Eutrophication in **Missisquoi Bay**

Sarah Dorner, Mouhamed Ndong, and Natasha McQuaid

Missisquoi Bay: Source Water Protection and Monitoring for a Transboundary Lake Impacted by Cyanobacteria

Eutrophication in Missisquoi Bay

Harmful cyanobacterial blooms accompanied by toxin production can be harmful for aquatic communities and threaten sources of drinking water. Missisquoi Bay, a large bay of Lake Champlain with recurrent cyanobacterial blooms, is used as a source of drinking water for approximately 4100 residents in Québec. Public health authorities have restricted recreational access to the lake repeatedly over the last decade as a result of cyanobacterial blooms (Figures 1 and 2). Lake Champlain's watersheds are shared among New York and Vermont in the United States and Québec in Canada. Missisquoi Bay, shared by Québec and Vermont, is the most impaired region of Lake Champlain.

The eutrophic character of the bay has been the target for the reduction of the phosphorus concentration by a bilateral agreement in 2002 between the province of Québec (Canada) and the state of Vermont (United States). In 1991, it was determined that 60 percent of the phosphorus load to Missisquoi Bay was from Vermont and 40 percent was from Québec. Therefore, by 2016, the total phosphorus loads are to be reduced to 58.3 metric tons (mt)/yr for Vermont and 38.9 mt/yr for Québec. The in-lake criterion for total phosphorus in Missisquoi Bay has been set at 0.025 mg/L, a criterion that has not been met (Figure 3) in recent years.

As a result of its high phosphorus and chlorophyll-*a* concentrations and low transparency, Missisquoi Bay has been classified as eutrophic. It is also relatively shallow, particularly in relation to other regions of Lake Champlain, with an average depth of 2.8 m and a surface area of 77.5 km^2. The Bay's main inputs are groundwater, tributary rivers, and runoff from predominantly agricultural lands. Water from many of the Bay's tributary rivers has been classified as "poor" or "very poor" by Québec's bacterial and physico-chemical indicators due to high turbidity and excessive concentrations of nitrogen and phosphorous (OBVBM 2011). In addition to being a source of drinking water, it serves as a recreational site for boating, fishing, and swimming activities.

Figure 1. A cyanobacteria bloom along the shores of Missisquoi Bay in 2008.

One of the challenges for source water protection in Missisquoi Bay is that the nutrient concentrations are generally high and are not related to cyanobacterial blooms at the drinking water treatment plant intakes likely because other factors are limiting cyanobacterial growth. Figures 3 and 4 illustrate the variability of average total phosphorus and total nitrogen concentrations from May to October in Missisquoi Bay from 1992 to 2008. It is interesting to note that 2007 was a year with minimal cyanobacterial contamination of the drinking water treatment plant, whereas in 2008, large densities of cyanobacteria were present despite similar nutrient concentrations in Missisquoi Bay. Our hypothesis is that cyanobacterial occurrence at the drinking

Figure 2. A warning sign advising residents not to use the water.

water treatment plant is more related to the hydrodynamics of the Missisquoi Bay, as influenced by wind speed and direction, than the concentrations of nutrients in the Bay.

Land Use and Sources of Phosphorus in the Lake Champlain Watershed

Approximately 95 percent of the total phosphorus load to Lake Champlain is from non-point sources such as soil erosion and runoff from agricultural lands, stormwater from roads and lawns and 5 percent from point sources such as wastewater treatment plants (Smeltzer et al. 2009). In Missisquoi Bay, approximately 68 percent of the phosphorus load is from agricultural land (Figure 5) and Missisquoi Bay is the single largest contributor to phosphorus in Lake Champlain (Troy et al. 2007). Although phosphorus concentrations remain above the water quality criteria values, there has been a marginally significant downward trend in phosphorus loading in Québec's Pike River but no downward trend for the Missisquoi River (two rivers discharging to Missisquoi Bay, Figure 6) (Smeltzer et al. 2009).

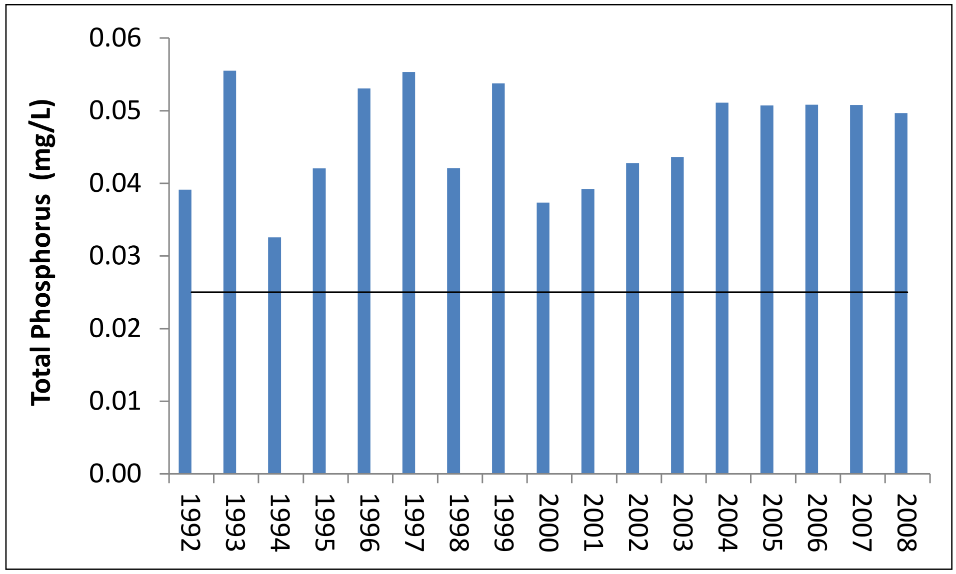

Figure 3. Average seasonal (May to October) total phosphorus concentration in Missisquoi Bay. The line represents the total phosphorus criterion established for Missisquoi Bay.

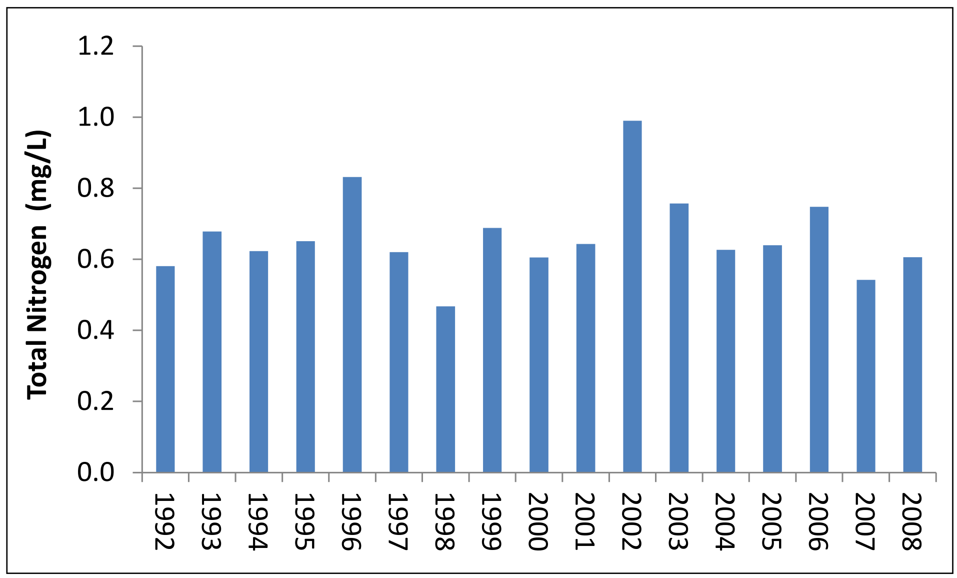

Figure 4. Average seasonal (May to October) total nitrogen concentrations in Missisquoi Bay.

Protecting Missisquoi Bay and Lake Champlain

Given its position as a transboundary surface water, Missisquoi Bay, Lake Champlain, and their watersheds are managed in accordance to trilateral and bilateral agreements, federal and state/provincial regulations with the participation of local watershed organizations and diverse citizen and interest groups within their communities (Stickney 2008). In Québec, the Organisme de bassin versant de la baie Missisquoi (OBVBM) is the organization given the responsibility through Québec's Water Policy for developing a management plan for the watersheds draining into Missisquoi Bay. In 2011, they released a management plan identifying specific issues and their associated goals and priorities. Management goals related to cyanobacteria and water quality are a high priority and examples of specific actions to be taken include tree planting, enforcing a 3-m buffer zone, and river bank stabilization (OBVBM 2011).

At the whole basin level, the Lake Champlain Basin Program coordinates and funds efforts to improve water quality in the basin in accordance with the *Opportunities for Action* plan and is administered by the U.S. Environmental Protection Agency (New England and

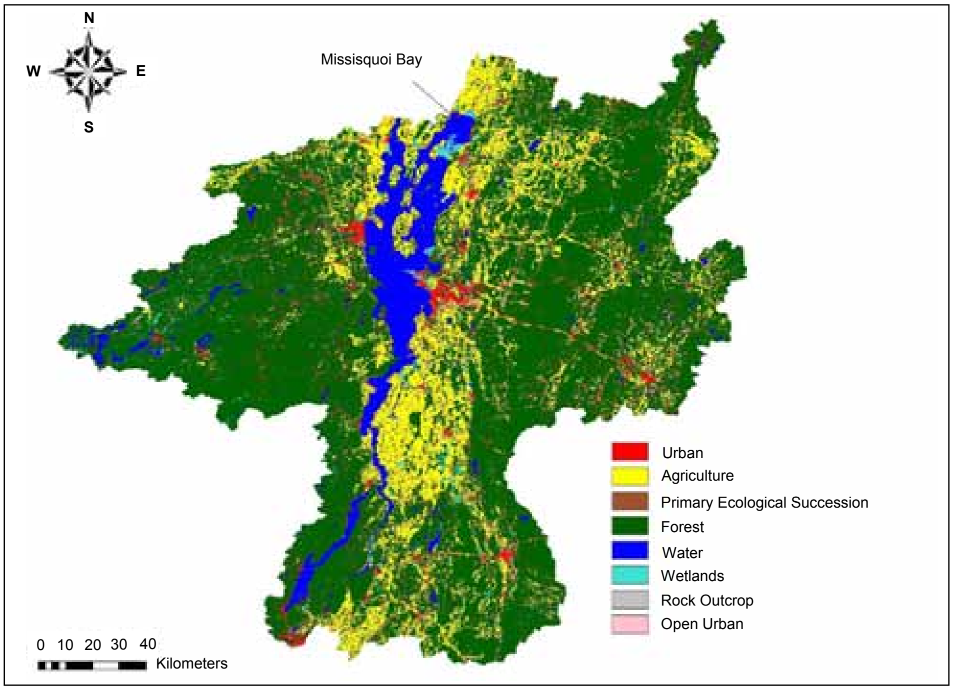

Figure 5. Land use/land cover in the Lake Champlain basin (Troy et al. 2007).

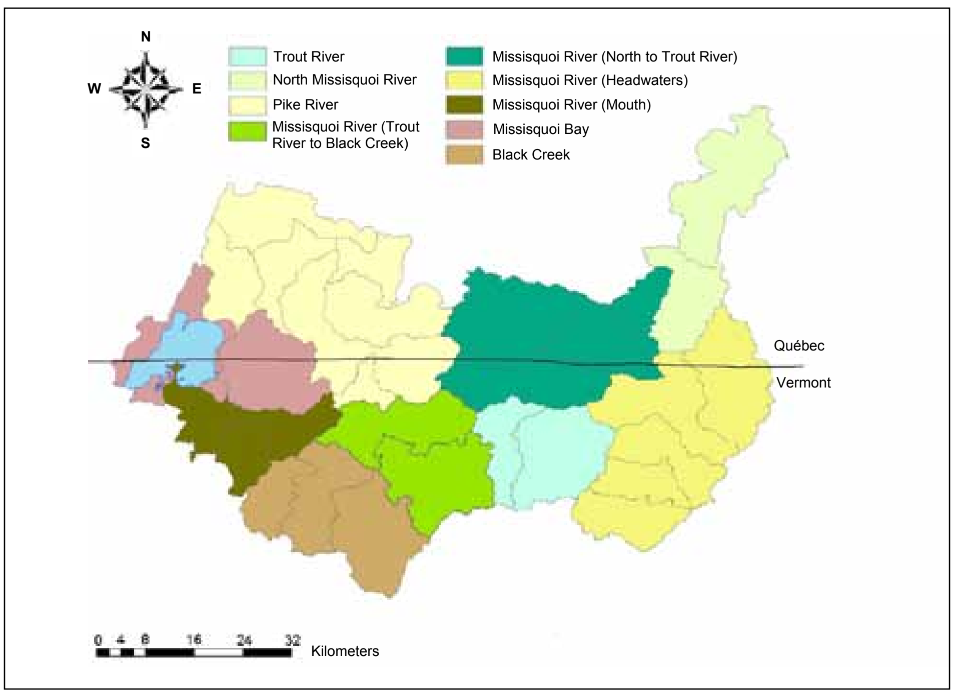

Figure 6. Missisquoi Bay Watersheds.

Region 2), New York State Department of Environmental Conservation, Vermont Agency of Natural Resources, Québec Ministry of Environment, and New England Interstate Water Pollution Control Commission. In 2010, the *Opportunities for Action* plan was updated and phosphorus reduction and the minimization of human health risks from cyanobacteria remain as primary goals for Lake Champlain (Lake Champlain Steering Committee 2010).

Cyanobacteria and Source Water Protection in Québec

The documented number of lakes in Québec that have had at least one cyanobacterial bloom with cell counts greater than or equal to 20,000 cells/ml has increased from 21 in 2004 to 150 in 2010 (MDDEP 2011). The increase in the number of affected lakes is partly the result of a greater awareness of cyanobacteria issues among the population who report the cyanobacterial blooms to the Ministry. The increase in reported bloom events prompted Québec's Ministry of Sustainable Development, the Environment and Parks to develop the 2007-2017 Québec Action Plan on Blue-Green Algae to deal with current issues and to research practical solutions to prevent a worsening of the problem.

Drinking water sources in Québec are protected through its Water Policy (Politique nationale de l'eau) implemented in 2002 that established a governance framework of integrated watershed management. A new policy for source water protection in Québec is expected in the coming months because Québec's Water Policy treated all surface waters equally and did not provide specific measures to characterize threats and protect drinking water sources. However, even with new legislation for source water protection, the challenge of existing eutrophication and cyanobacteria blooms will remain because these problems are less easily solved by delineating drinking water source protection zones and restricting activities within them. Problems associated with eutrophication and cyanobacteria blooms are related to the multitude and cumulative impacts of diffuse sources of nutrients within affected watersheds.

The solution requires integrated watershed management, with a particular emphasis on restricting or mitigating the effects of activities that lead to elevated nutrients loads. These approaches have already been adopted in the Lake Champlain Basin and in the watersheds of Missisquoi Bay. However, since 2004, there have been cyanobacterial blooms every summer and total phosphorus concentrations in Missisquoi Bay have not decreased. Thus, it is necessary to identify strategies not only for source water protection that may take years to implement, but strategies that are needed immediately for responding to the problem of cyanobacteria and toxins entering drinking water treatment plants, a common occurrence in Missisquoi Bay.

Managing Problems of Cyanobacteria at the Drinking Water Intake – Online Monitoring

Given that source water protection measures implemented today may take years to have a noticeable effect, other strategies for responding to rapidly evolving water quality are needed at drinking water treatment plants. New online cyanobacterial monitoring tools can complement conventional monitoring methods to reduce problems often encountered during conventional environmental monitoring such as time limitations, geographical restrictions, and individual capabilities. Traditional monitoring methods include taxonomic enumerations and pigment extractions that are fastidious and costly because they necessitate analysis by highly trained personnel and expensive equipment. These methods are also inconvenient for drinking water treatment plant operators, who often receive analysis results days after sampling, therefore preventing them from responding quickly to a contamination event of toxic cyanobacteria.

In vivo fluorescence with submersible probes provides advantages such as sampling in the benthic zone of water bodies, monitoring multiple points quickly near recreational areas, and the rapid assessment of water quality at drinking water treatment plant intakes. This technology has been used in recent studies to measure cyanobacterial abundance at the intakes of drinking water treatment plants. An online multi-probe system (YSI type 6600V2-4, Yellow Springs, Ohio), measuring in vivo phycocyanin (PC) fluorescence (a pigment specific to fresh water cyanobacteria), chlorophyll fluorescence, pH, dissolved oxygen, temperature, specific conductivity and turbidity has been used to monitor cyanobacteria in the raw water and source water a drinking water treatment plant on Missisquoi Bay since 2007.

We have assessed the validity of the monitoring tool for in vivo phycocyanin fluorescence to estimate cyanobacterial abundance in situ and found that it was well correlated to cyanobacterial biomass as well as toxin concentrations (McQuaid et al. 2011). Cyanobacterial biovolume (an indicator of biomass), as measured by the probe was not related to nutrients in Missisquoi Bay (Figure 7).

Although the estimation of cyanobacteria by in vivo fluorescence has been demonstrated to be possible and accurate, the quality of the instrument's estimates will depend on the specificity of the instrument and/or the algorithm used for conversion. Rigorous testing of instruments in the field is highly recommended. Additionally, pigment fluorescence can be affected by exposure to sunlight intensity, nutrient availability, interferences with algae, turbidity in the water matrix, cell age and history (Gregor et al. 2007).

Continuous monitoring has the potential to improve decision-making with regards to water treatment as well as evaluating and guiding source water protection measures. The continuous monitoring will also assist with the development of a 3D hydrodynamic model of Missisquoi Bay to understand the effects of the Bay's hydrodynamics on cyanobacteria densities at the drinking water treatment plant intake. The model is expected to facilitate the interpretation of monitoring results and could be used to guide decision-making with regards to the occurrence of bloom formation and the effects of source water protection measures on water quality at the drinking water treatment plant intake.

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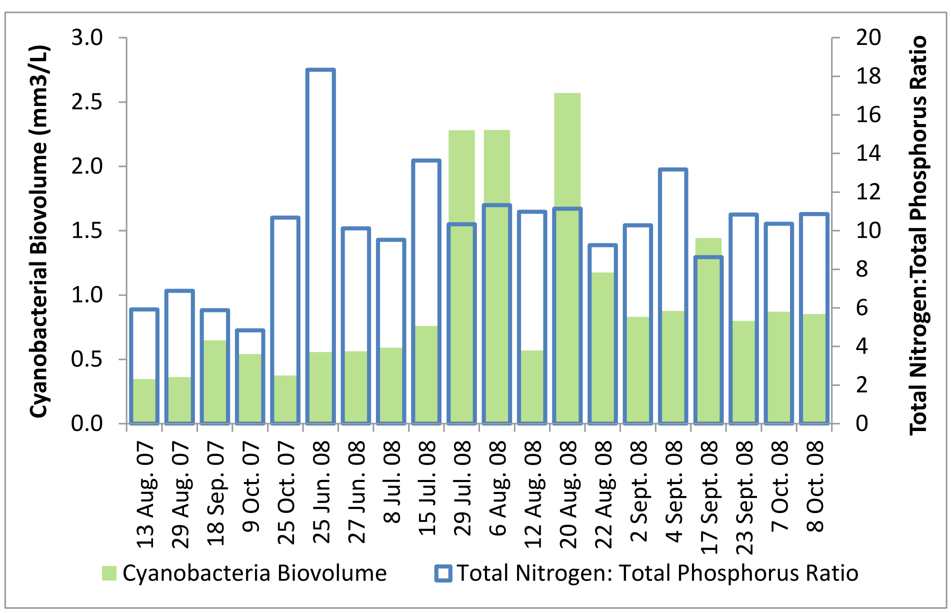

Figure 7. Cyanobacterial biovolume as estimated by phycocyanin fluorescence in relation to the ratio of total nitrogen to total phosphorus.

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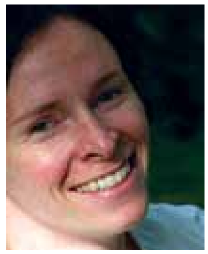
Sarah Dorner is an assistant professor in the Department of Civil, Geological and Mining Engineering at École Polytechnique de Montréal and holds a Canada Research Chair on Microbial Contaminant Dynamics in Source Waters.

Mouhamed Ndong is a doctoral candidate in the Department of Civil, Geological and Mining Engineering at École Polytechnique de Montréal. His research focuses on the development of a coupled cyanobacteria-hydrodynamic model for Missiquoi Bay.



Natasha McQuaid's graduate research focused specifically on toxic cyanobacteria blooms in source waters of drinking water treatment plants. Natasha currently works at the Secretariat of the Convention on Biological Diversity researching the interactions between poverty alleviation strategies and biodiversity conservation.

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