Observations on the management of cyanobacterial blooms in Canada
The NSW Office of Water is a separate office within the Department of Environment, Climate Change and Water. The Office manages the policy and regulatory frameworks for the State’s surface water and groundwater resources to provide a secure and sustainable water supply for all users. The Office also supports water utilities in the provision of water and sewerage services throughout New South Wales.

Observations on the management of cyanobacterial blooms in Canada
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Cover pictures: centre, Québec Province; centre bottom, Québec harbour; bottom right, Nova Scotia with Bay of Fundy in the distance

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1. Introduction

The Australian Academy of Science has a program of international scientific and technological collaborations aimed to improve Australian access to science and technology and to increase awareness of Australian research. In 2008 an international travel grant was sought and awarded to Dr Lee Bowling, Principal Limnologist with the New South Wales (NSW) Office of Water (at the time, the Department of Water and Energy), through the Academy’s Scientific Visits to North America program with funding from the Commonwealth Department of Innovation, Industry, Science and Research. The aim of the travel research grant to Canada was to enhance cyanobacterial bloom research and response management through the sharing of both Australian and Canadian experiences in these fields and to study cyanobacterial blooms, the presence of cyanotoxins and underlying environmental factors influencing bloom and toxin production in Missisquoi Bay.

The grant also enabled Dr Bowling to study new developments in research and management of cyanobacterial blooms in Québec, Canada. The visit was hosted by the Québec Government’s Ministère du Développement durable, de l’Environnement et des Parcs (MDDEP). The study period of five weeks between August and October 2009 corresponded with the height of the cyanobacterial season in Canada. The majority of this time was spent at the MDDEP head office in Québec City, with a short self funded trip to Nova Scotia to liaise with colleagues working there within limnology and algal management before returning to Australia.

Cyanobacterial blooms pose major environmental, economic and public health risks each year in both NSW and in Québec. In recent years blooms and cyanotoxins have become major water quality management issues in Québec.

Scientific and management staff from the MDDEP first contacted NSW for information on cyanobacterial bloom management in early 2002. Information exchange between the two jurisdictions has continued on a regular basis since that time. The Québec Government undertakes an active program to manage blooms that occur in that province and to support research into the causes and mitigation of such blooms. Québec’s first plan to manage cyanobacterial bloom episodes was prepared for 2004, with subsequent annual improvements, including programs to reduce the problem. Cyanobacterial bloom management practices and skills in Québec have developed to the point where they are now very professional and employ the latest scientific knowledge and technology.

The visit to Québec had several components. These involved formal presentations and discussions with colleagues in Québec involved in the research into, and management of, cyanobacterial blooms in that province. The principal project, involving much of the time spent in Québec, was to study cyanobacterial blooms, the presence of cyanotoxins and underlying environmental factors influencing bloom and toxin production in Missisquoi Bay. Participation in this project was to provide first hand experiences of algal monitoring and management protocols and procedures as practiced in Québec, for direct comparison with those used in NSW.

Finally, although it was not part of the project supported by funding through the Australian Academy of Science, the visit to Québec also made it possible to visit other researchers and managers of cyanobacteria elsewhere in Canada, most notably in the province of Nova Scotia.

The purpose of this report is to summarise the visits to both Québec and Nova Scotia, outline the work undertaken and progress to date, the presentations provided by the author and the contacts made. It also summarises potential future collaborations that will enhance cyanobacterial bloom management in NSW. A separate scientific report on the studies of Missisquoi Bay will be completed within the next 12 months.
2. Project work undertaken in Québec

Missisquoi Bay forms the very northern end of Lake Champlain, and is divided in two by the international frontier between Canada and the United States of America (USA). The northern half of the bay is monitored and managed by the Canadian province of Québec, while the southern half of the bay is monitored and managed by the American state of Vermont. A focus of the study of Missisquoi Bay was to combine cyanobacterial and environmental data from both the Canadian and American halves in a “whole of bay” assessment of factors influencing cyanobacterial blooms in the bay each summer, to provide a more detailed picture of these for adoption into future management plans for the bay. A combined study of the entire Missisquoi Bay has never been undertaken before. The visit therefore also included discussions with researchers and others managing bloom responses in Vermont, and an opportunity to also become familiar with their monitoring and management protocols.

The visit to Quebec was from the 31 August to the 2 October 2009. The project work was undertaken mostly at the head office of the MDDEP in Québec City, who provided office space, access to their computer network, access to their data base to obtain cyanobacterial data for the case study, and other facilities. It also facilitated close communication with MDDEP staff involved in cyanobacterial bloom response management, including at this office, at their laboratory in Québec City, and at regional offices in the south of Québec province (Montérégie Region). A visit to Montérégie to meet with regional staff was undertaken on the 3 and 4 of September and a visit to the MDDEP laboratory was undertaken on the 23 September. This enabled access to first hand knowledge of cyanobacterial bloom management practices in Québec.

An important component of the work during the visit to Québec was the commencement of a collaborative study on the causes and occurrence of cyanobacterial blooms and their toxicity in Missisquoi Bay, Lake Champlain. This work, involving the collaboration of scientific and cyanobacterial bloom management staff from MDDEP in Quebec, Canada; the University of Vermont in Vermont, USA and The Office is ongoing. The work undertaken for this project whilst in Québec included:

- A field trip to Missisquoi Bay at the northern end of Lake Champlain to familiarise with the study location, sampling sites, sampling methods and to observe a cyanobacterial bloom that was present in the bay at that time. This field trip was undertaken on 4 September.
- A visit to the University of Vermont, Burlington, Vermont, to discuss collaboration with, and data provision by, staff at the university who undertake monitoring of cyanobacterial presence in the southern (American) half of Missisquoi Bay. This visit was made on 5 September.
- A review of the data collected for the northern (Québec) half of Missisquoi was undertaken at the Québec City offices of MDDEP over the following four weeks (8 September to 2 October). The MDDEP cyanobacterial data base was searched for data relevant to the project. The MDDEP have collected extensive data for four sites on Missisquoi Bay since 1990, but much of the cyanobacterial species abundance and biomass data was stored in MS Excel® files on an annual basis. These data then had to be compiled into new files spanning the entire study period (2000 to 2008).
- Other data, including total cyanobacterial cell count to species level, biomass and toxin analysis; other phytoplankton presence to genus level and some water quality and environmental data were available for the entire nine years in a single MS Excel file. It was however necessary to become familiar with this data file and decide which data were of most value for analysis and reporting as part of this project.
• Analysis of the data below and the initial drafting of the project report was commenced, with the following sections completed whilst in Québec:
  o An analysis of the annual variation in cyanobacterial presence at the four sites sampled by MDDEP on Missisquoi Bay. This includes reporting year to year differences in cyanobacterial community composition and the percentage of the total cyanobacterial presence contributed by potentially toxic species. Both cell count data and biomass data have been used for this analysis.
  o An examination of the contribution by cyanobacteria to the total phytoplankton biomass, and whether there was any evidence of a seasonal successional pattern within the phytoplankton communities of Missisquoi Bay.
  o An examination of the toxin data, looking at variation in toxin concentrations and type (microcystin LR, RR and YR and anatoxin-a) since 2000.
  o Initial exploratory analysis of relationships between various measures of cyanobacterial presence (both total cyanobacteria and at a species by species level) with toxin measurements and water quality and environmental data.
  o Collation of some of the MDDEP data into a format amenable for further statistical analysis, including some multi-variate analysis.
  o A preliminary examination of the summary data for the southern (American) portion of Missisquoi Bay provided by the University of Vermont.

The MDDEP's cyanobacterial and water quality data base for Missisquoi Bay is considerable, meaning that completion of the project within the five weeks allocated was unlikely, especially given the requirement for some data collation and manipulation prior to use in the analyses. There were still considerable amounts of data from both Québec and Vermont to be analysed and reported following the completion of the visit.

The main problem encountered was obtaining adequate data for the Vermont portion of Missiquoi Bay. The University of Vermont initially supplied only a summary data set that listed only three species of potentially toxic cyanobacteria found at their sampling sites. It was only late during the final (fifth week) of the visit that the University supplied some more detailed data sets, and consequently there was insufficient time to examine these data closely and incorporate them into the case study analysis and reporting.

There is still a requirement to complete the case study and publish the outcomes. The analysis of the Québec data is almost complete, although some more detailed statistical analysis of the data using multivariate statistical methods is still required. The data from Vermont have been analysed since Dr Bowling’s return to Australia, but differences in the way data are reported in Vermont compared to Québec, and in the taxonomy of the cyanobacterial species reported continue to make it difficult for the two data bases to be combined. Correspondence is still in progress to try and resolve these differences otherwise the two data sets will need to be reported separately within the final report. The study will be written up and completed during 2011. This is seen as a necessary conclusion for the study, and an essential outcome arising from the award of the travel grant by the Australian Academy of Science.
3. Presentations made to institutions and universities during the visit

The following is a timeline and summary of presentations made to institutions during the study grant period.

3.1. Based at host institution, Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP), Québec, Canada
31 August to 2 October 2009

- 1 September 2009
  Formal day-long workshop "Les cyanobactéries. Rencontre d'échanges d'informations Québec - Australie - France", Université Laval, Québec City hosted by Mme Sylvie Blais, MDDEP. Presentations were made by several staff from MDDEP, the Québec Ministry for Public Health and from the École Polytechnique de Montréal during the morning, and by Dr Lee Bowling (Australia) and by Dr Luc Brient (Université de Rennes, France) during the afternoon. Further details of this workshop are provided later in this report. A summary report of this workshop that was placed on the MDDEP website http://www.mddep.gouv.qc.ca/eau/algues-bv/bulletin/quebec-australie-france.pdf (in French) is attached in Appendix A.

  Presentations made by Dr Bowling included:
  1. Cyanobacterial blooms in NSW - Causes, monitoring and management
  2. A recent case study - a bloom of over 1,000 kilometres in the Murray River during April 2009
  3. Studies of fluorometry and biovolume in NSW.

- 2 September 2009
  Formal meeting at the MDDEP offices in Québec City of staff and managers from MDDEP and the Québec Ministry of Public Health who are involved in the management of toxic cyanobacterial blooms in Québec, Dr Lee Bowling (Australia) and Dr Luc Brient (France). This was a three hour question and answer session where Dr Bowling and Dr Brient were presented with a series of questions from Québec staff regarding cyanobacterial bloom management in Australia and France respectively, and in turn were given more details of bloom management as practised in Québec.

- 2 September and 3 September 2009
  Visit to the MDDEP Regional Office for the Montérégie Region in Bromont, and (along with Mme Sylvie Blais and Mme Sonia Néron of MDDEP and Dr Brient from France) meet with staff there who undertake cyanobacterial monitoring in this part of Québec province. Visit Granby to inspect a cyanobacterial bloom in Lemieux Reservoir (evening of 2 September), and Missisquoi Bay to undertake sampling of a cyanobacterial bloom there (3 September). Missisquoi Bay is the water body for the case study for this project.

- 4 September 2009
  Visit to the University of Vermont, Burlington, Vermont, USA, hosted by Professor Mary Watzin, Rubenstein School of Environment and Natural Resources, University of Vermont. The visit included discussion on the input of data from the Vermont to the case study project on Missisquoi Bay. A presentation was made by Dr Bowling titled; The Murray River cyanobacterial bloom autumn 2009 - Monitoring results and implications.
• 17 September 2009
  Seminar presented at MDDEP titled:
  *Cyanobacterial blooms in NSW and a recent case study - the bloom in the Murray River, April 2009*

• 23 September 2009
  Visit the laboratories of the MDDEP in Québec City (Centre d'expertise en analyse environnementale du Québec) hosted by M. Christian Bastien and M. Christian Deblois. The operations of the laboratory in terms of cyanobacterial identification and enumeration, and the analysis of cyanotoxins were discussed. The measurement and use of biovolume as a tool for the management of cyanobacterial as practiced in NSW was also discussed, as was the use of in-situ fluorometry. This laboratory has been trialing two makes of fluorometers, including one model (YSI) trialed in NSW.

• 25 September 2009
  Visit to Environment Canada (Centre Saint-Laurent), 105 rue McGill, Montréal, Québec, hosted by Dr Christiane Hudon. Discussion of cyanobacteria in the St Lawrence River, and other invasive species (lamperies, zebra mussels, etc.) causing water quality and environmental problems in waterways in eastern Canada. The visit included meetings with staff and postgraduate students from the University of Québec in Montreal and from the École Polytechnique de Montréal. The Letter of Invitation from Environment Canada is attached in Appendix B. Dr Bowling made the presentation titled:
  *Cyanobacterial blooms in NSW and a recent case study - the bloom in the Murray River, April 2009*

3.2. Based at Nova Scotia
5 October to 10 October 2009

• 5 October 2009
  Visit to Nova Scotia Environment, 5151 Terminal Road, Halifax, Nova Scotia, Canada, hosted by Ms Judy A. MacDonald, Supervisor, Drinking Water Management, Environment and Natural Areas Management Division. The three hour visit involved a presentation and subsequent discussion on cyanobacterial management applications used in Australia and those that may be useful and applicable to Nova Scotia. Dr Bowling made the presentation titled:
  *Cyanobacterial blooms in NSW and a recent case study - the bloom in the Murray River, April 2009*

• 7 October 2009
  Visit to Jellett Rapid Testing Ltd, 4654 Route #3, Chester Basin, Nova Scotia, Canada, hosted by Dr Maurice Laycock, Chief Research Scientist. This visit (2 hours) was made because the Office had purchased some rapid test strips from this company to test for saxitoxins produced by cyanobacterial blooms in NSW during the 2009-2010 summer. Dr Laycock described and demonstrated the use of the test strips, and discussed some of the problems involved in their use. Dr Bowling in turn described the extent of toxic cyanobacterial blooms in NSW and issues involving their management, and presented some data collected during the bloom in the Murray River in April 2009. Dr Laycock presented Dr Bowling with 50 free samples of their rapid test strips to trial toxin extraction and hydrolysis techniques upon his return to Australia.
• 8 October 2009
   Visit to Acadia University, Wolfville, Nova Scotia for discussions (1 hour) with Dr Michael Brylinsky at the Acadia Centre for Estuarine Research regarding cyanobacterial bloom problems in lakes in the provinces of Nova Scotia and New Brunswick that Dr Brylinsky is currently investigating. Dr Bowling agreed to provide further advice and review of manuscripts reporting Dr Brylinski's work at a later date.

• 9 October 2009
   Visit to the Biology Department, Acadia University, Wolfville, Nova Scotia, hosted by Associate Professor Anna Redden (2 hours). Dr Bowling made a presentation to students and staff from the department, as well as two visitors from Nova Scotia Environment and four visitors from local environmental groups. There was subsequent discussion with Associate Professor Redden and the visitors regarding potential for further visits to Nova Scotia by Dr Bowling to undertake research and provide further management advice. The notice of this presentation produced by Acadia University is attached in Appendix C. Dr Bowling made the presentation titled Cyanobacterial blooms in NSW - Causes, monitoring and management.
4. Establishment of contacts with cyanobacterial bloom managers and other scientists in Canada

Dr Bowling and his immediate host at the MDDEP in Québec, Mme Sylvie Blais perform similar roles in undertaking cyanobacterial bloom response management in their respective jurisdictions. Dr Bowling has maintained correspondence with Mme Blais on cyanobacterial bloom management issues since 2002, when Mme Blais sought bloom management advice from New South Wales. Mme Blais is an extremely important contact with whom to discuss respective management roles, and the similarities and differences in management as practiced in NSW and Québec.

Other valuable contacts established by Dr Bowling during the visit include:

1. **M. Marc Sinotte** who has worked in the MDDEP in Québec for almost 20 years. M. Sinotte has completed studies for a Ph.D in December 2010 and has expertise in cyanobacterial toxicity, the measurement of cyanobacterial toxins, and the use of toxicity data in cyanobacterial bloom management. He has been testing the use of rapid field tests for the cyanobacterial hepatotoxin microcystin, the findings of which have direct application to NSW because of planned similar use of field test strips in coming summers.

2. **Dr Maurice Laycock** of Jellett Rapid Testing Ltd in Nova Scotia. This company manufactures some of the rapid field test strips for cyanotoxins that are planned for use in NSW during summer. As a result of the visit to Jellett Rapid Testing Ltd, Dr Laycock provided 50 additional saxitoxin test strips for free for use by the Office in developing methods of cell lysis and toxin testing in species of cyanobacteria responsible for the production of this cyanotoxin in NSW’ freshwaters.

3. **M. Christian Bastien** who manages the MDDEP algal laboratory. As well as comparing methods of algal sample analysis as undertaken in our respective laboratories in Québec and NSW, M. Bastien has also been researching the use of various fluorometric equipment (both Yellow Springs Instruments (YSI) and TriOS equipment) to measure cyanobacterial presence in-situ. This work is very similar to that which has been undertaken by the Office during the 2008-2009 Australian summer, testing the applicability of YSI fluorometry equipment on the Murray River. M. Bastien also has an interest in the application of biovolumes as a tool for cyanobacterial bloom management.

4. **M. Christian Deblois** who manages the analysis of cyanobacterial toxins at the MDDEP laboratory. M. Deblois provided valuable information on how this laboratory analyses for cyanotoxins, especially using LC-MS-MS. NSW currently has only limited capacity to measure cyanobacterial toxins, although this is set to expand shortly. The information from Québec will be helpful in establishing the Office toxin analysis program.

5. **M. Arash Zamyadi** is a Ph.D student currently enrolled at École Polytechnique de Montréal. M. Zamyadi has undertaken part of his Ph.D research at the Australian Water Quality Centre (AWQC) in Adelaide, South Australia, which has included the evaluation of fluorometry using YSI equipment to measure cyanobacterial presence in-situ. M. Zamyadi is undertaking further studies at AWQC during 2010, and visited the Office, along with his supervisor Professor Michèle Prévost on 19 March 2010 to discuss further collaboration on topics of similar interest.

6. **Dr Christiane Hudon** of the St. Lawrence Centre, Environment Canada, Montreal. Environment Canada is a federal Canadian government agency, and the St. Lawrence Centre studies biological and water quality issues, including cyanobacteria, macrophytes, invertebrates and fish in the St. Lawrence River and other waterways forming the international boundary between Canada and the United States. Dr Hudon provides a contact for exchange of information with this agency on these issues.
7. **Professor Mary Watzin** from the University of Vermont (USA). The site of the case study for this project, Missisquoi Bay, is divided in half by the international boundary between Canada and the United States. One aim of the case study is to combine data collected in both the Canadian and American portions of the bay since 1990 and use these data to provide an overall description of the processes driving cyanobacterial blooms there. This has not been done previously. Professor Watzin oversees the collection and reporting of the data collected from the American (Vermont) portion of the bay. Completion of the joint Quebec - Vermont - Australian report on cyanobacterial blooms in Missisquoi Bay will involve ongoing collaboration with Professor Watzin.

8. **Ms Judy MacDonald** of Nova Scotia Environment, Halifax Nova Scotia. Ms MacDonald oversees cyanobacterial bloom response management in Nova Scotia, and is the main contact in that province for the exchange of information.

9. **Dr Michael Brylinsky** of Acadia University, Wolfville, Nova Scotia. Dr Brylinsky is undertaking the analysis of data from lakes in Nova Scotia and New Brunswick where cyanobacterial blooms occur. Exchange of ideas and information on blooms in Nova Scotia and New South Wales will continue between Dr Brylinsky and Dr Bowling.

10. **Associate Professor Anna Redden** at Acadia University, Nova Scotia. Dr Redden worked previously at the University of Newcastle in Australia, and this trip allowed the opportunity to reestablish contact with and discuss possible means for further collaboration. Dr Redden has a broad range of research interests of relevance to New South Wales, including cyanobacterial blooms in lakes (having previously published on phytoplankton in the Myall Lakes), and in estuarine and coastal research.

11. **Dr Luc Brient** of the Universite de Rennes, France. Dr Brient has published on the use of in-situ fluorometry for assessing cyanobacterial bloom presence in France.
5. Details of the “Québec – Australie – France” workshop held on 1 September

This workshop was held at the Université Laval, Québec City, on 1 September 2009 and involved presentations by speakers from Québec, Australia (New South Wales) and France. Most of the presentations were made in French, apart from those for Australia, which were in English. However all speakers, both francophone and anglophone, provided duplicate sets of PowerPoint overhead slides, with one set in French and the other in English. Translations of the New South Wales overheads from English to French were made by the presenter.

The following is a summary of the presentations made:

1. **Québec’s general management plan for blue-green algal blooms**
   
   This seminar, presented by Mme Sylvie Blais (MDDEP, Québec), discussed a decision support flow chart and how it was applied to cyanobacterial bloom management in Québec. It detailed what field observations and sampling strategies were to be used for monitoring cyanobacteria, and what actions were to be taken in the event that the monitoring detected nil or low levels of cyanobacteria, or if it detected a bloom. Bloom management is also based on the sampling results (including total cyanobacteria cell counts, total potential toxic cyanobacterial presence and toxin presence) and the risk of exposure to the population, including for small private drinking water supplies and for recreation. Possible actions in the event of a bloom in a high risk area were discussed, including continued surveillance and the issue of a public health advisory, as well as follow-up actions such as end of season reporting.

2. **Public organized beach management**
   
   This paper, presented by M. Jean-François Duchesne (Department of Public Health, Québec), discussed the management of cyanobacterial blooms at public beaches on freshwater lakes in Québec and a decision support flow chart for this purpose. Beaches with public access and a lifeguard are termed “organized beaches”. Beach owners or managers are requested to inspect their beach daily to determine if a bloom is present or not, and to complete a register. If there is a bloom, the owner or manager are asked to evaluate the bloom in terms of a visual category and to advise the MDDEP and public health officers. Beaches affected by dense cyanobacteria blooms or scums should be closed and warning signs erected. Depending on the situation, MDDEP and public health officers can ask the beach owner or manager to sample major blooms or scums, including sampling after the blooms have gone to determine if there are still cyanotoxins remaining above the alert level. Support is provided by regional MDDEP and public health officers. The protocols for the lifting of warnings were also described.

3. **Intervention criteria for blue-green algae and cyanotoxins**
   
   This seminar, presented by M. Jean-François Duchesne (Department of Public Health, Québec), discussed alert level thresholds used in Québec that are recommended by a provincial government agency called the Institut national de la Santé publique du Québec (INSPQ). They propose drinking water criteria for microcystins based on microcystin-LR and the use of Toxic Equivalency Factors (TEFs) to compute equivalent toxicity for other microcystin variants. TEFs are available for variants such as microcystin-LA, YR, YM and RR, with others proposed for other variants. INSPQ also recommend criteria for anatoxin-a presence. They also recommend recreational water quality criteria based on total cyanobacterial cell counts and concentrations of microcystins and anatoxin-a, with greater emphasis on cyanotoxin concentrations than on cell counts. The criteria used in the Québec Cyanobacterial Management Plan were also described, for both recreational use and raw water sourced for potable supply. These include both cell count and toxin concentration thresholds, with different values for decision making and for the protection of public health.
4. **Validation study of microcystins screening strips**

This seminar, presented by M. Marc Sinotte (MDDEP, Québec), discussed the performance of two commercially available brands of test strips (Abraxis and Agdia) used as screening tools compared against laboratory measurements of microcystin during 2008. Use of both test strips included a cell lysis step, to give total (both intercellular and extracellular) toxicity. Toxicity screening is seen as potentially useful as many laboratory test results are below the level of detection, or below health alert levels for sources of drinking water and for recreation. Screening methods are much less expensive than laboratory analysis. The sensitivity and specificity of the kits was examined. Both strips showed high sensitivity and specificity, although one more so than the other. Tests of another test strip for drinking water (with a lower Level of Detection) were 100 per cent for both measures, although sample numbers were small. Further evaluation is continuing in 2009, including an examination of regional variations in results obtained, and to define operating procedures.

5. **Validation of a phycocyanin probe for cyanobacteria monitoring**

This seminar, by M. Christian Bastien (MDDEP, Québec), presented a lot of data on the laboratory testing of both Yellow Springs Instruments (YSI) and TriOS equipment for measuring phycocyanin (and thus cyanobacterial presence) *in-situ*. The study examined the minimum detection limits, linearity, fidelity and repeatability of measurements made with these instruments against a range of water sources, including natural lake and river water, cultures of *Microcystis aeruginosa*, and dechlorinated municipal water. The authors found good linearity in measurements made by both instruments regardless of whether it was used with the manufacturer’s calibration, or when calibrated against cell densities (a number of calibrations made at different cell densities were tested) (YSI) or phycocyanin concentrations (TriOS). However the fidelity of the readings given was poor when compared against actual cell densities measured over most calibrations. Comparisons of two YSI instruments gave similar results. Measurements on replicate samples indicate that the instruments provide good repeatability. Interference by chlorophyte algae was low, but interference from extracellular phycocyanin was high. Variations in data as cells mL$^{-1}$ provided by the YSI were often one order of magnitude less than the cell count determined by microscopy. Variations in biomass determined by microscopy generally followed the variation in cell count data provided by the YSI instrument when the two were compared using field samples, although an estimate of how closely (i.e. a correlation coefficient) was not provided.

6. **Validation and application of online fluoroprobes for the detection of cyanobacteria in source waters**

This paper, presented by M. Arash Zamyadi and Ms. Natasha McQuaid (École Polytechnique de Montréal, Québec), focussed on a study of tools or procedures for the on-line detection of cyanobacteria in drinking water treatment plant raw source water intakes using a YSI phycocyanin, chlorophyll-a and turbidity multiprobe system. Part of the work was undertaken at the Australian Water Quality Centre in Adelaide (Australia), and part in Québec. The phycocyanin probes were calibrated against *Microcystis aeruginosa* cell densities. This caused bias in the YSI measurements when species other than *M. aeruginosa* were present. Bias was also caused by the presence of chlorophyte algae when utilizing results from the chlorophyll-a probe. The authors found little interference due to mineral turbidity except at low counts. Field studies in Missisquoi Bay, Québec found different alert levels could be applied to the water body dependant on which data collected by the instrument were used for management applications. In vivo phycocyanin fluorescence usually correlated with other measures of cyanobacterial presence, although poorest correlation was found with cell count data, and best correlation with total phytoplankton chlorophyll-a. The authors consider that cyanobacterial biovolume (rather than cell counts) is the most appropriate means of validating in vivo phycocyanin fluorescence as it was a standardised measurement compared to cell density.
7. **Cyanobacterial blooms in NSW – Causes, monitoring and management**

This presentation, by Dr Lee Bowling (Office of Water, NSW, Australia), provided an overview of cyanobacterial bloom occurrence and management in NSW, Australia. It discussed the causes, geographic and temporal variation of cyanobacterial blooms in NSW, and in particular geographic factors such as topography and climate that determine the distribution of surface freshwaters in the state, nutrient enrichment and flow regulation, and hence bloom occurrence. The most common toxic taxa were described and current monitoring, laboratory analysis and the assessment of data against national guidelines were discussed. The various management options potentially available in NSW to mitigate bloom occurrence and severity were described.

8. **The Murray River cyanobacterial bloom autumn 2009 – monitoring results and implications**

This presentation, also by Dr Bowling, discussed the extensive cyanobacterial bloom that occurred over 1100 km of the Murray River in NSW between March and May 2009. The presentation formed the basis of a case study to illustrate cyanobacterial bloom response management in action within NSW. The development and decline of the bloom was described, as was the monitoring, including the aerial surveillance and toxicity testing. Environmental conditions, temporal and spatial changes in cyanobacterial community composition and management undertaken by the Murray Regional Algal Coordinating Committee were also described.

9. **Preliminary results of investigations into in-situ fluorometry and biovolume as management tools**

A further presentation by Dr Bowling described investigations into the use of a YSI fluorometer for the rapid in-situ assessment of cyanobacterial presence for management purposes undertaken along the Murray River between November 2008 and May 2009. Mean phycocyanin concentrations (as Relative Fluorescence Units) calculated per sampling site and visit were compared with total cyanobacterial biovolume calculated from samples collected at the same time. Initial results indicate a skewed data distribution, some interference from suspended particulate material, and poor correlation at low concentrations. However there was a general trend of increasing phycocyanin fluorescence with increasing total cyanobacterial biovolume. The temporal and spatial variation of cell size within certain common cyanobacterial species noted during the study, and the implications of this for using biovolume as a management tool were also discussed.

10. **Issues with cyanobacterial management in France**

Dr Luc Brient (Université de Rennes, France) described the management guidelines currently recommended for use for drinking water, recreational management and fish consumption in France. A range of different toxins have been identified in both blooms and in benthic cyanobacteria, including cylindrospermopsin, anatoxins and saxitoxins. There are sanitary and other management problems associated with some artificially created swimming areas, including from cyanobacteria, as there is little monitoring or regulation of these waters. Dr Brient described research into the possible cyanobacteria neurotoxin BMAA, its possible neurological degenerative effects on humans, its possible impacts on fish and other wildlife, and the need for further research on it. Other topics briefly discussed included the use of in-situ fluorometry to detect benthic cyanobacterial presence and the use of rapid test strips for detecting microcystins.

Copies of the English versions of the PowerPoint presentations are available from the author of this report. A brief summary of the workshop, published on the MDDEP Web site (in French) is attached (Appendix A).
6. Cyanobacterial bloom response management in Canada

A critical review of cyanobacterial bloom response management as practiced in Québec (or elsewhere in Canada) was not an objective of this project. The project however, did provide opportunities for comparisons and shared learnings. Cyanobacterial bloom response management in Québec is tailored to the specific environmental conditions and management requirements of that particular province of Canada, just as cyanobacterial bloom response management in NSW is tailored to the environment and management requirements of this state.

The government and the public of Québec maintain an active interest in cyanobacterial bloom management for the safety of the public while maintaining an equilibrium with economic activities (especially recreational use and tourism), and hence there is considerable support at all levels for their management programs. Being a government agency the focus of the MDDEP is on cyanobacterial bloom management rather than research, but the Ministry actively promotes research done by universities and other organisations located in Québec province. The MDDEP management practices and the science and technology to support this has developed to a high level of professionalism and scientific involvement.

The following discusses cyanobacterial bloom response management as practiced in Québec from observations made during this visit, with limited additional comments on management in Nova Scotia.

6.1. Monitoring in Québec

Unlike NSW, there is no routine year-round monitoring of water bodies for cyanobacterial blooms in Québec, as most surface freshwater bodies are ice-covered during the winter months. Moreover, the monitoring strategies to study bloom development are usually different from that undertaken for the general management plan for human health protection. In the latter case, monitoring usually commences only after a bloom has been reported by a member of the public or the manager of a water body.

6.1.1. Monitoring for studies of bloom development

The monitoring commences after the spring thaw as the water warms but before blooms first appear. This provides a control for later in the summer. After a bloom appears, monitoring commences on a regular basis and may continue to late autumn. For the study of Missisquoi Bay, for example, the earliest that samples have been collected in any year was late May or June (late spring), and the latest samples have been collected was early November (late autumn).

6.1.2. Monitoring for the general management plan

Except perhaps for those water bodies that have a recurring history of major blooms each year, most water bodies are not routinely sampled. Usually, sampling does not commence until the MDDEP regional office obtains advice from the public or a water body manager about the appearance of potential cyanobacteria bloom in a specific water body. For recreational waters, the regional offices of MDDEP try to obtain voluntary partnerships with citizens living near the water body, waterfront associations or watershed organisations. In this way, it is easier for the MDDEP to know when sampling is required.

Water treatment plant and beach managers are required to maintain a log of their visual observations. There is a flow chart for bloom response management at water treatment plants and another for management at “organised beaches”. These decision support schemes indicate what to do and when (e.g. observation, sampling, communication, etc.).
The investigation of reported blooms and sampling if necessary is undertaken by regionally based staff of MDDEP. Sampling of a water body is triggered after increasing densities of phytoplankton have been detected visually, and may continue until the bloom declines to low cell densities. The duration of the sampling period, the frequency of sampling, and the number of samples collected differs between water bodies and years. These depend on factors such as the date the bloom begins and ends; if the density of toxic cyanobacteria is low; or if it is an important water body with a high density of users, and available budget. Some blooms are sampled into late autumn. For example, for sites on Missisquoi Bay examined as part of the case study for this project, there were considerably more samples collected during years when there were extensive blooms compared to years with reduced cyanobacterial presence. Blooms and scums are often monitored separately, and the location of sampling sites is often based on the distribution of the bloom within the water body, the location of the scums, and the locations of points of public access such as beaches or off takes for potable water supply.

For Missisquoi Bay, there were four sites which were sampled on most sampling occasions, plus a number of other sites sampled on an ad-hoc basis (sometimes only one or twice during the entire nine years of data collection from 2000 to 2008) depending on bloom conditions. The location of the two control sites sampled prior to bloom commencement is always the same each year. The main objective of the Missisquoi Bay data collection is to evaluate the importance of cyanobacterial bloom densities and cyanotoxin concentrations at the more critical locations in the bay and to compare these with the alert levels for the protection of human health. Another objective is to evaluate the relationships between cyanobacteria or cyanotoxins with other water quality attributes. The same samples have to be used to inform both objectives.

The collection of algal and water quality samples was observed during the field trip to Missisquoi Bay on September 3. Methods employed are basically similar to those used in NSW. Integrated water column samples are collected from the surface to one metre depth at pelagic sampling locations using a PVC pipe sampler of this length. Integrated samples from the surface to the euphotic depth, calculated as 2.7 times the Secchi disc depth may also be collected, but Missisquoi Bay is shallow and most of the time euphotic depth is the same or greater than that water column depth. In these circumstances, the sample is taken from between the surface and a minimal distance above the sediment (for example 30 to 50 cm) to ensure that the water sample is not contaminated with sediment. Surface scum samples may also be collected during blooms.

Field measurements of water temperature, dissolved oxygen, pH, electrical conductivity and Secchi disc are also made using appropriate equipment, and water samples collected for nutrient, chlorophyll, turbidity, and for cyanobacterial (and eukaryotic algae) identification and counting and cyanotoxin analysis at the laboratory.

6.2. Laboratory analysis in Québec

Algal samples are analysed at the MDDEP laboratory, called Centre d’expertise en analyse environnementale du Québec (CEAEQ). This is a large modern facility located in Québec City, and was visited on 23 September. This laboratory analyses all samples collected by:

- MDDEP regional office staff from water bodies throughout the province;
- Municipalities at their water treatment plants; and
- Beaches by the managers of that beach.

The algal laboratory is equipped with three modern Nikon Eclipse inverted microscopes, with algal sample analyses being done following the sedimentation of a subsample in Utermöhl counting chambers. One of the microscopes is also fitted with software that enables a photograph to be taken of each micron through the focal plane, and the photographed cells are then reconstructed as a three
dimensional image on a desktop computer. This is used for aiding the identification of unknown species and for doing cell size measurements for biovolume calculations.

The algal laboratory at CEAEQ has four staff. It offers two levels of analysis – a screening analysis and a complete analysis. The screening analysis is limited to only the dominant four or five genera in each sample. The results for those genera are limited at class densities (not precise density). The complete analysis provides identification and counting of all cyanobacteria to species level of taxonomy, and of all other phytoplankton to genus level, to at least ± 20% precision. They analyse more than 1000 algal samples per year, the majority being for cyanobacterial screening and approximately 100 with analysis. Biovolume is also calculated using cell size data obtained from either direct measurements made at the laboratory, or from the literature. These are generally converted to biomass with the assumption that the phytoplankton possesses the same density as water (that is, 1 mm³ L⁻¹ is equal to 1 mg L⁻¹). Data for Missisquoi Bay were reported as cells mL⁻¹ for each taxa identified, and also as a biomass for each taxa.

The laboratory has a requirement set by the Québec government to undertake screening analysis of samples collected under the management plan for human health protection and to report these results within 48 hours of sample receipt. The laboratory places the analysis certificates on a website with access limited to cyanobacterial management staff (and their managers) at the MDDEP, at the Ministère de la Santé et des services Sociaux (MSSS) (Ministry of Health and Social Services) and at the regional offices of the “Directions de santé publique” (Management of public health). The laboratory sends an email to advise these staff whenever new analysis certificates are placed on this website.

Commonly occurring potentially toxic taxa in Québec include Anabaena flos-aquae, Anabaena spiroides, Aphanizomenon flos-aquae and Microcystis flos-aquae. However a range of other potentially toxic taxa also occur, including Microcystis aeruginosa, Coelospharium kuetzingianum and Woronichiana nargiliana. The major toxins of concern are microcystin and anatoxin-a.

The CEAEQ laboratory also has an organic chemistry laboratory that can undertake the analysis of cyanobacterial toxins. This laboratory is equipped with four liquid chromatographs with tandem mass spectrometry (LC-MS-MS) that can be used for this purpose. The laboratory can analyse seven different variants of microcystin (microcystin-LR, RR, YR, LA, LY, LW, and LF), with several of these being converted and reported as microcystin-LR equivalents. The laboratory has also commenced some exploratory analysis of saxitoxin, neosaxitoxin and cylindrospermopsin in samples where species known to produce those toxins in other countries are also present. Until now all of the results for these cyanotoxins have been less than the level of detection.

6.3. Bloom Response Management in Québec

The Québec Ministry of Health (Ministère de la Santé et des Services sociaux – MSSS) has published general recommendations (in French) on their web site that explain what to do (for both drinking water supply and recreation) when a water body is affected by cyanobacterial blooms. These general recommendations are applicable to all water bodies.

Cyanobacterial bloom response management in Québec has a tiered approach. Regional staff of the MDDEP form the front line response during bloom episodes, receiving notification of blooms, undertaking sampling, consulting with public health officials, and providing information memos to municipalities. The information memos include the analytical results of cyanobacterial and cyanotoxin sampling with interpretations, and a reminder of the MSSS general recommendations. The public health offices (Directions de la santé publique - DSP) for each region produce public health advisories when the general recommendations are insufficient for a specific water body. This would be when a bloom presents a high level of risk to recreational or drinking water users.
Province-wide management is undertaken by a head office branch of MDDEP in Québec City (Direction du suivi de l’état de l’environnement - DSÉE). This branch:

- coordinates knowledge and implements government policy on cyanobacterial management;
- chairs provincial cyanobacterial committees;
- coordinates the development of cyanobacteria management tools and the review of technical, scientific and management reports;
- provides annual cyanobacteria training courses;
- provides scientific support for regional staff;
- produces bi-annual reports on blooms in Québec;
- and produces other reference documents on cyanobacteria.

DSÉE also coordinate province-wide weekly teleconferences during the cyanobacterial bloom risk period. At the end of each season DSÉE and other departments undertake a survey to be completed by each regional office of MDDEP. The objective of this is to evaluate what went well during the previous summer (for the MDDEP, for the public, for partners, etc.), things that did not run so well, and suggestions for improvement.

During winter, DSÉE coordinates other provincial committees with the objective to improve management plans and tools and to prepare for the next bloom season. There is an overall management committee where the results of other committees are presented for discussion and authorisation. These other committees include a general flow chart committee, a beach committee, a cyanobacteria committee, a cyanotoxin committee and a partnership and visual observations committee. There is also a drinking water committee which is coordinated by another department other than DSÉE.

A decision support flow chart for the general management of cyanobacterial blooms in Québec is shown in Appendix D. Once a bloom is reported to, and thence sampled by MDDEP staff, the actions that subsequently occur depend on the results of the sampling.

If there are fewer than 20,000 cells mL\(^{-1}\) of total cyanobacteria present, or if the problem is caused by something else (eukaryotic algae, small aquatic plants), the MDDEP sends a memo to advise the municipality of the cause. The municipality thence requests someone (often a volunteer from the community) to take a partnership role and to commence or to continue visual monitoring. Other actions by the MDDEP are not necessary. Later, if a member of the public or the person responsible for monitoring (“partner”) advises the MDDEP that algal density or area had visually increased, MDDED may return for further field work. Cell counts below 20,000 cells mL\(^{-1}\) of total cyanobacteria are not considered to constitute a bloom.

A cell count of total cyanobacteria above 20,000 cells mL\(^{-1}\) is used as an indicator that there is a bloom. The following text describes the situations that apply when cyanobacterial density is higher than this criteria.

If cyanotoxin concentrations are less than the toxins guidelines (1.5 µg L\(^{-1}\) of microcystin-LR equivalents or less than 3.7 µg L\(^{-1}\) of anatoxin-a present in water used for potable supply, or less than 16 µg L\(^{-1}\) of microcystin-LR equivalents or 40 µg L\(^{-1}\) of anatoxin-a in water used for recreation), the following actions take place, depending on the situation:

- If cell counts of potentially toxic taxa are under 50,000 cells mL\(^{-1}\), the MDDEP sends a memo to advise the municipality who is advised to request a person (usually a volunteer) take a partnership role to commence or to continue visual monitoring. Other actions by the MDDEP are not necessary. Later, if a member of the public or the person responsible for monitoring
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advises the MDDEP that algal density or area has visually increased, MDDEP may return for further field work.

- If cell counts of potentially toxic taxa exceed 50,000 cells mL\(^{-1}\), a risk assessment of the area where the bloom occurs is then undertaken by local MDDEP and public health officers (DSP) to determine if the area impacted within the water body is an “Important Area”. The “Important Area” concept depends on what percentage of the area of the water body is impacted, a significant presence of scum, or what major uses are affected. (The general management decision support flow chart excludes a public potable supply or a public organized beach as a major use. These uses have their own tiered management approaches detailed in separate decision support flow charts).

  o If the area is not considered to be an “Important Area”, the MDDEP sends a memo to advise the municipality who is advised to request a person (usually a volunteer) take a partnership role to commence or to continue visual monitoring. Other actions for MDDEP are not necessary. Later, if a member of the public or the person responsible for monitoring advises the MDDEP that algal density or area had visually increased, MDDEP may return for further field work.

  o If the area is considered an “Important Area”, monitoring may be continued by the MDDEP, which will include sampling. If there are no major scums present and toxin concentrations are below the alert level, public advisories are not issued, and the public are referred to take advice from general recommendations provided by the MSSS. The MDDEP advises the municipality by a memo who is advised to request a person take a partnership role to commence or to continue visual monitoring.

- If the toxin concentrations guidelines are exceeded, or if significant amounts of scum are present, further risk assessment criteria are applied, including whether the bloom is at a location deemed to be an “Important Area” or not.

  o If not at an “Important Area”,
    - If the surface area of bloom is 1000 m\(^2\) or more or if there is a significant scum the MDDEP will put this water body under surveillance. This means that the MDDEP will continue to monitor and to collect samples. After each risk assessment (field work and analytical results becoming available), the MDDEP advises the municipality by a memo which includes advice to request a person (usually a volunteer) take a partnership role to commence or to continue visual monitoring. The MDDEP will continue to sample even if there is no increase in the bloom, as required within the decision support flow chart.
    - The MDDEP will not plan another sampling campaign if the bloom area is less than 1000 m\(^2\) or if there is no significant scum present. The MDDEP advises the municipality by a memo who is advised to request a person take a partnership role to commence or to continue visual monitoring. Other actions by the MDDEP are not necessary. Later, if a member of the public or the person responsible for monitoring (”partner”) advises the MDDEP that algal density or area has visually increased or if it is considered that the bloom has begun to encroach on an “Important Area” or to cover the entire water body, in this case MDDEP may return for further field work and keep this water body under surveillance.
If the area is considered an “Important Area”, DSP may make a public health advisory declaring that the entire or a part of a water body should be avoided for recreational uses or for private or individual drinking water supply. These advisories appear on the MDDEP Website: The MDDEP sends a memo to inform the municipality. The memo is also sent to the government operations center (COG). COG is associated with the Ministry for Public Security, and will automatically advise other ministries which should know of the DSP advisory, in case emergency actions need to be undertaken by these ministries. For example, this advice would include what actions should be done to provide drinking water to a town where there may be a non-consumption advisory. Beaches may also be closed to the public. However DSP does not generally make public health advisories for “Organized beaches”, where the responsibility lies with the beach manager. The manager should erect signs and advise the MDDEP, who then publish this on their web site.

When a water body is subject to a public health advisory, there is weekly communication on the state of the bloom between the partner responsible for the water body and the Québec government agencies. New information arising from this communication can lead to the lifting of the public health advisories and a return to conformity. Factors that can lead to the lifting of the warnings include a marked and sustained decrease in the intensity and areal extent of the bloom, the movement of the bloom away from an “Important Area”, and if additional monitoring reveals that toxin concentrations have fallen below threshold levels and the cell count of potentially toxic taxa has fallen below 50,000 cells mL⁻¹.

In addition to the decision support flow chart for general cyanobacterial management explained above, the Québec government also has two other decision support flow charts, one for drinking water (water treatment plan) and the other is for public organized beaches.

Municipalities who supply potable water must ensure the quality of water to users at all times. The municipalities must apply a decision support flow chart developed by MDDEP for sampling and monitoring water at water treatment plants. MDDEP advises the municipality by a drinking water memo which includes laboratory results and whether the sampling at the drinking water treatment plant should be continued.

Managers of “organized beaches” are required to apply a tiered approach to the management of cyanobacterial blooms at these beaches following the specific decision support flow chart for this purpose provided by MDDEP. They are asked to visually monitor their water bodies on a daily basis and keep a log of their observations. When there is a bloom they are required to inform the MDDEP and the DSP. If the bloom is concentrated enough to cause major colouration of the water or scums, the manager must close the parts of the beach which are affected, inform the beach users and also inform the regional tourist association. The MDDEP will provide a notification of the beach closure on its website. Depending on situation, the DSP and the MDDEP may ask the beach manager to undertake sampling.

All municipalities must advise residents of public health notifications for drinking water and for recreational water. However only some beaches are managed by municipalities; many are managed privately.

Québec has also developed a detailed intervention plan for managing cyanobacteria for implementation between 2007 and 2017. This action plan includes a program of research to improve knowledge for better management action; a program to reduce the export of phosphorus to water bodies; and a program to increase the awareness and to protect the health of the public.
6.4. Some comparisons – Québec and New South Wales

Cyanobacterial bloom response management in Québec differs in many ways from that undertaken in NSW. To a great extent, this is due to fundamental differences in geography, climate and culture. Québec is predominantly an inland province, with only a limited coastal area along the Gulf of St. Lawrence. It also has a humid cool temperate climate and a topography that supports a large number of freshwater lakes throughout the inland areas of the province. The season for water based recreational activities is also shorter in Québec compared to NSW. Most of the population is located in southern Québec and along the St Lawrence River valley, in closer proximity to these lakes than to the sea. As a consequence, it is the freshwater lakes and other inland freshwaters that are used extensively for recreation and other consumptive uses. Use of freshwater lakes for recreation during the warmer months of the year is a major component of Canadian culture in general, in Québec, and other provinces. Cyanobacterial management in Québec reflects this, with the major emphasis of their management activities being focused on the management of blooms at beaches on freshwater lakes or rivers as well as in potable water supplies. However, the total number of freshwaters within Québec that are impacted with cyanobacterial blooms is tiny compared to the 500,000 freshwater bodies within that province.

In comparison, NSW has a long coastline, with a large proportion of its population living within easy access of the coast. Coastal waters are also warm and conducive for recreational activities for many months of the year. In contrast to Québec, inland NSW is largely arid, and surface freshwaters are few. While NSW inland freshwaters, in particular the major headwater storages of the river systems, and some of the main lowland inland rivers themselves are used for recreation, this is only one of a number of uses the rivers are put to. Finally, a large proportion of the limited number of freshwater bodies in NSW is subject to cyanobacterial blooms. The continual surveillance for bloom occurrence becomes a necessity as these blooms can have major impacts on many of the environmental and human uses that the waters are put to, as with limited water availability each bloom becomes a major management issue.

These basic differences, especially in geography, lead to some differences in the ways that cyanobacteria are managed in each jurisdiction. For example, most monitoring in NSW, especially in the Murray Darling Basin is based on a routine sampling program. Only where blooms are uncommon such as coastal rivers is monitoring instigated once a bloom is detected. In Québec there are few routine sampling programs and monitoring is mainly visual, and sampling of blooms usually takes place in response to reports of a bloom appearing within a water body. The monitoring is then conducted within a risk management framework based on the importance of the area where the bloom occurs in terms of potable supply or recreational use, and on the extent, intensity and toxicity of the bloom. NSW utilises cyanobacterial management guidelines for various water uses that were developed at mainly a national level by the National Health and Medical Research Council, and relies mainly on management thresholds based on total cyanobacterial biovolume. Québec on the other hand currently utilizes recreational guidelines developed at a provincial level, and that depend mainly on concentrations of cyanotoxins present within the bloom, but also on total cell counts of total cyanobacteria taxa. Québec’s provincial guidelines however are also based on concentrations of potentially toxic cyanobacteria which came from other jurisdictions. Cyanobacterial bloom response managers in Québec are able to utilize these data for management through rapid responses to reported blooms and a mandatory requirement for samples sent to their laboratory to be screened and reported within 48 hours of receipt. Blooms in Québec are often of different species composition to those in NSW, and many produce microcystins. Some species found in Quebec could produce anatoxin-a but this is detected only in rare samples. NSW has species that can commonly produce microcystins, but also other species that produce saxitoxins or cylindropsermopsin.
Despite these differences in how and where monitoring is undertaken in Québec, and the guidelines that they base their management decisions upon, there are also many similarities with cyanobacterial bloom response management there compared to NSW, especially at an overall provincial scale. Blooms in Québec are managed locally by regional offices of MDDEP in conjunction with local health authorities (DSP), whereas in NSW these are managed locally by Regional Algal Coordinating Committees, or devolved to the body responsible for their management of the water body. There is higher level province-wide and state-wide management of cyanobacteria in both Québec and NSW respectively, with similar activities in both jurisdictions. These include jurisdiction-wide coordination, teleconferences, reporting, advice to Ministers, provision of expert technical advice and the provision of training.

Missisquoi Bay provides an interesting comparison of cyanobacterial management in Québec and Vermont. The bay is divided in two by the international frontier between Canada and the United States, with cyanobacterial blooms in the two halves being managed somewhat differently. Monitoring and sampling routines in the Vermont section differ from those in use in the Québec section. Different cell counts for various management purposes also apply in Vermont. The two halves of the bay are managed as if they were entirely separate water bodies. This is possible because of the limited interactions between each half due to the international border. However if similar arrangements had been in place between NSW and Victoria during the cyanobacterial bloom in the Murray River, Australia in autumn 2009, management of that bloom would have been extremely difficult. Instead effective management of the Murray River bloom was achieved because both Australian states used similar monitoring protocols and the national guidelines, and through cross-border coordination through the Murray Regional Algal Coordinating Committee.

6.5. Observations from elsewhere in Canada

Discussions with other Canadian researchers and managers of cyanobacterial blooms while visiting Nova Scotia and in Manitoba (by correspondence) indicate that Québec is well at the forefront of cyanobacterial bloom response management in Canada. In contrast to Québec, cyanobacterial bloom management and research appears to be less developed in Nova Scotia, because problem blooms in that province are only a very recent phenomenon. Dr Brylinsky of Acadia University has stated that despite the many lakes in that province, there are very few limnologists and freshwater phycologists or phytoplankton ecologists. Most aquatic ecologists have instead, been trained in coastal and marine sciences. The two seminars delivered in Nova Scotia attracted a considerable amount of interest and were well received. There was considerable discussion following the presentations on the management activities that may be most appropriate for that province.
7. Outcomes and other benefits to New South Wales

There are a number of potential outcomes yet to be realised from this visit. These include the joint publication of papers and reports, continued sharing of information and research outcomes, visits to NSW by Canadian scientists, and possible further collaboration with researchers and managers in Québec, Nova Scotia and Manitoba.

The collaborative study between Québec, Vermont and NSW on cyanobacterial blooms in Missisquoi Bay will be reported and published once the data analysis is completed and written up. An initial report will be prepared in English, to be translated into French by MDDEP staff following completion. Both the English and French versions will then be published on the MDDEP web site (http://www.mddep.gouv.qc.ca/eau/frivlac/algues.htm). The English version will also be published on the NSW Office of Water web site (http://www.water.nsw.gov.au), and also on the web site of the Lake Champlain Basin Program (LCBP) (www.lcbp.org) maintained by the relevant United States collaborators should they wish to do so. It is also intended to summarise the report and publish it as a paper in the international peer reviewed scientific literature. Co-authors will include Mme Sylvie Blais of MDDEP, Professor Mary Watzin of the University of Vermont, and Dr Lee Bowling of the NSW Office of Water, as well as any others as appropriate. Finally, a brief plain English (and French) report will also be prepared for posting on the MDDEP and LCBP web sites, for the general public and organisations who do not need detailed scientific information but would be interested in the overall outcomes of the study.

Ongoing collaboration with Québec is also envisaged. Contacts with cyanobacterial bloom managers in the MDDEP were already well established prior to this visit, having been ongoing for the past seven and a half years. This visit has now strengthened and expanded these contacts. These will involve the continued exchange of experiences and information on bloom response management and research undertaken in both jurisdictions. An example of proposed future collaboration is for further consultations and data sharing of studies on in-situ fluorometry undertaken in Québec and NSW. Further invitations have been extended to visit Québec should new funding become available.

As a result of the visit to Québec and associated information exchange, Professor Michèle Prévost and Mr Arash Zamyadai of École Polytechnique de Montréal visited the NSW Office of Water on Friday 19th March 2010, where they presented seminars on their work on the applied use of fluorometers to monitor cyanobacteria in the influent raw waters entering drinking water treatment plants, and on the oxidation of cyanobacteria and cyanotoxins by chlorine. As well as Office staff, visitors from the Sydney Catchment Authority, the Sydney Water Corporation, Hunter Water and from NSW Health also participated, to hear the Canadian visitor’s seminar. Following the seminar, Dr Bowling from the Office held detailed discussions on further collaboration with this university, including review of each other’s work and discussion of projects of common interest, especially the use of fluorometers for detecting cyanobacterial blooms, and on cyanobacterial presence and ecology in Missisquoi Bay. Dr Bowling again met with Mr Zamyadi when he was in Sydney in July 2010, to follow up the initial discussions.

One direct consequence of the visit to Canada and the studies of Missisiquoi Bay has been the recent establishment of contact with Dr Hedy Kling, a cyanobacterial taxonomist and ecologist in Winnnipeg, Manitoba, Canada. Dr Kling provided a considerable amount of additional information on cyanobacterial blooms in Missisiquoi Bay, and on management in Canada based on her many years of experience. She has also expressed an interest to visit NSW and undertake studies of the taxonomy and ecology of cyanobacteria here, and also has extended invitations for NSW managers and researchers to visit Winnipeg.

There were also proposals to conduct further joint research with colleagues in Nova Scotia should funding become available. Ongoing collaboration with Acadia University and Nova Scotia Environment
have been discussed. This includes collaboration with Dr Michael Brylinski with his work analysing and reporting limnological and cyanobacterial bloom data from lakes in Nova Scotia and New Brunswick. In addition, Dr Redden and Nova Scotia Environment have proposed seeking new funding for research into blooms in Nova Scotia.

An important outcome of the visit to Jellett Rapid Testing Ltd in Nova Scotia and discussions with their Chief Research Scientist Dr Maurice Laycock has been the testing of Jellett rapid test strips for use in determining saxitoxin presence in *Anabaena circinalis* blooms in NSW. The company provided the Office with 50 free samples of their test strips, over and above those that had been previously ordered from them. These will be used to develop methods of toxin extraction from this species of cyanobacteria. Ongoing consultation with Dr Laycock is expected.

Since his return from Canada, Dr Bowling has received requests to review a number of manuscripts and other documents prepared by Canadian authors. This results directly from the contacts he made during his visit, and is also a recognition of the cyanobacterial management expertise within NSW. Review of such documents also provides first hand access to the current research outcomes of these Canadian authors, including much which is also relevant to cyanobacterial management in NSW. The following documents have been reviewed:

- A manuscript on the *in-situ* use fluorometry to manage cyanobacteria at a water treatment plant drawing water from Missisquoi Bay, submitted to the international scientific journal *Water Research*.
- A report by Dr Brylinsky (Acadia University, Nova Scotia) on water quality and cyanobacterial blooms in Lake Utopia, New Brunswick.
- A research proposal and funding application submitted to the Natural Sciences and Engineering Research Council of Canada by researchers from a university in Quebec.
- A manuscript describing the laboratory evaluation of YSI and TriOS fluorometric equipment, submitted to the international scientific journal *Journal of Environmental Monitoring*.
8. Conclusions

The focus of this visit to Canada and the support provided by the Australian Academy of Science was to undertake collaborative studies on the causes and management of cyanobacterial blooms in Québec. Québec is the leading province in terms of cyanobacterial bloom response management in Canada at present. As well as examining cyanobacterial bloom response management protocols and procedures as undertaken in Québec, a major component of the visit was a case study of blooms in Missisquoi Bay, at the northern end of Lake Champlain. This case study is comparable with similar recent studies and ongoing investigations undertaken in NSW, including the autumn 2009 cyanobacterial bloom in the Murray River (unpublished). The results of the Missisquoi Bay study enhance the knowledge of cyanobacterial ecology and the causes of bloom occurrence and toxin production for application when managing blooms in NSW, as well as providing similar information for local use in bloom management in Québec and Vermont. The findings of the study will be applied to capacity building amongst cyanobacterial bloom response managers in the Office and amongst stakeholders in the NSW Regional Algal Coordinating Committees.

The experiences gained from the visit to Canada will have direct application to NSW through the review of developing cyanobacterial management strategies, the training of field staff and operatives from water utilities in cyanobacterial bloom awareness and management, and the setting of future research and management priorities for problem cyanobacterial blooms in NSW. In particular, the exchange of advice on new technologies to measure cyanobacterial presence in-situ through the use of fluorometry, the use of rapid test strips for the qualitative assessment of the toxicity of cyanobacterial blooms, and on the use of biovolume or biomass as a management tool have also been valuable, and has the potential to introduce both time and cost efficiencies for bloom response management in NSW. Similar studies of both these management tools are being undertaken in both Australia and Quebec, and comparisons of the results will be extremely useful in determining new rapid monitoring methods for the water industry. Improved monitoring and management techniques will lead to a safer and more reliable water supply for potable use, for recreation, and for livestock watering.


Bulletin d’information

Rencontre d’échanges Québec–Australie–France sur les algues bleu-vert


Présentations de la journée

- Le processus général de gestion des épisodes de fleurs d’eau de cyanobactéries, Mme Sylvie Blais, Direction du suivi de l’état de l’environnement, Ministère du Développement durable, de l’Environnement et des Parcs
- La gestion des plages organisées, M. Jean-François Duchesne, Table nationale de concertation en santé environnementale
- Les seuils d’alerte et d’intervention, M. Jean-François Duchesne, Table nationale de concertation en santé environnementale
• **Validation de trousses de dépistage des microcystines**, M. Marc Sinotte, Direction du suivi de l'état de l'environnement, Ministère du Développement durable, de l'Environnement et des Parcs

• **Validation de sondes pour la mesure de la phycocyanine *in vivo***, M. Christian Bastien, Centre d'expertise en analyse environnementale du Québec

• **Validation et application des fluoroprobes *in situ* pour la détection des cyanobactéries dans les sources d'eau potable**, M. Arash Zamyadi et Mme Natasha McQuaid, École polytechnique de Montréal

• **Fleurs d'eau de cyanobactéries au New South Wales – Causes, échantillonnage et gestion, étude de cas récent – Fleur d'eau sur 1 000 km du fleuve Murray en avril 2009 et Études de fluorométrie et biovolume** M. Lee Bowling, Département de l'eau et de l'énergie, Gouvernement du New South Wales, Australie

• **La gestion des cyanobactéries en France et sujets de recherche particuliers**, M. Luc Brient, Université de Rennes

Les présantateurs. De gauche à droite, à l'avant : M. Christian Bastien (Centre d'expertise en analyse environnementale du Québec), Mme Sylvie Blais (DSEE), Mme Natasha McQuaid (École polytechnique), M. Arash Zamyadi (École polytechnique) et M. Lee Bowling (Gouvernement du New South Wales, Australie); à l'arrière : M. Luc Brient (Université de Rennes, France), M. Marc Sinotte (DSEE) et M. Jean-François Duchesne (Table nationale de concertation en santé environnementale)

Les discussions entourant les expériences internationales de gestion des épisodes de fleurs d'eau d'algues bleu-vert ont permis de constater que l'objectif central des actions des intervenants est identique au Québec, en France et en Australie. En effet, la protection de la santé des usagers des plans d'eau est le but visé. Ces trois États font aussi des efforts en matière de recherche et développement, entre autres, pour améliorer la détection des cyanotoxines et l'évaluation d'outils de mesure *in situ*.

Bien que l'objectif de protection de la santé publique soit le même, les moyens employés pour l'atteindre diffèrent d'un territoire à l'autre, notamment en raison des contextes différents.

Les résultats de ces échanges confirment une fois de plus la pertinence du plan de gestion des épisodes de fleurs d'eau de cyanobactéries au Québec. De plus, de nouvelles connaissances permettront au MDDEP et au ministère de la Santé et des Services sociaux (MSSS) d'optimiser certaines façons de faire dans les années à venir.
Appendix B: Invitation to visit Environment Canada in Montréal

Dr. Lee Bowling
Limnologist
New South Wales Dept. Of Water and Energy

Visiting scientist at MDDEP - Quebec

September 22, 2009

Subject: Invitation to give a seminar at St. Lawrence Centre, Environment Canada

Dear Dr. Bowling

We are pleased to invite you to give a seminar in the series I am in charge of organizing at St. Lawrence Centre (Environment Canada). We are confident the topic of your research, dealing with « Cyanobacteria in New South Wales, Australia : causes, sampling, management and a recent case history of a 1000-km bloom », will be of great interest to our scientific staff. Our usual audience includes about 30 persons and covers a wide range of disciplines, including ecotoxicologists, chemists, sedimentologists, biologists and ecologists, all of which focus their studies on the St. Lawrence River and other freshwater aquatic ecosystems. We will also invite scientists from universities who are interested in the ecology of cyanobacteria.

The seminar will take place at 11:00, on Friday, September 25. I will be expecting you at about 10:00 at the entrance of 105 McGill st., where the Commissioner in charge will welcome you and call me (514-283-6195) after providing you a guest identity card.

In order to facilitate your visit to Montreal, we will reimburse your travel by bus from Quebec City (2-way fare) and luncheon expense.

I trust this meeting will be fruitful to get acquainted with our research interests and, possibly, to examine possible collaborations and exchanges in the future.

Sincerely yours,

Christian Gagnon, Ph. D.
Chef int.
Recherche sur les Écosystèmes Fluviaux
Direction des sciences et technologies de l’eau
Environnement Canada
Appendix C: Notification of seminar at Acadia University, Nova Scotia

International Guest Seminar

Cyanobacterial Blooms and their Management in Australia

Dr Lee Bowling
NSW Department of Water and Energy, Australia

Friday, 9 Oct 2009
10:30 am
New Biology Building
Seminar Room 322
Westwood Ave, Wolfville, NS
Appendix D: Decision support flow chart for cyanobacterial management in Québec.

2009 General decision scheme (May 1st version)
Management plan for blue green algae blooms

Field check by MDDEP: observations and sampling

- < 20 000 cel/ml tot. cyano or other event
  - Type A Info Memo or other event
  - Increase in bloom size or intensity

- ≥ 20 000 cel/ml tot. cyano = Bloom
  - Type B Info Memo
  - Important Area (2)?
    - Surveillance? Bloom size ≥ 1 000 m² or significant scum
      - Yes
        - Public Health Advisory
      - No
        - No

- Type B Info Memo
  - Important Area (2)?
    - No
      - Yes
        - Type C Info Memo

Water body under surveillance Sampling by MDDEP (see decision scheme to end surveillance)

- Municipalities must advise people in charge of:
  - Official beaches
  - Drinking water treatment plants

Visual surveillance by partner

(1) Except for water bodies without individual, private or municipal water intake (use of swimming thresholds 16 µg/l MC-LR t.eq. or de 40 µg/l anatoxine-a)
(2) See the document « Notions de secteur important » for information on bloom size, affected uses and exposed or potentially exposed populations