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Water Quality Monitoring and Lake Ecosystem Modelling: an Integrated Approach to Assess Cyanobacterial Blooms

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Abstract

In the last decades, the incidence of harmful algal blooms in surface waters has increased in frequency, severity and duration. Short and long term management approaches can address the problem of cyanobacteria blooms. A real-time, autonomous, monitoring program, coupled with a one dimensional deterministic model, was initiated for Missisquoi Bay, Canada in the summer of 2007. Preliminary results from vertical profiles in a pelagic zone show a homogenous distribution of temperature, pH, chlorophyll *a* concentration and cyanobacteria density. Phycocyanin measurements by an *in vivo* fluorescence probe show high cyanobacteria concentration varying between 1×10^4 to 1×10^5 cell/mL.

Keywords

Cyanobacteria; lake; water; treatment; modeling

INTRODUCTION

Anthropogenic eutrophication of water bodies and its consequences are of concern especially in waters used for recreation or as sources of drinking water (VASCONCELLO, 2006). High nutrient inputs, mainly phosphorus and nitrogen in their diverse forms, cause excessive algal growth and make freshwater lakes more vulnerable to the occurrence of cyanobacteria, also known as blue-green algae (BGA). Because highly toxic cyanobacteria can produce toxins, these microorganisms pose a significant threat to the quality of water (BARTAM and CHORUS, 1999).

Specific strategies to address algal bloom problem in lakes depends on numerous considerations such as properties of the lake (size, depth, currents, physico-chemical and biological characteristics, etc), users, available budgets and activities in the watersheds. Lake management

approaches can be classified into two categories: short-term management and long-term management.

In-lake treatments such as artificial mixing, ultrasound and algicides are short-term treatments. Mechanical and physico-chemical methods have been devised in attempts to manage cyanobacterial blooms, with limited success (GUMBO et al., 2008). Algicides such as copper based products (HAVENS, 1994; COOKE et al., 2005; TUBBING et al., 1994) and potassium permanganate (LAM et al., 1995) induced cyanobacterial cell lysis, followed by the release of toxins into surrounding waters. These chemicals are toxic to other aquatic microorganisms, may accumulate in the sediment at harmful concentrations and may cause long-term damage to the lake ecology (MASON, 1996). Moreover, public acceptance of algicides is continuously decreasing because of their toxic by-products and their adverse ecological impact.

Augmentative biological control or bioaugmentation is the practice of enhancing the populations of predators to help in regulating the populations of the pest in its natural habitat (GUMBO et al., 2006). With this method, biodegradation of cyanobacteria cells have been clearly demonstrated (NAKAMURA et al., 2003 a, b). Effective biodegradation of microcystin has also been reported (JONES and ORR, 1994; BOGOSIAN and BOURNEUF, 2001; HO et al., 2006; HO et al., 2007). However, very few predators have been tested and the mechanisms of cyanobacterial degradation are not well understood.

On the other hand, sophisticated monitoring programs have been developed to follow phytoplankton blooms on a longer period and to assist with effective management of cyanobacteria. In Europe, aquatic ecosystems are monitored according to the Water Framework Directive. This program requires that by 2015, lakes whose surface area is greater than 50 ha need to achieve a good ecological status (ECE, 2000). Thus, rapid and precise methods are needed in order to monitor water quality in lakes.

Submersible *in vivo* fluorescence (IVF) profilers are commonly used for high frequency monitoring plans (LEE et al., 2005; BRIENT et al., 2008; MCQUAID, 2009). They are particularly suitable for monitoring cyanobacteria where the spatial heterogeneity of these microorganisms becomes a major problem (CAGNARD et al., 2006). Furthermore, they are simple detection methods, faster than conventional microscopy and do not require highly trained personnel to perform chemical analyses and biological characterization of samples (CAGNARD et al., 2006; GREGOR and MARSALEK 2005).

This paper presents the second part of a joint Canadian-French research project that aims at a deeper understanding of the physical, chemical and biological determinants of BGA blooms. It proposes a long-term water quality monitoring system, adapted to a Canadian lake and coupled with one dimensional modeling. The first part of this research project – the development of a biological treatment against *Microcystis aeruginosa* – is beyond the scope of this paper.

Preliminary results from the data collected during summer 2010, in Missisquoi Bay (Quebec, Canada), will be presented. The one dimension modeling is undergoing and will only be briefly presented.

MATERIAL & METHODS

Study site

Missisquoi Bay (figure 1) is situated in the northeastern part of Lake Champlain which flows from Whitehall (New York, U.S.), across the U.S./Canadian border to its outlet, the Richelieu River in Canada (BALLINGER, 2004). The bay has a surface area of 77 km² and a maximum depth of 4 m. The mouth of the bay, at the southern end, is delimited by two causeways, extending from each shore and a bridge section of 170 m (MENDELSON et al., 1997). Missisquoi Bay has three major tributaries: Missisquoi River, Pike River (also called Rivière-aux-Brochets) and Rock River which drain a watershed of 3 105 km². Due to high turbidity and excessive concentrations of nitrogen (N) and phosphorus (P), the environmental department of Quebec (MDDEP) has classified water quality from these tributary rivers as “poor” or “very poor” (SIMONEAU, 2007). Missisquoi Bay is also a source of drinking water for 4100 residents. Because of the high nutrient loading, this northern shallow freshwater bay experiences recurrent toxic cyanobacteria blooms during the summer months.

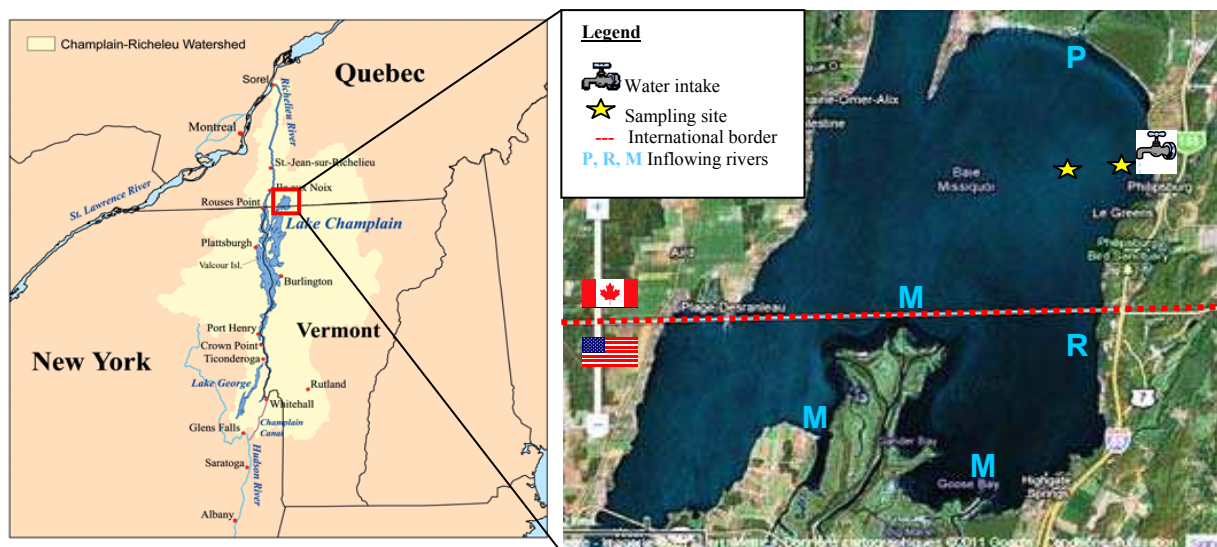


Figure 1: Missisquoi Bay study and sampling locations
(adapted from www.icsd.k12.ny.us and www.maps.google.ca)

Continuous water monitoring and vertical depth profiles

In 2007, a real-time monitoring program was developed and implemented in Missisquoi Bay, using an online multi-probe system. The system was an on-line 6600V2-4 multi-probe from YSI (YSI, yellow Springs, Ohio, USA). YSI probes were chosen because of their relatively low cost making them more likely to be used by small municipalities than other more expensive probes using similar technology (MCQUAID, 2009). The multi-probe system consists of eight sensors: temperature (T), depth, conductivity, turbidity, pH, dissolved oxygen, chlorophyll fluorescence and phycocyanin fluorescence.

Extensive field data have been acquired during the summer period, from 2007 to 2010. A probe was installed inside the drinking water treatment plant (DWTP) to monitor raw water and recorded measurements every hour. The probe was in service from August to early November in 2007, from May to October in 2008, from June to October in 2009 and from July to late November in 2010. Data were downloaded once week. Another probe was used to measure vertical depth profiles above the DWTP’s intake point and in the pelagic zone, once or twice a week.

Calibration and field samplings

The probes were calibrated once a month. For pH, turbidity and conductivity, the sensors were calibrated with purchased standard products from the manufacturer. For chlorophyll, dissolved oxygen and phycocyanin sensors a one point calibration with de-ionized water was done according to the user manual of the manufacturer. Depth and temperature readings were compared with respectively a light depth probe and a thermometer.

At the same time depth profiles were conducted, water samples were taken in duplicates every meter in clean 500 mL plastic bottles for chemical analysis and biological extractions, and in sterile 20 mL vials for taxonomic counts and toxins analysis. Raw water samples were also collected in duplicate inside the DWTP. Bottles and vials were rinsed three times with sampled water before they were filled completely and tightly closed. Lugol's iodine was added in vials for taxonomic counts according to LUND et al. (1958). All samples were preserved on ice in coolers for transport and processed later the same day. Samples for microcystin analysis were frozen at -15°C.

Biological and chemical analyses

Vials with Lugol's iodine were sent to Quebec Environmental Analysis Expertise Centre and to Université du Québec à Montréal's (UQAM) Biological Sciences department for species identification, taxonomic counts, biomass and biovolume calculations using inverted microscopy according to LUND et al. (1958).

Microcystin LR was monitored using ELISA kits (Abraxis, Warminster, Pennsylvania, USA). Water samples were filtered through a Whatman GF/C glass filter before freezing. Total intra and extra cellular toxins were measured after three thaw cycles to lyse cells.

Chlorophyll-*a* and phycocyanin extractions were performed according to Standard Methods (APHA *et al.*, 2005).

Field samples were also analyzed for total phosphorus (TP), total Kjeldhal nitrogen (TKN), orthophosphate (o-PO₄) and nitrate/nitrite (NO_x). All chemical analyses were carried out according to Standard Methods. For TP and TKN determination, 5 mL H₂SO₄ were added to 20 mL water samples. o-PO₄ and NO_x determinations were carried out on filtered samples.

One dimension modeling

The study uses the one-dimensional coupled hydrodynamic-ecological model DYRESM-CAEDYM for the simulation of phytoplankton dynamics. The model simulates the temporal course of vertical temperature and salinity distribution, and quantify the feedback from the algal population to the thermal structure of the lake. Expected results will yield information to assess cyanobacterial blooms occurrence.

RESULTS AND DISCUSSION

Depth profiles using the multiprobe were used to understand the spatial distribution of cyanobacteria throughout the water column. Depth profile made on July 20th, 2010 in a pelagic zone indicated homogenous distribution for T and pH (Figure 1). Concentration of chl-*a* and cyanobacteria were also relatively uniform.

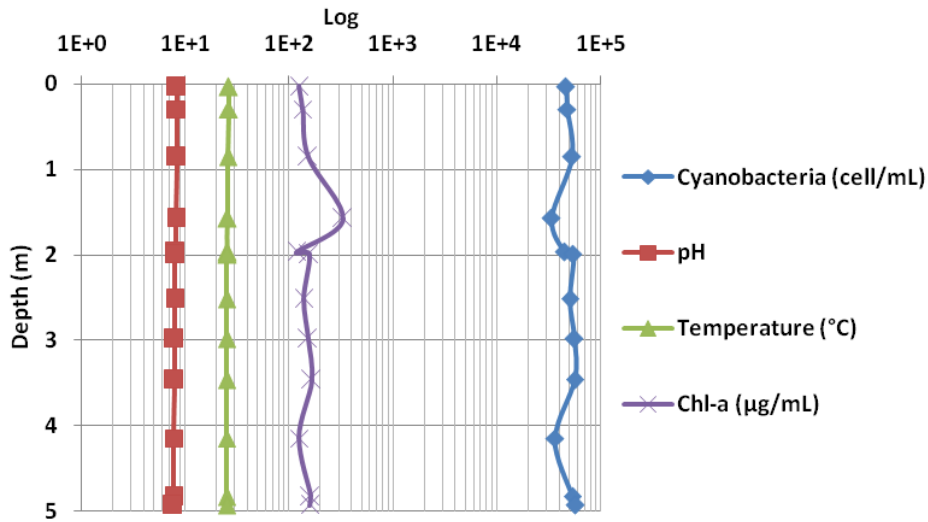


Figure 2: Depth profile of cyanobacteria density, pH, temperature and chl-a concentration in the middle of the bay, on July 20th 2010.

A previous study by MCQUAID (2009) has highlighted that in this shallow bay, turbulent mixing of the water matrix, due to wind and waves, caused relatively homogenous distribution of phycocyanin readings. Temperature, pH and chl-a concentrations also follow similar trends. However, on July 20th wind speed was low and never exceeded 9 km/h (Figure 2).

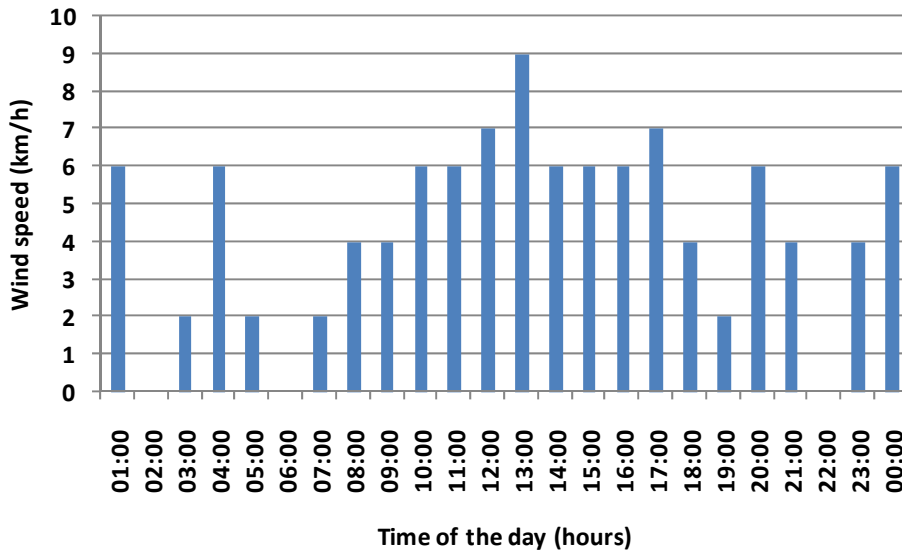


Figure 3: Mean hourly wind speed on July 20th 2010 at the weather station of Frelighsburg. Data from the Climate Weather Office of Environment Canada.

This unusual profile can be explained by considering wind and precipitation of the three previous days (Table 1). Strong winds on July 17th and 18th have mixed the water. Mixing of the water was also facilitated by the near uniform temperature from top to bottom (Figure 1) and the shallowness of the bay. In addition, abundant rain on July 19th swelled the tributary rivers. The important water inflows may have created strong currents that also contributed to mixing in the bay.

Table 1: Total rain and speed of maximum guts, from July 17th to 20th 2010 at the weather station of Frelighsburg. Data from the Climate Weather office of Environment Canada.

Parameters	Date			
	07-17-10	07-18-10	07-19-10	07-20-10
Rain (mm)	1.6	0.2	12.6	0
Speed of maximum guts (km/h)	43	32	< 31	< 31

High concentrations of cyanobacteria (between 1×10^4 and 1×10^5 cell/mL; figure 1) and homogenous density profiles increased the risk that toxic cyanobacteria entered the DWTP through the water intake situated at the bottom of the bay, thereby creating a more difficult situation for operators of the DWTP to ensure that less than $1 \mu\text{g/L}$ of microcystin is present in water, according to the World Health Organization guidelines and standards for cyanotoxins in treated drinking water.

CONCLUSION

Preliminary results from this study demonstrated that real-time monitoring system was useful to better understand the spatial distribution of cyanobacteria and to detect high risk situations. Thus, real-time, autonomous monitoring program can provide reliable information for DWTP operators and help them anticipating cyanobacteria bloom and adjusting their treatment. Such a system can also assist lake managers in decision making.

Globally, most countries have experienced or routinely experience cyanobacterial presence in surface waters (CODD et al., 2005). The availability of information is, however, highly variable. In North America, some parts of Europe, Australia, New Zealand and highly developed parts of Asia the access to scientific and management information and reports is relatively easy. It is more complicated in much of Africa and for parts of Latin America and Asia. Awareness of the threats posed by eutrophication, and its consequences for health and water supply, is limited or non-existent in many developing countries (CODD et al., 2005). The presence of cyanotoxins is not commonly reported in all countries. The non-reporting of cyanotoxins, may be due to the non-availability of the necessary facilities and skills (CODD et al., 2005).

Long-term monitoring programs with sophisticated tools are relatively costly. Therefore they are mostly used in developed countries and are generally not accessible to developing countries. However, both in developed and developing countries, the availability of monitoring and analytical facilities, appropriately trained personnel and facilities capable of undertaking reliable cyanobacterial identification and enumeration, are severely under-resourced (CODD et al., 2005).

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