The Water Quality of Lake Memphremagog

Results of the Joint Quebec-Vermont Water Quality Monitoring Initiative

and

Recommendations for Strategy Development

Approved by the Quebec/Vermont Steering Committee on Lake Memphremagog

May 8, 2008

Prepared by the Monitoring and Assessment Work Group of the
Quebec/Vermont Steering Committee on Lake Memphremagog

Whose members represent:

Memphremagog Conservation, Inc.

Ministère du Développement durable, de l'Environnement et des Parcs

MRC de Memphremagog

Northwoods Stewardship Center

Vermont Agency of Natural Resources

City of Newport, Vermont

Ville de Magog, Quebec

Ville de Sherbrooke, Quebec

Table of Contents

1.0 Introduction and Executive Summary

1.1 Preface

Lake Memphremagog, which flows north from the U.S. to Canada, is a highly-valued resource providing recreational opportunities and serving as a public water supply for residents of Canada and the United States. In the past several years, there has been a growing interest in the quality of the lake. This has in part been accentuated by focused media attention on water quality issues in general, but also due to the increasing incidence of cyanobacteria (blue-green algae) blooms. Such blooms can be caused by excessive nutrient concentrations, particularly phosphorus. The appearance of these blooms in 2005 culminates several years of growing concern over the general water quality conditions in the Lake.

In 2004 the Lake Memphremagog Steering Committee, an international partnership of municipal, State, and Federal stakeholders from the United States and Quebec, recognized this growing public concern. The Committee directed its partner agencies to re-invigorate water quality monitoring efforts, and to seek to align disparate monitoring efforts occurring on both sides of the Quebec-Vermont border. This report summarizes on-going monitoring initiatives carried out by the partnering agencies and organizations of the Steering Committee. The goal of this initiative has been to support an on-going Quebec-Vermont initiative to maintain or improve the quality of Lake Memphremagog. Specific objectives are to: document current water quality conditions in the Lake Memphremagog watershed; assess compliance with applicable Water Quality Standards; and, for United States waters, to determine whether the need exists for a comprehensive pollution control plan known as a Total Maximum Daily Load (TMDL), as required by Section 303(d) of the U.S. Clean Water Act. This work complements that of Operation Healthy Lake, an initiative spearheaded by Memphremagog Conservation, Inc. (MCI) during 2004 and 2005.

The monitoring programs of five partner agencies are presented in this document. The MRC de Memphremagog has responsibility for monitoring water quality conditions in tributaries draining the Quebec portions of the Memphremagog watershed. The Northwoods Stewardship Center of East Charleston, VT, has partnered with the Vermont Agency of Natural Resources (VTANR) to assume responsibility for monitoring tributary water quality in the United States portion of the watershed. The Quebec Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP), in concert with MCI, has responsibility for monitoring the open waters of the lake in Quebec, while VTANR carries this responsibility in the United States. MCI has assumed responsibility for a comprehensive assessment of littoral habitat quality under Operation Healthy Lake. This report presents recent monitoring program results with the goal of providing a unified view of water quality conditions facing the Lake Memphremagog watershed.

This report follows from several prior water quality reports describing Lake Memphremagog and its environs. In particular, this information contained in this document provides a natural extension to the 1993 *Final Report of the Quebec/Vermont Working Group on Managing Lake Memphremagog and it's Environment.* The Recommended Action Items provided by Section 5 are an extension of the items listed by the 1993 report, modified to omit actions that have been accomplished, and include new activities as well. Relevant publications supporting the findings in this report are provided in Section 6.

In this report, we highlight monitoring results from the period 2005-2006 in three sections, addressing water quality in tributaries, littoral habitat, and the open waters of Lake Memphremagog. For each section, maps are presented that depict the water quality results corresponding to excellent, acceptable, and poor conditions.

Finally, a series of action item recommendations are provided to facilitate the implementation of remediation projects in the watershed, even while additional monitoring may be warranted. This report was prepared by the members of the Memphremagog Steering Committee's subcommittee on monitoring. Members of this committee include the technical experts representing the partner organizations listed above.

1.2 Water Quality in Lake Memphremagog Tributaries

Since 1998, the MRC of Memphremagog has been conducting sampling at various sites on tributaries of Lake Memphremagog in Quebec. A total of 24 tributaries have been sampled, for at least one year, under this program. Each year, samples are taken in order to identify pollution sources and problematic brooks. This program is undertaken in collaboration with MRC-member municipalities and, since 2003, with the City of Sherbrooke. Samples are analyzed for the following five parameters: total phosphorus (TP), total suspended solids (TSS), fecal coliform (FC), pH, and total organic carbon (TOC). Sampling results are compared to existing Province of Quebec government guidelines to assess surface water quality. Areas of concern with elevated TP and TSS have been identified in the north and north-eastern portions of the watershed (Cherry River; Hermitage, Oliver, Price and McAuley brooks), in Fitch Bay (Bunker, Gale and McCutcheon Brooks) and in Ogden (Tomkin Brook).

Since 2005, VTANR and the Northwoods Stewardship Center have carried out a similar sampling initiative. The results of these surveys indicate that all four major VT tributaries discharge phosphorus, nitrogen, and total suspended solids into Lake Memphremagog, at varying levels. In Vermont, water quality is poorest in the John's River Watershed, which suffers the highest levels of phosphorus, nitrogen, NO_x, and total suspended solids. The Black River Watershed, where agricultural development is most extensive, has the second poorest water quality, with high levels of total suspended solids and phosphorus at most sample sites during high-flows. The Barton River Watershed also has extensive agriculture, and occasionally exhibits high levels of phosphorus and TSS at some sample sites. Finally, the Clyde River, especially the upper watershed, has relatively low levels of phosphorus, nitrogen, and total suspended solids. Restoration and/or protection efforts can be identified to mitigate the sources of these pollutants and improve water quality in all four tributary watersheds.

1.3 Littoral Habitat and Shorelines - Operation Healthy Lake

In the summer of 2004, MCI commissioned the *Regroupement des Associations pour la Protection de l'Environnement* (RAPPEL) to execute a study to examine the health of the Québec shoreline of Lake Memphremagog. The study was made public in May of 2005. Vermont's Agency of Natural Resources then asked MCI to arrange for the identical study to be executed on the Vermont shoreline. This request was completed during the summer of 2005. The Québec and Vermont studies produced for the first time a global picture of the health of the shorelines of Lake Memphremagog.

Data related to the condition of the shoreline and littoral habitat (sediments, aquatic plants, green algae, shoreline alterations) were gathered. For discrete lake sections, data concerning the condition of the shore and littoral was obtained by a team of biologists from RAPPEL.

The lake shows signs of silting in several areas. Sedimentation is clearly a problem in Vermont waters and Fitch Bay (north-east). A high density of aquatic plants was found in six sectors. Eurasian milfoil is a dominant and invasive species. Green algae is abundant in three areas. Identified problems include non-conforming septic systems, residential construction sites, pesticide and fertilizer use, development and alterations of the lakeshore, and clearcutting mature forest. In late summer of 2006, the appearance of cyanobacteria (blue-green algae, see below) presented a toxic threat to the Lake at countless locations. Warnings were issued with respect to drinking water and water used for washing and bathing activities. Corrective actions to improve lake health that were recommended in the Operation Healthy Lake studies of 2004 and 2005 are equally appropriate to battle the cyanobacteria threat with which we are currently faced. The Operation Healthy Lake studies are comprehensive stand-alone assessments that are only cursorily summarized herein. The reader is encouraged to review the final reports for Operation Healthy Lake 2004 (Quebec) and 2005 (Vermont), which are referenced in Section 6.

1.4 Water Quality in the Lake

Water quality has also been measured by VTANR and its citizen volunteers, as well as by MDDEP in partnership with MCI. In the lake itself, water quality conditions are variable, reflecting both the natural background nutrient levels in the segments, and potential watershed-based loadings. In the United States portion of the lake, water quality conditions meet Vermont standards in the South Bay, but not in the openwater segments of the lake, where total phosphorus concentrations are elevated by ~2 parts-per-billion (ppb) above standards. In Quebec waters, nutrient concentrations become quite low along the central axis of the lake. However, localized areas within and adjacent to the Fitch Bay exhibit high or excessive phosphorus concentrations, low Secchi transparency, and excessive algal growth.

Cyanobacteria (blue-green algae) have been observed in numerous locations in the lake with increasing frequency, particularly in 2006. However, measured cell densities are low relative to heavily impacted locations such as the Missisquoi Bay of Lake Champlain, and concentrations of algal toxins are very low, when detected at all. As such, while Lake Memphremagog may not at this time have a serious cyanobacteria problem, it is a phenomenon that must be monitored and prevented to the extent possible. The degree to which newly observed cyanobacterial blooms in sections of the lake are related to phosphorus sources in the Johns or Black Rivers, or from sources in the Fitch Bay watershed, is unclear.

2.0 Water Quality in the Lake Memphremagog Watershed Tributaries

2.1 Tributary Monitoring in Quebec

2.1.1 Methods

Every year, sampling stations are positioned 1) at the outlet of the tributaries to monitor water quality entering the Lake; and, 2) at some specific points on the tributaries to identify problematic areas (see map below). Each station is sampled five times from early June to early September: two times during wet periods (more than 10 mm of rain in 24 hours) and three times in dry periods (48 hours without any rain). Samples are preserved in ice, transported within 8 hours and analyzed following strict procedures in a private laboratory accredited by the Quebec government (Table 1). Water temperature, depth, color and changes to the brook at the sampling point and surrounding area are noted at each station.

Table 1: Laboratory methods and detection limits.

Parameter	Method	Detection limit
Total phosphorus	Persulfate digestion / colorimetry	2 ppb P/L
Total suspended solids	Gravimetry	1 ppm
pH	Electrode	n/a
Fecal coliform bacteria	Membrane filtration	2 colonies/100ml
Total organic carbon	Combustion	5 ppb C/L

2.1.2 Results

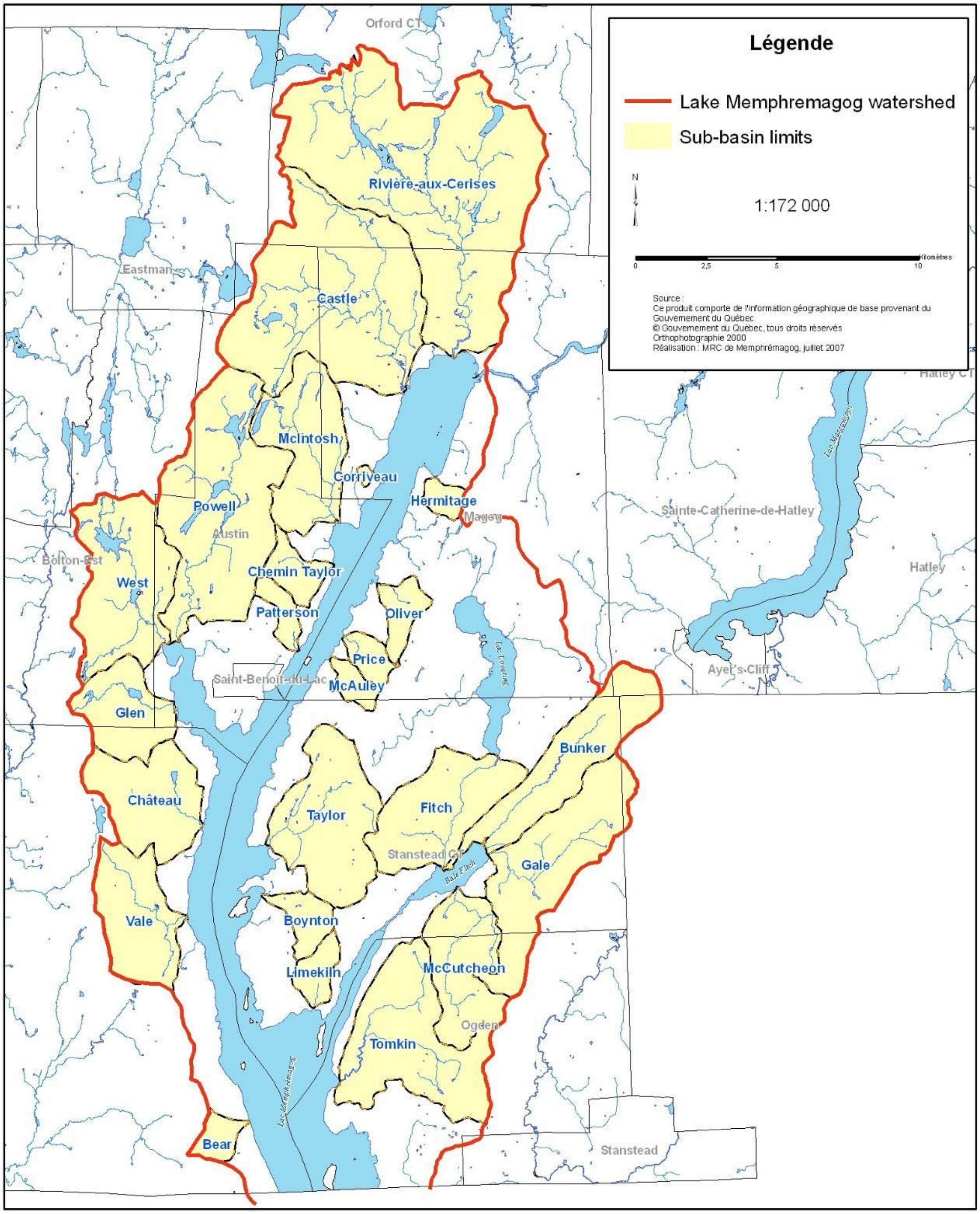
Results were interpreted in light of Quebec government criteria for aquatic life protection using the following thresholds: 20 ppb for TP; 5 ppm for TSS; and 200 colonies/100ml for FC. The TP criterion ensures that the tributary's contribution to the Lake's eutrophication will be minimal.

For every tributary outlet sampled since 1998, Figures 1, 2 and 3 represent annual median values for TP, TSS and FC, respectively.

Since 1999, there is an overall trend for higher TP and TSS concentrations in certain areas of the watershed, which are the north and north-eastern sides of the lake, Fitch Bay and Tomkin Brook's subbasin in Ogden.

The Cherry River outlet has been sampled since 2003. In 2004 and 2005, annual TP median concentrations were above 20 ppb. Since 2003, TP concentrations in all samples taken in wet periods were above 20 ppb. TSS and FC levels are under government criteria but higher concentrations have been noted during wet periods. While this part of the basin is heavily developed by residential, commercial, agricultural and recreational uses, pollution is mainly attributed to urbanization and agricultural runoff. Point and non-point sources have been identified, but the work is still in progress.

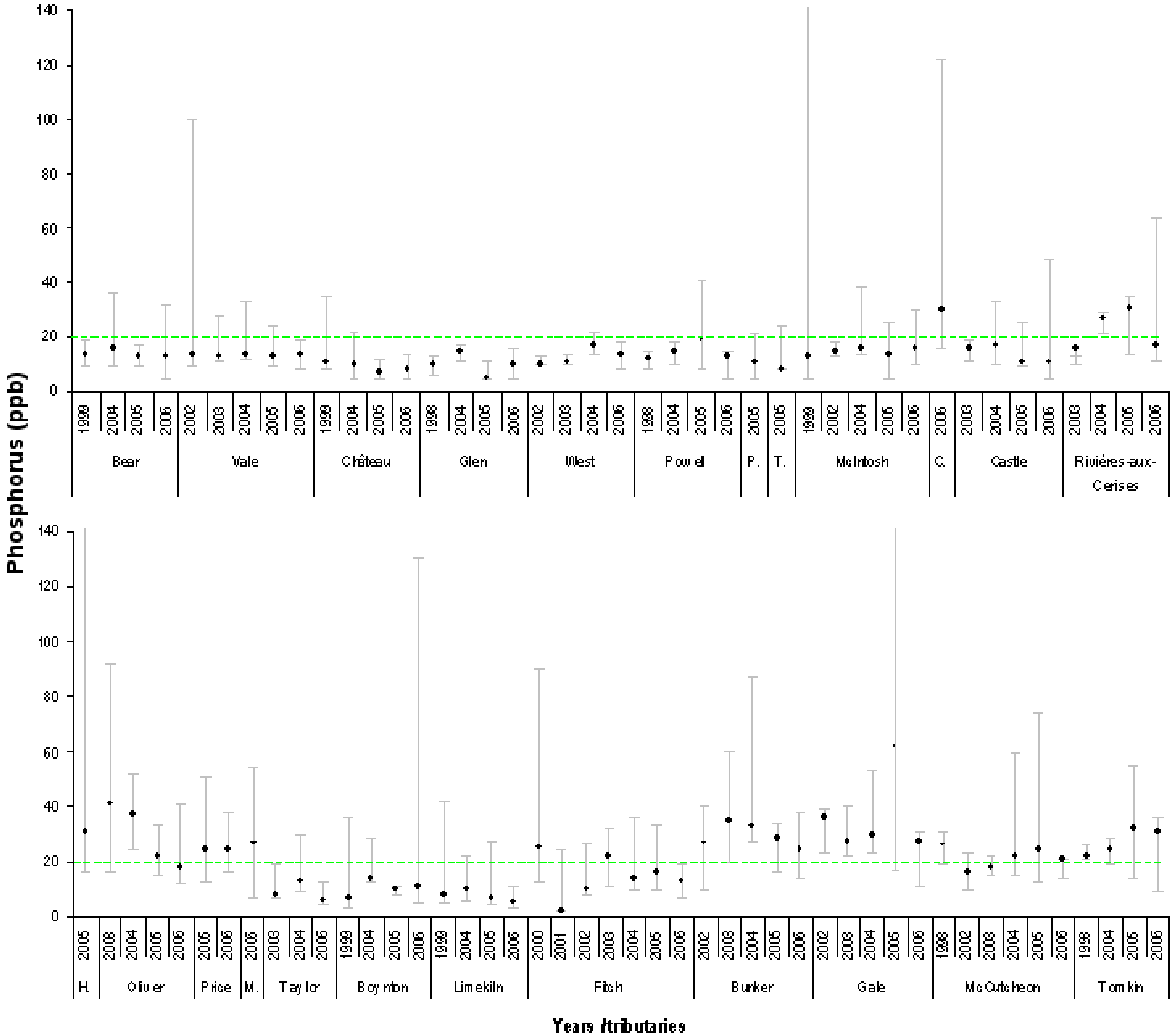
Quebec portion of Lake Memphremagog watershed and tributaries



On the north-eastern side of the Lake, Hermitage, Oliver, Price and McAuley Brooks have been assessed. Results showed that maintenance of golf courses, silvicultural activities, and agricultural practices in this part of the watershed have consequences on the water quality of these tributaries. Annual TP median concentrations were all above 20 ppb, except for Oliver Brook in 2006. High TP concentrations have been noted during wet periods. Additional sampling is needed to evaluate the McAuley and Hermitage Brooks' contribution to water quality conditions in the lake.

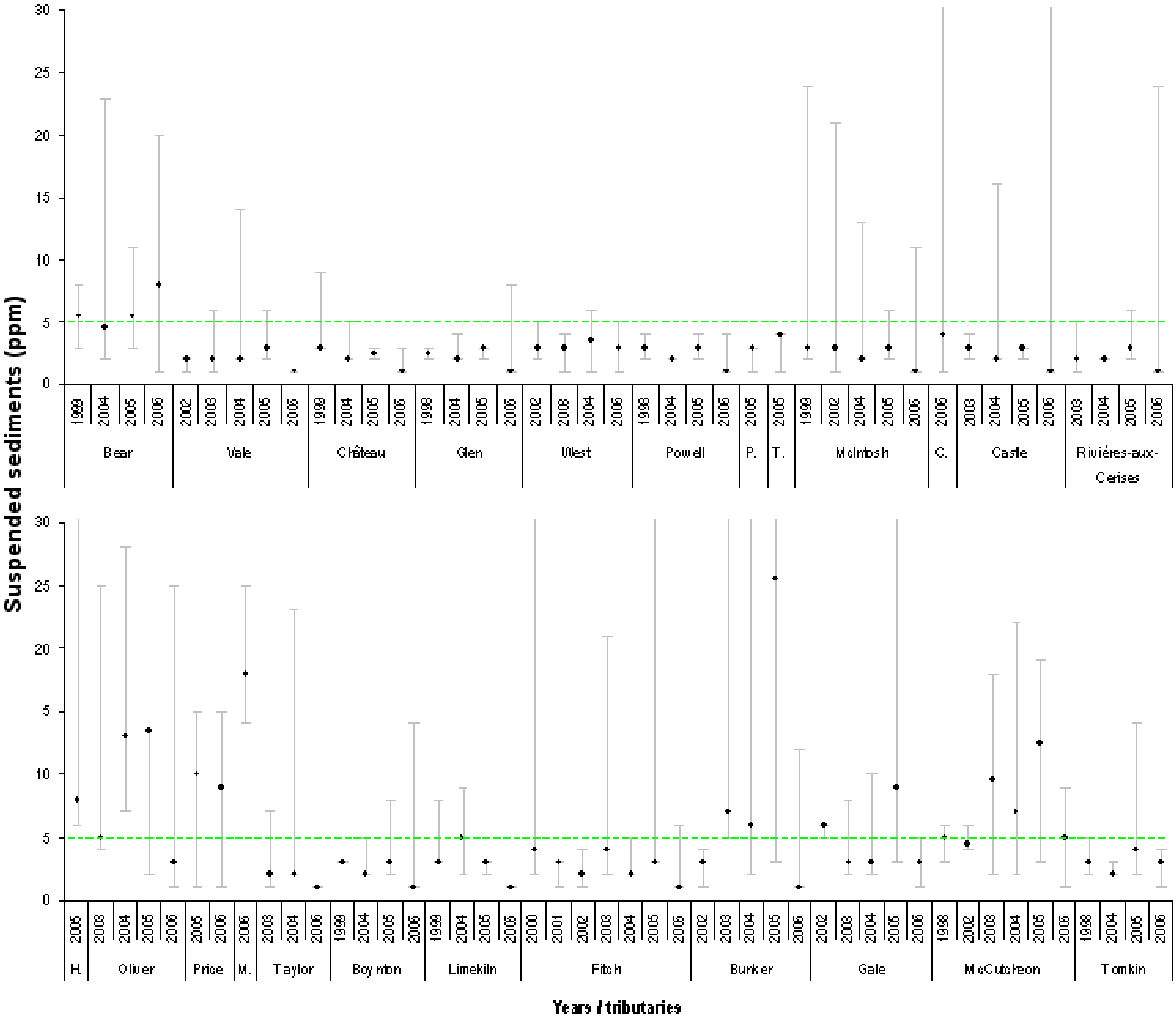
Tributaries of the Fitch Bay area have been sampled several times since 2006 and are therefore well characterized. TP, TSS and FC concentrations are problematic for Bunker, Gale and McCutcheon Brooks, especially in 2003, 2004 and 2005. Fitch Brook showed high TP concentration in 2003, but annual median concentrations were less than 20 ppb in 2004, 2005 and 2006. FC annual median levels were above the government criterion in 2000, 2003 and 2005. TSS concentrations are not problematic. Pollution in this area is mainly due to erosion and agricultural runoff from cornfields, pasture and manure storage areas.

Tomkin Brook showed high TP levels. TSS and FC levels are under government criteria. Over 18% of the Tomkin subbasin is used for agriculture. Runoff and erosion are therefore principal pollution sources to the Tomkin Brook. Since wetlands account for more than 9% of this subbasin, organic decomposition in these ecosystems may also be a source of phosphorus. However, this is likely offset by the function of wetlands as settling basins for pollutants derived from upstream sources.



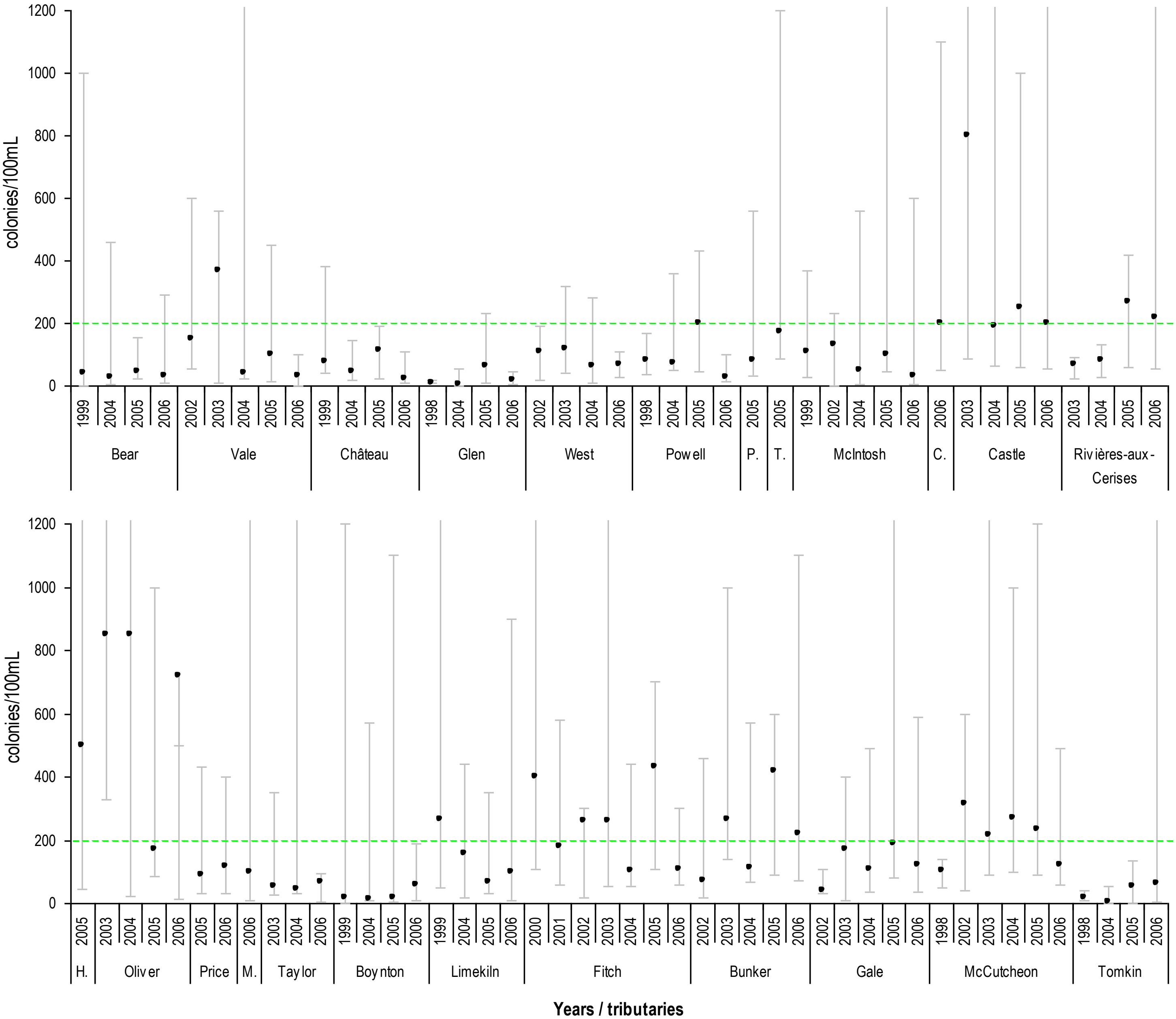
Legend :
P. = Patterson brook
T. = Du chemin Taylor brook
C. = Corriveau brook
H. = Hermitage brook
M. = McAuley brook
• = Annual median value ——— maximum and minimum annual value
- - - - - - government criterion for aquatic life protection (20 ppb)

Figure 1: Annual median concentration of total phosphorus - Lake Memphremagog tributaries



Legend :
P. = Patterson brook
T. = Du chemin Taylor brook
C. = Corriveau brook
H. = Hermitage brook
M. = McAuley brook
• = Annual median value ——— maximum and minimum annual value
- - - - - government criterion for aquatic life protection (5 ppm)

Figure 2: Annual median concentration of total suspended solids - Lake Memphremagog tributaries



Legend :
P. = Patterson brook
T. = Du chemin Taylor brook
C. = Corriveau brook
H. = Hermitage brook
M. = McAuley brook
• = Annual median value ——— maximum and minimum annual value
- - - - - government criterion for nautical activities (200colonies/ 100mL)

Figure 3: Annual median concentration of fecal coliform bacteria - Lake Memphremagog tributaries

2.2 Tributary Monitoring in Vermont - Northwoods Stewardship Center

To assess water-quality problems in the Lake Memphremagog Basin, the Northwoods Stewardship Center undertook a multi-year monitoring and assessment program to identify water quality problems and their sources as the first step towards developing restoration and mitigation plans to resolve these problems. This program has included both stream geomorphic assessments (starting with the Clyde River) and water quality monitoring along the four principal tributaries of Lake Memphremagog in Vermont. The results of the water quality analyses are summarized in this report. The goal of these analyses has been to identify and pinpoint the sources of phosphorus and other nutrients and sediments entering the Southern Basin of Lake Memphremagog. The complete reports can be accessed at www.northwoodscenter.org/conservationscience.

2.2.1 Methods

During May-October 2005 and 2006, we conducted monthly sampling of water quality at multiple sites distributed throughout the watersheds of the four Vermont tributaries of Lake Memphremagog (Figure 4). In 2005, we sampled 22 sites distributed throughout the Barton, Black, Clyde, and John's River Watersheds. Based on the data collected in 2005, we sampled a total of 38 sites in 2006 to better pinpoint the sources of nutrient and sediment inputs in these watersheds, especially along the John's River. All water samples were analyzed at the VTANR LaRosa Analytical Laboratory in Waterbury, Vermont for alkalinity, TP, total nitrogen (TN), NO_x, chloride, and TSS. In addition, we measured water depth, flow, temperature, pH, conductivity, and dissolved oxygen at each site in the field. Herein, we present results for TP, TN, NOx, and TSS.

2.2.2 Results

Total Phosphorus

Total phosphorus values measured in 2005 and 2006 ranged between <5 (detection limit) and 655 ppb. During 2005 and on the John's River in 2006, values peaked in midsummer and were lowest in spring and fall (Figure 5). In 2006, values were highest in May and October on the other three tributaries. In both 2005 and 2006, values were consistently highest along the John's River, especially on the main stem and along Crystal Brook, where values almost always exceeded 25 ppb and peaked at 655 ppb. The Black River generally had the second highest phosphorus values, although much lower than those along the John's River. Phosphorus values exceeded 25 ppb one or more times during both 2005 and 2006 at two sites (Coventry Bridge and Griggs Pond) and in one of the two years at three other sites. The Barton River ranked third in terms of total phosphorus levels: Levels exceeding 25 ppb were infrequent and only occurred at the three downstream-most sites. Finally, in both 2005 and 2006, phosphorus levels were generally lowest in the Clyde River Watershed, especially in the upper watershed. Phosphorus values only exceeded 25 ppb at two small tributaries (Coche Brook and Town Garage). Thus, the worst phosphorus problems in the Lake Memphremagog Basin originate on Crystal Brook and spread downstream from there. However, when flow is incorporated to calculate instantaneous mass estimates, the Clyde River may actually discharge the most phosphorus into Lake Memphremagog during the sampled days, because it has the highest flows of the four tributaries. In contrast, despite its high phosphorus concentrations, the low flow levels result in the John's River sending the least phosphorus into Lake Memphremagog. Nonetheless, it is likely that the discharges from the John's River have localized effects on the Derby Bay and surrounding waters.

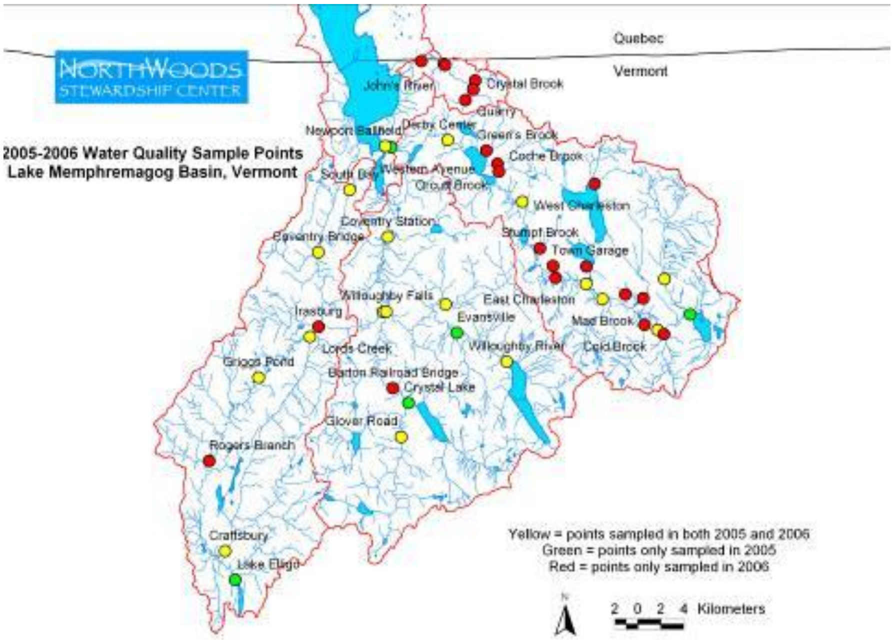


Figure 4. Water quality sites sampled during May–October 2005 and 2006 along the four principal tributaries of Lake Memphremagog in Vermont.

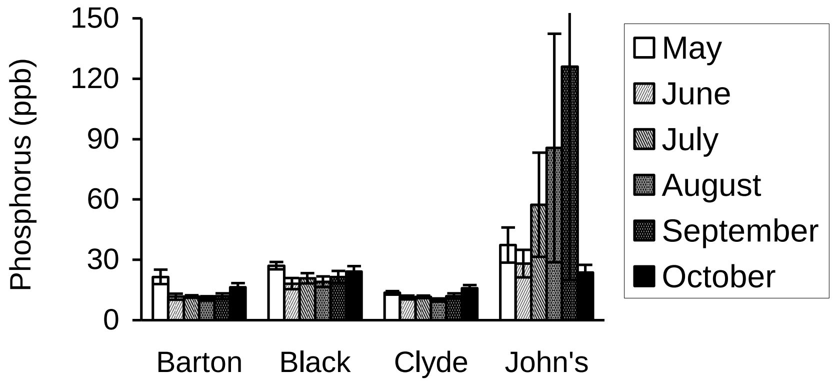


Figure 5. Mean monthly total phosphorus values (±1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006.

Total Nitrogen and NO_x

Total nitrogen values measured in 2005 and 2006 ranged between <0.1 (detection limit) and 6.17 ppm. In both years, values peaked during the summer and were lowest in spring and fall (Figure 6). Values were consistently highest in the John's River Watershed; otherwise, values were generally low in the other three tributaries. Four sites on the John's River exceeded 2 ppm, and three of these sites exceeded 5 ppm but only in September (Darling Hill and the two downstream sites at John's River and North Derby

Road). Thus, the nitrogen in this watershed is likely coming from the area drained by the Darling Hill tributary and the main stem immediately upstream of its confluence with the Darling Hill tributary. However, when instantaneous mass estimates were calculated, the John's River contributed the least total nitrogen into Lake Memphremagog due to its small size, and the Clyde River, because of its greater flow, contributed the most nitrogen into Lake Memphremagog. The effect of the high concentrations of nitrogen in the John's River may, however, have important impacts on the Derby Bay.

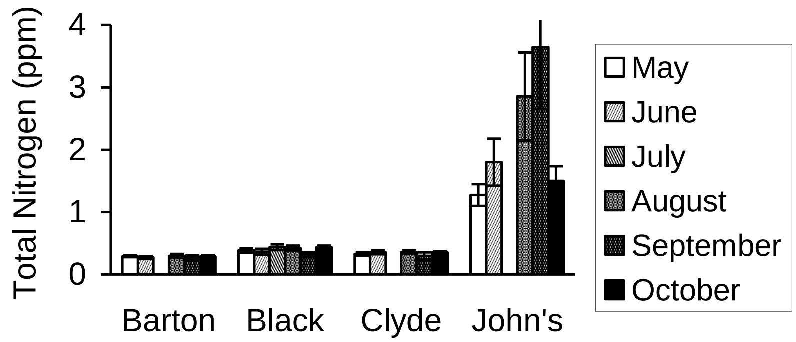


Figure 6. Mean monthly total nitrogen values (±1 SEM) observed in the four principal Vermont tributaries of Lake Memphremagog during May-October 2006 (July values are missing).

Because elevated levels of total nitrogen were measured on the John's River in 2005, we also analyzed for NO_x at the John's River sites in 2006 to determine what proportion of the total nitrogen occurred in this form (Figure 7). In general, NO_x levels peaked during summer and early fall (as did total nitrogen in this watershed). As was true for total nitrogen, NOx levels exceeded 5 ppm at the same three sites (Darling Hill, John's River, and North Derby Road) in September. Thus, the total nitrogen being observed in this watershed occurred almost entirely in the form of nitrate and nitrite and originated from the same area identified for total nitrogen.

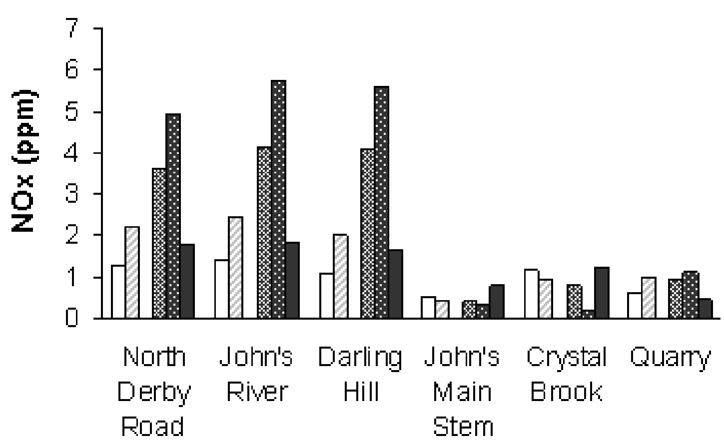


Figure 7: NOx values observed in each of the John's River sample sites during May-October 2006 (July values are missing).

Total Suspended Solids

In 2005, we sampled total suspended solids (TSS) along all four tributaries, but, in 2006, we only sampled TSS along the Black and John's Rivers. TSS values in 2005 and 2006 ranged between <1 (detection limit) and 27.7 ppm, and varied with flow. In 2005, values peaked during the summer months in all four tributaries (Figure 8). However, in 2006, TSS levels were highest in May and lower in the other months. TSS levels were generally lowest on the Clyde River, intermediate on the Barton and Black Rivers, and highest on the John's River, although, in 2006, they were higher in the Black than John's Rivers. In the John's River, TSS levels exceeded 10 ppm at only two sites (John's River and Darling Hill), whereas, in the Black River, they exceeded 10 ppm at many sites in 2005 and at all sites in 2006. In 2005, TSS levels also exceeded 10 ppm at the downstream-most sites in both the Barton (Coventry Station, Orleans Wastewater, and Willoughby Falls) and Clyde Rivers (Newport Ballfield). For the two tributaries sampled in 2006, incorporating flow into instantaneous mass estimates showed that the Black River was contributing higher levels of sediment into Lake Memphremagog than the John's River, for the days sampled.

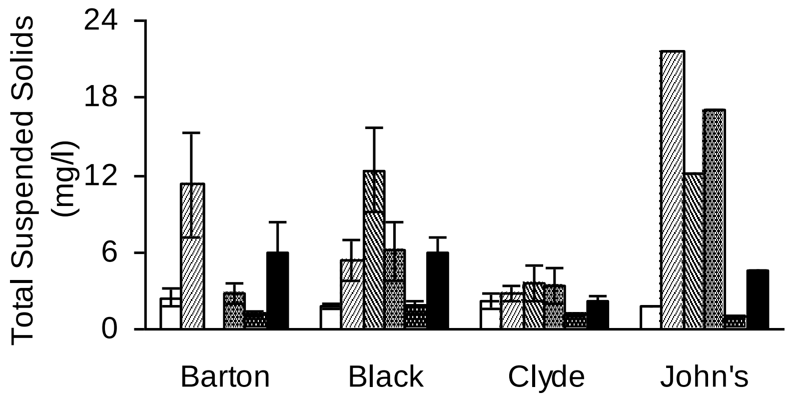


Figure 8: Mean monthly total suspended solids values observed at each of the four principal Vermont tributaries of Lake Memphremagog, May-Oct 2005.

2.3 Tributary Monitoring in Vermont - VTANR

2.3.1 Methods

As part of its Lake Memphremagog monitoring initiative, VTANR carries out measurements of total phosphorus and nitrogen at the downstream-most bridges on the Black, Barton, and Clyde Rivers (Figure 9). Tributaries are sampled using depth-integrating suspended sediment samplers from the centroid of flow for each river. Sampling is carried out approximately bi-weekly, and also in response to high-flow events. In cooperation with the United States Geological Survey (USGS), VTANR and other watershed stakeholders fund the operation of river flow gauges at the Black and Clyde Rivers, and a lake-level gauge in downtown Newport, VT. The measurement of flow is critical to determining annual loads of TP and TN to the South Bay and Lake Memphremagog.

2.3.2 Results

Measured concentrations of TP in the Barton and Black Rivers are dependant on flow conditions ($R^2 = 0.50$ and 0.61, respectively, $p<0.05$), while this expected relationship is damped in the Clyde River owing to upstream impoundments in that watershed. The mean measured phosphorus concentrations were 53 ppb +/- 11.2 (std. err.), 39 ppb +/- 9.4, and 19 ppb +/- 0.9, for the Black, Barton, and Clyde Rivers, respectively (Figure 10). Vermont Water Quality Standards do not articulate numeric criteria for in-stream total phosphorus concentrations applicable to these rivers. While these data show that the Black River has the highest phosphorus concentrations of sites monitored by VTANR, total mass discharges of TP to the lake may be higher at times in the Clyde River, which discharges on average 26% more water to Lake Memphremagog based on long-term USGS gauging records. Such a conclusion should be treated cautiously. Efforts to apportion phosphorus loads from rivers to downstream lakes must account for the specific concentration–flow relationship; an analysis that is beyond the scope of this document. Load apportionment analyses are a normal component of a comprehensive pollution

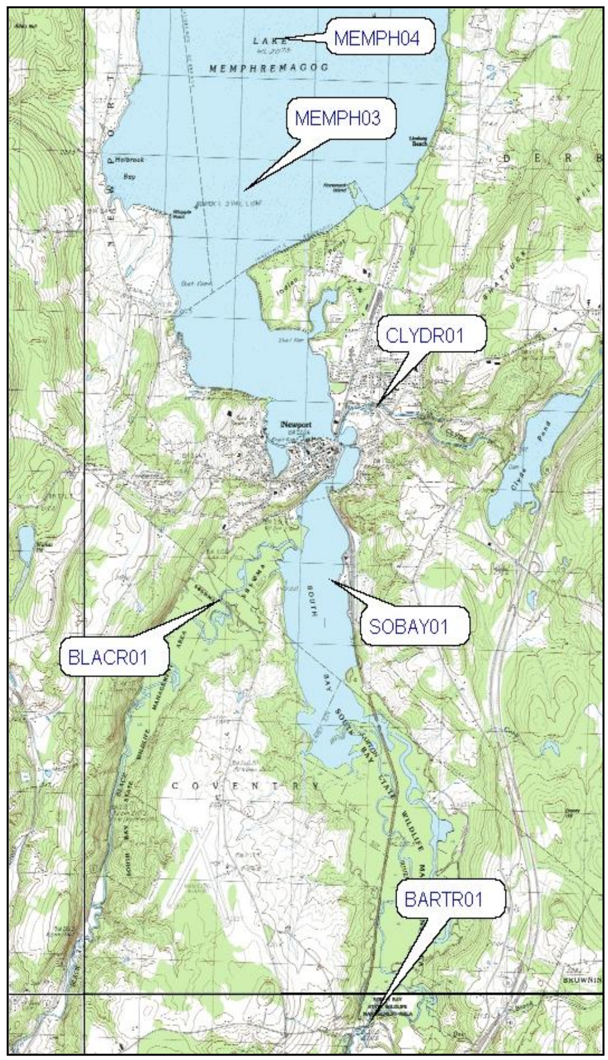


Figure 9. VTANR monitoring locations

control planning initiative such as a TMDL. In addition, the reader should exercise caution comparing these results to the average values presented above in Section 2.2.2. In that section, the river-wide mean values capture stations throughout the watershed, from the upstream-most to downstream-most. By contrast the VTANR results were collected only at the downstream-most sampling locations. Therefore, the means concentrations for VTANR results are necessarily higher in those provided by the Northwoods Stewardship Center.

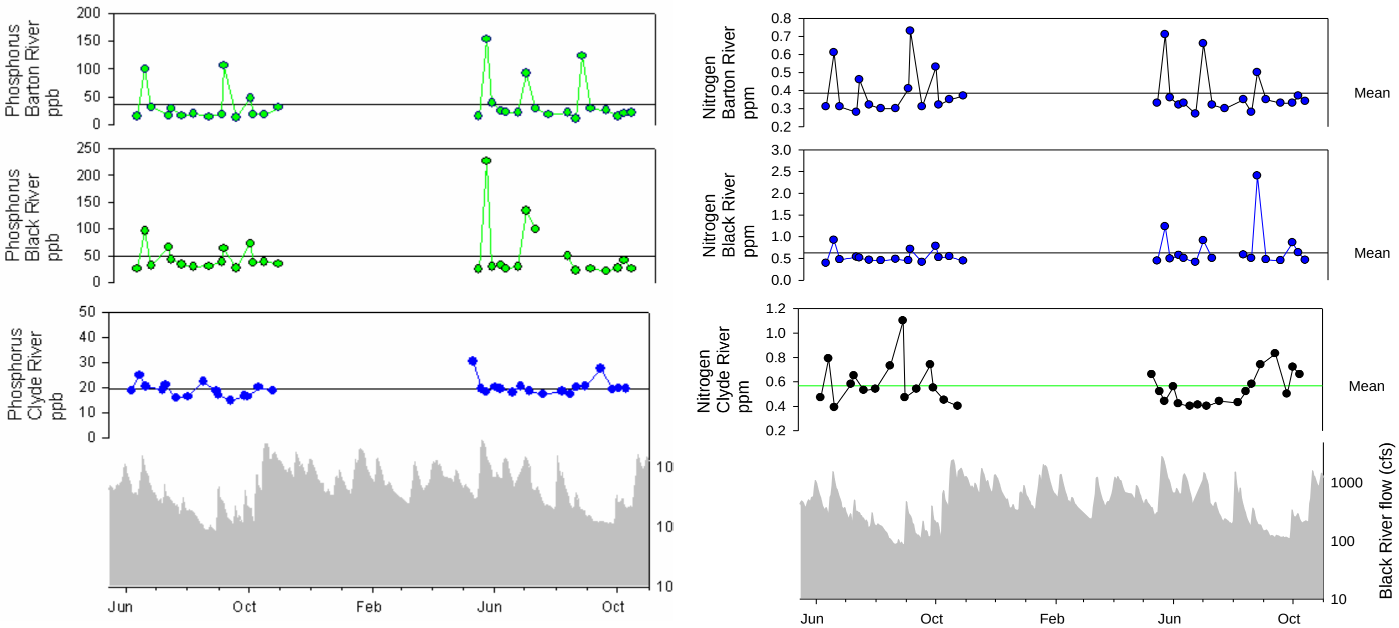


Figure 10. Total phosphorus and nitrogen and measured flow for the Black, and Clyde Rivers, for the period 2005-2006. Flows represent the mean daily flows based on the USGS gauges.

Measured concentrations of total nitrogen in the Black River are marginally dependant on flow conditions ($R^2 = 0.44$, $p<0.05$). For the Barton River, there is no significant relationship between nitrogen and flow. For the Clyde, concentrations are marginally and inversely related to flow ($R^2 = 0.32$, $p<0.05$), showing the effect of the Newport wastewater treatment facility, the outlet of which is located approximately 200 meters upstream of the sampling location. The mean measured total nitrogen concentrations were 0.62 ppm +/- 0.07 (std. err.), 0.38 ppm +/- 0.02, and 0.56 ppm +/- 0.03, for the Black, Barton, and Clyde Rivers, respectively. These concentrations are well below the Class B Vermont water quality criteria of 2.0 ppm nitrate-nitrogen.

2.4 Tributary Maps

In the following section, we present maps depicting water quality conditions in Lake Memphremagog tributaries. These maps show monitored sites in relation to thresholds that equate to good conditions, minor to moderate enrichment, or to a high degree of enrichment. These thresholds are not regulatory limits per-se, but rather represent the consensus of the partner agencies authoring this report, and represent median concentrations. Thresholds for TP are: good, <20 ppb; minor to moderate enrichment, 20-30 ppb; high degree of enrichment, >30 ppb. Thresholds for TN are <0.7, 0.7 - 2.0, and >2.0, respectively. Thresholds for TSS are <5, 5-10, and >10. Thresholds for fecal coliform are <200 colonies /100ml (meets Quebec standards) or >200 (does not meet Quebec standards), and are only available for Quebec waters.

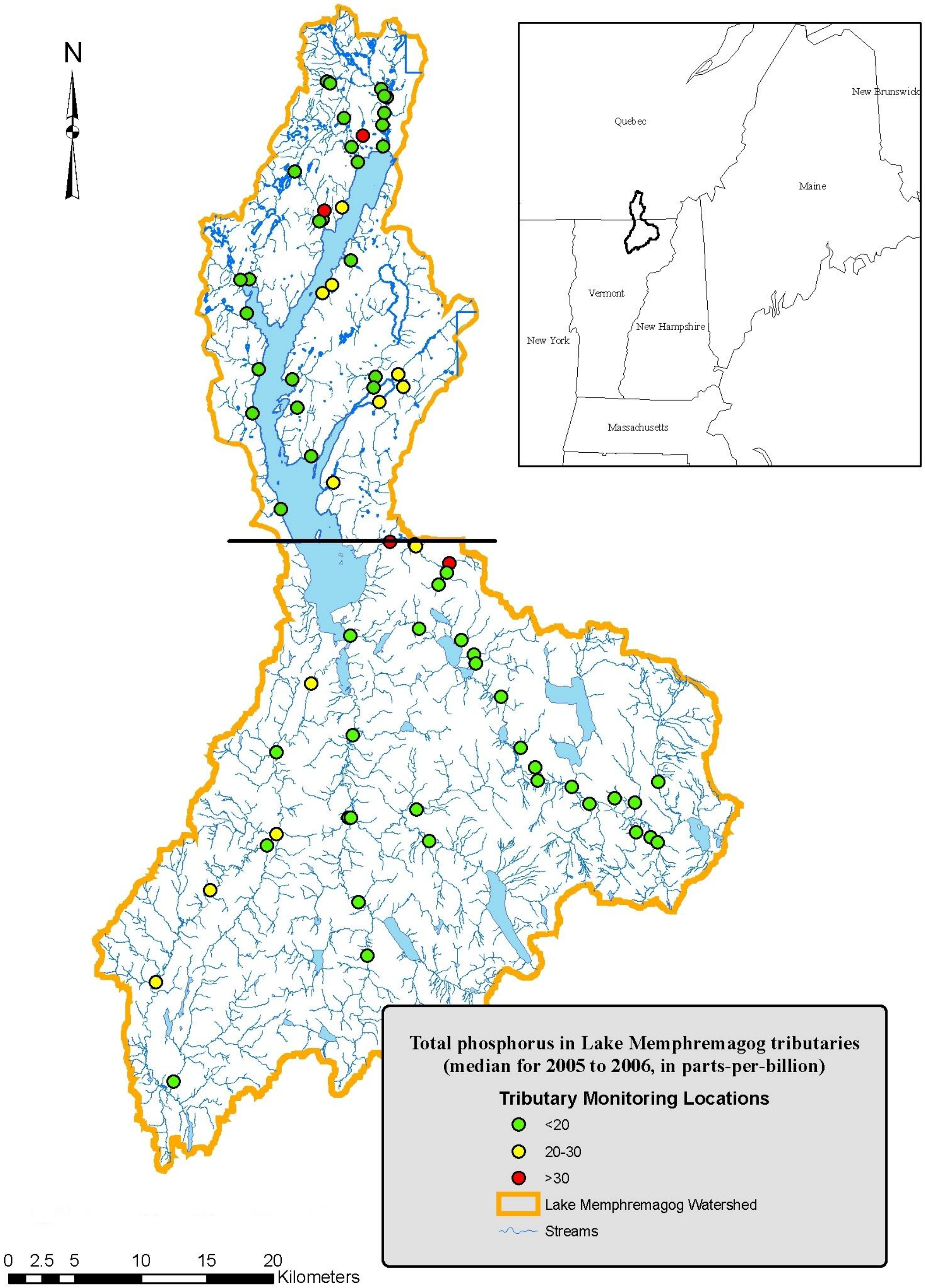


Figure 11. Total phosphorus in Memphremagog tributaries

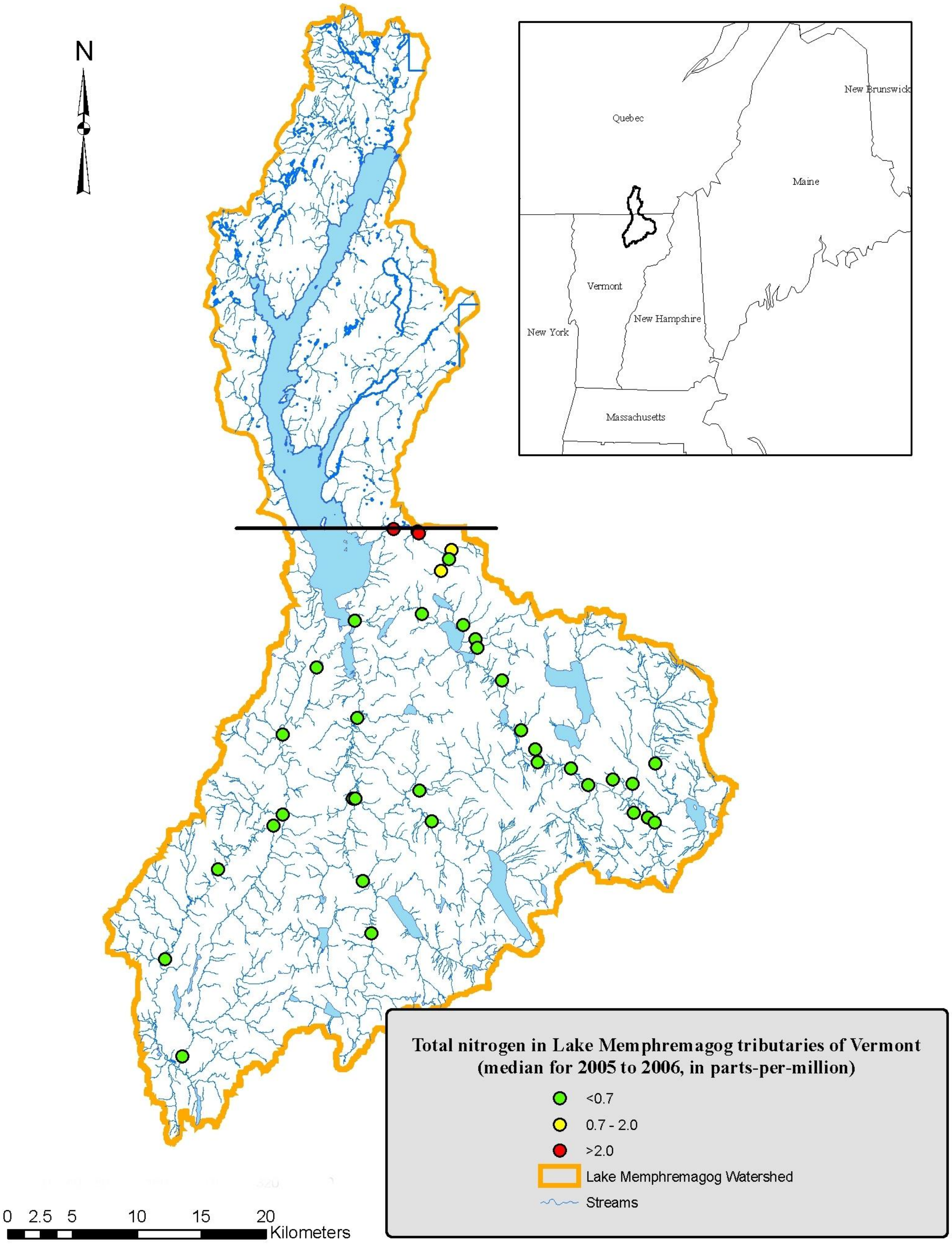


Figure 12. Total nitrogen in Lake Memphremagog tributaries

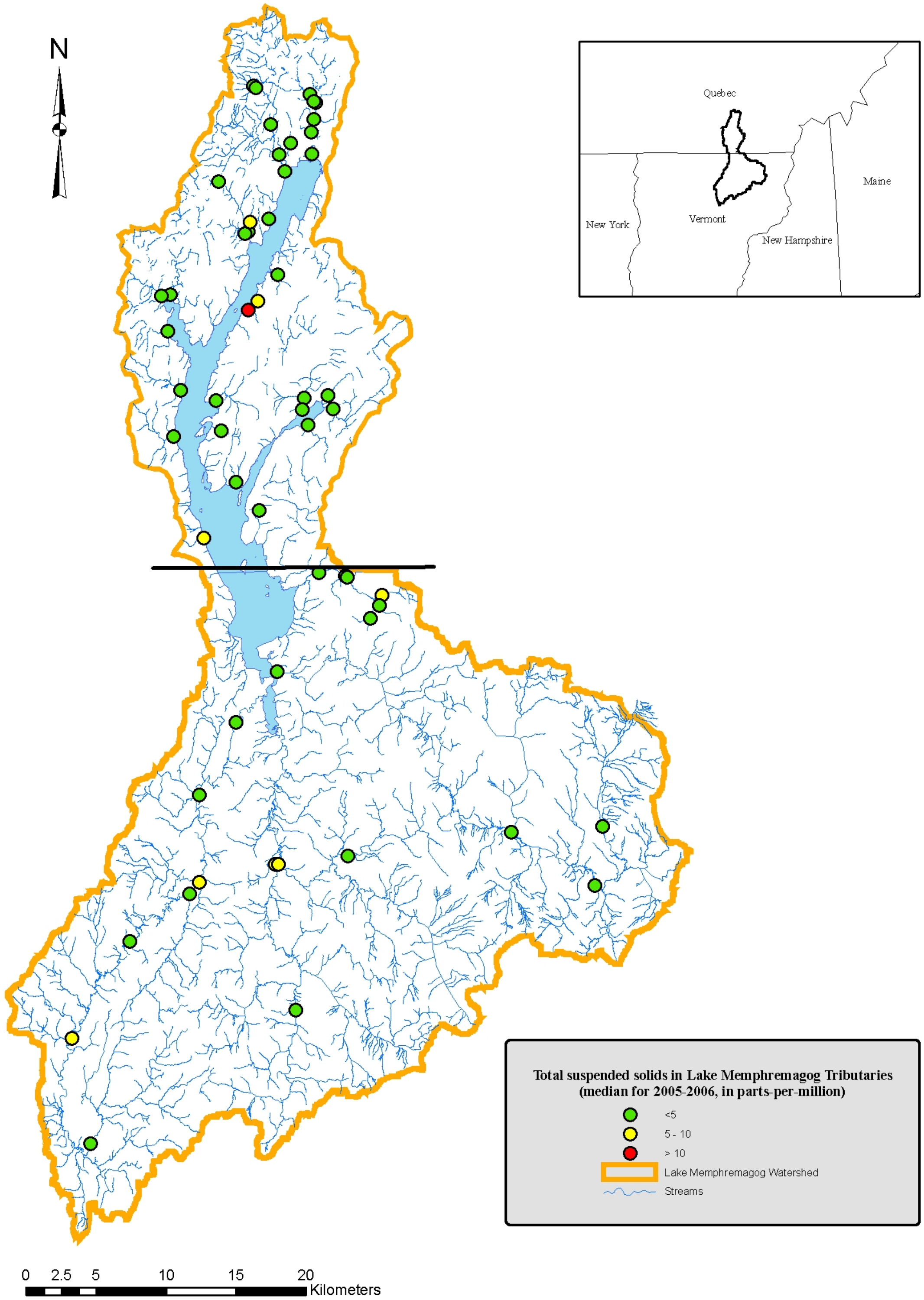


Figure 13. Total suspended sediments in Lake Memphremagog tributaries

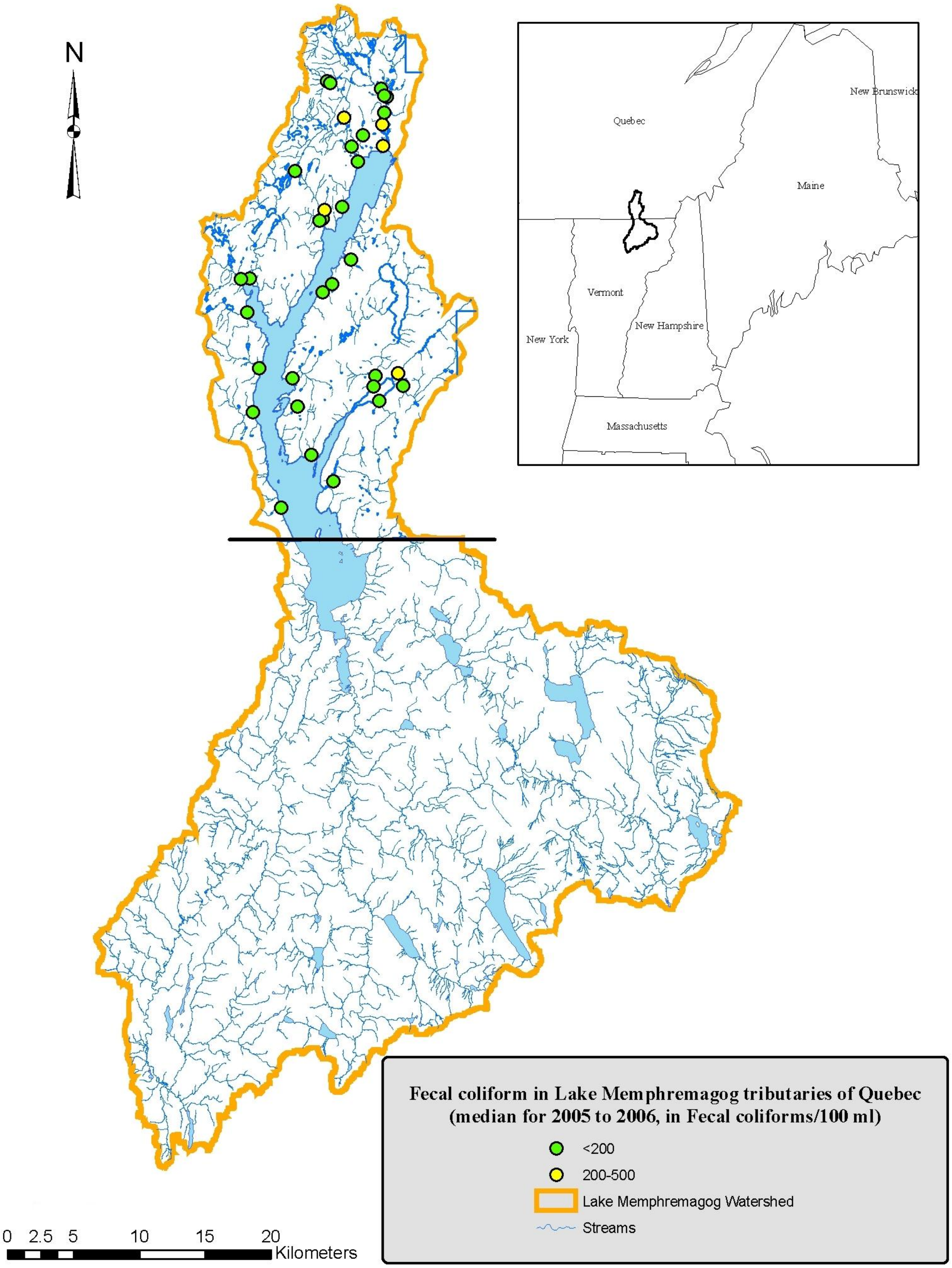


Figure 14. Fecal coliform in Lake Memphremagog tributaries

3.0 Littoral Habitat Quality in Lake Memphremagog

3.1 Operation Healthy Lake

3.1.1 Methods

The inventory of the littoral zone and the shoreline was carried out during the summers of 2004 and 2005. The entire perimeter of the littoral zone extending to 3 meters of depth was divided into sections (portions of the littoral measuring about 100 meters in length). Each section followed the last, so that the end of one corresponds to the beginning of the next.

For each section, information concerning the condition of the shore and littoral was obtained and noted by a team of biologists from RAPPEL. The degree of shoreline alteration was assessed visuall. Indicators of sedimentation, aquatic plants, and periphyton algae were gathered along transects (Figure 15). For each section studied, three transects were inventoried (one transect at one meter in depth, one at two meters and a third at three meters in depth). These three depths were chosen to give a good representation of the littoral zone, the zone where aquatic plants grow.

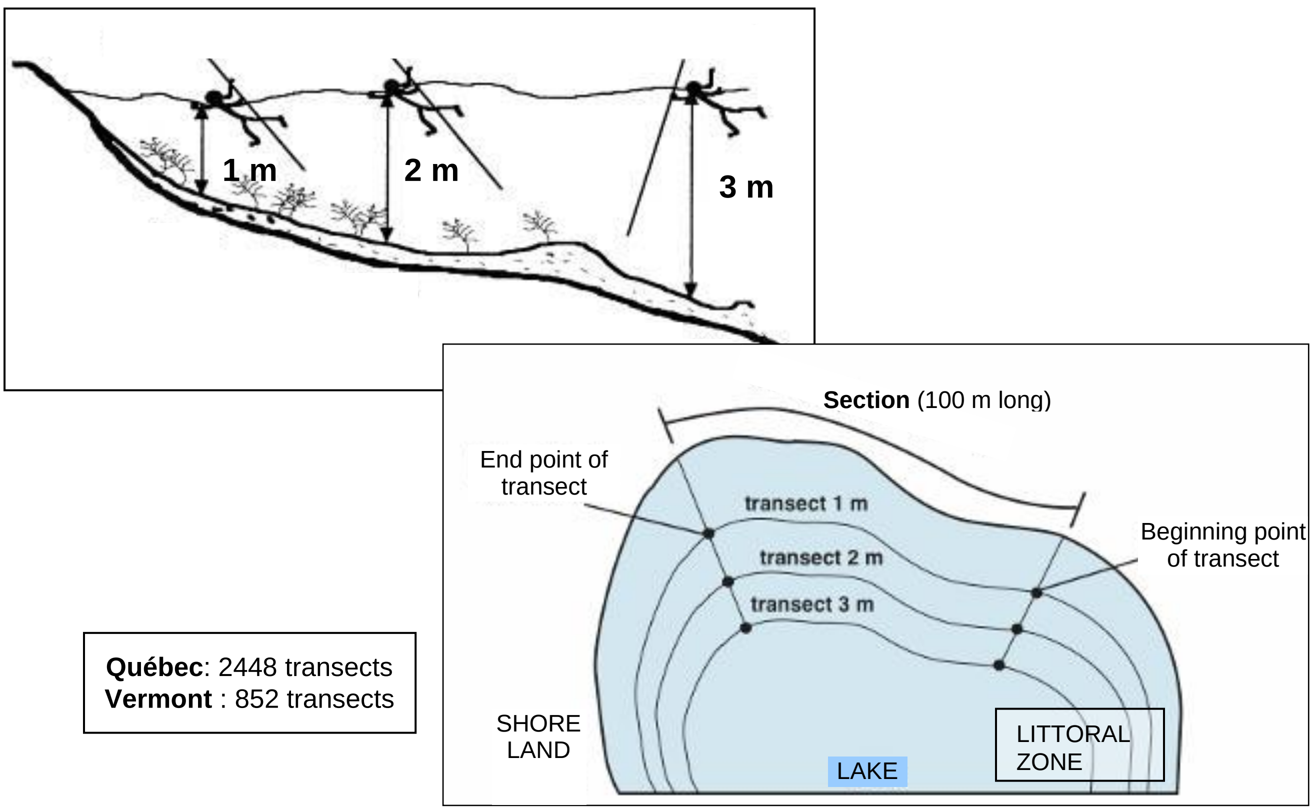


Figure 15: Location of transects for inventorying the condition of the shoreline and littoral zone.

3.1.2 Results

The lake shows signs of siltation in several areas. Sedimentation is clearly a problem in Vermont waters and in Fitch Bay (north-east). The Three Sisters, Southière-sur-le-lac, Cummins and Channel Bays, Vermont, and Fitch Bay (north-east) sectors present a high density of aquatic plants. Eurasian watermilfoil *(Myriophyllum spicatum*, an aquatic invasive plant) is one of the dominant species throughout the littoral zone of the lake. Green algae are particularly abundant in Vermont, the Fitch Bay (north-east) and Georgeville. The South Bay (Vermont), Derby Bay (Vermont), and Fitch Bay NE (Quebec) show the greatest signs of premature eutrophication, including sediment accumulation, and green algae and aquatic plant growth. Operation Healthy Lake identified several stressors that result in sediment and nutrient accumulation from surrounding environment, within five general categories.

- *Shoreline areas:* non-conforming septic systems; fertilizers used on lawns and flower beds; shoreline alteration; residential construction; and, leakage from sewage collectors or illegal hook-ups of domestic sewage to outfall sewers and storm sewers
- *Agriculture:* excessive spreading of manure, liquid manure, compost or chemical fertilizers; erosion of soils left unplanted; agricultural ditches stripped of vegetation; access by animals to watercourses; improper barnyard waste storage; and, runoff from exercise yards.
- *Forestry:* erosion of soils left bare; forest ditches left bare.
- *Municipal and private land management:* road ditches scraped and left bare; fertilizer spread near a body of water.
- *Construction and development:* erosion of soils left bare; leachate

3.1.3 Plan of Action – Getting Started

Following Operation Healthy Lake in 2004, action was taken in the summer of 2005 to deal with one of the most worrisome sectors of the Québec portion of the lake, the Fitch Bay. MCI, in conjunction with RAPPEL instituted the latter's SAGE (Schéma d'action global pour l'eau) program. The task was to carry out a complete watershed survey for the Fitch Bay. This initiative featured direct involvement of local citizens working with MCI and RAPPEL staff, along with financial assistance from the Canton of Stanstead, the municipality in which Fitch Bay is located. The results were assessed and recommendations made for implementation.

In the summer of 2006, MCI and the Municipality of Ogden (on the east side of the Lake at the Vermont border) undertook the renaturalization of the shoreline of Weir Memorial Park. MCI hired two professionals to teach interested citizens how to plant a dozen varieties of indigenous shrubs between shoreline rocks which then developed into a planting "blitz" engaged in by all. About 300 lakeshore feet was renaturalized with the expectation of completing the remaining 300 feet in the spring/summer of 2007. Although no municipal financing was available for this project, a generous contribution from a local financial institution was received. The complete reports for Operation Healthy Lake are provided online at: http://www.memphremagog.org/rubrique.php3?id_rubrique=4&lang=en.

3.2 Maps of Littoral Quality

In the following, we provide maps depicting shoreline and littoral habitat quality throughout Lake Memphremagog. These figures show a global assessment of the shoreline and littoral zone with respect to levels of shoreline alteration ("artificialization," Figure 16), sedimentation (Figure 17), aquatic plant growth (Figure 18), and periphyton (green algae) growth (Figure 19). Locations noted by red symbols were determined to be of poor quality, while locations noted by yellow or green were determined to be questionable or good, respectively.

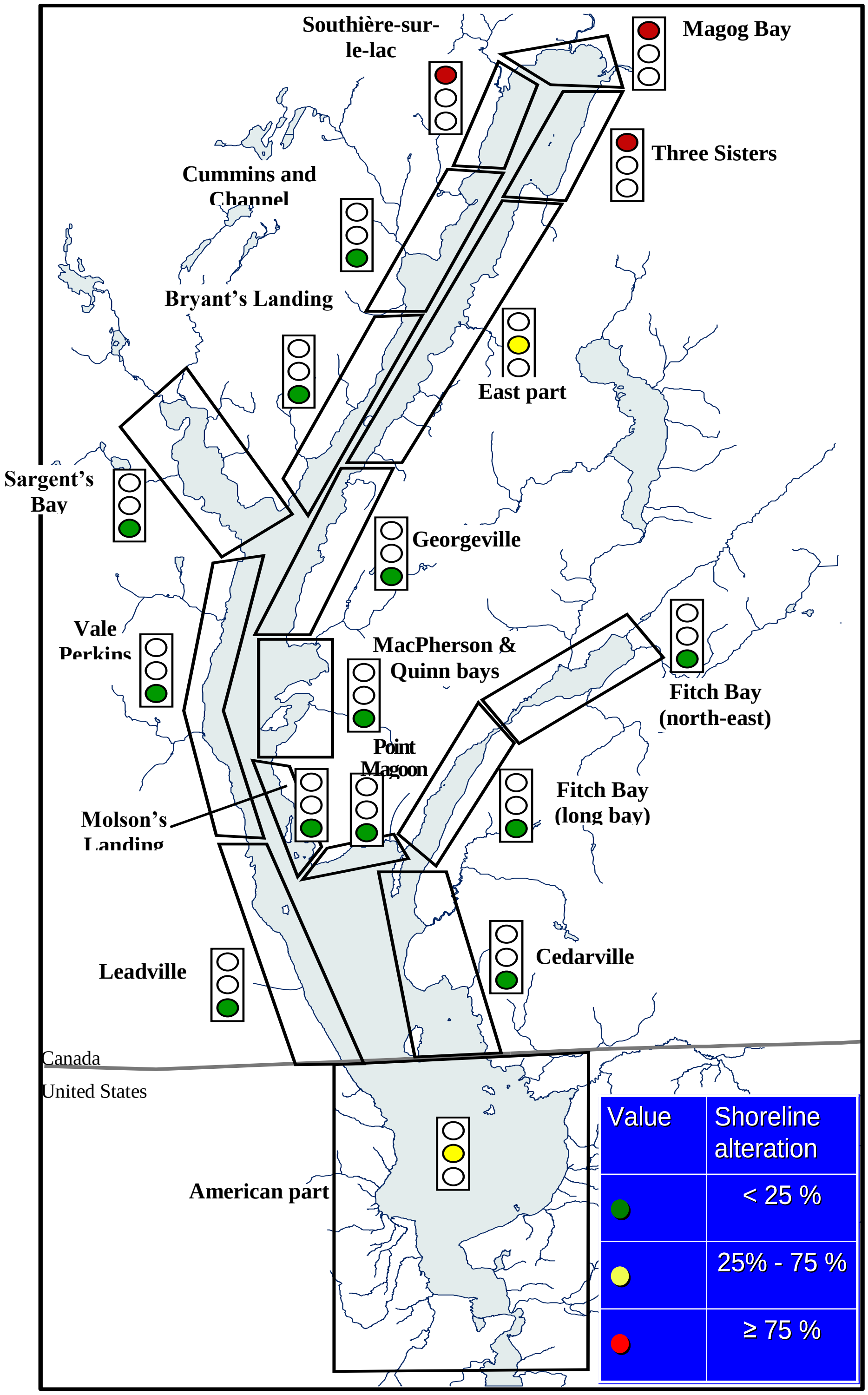


Figure 16. The condition of the shore in each sector of Lake Memphremagog, based on the median value for shoreline alteration.

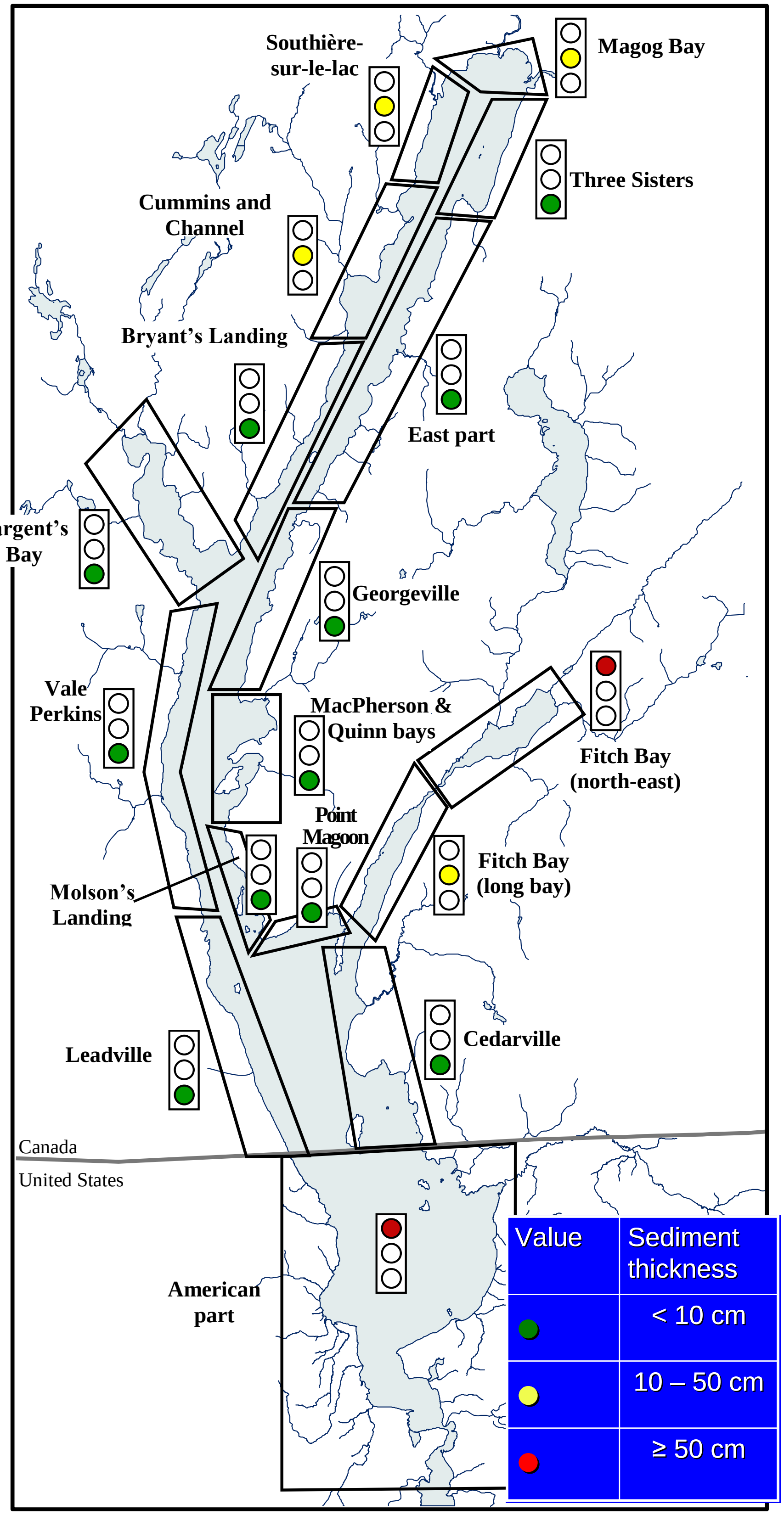


Figure 17. Sediments in the littoral zone of Lake Memphremagog

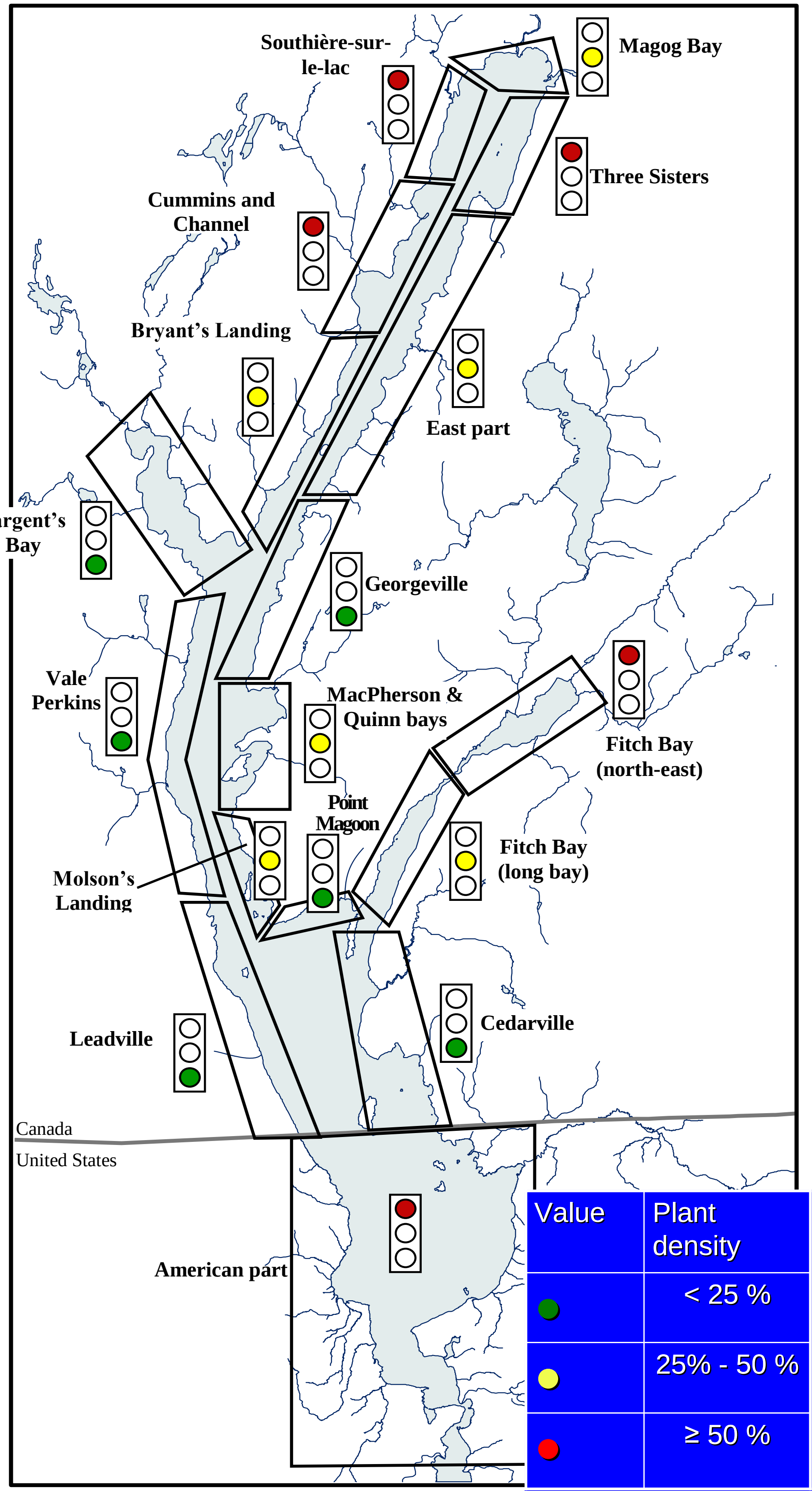


Figure 18. Aquatic plants in the littoral zone of Lake Memphremagog

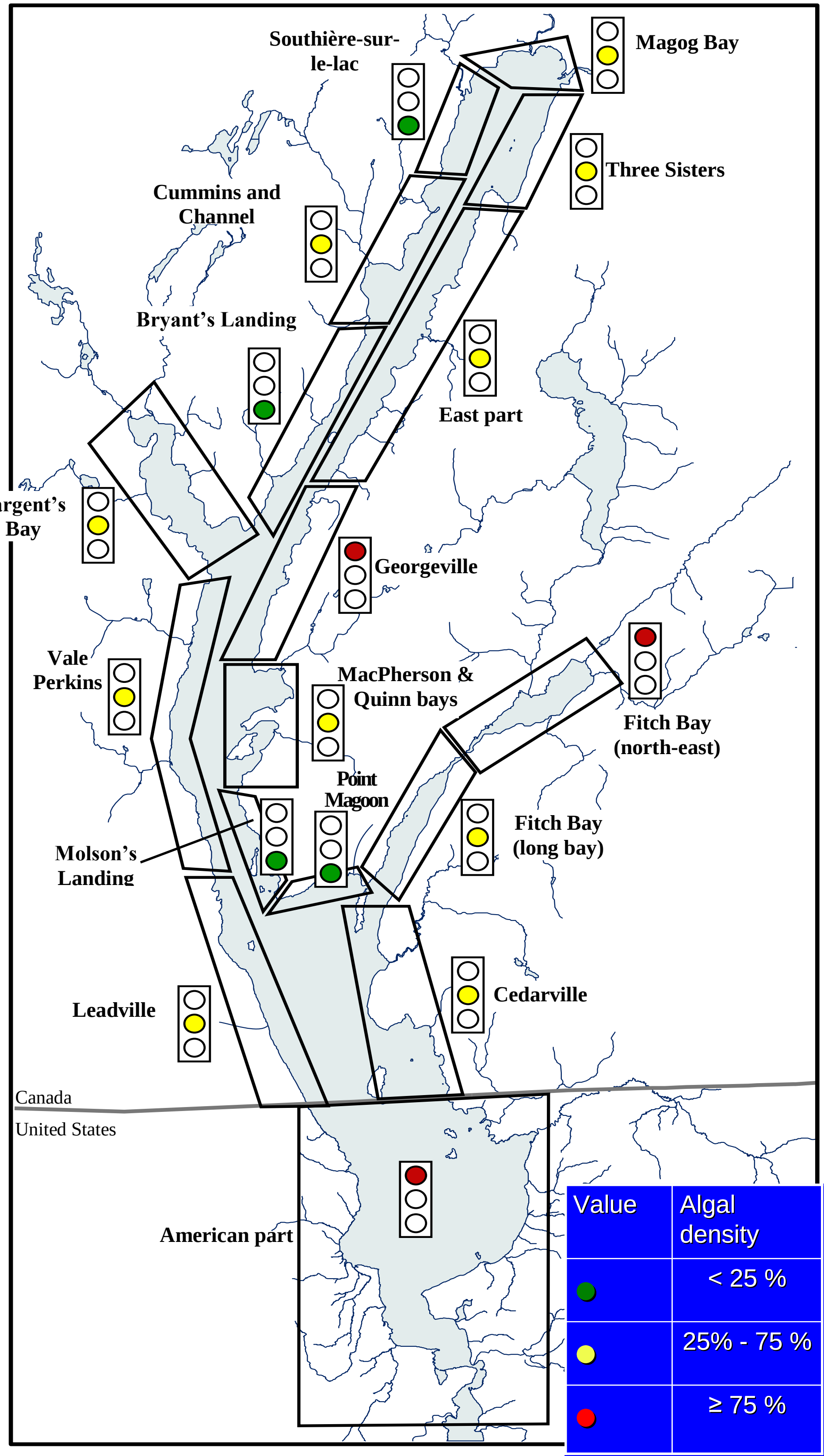


Figure 19. Green algae in the littoral zone of Lake Memphremagog

4.0 Water Quality in Lake Memphremagog

4.1 Lake Water Quality Monitoring by VTANR

4.1.1 Methods

VTANR has operated a bi-weekly testing program in the lake from early May through November, since 2005. VTANR monitoring locations are shown by Figure 9. Since 1985, the Vermont Lay Monitoring Program has also enabled citizen monitors to collect weekly observations and water quality samples in the South Bay and main lake (MEMPH03 only), from June through August. Water quality testing by VTANR includes depth-stratified measurements of TP and TN, chlorophyll-a (CHA), and Secchi transparency. Similar measurements are made by VTANR citizen volunteers using a more simplified approach. Ancillary chemical parameters collected by VTANR include alkalinity, total calcium, magnesium, and calculated hardness, and a Hydrolab™ multiprobe sonde is used to capture water temperature, conductivity, pH and dissolved oxygen with depth.

All sampling methodologies conform to VTANR's Field Methods Manual (http://www.vtwaterquality.org/ bass/docs/bs_fieldmethodsmanual.pdf), which provides standard operating procedures for water quality monitoring. The project has also been carried out in conjunction with a USEPA-approved quality assurance project plan that regulates water sampling and laboratory analysis activities undertaken by the VTANR. Standard indicators of sampling accuracy and contamination control indicate that the project results are of excellent quality.

4.1.2 Results

Vermont Water Quality Standards for total phosphorus in Lake Memphremagog vary by lake segment, and are expressed as the annual mean total phosphorus concentration in the photosynthetic depth (euphotic) zone in central, open water areas of each lake segment. Station MEMPH04 is used by VTANR to assess compliance with the criterion of 14 ppb P, while station SOBAY01 is used to assess compliance with the South Bay criterion of 25 ppb P. Vermont Water Quality Standards also indicate that nitrogen shall not exceed 5 ppm as nitrate in these lake segments.

To provide context, the results of the long-term citizen monitoring supported by VTANR on Lake Memphremagog near the Memphremagog Light (MEMPH03) are provided in Figure 20. These data show that water quality in the lake has been variable with time, but showed general improvement during the period 1993-1997. During the period 2004 to 2006, total phosphorus was slightly elevated from prior years, and water transparency declined. The mean concentration of chlorophyll-a remained stable.

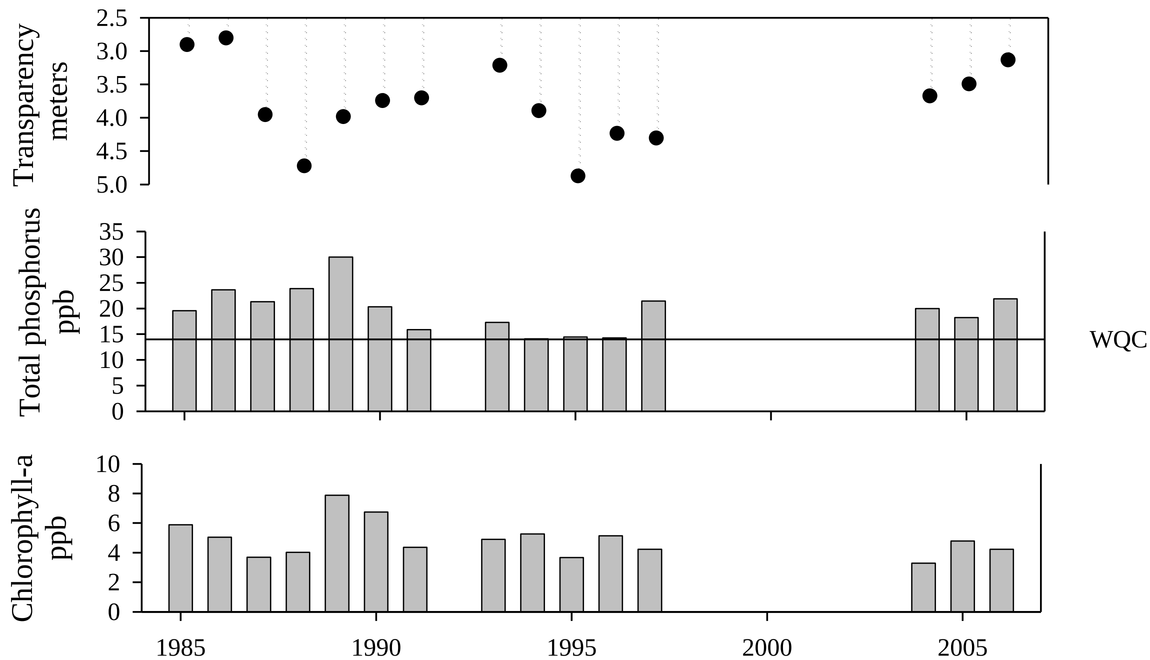


Figure 20. Total phosphorus, chlorophyll-a, and Secchi transparency measured by the Vermont Lay Monitoring Program, in Lake Memphremagog at the Memphremagog Light.

Lay Monitoring program volunteers only began monitoring the South Bay in 2005. The mean Secchi transparency, CHA, and TP across this period was 1.8 meters, 5.8 ppb, and 19.6 ppb, respectively.

Findings from the VTANR-led monitoring indicated the following. Near MEMPH03, Secchi transparency varied with total phosphorus concentrations (Figure 21). Transparency ranged from <2 meters to just over 4 meters in 2005, with slightly lower observed values in 2006. The daily mean total phosphorus concentration varied seasonally in 2005, and was generally higher and more affected by river inflows in 2006. The average total nitrogen for the period was 0.33 ppm (+/- 0.02 std. err.).

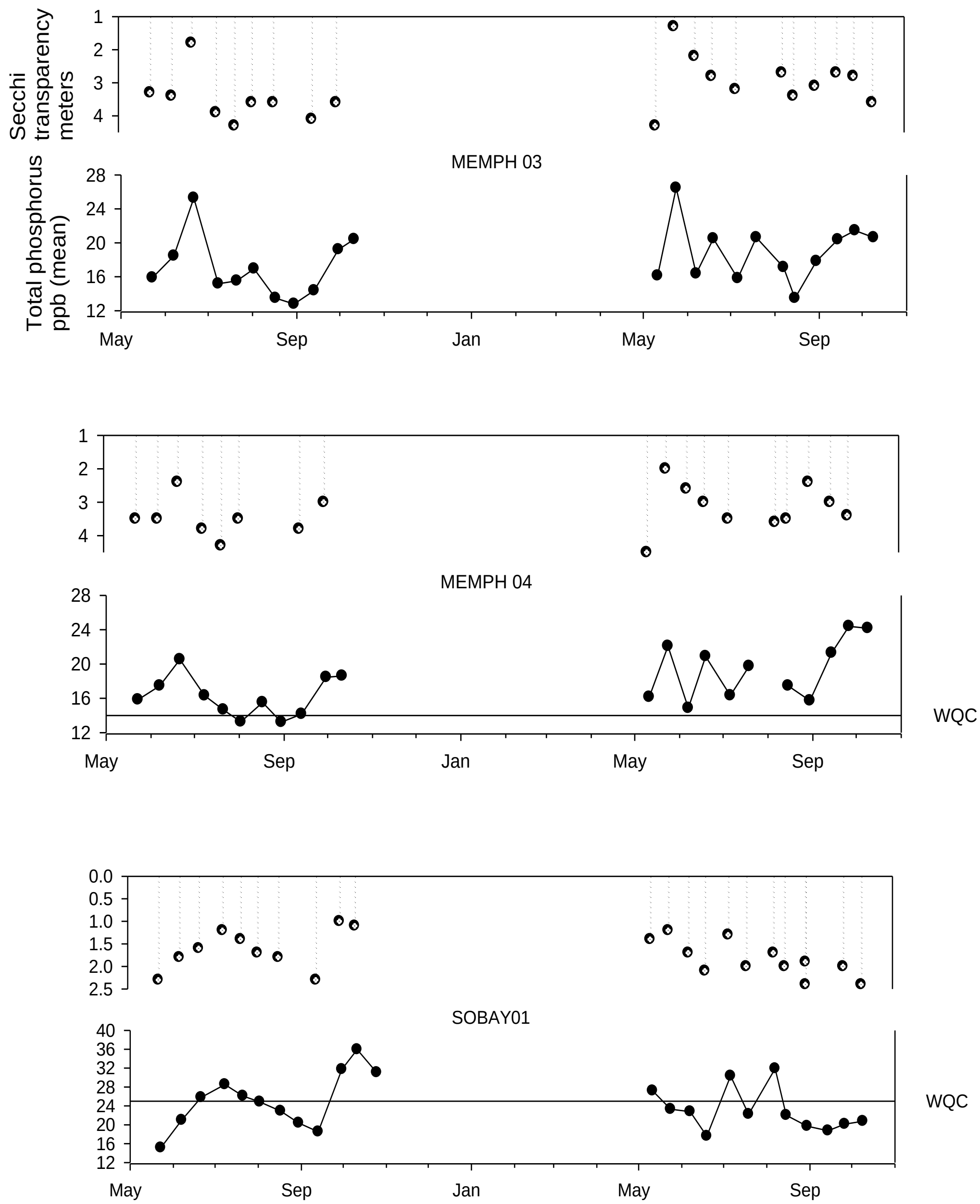


Figure 21. Total phosphorus and Secchi transparency for Lake Memphremagog. WQC: water quality criterion. Y-axis units identical for all figures.

In the open waters of Lake Memphremagog (MEMPH04), Secchi transparency varied to a lesser degree with total phosphorus concentrations (Figure 21), again ranging from <2 meters to just over 4 meters in 2005, with somewhat lower observed values in 2006. The daily mean total phosphorus concentration varied seasonally, and was again significantly higher and more variable in 2006. At this station, the annual mean total phosphorus concentrations exceeded the Vermont water quality criterion of 14 ppb in 2005 and 2006 (16 ppb +/- 0.48 std. err. and 18 +/- 0.48, respectively). The average total nitrogen for the period was 0.30 (+/- 0.03 std. error).

In the South Bay (SOBAY01, Figure 9), Secchi transparency was tightly coupled with total phosphorus concentrations (Figure 21). Transparency ranged from <1 meter to just over 2.5 meters for both years. The mean total phosphorus concentration varied with river inflow concentrations (data not shown). The mean concentrations for 2005 and 2006 of 23 ppb (+/- 1.3) and 21 ppb (+/- 1.0) indicate that water quality standards for total phosphorus are met in the South Bay. The average total nitrogen for the period was 0.37 (+/- 0.02 std. error).

Since TP concentrations in the lake exceed water quality standards, the development of a TMDL will need to characterize all possible nutrient sources to the Lake. In certain lakes, legacy phosphorus stored in sediments can be released to the overlying waters, under certain geochemical conditions. This results in periodic pulses of nutrients to the overlying waters, and accompanying algae blooms. VTANR assessed the likelihood of possible internal nutrient recycling from lake sediments using discrete-depth measurements of temperature, dissolved oxygen, total phosphorus, and in-situ fluorometrically measured chlorophyll-a. This analysis showed no evidence of increased deep-water phosphorus concentrations corresponding to the period of hypolimnetic oxygen depletion or post-stratification. In lakes where internal nutrient cycling is important, elevated total phosphorus and accompanying algal blooms are temporally co-incident with periods of hypolimnetic dissolved oxygen depletion. While elevated chlorophyll-a and phosphorus in the lake were temporally consistent in 2005, this preceded the onset of thermal and oxygen stratification, and reflects typical spring algal blooms. There was no notable hypolimnetic oxygen depletion in 2006.

The 2005-2006 mean measured alkalinity value was 52.5 ppm as $CaCO_3$, and alkalinity did not differ between MEMPH03 to MEMPH04 (p>0.1). This level of alkalinity indicates a well-buffered system that is not subject to stresses of acidic precipitation. The mean alkalinity in the South Bay of 72.3 ppm was significantly higher than open water lake segments (p<0.001), and varied widely depending on river flow conditions. The concentrations of earth metals and hardness displayed similar trends.

4.2 Lake Water Quality Monitoring by MCI and MDDEP

4.2.1 Methods

Since 1996, MDDEP has partnered with MCI to carry out open water sampling of Lake Memphremagog. This testing is done by the MCI Lake Patrollers four times annually (every three weeks) from June through August, at nine stations (Figure 20), including one station that is co-located with MEMPH04. Water quality is also monitored on a monthly basis throughout the year on the Magog River, near the outlet of Lake Memphremagog. Lake water samples are depth-integrated samples taken between 0 and 1 meter. Water quality analyses include total phosphorus (TP, method 303-P 5.0), chlorophyll-a (CHA, method 800-CHLO. 1.1), Secchi transparency, and water temperature. The station located at the outlet of Lake Memphremagog belongs to the River Monitoring Network operated by the MDDEP. Ancillary chemical analyses obtained for depth-integrated samples collected at this station include fecal coliform, dissolved organic carbon, conductivity, pH, ammonia nitrogen, nitrates-nitrites nitrogen, total nitrogen, dissolved

(1.2 µm filtration) and suspended P, trace P (persulfate method), suspended solids and turbidity.

All sampling methodologies conform to MDDEP'S Field Methods Manual (http://www.mddep.gouv.qc.ca/eau/rsv-lacs/methodes.htm) which provides standard operating procedures for lake water quality monitoring. The project has also been carried out in conjunction with a quality assurance project plan that regulates water sampling and laboratory analysis activities undertaken by the MDDEP. Standard indicators of sampling accuracy and contamination control indicate that the sampling program results are of excellent quality.

4.2.2 Results

Boxplot diagrams showing median values, upper and lower quartiles and maximum and minimum data values have been used to summarize the results collected during the 2005 and 2006 sampling seasons (Figures 22 through 24). The diagrams reveal that the four northernmost stations, located in the deepest section of the lake, have slightly more transparent waters as shown by Secchi disk readings. They also show that the same stations have slightly lower median chlorophyll a and total P values compared to the rest of the lake.

The sampling record suggests that, at most locations, TP, CHA, and water transparency are stable (Table 2). Although a regression analysis shows a significant increase in chlorophyll a values between 1999 and 2006 in Magog Bay, which implies some water quality degradation, this result is not matched by a similar significant increase in total P concentrations. Encouragingly, results show significant water quality improvements in the northeast section of Fitch Bay and at the U.S. Border. For Fitch Bay, both total P and chlorophyll a values have decreased between 1999 and 2006, whereas total P concentrations have shown the same downward trend at the U.S. Border over the same time period.

The long term total P values, recorded between 1996 and 2006 for the Magog River near the outlet of the lake (Figure 25), do not vary significantly over time. Although a few high values were observed at the end of the phosphorus time series, those were only random events that do occur from time to time depending upon the particular hydrological conditions of the river at the time sampling takes place. Overall, these values did not have any effect on the time series. No statistically significant trend was detected and, therefore, we must conclude that P levels measured at the outlet of Lake Memphrémagog have remained stable during the 1996-2006 period.

VTANR and MCI carried out one round of joint sampling in 2006 to assess the comparability of the sampling results for these two jurisdictions. While the results were somewhat favorable, additional paired sampling is planned in 2008 to accurately calibrate the Vermont and Quebec datasets.

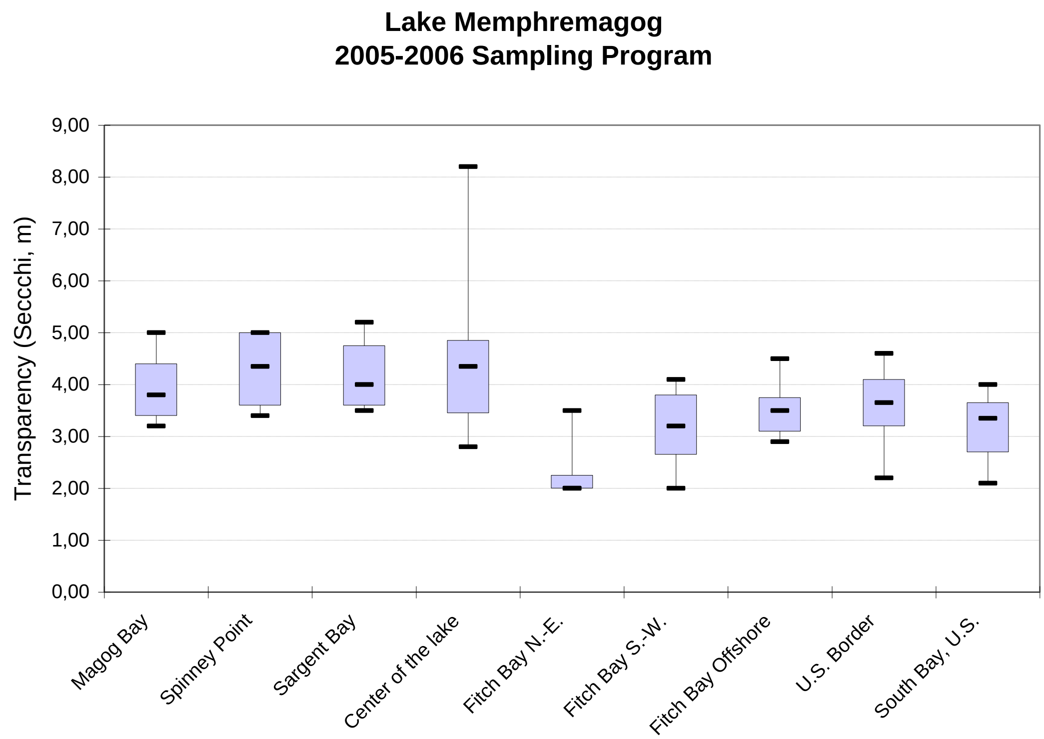


Figure 22. Secchi transparency results for Lake Memphremagog open water sampling stations.

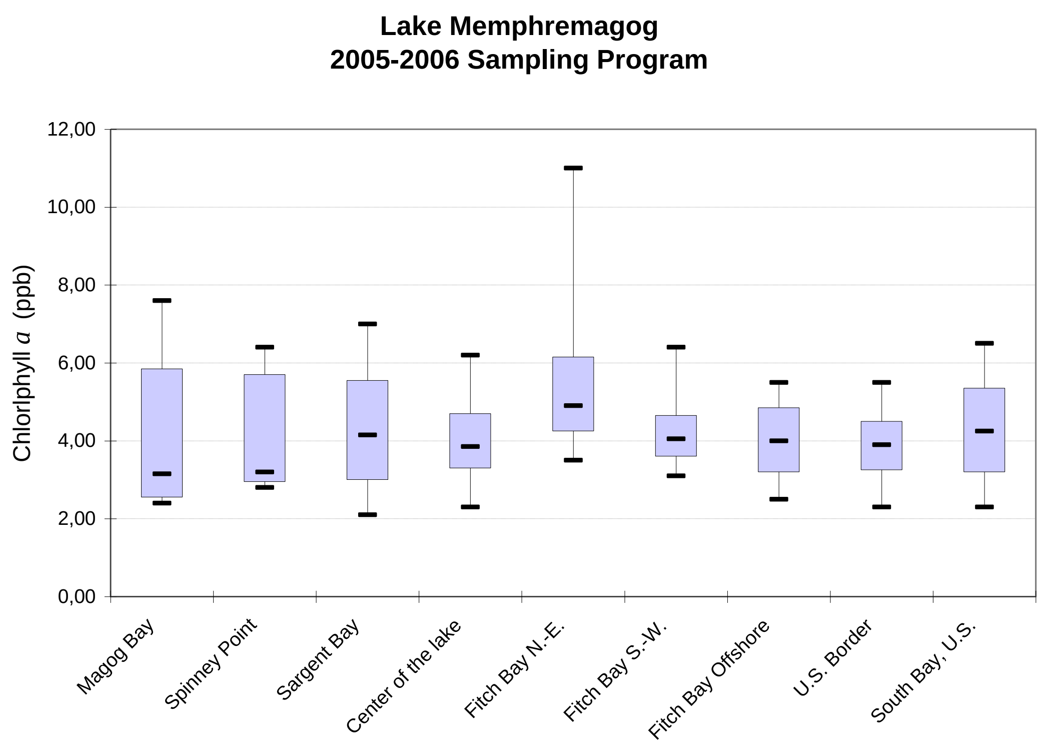


Figure 23. Chlorophyll a results for Lake Memphremagog open water sampling stations.

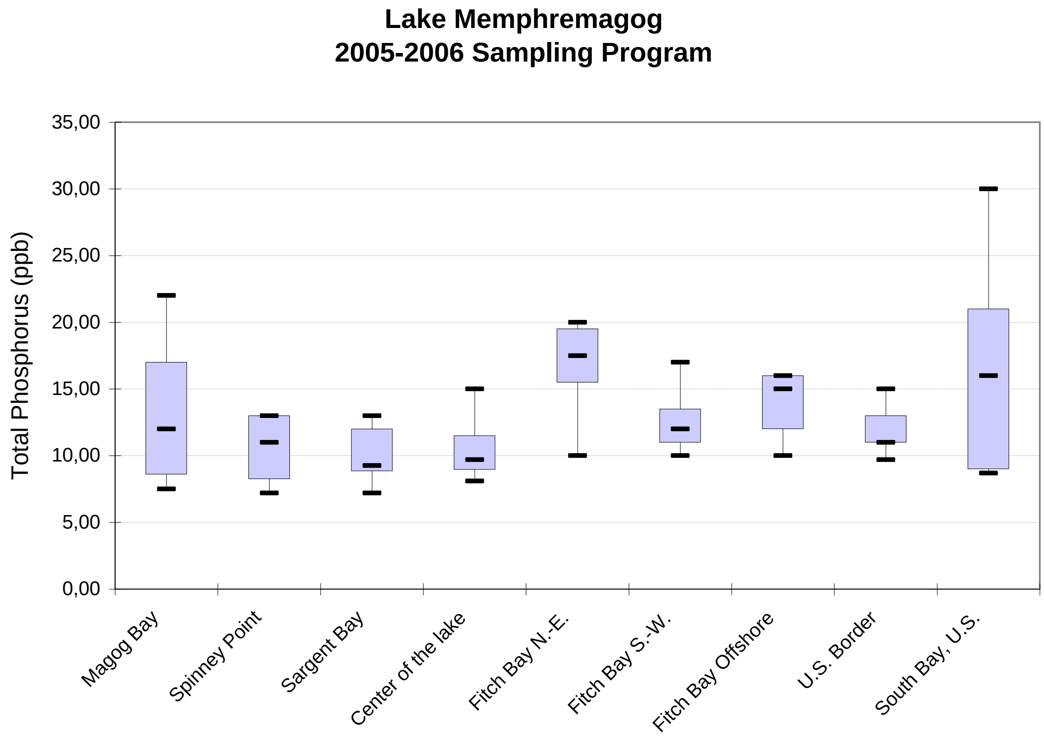


Figure 24. Total phosphorus values for Lake Memphremagog open water sampling stations.

Table 2. Trend detected in water quality data recorded in Lake Memphremagog open water sampling stations.

Station ID	Station Name	Transparency 1997-2006	Total phosphorus 1999-2006	Chlorophyll a 1999-2006
090	Magog Bay	P = 0.491[1]	P = 0.171	**P = 0.021; (+)**
246	Spinney Point	P = 0.838	P =0.563	P = 0.279
095	Sargent Bay	P = 0.568	P = 0.392	P = 0.076
091	Center of the lake	P = 0.454	P = 0.747	P = 0.453
093	Fitch Bay N.-E.	P = 0.356	**P = 0.015; (-)**	**P = 0.001; (-)**
092	Fitch Bay S.-W.	P = 0.413	P = 0.560	P = 0.270
096	Fitch Bay Offshore	P = 0.437	P = 0.521	P = 0.406
094	U.S. Border	P = 0.954	**P = 0.046; (-)**	P = 0.704
249	South Bay, U.S.	P = 0.751	P = 0.831	P = 0.312

[1] Bold P values show statistically significant upward (+) or downward trend (-); ($P<0.05$)

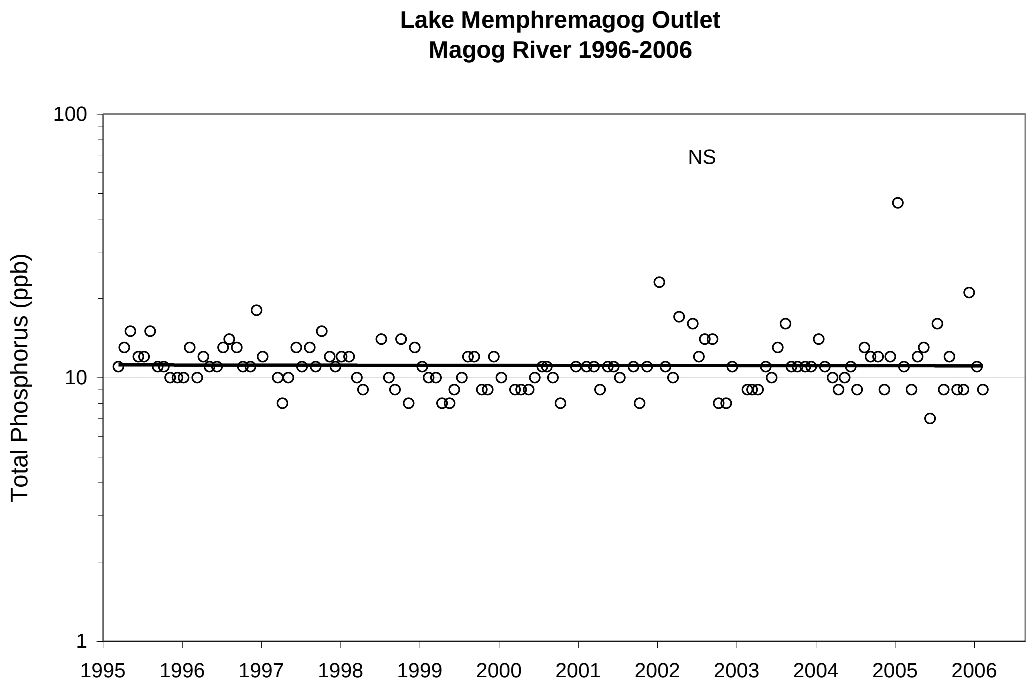


Figure 25. Total phosphorus concentrations recorded for the Magog River near the outlet of Lake Memphremagog (NS indicates no significant trend over time).

4.3 Cyanobacteria (Blue-green Algae) in Lake Memphremagog

Cyanobacteria, or blue-green algae, are one of many types of aquatic algae that are capable of producing heavy accumulations of algal scum, known as blooms. Some species of cyanobacteria are also capable of producing toxic compounds known as cyanotoxins. These compounds serve as a defense mechanism against predators (in this case, the tiny zooplankton that graze upon algae). The most common cyanobacteria species that produce toxins include *Anabaena spp.*, *Microcystis spp.*, and *Aphanizomenon spp.* Many lakes are affected by proliferation of cyanobacteria, and the incidence of blooms is on the rise in many locations worldwide. When heavy, cyanobacteria blooms can impact both swimming and water supply uses, to the extent that some beaches may even be closed to swimmers. Beach closures are commonly instituted as a preventative action, since the occurrence of toxins within the blooms cannot yet be predicted with confidence. In addition, the cyanotoxins can be difficult to remove from water without aggressive treatment systems. Lake Memphremagog supports several community water supplies in Quebec, including the municipalities of Sherbrooke and Magog. There are also numerous property owners who withdraw water from the lake directly for domestic uses with varying treatment systems

Beginning in summer 2004 and 2005, MDDEP sampled algae where people had reported blooms in order to:

- Verify and identify the presence of cyanobacteria
- Measure the concentration of cyanotoxins in the water of those locations.

In the summer of 2004, public reports of algal growth in the middle sections of Lake Memphremagog led to evaluations at three locations: Bryant Landing, Yacht Club in Sargent Bay, and the Wharf at Canton Potton. Cyanobacteria were noted to be present in all locations, but the concentration of toxins (measured in the water with the scum, near the shore) was near the detection limit of 0.01 ppb cyanotoxin. The health criterion is 1.5 ppb (of the cyanotoxin microcystin) for drinking water, and 16 ppb for swimming contact in recreational waters.

In September 2005, two samples were taken at North-East section of Fitch Bay. No other location was reported in the Quebec portion of the lake. The results showed the presence of cyanobacteria, but again with very low concentrations of toxins (0.01-0.02 ppb).

In the summer of 2006, a systematic sampling was initiated from July to October. Almost all of the Quebec portion of lake Memphremagog was affected, with an unusual density of cyanobacterial growth peaking in September and October. Samples were taken near water supply inlets, but all results were lower than standards. The worst results indicated 5,000 to 10,000 algal cells/ml, with a toxin concentration of 0.014 ppb. Three preventative, public warnings were issued: one for the beach at Ogden (July 11th), one for the Potton and Ogden areas (September 14th) and the last one for Abbaye St-Benoît and Fitch Bay (October 13th).

Cyanobacteria were reported on the Vermont side of the lake beginning in mid-August. A sample collected near Eagle Point contained a large amount of cyanobacteria including several cyanobacteria species, but it was poorly preserved and therefore density was not determined. Samples collected by the Vermont Department of Health on August 21 did not contain detectable levels of the cyanotoxin microcystin. On September 6th, surface accumulations were reported from the Newport VT waterfront area. On September 13th, samples collected from the Newport waterfront contained elevated densities of cyanobacteria including *Anabaena, Microcystis, and Aphanizomenon* spp. Once again, microcystin was below detection in these samples. At this time, preventative notification signs were posted at lake accesses and press releases were issued. On October 9th, a surface sample collected from the lake by the VTANR monitoring team documented that a number of *Anabaena, Microcystis, and Aphanizomenon* spp. were still present in the lake. No samples were collected after this date, nor were any additional reports about algae received in Vermont.

For the summer 2007, a systematic sampling regimen will be maintained in Quebec and Vermont, and specific protocols are in preparation, including an electronic distribution list to facilitate cross-agency notification of emerging blooms. Lake users should be mindful that cyanobacteria can pose a risk to swimmers, and are encouraged to contact their local health agency should they suspect a bloom in progress. As communities that withdraw water from Lake Memphremagog implement infrastructure upgrades, they should be mindful of this emerging threat to drinking water supply, and plan treatment systems accordingly. Additional information regarding cyanobacteria is available at http://www.lcbp.org/bgalgae.htm (Lake Champlain Basin Program) or http://www.mddep.gouv.qc.ca/eau/ eco_aqua/cyanobacteries/index.htm (MDDEP).

4.4 Lake Water Quality Maps

In the following section, we present maps depicting water quality conditions in Lake Memphremagog based on TP and Secchi transparency. These maps show monitored sites in relation to threshold levels of trophic enrichment. In lakes, trophic enrichment is classified along a gradient from oligotrophic (nutrient poor, low plant density, high transparency) to mesotrophic (moderate nutrients, plant growth, reduced water clarity), to eutrophic (nutrient-rich, algal dominance, low clarity). For this report, the following threshold values were applied for TP: oligotrophic, < 10ppb; mesotrophic, 10-20 ppb; eutrophic, >20 ppb (Figure 26). Trophic states were also classified based on Secchi transparency into: oligotrophic, >4 m; mesotrophic, 2m - 4m; eutrophic, <2 m (Figure 27).

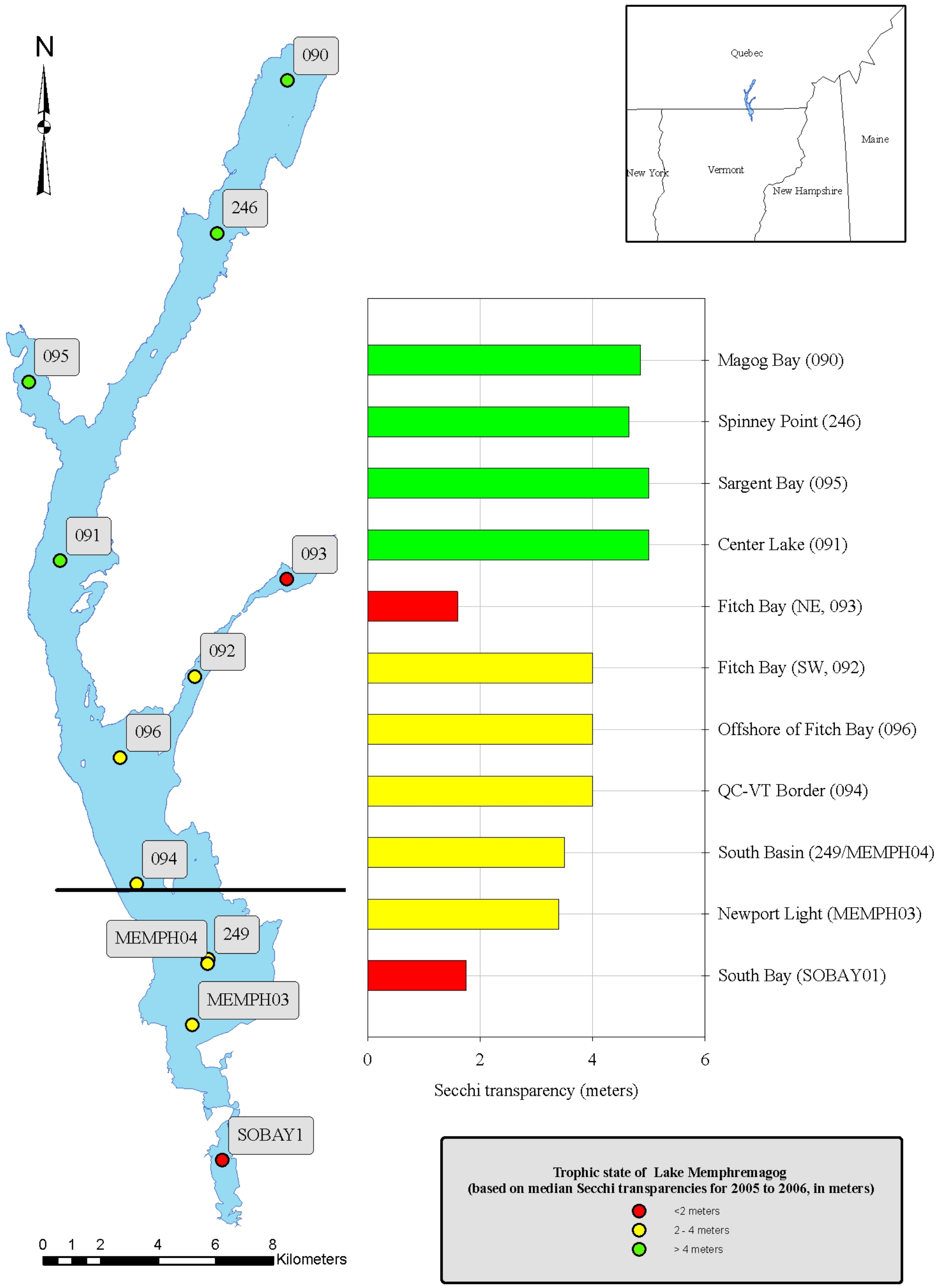


Figure 26. Secchi transparency in Lake Memphremagog

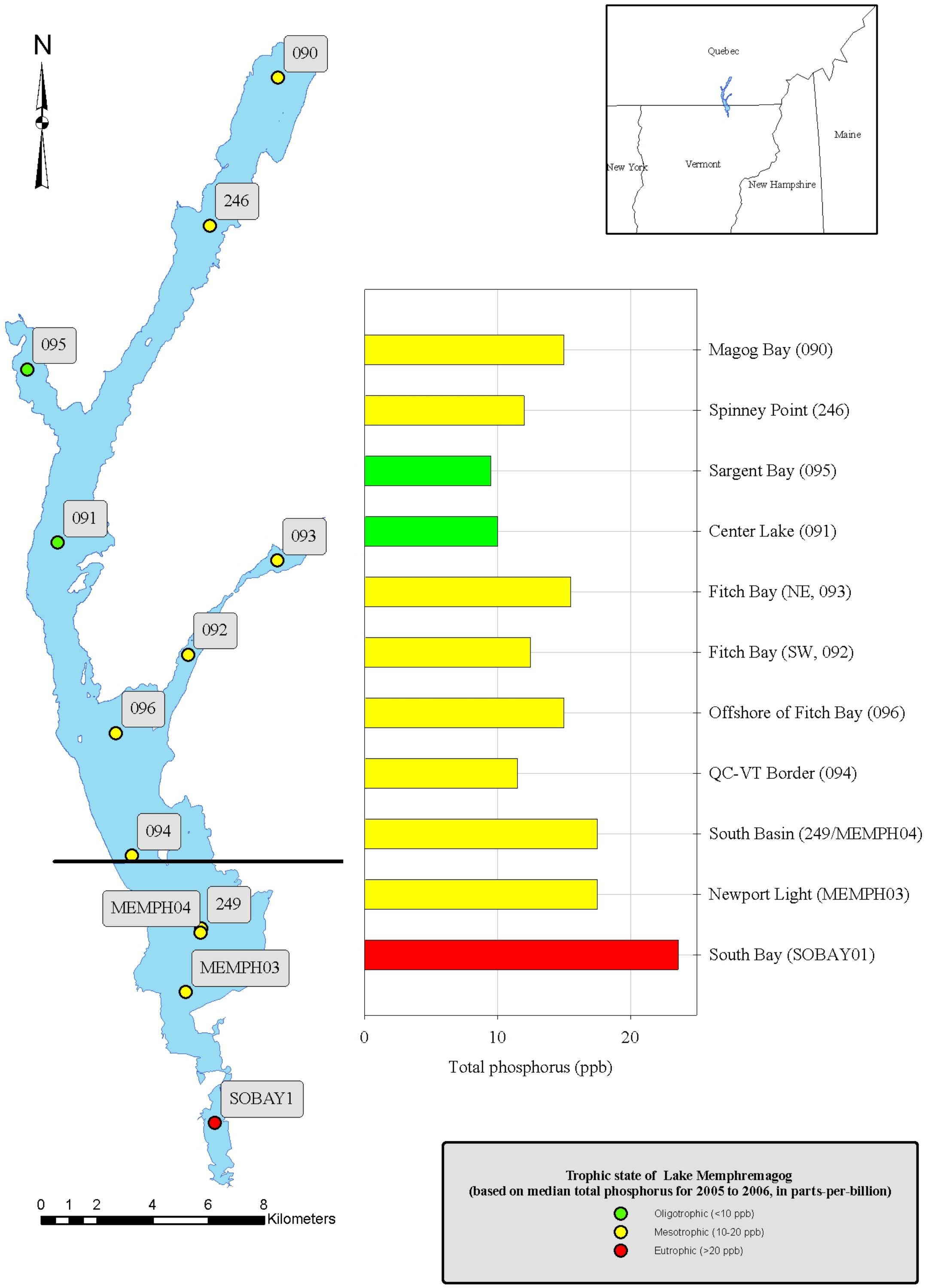


Figure 27. Total phosphorus in Lake Memphremagog

5.0 Recommended Action items

In 1993, the Quebec/Vermont Lake Memphremagog Steering Committee made 47 recommendations which were intended to improve watershed and lake conditions. These are contained in Final Report of the Quebec/Vermont Working Group on Managing Lake Memphremagog and Its Environment. In 2005, it was determined by the Quebec/Vermont Steering Committee that progress had been made on 37 of these recommendations, and, of these 27 were completed. However, the Joint Monitoring Report presented here shows that it is necessary to continue efforts to improve and protect the water of Lake Memphremagog and its watershed, particularly in the area of phosphorus and sediment pollution in the tributaries and in the lake itself.

Accordingly, the Quebec/Vermont Monitoring and Assessment Work Group makes the following recommendations:

1. Continue to monitor water quality both in the tributaries and in the lake. Focus on nutrient and sediment parameters and ensure monitoring program designs will address the following:
    a. Monitor long-term trends in water quality in the mid-lake and track compliance with water quality standards;
    b. Monitor tributaries and sub-tributaries for such parameters as phosphorus, nitrogen, bacteria and sediment pollution, to pinpoint "hot spots" and thus be able to direct remedial actions;
    c. In order to determine phosphorus and suspended solid loads in the main tributaries of the lake, it is recommended that continuous flow measuring stations on Barton, Clyde, Black, Johns, Cherry River and Castle Brook be established, and;
    d. Through Quebec and Vermont cooperation, conduct additional monitoring and modeling as needed to develop a phosphorus budget for the lake useful for source-area targeting and "TMDL" development. Modeling will apply to all the watershed of Lake Memphremagog. The methodology will be discussed and approved by the Work Group members.

2. Update the Recommendations in the 1993 Final Report. In most cases, the recommendations either need to be updated due to new issues or regulations, or having been accomplished, they need to go further to address a particular water quality issue. Consider that some issues may not need further action. Establish means to monitor progress on the updated recommendations. Identify stakeholders concerned with the various activities and consider means to bring them together to ensure progress. The issue categories are:
    a. Wastewater treatment facilities
    b. Solid waste disposal
    c. Nonpoint sources in general
    d. Agriculture
    e. Septic systems
    f. Shoreline protection

g. Soil erosion and sedimentation
h. Road salt/cleared snow
i. Water level management
j. Lake water quality
k. Fish, wildlife and wetlands
l. On-lake activities
m. Non-native nuisance species
n. Pesticide regulations (NEW)
o. Forestry practices (NEW)

3. In Vermont, support the Basin Planning effort recently begun in the Memphremagog watershed (includes the Tomifobia and Coaticook watersheds in Vermont). A Watershed Council of stakeholders has been formed and an Action Plan will be written. Ensure a means for continuing progress implementing the Action Plan after the planning process is complete.

4. In Quebec, hire one person full-time to coordinate with the existing Vermont Memphremagog Basin Planner, to ensure the recommendations are carried out.

5. Together, the Vermont and Quebec coordinators, with support from the Monitoring and Assessment Work Group and the Quebec/Vermont Steering Committee should:
    a. Update the recommendations in the 1993 Report so that it represents a current Action Plan;
    b. Pursue action on the various recommendations in the Action Plan with the appropriate stakeholders;
    c. Depending on particular needs of stakeholders or each issue, provide or seek research, management and implementation funds as needed; and
    d. Provide administrative support to the Quebec/Vermont Committee including preparation of minutes, preparation of annual report, and follow-up on action items that arise at the meetings.

6.0 References and relevant literature

Memphremagog Conservation, Inc. and RAPPEL. 2005. Operation Healthy Lake. http://www.memphremagog.org/fr/centre_docs.php?id=Études. Magog, QC, CA.

MRC Memphremagog. 2008. Programme D'échantillonnage des Tributaires. http://www.mrcmemphremagog.com/program_echantillon.html. Magog, PQ, CA.

Northwoods Stewardship Center. 2006. Restoring Water Quality in the Lake Memphremagog Basin: Water Quality in the Four Vermont Tributaries Final Report for the 2006 Nonpoint Source Pollution Reduction Project/LaRosa Analytical Partnership/Town of Charleston Supplemental Environmental Project. http://www.northwoodscenter.org/pdfs/tributaries06.pdf East Charleston, VT.

Quebec Ministère du Développement durable, de l'Environnement et des Parcs and Vermont Department of Environmental Conservation. 1993. Final Report of the Quebec/Vermont Working Group on Managing Lake Memphremagog and it's Environment. Waterbury, VT. USA and Quebec City, QC, CA.

Quebec Ministère du Développement durable, de l'Environnement et des Parcs and Vermont Department of Environmental Conservation. 2007.Critères de qualité de l'eau de surface au Québec. http://www.mddep.gouv.qc.ca/eau/criteres_eau/index.htm. Quebec, CA.

Quebec/Vermont Working Group on Managing Lake Memphremagog and Its Environment. Final Report and Recommendations. 1993.

Vermont Water Resources Panel. 2008. Vermont Water Quality Standards. Montpelier, VT.