosphorus levels in Crystal Brook and further downstream along the Johns River (Figure 19). If the results of the biological assessments concur with this assessment, it seems likely that Crystal Brook could be delisted from the Vermont list of impaired waters (State of Vermont 2008), and further sampling may not be warranted.

In contrast, we do recommend undertaking additional monitoring and assessment efforts to identify possible phosphorus sources along five of the seven smaller tributaries flowing directly into Lake Memphremagog. In both 2008 and 2009, phosphorus levels were high in all four tributaries located in the southern-most section of Lake Memphremagog (Holbrook Bay, Strawberry Acres, Wishing Well, and East Side) as well as the Eagle Point tributary. However, the specific sources of these high phosphorus levels remain unclear. The Holbrook Bay, Wishing Well, and Eagle Point tributaries, in particular, have large areas of agricultural lands (including pasture and hayfield), which may be contributing to the high phosphorus levels in those tributaries (Figure 14). The Eagle Point tributary also drains a large wetland complex, which, like the wetlands along the downstream-most section of the Johns River, may be releasing phosphorus into the stream, especially at low flows. Finally, all five tributaries drain areas of urban, suburban, and exurban land uses; and a number of activities in these areas may be contributing to the high phosphorus levels in these tributaries. Effectively identifying the specific phosphorus sources along these tributaries will require a three-pronged approach. First, we recommend undertaking on-the-ground surveys along the lengths of these tributaries to identify possible phosphorus sources. Second, when potential sources are identified, we recommend approaching individual landowners or land managers to involve them in efforts to remediate any sources identified on their properties. Finally, if necessary to verify potentially significant sources, we recommend collecting additional surface water samples above and below the location(s) of these sources to evaluate their contributions to phosphorus levels flowing out of these tributaries.

Nitrogen

Based on this and previous studies, we have identified several areas along the Johns River and the Sunset Acres tributary where nitrogen levels were problematic. These areas included the middle section of the main stem of the Johns River, the upper section of the Darling Hill tributary, and the southern branch of the Sunset Acres tributary (Figure 29). As noted previously, we hypothesize that the high nitrogen levels are originating from nitrogen fertilizers being applied to cornfields located on porous sand and gravel deposits and then leaching into the groundwater. All of the results obtained to date are consistent with this hypothesis; however, confirming this hypothesis will require additional surface water and groundwater studies. In 2009, we were able to confirm that the high nitrogen levels in the Darling Hill and Sunset Acres tributaries were originating from groundwater flowing from groundwater seeps and springs. Unfortunately, we were unable to survey potential nitrogen sources along the main stem of the Johns River, although we suspect that they are located somewhere between Elm Street and U.S. Route 5. Based on the estimated daily nitrogen loads calculated for each sample site in 2008 (Gerhardt 2009), it is clear that nitrogen loads were significantly greater along the main stem of the Johns River than along the Darling Hill and Sunset Acres tributaries. Thus, efforts to reduce nitrogen levels in these watersheds will ultimately need to include the main stem of the Johns River in order to be successful.

Before expending the considerable resources necessary to conduct such studies, we need to determine whether or not the nitrogen levels in the Johns River and adjacent tributaries are sufficiently problematic to warrant the expenditure of these resources. We have identified three main areas of concern in regards to these high nitrogen levels. First, high nitrogen levels in the surface waters flowing into Lake Memphremagog, especially when combined with high phosphorus and iron levels, can accelerate eutrophication and dramatically increase the incidence and toxicity of algal and cyanobacterial blooms. However, such impacts would likely be localized to the areas where these tributaries flow into the lake (i.e. Derby Bay and environs). Second, high nitrogen levels can also impact the health and integrity of the aquatic communities in the streams themselves. However, based on preliminary biological assessments of these rivers and streams, these impacts do not appear to be problematic. Finally, high nitrogen levels can impact human health if they contaminate drinking water supplies in the area. Environmental Protection Agency standards for drinking water are 10 mg/l of nitrogen, and one of the two disused springs flowing into the Darling Hill tributary consistently exceeded this standard. Although nitrogen was not detected in four deep, drilled wells in the area, no shallow wells, which may be drawing drinking water from shallower surficial deposits, have been tested for nitrogen. Evaluating the importance of the observed nitrogen levels for these three areas of concern will be critical in determining the rationale for additional surface water and groundwater studies.

Effectively evaluating the hypothesized mechanism whereby nitrogen enters these surface waters will require parallel studies of surface water and groundwater in order to develop a more comprehensive understanding of nitrogen and groundwater dynamics in these watersheds and to identify and prioritize projects and practices that reduce nitrogen inputs. These studies are needed to verify that the nitrogen in the Johns River and adjacent tributaries is originating from nitrogen-based fertilizers being applied to cornfields on porous sand and gravel deposits and to better understand the pathways by which this nitrogen is flowing through the groundwater into the rivers and streams. Specifically, these studies will identify specific nitrogen source areas, the underlying bedrock and surficial geology, the rate and direction of groundwater flow, the "age" and residence times of both groundwater and nitrogen, and historical and current nutrient management practices in the area. The latter will be particularly important in evaluating the cause(s) and implications of the observed decreases in nitrogen concentrations in 2008 and 2009 compared to prior years. In addition, we will need to evaluate whether nitrogen levels in the Johns River and adjacent tributaries exceed Vermont water quality standards (State of Vermont 2006b), to identify the magnitude of nitrogen reductions needed to meet those standards, and to identify specific management practices and projects that would achieve those reductions.

In 2008 and 2009, we undertook preliminary steps to develop these parallel surface water and groundwater studies. Specifically, we established an informal partnership with personnel, who have expertise in surface water and ground water studies, from the Vermont Department of Environmental Conservation, Vermont Geological Survey, Vermont Agency of Agriculture, and Vermont Association of Conservation Districts. Based on our discussions, we identified and initiated several preliminary steps towards identifying the source(s) of nitrogen in these watersheds. First, as noted previously, we surveyed the lengths of the Darling Hill and Sunset Acres tributaries to identify potential groundwater inputs. Second, we sampled herbicides and herbicide degradates at several of our surface water sampling sites, as the presence of these compounds would support the hypothesis that the nitrogen in these tributaries was originating from agricultural sources. Third, we sampled nitrogen and herbicide levels in water drawn from four deep, drilled wells (>100 m deep) in the area. Finally, we began reviewing well logs for groundwater wells in the area to better map the underlying surficial and bedrock geology. Although these data have not been reviewed and analyzed thoroughly, preliminary analyses indicated that 1) herbicide and herbicide degradate levels in the surface waters generally paralleled nitrogen levels (that is, areas with high nitrogen levels also had higher levels of herbicides and herbicide degradates) and 2) the groundwater drawn from the deep, drilled wells revealed no detections of either nitrate or herbicides and herbicide degradates. All of these data were consistent with the hypothesis that the nitrogen was originating from nitrogen-based fertilizers being applied to cornfields located on porous sand and gravel deposits and leaching into the groundwater. However, confirming this hypothesis will require that we continue developing these partnerships and projects to coordinate surface water and groundwater studies in these watersheds.

Protection and Restoration Projects

Although additional studies are still needed, our results did suggest several protection and restoration projects and practices that can be implemented immediately to improve water quality conditions along these tributaries and in Lake Memphremagog. First, although apparently not the primary source of the high phosphorus levels in the downstream-most section of the Johns River, we continue to recommend fencing the pasture along North Derby Road to prevent cattle from entering the stream and eroding the streambanks and stream channel (Figure 43). In addition, we also recommend planting riparian buffers along this reach to reduce erosion, filter sediments and 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. The high phosphorus levels observed elsewhere may also be the result of livestock grazing in unfenced pastures along streams (e.g. the Darling Hill, Holbrook Bay, and Wishing Well tributaries), and water quality in these streams would also benefit from fencing and the planting of riparian buffers. In addition, we observed that the manure lagoon overlooking the Darling Hill tributary overflowed at times, and we would encourage efforts to rehabilitate or replace this lagoon, so that such overflows do not occur in the future (Figure 44). Unlike the manure lagoon on Crystal Brook, this manure lagoon was located >20 m from the stream, so that overflows were less likely to reach the stream directly.

Figure 43. *Cattle grazing and streambank erosion along the Johns River near Beebe Plain, Vermont may have contributed to the high phosphorus levels measured at the North Derby Road site (photographed on 20 August 2008 by Melissa Dyer).*

Although we still do not have conclusive proof that the high nitrogen levels in the Johns River and adjacent tributaries are originating from nitrogen-based fertilizers being applied to the cornfields located on porous sand and gravel deposits, we do recommend continuing to develop 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 implement nutrient management practices that reduce the amounts of nitrogen being applied to these cornfields. 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 and being lost to their crops. However, because we still have not confirmed the source(s) of the high nitrogen levels in these streams, it seems premature to recommend drastic changes in agricultural practices until we confirm that 1) nitrogen fertilizers being applied to the cornfields are the source of the problem and 2) that the current practices aren't already reducing nitrogen levels in the groundwater and surface waters.

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

Education and Outreach

As part of this project, we incorporated the processes and results of this study into several educational and outreach programs. Numerous individuals from the local community volunteered to collect and process water samples. In addition, the results of this and previous water quality studies were presented at two public meetings in 2009: the Annual Meeting of the Memphremagog Watershed Association and the Annual General Meeting of Memphrémagog Conservation Inc. These results were also presented to both the Technical Committee and the Steering Committee of the Quebec/Vermont Steering Committee on Lake Memphremagog. Furthermore, we discussed the results of this study and their implications for protecting and improving water quality in the Lake Memphremagog Basin with staff from the Northeastern Vermont Development Association, the Orleans County Natural Resources Conservation District, the Vermont Association of Conservation Districts, the Vermont DEC, the Vermont Geological Survey, and the Vermont Agency of Agriculture. We 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); the Memphremagog-Tomifobia-Coaticook Watershed Council; Quebec Ministère du Développement durable, de l'Environnement et des Parcs; MRC de Memphrémagog; cities of Newport, Sherbrooke, and Magog; Memphrémagog Conservation Inc., Memphremagog Watershed Association, and the NorthWoods Stewardship Center.

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Appendix A. Descriptions of the 27 sample sites located along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009 (locations are mapped in Figure 3).

Smaller tributaries (11 sites):

Site name	Dates sampled	Site description
Holbrook Bay	1 July-21 October	Unnamed tributary downstream of Beaver Cove Road in Newport Town (also sampled in 2008)
Strawberry Acres	1 July-21 October	Unnamed tributary downstream of Fishing Access Road in Newport Town (also sampled in 2008)
Wishing Well	1 July-21 October	Unnamed tributary downstream of snowmobile bridge north of Lake Road in Newport City (also sampled in 2008)
Upper Wishing Well	1 July-21 October	Unnamed tributary upstream of Vermont Route 105 in Newport City
East Side	1 July-21 October	Unnamed tributary south of Landing Street boat launch in Newport City (also sampled in 2008)
Lindsay Beach	1 July-21 October	Unnamed tributary along bike path off north end of Lindsay Road Extension in Derby (also sampled in 2008)
Sunset Acres	1 July-21 October	Unnamed tributary downstream of North Derby Road in Derby (also sampled in 2008)
Sunset Acres North	22 April-21 October	North branch of unnamed tributary upstream of North Derby Road in Derby
Sunset Acres South	22 April-21 October	South branch of unnamed tributary upstream of North Derby Road in Derby
Upper Sunset Acres	17 June-21 October	South branch of unnamed tributary upstream of Darling Hill Road in Derby
Eagle Point	1-29 July	Hall’s Brook upstream of Eagle Point Road in Derby (also sampled in 2008)

Johns River (16 sites):

Site name	Dates sampled	Site description
North Derby Road	22 April-21 October	Main stem downstream of North Derby Road in Derby (also sampled in 2006 and 2008)

Site name	Dates sampled	Site description
Granite	22 April-21 October	Main stem downstream of North Derby Road in Derby
Johns River	22 April-21 October	Main stem beside old well house off Beebe Road in Derby (also sampled in 2005, 2006, and 2008)
Confluence	22 April-21 October	Main stem downstream of Beebe Road in Derby (also sampled in 2008)
Darling Hill	22 April-21 October	Unnamed tributary upstream of confluence with Johns River in Derby (also sampled in 2006 and 2008)
Upper Darling Hill	22 April-21 October	Unnamed tributary upstream of Darling Hill Road (upper crossing) in Derby (also sampled in 2008)
DHM Main Stem	9 Sept.-21 October	Unnamed tributary upstream of Darling Hill Road (upper crossing) in Derby
DHT Main Spring	9 Sept.-21 October	Outflow of lower spring east of Darling Hill Road
DHT Spring West	9 Sept.-21 October	Outflow of upper spring east of Darling Hill Road
Elm Street	22 April-21 October	Main stem upstream of Elm Street and downstream of snowmobile bridge in Derby (also sampled in 2008)
Nelson Hill	22 April-21 October	Crystal Brook downstream of Herrick Road in Derby
Crystal Brook	22 April-21 October	Crystal Brook downstream of U.S. Highway 5 and upstream of snowmobile crossing in Derby (also sampled in 2006 and 2008)
Lower Silage Seep	22 April-12 August	Crystal Brook downstream of U.S. Highway 5 and snowmobile crossing in Derby
Quarry East	22 April-21 October	Unnamed tributary downstream of U.S. Highway 5 in Derby
Quarry West	22 April-21 October	Unnamed tributary downstream of Derby Fish and Game Club Pond in Derby
Upper Quarry West	26 Aug.-21 October	Unnamed tributary upstream of Derby Fish and Game Club Pond in Derby

Appendix B. Water quality data collected at 27 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. Colored fonts highlight concentrations greater than Vermont water quality standards (State of Vermont 2006b) 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 NO$_x$ >2 mg/l (italics) or >5 mg/l (bold).

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO$_2$ - NO$_3$ (mg/l)**	**Total phosphorus (µg/l)**
Confluence	4/22/2009	6.4	*2.4*	*2.24*	16.2
Confluence	5/6/2009	2.8	*3.04*	*2.73*	12.9
Confluence	5/20/2009	5.1	*2.18*	*2.06*	12.8
Confluence	6/3/2009	2.3	*2.63*	*2.47*	13
Confluence	6/17/2009	3.6	*2.03*	1.8	18.3
Confluence	7/1/2009	3	*2.02*	1.8	19.4
Confluence	7/15/2009	8.9	1.82	1.59	15.2
Confluence	7/29/2009	3.8	*2.41*	*2.23*	15
Confluence	8/12/2009	8.9	1.69	1.46	*20.4*
Confluence	8/26/2009	5.1	*2.8*	*2.43*	15.8
Confluence	9/9/2009	-	*4.19*	*4.05*	11.5
Confluence	9/23/2009	-	*4.48*	*4.54*	13.1
Confluence	10/7/2009	22.1	*3.09*	*2.16*	162
Confluence	10/21/2009	-	*3.96*	*3.66*	11.2
Crystal Brook	4/22/2009	18.8	1.11	0.9	17.7
Crystal Brook	5/6/2009	12.1	1.26	0.98	*24.9*
Crystal Brook	5/20/2009	19.8	1.18	1	17
Crystal Brook	6/3/2009	15.7	1.22	1.02	*26*
Crystal Brook	6/17/2009	14	1.17	0.82	*28.7*
Crystal Brook	7/1/2009	17.5	1.17	0.88	*21.6*
Crystal Brook	7/15/2009	20.3	1.31	1.06	18.2
Crystal Brook	7/29/2009	22.6	1.45	1.27	16.5
Crystal Brook	8/12/2009	22.4	1.27	0.97	*20.4*
Crystal Brook	8/26/2009	17.3	1.57	1.26	*23.9*
Crystal Brook	9/9/2009	12.1	1.76	1.68	19.9
Crystal Brook	9/23/2009	17.8	*2.12*	1.93	*30.4*
Crystal Brook	10/7/2009	31.8	1.48	0.48	**214**
Crystal Brook	10/21/2009	15.5	1.64	1.36	11.2

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Darling Hill	4/22/2009	2	*2.03*	1.89	17.6
Darling Hill	5/6/2009	0.8	*2.63*	*2.31*	12.6
Darling Hill	5/20/2009	3	*2.27*	*2.13*	18.4
Darling Hill	6/3/2009	2.5	*2.52*	*2.34*	18.4
Darling Hill	6/17/2009	3.6	1.65	1.42	*26.3*
Darling Hill	7/1/2009	3.3	1.76	1.43	**36.7**
Darling Hill	7/15/2009	5.8	1.42	1.12	*26.4*
Darling Hill	7/29/2009	0	*2.21*	*2.03*	*22.4*
Darling Hill	8/12/2009	3	1.21	0.97	*29.9*
Darling Hill	8/26/2009	-1.3	*2.52*	*2.17*	*21.8*
Darling Hill	9/9/2009	-2.5	*3.05*	*2.96*	13.9
Darling Hill	9/23/2009	-2	*3.47*	*3.34*	14.1
Darling Hill	10/7/2009	27.9	*2.89*	0.51	**762**
Darling Hill	10/21/2009	0.5	*3.24*	*2.95*	11.8
DHM Main Stem	9/9/2009	-	0.88	0.71	**39.8**
DHM Main Stem	10/7/2009	-	0.9	0.17	**102**
DHM Main Stem	10/21/2009	-	0.35	0.17	19.6
DHT Main Spring	9/9/2009	-	**18.8**	**13.3**	9.77
DHT Main Spring	10/7/2009	-	**14.8**	**13.4**	8.94
DHT Main Spring	10/21/2009	-	**15.3**	**14.3**	9.38
DHT Spring West	9/9/2009	-	**6.66**	**6.07**	9.42
DHT Spring West	10/7/2009	-	**6.3**	**5.82**	9.05
DHT Spring West	10/21/2009	-	**6.32**	**6.14**	8.62
Eagle Point	7/1/2009	27.9	0.52	-	**37.1**
Eagle Point	7/15/2009	50.8	0.41	-	**37**
Eagle Point	7/29/2009	8.9	0.59	-	**45.2**
East Side	7/1/2009	17.1	1.81	-	**36**
East Side	7/15/2009	20.3	1.41	-	*28.8*
East Side	7/29/2009	18.4	1.51	-	**61.8**
East Side	8/12/2009	10.8	1.39	-	**36.9**
East Side	8/26/2009	7.6	1.56	-	*25.4*
East Side	9/9/2009	12.7	1.66	-	*26.7*
East Side	9/23/2009	7.9	1.71	-	**47.5**
East Side	10/7/2009	27.9	1.11	-	**294**
East Side	10/21/2009	13.3	1.59	-	**92.8**

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Elm Street	4/22/2009	-	*2.18*	*2.08*	13.6
Elm Street	5/6/2009	-	*2.59*	*2.38*	13.6
Elm Street	5/20/2009	-	1.99	1.91	12.7
Elm Street	6/3/2009	-	*2.37*	*2.22*	14.6
Elm Street	6/17/2009	-	1.88	1.68	17.8
Elm Street	7/1/2009	-	1.85	1.61	19
Elm Street	7/15/2009	-	1.69	1.23	15.9
Elm Street	7/29/2009	-	*2.21*	*2.02*	15.1
Elm Street	8/12/2009	-	1.63	1.37	19.7
Elm Street	8/26/2009	-	*2.68*	*2.19*	18.6
Elm Street	9/9/2009	-	*3.57*	*3.46*	16
Elm Street	9/23/2009	-	*4*	*3.92*	14.3
Elm Street	10/7/2009	-	*2.46*	1.8	**97.7**
Elm Street	10/21/2009	-	*3.5*	*3.2*	13
Granite	4/22/2009	-	*2.34*	*2.24*	*20.6*
Granite	5/6/2009	-	*2.92*	*2.72*	13.5
Granite	5/20/2009	-	*2.13*	*2.03*	13.3
Granite	6/3/2009	-	*2.61*	*2.45*	15.6
Granite	6/17/2009	-	1.86	1.66	*20*
Granite	7/1/2009	-	1.9	1.67	*21.7*
Granite	7/15/2009	-	1.77	1.58	17.9
Granite	7/29/2009	-	*2.37*	*2.22*	17.2
Granite	8/12/2009	-	1.56	1.26	**35.4**
Granite	8/26/2009	-	*2.75*	*2.35*	17.9
Granite	9/9/2009	-	*3.79*	*3.68*	13.1
Granite	9/23/2009	-	*4.13*	*4.03*	13.6
Granite	10/7/2009	-	*2.88*	1.79	**226**
Granite	10/21/2009	-	*3.75*	*3.45*	11.2
Holbrook Bay	7/1/2009	25.4	0.43	-	**45**
Holbrook Bay	7/15/2009	22.9	0.35	-	*29.9*
Holbrook Bay	7/29/2009	27.9	0.52	-	**74.8**
Holbrook Bay	8/12/2009	12.7	0.41	-	**53.4**
Holbrook Bay	8/26/2009	4.4	0.62	-	**109**
Holbrook Bay	9/9/2009	-2.5	0.57	-	**89.2**
Holbrook Bay	9/23/2009	3.8	1.5	-	**183**
Holbrook Bay	10/7/2009	10.2	0.66	-	**156**
Holbrook Bay	10/21/2009	4.4	0.19	-	*30.3*

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Johns River	4/22/2009	19.1	*2.37*	*2.26*	15.6
Johns River	5/6/2009	16.5	*2.89*	*2.64*	13.4
Johns River	5/20/2009	17.3	*2.18*	*2*	13
Johns River	6/3/2009	14.7	*2.66*	*2.36*	13.6
Johns River	6/15/2009	62.2	-	-	**214**
Johns River	6/17/2009	18.8	1.91	1.96	*29.7*
Johns River	7/1/2009	20.3	1.95	1.73	19.4
Johns River	7/15/2009	20.3	1.76	1.54	16.9
Johns River	7/29/2009	17.8	*2.45*	*2.23*	15.2
Johns River	7/31/2009	30.5	-	-	**135**
Johns River	8/12/2009	22.4	1.58	1.34	*23.8*
Johns River	8/26/2009	14.5	*2.82*	*2.43*	17.6
Johns River	9/9/2009	10.2	*4.07*	*3.91*	11.8
Johns River	9/23/2009	10.8	*4.49*	*4.41*	12.5
Johns River	10/7/2009	35.1	*3.38*	1.84	**376**
Johns River	10/21/2009	11.9	*3.91*	*3.59*	10.3
Lakemont	8/12/2009	36.8	0.32	-	**37.3**
Lindsay Beach	7/1/2009	29.8	0.32	-	*20.5*
Lindsay Beach	7/15/2009	27.6	0.29	-	16.1
Lindsay Beach	7/29/2009	19.7	0.27	-	14.9
Lindsay Beach	8/12/2009	20.3	0.27	-	10
Lindsay Beach	8/26/2009	8.6	0.25	-	19.7
Lindsay Beach	9/9/2009	15.9	0.21	-	16.3
Lindsay Beach	9/23/2009	16.5	0.25	-	15.6
Lindsay Beach	10/7/2009	22.5	0.53	-	**73.5**
Lindsay Beach	10/21/2009	19.1	0.19	-	14.2
Lower Silage Seep	4/22/2009	-	1.19	0.99	16.5
Lower Silage Seep	5/6/2009	-	1.3	1.13	*26.7*
Lower Silage Seep	5/20/2009	-	1.19	1.09	*20.6*
Lower Silage Seep	6/3/2009	-	1.24	1.16	*25.2*
Lower Silage Seep	6/17/2009	-	1.19	0.93	*28.5*
Lower Silage Seep	7/1/2009	-	1.17	0.94	*24.6*
Lower Silage Seep	7/15/2009	-	1.32	1.08	*28.5*
Lower Silage Seep	7/29/2009	-	1.46	1.31	19.3
Lower Silage Seep	8/12/2009	-	1.25	1	*24.6*

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Nelson Hill	4/22/2009	-	0.82	0.65	13.3
Nelson Hill	5/6/2009	-	0.67	0.44	15
Nelson Hill	5/20/2009	-	0.78	0.57	11.8
Nelson Hill	6/3/2009	-	0.57	0.39	9.77
Nelson Hill	6/17/2009	-	0.8	0.3	*29.4*
Nelson Hill	7/1/2009	-	0.84	0.34	*21*
Nelson Hill	7/15/2009	-	0.78	0.43	14.3
Nelson Hill	7/29/2009	-	0.81	0.53	11.1
Nelson Hill	8/12/2009	-	0.96	0.5	18
Nelson Hill	8/26/2009	-	0.78	0.43	12
Nelson Hill	9/9/2009	-	0.81	0.63	10.8
Nelson Hill	9/23/2009	-	1.12	0.26	**73.5**
Nelson Hill	10/7/2009	-	0.81	0.17	**54**
Nelson Hill	10/21/2009	-	0.84	0.66	8.67
North Derby Road	4/22/2009	-16.8	*2.11*	1.94	*20.4*
North Derby Road	5/6/2009	-22.1	*2.54*	*2.32*	*27.1*
North Derby Road	5/20/2009	-24.1	1.98	1.84	*22.3*
North Derby Road	6/3/2009	-25.4	*2.25*	*2.04*	*26.6*
North Derby Road	6/17/2009	-24.1	1.53	1.27	*32.8*
North Derby Road	7/1/2009	-23.4	1.6	1.29	*32.4*
North Derby Road	7/15/2009	15.9	1.58	1.29	*27.5*
North Derby Road	7/29/2009	-29.2	*2.17*	1.95	*30.8*
North Derby Road	8/12/2009	-5.1	1.28	0.96	**38**
North Derby Road	8/26/2009	-27.9	*2.17*	1.88	**36.1**
North Derby Road	9/9/2009	-43.2	*2.79*	*2.62*	*33.7*
North Derby Road	9/23/2009	-33.0	*3.4*	*3.13*	**44.4**
North Derby Road	10/7/2009	-12.7	*2.2*	1.81	**59.9**
North Derby Road	10/21/2009	-26.7	*3.3*	*2.98*	**36.7**

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	NO_2 - NO_3 (mg/l)	Total phosphorus (µg/l)
Quarry East	4/22/2009	-	0.6	0.52	13.7
Quarry East	5/6/2009	-	0.61	0.49	9.32
Quarry East	5/20/2009	-	0.59	0.53	12.9
Quarry East	6/3/2009	-	0.56	0.52	9.68
Quarry East	6/17/2009	-	0.58	0.44	14.1
Quarry East	7/1/2009	-	0.52	0.42	13
Quarry East	7/15/2009	-	0.51	0.43	11.3
Quarry East	7/29/2009	-	0.5	0.42	10.4
Quarry East	8/12/2009	-	0.47	0.38	12.9
Quarry East	8/26/2009	-	0.5	0.39	10.6
Quarry East	9/9/2009	-	0.48	0.44	10.3
Quarry East	9/23/2009	-	0.54	0.44	16.1
Quarry East	10/7/2009	-	0.5	0.23	**39.7**
Quarry East	10/21/2009	-	0.51	0.51	8.5
Quarry West	4/22/2009	-	1.04	0.9	11.1
Quarry West	5/6/2009	-	1.12	0.9	13.2
Quarry West	5/20/2009	-	0.91	0.74	13.8
Quarry West	6/3/2009	-	0.88	0.72	13.2
Quarry West	6/17/2009	-	0.71	0.33	*22*
Quarry West	7/1/2009	-	0.71	0.31	*26.7*
Quarry West	7/15/2009	-	0.7	0.42	18.4
Quarry West	7/29/2009	-	0.94	0.71	16.1
Quarry West	8/12/2009	-	0.7	0.4	*22.3*
Quarry West	8/26/2009	-	1.08	0.67	*27*
Quarry West	9/9/2009	-	1.23	1.02	*30.9*
Quarry West	9/23/2009	-	1.32	1.11	*20.1*
Quarry West	10/7/2009	-	0.82	0.4	**38**
Quarry West	10/21/2009	-	0.78	0.6	12
Strawberry Acres	7/1/2009	15.2	0.48	-	**48.3**
Strawberry Acres	7/15/2009	16.5	0.46	-	**36**
Strawberry Acres	7/29/2009	8.9	0.72	-	**43.2**
Strawberry Acres	8/12/2009	21.6	0.53	-	**63.2**
Strawberry Acres	8/26/2009	5.1	0.27	-	*32.7*
Strawberry Acres	9/23/2009	3.8	0.27	-	17.8
Strawberry Acres	10/7/2009	12.7	0.36	-	**40**
Strawberry Acres	10/21/2009	7.6	0.14	-	13.4

Site	Date	Water depth (cm)	Total nitrogen (mg/l)	NO_2 - NO_3 (mg/l)	Total phosphorus (µg/l)
Sunset Acres	7/1/2009	18.4	*2.69*	-	18.9
Sunset Acres	7/15/2009	21.6	*2.64*	-	14.5
Sunset Acres	7/29/2009	17.8	*4.83*	-	13.2
Sunset Acres	8/12/2009	20.3	*2.01*	-	19.2
Sunset Acres	8/26/2009	10.2	**5.79**	-	15.6
Sunset Acres	9/9/2009	12.7	**6.22**	-	16.5
Sunset Acres	9/23/2009	12.7	**6.52**	-	12.4
Sunset Acres	10/7/2009	18.7	*3.52*	-	**71.6**
Sunset Acres	10/21/2009	16.5	**5.59**	-	9.88
Sunset Acres North	4/22/2009	-	0.59	0.32	*24.5*
Sunset Acres North	5/6/2009	-	0.46	0.18	*24.6*
Sunset Acres North	5/20/2009	-	0.46	0.18	14.4
Sunset Acres North	6/3/2009	-	0.33	0.13	14.3
Sunset Acres North	6/17/2009	-	0.37	<0.05	*24.7*
Sunset Acres North	7/1/2009	-	0.58	<0.05	**51.8**
Sunset Acres North	7/15/2009	-	0.49	0.07	**42.2**
Sunset Acres North	7/29/2009	-	0.47	0.18	19.8
Sunset Acres North	8/12/2009	-	0.49	0.08	*28.1*
Sunset Acres North	8/26/2009	-	0.5	0.16	*26.3*
Sunset Acres North	9/9/2009	-	0.54	0.16	**36**
Sunset Acres North	9/23/2009	-	0.29	0.11	18.1
Sunset Acres North	10/7/2009	-	0.72	0.09	**87.5**
Sunset Acres North	10/21/2009	-	0.21	0.11	12.1
Sunset Acres South	4/22/2009	-	*4.15*	*4.05*	12.6
Sunset Acres South	5/6/2009	-	**5.73**	**5.37**	14.3
Sunset Acres South	5/20/2009	-	*4.92*	*4.83*	10.6
Sunset Acres South	6/3/2009	-	**5.71**	**5.63**	9.74
Sunset Acres South	6/17/2009	-	*3.68*	*3.33*	14.3
Sunset Acres South	7/1/2009	-	*3.32*	*3.13*	*21.2*
Sunset Acres South	7/15/2009	-	*3.14*	*2.98*	17.7
Sunset Acres South	7/29/2009	-	**5.6**	**5.49**	11.6
Sunset Acres South	8/12/2009	-	*2.8*	*2.42*	17.9
Sunset Acres South	8/26/2009	-	**6.7**	**5.97**	14.1
Sunset Acres South	9/9/2009	-	**6.55**	**7.03**	12.4
Sunset Acres South	9/23/2009	-	**7.08**	**7.05**	14.1
Sunset Acres South	10/7/2009	-	*3.25*	*2.52*	**103**
Sunset Acres South	10/21/2009	-	**6.39**	**6.08**	8.98

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Upper Darling Hill	4/22/2009	-	*2.73*	*2.57*	*21.2*
Upper Darling Hill	5/6/2009	-	*3.35*	*2.85*	**36.4**
Upper Darling Hill	5/20/2009	-	*3.5*	*3.33*	*23.7*
Upper Darling Hill	6/3/2009	-	*4.57*	*4.34*	*26.7*
Upper Darling Hill	6/17/2009	-	*2.58*	*2.18*	*30.9*
Upper Darling Hill	7/1/2009	-	*2.34*	*2.02*	*32.1*
Upper Darling Hill	7/15/2009	-	1.8	1.34	*30.9*
Upper Darling Hill	7/29/2009	-	*4.35*	*4.28*	*29.3*
Upper Darling Hill	8/12/2009	-	1.78	1.53	*33.1*
Upper Darling Hill	8/26/2009	-	**6.36**	**5.63**	*29.1*
Upper Darling Hill	9/9/2009	-	**9.4**	**9.07**	*23.2*
Upper Darling Hill	9/23/2009	-	**8.78**	**8.7**	*21*
Upper Darling Hill	10/7/2009	-	1.65	0.39	**258**
Upper Darling Hill	10/21/2009	-	**5.85**	**5.5**	17.8
Upper Quarry West	8/26/2009	-	-	0.92	*24.9*
Upper Quarry West	9/9/2009	-	1.44	1.37	18.7
Upper Quarry West	9/23/2009	-	1.31	1.15	17.6
Upper Quarry West	10/7/2009	-	0.9	0.22	**66.9**
Upper Quarry West	10/21/2009	-	0.78	0.63	12.2
Upper Sunset Acres	6/3/2009	-	0.2	0.13	-
Upper Sunset Acres	6/17/2009	-	0.35	0.19	*21.4*
Upper Sunset Acres	7/1/2009	-	0.34	0.15	*26*
Upper Sunset Acres	7/15/2009	-	0.28	0.13	17
Upper Sunset Acres	7/29/2009	-	0.33	0.18	18.5
Upper Sunset Acres	8/12/2009	-	0.31	0.11	19.2
Upper Sunset Acres	8/26/2009	-	0.27	0.13	17
Upper Sunset Acres	9/9/2009	-	0.24	<0.05	*22.1*
Upper Sunset Acres	9/23/2009	-	0.36	<0.05	**37.9**
Upper Sunset Acres	10/7/2009	-	0.63	0.09	**70.7**
Upper Sunset Acres	10/21/2009	-	<0.1	<0.05	10.4

Site	**Date**	**Water depth (cm)**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
Upper Wishing Well	7/1/2009	21.0	0.68	-	**67.9**
Upper Wishing Well	7/15/2009	24.1	0.59	-	**45.9**
Upper Wishing Well	7/29/2009	19.1	0.7	-	**47.8**
Upper Wishing Well	8/12/2009	20.3	0.74	-	**110**
Upper Wishing Well	8/26/2009	11.4	-	-	**46.1**
Upper Wishing Well	9/9/2009	6.4	0.5	-	*25.6*
Upper Wishing Well	9/23/2009	10.2	0.45	-	*21.1*
Upper Wishing Well	10/7/2009	27.9	1.05	-	**254**
Upper Wishing Well	10/21/2009	12.7	0.35	-	*22.1*
Wishing Well	7/1/2009	15.9	0.58	-	**50.5**
Wishing Well	7/15/2009	24.1	0.53	-	**36.3**
Wishing Well	7/29/2009	10.2	0.64	-	*32.6*
Wishing Well	8/12/2009	15.2	0.73	-	**96.2**
Wishing Well	8/26/2009	8.9	0.55	-	**35.7**
Wishing Well	9/9/2009	6.4	0.48	-	*33.3*
Wishing Well	9/23/2009	7.6	0.4	-	*26.3*
Wishing Well	10/7/2009	17.8	0.95	-	**216**
Wishing Well	10/21/2009	10.2	0.3	-	16.4

Appendix C. Quality assurance data, including field blanks and field duplicates, from 27 sample sites along the Johns River and seven smaller tributaries of Lake Memphremagog during April-October 2009. Bold values indicate field blanks that exceeded detection limits (5 µg/l for total phosphorus, 0.1 mg/l for total nitrogen, and 0.05 mg/l for NO_x) or field duplicates that differed by >30% for total phosphorus, >20% for total nitrogen, and >10% for NO_x.

Field blanks:

Date	**Site**	**Total nitrogen (mg/l)**	**NO_2 - NO_3 (mg/l)**	**Total phosphorus (µg/l)**
4/22/2009	Sunset Acres South	<0.1	<0.05	<5
4/22/2009	Upper Darling Hill	<0.1	<0.05	<5
5/6/2009	Elm Street	<0.1	<0.05	<5
5/6/2009	Sunset Acres North	<0.1	<0.05	<5
5/20/2009	North Derby Road	<0.1	<0.05	<5
5/20/2009	Lower Silage Seep	<0.1	<0.05	<5
6/3/2009	Crystal Brook	<0.1	<0.05	<5
6/3/2009	Granite	<0.1	<0.05	<5
6/17/2009	Johns River	<0.1	<0.05	<5
6/17/2009	Nelson Hill	<0.1	<0.05	<5
7/1/2009	Confluence	<0.1	<0.05	<5
7/1/2009	Eagle Point	<0.1	-	<5
7/1/2009	Quarry West	<0.1	<0.05	<5
7/15/2009	Holbrook Bay	<0.1	-	<5
7/15/2009	Johns River	<0.1	<0.05	<5
7/15/2009	Nelson Hill	<0.1	<0.05	<5
7/29/2009	Confluence	<0.1	<0.05	<5
7/29/2009	Eagle Point	<0.1	-	<5
7/29/2009	Quarry West	<0.1	<0.05	<5
8/12/2009	Darling Hill	<0.1	<0.05	<5
8/12/2009	Quarry East	<0.1	<0.05	<5
8/12/2009	Wishing Well	<0.1	-	<5
8/26/2009	Upper Darling Hill	<0.1	<0.05	<5
8/26/2009	Upper Sunset Acres	<0.1	<0.05	<5
8/26/2009	Upper Wishing Well	<0.1	-	<5
9/9/2009	Lindsay Beach	<0.1	-	<5
9/9/2009	Crystal Brook	<0.1	<0.05	<5
9/9/2009	Sunset Acres North	<0.1	<0.05	<5

Date	Site	Total nitrogen (mg/l)	NO_2 - NO_3 (mg/l)	Total phosphorus (µg/l)
9/23/2009	East Side	<0.1	-	<5
9/23/2009	Elm Street	<0.1	<0.05	<5
9/23/2009	North Derby Road	<0.1	<0.05	<5
10/7/2009	North Derby Road	<0.1	<0.05	<5
10/7/2009	Quarry East	<0.1	<0.05	<5
10/7/2009	Strawberry Acres	<0.1	-	<5
10/21/2009	Sunset Acres South	<0.1	<0.05	<5
10/21/2009	Upper Darling Hill	<0.1	<0.05	<5

Field duplicates:

Total phosphorus

Date	**Site**	**1st total phosphorus (µg/l)**	**2nd total phosphorus (µg/l)**	**Relative % difference**
4/22/2009	Sunset Acres South	12.6	11.3	11
4/22/2009	Upper Darling Hill	21.2	21.4	-1
5/6/2009	Elm Street	13.6	12.1	12
5/6/2009	Sunset Acres North	24.6	24.4	1
5/20/2009	North Derby Road	22.3	22.9	-3
5/20/2009	Lower Silage Seep	20.6	20.5	0
6/3/2009	Crystal Brook	26	28.2	-8
6/3/2009	Granite	15.6	15.6	0
6/15/2009	Johns River	214	216	-1
6/17/2009	**Johns River**	**29.7**	**19**	**44**
6/17/2009	Nelson Hill	29.4	24.7	17
7/1/2009	Confluence	19.4	19.1	2
7/1/2009	Eagle Point	37.1	37.8	-2
7/1/2009	Quarry West	26.7	26	3
7/15/2009	Holbrook Bay	29.9	28.8	4
7/15/2009	Johns River	16.9	16.5	2
7/29/2009	Confluence	15	14.6	3
7/29/2009	Eagle Point	45.2	43.8	3
7/29/2009	Quarry West	16.1	18.4	-13
7/31/2009	Johns River	135	145	-7
8/12/2009	Darling Hill	29.9	29.4	2
8/12/2009	Quarry East	12.9	12.2	6
8/12/2009	Wishing Well	96.2	97	-1
8/26/2009	Upper Darling Hill	29.1	27.4	6
8/26/2009	Upper Sunset Acres	17	16.7	2
8/26/2009	Upper Wishing Well	46.1	45	2
9/9/2009	Crystal Brook	19.9	18.1	9
9/9/2009	Lindsay Beach	16.3	15.4	6
9/9/2009	Sunset Acres North	36	31.5	13
9/23/2009	East Side	47.5	48.6	-2
9/23/2009	Elm Street	14.3	14.3	0
9/23/2009	North Derby Road	44.4	51	-14
10/7/2009	North Derby Road	59.9	64	-7
10/7/2009	Quarry East	39.7	40.8	-3
10/7/2009	Strawberry Acres	40	41.9	-5
10/21/2009	Sunset Acres South	8.98	9.01	0
10/21/2009	Upper Darling Hill	17.8	16.9	5

Total nitrogen

Date	Site	1st total nitrogen (mg/l)	2nd total nitrogen (mg/l)	Relative % difference
4/22/2009	Sunset Acres South	4.15	4.3	-4
4/22/2009	Upper Darling Hill	2.73	2.73	0
5/6/2009	Elm Street	2.59	2.56	1
5/6/2009	Sunset Acres North	0.46	0.47	-2
5/20/2009	North Derby Road	1.98	1.94	2
5/20/2009	Lower Silage Seep	1.19	1.2	-1
6/3/2009	Crystal Brook	1.22	1.22	0
6/3/2009	Granite	2.61	2.59	1
6/17/2009	Johns River	1.91	1.96	-3
6/17/2009	Nelson Hill	0.8	0.79	1
7/1/2009	Confluence	2.02	2.02	0
7/1/2009	Eagle Point	0.52	0.49	6
7/1/2009	Quarry West	0.71	0.71	0
7/15/2009	Holbrook Bay	0.35	0.35	0
7/15/2009	Johns River	1.76	1.79	-2
7/29/2009	Confluence	2.41	2.4	0
7/29/2009	Eagle Point	0.59	0.59	0
7/29/2009	Quarry West	0.94	0.93	1
8/12/2009	Darling Hill	1.21	1.22	-1
8/12/2009	Quarry East	0.47	0.47	0
8/12/2009	Wishing Well	0.73	0.71	3
8/26/2009	Upper Darling Hill	6.36	6.29	1
8/26/2009	Upper Sunset Acres	0.27	0.29	-7
9/9/2009	Crystal Brook	1.76	1.75	1
9/9/2009	Lindsay Beach	0.21	0.21	0
9/9/2009	Sunset Acres North	0.54	0.55	-2
9/23/2009	East Side	1.71	1.68	2
9/23/2009	Elm Street	4	4.07	-2
9/23/2009	North Derby Road	3.4	3.44	-1
10/7/2009	North Derby Road	2.2	2.21	0
10/7/2009	Quarry East	0.5	0.5	0
10/7/2009	Strawberry Acres	0.36	0.34	6
10/21/2009	Sunset Acres South	6.39	6.47	-1
10/21/2009	Upper Darling Hill	5.85	5.95	-2

NO_2 - NO_3

Date	**Site**	**1^{st} NO_x (mg/l)**	**2^{nd} NO_x (mg/l)**	**Relative % difference**
4/22/2009	Sunset Acres South	4.05	4.02	1
4/22/2009	Upper Darling Hill	2.57	2.53	2
5/6/2009	Elm Street	2.38	2.39	0
5/6/2009	Sunset Acres North	0.18	0.18	0
5/20/2009	North Derby Road	1.84	1.82	1
5/20/2009	Lower Silage Seep	1.09	1.08	1
6/3/2009	Crystal Brook	1.02	1.01	1
6/3/2009	Granite	2.45	2.46	0
6/17/2009	**Johns River**	**1.96**	**1.7**	**14**
6/17/2009	Nelson Hill	0.3	0.3	0
7/1/2009	Confluence	1.8	1.79	1
7/1/2009	Quarry West	0.31	0.31	0
7/15/2009	Johns River	1.54	1.64	-6
7/29/2009	Confluence	2.23	2.23	0
7/29/2009	Quarry West	0.71	0.71	0
8/12/2009	Darling Hill	0.97	0.97	0
8/12/2009	Quarry East	0.38	0.38	0
8/26/2009	Upper Darling Hill	5.63	5.53	2
8/26/2009	Upper Sunset Acres	0.13	0.13	0
9/9/2009	Crystal Brook	1.68	1.68	0
9/9/2009	Sunset Acres North	0.16	0.16	0
9/23/2009	Elm Street	3.92	3.96	-1
9/23/2009	North Derby Road	3.13	3.19	-2
10/7/2009	North Derby Road	1.81	1.8	1
10/7/2009	Quarry East	0.23	0.23	0
10/21/2009	Sunset Acres South	6.08	6.1	0
10/21/2009	Upper Darling Hill	5.5	5.48	0

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

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

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

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

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

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

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 (usually measured as cubic feet per second or cubic meters per second).

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

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

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

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

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

Nutrient – A chemical required for growth, development, or maintenance of a plant or animal. Nutrients are essential for sustaining 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.

Quartile – The value of the boundary at the 25th, 50th, or 75th percentiles of an ordered set of numbers divided into four equal parts, each containing a quarter of the numbers.

Riparian buffer – A strip of unmanaged vegetation growing along the shoreline of a river or stream. Riparian buffers reduce erosion, filter sediments and pollutants, and enhance aquatic and riverine habitats.

Standard deviation (SD) – A statistic that measures the variability of a set of data.

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

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

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

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

Watershed – See basin.

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