LAKE MEMPHREMAGOG WATER QUALITY, 1996-2002

August 2004

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INTRODUCTION

Lake Memphremagog is the largest body of water in the Estrie region. Its water quality is a major regional concern due to the fact that this lake is the source of drinking water for nearly half of the region’s population and offers a unique potential for recreational and vacationing use in Québec. Recognizing the international importance of this lake, the governments of Vermont and Québec, signed an Environmental Cooperation Agreement on Managing the Waters of Lake Memphremagog in September 1989. In the wake of the agreement, a Vermont/Québec Working Group tabled in 1993 a report that summarizes the current situation and makes several recommendations to protect and improve the water quality of the lake and its watershed (Québec/Vermont Working Group on Managing Lake Memphremagog and its Environment, 1993).

One of the report’s many recommendations was the need to establish a permanent and comprehensive program to monitor the water quality of Lake Memphremagog. While several research organizations have done studies on the lake over the years, it was not until 1996 that the Direction du suivi de l’état de l’environnement (DSEE, formerly the Direction des écosystèmes aquatiques) of the ministère de l’Environnement du Québec (MENV) implemented a summer program to monitor the lake’s water quality in collaboration with Memphremagog Conservation Inc. (MCI).

In December 2003, Vermont’s Governor and Québec’s Premier signed a new Cooperation Agreement on Managing Lake Memphremagog and its Watershed. Improving the knowledge of the water quality of the lake and its watershed is one of the objectives of this agreement which replaces the one signed in 1989.

This report analyzes the data collected since 1996. It attempts to identify trends in the results of certain water quality variables and to determine the lake’s trophic level, i.e. its productivity level. Lakes that are rich in nutrients such as phosphorus have a greater biological productivity, which translates into a tendency to produce more plant biomass (aquatic plants or algae).
STUDY AREA AND METHODOLOGY

Sampling sites

Overall, nine sampling sites were visited during the sampling surveys (Figure 1 and Table 1). Lake Memphremagog is divided into three basins:

- Northern basin;
- Central basin;
- Southern basin.

The sampling sites are distributed as follows: two sites per basin, one site in Sargent’s Bay and two sites in Fitch Bay. Over the study period, water quality variables were measured on average four times during summer between the months of July and September.

Sampling method

Details concerning the sampling methodology are presented in Primeau (2000). Water samples were collected in the epilimnion, i.e. the upper water layer, by integrating a water column five meters in depth. For this purpose, bottles were attached to a “sampling iron”, quickly lowered to a depth of five meters and then gradually raised, in order to integrate the entire water column. The sight of bubbles coming out of the bottle’s mouth was an indication that filling had taken place properly.

Figure 1   Location of the water sampling sites in Lake Memphremagog
Table 1 Lake Memphremagog sampling sites

<table>
<thead>
<tr>
<th>Sampling site no.</th>
<th>Number on the map</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>03020090</td>
<td>90</td>
<td>Magog Bay</td>
</tr>
<tr>
<td>03020246</td>
<td>246</td>
<td>Spinney Point</td>
</tr>
<tr>
<td>03020095</td>
<td>95</td>
<td>Sargent’s Bay</td>
</tr>
<tr>
<td>03020091</td>
<td>91</td>
<td>Centre of the lake</td>
</tr>
<tr>
<td>03020093</td>
<td>93</td>
<td>Fitch Bay, northeast</td>
</tr>
<tr>
<td>03020092</td>
<td>92</td>
<td>Fitch Bay, southwest</td>
</tr>
<tr>
<td>03020096</td>
<td>96</td>
<td>Fitch Bay, offshore</td>
</tr>
<tr>
<td>03020094</td>
<td>94</td>
<td>U.S. border</td>
</tr>
<tr>
<td>03020249</td>
<td>249</td>
<td>Southern basin, U.S.</td>
</tr>
</tbody>
</table>

Water quality variables

From 1996 to 1998, the list of water quality variables included calcium, chloride, fecal coliforms, chlorophyll $a$ and pheophytin, total nitrogen, dissolved phosphorus (1.2 micron filter), suspended phosphorus, temperature and water transparency, as measured by a Secchi disk. The Secchi disk is a black and white disk measuring 20 cm in diameter that is lowered from the water surface towards the bottom until it is no longer visible. The depth at which the disk disappears is the water transparency measurement.

Beginning in the 1999 summer survey, only four variables were measured, namely chlorophyll $a$, total phosphorus, temperature and transparency. At the same moment, the total phosphorus analytical method, which in the past required measuring both the dissolved and particulate forms, the detection limit (D.L.) of each being 10 µg P/l and 1 µg P/l respectively, was replaced by the total phosphorus trace method which has a D.L. of 2 µg P/l.

The convention used to report values that were below the D.L. of the analytical method was to assign a value equal to half the D.L. Since the adoption of a more sensitive method for the analysis of total phosphorus in 1999 has allowed the recording of lower minimum values, the downward trend detected for this variable at certain sites is questionable.

Given the limited number of variables measured since 1999 and the change in the phosphorus analytical method, we chose to focus on the results obtained from 1999 to 2002, inclusively, to characterize the water quality of each sampling site.

To illustrate the variability in the results recorded at each sampling site, we used box-and-whiskers plots. The superimposition on these illustrations of the limit values corresponding to the various trophic levels makes it possible to classify the sites visually.
We also examined the relationships that exist between the variables, in particular those between water transparency and total phosphorus, water transparency and chlorophyll $a$, and chlorophyll $a$ and total phosphorus.

Finally, we calculated Carlson’s Trophic State Indices based on the mean summer levels of total phosphorus, chlorophyll $a$ and water transparency (Carlson, 1977) in order to validate the classification obtained by the other methods.
RESULTS

Total phosphorus

Figure 2 illustrates the distribution of total phosphorus concentrations recorded at each sampling site during the summer surveys of 1999 to 2002. It also shows the percentage of values that exceed 10 µg P/l, i.e. the limit which separates oligotrophic lakes from mesotrophic lakes. The northeastern site of Fitch Bay and that of the southern basin differ markedly from the other sampling sites, in that they consistently exceed this level. The northeastern site of Fitch Bay even exceeds the level of 20 µg P/l in more than 50% of the collected samples.

The sampling sites located southwest and off-shore of Fitch Bay and those located at the border display values greater than 10 µg P/l in more than 50% of the collected samples, whereas the sampling sites of the northern basin (Magog Bay and Spinney Point), Sargent’s Bay and the central portion of the lake exceed the reference value in less than 50% of the samples.

Based on the median phosphorus concentrations observed, four sampling sites of Lake Memphremagog are at the upper limit of the oligotrophic (nutrient poor) lake class, the northeastern Fitch Bay site reaches the eutrophic (nutrient rich) level, while four other sites are at the mesotrophic (intermediate between oligotrophic and eutrophic) level. According to the classification criteria used by the State of Vermont, the lake’s trophic level is, on the whole, mesotrophic. This level of productivity denotes a significant increase in nutrient richness for Lake Memphremagog, as a lake of this size should normally be at the oligotrophic level.

Since the only significant trends detected in the phosphorus concentrations of 1996 to 2002 are a decline at the four sampling sites showing the lowest values, it appears that the change made in
1999 in the analytical method is the origin of the downward trends. On the other hand, the absence of a significant increase for all sampling sites suggests a stability of concentrations during the time period.

**Total chlorophyll $a$**

Due to the sampling problems encountered during the 1999 and 2000 surveys, only the data of 2001 and 2002 is used to illustrate the distribution of the total chlorophyll $a$ concentrations (Figure 3). Once again, it is the northeastern part of Fitch Bay (sampling site 93) that displays the highest median. It also differs markedly from the rest of the lake, with values in excess of 8.0 µg/l in more than 80% of the collected samples. This high level of total chlorophyll $a$, which reflects the presence of a major phytoplankton biomass, is typical of eutrophic environments. It agrees with the high phosphorus levels measured at the same sampling site. The median values observed at the other sites indicate a lower productivity level, which classifies them in the mesotrophic lakes category. The classification system used by the State of Vermont evaluates, in the same way, all of the lake’s sites in relation to this variable.

![Figure 3](image_url)

**Figure 3** Distribution of total chlorophyll $a$ readings recorded at Lake Memphremagog’s sampling sites during the 2001 and 2002 sampling surveys

The data series analysis revealed no significant trend ($P > 0.05$) in the chlorophyll $a$ concentrations recorded at the sampling sites of Lake Memphremagog, suggesting stability in the lake’s productivity. This absence of a trend is in line with the absence of changes also observed in phosphorus concentrations.
**Transparency**

Unlike the other measured variables, water transparency obtained using a Secchi disk is a direct measurement that may be performed by a layman. This measurement makes it possible to obtain a rapid assessment of a body of water. Contrary to the other variables, the greater the transparency value obtained, the lower the productivity level, and therefore, the better the general state of a body of water.

The northeastern sampling site of Fitch Bay has the lowest transparency among the sampled sites (Figure 4), with a median value of 2 meters. This observation is no surprise, as it is also the site where we find the highest concentrations of total phosphorus and total chlorophyll $a$. In contrast, the sampling sites of the northern basin (sites 90, 246 and 95) and of the central zone (site 91) have the highest median transparency, with values of 4.5 meters or greater, which agree with their low phosphorus and total chlorophyll $a$ levels. Lastly, the sampling sites located southwest and off-shore of Fitch Bay (sites 92 and 96) and that of the border (site 94) have an intermediate transparency level which, again, is in line with their phosphorus and chlorophyll $a$ concentrations, putting them in an intermediate position. The southern basin sampling site differs somewhat from the others, with a median value that is less than 4 meters. Its slightly lower transparency appears to be linked to a phosphorus concentration which always remains above 10 $\mu$g P/l. Furthermore, it should be pointed out that no significant trend was detected in the data series collected.
Relationships between water quality variables

The analysis of the relationships between variables underscores some of the classic links in limnology (science that studies lakes). For instance, there is a very significant relationship between water transparency and total phosphorus concentrations (Figure 5) measured at Lake Memphremagog’s sampling sites. The four sampling sites with the lowest phosphorus concentrations display the best transparency, while the sampling site with the highest median concentration of phosphorus (Fitch Bay north-east) shows the lowest transparency. As Figure 5 illustrates, the phosphorus levels of the sampling sites of the northern basin and the centre of the lake put these sites close to the upper limit of the oligotrophic lake class, while their transparency ranks them in the oligotrophic lakes class.

The sampling sites located southwest and off-shore of Fitch Bay, as well as in the southern basin, are classified at the mesotrophic level, based on their phosphorus and transparency values, whereas the northeastern site of Fitch Bay is at the eutrophic level, due to its higher measurements.

Moreover, a similar relationship exists between water transparency and the chlorophyll $a$ content of Lake Memphremagog’s sampling sites (Figure 6). One notes that water transparency declines as the algal biomass, i.e. the quantity of microscopic algae, increases. Figure 6 shows that eight of
the lake’s nine sampling sites are at the mesotrophic level in this double classification system, whereas the northeastern site of Fitch Bay is at the eutrophic level. This latter relationship results from the link that exists between the productivity of a body of water and its total phosphorus concentration level (Figure 7). As phosphorus is usually the factor that controls the growth of algae in a natural environment, an increase in concentration stimulates primary production. The four sampling sites with the lowest median phosphorus levels are also those that show the lowest chlorophyll \(a\) levels, whereas the northeastern site of Fitch Bay, which displays the highest median concentration, also produces the greatest algal biomass.

![Lake Memphremagog Transparency - Chlorophyll \(a\) relationship](image)

**Figure 6** Relationship observed between water transparency (depth of the Secchi disk) and chlorophyll \(a\) content at Lake Memphremagog’s sampling sites

**Carlson’s Trophic State Index**

To complete our evaluation of the water quality of Lake Memphremagog, we calculated the *Trophic State Index*, or TSI, developed by Carlson (1977). Used by several American states to classify lakes, this concept is based on the observation that in several lakes, the degree of eutrophication is closely linked to the increase in the concentration of nutrients, namely phosphorus. An increase in the phosphorus concentration results in a rise in the quantity of microscopic algae, as revealed by chlorophyll \(a\) values. At the same time, water transparency measured with the Secchi disk declines. Elaborated on the basis of transparency measurements and phosphorus and chlorophyll \(a\) concentrations, Carlson’s Trophic State Index is compatible with the behavior of northern lakes (Holdren and Taggart, 2001). According to the established
convention, high values in excess of 50 on the TSI scale are typical of eutrophic lakes, whereas values below 40 on this same scale are usually representative of oligotrophic lakes. Intermediary values correspond to mesotrophic lakes.

Carlson’s TSI produces good results when it is applied to lakes, whose primary production is limited by the total phosphorus content. On the other hand, this index does not work very well when (1) the productivity of lakes is controlled by nitrogen; (2) the turbidity of the water is attributable more to mineral factors (linked to erosion) than to biological factors (related to phytoplankton production); or when (3) lakes’ primary production results in the production of more aquatic plants (macrophytes) rather than phytoplankton (Holdren and Taggart, 2001).

While a link is sometimes established between the trophic level of a lake and its water quality, it is important to point out that while these concepts are related, the terms should not be used interchangeably. The trophic level of a lake is an absolute scale that describes the biological state of a body of water. The trophic scale, which is a division of the variable or variables used to define the trophic level, is not influenced by the observer’s attitude or biases. An oligotrophic or a eutrophic lake has productivity characteristics that remain constant, irrespective of the use that is made of its water or its location (Carlson and Simpson, 1996).
Conversely, the concept of water quality is used to define the state of a body of water in relation to human needs or values. Water quality is not an absolute concept, as the term “good” or “bad” when applied to water quality is only meaningful in relation to the use made of the water or the attitude of a user (Carlson and Simpson, 1996).

As Figure 8 illustrates, Carlson’s Index calculated on the basis of the mean summer phosphorus and chlorophyll \( a \) concentrations reveals that eight sites out of nine are at the oligotrophic-mesotrophic level, whereas the ninth site is clearly classified at the mesotrophic level. Moreover, if greater emphasis is put on chlorophyll \( a \) (active or total) values, the same eight sampling sites that were at the oligotrophic-mesotrophic level would rank at the mesotrophic level, while the northeastern sampling site of Fitch Bay, the ninth site, is clearly classified at the eutrophic level. Algal biomass is a clear sign of the physicochemical conditions that exist in the various sectors of Lake Memphremagog. As the evaluation of the trophic level on the basis of chlorophyll \( a \) concentrations constitutes a realistic image of the biological state of a body of water, this evaluation is chosen to establish Lake Memphremagog’s biological state when the indicators present divergent results.

Although the evaluation of Carlson’s Trophic State Index was made using only data from the last two sampling surveys (2001 and 2002), such that the three variables’ data come from the same period, we believe that the results are representative of the lake’s biological state since the data of
the entire 1996-2002 sampling period revealed no significant trend for the three water quality variables.

**Other water quality results**

In addition to the results of the nine sampling sites spread out over Lake Memphremagog, the MENV also has data on the water quality of the Rivière aux Cerises, at the bridge located on road 10 south of Cherry River, and at the outlet of Lake Memphremagog on the Magog River.

The water of the Rivière aux Cerises is colored, as shown by its median dissolved organic carbon content (DOC = 5.8 mg/l) calculated using 2000 to 2002 data inclusively; and contains a median phosphorus concentration of 13 µg P/l. Close to 30% of the readings taken during the three-year period reach or exceed the criterion of 20 µg P/l set for the protection of lakes and reservoirs. A portion of the residual pollution that affects the river comes from the pressure exerted by vacationing in this region, which is very busy during some periods of the year.

The physicochemical composition of the water of the Magog River at the outlet of Lake Memphremagog shows water whose overall quality was good during the 2000 to 2002 period, inclusively. The water was slightly colored (DOC = 3.3 mg/l) and weakly turbid, and the median phosphorus concentration stood at 10 µg P/l. These results are in line with the quality observed in the Magog Bay sector.
DISCUSSION

Data collected during the 1996 to 2002 sampling surveys showed no significant evolution in the values of the three main variables selected to document water quality and to evaluate Lake Memphremagog’s biological state. In the absence of significant trends in the data, the results of the last four surveys carried out from 1999 to 2002 allowed us to obtain a representative portrait of the situation.

The sampling sites of the northern basin, Sargent’s Bay and the centre of the lake show a slightly lower productivity level than the other sampling sites and display phosphorus levels at the upper limit of the oligotrophic lakes class. These are sampling sites located in the lake’s deepest sectors. However, due to the fact that the results were obtained during summer, a period when a portion of the phosphorus has already been assimilated by the aquatic plants and algae, the measured concentrations could be underestimated.

The sampling sites of the southern basin have slightly higher phosphorus values, exceeding $10 \mu g P/l$ more frequently. They also have higher chlorophyll $a$ readings, while presenting a lower water transparency. The southernmost sampling site stands out from the other sites by having phosphorus concentrations that are consistently in excess of $10 \mu g P/l$ and water that is the least transparent of the entire lake. The southern basin, which is the shallowest sector of Lake Memphremagog, is fed by three major tributaries (the Barton, Clyde and Black rivers), which drain a territory made up mainly of farm lands and forests. While 73% of Lake Memphremagog is located in Québec’s territory, 71% of its watershed is located in the State of Vermont (Québec/Vermont Working Group on Managing Lake Memphremagog and its Environment, 1993).

It is the northeastern sampling site of Fitch Bay which presents the least favorable results for the measured variables and consequently, the highest trophic level among all Lake Memphremagog’s sampling sites. Fitch Bay is a closed bay which has an average depth of 3 meters. It was formed by the flooding of the land following the construction of the Magog dam in 1883 (Michaud and Deslandes, 2003). The dam’s construction resulted in a more than two meter increase in Lake Memphremagog’s water level. The shallow depth of Fitch Bay and the clearing of a portion of its shores contribute to the warming of the bay’s water in summer. In addition, the long residence time and the physicochemical composition of its water appear to offer ideal conditions to support, locally, an important primary production (Jeudi, 2001). The physicochemical characteristics of the bay’s water stem from the multiple inputs from the immediate perimeter of the bay and its tributaries: the Fitch, Gale, Bunker and McCutcheon streams.

Local factors, such as the deterioration of the riparian strip and the artificialization of the shores in certain sectors, could facilitate sediment transport to Fitch Bay. Furthermore, the septic facilities of isolated homes could play a role in the deterioration of water quality by contributing nutrients.

Moreover, the watercourses that feed Fitch Bay drain farm and wetland sectors in their respective basins. Their water is of questionable quality (Doucet, 1999), and they transport significant quantities of nutrients into the bay (Jeudi, 2001). Although the works of Michaud and Deslandes (2003) show that agricultural nonpoint source pollution appears to play a minor role, we found
that the phosphorus concentrations measured by Barmon (2002; in Michaud and Deslandes, 2003) vary between 20 and 80 µg P/l. Hence, they are above the criterion set to prevent the accelerated eutrophication of lakes and reservoirs. In the absence of point-source pollution of urban origin in the basins of the Bunker, Gale and McCutcheon streams, it is likely that agricultural land makes a significant contribution to sediment and nutrient inputs during certain storm events.

The poor conditions observed in Fitch Bay are partly attributable to the physical characteristics of the bay and its origins. They also result from the numerous human activities that have taken place in the bay’s territory over the last few years. Past and current inputs have probably contributed to the enrichment of the bay’s sediments with phosphorus. Given the shallow depth of the bay, it is likely that the water column is not stratified during the summer period. The mixing caused by the wind and wake waves promotes the redistribution of the phosphorus in the water column. This recycling of the phosphorus, added to the external inputs, contributes to the strong productivity observed in the bay.
CONCLUSION

Whether phosphorus, chlorophyll $a$ or water transparency measurements are used, we find that a majority of Lake Memphremagog’s sampling sites show a biological state that is characteristic of a mesotrophic body of water. The most obvious signs of the accelerated aging of the lake are observed in the lake’s shallowest sectors, namely the northeastern part of Fitch Bay and the southern basin. However, the analysis of the data collected since the beginning of the sampling program in 1996 reveals no significant trend in the results of the three water quality variables.

An updating of the land use information and an evaluation of the pressures linked to point and nonpoint pollution sources at the watershed level are needed to better understand Lake Memphremagog’s current state. In addition, an assessment of the various clean-up programs undertaken over the years would help to better target future initiatives. Moreover, this exercise would make it possible to see to what extent the past recommendations of the Vermont/Québec Working Group have been applied.

In the meantime, it is advisable to maintain the water quality monitoring program started in 1996; and to publish, on a regular basis, the results obtained, in order to inform government officials and to make Vermont’s and Québec’s population aware of Lake Memphremagog’s health state and evolution.
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BIBLIOGRAPHY


