

A Pan-Canadian Comparison of Cyanobacteria Bloom Management Policies, Programs, and Practices

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Abstract

Across the globe, reports of cyanobacteria blooms are on the rise. The increasing occurrence of cyanobacteria blooms and cyanotoxins is attributed to phosphorous (P) loading, climate change, among a mix of other factors. While eutrophic lakes have a higher risk of blooms, oligotrophic and mesotrophic lakes are also experiencing blooms. This means governments' need to develop a robust cyanobacteria management strategy (prevent, control, and mitigate) to protect public health. In Canada, water management is a shared responsibility among the federal, provincial, and local governments; however, cyanobacteria management is mainly a provincial and local government responsibility. This research compares and contrasts five provincial cyanobacteria management strategies from Alberta, Manitoba, Nova Scotia, Ontario, and Saskatchewan. Using a policy analysis framework, the methods of data collection include a review of grey and academic literature, legislation/regulations, and interviews with actors involved in cyanobacteria bloom management in each province. Also, three case studies – Lake Erie, Ontario; Lake Winnipeg, Manitoba; and Pigeon Lake, Alberta – were selected to analyze the policies and programs in practice. A robust cyanobacteria management strategy involves prevention, control, and mitigation to avoid public health risks. All jurisdictions in Canada have initiatives to manage cyanobacteria blooms. Nutrient management continues to be the cornerstone of bloom prevention by controlling point and diffuse sources of P runoff control. Nutrient management mostly relies on voluntary participation, so reductions in nutrient loading are heavily dependent on financial incentives, and education and outreach programs; however, there is little to no understanding or tracking of implementation. Also, P control will not reduce the risk of blooms in low P lakes. Monitoring programs and targets should include dissolved oxygen. Public health risks associated with cyanotoxins are mitigated through public reporting or monitoring drinking water sources and recreational waters. The monitoring and reporting programs vary by province. For instance, certain drinking water sources and recreational waterbodies are routinely monitored, whereas in other provinces sampling is driven by public reporting.

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Table of Contents

| | |
|---|-------------|
| <i>Abstract</i> | <i>ii</i> |
| <i>Acknowledgements</i> | <i>iii</i> |
| <i>Table of Contents</i> | <i>iv</i> |
| <i>List of Tables</i> | <i>vi</i> |
| <i>List of Figures</i> | <i>viii</i> |
| <i>List of Abbreviations</i> | <i>ix</i> |
| Chapter 1.0: Introduction | 1 |
| 1.1 Problem Statement | 4 |
| 1.2 Research Objectives | 4 |
| 1.3 Outline of Chapters | 4 |
| Chapter 2: Cyanobacteria Bloom Management | 6 |
| 2.1 Cyanobacteria Blooms: Science, Research, and Monitoring | 9 |
| 2.1.1 Eutrophication | 9 |
| 2.1.2 Scientific Uncertainty and Bloom Research..... | 10 |
| 2.1.3 Monitoring Programs..... | 12 |
| 2.2 Cyanobacteria Bloom Management: Prevention, Control, and Mitigation | 16 |
| 2.2.1 Cyanobacteria Bloom Prevention: Nutrient Management..... | 16 |
| 2.2.2 Cyanobacteria Bloom Mitigation: Chemical and Physical In-Lake Treatments..... | 20 |
| 2.2.3 Cyanobacteria Bloom Control: Risk Management..... | 22 |
| 2.3 Canadian Water Management: Jurisdictions and the Roles of Federal and Provincial Governments | 39 |
| 2.3.1 Federal Cyanobacteria Recreational and Drinking Water Guidelines..... | 43 |
| 2.3.2 Effluent Water Standards | 45 |
| 2.3.3 P in Detergents | 46 |
| 2.3.4 NPS Nutrient Management Practices | 47 |
| 2.3.5 Agri-Environmental Cost-Share Funding..... | 49 |
| 2.4 Summary of Key Findings | 51 |
| Chapter 3: Methods | 53 |
| Chapter 4: Cyanobacteria Management – A Case Study Approach | 59 |
| 4.1 Bloom Control Programs: Cyanobacteria Risk Management | 59 |
| 4.1.1 Cyanobacteria Water Quality Standards..... | 60 |
| 4.1.2 Source/Drinking Water Monitoring | 61 |
| 4.1.2 Recreational Water Monitoring | 68 |
| 4.1.3 Monitoring Waters for Agricultural Use | 70 |
| 4.1.4 Advisories..... | 72 |
| 4.1.5 Education and Outreach | 76 |
| 4.2 Bloom Prevention Programs: Nutrient Management | 78 |
| 4.2.1 PS Nutrient Management | 79 |
| 4.2.2 Regulated NPS Nutrient Management | 82 |
| 4.2.3 Encouraged, Voluntary, and Incentivized NPS Nutrient Management..... | 84 |

| | |
|---|------------|
| 4.2.3 Education and Outreach | 89 |
| 4.3 Bloom Mitigation Programs: Chemical and Physical Treatment..... | 90 |
| 4.4 Integrated Watershed Management..... | 91 |
| 4.5 Summary of Key Findings..... | 94 |
| Chapter 5: Case Studies..... | 96 |
| 5.1 Background Information..... | 96 |
| 5.1.1 Lake Erie, Ontario | 96 |
| 5.1.2 Lake Winnipeg, Manitoba | 98 |
| 5.1.3 Pigeon Lake, Alberta | 100 |
| 5.2 Comparative Analysis/Results..... | 103 |
| 5.2.1 Scientific Understanding, Nutrient Targets, and Nutrient Management..... | 103 |
| 5.2.2 Agreements/Coordination..... | 113 |
| 5.2.3 Monitoring..... | 116 |
| 5.2.4 Funding..... | 118 |
| 5.2.5 Risk Management..... | 119 |
| 5.2.6 Adaptive Management..... | 119 |
| 5.2.7 Education and Outreach | 120 |
| 5.3 Summary of Key Findings..... | 121 |
| Chapter 6.0: Interviews..... | 123 |
| 6.1 Science, Research, and Blooms in Oligotrophic Systems..... | 123 |
| 6.1.1 P vs. N and P | 123 |
| 6.1.2 Blooms in Oligotrophic Systems and Internal Loading | 125 |
| 6.1.3 Cyanobacteria Research Programs | 129 |
| 6.2 Funding, Capacity, and Regime Changes | 134 |
| 6.2.1 Routine Recreational Beach Monitoring | 135 |
| 6.2.2 General Water Quality Monitoring..... | 137 |
| 6.2.3 NPS Nutrient Loading | 138 |
| 6.3 A Focus on Cyanobacteria Control Over Mitigation or Prevention | 139 |
| 6.3.1 NPS Nutrient Management..... | 139 |
| 6.3.2 PS Nutrient Management | 142 |
| 6.4 Summary of Key Findings..... | 143 |
| Chapter 7: Discussion and Conclusions | 144 |
| 7.1 Assessment of Provincial Cyanobacteria Management Programs | 144 |
| 7.1.1 Provincial Health Risk Control Programs | 144 |
| 7.1.2 Provincial Nutrient Control (Indirect Bloom Mitigation) Programs | 148 |
| 7.1.3 Provincial In-Lake Prevention Programs | 148 |
| 7.2 Provincial Scientific Understanding of Blooms | 149 |
| 7.3 Assessment of Case Studies | 149 |
| 7.4 Conclusions | 151 |
| Works Cited | 154 |

List of Tables

| | |
|--|----|
| Table 1: A list of cyanotoxins, their known toxicity levels (if available), the genus capable of producing them, and any acute or chronic symptoms associated with exposure. (Lopez et al., 2008; Davis et al., 2009; Hudnell, 2010; Cheung et al., 2013; Ibelings et al., 2014; Otten and Paerl, 2015). | 7 |
| Table 2: Cyanotoxin mode and risk of exposure to cyanotoxins by different activities (recreational and otherwise) (Stone and Bress, 2007; Codd et al., 2017). | 8 |
| Table 3: Cyanotoxin threshold values for treated drinking water, recreational water, and freshwater seafood used in a variety of jurisdictions and those suggested by the WHO (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014; Farrer et al., 2015). | 24 |
| Table 4: Other cyanobacteria threshold values, beyond cyanotoxins (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014; Chorus and Welker, 2021). | 25 |
| Table 5: Cyanobacteria Bloom Monitoring Programs in Canada. All five provinces have routine bloom monitoring requirements for surface source water DWTPs. Routine recreational monitoring programs for blooms are the provincial beach monitoring programs, which in Alberta, Manitoba, and Saskatchewan are tied to their reactive monitoring programs. All provinces respond to public reports of bloom activity, though not all programs involve sampling. | 60 |
| Table 6: Jurisdictional cyanotoxin (MC-LR) MACs and the related legislation and standards documents. | 60 |
| Table 7: Provincial recreational water quality values for cyanobacteria and total microcystins. Manitoba and Alberta’s recreational water values for cyanobacteria and total microcystins are legislatively backed, while Saskatchewan’s are not. | 61 |
| Table 8: Drinking water routine monitoring, sampling, and testing methods for provincially managed DWTPs within five Canadian provinces. | 62 |
| Table 9: Provincial reactive monitoring programs reporting, response, sampling, and analysis methods for cyanobacteria blooms and their associated toxins in surface source waters. | 63 |
| Table 10: Monitoring and sampling protocols for the provincial routine beach monitoring programs in Alberta, Manitoba, and Saskatchewan. | 68 |
| Table 11: Provincial reactive monitoring programs response, sampling, and analysis methods and protocols for recreational waters. | 69 |
| Table 12: Cyanobacteria Bloom Drinking Water Advisory Criteria in Canada. | 73 |
| Table 13: Recreational Water Advisories for Cyanobacteria Blooms and their criterion. | 74 |
| Table 14: Advisory issuance methods utilized in each province to mitigate risk to public health. Not all methods used apply to drinking waters. | 75 |
| Table 15: Education and outreach initiatives within each of the five jurisdictions. | 76 |
| Table 16: Information on blue-green algae blooms provided by government websites | 76 |
| Table 17: Cyanobacteria bloom descriptions published on provincial webpages. | 77 |
| Table 18: The number of factsheets found in each province dedicated to cyanobacteria blooms and their “type”. | 77 |
| Table 19: Information on blue-green algae blooms provided by government factsheets. Note: Not all information found on each factsheet. | 78 |
| Table 20: Regulated nutrient management programs and practices used across Canada. | 79 |
| Table 21: Encouraged, Incentivized, or recommended nutrient management programs and practices. | 79 |

| | |
|--|-----|
| Table 22: Provincial Nutrient Wastewater Effluent Standards for Provincially Managed Wastewater Treatment Plants, listed best to worst for cyanobacteria bloom management. | 80 |
| Table 23: Provincial legislation and regulations for agricultural NPS nutrient management and the operations they apply to, listed best to worst for cyanobacteria bloom management. | 82 |
| Table 24: Manure production rates that require the development of a provincially approved nutrient or manure management plan | 83 |
| Table 25: Provincial Soil P and N Threshold Levels, listed best to worst for cyanobacteria bloom management. | 83 |
| Table 26: Provincial definitions of EFP programs | 84 |
| Table 27: Provincial EFP Programs and their link to the CAP funding program..... | 85 |
| Table 28: NPS education and outreach material available within each province. | 90 |
| Table 29: Canadian jurisdictions different definitions of IWM (SWA, 2002; GOC, 2010; NSWAG, 2010; GoA, 2015; CCME, 2016; Conservation Ontario, 2019; GoM, 2020). | 91 |
| Table 30: IWMPs link to cyanobacteria bloom management in five provinces. Eutrophication is listed as a risk to water quality in 62 of the 65 plans. Algae, algal blooms, or cyanobacteria were mentioned in 35 of the plans. | 92 |
| Table 31: Provincial surface water nutrient concentration guidelines/targets to avoid excessive algae bloom growth..... | 93 |
| Table 32: Waterbody Lake Characteristics and Nutrient Loading Sources..... | 96 |
| Table 33: Cyanobacteria bloom management..... | 103 |
| Table 34: Nutrient targets for the different waterbodies..... | 109 |
| Table 35: Provincially Regulated Nutrient Management for Lake Erie, Lake Winnipeg, and Pigeon Lake | 111 |
| Table 36: Encouraged and incentivized nutrient management programs and methods for Lake Erie, Lake Winnipeg, and Pigeon Lake | 111 |
| Table 37: Agreements and MOUs between the Federal Government and provinces of Canada that are related to cyanobacteria management, directly and indirectly..... | 113 |
| Table 38: Cyanobacteria bloom monitoring programs | 116 |

List of Figures

| | |
|--|-----|
| Figure 1: A diagram depicting the multitude of factors that contribute to bloom proliferation both in and ex situ. These factors can work in combination or individually. | 6 |
| Figure 2: Alert Level Framework suggested by the WHO for cyanobacteria and their toxins in drinking and recreational waters (Chorus and Welker, 2021). | 28 |
| Figure 3: The Vermont, USA five-tiered recreational response protocol, which includes surveillance and notification requirements. Adapted from Stone and Bress (2007). | 29 |
| Figure 4: Original RTE policy analysis framework seen in Hanberger (2001). | 53 |
| Figure 5: The 12 points of “Ontario’s 12-point plan on blue green algal blooms”. | 54 |
| Figure 6: the framework developed for the comparative analysis used in this research | 54 |
| Figure 7: Nova Scotia Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters. | 65 |
| Figure 8: Ontario Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters. | 66 |
| Figure 9: Manitoba Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters. | 66 |
| Figure 10: Saskatchewan Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters. | 67 |
| Figure 11: Alberta Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters. | 67 |
| Figure 12: Saskatchewan Agricultural Water Cyanobacteria Response Protocol..... | 70 |
| Figure 13: TP loads into Lake Erie from 1967 to 2013 [Source: QLWQANAS, 2019; modified from Maccoux et al., 2016]. | 103 |
| Figure 14: TP loads and sources into Lake Erie [Source: ECCC, 2020]. | 104 |
| Figure 15: Lake Winnipeg TP (a) and TN (b) concentrations from 1999 to 2016 [Source: GOM, 2019] | 104 |
| Figure 16: NPS TP (left) and TN (right) loading sources into Lake Winnipeg from the four major tributaries [Source: GOM, 2019]. | 105 |
| Figure 17: Open Water Season Average TP Concentrations (mg/L) for Pigeon Lake, 1983-2019 [Data Source: AE, 2021]. | 106 |
| Figure 18: 2013 Pigeon Lake TP Concentrations from June to August [Data Source: AE, 2021] | 107 |
| Figure 19: Pigeon Lake Annual Average TP concentrations and cyanobacteria bloom biomass from 1983 to 2016 (PLWMSC, 2018). | 107 |
| Figure 20: Pigeon Lake P loading sources [Source: Teichreb, 2014]. | 108 |

List of Abbreviations

| Acronym | Meaning |
|---------------|--|
| AAFC | Agriculture and Agri-Food Canada |
| AE | Alberta Environment |
| AEFP | Alberta Environmental Farm Plan |
| AFFIRM | Alberta Farm Fertilizer Information and Recommendation Manager |
| AH | Alberta Health |
| AHS | Alberta Health Services |
| AIS | Aquatic Invasive Species |
| ALF | Alert Level Framework |
| ALMS | Alberta Lake Management Society |
| APLM | Alliance of Pigeon Lake Municipalities |
| ARD | Manitoba Agriculture and Resource Development |
| BGA | Blue-Green Algae |
| BMP | Best Management Practice or Beneficial Management Practice |
| BNR | Biological Nutrient Removal |
| BPRS | Binational Phosphorus Reduction Strategy |
| BRWA | Battle River Watershed Alliance |
| CAP | Canadian Agricultural Partnership |
| CAS EA | Conventional Activated Sludge with Extended Aeration |
| CBOD | Carbonaceous Biochemical Oxygen Demand |
| CCME | Canadian Council of Ministers of the Environment |
| CDW | The Federal-Provincial-Territorial Committee on Drinking Water |
| CDWQG | The Guidelines for Canadian Drinking Water Quality |
| COA | Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health |
| COLEAP | Canada-Ontario Lake Erie Action Plan |
| DO | Dissolved Oxygen |
| DO | District Office |
| DOA | Department of Agriculture |
| DOH | Nova Scotia Department of Health |
| DWT | Drinking Water Treatment |
| DWTP | Drinking Water Treatment Plant |
| ECCC | Environment and Climate Change Canada |
| ECO | Environmental Commissioner of Ontario |
| EFP | Environmental Farm Plan |
| ELISA | Enzyme-Linked Immunosorbent Assay |
| EPA | USA Environmental Protection Agency |
| EQIP | Environmental Quality Incentives Program |
| EU | European Union |
| FAQ | Frequently Asked Questions |
| FB | Facebook |
| FPT | Federal-Provincial-Territorial Governments |
| GAC | Granular Activated Carbon |
| GCRWQ | The Guidelines for Canadian Recreational Water Quality Third Edition |

| | |
|----------------------|--|
| GF | Growing Forward |
| GF2 | Growing Forward 2 |
| GI | Gastrointestinal |
| GLWQA | Great Lakes Water Quality Agreement |
| GOA | Government of Alberta |
| GOC | Government of Canada |
| GOM | Government of Manitoba |
| GONS | Government of Nova Scotia |
| GOO | Government of Ontario |
| GOS | Government of Saskatchewan |
| GRCA | Grand River Conservation Authority |
| HABISask | Hunting, Angling and Biodiversity Information of Saskatchewan |
| HPE | AHS Healthy Physical Environments |
| IJC | International Joint Commission |
| IRP | Incident Response Plan |
| IWM | Integrated Watershed Management |
| IWMP | Integrated Watershed Management Plan |
| IWRM | Integrated Watershed Resource Management |
| KAP | Keystone Agricultural Producers |
| LaSB | MECP Laboratory Services Branch |
| LC-(ESI)MS/MS | Liquid Chromatography-(Electrospray Ionization) Tandem Mass Spectrometry |
| LC-MS | Liquid Chromatography-Mass Spectrometry |
| LHU | Local Health Unit |
| LMMR | Livestock Manure and Mortalities Management Regulation |
| MAA | Master Agreement on Apportionment |
| MAC | Maximum Acceptable Concentration |
| MC | Microcystin |
| MCC | Manitoba Conservation and Climate |
| MC-LR | Microcystin-LR |
| MECP | Ontario Ministry of the Environment, Conservation and Parks |
| MOA | Ministry of Agriculture |
| MOE | Ministry of the Environment |
| MOECC | Ontario Ministry of the Environment and Climate Change |
| MOH | Ministry of Health |
| MOHLTC | Ontario Ministry of Health and Long-Term Care |
| MOU | Memorandum of Understanding |
| MPBRB | Approved Management Plan for the Battle River Basin |
| N | Nitrogen |
| NASM | Non-Agricultural Source Material |
| NASMP | Non-Agricultural Source Material Plan |
| NGO | Non-Governmental Organization |
| NMA | Nutrient Management Act (Ontario) |
| NMP | Nutrient Management Plan |
| NMR | Nutrient Management Regulation (Manitoba) |
| NOAA | National Oceanic and Atmospheric Administration |

| | |
|----------------|--|
| NOD | Nodularin |
| NPS | Nonpoint Source |
| NSE | Nova Scotia Environment |
| NSEFP | Nova Scotia Environmental Farm Plan |
| NSMOA | Nova Scotia Ministry of Agriculture |
| ODW | Manitoba Office of Drinking Water (MCC) |
| OMAFRA | Ontario Ministry of Agriculture, Food and Rural Development |
| P | Phosphorus |
| PC | Phycocyanin |
| PE | Phycoerythrin |
| PEI | Prince Edward Island |
| PHI | Public Health Inspector |
| PLRCC | Pigeon Lake Regional Chamber of Commerce |
| PLWA | Pigeon Lake Watershed Association |
| PLWMP | Pigeon Lake Watershed Management Plan |
| PLWMPSC | Pigeon Lake Watershed Management Plan Steering Committee |
| PLWMS | Pigeon Lake Watershed Management Society |
| POW | Permit to Operate |
| PPI | Protein Phosphatase Inhibition |
| PS | Point Source |
| PWS | Private Water Supplies |
| RTE | Real-Time Policy Evaluation |
| RWQ | The Federal-Provincial-Territorial Working Group on Recreational Water Quality |
| SAC | Spills Action Centre (Ontario) |
| SAS | NSE Sustainability and Applied Sciences Division |
| SDWB | MECP Safe Drinking Water Branch |
| SDWS | Small Drinking Water System |
| SHA | Saskatchewan Health Authorities |
| SHE | AHS Safe Healthy Environments |
| SLWA | Save Lake Winnipeg Act |
| SRP | Soluble Reactive Phosphorus |
| TDI | Tolerable Daily Intake |
| TKN | Total Kjeldahl Nitrogen |
| TMC | Total Microcystin |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| US | United States |
| USA | United States of America |
| WHO | World Health Organization |
| WSA | Saskatchewan Water Security Agency |
| WW | Wastewater |
| WWTP | Wastewater Treatment Plant |

Chapter 1.0: Introduction

Cyanobacteria, commonly named blue-green algae, are a naturally occurring group of photosynthetic bacteria found in marine, brackish, and freshwater systems (O’Keefe, 2019). Under ideal conditions cyanobacteria rapidly proliferate and form nuisance or toxic blooms, commonly known as harmful algal blooms (HABs) (Paerl, 1988; CWN, 2016, 2017; Urquhart et al., 2017). Globally, cyanobacteria blooms are increasing in severity, frequency, and extent (Heisler et al., 2008; Winter et al., 2011; Pick, 2015; Urquhart et al., 2017; Huisman et al., 2018). Blooms are primarily associated with nutrient-rich (eutrophic) waters, although smaller blooms also occur in nutrient-poor (oligotrophic) waters (Downing et al., 2001). Cyanobacteria blooms negatively impact water quality through the production of noxious taste-and-odour compounds, the build-up of surface scum, and their contribution to hypoxic (low dissolved oxygen) or anoxic (no dissolved oxygen) events that can kill multicellular life (Zamyadi et al., 2012; Molot et al., 2014; Buratti et al., 2017; Verschoor et al., 2017). Blooms are also able to produce cyanotoxins, which, in high enough concentrations, can also kill multicellular life (Zamyadi et al., 2012; Molot et al., 2014; Buratti et al., 2017; Verschoor et al., 2017). Cyanobacteria blooms reduce the recreational, aesthetic, industrial, residential, ecological value, and overall health of waterbodies (Molot et al., 2014; Smol, 2019).

Cyanobacteria blooms are often associated with eutrophic (nutrient enriched) lakes and rivers, which is why cultural eutrophication is believed to be the largest contributing factor (Downing et al., 2001; Nürnberg, 2017). Although, the timing and severity of blooms is also affected by sunlight, air temperature, thermal stratification, anoxia, and other factors (Paerl, 1988; Molot et al., 2014; Persaud et al., 2015; Molot et al., 2021a, 2021b). However, cyanobacteria blooms are also being reported in oligotrophic (nutrient poor) lakes across Canada (Winter et al., 2011; Sorichetti et al., 2014; Verschoor et al., 2017). While not a lot of research has been done on the subject, the current suspected cause of blooms in these nutrient-poor systems is seasonal stratification induced pulses of high phosphorus (P) and iron related to sediment anoxia, as opposed to high P concentrations (Molot et al., 2014; Verschoor et al., 2017; Molot et al., 2021b).

Given the complexity of factors that contribute to bloom formation and the fact that bloom productivity is still be studied, managing the occurrences of blooms is challenging, though current management strategies often focus on three factors: (1) prevention of bloom

formation (2) control of health risks and (3) in-lake mitigation. Where prevention is nutrient management strategies focused on preventing blooms, control refers to risk mitigation strategies meant to protect human and animal health, and mitigation is the chemical or physical treatment of blooms.

Nutrient management can lower the risk of a cyanobacteria blooms by reducing nutrient loading from point sources (PS) and non-point sources (NPS) (Sorichetti et al., 2014; Pick, 2015; Verschoor et al., 2017). Effluent from wastewater treatment plans (WWTP) is a key PS of phosphorus enrichment for lakes and rivers (Oleszkiewicz, 2015; Oleszkiewicz et al., 2015). Controlling NPS nutrient loading – the product of agricultural and urban runoff from tens of thousands of farms and cities across multiple jurisdictions – is more complex (Conley et al., 2009; Patterson et al., 2013; Bennett, 2017). Agricultural runoff is the main source of NPS nutrient loading into freshwater systems because commercial fertilizers and manure contain large concentrations of P (Patterson et al., 2013; O’Keefe, 2019); even small losses from individual farms have a cumulative impact on aquatic ecosystems. Efforts to promote and incentivize non-point source nutrient management include environmental stewardship programs, nutrient calculators, Environmental Farm Plans (EFPs), regulations, and more, meant to minimize environmental footprints by promoting ‘environmentally friendly’, and mostly voluntary, farming practices (Logan, 1993; Robinson, 2006; Atari et al., 2009). While there have been significant efforts to reduce point and non-point sources of nutrients, cyanobacteria blooms are reported to be on the rise. Therefore, mitigating the health risks associated with cyanobacteria blooms is a key component of cyanobacteria management.

Cyanobacteria bloom risk mitigation strategies aim to minimize human health risks that cyanotoxins may pose (Codd et al., 2005; Health Canada, 2012, 2017). In this case, risk management “is the process which evaluates how to protect public health” (Kwiatkowski, 1998; EPA, 2017, para. 3) and more recently, environmental health (Codd et al., 2005) from the risks posed by blooms. The increasing occurrence of blooms globally has resulted in many countries developing risk management strategies for cyanobacteria blooms and their toxins after health incidents affecting animals and humans occurred (Codd et al., 2005). However, “implementation of risk management varies greatly according to the political, social, and economic context in which it takes place” (Christoffersen and Kaas, 2000, p. 186). That is, implementation tends to

vary across different legal, social, economic, and political contexts and is centred around reacting to the presence of blooms rather than preventing them (Codd et al., 2005).

While there are works describing cyanobacteria policies across Canada (O’Keefe, 2019), these often overlook the details of prevention, control and mitigation processes, implementation, and how science informs policy choices. This research will use a policy analysis framework to describe and evaluate nutrient management, monitoring and reporting, communication, adaptive management, risk management, legislation and regulations, and support, funding, and agreements around cyanobacteria management in the five provinces chosen.

Policy science is ‘problem-oriented’ (Lasswell, 1970); a problem is identified and from that a plan is put in place to deal with that problem. Therefore, a policy scientist must consider and understand both the scientific aspects of the problem, as well as the local social context in which it is found (Lasswell, 1970). This requires policy scientists to be interdisciplinary (Farr et al., 2008). Policy analysis needs a detailed understanding of the functions and structures of policy making; it is essential for the participants, perspectives, situations, base values, contexts, power relationships, strategies, outcomes, and effects to be identified for any policy decision (Lasswell, 1970). This analysis not only maps the policy process, but also the interactions between policy and the social context it is a part of (Lasswell, 1970). Once these data are collected and analysed by the policy scientist, a decision must be made on how best to represent that data, especially to those with decision-making powers (governance positions) who might not have as firm a grasp on the scientific theory and knowledge behind the problem being managed (Lasswell, 1970; Hanberger, 2001).

The scope of this pan-Canadian comparison includes five provinces. In 2018, Ontario and Alberta reported the highest number of cyanobacteria blooms, with 66 and 44, respectively (O’Keefe, 2019). Manitoba, while not having as many bloom events, has been experiencing an increase in the number of long-lasting blooms (O’Keefe, 2019) and Lake Winnipeg, one of the largest lakes in the world, suffers from extensive cyanobacteria blooms because of excessive nutrient enrichment (Kling et al., 2011; Schindler et al., 2012). Saskatchewan and Nova Scotia are reporting increasing incidences of blooms (O’Keefe, 2019), with several requiring public health/algae advisories and beach closures (CBC News, 2019; GOS, 2019).

1.1 Problem Statement

Many provinces across the country have implemented policies, programs, and practices to mitigate the size, frequency, and severity of cyanobacteria blooms and minimize their risk to public health (Pick, 2015; O’Keefe, 2019). However, in the absence of national standards, management strategies may vary between provinces. The extent to which these policies and programs vary, their effectiveness, what coordination exists between agencies and jurisdictions, and whether they are based on current science is presently unknown. And with increasing incidences of blooms in oligotrophic systems the applicability of nutrient management programs based on lowering P or P and N, originally designed to fight blooms in eutrophic systems, to nutrient-poor systems is problematic. So, while the cornerstone of cyanobacteria management is still reducing P, or P and N, inputs to surface waters (Pick, 2015), current nutrient management strategies are not applicable to oligotrophic systems. Moreover, recent ideas that link development of sediment anoxia to bloom formation may not have been incorporated into nutrient management strategies yet.

1.2 Research Objectives

The main research objective is to compare and contrast cyanobacteria bloom management strategies (prevention, control, mitigation) for five provinces in Canada – Alberta, Manitoba, Nova Scotia, Ontario, and Saskatchewan – to document the best processes, practices, and identify gaps.

Three primary research objectives guide this study:

1. Describe the provincial cyanobacteria prevention (e.g., nutrient management), risk control (e.g., bloom monitoring, public reporting, public communication), and mitigation (e.g., in-lake chemical and/or physical treatments) plans.
2. Assess the provincial scientific understanding of cyanobacteria bloom formation and its incorporation into policy.
3. Explore cyanobacteria management practices in different provinces using selected case studies.

1.3 Outline of Chapters

Chapter 1 provides an overview of the ‘cyanobacteria bloom problem’ and the complexity of bloom management. It introduces the core concepts as to the range of bloom causes and the methods of management that are currently used. Chapters 2 expands on cyanobacteria mitigation/prevention, current risk management around bloom management within

current literature, and how water and nutrients are managed in Canada. Chapter 3 introduces the methods used to conduct the comparative analyses between provinces and case studies for cyanobacteria bloom management. Chapter 4 is the comparative analysis of the provincial cyanobacteria nutrient management and risk management policies, programs, and practices used in Canada. Cyanobacteria risk management and therefore control methods are the greater focus provincially over nutrient management. Regulated and unregulated nutrient management provincial programs and practices are not cyanobacteria focused and therefore may or may not be effective at reducing nutrient loading, especially from NPSs. Chapter 5 is the in-depth analysis of the case studies and the implementation of the policies and programs introduced in Chapter 4. Chapter 6 presents a thematic analysis of the interview data. Chapter 7, the final chapter, present the main findings of this research.

Chapter 2: Cyanobacteria Bloom Management

This chapter has three sections providing a literature review on cyanobacteria and their management. Section 2.1 reviews cyanobacteria bloom science and research, section 2.2 introduces bloom prevention, mitigation, and control measures, and section 2.3 focuses on the roles of Canadian governments in water management and bloom and nutrient management programs in Canada.

Cyanobacteria are ubiquitous; they are found in fresh, brackish, and marine waters around the globe (Paerl, 1988; CWN, 2016, 2017; Urquhart et al., 2017). These photosynthetic prokaryotic organisms are primary producers, and an important part of maintaining aquatic trophic levels (Sharma et al., 2014, Chapter 1). Under the right conditions, cyanobacteria are capable of rapid growth, resulting in the formation of blooms (Heisler et al., 2008; Winter et al., 2011; Pick, 2015; Urquhart et al., 2017; Huisman et al., 2018). The primary factors for cyanobacteria bloom formation are nutrient concentrations, light, temperature, thermal stratification, and anoxia (Figure 1) (Paerl, 1988; Molot et al., 2014, 2021a; Persaud et al., 2015), with the highest risk of bloom formation being in calm, warm, eutrophic waters (Pick, 2015).

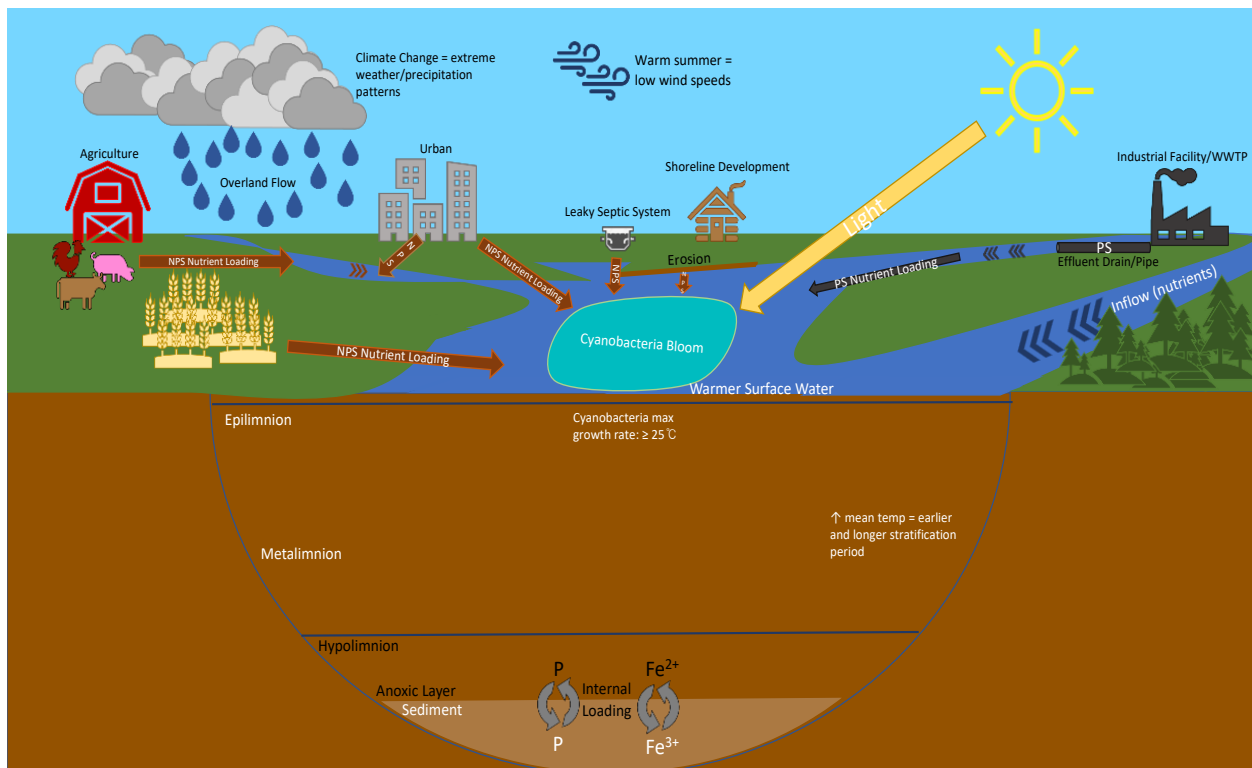


Figure 1: A diagram depicting the multitude of factors that contribute to bloom proliferation both in and ex situ. These factors can work in combination or individually.

Cyanobacteria prefer warm temperatures, with optimal growth occurring at 25°C (Paerl, 2014; Paerl, 2016), although blooms can occur in winter and under ice (Bertilsson et al., 2013). Cyanobacteria contain gas-vacuoles which allow them to alter their buoyancy and move throughout the water column, increasing positioning to optimize nutrient and light availability (Sharma et al., 2010). Due to certain species' ability to migrate through the water column, blooms need not form on surface water; they can form below the surface, usually within the metalimnion (middle transitional layer) or benthic (bottom) layer, depending on the species and light availability (Dokulil and Teubner, 2000; Sharma et al., 2010; Verschoor et al., 2017; Wood et al., 2020). Benthic blooms have been increasing since the 1990's and are linked with animal deaths due to cyanotoxin production (Wood et al., 2020).

Table 1: A list of cyanotoxins, their known toxicity levels (if available), the genus capable of producing them, and any acute or chronic symptoms associated with exposure. (Lopez et al., 2008; Davis et al., 2009; Hudnell, 2010; Cheung et al., 2013; Ibelings et al., 2014; Otten and Paerl, 2015).

| Cyanotoxin | Cyanobacteria Genus | Toxicity (LD ₅₀)* | Acute Symptoms | Chronic Symptoms |
|-------------------------------------|--|-------------------------------|--|--|
| Anatoxin-a | <i>Anabaena, Aphanizomenon, Cyndrospermopsis, Lyngbya, Oscillatoria, Planktothrix</i> | 200 µg/kg | - Tingling - Burning - Numbness - Drowsiness - Incoherent Speech - Respiratory paralysis - Death | - Cardiac arrhythmia - Death |
| Anatoxin-a(S) | <i>Anabaena</i> | 20 µg/kg | See Anatoxin-a | See Anatoxin-a |
| Beta-N-methylamino-L-alanine | <i>Anabaena, Cyndrospermopsis, Microcystis, Nostoc, Oscillatoria, Planktothrix</i> | | N/A | Neurodegenerative disease (?) |
| Cyndrospermopsis | <i>Anabaena, Aphanizomenon, Cyndrospermopsis, Oscillatoria, Umezakia</i> | 300/180 µg/kg | - GI symptoms - Liver inflammation or hemorrhage - Pneumonia - Dermatitis | - Malaise - Anorexia - Liver Failure - Death |
| Homoanatoxin-a | <i>Anabaena, Aphanizomenon, Cyndrospermopsis, Lyngbya, Oscillatoria, Planktothrix</i> | | N/A | N/A |
| Lipopolysaccharide | <i>Aphanizomenon, Oscillatoria, Planktothrix</i> | | - GI Symptoms - Dermatitis | Unknown |
| Lyngbyatoxin | <i>Lyngbya</i> | | - Dermatitis | - Skin tumors - Unknown |
| Microcystin | <i>Anabaena, Aphanizomenon, Cyndrospermopsis, Hapalosphon, Microcystis, Nostoc, Oscillatoria, Planktothrix</i> | 50 µg/kg | - Liver inflammation or hemorrhage - GI symptoms - Liver Failure - Pneumonia - Dermatitis - Death | - Promotes tumors (liver and colorectal) - Liver Failure - Death |
| Nodularin | <i>Nodularia</i> | | See Microcystin | See Microcystin |
| Saxitoxin | <i>Anabaena, Aphanizomenon, Cyndrospermopsis, Lyngbya, Oscillatoria, Planktothrix</i> | 10 µg/kg | See Anatoxin-a | Unknown |

There are over 2,000 known species of cyanobacteria, 5% of which are able to produce cyanotoxins, with some species capable of producing more than one type of cyanotoxin (Table 1) (O'Keefe, 2019). Cyanotoxins, at certain concentrations, can affect a range of organs, such as the liver (hepatotoxins), skin (dermatotoxins), or nervous system (neurotoxins) (Table 1) (Chorus and Bartram, 1999; Ferrão-Filho and Kozlowsky-Suzuki, 2011; Carmichael and Boyer, 2016;

O’Keefe, 2019). Exposure to some cyanotoxins can cause acute reactions including vomiting, diarrhoea, skin irritation, fever, rash, and headaches (Table 1) (O’Keefe, 2019). Cyanotoxins are also possible carcinogens, promoting the growth of various types of tumours – skin, brain, and liver (Table 1) (Codd, 2000; WHO, 2010; Chen et al., 2020). Cyanotoxins are mainly found within the cyanobacterial cell and released during lysis (Cheung et al., 2013; Sharma et al., 2014, Chapter 15). However, certain cyanotoxins can be found extra-cellularly (without lysis) – saxitoxins or cylindrospermopsin, for example (Ibelings et al., 2015).

Table 2: Cyanotoxin mode and risk of exposure to cyanotoxins by different activities (recreational and otherwise) (Stone and Bress, 2007; Codd et al., 2017).

| Mode of Exposure | Exposure Risk | Activity |
|----------------------|---------------|---|
| Oral | High | Drinking Water (untreated), swimming/wading, water skiing, wake boarding, knee boarding, wind surfing, jet skiing |
| | Moderate | Fish/Shellfish/Crustaceans/Plant Food Consumption |
| | Low | Crop consumption*, Hiking ^a |
| Dermal | High | Swimming/wading, showering |
| | Moderate | Canoeing, Rowing, Sailing, Kayaking |
| | Low | Catch and release fishing |
| Inhalation | High | Water skiing, wake boarding, knee boarding, wind surfing, jet skiing, showering, work |
| | Moderate | Canoeing, rowing, sailing, kayaking, motorboat cruising |
| | Low | --- |
| Haemodialysis | High | Only if cyanotoxin containing water used for dialysis treatment |
| | Moderate | --- |
| | Low | --- |

*When/if cyanotoxin containing spray-irrigation water used

^a Possible risk of hikers consuming contaminated water should surface water be used for consumption

Exposure can occur via consumption of contaminated water, by physical contact with the bloom, by inhalation of water molecules containing cyanotoxins, through haemodialysis with contaminated water, or potentially by the consumption of fish or produce that have been exposed to a bloom and its toxins (Table 2) (Codd, 2000; Stone and Bress, 2007; Hilborn and Beasley, 2015; Codd et al., 2017; Chorus and Welker, 2021). Not all cyanobacteria species produce toxins, therefore, not all blooms produce toxins, nor are blooms always visible when toxins are discovered (O’Keefe, 2019). This is because cyanotoxins are able to accumulate during periods of low-level growth where no bloom is present (O’Keefe, 2019). The purpose and cause of cyanotoxin production by a bloom is not well understood and is highly variable between and within blooms (Stone and Bress, 2007; Cheung et al., 2013). Toxicity within a single bloom can vary by only meters (Stone and Bress, 2007). Even the toxicology of cyanotoxins is not well established, with only a handful of toxins having known toxicity levels and established tolerable daily intake (TDI) or Maximum Acceptable Concentration (MAC) levels (Table 1) (Stone and Bress, 2007; Ibelings et al., 2014; Sharma et al., 2014).

Cyanobacteria and their toxins pose a threat to more than just humans; aquatic and terrestrial species are also at risk (Hilborn and Beasley, 2015; Codd, 2000). In high enough concentrations, cyanotoxins can poison aquatic animals, cattle, domesticated pets, and various other wildlife (Ettoumi et al., 2011; Jacoby and Kann, 2007; Kotak and Zurawell, 2007). Blooms also pose a risk to aquatic animals through their contribution to anoxic (no DO) or hypoxic (defined as < 2 mg/L DO) events in lake systems (Paerl, 2014; Paerl and Otten, 2013). These anoxic and hypoxic events can result in death for various forms of multicellular life due to oxygen deprivation (Paerl, 2014; Paerl and Otten, 2013). Such as in 2009, when a bloom in Chesapeake Bay along the eastern US resulted in DO levels so low that a “dead zone” (DO is so low, multi-cellular life cannot be supported) formed (Greenhalgh and Selman, 2012; Bennett, 2017).

2.1 Cyanobacteria Blooms: Science, Research, and Monitoring

2.1.1 Eutrophication

Cultural eutrophication is believed to be the leading cause of cyanobacteria bloom formation and thus, the largest threat to surface water quality today (Nürnberg, 2017). Eutrophication – excess concentrations of nutrients in a waterbody (Harper, 1992) – is a slow, natural process, whereas, cultural eutrophication is the result of two forms of anthropogenic pollution: point source (PS) and nonpoint source (NPS) nutrient loading. PS nutrient loading is pollution that enters the environment from easily identified and confined spaces, such as sewage lagoons, wastewater treatment plants (WWTPs), and storm drains (Patterson et al., 2013; O’Keefe, 2019). NPS nutrient loading is pollution that enters the environment from diffuse sources across the landscape, such as agricultural runoff, urban runoff, and septic systems (Patterson et al., 2013; O’Keefe, 2019). The nutrients of concern are phosphorus (P) and, to a lesser extent for cyanobacteria blooms, nitrogen (N) (Schindler, 2012; Smith and Schindler, 2009; Verschoor et al., 2017) because P is one of the limiting factors for cyanobacteria production (Harper, 1992). P loading in waterbodies can also be the result of internal P loading, where ‘legacy’ P bound within lake sediment is released during conditions of anoxia (Orihel et al., 2017). Internal loading is intrinsically linked with external loading, with legacy P increased under high NPS and PS loading and lake retention times (Nürnberg and Lazerte, 2016).

Eutrophication has two major environmental impacts: increased biological productivity and low DO (Harper, 1992; Crossman et al., 2013). Low DO produces anoxic or hypoxic events, putting a strain on fish and other multi-cellular life within a lake system (Molot et al., 2014).

Increased biological productivity also results in a DO positive feedback loop; as increased organic matter eventually decomposes, it decreases DO concentrations, especially towards the bottom of the lake causing anoxic or hypoxic conditions (ECCC and MWS, 2011; Dorgham, 2014).

Nutrient management remains the cornerstone of cyanobacteria management due to reduced nutrient enrichment decreasing the risk of blooms. However, nutrient poor (oligotrophic) lakes are experiencing cyanobacteria blooms with greater frequency, therefore limiting nutrient loading is not a universal means of mitigating cyanobacteria blooms.

2.1.2 Scientific Uncertainty and Bloom Research

Despite bloom formations associated with cultural eutrophication, there is still scientific uncertainty around the cause of blooms (Sharma et al., 2010) because, in addition to numerous large eutrophic lakes, such as Lake Erie, Lake Ontario, Lake of the Woods and smaller inland lakes, blooms are now being reported in oligotrophic (nutrient-poor) lakes across Canada and elsewhere (Winter et al., 2011; Sorichetti et al., 2014; Verschoor et al., 2017; Reinl et al., 2021). While not a lot of research has been done on the subject, the current suspected cause of blooms in these nutrient-poor systems is climate change-enhanced seasonal stratification (separation of water into two distinct layers) induced sediment anoxia (Molot et al., 2014, 2021a, 2021b; Verschoor et al., 2017). Seasonal stratification can produce anoxia along the sediment-water interface, which triggers internal ferrous iron (Fe^{2+}) loading and internal P loading, i.e., the release of critical nutrients from anoxic sediments into overlying waters (Figure 1) (Molot et al., 2014, 2021b; Verschoor et al., 2017). Certain species of cyanobacteria are able to migrate into, or adjacent to, these anoxic waters to secure Fe^{2+} and P in order to support population growth (Molot et al., 2014, 2021b; Verschoor et al., 2017). This procurement of Fe^{2+} is significant, as it allows cyanobacteria to outcompete eukaryotic algae, shifting the dominant species present in the bloom (Molot et al., 2014; 2021b; Verschoor et al., 2017). This increase in seasonal thermal stratification and the subsequent anoxic events are believed to be climate change induced (Deng et al., 2018; Molot et al., 2021b). Increasing temperatures and decreased terrestrial wind speeds under climate change (Deng et al., 2018) increase water temperature, allowing for thermal stratification events to occur more frequently (Molot et al., 2014, 2021b; Verschoor et al., 2017).

Climate change is also a compounding factor for cyanobacteria blooms in more nutrient rich mesotrophic, eutrophic, and hypereutrophic systems (Pick, 2015). Winter and under-ice

blooms are predicted to increase as a result of warmer winter temperatures and decreased snow cover. Longer warm periods can intensify early winter stratification in small shallow lakes due to the release of increased heat stored in sediment; the subsequent discharge of nutrients allowing for bloom activity (Bertilsson et al., 2013). Warming temperatures also increase winter snow melt, revealing clear lake ice cover, which allows light to penetrate the ice, warming surface waters (Bertilsson et al., 2013). Under ice water heated by solar radiation can trigger stratification and therefore internal loading allowing for bloom formation under ice (Bertilsson et al., 2013). Decreased snow cover to insulate river ice can also increase ice jam events in the spring, increasing flood events and nutrient loading (Lindenschmidt et al., 2010). Precipitation patterns under climate change are increasing the occurrence of heavy rainfall, flooding events, and other extreme weather events, affecting hydrology/overland flow patterns, exacerbating nutrient loading, especially from NPSs, increasing bloom occurrence (Pick, 2015). At the other end of the spectrum, bloom formation can also increase under low precipitation patterns – warming surface temperatures result in longer periods of warm, dry, and low turbidity days producing optimal conditions for blooms (Pick, 2015).

The presence of certain aquatic invasive species is a known compounding factor for the presence of cyanobacteria blooms (Pick, 2015). Some studies have shown that zebra and quagga mussels (*Dreissena*) selectively filter *Microcystis*, which can increase toxic bloom formation (Raikow et al., 2004; Higgins and Vander Zanden, 2010; Horst et al., 2014; Pick, 2015). For example, in Michigan, blooms on lakes with zebra mussels are, on average, four times more toxic than on lakes where mussels are absent (Knoll et al., 2008; Pick, 2015). On the other hand, mussels divert nutrients inshore (Hecky et al. 2004) which may exacerbate blooms.

While P is the main nutrient of concern for cyanobacteria blooms (Watson et al., 2016), some research also considers N or a N:P ratio important for bloom formation (Paerl et al., 2011), despite recent papers showing the efficacy of N removal on reducing bloom events being ineffective and the removal costly (Schindler et al., 2008; Schindler, 2012; Higgins et al. 2018; Molot, 2017; Molot et al., 2021a, 2021b).

Some studies have shown that reducing N and/or maintaining a N:P ratio can limit bloom toxicity (reduces cyanotoxin production) as a number of cyanotoxin producing species are not N-fixers (Orihel et al., 2012; Horst et al., 2014; Gobler et al., 2016). However, limiting N serves to shift species composition towards N-fixing cyanobacteria, especially in eutrophic conditions

(Schindler et al., 2008; Molot et al., 2021a, 2021b). This shift in species composition can also increase dissolved N availability, as when cyanobacteria fix atmospheric N, leakage from the cell occurs making N available to non-N fixing species (Schindler et al., 2008b; Pinto and Litchman, 2010; Beversdorf et al., 2013; Molot et al. 2021a, 2021b). While limiting nitrogen or using a low N:P ratio may lower cyanobacteria toxin production, it will not decrease bloom frequency and/or extent (Schindler, 2012; Molot et al., 2021a, 2021b). Even so, some provinces have opted to set P and N targets for waterbodies to manage blooms, such as Lake Winnipeg in Manitoba and 4 lakes located in the Upper Qu'Appelle River Watershed in Saskatchewan (SWA and UQRWCWAC, 2008; GOC, 2021). Limiting both N and P is also a method utilized in the US to deal with cyanobacteria blooms (Lopez et al., 2008) and for the Baltic Sea in Europe (Bianchi et al., 2000).

Scientific research is continuing to learn about the mechanisms that promote bloom formation. While there is ongoing uncertainty, cyanobacteria management must move beyond just nutrient management and dissolved oxygen at the sediment-water interface might be a better solution, especially for oligotrophic and mesotrophic lakes.

2.1.3 Monitoring Programs

Given the difficulty predicting the occurrence of a cyanobacteria bloom, monitoring cyanobacteria blooms in high-risk areas is essential for mitigating the risk of exposure. Local knowledge about blooms, such as when and where they occur, is an integral component for preventing, controlling, and mitigating the risk (Codd et al., 1999; Codd, 2000; Ibelings et al., 2016).

Monitoring programs and the methods used depend on program objectives and resources (Codd et al., 1999). According to Codd et al. (1999), monitoring programmes can be based on: risk management (bloom and toxin presence), areas of common contamination, the development of regulations for public areas/recreational sites, outreach and education, understanding the cause of blooms, monitoring for compliance (recreational and/or drinking water), predicting occurrences and changes for cyanobacteria populations and cyanotoxin concentrations, understanding the effectiveness of interventions from the watershed scale to in-situ treatments, and adaptive management (the incorporation of the latest scientific literature including ecology, hydrobiology, and environmental conditions). The main component of the majority of monitoring strategies are based on the identification of threshold values that define public

notification protocols and intervention methods (Zamyadi et al., 2016), often using Federal Guidelines and/or provincial regulations (Watson et al., 2017). These programs are, therefore, centred on source and recreational waters to mitigate risk to public health (compliance monitoring) (Zamyadi et al., 2016; Health Canada, 2017; Chorus and Welker, 2021).

There are three main methods of waterbody monitoring for blooms: visual, sampling, and remote sensing, with visual and sampling being either routine or reactive (see Chapter 3, section 3.3) and often used in combination.

Visual monitoring is as it sounds, a visual inspection of surface water for the presence of blooms. This method requires the ability to recognize cyanobacteria blooms and distinguish them from other phytoplankton blooms (Jang et al., 2003; Ibelings et al., 2014; Health Canada, 2017). It also requires that the bloom is visible – either on the surface or condensed to a single area or if benthic or metalimnetic, visible from the surface (Health Canada, 2017). Cyanobacteria blooms can be blue, green, blue-green, yellow, red, brown, purple or almost black depending on pigment ratios of the cells and the quality of light (Sharma et al., 2014; Chorus and Welker, 2021). Odour can also be an indicator, with some blooms producing a bad smell, though others do not (Sharma et al., 2014; Chorus and Welker, 2021). Given the range of colours, the varying depths at which blooms can occur, and the fact that a bloom can contain cyanobacteria but not in an abundance great enough to constitute a cyanobacteria bloom (greater than 50% cyanobacteria), confirmation visually is difficult to say the least.

Samples can be collected upon visual confirmation of a bloom (reactive) or as part of a routine monitoring program (Health Canada, 2017; Chorus and Welker, 2021). Sampling methods are generally discrete (single depth) grab or multi-depth composite, which are then analyzed for species composition, cell count, and toxin levels using a variety of methods (Health Canada, 2017; Chorus and Welker, 2021). Cyanobacteria speciation and counts are done visually under a microscope (microscopy), which requires expertise and time (Chorus and Bartram, 1999; Sharma et al., 2014, Chapter 16; Health Canada, 2017) and is thus expensive. Monitoring species and their counts within a bloom can help inform the potential for a bloom to produce toxins, an important aspect of risk management (Codd et al., 1999). Determining cyanotoxin concentrations requires laboratory analysis using assays or liquid chromatography/mass spectrometry. Some assay methods are Enzyme-Linked Immunosorbent Assay (ELISA) and Protein Phosphatase Inhibition (PPI) Assay (Sharma et al., 2014, Chapter 16; Health Canada, 2017; Chorus and

Welker, 2021). A high-performance liquid chromatography/high-resolution mass spectrometry method used is liquid chromatography-(electrospray ionisation) tandem mass spectrometry (LC-(ESI)MS/MS) (MOE, 2010). The method of analysis used depends on the type of cyanotoxin being tested for and the equipment available. Assays are predominantly used for Microcystin and Nodularin detection, as they are not as effective for other cyanotoxins (Sharma et al., 2014, Chapter 16). Assays are also generally used for preliminary screening, with mass spectrometry acting as the validator for the results (Sharma et al., 2014, Chapter 16). The ability to compare the results of the varying methods of cyanotoxin analyses are not well known, and not all methods of analysis are able to distinguish between the different types of toxins produced and their structural variants of which there are many (Sharma et al., 2014, Chapter 16; Gaget et al., 2017). For example, Microcystins have over 80 known structural variants (Davis et al., 2009; Cheung et al., 2013). Laboratory results are used even though they take time (several days to a week depending on the method of analysis) because there is no reliable means of rapidly testing blooms for toxin presence (O'Keefe, 2019). Given that laboratory analyses for cyanobacteria and their toxins are expensive and sampling and testing are often not part of routine water quality monitoring programs, rather these methods are applied when the risk of toxin exposure is high (Sharma et al., 2014, Chapter 16). In terms of timing, it is recommended that samples be collected during the visible bloom period and after, as decomposition is when cyanotoxin levels are likely to be the greatest (Health Canada, 2017; Chorus and Welker, 2021). That is, cyanotoxins are released upon cell lysis (breakdown), which can be induced by decomposition and/or chemical or physical rupture (Sharma et al., 2010; Sharma et al., 2014). The frequency and location of sampling is dependent on time, regulatory requirements, risk, cost, waterbody use, and sampling purpose (Codd et al., 1999).

Photosynthetic pigments can be used as a proxy for cyanobacteria bloom biomass. There are a range of in-situ fluorescence sensors that monitor for the presence of pigments produced by cyanobacteria, where pigment concentrations are used as an indicator of biomass (Zamyadi et al., 2016; Beck et al., 2017). The pigments used to indicate cyanobacteria biomass are: Chlorophyll-a (Chl-a), a green pigment produced by cyanobacteria and other phytoplankton, Phycocyanin (PC), a blue-pigment produced by cyanobacteria, or Phycoerythrin (PE), a pigment specific to red cyanobacteria (Zamyadi et al., 2016; Health Canada, 2017; Bertone et al., 2019). Fluorescence sensors are an efficient means of monitoring for cyanobacteria blooms as they can aid in rapid

detection and response, which is especially helpful for risk management (Zamyadi et al., 2016). Limitations include, results not being inclusive of whole-lake conditions given that the data are limited to sensor location, probes can be damaged or fouled by blooms or environmental conditions, limits to the range of pigments picked up, and the sensors are relatively expensive (Zamyadi et al., 2016).

Fluorescence sensors are not always in-situ; they can be carried by airplanes, helicopters, or be built into satellites (remote sensing), where images are collected and analyzed algorithmically for fluorescence reflectance to indicate bloom biomass in the top 1 m of a water body (Zamyadi et al., 2016; Beck et al., 2017). Limitations can vary depending on the pigment analyzed for – for example, PC reflectance can be masked by Chl-a, which, while Chl-a is an indicator of cyanobacteria biomass, it is also produced by eukaryotic algae making it difficult to distinguish whether or not a bloom is predominantly cyanobacteria (Mishra et al., 2009; Beck et al., 2017; Wood et al., 2020). Regardless of the pigment used, imagery analysis is impacted by the size and depth of a bloom, scale (lake and bloom), and environmental conditions. Moreover, it is costly and requires calibration and verification (Zamyadi et al., 2016; Beck et al., 2017). Low density, dispersed, and/or under-surface blooms are not well detected by imagery, nor is imagery as effective for small scale lakes (Zamyadi et al., 2016). Cloud cover, rain, etc. can also impact the quality of the imagery and therefore the suitability of the analysis (Zamyadi et al., 2016).

Monitoring should also include the variables likely to contribute to bloom formation – such as nutrient concentrations (TP levels), temperature, hydrological conditions, light, wind, phytoplankton species present, and other water quality indicators of bloom activity, like the pigments Chl-a or PC (Codd et al., 1999; Sharma et al., 2014, Chapter 16; Chorus and Welker, 2021). This can aid in cyanobacteria management by outlining the cumulative effects that cause bloom events, what treatment methods might work given site-specific conditions/variables, changes in trophic status that increase the risk of bloom formation, offer indicators of bloom activity over time, and provide evidence for whether or not prevention, control, or mitigation efforts are “successful” (meeting nutrient targets, seeing a reduction in nutrient loading, or observing a decrease in blooms over time, reduction of toxin production). Monitoring of sediment anoxia in high-risk systems may also generate an earlier warning before an increase in cyanobacteria is detected (Molot et al. 2021a).

2.2 Cyanobacteria Bloom Management: Prevention, Control, and Mitigation

Cyanobacteria bloom management is a complex/“wicked” problem because of the multitude of factors that contribute to bloom formation (Figure 1), not to mention the range of actors involved (Patterson et al., 2013). A ‘wicked problem’ is a management problem that is difficult to solve because it is on-going, “multi-scalar, multi-actor, dynamic, uncertain, and unclear” (Patterson et al., 2013, p.442). According to Ibelings et al. (2016), cyanobacteria management can occur in three forms: “prevention”, “control”, and “mitigation”. Prevention is the proactive management of nutrients in a system in order to stop blooms from forming (Ibelings et al., 2016). Control is the use of methods that limit the negative impacts of blooms to a negligible level (Ibelings et al., 2016), also known as risk management (Section 2.2.3). Mitigation is the use of chemical or physical strategies and programs to decrease the occurrence of blooms (Section 2.2.2) (Wang and Wang, 2009; Pick, 2015; Ibelings et al., 2016; ECO, 2017). Within these three forms is a suite of methods available to managers, though success is often limited or variable (Ibelings et al., 2016). Therefore, proper management of blooms requires the coordination of efforts (on land and water) at the watershed scale to be successful (Patterson et al., 2013; Ibelings et al., 2016). That is, “protecting lake water quality from the adverse effects of eutrophication by managing nutrients all the way from the catchment level to the lake-inflows and in-lake P-release from the sediment is the best way to ensure that cyanobacterial blooms do not occur so that cyanobacteria and the toxins they produce cannot compromise lake ecosystem services” (Ibelings et al., 2016, p. 329). All of these depend on a thorough scientific understanding of blooms and monitoring programs coupled with a transfer of this information to policy branches.

2.2.1 Cyanobacteria Bloom Prevention: Nutrient Management

As mentioned, despite the range of factors that contribute to bloom formation, cultural eutrophication of PS and NPS nutrients is still seen as the leading cause, which is why nutrient management has long been and still is the cornerstone of cyanobacteria bloom management in Canada and worldwide (Pick, 2015; Ibelings et al., 2016; ECO, 2017).

Point Source Management

PS nutrient loading was originally the primary form of loading controlled for to limit cyanobacteria blooms (ECO, 2017b), with Lake Erie being a prime example of the success limiting PS P loading into a waterbody can have for reducing blooms when PSs are the primary nutrient source (Schindler et al., 2016). However, since NPS nutrients are now the main source

of P loading into waterbodies, BMP implementation is required for bloom management. Currently, there are two main methods of implementing agri-environmental stewardship programs and their associated BMPs: enforcement and/or encouragement/incentivization, with these programs often used in combination (Rajsic et al., 2012).

PS nutrient loading of P and N is controlled by removing nutrients from effluent water in WWTPs before it is released back into freshwater systems (Oleszkiewicz, 2015; Oleszkiewicz et al., 2015). P can be removed from wastewater using biological or chemical means while N is removed using biological means, both of which can occur in primary, secondary, tertiary, or quaternary WWTPs, though tertiary treatment methods are the most effective (quaternary having cost limitations) (Zekri et al., 2014; Oleszkiewicz et al., 2015; ECO, 2017b).

Biological P removal utilizes microorganisms that uptake and store P in their cells (WEF, 2017). The microorganisms, and their now stored P, are then removed from the water as bio-sludge (WEF, 2017). Chemical P removal uses a binding agent – such as, salt of aluminum, iron, or calcium - to bind P, forming a solid, which is then removed from effluent waters (Oleszkiewicz et al., 2015). Biological N removal involves converting dissolved ammonia to nitrate (nitrification) and then converting nitrate to gaseous dinitrogen (N_2) gas (denitrification) which is an inert, non-toxic, and common component of the atmosphere (Oleszkiewicz et al., 2015; McCarty, 2018).

Primary treatment uses fine screens, sedimentation tanks, and/or flotation to remove suspended solids, floating materials, and some organic matter (ECCC, 2020a; Solt and Shirley, 1991). Secondary treatment biologically treats organic material via stabilization ponds, trickling filters, and/or activated sludge ponds relying on aeration to stimulate microbial removal of organic matter by aerobic decomposition (WEF, 2017). Tertiary treatment occurs after secondary treatment and covers a variety of methods that are used based on site-specific conditions, required effluent standards, and WWTP capacity (ECCC, 2020a; WEF, 2017). This level of treatment is generally only required for WWTPs that discharge into sensitive waterbodies and includes the specific removal of nutrients and other contaminants of concern (ECCC, 2020a; WEF, 2017). Quaternary treatment is a still more advanced form of water treatment that also covers a range of treatment methods (Mavinic et al., 2018). This level of treatment removes contaminants down to parts per billion and often involves oxidation and microfiltration methods (Mavinic et al., 2018).

Nonpoint Source Nutrient Management

NPS nutrient loading is largely the product of agricultural and urban runoff from tens of thousands of farms and cities across provinces, territories, and states, making it very difficult to control let alone enforce (Patterson et al., 2013). As such, it is the primary form of nutrient loading into systems, making the management of NPS nutrient loading a complex, coordinated and often voluntary effort to be successful.

Present-day methods of NPS nutrient management utilized are stewardship programs adapted for several provinces, states, and countries to minimize environmental footprints by promoting ‘environmentally friendly’ farming practices predominantly through the use of encouragement and incentivization, rather than regulatory means (Logan, 1993; Robinson, 2006; Atari et al., 2009). Stewardship is “the responsible use (including conservation) of natural resources in a way that takes full and balanced account of the interests of society, future generations, and other species, as well as of private needs, and accepts significant answerability to society” (Worrell and Appleby, 2000, p.269). Stewardship programs require government oversight, education, outreach, and monitoring and can be either voluntary, encouraged by financial enticements, or by government enforcement (Robinson, 2006; Atari et al., 2009).

Stewardship programs employ the use of best management practices or beneficial management practices (BMPs) to mitigate agriculturally induced impacts to the environment (Morrison and FitzGibbon, 2014). BMPs being “a practical, affordable approach to conserving a farm's soil and water resources without sacrificing productivity” (OMAFRA, 2020). BMPs call for NPS nutrient loading to be reduced through a combination of conservation tillage and various soil erosion control practices, livestock waste management, and nutrient/P management (Logan, 1993). This includes the use of methods that diminish the movement of nutrients by altering/minimizing erosion and runoff, like the installation of barriers and buffers to catch or divert sediments and nutrients transported from agricultural fields, and keeping livestock out of streams (Hassanzadeh et al., 2019). Basically, the idea is that new technological innovations and methods of farming (e.g. storage, tillage, transport, fertilizer use) can allow for production and productivity to remain the same, while minimizing environmental harm (Smithers and Furman, 2003).

Effectiveness of BMPs for reducing nutrient loading, particularly of P, is not well known (Foulon et al., 2020). Previous “studies have shown that BMPs are effective conservation

techniques for reducing the impact of agriculture on stream ecosystems” (Yates et al., 2012, p. 332); however, the research is often small scale and based on the use of a single BMP. Large-scale studies have been conducted, but the results are impacted by study sites being chosen for high BMP adoption rates, making them poor indicators of real-world conditions (Yates et al., 2012) since BMPs are not being adopted by the majority of farmers (Liu et al., 2018; Foulon et al., 2020). For example, Brethour et al. (2007) found that conservation tillage and soil sampling were adopted by 80% of surveyed farmers, while nutrient application and timing were only implemented by 65% and 60% of participants, respectively. Adoption rates for buffer strips, no-till, cover crops, and nutrient managements plans were even lower at 40% and 50% (Brethour et al., 2007). More recently, studies have shown that the adoption rates for BMPs can range from 30 to 80% depending on location and the BMP in question (Liu et al., 2018; Foulon et al., 2020). Furthermore, interpretation of the effectiveness of specific BMPs in large watersheds is confounded by implementation of many different types of BMPs by farmers.

Environmental conditions can also impact the effectiveness of BMPs (Mulla et al., 2006; Liu et al., 2016; Afroz et al., 2021). That is, varying geology, topography, soil characteristics, land-use, climate, and hydrological conditions can impact the efficacy of BMPs for reducing nutrient loading and even the optimal time of use for specific BMPs (Sharpley, 2015; Liu et al., 2016; Xu et al., 2019). For example, precipitation patterns and overland flow can make it difficult to apply manure or fertilizers without significant nutrient loss and therefore nutrient loading (Xu et al., 2019). As such, manure and fertilizers should not be applied before a rainstorm or during known flooding periods (Xu et al., 2019). This is corroborated by Liu et al. (2016) who found that the greatest reductions in TP export from agricultural fields occurred under nutrient management scenarios – when fertilizer and manure applications were reduced. As such, it is recommended that BMPs be allocated to areas based on environmental conditions and type of farming activity rather than generally applied, targeting areas of greater pollution potential, increasing cost effectiveness (Khanna et al., 2003; Yang and Weersink, 2004; Yang et al., 2005; Xu et al., 2019). This is the also called the ‘hot spot’ approach.

Climate change is also predicted to impact the effectiveness of BMPs with current BMP programs and practices likely insufficient to deal with nutrient loading scenarios under climate change (Woznicki and Nejadhashemi, 2014). As previously mentioned, various climate change impacts are predicted to increase nutrient loading because of increased runoff and frequency of

large storm events, which given the lack of adoption and current limited effectiveness of BMP implementation can only further cultural eutrophication, internal loading, and therefore blooms.

Given all these limitations the effectiveness and efficiency of NPS nutrient management practices still remain “elusive and more difficult to identify, quantify, target, and remediate” (Sharpley, 2015, p. 1).

2.2.2 Cyanobacteria Bloom Mitigation: Chemical and Physical In-Lake Treatments

P concentrations can also be controlled using in-lake (in-situ) treatments; chemical and/or physical means of reducing biologically available nutrients in the water column and/or limiting nutrients released from sediment (Ibelings et al., 2016). Chemical treatments include adding a chemical compound that forms a strong bond with P found within the water column (flocculation) or released from lake sediment to limit bioavailable P (chemical inactivation) (Zamparas and Zacharias, 2014; Lin et al., 2017; George et al., 2019). Physical treatment generally means using mechanical interventions to reduce nutrients stored within sediment (dredging) or that prevent the release of nutrients stored in lake sediments during anoxic conditions (aeration/oxygenation) (Ibelings et al., 2016).

Chemical Bloom Management

Two chemicals that have been employed to limit internal loading and prevent cyanobacteria blooms are Phoslock[®] and aluminum sulfate (alum).

Phoslock is a lanthanum-based compound; lanthanum binds to phosphate to form a stable mineral rhabdophane, reducing the bioavailability of P (Afsar and Groves, 2008; van Oosterhout and Lüring, 2013). Phoslock can strip bioavailable P in the water column and intercept P released from sediment (van Oosterhout and Lüring, 2013), though efficiency is impacted by varying climatological and limnological lake conditions (Yin et al., 2016). For example, according to Zeller and Alperin (2021), Phoslock is less effective under high DO sediment conditions and more effective under anoxic conditions. Phoslock has also been found to leach ammonia (NH₄⁺) under conditions that reduce the stability of the compound in lab settings (Spears et al., 2013; van Oosterhout and Lüring, 2013; Reitzel et al., 2017), which means that natural lake conditions, such as “low alkalinity and/or high humic substance content”, could trigger ammonia release (Zeller and Alperin, 2021, p. 100095). Phoslock must be applied every two-three years, depending on local conditions and lake characteristics.

Alum is an aluminium-based compound that, in its aluminum hydroxide precipitate form (floc), binds to P released from sediment or, to a lesser extent, found within the water column to

form an aluminium phosphate compound (Afsar and Groves, 2008; George et al., 2019). The aluminum phosphate compound is insoluble under most conditions, making the P biologically unavailable to phytoplankton even when sediments become anoxic unlike other chemical agents like ferric iron chloride (Afsar and Groves, 2008; George et al., 2019). Alum binds to various forms of P, resulting in the formation of a range of aluminum phosphate complexes and its effectiveness is impacted by the pH of water (Afsar and Groves, 2008; George et al., 2019). That is, alum requires a circumneutral (6-8) pH to be effective (Afsar and Groves, 2008; Zamparas and Zacharias, 2014; George et al., 2019). Using alum or an aluminum (Al) compound at pH levels below 6 can release toxic forms of Al into the water column, it is less effective at a pH of 8 or higher, and it can release toxic substances even when used in circumneutral waters, depending on water hardness and dissolved organic content (George et al., 2019).

Chemical controls to limit eutrophication all have varying negative impacts on aquatic organisms and the proper functioning of aquatic ecosystems (Afsar and Groves, 2008; Zamparas and Zacharias, 2014; George et al., 2019). Chemical controls also aren't recommended for large waterbodies due to the dosing size that would be required to achieve the desired results and the costs associated with those amounts (George et al., 2019). Then there is the fact that reapplication is necessary when external loading from anthropogenic sources isn't reduced or lake characteristics diminish the efficacy of the application (Sharma et al., 2014, Chapter 15). The longterm success of these applications is relatively unknown, with changing environmental conditions both seasonal and under climate change having the potential to trigger the release of nutrients bound to these compounds and the base chemicals themselves, which can be heavy metals and/or the decrease in effectiveness as the compounds are buried in sediment over time (Zeller and Alperin, 2021).

Physical Bloom Management

Dredging is the physical removal of nutrient rich sediments from the bottom of waterbodies, which is a standard treatment for Dutch urban ponds (Lürding and Faassen, 2012). It is used to decrease bloom events by reducing P and N stored within sediment (Lürding and Faassen, 2012; Wan et al., 2020). It can also increase DO, thus inhibiting internal loading and decreasing bloom events (Wan et al., 2020). Dredging is costly, energy intensive, and can act to resuspend nutrients stored in sediment during the process of removal (Lürding and Faassen, 2012; Wan et al., 2020). It can also negatively impact aquatic organisms by “affecting the stability of

freshwater ecosystems” (Wan et al., 2020, p. 8). Basically, dredging is an anthropogenic disturbance that can disrupt spawning grounds and alter the functionality and composition of other microbial communities within the aquatic ecosystem by shifting species composition towards disturbance loving species (Zhang et al., 2017; Wan et al., 2020). Dredging can also result in the resuspension of heavy metals, which are a risk to human, aquatic, and terrestrial organism health (Chen et al., 2019).

Aeration/oxygenation can be achieved using artificial mixing (surface or at depth), hypolimnetic oxygenation, and/or hypolimnetic siphoning using a variety of pumps (Sharma et al., 2014, Chapter 15; Visser et al., 2016). These are means of preventing blooms by alleviating anoxic conditions that lead to nutrient release from sediment (Visser et al., 1996; Visser et al., 2016). Basically, it is the physical manipulation of the water column, altering phytoplankton biomass and composition (Visser et al., 2016). Artificial mixing at depth (artificial destratification) is able to reduce bloom activity in two ways. First, it can increase competition with algae and/or other phytoplankton for nutrient resources by mixing them into the water column (Visser et al., 2016). Second, it can sequester buoyant light-loving cyanobacteria to the deeper portions of the lake and/or causes fluctuations in light availability, limiting cyanobacteria activity (Visser et al., 2016). There are a variety of environmental impacts depending on the method of aeration/oxygenation used due to disturbance of the water column. For example, artificial destratification tends to alter phytoplankton assemblages by producing turbulent waters that favour heavily silicified diatoms, which generally settle out of the water column under calm conditions during stratification (Sharma et al., 2014, Chapter 15). There are also the economic costs associated with the machinery used, which are impacted by the desired effect of the methods used and the size of the lake/waterbody (Sharma et al., 2014, Chapter 15).

2.2.3 Cyanobacteria Bloom Control: Risk Management

Risk Management “is the process which evaluates how to protect public health”

(Environmental Protection Agency, 2017; Kwiatkowski, 1998) and more recently, environmental health (Codd et al., 2005) when a potentially harmful event occurs. It is the control options, policies, regulations, guidelines, and decision making frameworks (social, economic, and environmental) that are used to mitigate risk (Hamilton et al., 2006; Dunn, Harris, et al., 2014). This includes consideration of the uncertainties around the decisions made and their effectiveness, as well as balancing potential exposure to the hazard against treatment options and

various other mitigative strategies, like education and outreach and advisories (Hamilton et al., 2006; Dunn, Harris, et al., 2014).

An important, but distinct component of risk management is risk assessment – the science-based processes that identify, measure, and characterize the hazard and analyze and characterise the risk and risk of exposure before a decision is made (Harvey et al., 1995; Burch et al., 1999; Dunn, Harris, et al., 2014). In terms of water quality, this usually includes a source-to-tap framework that provides an integrated understanding of all the risks posed to surface source waters quality and quantity (Harvey et al., 1995; Dunn, Harris, et al., 2014). Risk assessment and management are both used to develop policies, programs, practices, and protocols that mitigate risk, however, “implementation of risk management varies greatly according to the political, social, and economic context in which it takes place” (Christoffersen and Kaas, 2000, p. 186). It also tends to vary across scale, both within and between countries (Harvey et al., 1995; Burch et al., 1999; Dunn, Harris, et al., 2014).

In the case of cyanobacteria blooms, risk management focuses on producing strategies to protect human and environmental health from the risks posed by blooms and the toxins they produce in drinking and, to a lesser extent, recreational waters (Codd, Morrison, et al., 2005; Ibelings et al., 2015). Many countries developed these risk management strategies for blooms and their toxins after associated health incidents affecting animals and humans occurred (Codd et al., 2005). As such, risk management is often centred around responding to the presence of blooms rather than preventing or mitigating them (Codd, Morrison, et al., 2005; Ibelings et al., 2015). These risk management programs generally use threshold values for cell counts and toxin levels, where the number of cyanobacteria cells and/or a regulated MACs for cyanotoxins serve to trigger an alert or response protocol (Chorus, 2005; Ibelings et al., 2014; Chorus and Welker, 2021). These alert and response protocols are short-term actions taken to protect public health in the event that regulated levels are exceeded, such as public notifications and/or closures (beach and DWTPs) (Chorus, 2005; Ibelings et al., 2015). It is widely accepted that the needs of risk management would be smaller under programs meant to prevent the occurrence of blooms, rather than just dealing with the negative health effects in source and recreational waters (Codd et al., 2005). Despite this, “most countries that regulate cyanotoxins define limits for concentrations in finished drinking-water and, albeit less widely, in water used for recreational purposes” (Ibelings et al., 2015) rather than focusing on implementing frameworks to lower their occurrence.

According to Codd et al. (2005), a sequence of actions (risk assessment) are generally followed to produce risk management strategies that deal with blooms and their toxins, which are: (1) situational assessment, (2) action priorities, (3) identification of control points, (4) economic appraisal of feasible treatment options, (5) environmental appraisal of economically feasible treatment options, (6) selection of options, (7) development of an action plan, (8) implementation of the action plan, (9) monitoring the effectiveness, (10) and if necessary, modification the action plan and implementation of the revised plan. Action plans developed to mitigate the risks posed by blooms need to be based in science and regularly re-evaluated so that advances in research around treatment and mitigation methods can be integrated into these action plans (adaptive management) (Codd et al., 2005). As such, risk management involves monitoring, education and outreach, public advisories, and drinking water treatment (DWT) methods, which will be discussed further in this section.

Routine Vs. Reactive Monitoring

There are two types of monitoring programs for blooms to manage risk – routine/operational and reactive (Chorus and Welker, 2021). Routine monitoring is scheduled visual and/or sampling of waterbodies for cyanobacteria presence which “aims to ensure that the water-use system is “pro-actively” managed to avoid human exposure to unsafe water” (Chorus and Welker, 2021, p. 428). Reactive or “event-driven” monitoring (a form of passive monitoring) is responding to reports of blooms from external sources, such as the public, DWTP owners and operators, other government organizations, and/or NGO employees (Krokowski and Jamieson, 2002; Backer et al., 2015; Chorus and Welker, 2021). Both types of monitoring programs are generally centered around detecting “threshold levels” of specific variables in waterbodies significant to humans – surface source/drinking waters and recreational waters (Ibelings et al., 2014; Zamyadi et al., 2016; Chorus and Welker, 2021).

Table 3: Cyanotoxin threshold values for treated drinking water, recreational water, and freshwater seafood used in a variety of jurisdictions and those suggested by the WHO (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014; Farrer et al., 2015).

| Cyanotoxin | Treated Drinking Water TDI/MAC | Recreational Water MAC | Freshwater Seafood |
|-------------------------------------|---|---------------------------------------|---------------------------------------|
| Anatoxin-a | 0.4 µg/L – dog specific (Oregon, US) 3.0 µg/L (Oregon, US) 3.7 µg/L (Quebec) 6.0 µg/L (New Zealand) 30 µg/L (WHO) | 20 µg/L (Oregon, US) 60 µg/L (WHO) | 1100 ng/g wet weight (California, US) |
| Anatoxin-a(S) | 1 µg/L (New Zealand) | No Level | No Level |
| Beta-N-methylamino-L-alanine | No level | No Level | No Level |

| | | | |
|---------------------------|--|--|--|
| Cylindrospermopsin | 0.1 µg/L – dog specific (Oregon, US) 0.7 µg/L (WHO, lifetime) 1.0 µg/L (Australia; Oregon, US) 15.0 µg/L (Brazil) 3.0 µg/L (WHO, short term) | 6 µg/L (WHO; Oregon, US) | 18-39 µg/kg whole organism (Victoria, Australia) 66 ng/g wet weight (California, US) |
| Homoanatoxin-a | 2 µg/L (New Zealand) | No Level | No Level |
| Lipopolysaccharide | No Level | No Level | No Level |
| Lyngbyatoxin | No Level | No Level | No Level |
| Microcystin | 0.2 µg/L – dog specific (Oregon, US) 0.4 µg/L (WHO; Minnesota, US) 1.0 µg/L (WHO, Brazil, France, Finland, Singapore, Spain, Uruguay, South Africa, Ohio, Oregon for MC-LR or MC variants) 1.3 µg/L (Australia, New Zealand) 1.5 µg/L (Canada for MC-LR) 12.0 µg/L (WHO short term) | > 6 µg/L (Ohio, US) ≥ 10 µg/L (Australia) > 10 µg/L or > 100 µg/L (Brazil) 10 µg/L (Oregon, US) 10 µg/L to 50 µg/L (Hungary) > 10 µg/L < (Germany) < 10 to > 25 µg/L (Turkey) 12 µg/L (New Zealand) ≤ 20 µg/L (Canada, Netherlands) 24 µg/L (WHO) 25 µg/L ± 5% (France) > 25 µg/L (Italy) > 100 µg/L (Germany) | 24-51 µg/kg whole organisms (Victoria, Australia) 10 ng/g wet weight (California, US) 5.6 µg/kg fish tissue for adults (France) 1.4 µg/kg fish tissue for children (France) |
| Nodularin | No Level | No Level | No Level |
| Saxitoxin | 0.02 – dog specific (Oregon, US) 1.0 µg/L (New Zealand; Oregon, US) 3.0 µg/L (Australia, Brazil, WHO) | 10 µg/L (Oregon, US) 30 µg/L (WHO) | 800 µg/kg whole organism (Victoria, Australia) |

Different threshold values result in different response protocols, especially when more than one value is listed for the same country. Some indicators are viewed as equivalent for certain response protocols, such as cell count and biomass.

For cyanobacteria blooms, these threshold levels are generally TDIs/MACs for MC-LR or microcystins, levels that differ between drinking and recreational waters, though the values are all based on the WHO's lifetime Guideline Value (GV) of 1.0 µg/L for MC-LR in treated drinking water (Table 3) (Ibelings et al., 2015; Watson et al., 2017). Threshold levels can also be for other cyanotoxins, bloom biomass, percent bloom cover, chl-a levels, and/or more (**Error! Not a valid bookmark self-reference.**) (Ibelings et al., 2015). However, cyanotoxins other than MC-LR are rarely regulated or monitored for (Table 3) (Ibelings et al., 2015).

Table 4: Other cyanobacteria threshold values, beyond cyanotoxins (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014; Chorus and Welker, 2021).

| Parameter | Drinking Water Threshold Value | Recreational Water Threshold Value |
|----------------------------|---|---|
| Chl-a concentration | ≥ 1 µg/L (Czech Republic, Turkey) ≥ 10 µg/L (Czech Republic) | 10 µg/L (WHO) < 40 µg/L (Germany) 50 µg/L (WHO) |
| Cell Count | ≥ 2,000 cells/mL (Czech Republic) 6,500 cells/mL (Australia for MC) 10 – 20,000 cells/mL (Brazil) < 1,500 cells/mL (Cuba) > 5,000 cells/mL (Finland, Turkey) 40,000 cells/mL (Australia for NOD) ≥ 100,000 cells/mL (Czech Republic, Finland) | 2,000 cells/mL (Ohio, US) > 4,000 cells/mL (Ohio, US) < 500 cells/mL (Cuba) < 20,000 cells/mL ± 20% (France) 20,000 cells/mL (WHO) 20,000 to 100,000 cells/mL ± 20% (France) > 20,000 cells/mL (Czech Republic) ≥ 40,000 cells/mL toxin producing species (Oregon, US) ≥ 500 to < 50,000 cells/mL – species specific (Australia) ≥ 50,000 cells/mL toxin producing species (Australia) ≤ 100,000 cells/mL (Canada) > 100,000 cells/mL ± 10% (France) ≥ 100,000 cells/mL (WHO; Oregon, US; Czech Republic) |

| | | |
|----------------------------|---|---|
| Biomass/Biovolume | $\geq 0.2 \text{ mm}^3/\text{L}$ (Czech Republic) $0.6 \text{ mm}^3/\text{L}$ (Australia for MC) $1 \text{ mm}^3/\text{L}$ (Brazil) $> 1 \text{ mg/L}$ (Finland) $9.1 \text{ mm}^3/\text{L}$ (Australia for NOD) $\geq 10 \text{ mm}^3/\text{L}$ (Czech Republic) $> 20 \text{ mg/L}$ (Finland) | ≥ 0.4 to $< 4 \text{ mm}^3/\text{L}$ for toxin producing species (Australia) ≥ 0.4 to $< 10 \text{ mm}^3/\text{L}$ non-toxin producing species (Australia) $< 1 \text{ mm}^3/\text{L}$ (Germany) $\geq 4 \text{ mm}^3/\text{L}$ known toxin producers (Australia) $\geq 10 \text{ mm}^3/\text{L}$ (Australia) |
| Scum | Persistently present (Cuba) | Observation in bathing area (WHO) Cyanobacteria scum consistently present (Australia) Wide and heavy surface scum (Finland) |
| Species Composition | ≥ 1 colony/mL or ≥ 5 filaments/mL (Czech Republic) At least one toxin producing species present (Cuba) | At least one of the species toxin producing (Cuba) |
| Species Ratio | $> 50\%$ cyanobacteria (Cuba) | $> 50\%$ cyanobacteria (Cuba) $> 80\%$ cyanobacteria (Ohio, US) |

Different threshold values result in different response protocols, especially when more than one value is listed for the same country. Some indicators are viewed as equivalent for certain response protocols, such as cell count and biomass.

Routine monitoring requires site selection, which are generally source/drinking waters and, to a lesser extent, recreational waters, and these programs often operate over a designated time period, often the “open water season” (ice-free period) or summer months (June to September) (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2015; Chorus and Welker, 2021). Routine monitoring’s focus on drinking-water for blooms “may be attributed to its exceptional role as the basis for life, with daily consumption in the range of litres and little means for individuals to avoid exposures when it is contaminated” (Ibelings et al., 2015). Recreational waters are sometimes also routinely monitored because surface water blooms can be wind-blown to the shore, increasing the risk of exposure (Ibelings et al., 2015). Routine monitoring programs allow for blooms to be identified early (i.e., when they are small), in turn allowing for drinking water treatment before public consumption and/or for timely public announcements that limit exposure to cyanotoxins in recreational waters (Chorus and Welker, 2021). This requires site selection; the picking of waterbodies where blooms occur regularly selected and monitored based on historical reports, frequency of use, and risk of occurrence (High TP levels for example) (Chorus and Welker, 2021). The frequency and methods utilized by routine monitoring programs, along with the number of sites selected, and the time period the programs run vary depending on jurisdictional requirements (regulations), costs, and waterbody use (Codd et al., 1999).

Reactive monitoring programs are necessary because “monitoring and surveillance at sufficiently tight intervals both in time and in space to ensure capturing high-risk situations may not be feasible” (Chorus and Welker, 2021, Chapter 15, p. 820). That is, relying on public reporting is critical in jurisdictions where water bodies are too numerous to sample frequently,

such as Ontario and Manitoba. Reactive monitoring does not require site selection; however, it does require a response protocol for reacting to reports of bloom sightings in order to assess and mitigate risk (Krokowski and Jamieson, 2002). Bloom sightings for reactive monitoring are split into two categories – “old sites” and “new sites” (Krokowski and Jamieson, 2002). New sites are locations where blooms have not previously been reported (Krokowski and Jamieson, 2002). Old sites are locations where historically blooms have occurred (Krokowski and Jamieson, 2002). And, like routine monitoring, reactive monitoring tends to occur during the “bloom period”/summer months, when blooms are more likely to occur and be observed (Krokowski and Jamieson, 2002), however, reactive monitoring can result in reports outside of this period as well.

Reactive monitoring is beneficial because it allows for a greater number of lakes to be monitored (than routine monitoring), though the lakes still tend to be those significant to humans/society (frequented by people) (Krokowski and Jamieson, 2002; Chorus and Welker, 2021) and it is more difficult to mitigate risk. It can also result in some waterbodies having more data than others, due to frequency of use or the extent of education and outreach initiatives (Krokowski and Jamieson, 2002; Chorus and Welker, 2021). Blooms can, therefore, be missed due to a lack of recognition or response as a result of program constraints. Reactive monitoring programs also allow for frequency of blooms to be tracked with greater accuracy (Krokowski and Jamieson, 2002). With the public able to monitor and report bloom activity, there is a greater chance that rapidly forming and dissipating blooms will be observed and reported, meaning that frequency and extent can be tracked (Krokowski and Jamieson, 2002). This is limited by public knowledge, both in terms of recognizing blooms and knowledge of who and where to report sightings too, and frequency of use of a waterbody (Krokowski and Jamieson, 2002). Waterbodies with greater human use are more likely to be reported on (Krokowski and Jamieson, 2002), which means that blooms that may and likely do occur on lakes in remote locations are still unknown.

Reactive monitoring does not always result in sampling, which means that initial occurrences and re-occurrences are only tracked via visual confirmation (Krokowski and Jamieson, 2002). This means there is little to no information on the composition of the bloom and/or whether or not the bloom is toxic or capable of producing toxins. Reactive monitoring also means there is a fluctuation in the number of sites sampled and re-sampled annually

(Krokowski and Jamieson, 2002). While this could be due to a decrease in bloom events, it is more likely that blooms are going under reported, because they have occurred frequently before, or they might not have been confirmed via resampling due to program restraints (Krokowski and Jamieson, 2002).

Reactive and routine monitoring programs can be and often are combined (Krokowski and Jamieson, 2002), which means that public reporting and a response protocol are used along with site selected routine visual inspections and sampling.

Cyanobacteria bloom monitoring often use an Alert Level Framework (ALF), which triggers advisories (Figure 2). An ALF “is a monitoring and action sequence that operators and regulators can use for a graduated response to the onset and progress of a potentially toxic cyanobacterial bloom in a drinking water source” (Newcombe et al., 2010, p. 30), where threshold values or situational assessments result in certain risk mitigation responses (Hudnell, 2008; Newcombe et al., 2010; Ibelings et al., 2015). An ALF is multi-tiered, with each tier activated by a threshold value, which in turn triggers a variety of short term actions that mitigate risk of exposure, such as advisories (Figure 2) (Chorus and Bartram, 1999; Ibelings et al., 2014; Chorus and Welker, 2021). As mentioned, the “threshold values” can be for cyanobacteria cell counts and/or cyanotoxin concentrations, chl-a concentrations, bloom biomass, percent mat cover, visible scum, and more (Table 3;

For cyanobacteria blooms, these threshold levels are generally TDIs/MACs for MC-LR or microcystins, levels that differ between drinking and recreational waters, though the values are all based on the WHO's lifetime Guideline Value (GV) of 1.0 µg/L for MC-LR in treated drinking water (Table 3) (Ibelings et al., 2015; Watson et al., 2017). Threshold levels can also be for other cyanotoxins, bloom biomass, percent bloom cover, chl-a levels, and/or more (**Error! Not a valid bookmark self-reference.**) (Ibelings et al., 2015). However, cyanotoxins other than MC-LR are rarely regulated or monitored for (Table 3) (Ibelings et al., 2015). Table 4) (Ibelings et al., 2015).

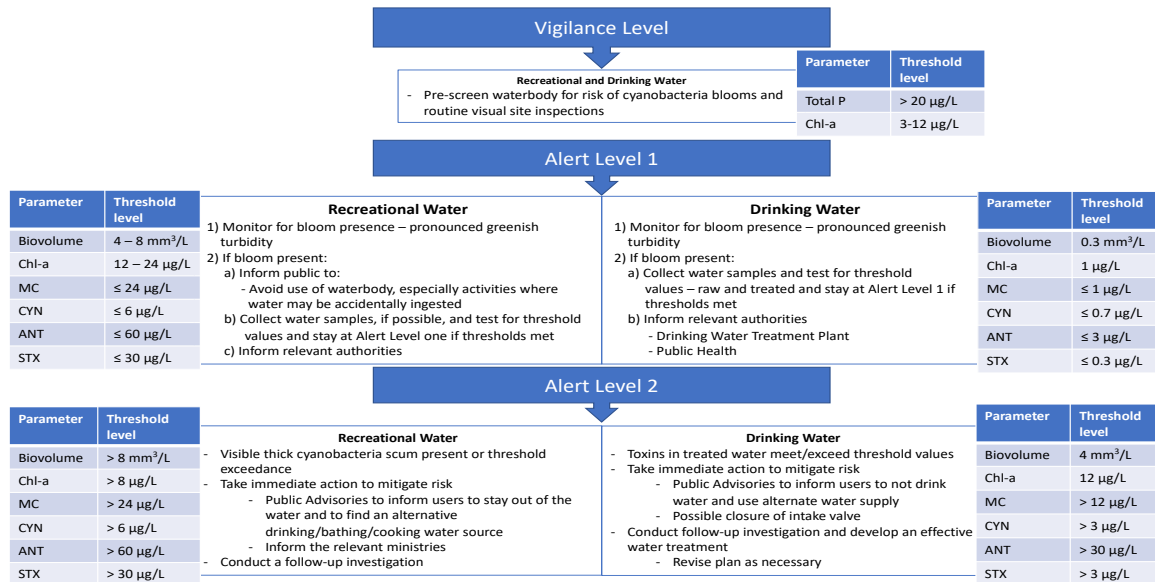


Figure 2: Alert Level Framework suggested by the WHO for cyanobacteria and their toxins in drinking and recreational waters (Chorus and Welker, 2021).

The World Health Organization (WHO) recommends a three-tiered ALF: Vigilance Level, Alert Level 1, and Alert Level 2, with the sequence of responses initiated by the initial detection of cyanobacteria in the Vigilance Level (Figure 2) (Chorus and Welker, 2021). Vigilance level requires site selection and routine monitoring or a reactive monitoring response protocol for cyanobacteria presence, TP levels, and chl-a concentrations (Figure 2) (Chorus and Welker, 2021). For routine monitoring, the sites selected should have an understanding of the risk of bloom occurrence and past bloom events (Chorus and Welker, 2021). Alert Level 1 is triggered by a pronounced greenish turbidity, sampling is conducted for chl-a, biovolume, and cyanotoxin levels, and the public are notified of the potential risks given certain parameter exceedances (Chorus and Welker, 2021). “An Alert Level 1 situation requires extensive public communication, particularly about the rationale for transiently tolerating levels above the lifetime GV’s” (Chorus and Welker, 2021, p. 324). Alert Level 2 is triggered by the presence of surface scum, sampling is conducted for chl-a, biovolume, and cyanotoxin concentrations, and public advisories are required to mitigate risk (Chorus and Welker, 2021). The ALF also tends to activate increased monitoring requirements (Stone and Bress, 2007; Ibelings et al., 2014). For example, in Vermont, USA, when threshold levels are exceeded during routine monthly phytoplankton sampling in recreational waters, sampling is increased to by-monthly, and then weekly depending on the results (Figure 3) (Stone and Bress, 2007).

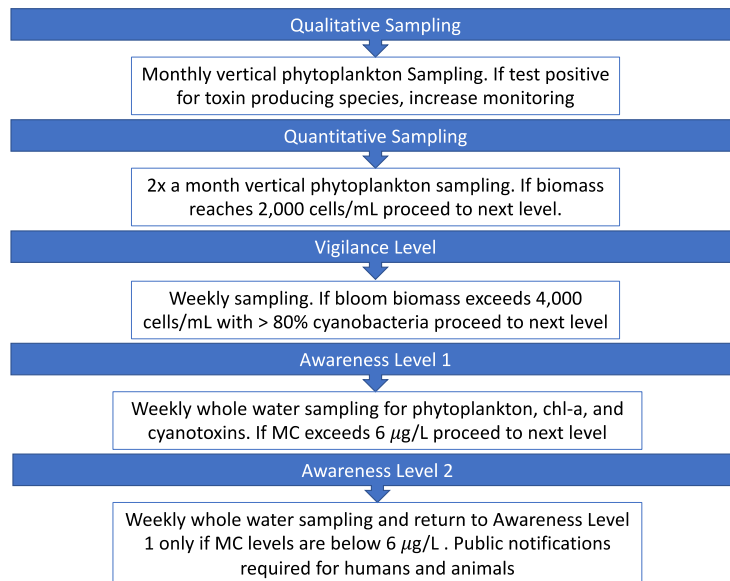


Figure 3: The Vermont, USA five-tiered recreational response protocol, which includes surveillance and notification requirements. Adapted from Stone and Bress (2007).

Advisories

An advisory is a method of notification that educates the public on what the/a risk is and the actions that should be taken to mitigate any means of exposure. As such, it is necessary that advisories raise awareness on the health effects, educate the public on the likelihood of toxins being present, and clearly indicate the precautions that should be taken to avoid contact with blooms – drinking and recreationally (Timmons et al., 2018). It is also important that the information is successfully delivered to the communities and people who are at risk during the event (Chorus and Welker, 2021). When advisories are triggered the relevant authorities – public health, beach and/or DWTP owners or operators – should ensure that the information reaches hospitals, dialysis centres, childcare facilities, nursing homes, schools, food and beverage companies, any recreational centres, public beaches and their visitors, local communities, and anyone who might use that source for drinking water (private or small drinking water plants or locals with intake pipes from the lakes). Basically, anyone potentially effected needs to be informed so that the proper risk mitigation actions can be taken. This requires that a variety of methods be utilized to ensure that all those at risk are informed (Chorus and Welker, 2021). These methods are what is termed “pathways of communication”, which are to be identified prior to any bloom events so that the means of notification and the advisories themselves can be issued rapidly in order to properly mitigate risk (Chorus and Welker, 2021). The pathways of communication can include “media releases and briefings, e-mail and text message alerts,

broadcasting, mass distribution through social media via Facebook, Instagram, Twitter, texts, others, posting on beaches and on websites, listservs by e-mail, phone messages, fliers, community meetings and any other locally effective way of communication” (Chorus and Welker, 2021, p. 818). These pathways should be paired with education and outreach materials available prior to any bloom event to improve understanding and therefore successful risk mitigation (Timmons et al., 2018; Chorus and Welker, 2021).

In terms of cyanobacteria blooms, advisories are split into two categories: drinking water advisories and recreational water advisories, both of which use an Alert Level Framework (ALF) to trigger advisory issuance, which will be discussed further in section 3.3 (Stone and Bress, 2007; Newcombe et al., 2010; Ibelings et al., 2014; Chorus and Welker, 2021). For drinking waters, advisories can be “Do Not Drink” or “Precautionary Advice”. “Do Not Drink” advisories inform the public that the water distributed by the DWTP is contaminated and therefore cannot be used for drinking water (Cheung et al., 2013; Chorus and Welker, 2021). As such, an alternative water source should be used until the “Do Not Drink” advisory has been rescinded or reversed (Du Preez et al., 2007; Chorus and Welker, 2021). “Precautionary Advice” is a drinking water advisory where public health authorities notify local communities of the potential risk the use of surface water might pose due to the presence of a bloom and recommend that an alternative water source be used (Chorus and Welker, 2021). This can be the result of frequent blooms in a surface water source used for small or private drinking water plants or the treatment plant is believed to provide insufficient treatment (Ibelings et al., 2015). Both advisories should provide information as to the cause of the advisory, safe uses for the effected water, and what the signs or symptoms are should one be exposed (Chorus and Welker, 2021).

For recreational waters, two advisories that can be used are: “Do Not Swim”/“No Contact” and/or “Beach Closed”. “Do Not Swim” advises the public of the risks associated with coming into physical contact with a bloom, or the risks posed by accidental ingestion during swimming (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014). “Beach Closed” is an advisory that shuts down public beaches for any activities with a high risk of water contact due to high risks posed by a bloom (Stone and Bress, 2007; Cheung et al., 2013). Some jurisdictions will also post educational advisories for waterbodies determined to be a high risk for blooms, such as waterbodies where blooms occur frequently and/or where blooms have occurred in the past (Stone and Bress, 2007). For example, Vermont, US utilizes two advisories

– one an informational poster that raises awareness of the risks posed by blooms and what the public should be looking for and the other is a “Beach Closed” sign (Stone and Bress, 2007).

Education and Outreach

Education and outreach are important for risk management in three ways. First, as a means of limiting exposure to blooms and their associated toxins (avoidance) (Cheung et al., 2013; Timmons et al., 2018; Chorus and Welker, 2021). Second, for reactive monitoring programs and/or citizen science initiatives (Krokowski and Jamieson, 2002; Chorus and Welker, 2021). And third, for prevention, control, and mitigative purposes (Foulon et al., 2020). No formal framework for effective education and outreach exists, which means that a variety of methods are used, which vary depending on governance structures, program goals, and available funding (Smith et al., 2014; Timmons et al., 2018).

According to Timmons et al. (2018) in order for an education and outreach initiative to successfully limit risk of exposure, it should fulfill three functions. First, raise awareness of the health risks associated with a bloom. Second, educate people on the potential for a bloom to produce toxins in a waterbody. Third, clearly indicate the precautions people should take if a bloom is present in/on a waterbody (both in terms of drinking and recreational use). These programs are needed to both educate and raise awareness (Timmons et al., 2018).

There are a variety of methods available to impart this information to the general public, from public advisories (see 3.2.2), to webpages (government and NGO), telephone hotlines, social media (Twitter, FB), signage (educational and warning), PowerPoint presentations, videos, posters, and government produced risk communication materials (termed Fact Sheets) (Nierenberg et al., 2011; Winter et al., 2011; Timmons et al., 2018; Chorus and Welker, 2021). “Traditional outreach initiatives” include press releases, local media interviews, and connections and collaborations with health care and Poison Information Centres (Nierenberg et al., 2011). Outreach can and should also include the use of educational materials (fact sheets) that can be easily distributed to the public which are created collaboratively with health care professionals, public health personnel, environmental managers, and outreach specialists (Timmons et al., 2018). These outreach materials can be “Frequently Asked Questions” or general information fact sheets, where background information, bloom identification, and risk mitigation methods are shared with the public in an accessible and understandable manner (Nierenberg et al., 2011; Timmons et al., 2018). These documents or details can be imparted on a website, which can also

provide the public with a means of communicating with those involved in risk management, research, or bloom management (Nierenberg et al., 2011). “Web-based education has become a very important branch of educational technology” (Timmons et al., 2018, p. 427) because it provides almost unlimited access to educational materials from a broad range of locations and can allow for a more customizable form of learning. Websites, contact information (emails, phone numbers), and telephone hotlines can also be an avenue by which the public report bloom sightings, health effects, or other environmental conditions associated with blooms, such as fish kills or animal deaths (Nierenberg et al., 2011; Farrer et al., 2015). However, websites and social media as a means to impart information or obtain it require constant monitoring and updating by researchers and IT to make sure the information is up-to-date, accessible, and that the online platform is as functional as possible (Nierenberg et al., 2011; Timmons et al., 2018). Signs are also commonly used to mitigate risk, especially for recreational waters (Sharma et al., 2014, Chapter 16), imparting information on health risks, bloom identification/awareness, and/or avoidance techniques (Nierenberg et al., 2011). Modern technology has resulted in an expansion for education and outreach, with hundreds to thousands of apps available, including some for reporting bloom sightings and education purposes (Nierenberg et al., 2011; Timmons et al., 2018). For example, there is an app called *Phyto* which was developed by the National Oceanic and Atmospheric Administration (NOAA) to aid volunteers in phytoplankton identification by providing reference guides for water sample analysis (Timmons et al., 2018). Another example is *BloomWatch* which allows the public to track bloom occurrences on their phones (Timmons et al., 2018). However, like webpages, the platforms require constant monitoring and updating and it should be understood that these technologies will have logistical issues over time and so data backups are essential (Nierenberg et al., 2011).

For education and outreach initiatives to be effective the education portion must be imparted in a manner understandable by the general public so that the knowledge can be applied successfully to mitigate risk (Kuhar et al., 2009; Smith et al., 2014; Timmons et al., 2018). That is, education is only an effective tool for risk mitigation when the science and risks are properly understood (Kuhar et al., 2009; Smith et al., 2014). For example, Kuhar et al. (2009) found that the more people were familiar with the risks associated with red tide events (oceanic HABs) in coastal Florida waters, the better able they were to assess the risks posed by different bloom scenarios, such as when eating fish was actually a risk. However, ensuring understanding is

difficult and best achieved when scientists work with outreach specialists to develop the means of imparting the information (Timmons et al., 2018). Imparting scientific material in a manner that can be understood by the general public requires both an understanding of the material as well as the ability to communicate it to a broader, non-scientific audience (Smith et al., 2014; Timmons et al., 2018). A major challenge to public understanding of scientific material is ‘scientific literacy’ – the general public’s ability, or inability, to understand scientific principles or concepts (Smith et al., 2014; Timmons et al., 2018). A survey conducted by the California Academy of Sciences in 2009 found that 4 out of 5 American adults did not know basic scientific principles (Science Daily, 2009; Timmons et al., 2018). Scientific literacy also requires government support, which changes over time depending on public opinion around science and scientists, the systems of governance in place, and available funding (economics) (Smith et al., 2014). For example, investment in scientific literacy increased in the US in the 1980’s when the government thought that they were going to suffer economically due to a lack of scientific innovators (Smith et al., 2014). Another limitation to public understanding is language barriers. As such, educational materials should be available in a variety of different languages (Chorus and Welker, 2021). Therefore, it may be necessary to “engage with knowledgeable regional partners to develop and or customise appropriate communication messages and materials” (Chorus and Welker, 2021, p. 816) so that materials in various languages can be distributed or made available based on local needs.

The effectiveness and efficiency of education and outreach initiatives centred around imparting information to the public on the health risks associated with blooms and the means of recognizing them are not well known (Fleming, 2007; Smith et al., 2014). Nor is the best or most effective means of exposure for education and outreach materials to general or targeted audiences (Fleming, 2007). This is because, while there are a lot of research, papers, and books available on the impacts of blooms on waterbodies socially, economically, and environmentally, a lot of the materials are geared towards scientists and not necessarily readily available or easily understood by the general public (Chorus and Bartram, 1999; Heisler et al., 2008; Smith et al., 2014). In a study by Smith et al. (2014), they looked at the impacts of cyanobacterial bloom education and outreach tactics on fisherman in Southern Louisiana. Smith and co. found that while the majority of study participants stated they knew what blue-green algae blooms were, not many were able to describe a bloom when asked for a definition. That is, only 21% of

respondents could describe blooms as a green, grassy and/or slimy masses. And significantly, 61% did not realize that blooms could be harmful. But, when provided with a pamphlet that had general information on blooms, participants were better able to answer the same questions. A limitation for this study was access and interest in the pamphlet, with a proportion of participants only having read it because it was provided to them before the second Q&A session, despite its availability in the marinas they frequented. Availability of education materials can improve bloom reporting by the public. In a study conducted by Winter et al. (2011), they attributed some of the increase in algal bloom reports in Ontario to the Ministry of the Environment's coordinated education and outreach initiatives with NGOs, Conservation Authorities (CAs), and cottage associations. This increased public awareness and understanding of the associated risks resulted in more people recognizing blooms and thus, reporting bloom activity (Winter et al., 2011). To that end, education and outreach can aid in monitoring by increasing awareness and therefore participation in reactive monitoring programs and/or by establishing citizen science monitoring initiatives (Timmons et al., 2018).

Education and outreach aids public participation in reactive monitoring programs because, if the public know what to look for, where to report it, and why it is important to do so, they are more likely to do so (Winter et al., 2011). However, this is limited by access and understanding, and as previously mentioned, economics. For example, Fleming (2007) found that the majority of people calling into The Aquatic Toxins Hotline in Florida were older English speaking female residents who called in to get information they were looking for suggesting that tourists and healthcare providers were/are either unaware of the hotline or the risks the hotline are supposed to mitigate (Fleming, 2007). Sightings might also be underreported by communities that understand the socio-economic implications of blooms in their waters. Cyanobacteria blooms can negatively impact property values, tourism/recreational uses, on top of the increased costs for local and provincial communities due to monitoring, water treatment (effluent and drinking) and bloom management, education and outreach initiatives, notifications, and research (Sharma et al., 2014, Chapter 15). For freshwaters in the US it is estimated that property values around lakes have declined anywhere from \$14.1 to \$141.1 billion dollars annually as a result of eutrophication and blooms (Dodds et al., 2009). It has also been estimated that algal blooms will impose equivalent annual costs (to 2015 prices) of \$272 million over a 30-year period for the

Canadian side of Lake Erie due to losses in tourism and recreational uses, if eutrophication and blooms are left unmanaged (Smith et al., 2019).

Citizen science programs are dependent on awareness and therefore education and outreach initiatives. Citizen science “is scientific research conducted by amateur or nonprofessional scientists” (Timmons et al., 2018, p. 428). The benefits for citizens is active participation in research and conservation while scientists benefit by receiving data that might otherwise be economically (time and labour) and/or geographically unfeasible to collect (McKinley et al., 2017; Timmons et al., 2018). Therefore, these programs can allow for adequate monitoring that conservation or environmental efforts require, especially for large scale problems like cyanobacteria blooms (McKinley et al., 2017; Timmons et al., 2018). Proper training is critical for data viability from citizen science programs, thus education initiatives should be performed regularly (McKinley et al., 2017; Timmons et al., 2018) and updated with any new information. These programs also act to increase education via hands-on involvement in scientific initiatives. The success of these programs is dependent on continued education and outreach and informing volunteers on the significance of their contributions (McKinley et al., 2017; Timmons et al., 2018). This can be done by allowing the public access to the data and/or any generated reports (both scientific and ones geared towards non-scientific communities). An example of this is the Red Tide Offshore Monitoring Program, established in 2000, which has increased monitoring and sampling efforts within the state by allowing the public to collect samples from routine monitoring locations (Timmons et al., 2018).

Education and outreach can improve prevention, control, and mitigation measures in three ways. First, education and outreach can inform individuals on initiatives or measures they can take to limit nutrient loading into waterbodies (Cheung et al., 2013), such as by maintaining riparian zones, keeping septic systems in proper working order, and by reducing fertilizer application to lawns, gardens, and crops, thus reducing runoff. Second, when people are more aware of the negative effects of blooms, they are more likely to raise awareness with others and demand greater mitigative actions from governance structures (Timmons et al., 2018). And finally, when people are aware of bloom mitigative measures, they are more likely to educate others, encouraging measures to reduce bloom occurrences in their community.

Proper education and outreach requires adaptive management, in that, it should be updated regularly as new information becomes available and/or new methods of sharing

information or allowing reporting become available (Nierenberg et al., 2011). This is especially important as new technologies become available for imparting information and more people have access to greater sources of information.

Criteria for Closure Vs. Health Advisories

Blooms can and have resulted in beach closures and the shutdown of DWTP intake pipes. July of 2021 saw all beaches in Burlington, Ontario closed due to the presence of cyanobacteria blooms (CNN, 2021). And in 2014, Toledo, Ohio shutdown the DWTP intake pipe from Lake Erie for 3-days during a cyanotoxic bloom event because the toxin concentrations exceeded the DWTPs treatment capacity, leaving people without access to potable water (Wines, 2014; Pick, 2015). When these advisories and closures are issued depends on the level of risk associated with the activity and the method of exposure (Table 2) and are often issued by public health officials (Stone and Bress, 2007; Cheung et al., 2013; Chorus and Welker, 2021). The criteria for closures vs. advisories is also dependent on the waterbodies use (source waters vs. recreational) and the designated threshold values and associated response protocols (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014; Chorus and Welker, 2021). Therefore, when and how advisories or closures are issued varies depending on regulations/guidelines, government authorities, monitoring, waterbody use, and available funding (Burch et al., 1999; Chorus and Welker, 2021). Issuing an advisory is often under the discretion of public health officials, and is based on sampling results and threshold values.

For drinking water, the criteria for issuing an advisory are related to the ALF used and regulated or unregulated treated drinking water threshold levels (Ibelings et al., 2015; Chorus and Welker, 2021). Several countries have regulated or guideline values for cyanotoxins, which trigger advisory issuance so that the public is properly informed of any risks drinking water might pose to their health when a threshold value is met or exceeded in treated water (Ibelings et al., 2015). This can be extended to raw water if it is deemed that the treatment capacity of the DWTP is insufficient to remove the risks posed to the general public by the cyanotoxin in question or when the population being serviced is more vulnerable to cyanotoxin exposure (Ibelings et al., 2015). Canada, New Zealand, Australia, Brazil, the Czech Republic, France, Singapore, Spain, Turkey, South Africa, Florida, Ohio, and Oregon all have regulatory or guidelines values for Microcystins (Table 3) (Ibelings et al., 2015). Some countries and certain states in the US also have guideline, or more rarely, regulated threshold levels for Anatoxin-a,

Saxitoxin, Nodularin, and Cylindrospermopsin (Table 3) (Cheung et al., 2013; Sharma et al., 2014, Chapter 16). For example, New Zealand has guideline threshold levels for Nodularin, Saxitoxin, Anatoxin-a(s), and Cylindrospermopsin, and a regulated threshold levels for MC-LR (Table 3) (Sharma et al., 2014; Ibelings et al., 2015). Similarly, in Ohio, there are “Do Not Drink” guideline threshold levels for Microcystin, Anatoxin-a, Cylindrospermopsin, and Saxitoxin (Table 3) (Cheung et al., 2013). The latest guideline recommendations from the WHO include threshold levels for Saxitoxin, Anatoxin-a, and Cylindrospermopsin, in addition to the recommended level for MC-LR (Table 3) (Chorus and Welker, 2021, Chapter 5).

For recreational waters, advisories and limitations to waterbody use are dependent on local government authorities and education and outreach initiatives (Sharma et al., 2014, Chapter 16). Public advisories are often tiered based on the threshold levels selected, with certain threshold values triggering a range of advisory responses (Ibelings et al., 2015). Most countries employ a two or three-tiered ALF for recreational waters, though Vermont, US uses a five-tiered one (Figure 3) (Stone and Bress, 2007; Ibelings et al., 2014). The lowest level is usually the Vigilance Level or ‘Surveillance Mode’, where the public are not notified; instead monitoring efforts are continued or intensified (Ibelings et al., 2015). For example, the first two tiers in the Vermont ALF are dedicated to monitoring efforts (Figure 3) (Stone and Bress, 2007). The first Alert Level is dependent on the exceedance of a threshold value and this is also when the public is typically warned about the risks associated with the use of the recreational waterbody effected (Ibelings et al., 2014; Chorus and Welker, 2021). On-site signage, media advisories, internet publications/webpages, and telephone hotlines are often the means utilized to impart this information (Stone and Bress, 2007; Ibelings et al., 2014). Warning signs can also be used to educate the public on health effects, such as skin irritations or gastrointestinal effects (Ibelings et al., 2015). The last or highest level Alert Level or ‘Action Mode’ is based on a range of factors, such as: the persistent presence of surface scum, exceedances for threshold levels assigned to this action modes level, and/or any reports of the toxic effects of the bloom such as fish kills, human illness, or animal deaths (domesticated or otherwise) (Ibelings et al., 2015). This level always requires that the public be notified of the risks associated with the use of recreational waters, and may even result in beach closures (Stone and Bress, 2007; Cheung et al., 2013; Ibelings et al., 2014).

Drinking Water Treatment

For DWTPs effected by blooms, treatment methods are generally triggered by routine monitoring (see Chapter 3, Section 3.1) (Zamyadi et al., 2012; Zamyadi et al., 2013) and tend to vary based on plant capacity, with some DWTPs unable to treat for the presence of blooms (Cheung et al., 2013). In terms of treatment, it is recommended that testing for toxins should occur from the source water, within the plant before treatment, after each treatment stage, and within the plant after treatment in order to properly limit risks to public health (Zamyadi, MacLeod, et al., 2012). This is because breakthrough events of cyanotoxins for drinking water have happened, and even if the levels are below the regulated threshold values, they still need to be monitored and tracked to limit health risks (Zamyadi, MacLeod, et al., 2012; Health Canada, 2017).

A multi-barrier approach is used to remove cyanobacteria from drinking water. The first approach being avoidance – intake valves are placed in areas where blooms are less likely to occur (Cheung et al., 2013; O’Keefe, 2019). The second approach is the physical removal of cells via filtration or absorption methods (Cheung et al., 2013; O’Keefe, 2019). Some commonly used methods to remove cyanobacteria cells are micro-screening, gravity filters, coagulation/flocculation, and sedimentation (Zamyadi, MacLeod, et al., 2012; Cheung et al., 2013). Regular maintenance and cleaning of filtration methods for cell removal are necessary to prevent significant accumulation (Zamyadi et al., 2012). The third and final approach is the advanced treatment of water to remove cyanotoxins (O’Keefe, 2019). This is usually done using powdered activated carbon (PAC), granular activated carbon (GAC) or ozone treatment (Zamyadi, MacLeod, et al., 2012; O’Keefe, 2019). The accumulation and removal of cyanobacteria cells and their toxins during treatment processes is affected by cyanobacteria size, charge, motility, morphology, and resistance to sheer stress and pressure; factors which differ widely between species (Zamyadi et al., 2012; Zamyadi et al., 2013). Cyanotoxin management plans for DWTPs should include mandatory standards for cyanotoxin concentrations in drinking water, a plan to actively monitor water for cyanobacteria and their toxins, and treatment methods for removing cyanotoxins (Codd et al., 2005; Zamyadi et al., 2012; Zamyadi et al., 2013) – all of which increase time and costs for water treatment (O’Keefe, 2019).

2.3 Canadian Water Management: Jurisdictions and the Roles of Federal and Provincial Governments

Water is an important environmental resource both socially and economically, which is why state entities all over the world have developed policies around the ‘sustainable’ use of water to maintain both quantity and quality (Akhmouch and Correia, 2016). Public health, the environment, agriculture, industry, energy, and transportation are all impacted by water availability and quality (Akhmouch and Correia, 2016). Despite this reliance on water, water management in Canada is often seen as something of little concern, largely because of the ‘myth of abundance’ (Bakker, 2007; Bakker and Cook, 2011). The ‘myth of abundance’ is the common overestimation Canadians have around the water supply in Canada (Sprague, 2007). That is, the majority of Canadians think that Canada has “more than one fifth of the worlds freshwater supply” when in actuality, Canada has approximately 6.5% of the worlds annual renewable freshwater supply, only 2.6% of which is available to populated areas (Sprague, 2007). Despite these limitations around water availability, the misuse of water in Canada persisted until the ‘water crisis’ in the mid-1960’s (Sprague, 2007). Increasing demand for water under decreasing availability and quality made it understood that water is a finite resource which increased public expectations around its management (Bakker, 2007; Urteaga-Crovetto, 2016). By the mid-1970’s, water was no longer seen as a commodity to be used solely for economic gain, but rather as a resource that needed/needs to be protected from the increasing demands of the economy and industry (Pearse et al., 1986).

Water management in Canada also falls into the trap of jurisdictional fragmentation. Jurisdictional fragmentation is the unclear division of power between Federal and provincial governments around the management of natural resources, especially water (Bakker and Cook, 2011; Dunn et al., 2014; Saunders and Wenig, 2007). The Federal Government, under the Canadian Constitution Act (1982), is responsible for navigation, fisheries, Indigenous lands, federal/crown land, and international or boundary waters (Bakker and Cook, 2011; Shrubsole et al., 2017; GOC, 2020b). The provinces and territories handle natural resources, including, but not limited to, freshwaters (Hill et al., 2008; Bakker and Cook, 2011). This fragmentation exists at and across all levels of Government and is further complicated by the fact that implementation of water management frequently occurs at the municipal scale (Bakker, 2007; Bakker and Cook, 2011), where municipalities are provided power by the province, sometimes through legislative means, to put provincial environmental/water conservation and sustainability goals into practice

(Furlong and Bakker, 2011). Then there is the inclusion of non-governmental organizations (NGOs) in some decision-making processes where they work “as watchdogs with considerable legal capacity” (Bakker and Cook, 2011, p.278). Although necessary, Canadian water management often lacks inter-governmental coordination, subsequently causing the duplication of efforts, poor data collection and dissemination of information, and inadequate monitoring and enforcement (Bakker and Cook, 2011).

While the Federal Government does have the authority to set standards for environmental concerns, provinces often resist citing constitutional control over natural resources, since they are a large source of income for the jurisdictions and a means of maintaining autonomy (Bakker and Cook, 2011; Dunn et al., 2014; Hill et al., 2008). Then there are questions around the capacity of local municipalities to handle assigned roles of implementation (Furlong and Bakker, 2011; Shrubsole et al., 2017). All these problems, along with international shared responsibilities, Indigenous rights, and local concerns make the coordination of efforts, and therefore water governance, a necessity in Canada (Bakker and Cook, 2011; Hill et al., 2008; Shrubsole et al., 2017).

‘Water Governance’ is “the range of political, social, economic, and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society” (Rogers and Hall, 2003, p.7). Water governance has three main principles: effectiveness, efficiency, and trust and engagement (OECD, 2015; Akhmouch and Correia, 2016). Effectiveness within governance is the clear definition of goals and targets within policy for each level of government so that implementation across all scales is able to meet goals and targets (OECD, 2015). Efficiency is governances’ goal to maximize the benefits of sustainable water management and welfare while incurring minimal costs to society (OECD, 2015). Finally, trust and engagement are the building of public confidence around water management strategies (trust) and including stakeholder participation through democratic legitimacy and fairness (engagement) (OECD, 2015). Under the umbrella of water governance there is ‘water resource management’, which links all the sectoral uses of water within society, the market, and the environment (Akhmouch and Correia, 2016). Water management strategies and water governance are both understood to vary within and across countries depending on the organizational systems in place and the requirements for water in each of the areas where implementation occurs (Akhmouch and Correia, 2016). Therefore, the idea of ‘good’ water

governance is the capacity of water governance to achieve results in a fair and inclusive manner, which produce policies and management practices that achieve long-term goals established by society and the international community (Akhmouch and Correia, 2016).

Water Governance in Canada is implemented using Integrated Watershed Resource Management (IWRM) or Integrated Watershed Management (IWM). IWM, according to the Government of Canada (GOC, 2010), is “a multidisciplinary and iterative process that seeks to optimize the contribution of aquatic resources to the social, environmental, and economic welfare of Canadians, while maintaining the integrity of aquatic ecosystems, both now and into the future” (para.11). IWM is implemented either formally or informally in all provinces and territories within Canada, save for the Yukon (CCME, 2016).

IWM is the approach being utilized in Canada to protect water resources because it is a more encompassing approach to water management (Cervoni et al., 2008). However, it has garnered criticism because it is deemed a “Nirvana Concept” (Molle, 2008); there is heavy investment in the idea that it is the solution to our water management problem because it is ‘elastic and amorphous’ but in reality it is quite vague and not necessarily achievable (Petit, 2016; Butterworth et al., 2010). Consequently, there are often disagreements on fundamental issues, such as what should be integrated into the management process, how implementation should occur, who will be responsible for implementation, and who should be included in these processes (Butterworth et al., 2010). Another criticism of IWM is that, while the concepts behind it are sound, implementation is difficult, resulting in gaps between action and strategy (Petit, 2016). There is also a need for IWM to be adaptive (adaptive management), which requires monitoring, reporting on progress, and updating the plan when necessary (Shrubsole et al., 2017). This entails expertise and funding, which, with implementation at the municipal or local level and the effects of jurisdictional fragmentation, raises questions around who is responsible for what and what capacity these authorities have for the proper implementation of IWM (Shrubsole et al., 2017). Despite these criticisms, IWM is still perceived to be the best available approach for dealing with wicked problems, like blooms and NPS nutrient loading.

IWM requires adaptive management to be successful; “a structured process for improving systemic management policies and practices by learning from the outcomes of implemented management strategies” (Pahl-Wostl, 2007; Huntjens et al., 2011, p. 148). It allows for a programs policies, goals, objectives, and methods of implementation to be re-evaluated and

updated as new information, insights, and understandings under changing conditions, demands on ecosystems, and research insights become known (Huntjens et al., 2011). It is centred around social, scientific, and technological learning and advancements, and the need to integrate this knowledge into current practices to improve the understanding and functionality of implemented methods (Huntjens et al., 2011). Basically, it emphasizes that knowledge and the ability to act upon that knowledge should be continuously enacted in social processes (Pahl-Wostl, 2007; Huntjens et al., 2011). In terms of water management, complexity and uncertainty are inherent, which requires that management and governance structures be “adaptive, flexible and capable of learning from experience and responding to unexpected developments” (Huntjens et al., 2011; Pahl-Wostl et al., 2013; Patterson et al., 2013).

The Federal GOC, in terms of water governance, often takes on responsibilities for agriculture, health, and the environment by creating national guideline documents for risk management, installing legislation and regulations (where applicable), providing research to aid in adaptive or mitigative efforts, and providing financial support to provincial efforts (GOC, 2020). While the installation of legislation and regulations is a means the Federal Government can use to protect water quality (Bakker and Cook, 2011), the GOC often either defers to the provinces or, under the *Canada Water Act* (1985), establishes agreements and/or memorandums of understanding (MOUs) instead to coordinate/harmonize efforts and provide support to various levels of governance and at the international scale (GOC, 2010; Shrubsole et al., 2017).

2.3.1 Federal Cyanobacteria Recreational and Drinking Water Guidelines

For cyanobacteria, there are two Federal guideline documents: the *Guidelines for Canadian Recreational Water Quality Third Edition* (GCRWQ) and the *Guidelines for Canadian Drinking Water Quality* (CDWQG) which were developed by The Federal-Provincial-Territorial Working Group on Recreational Water Quality (RWQ) and the Federal-Provincial-Territorial Committee on Drinking Water (CDW), respectively (CESD, 2005; Health Canada, 2006; Health Canada, 2012; Health Canada, 2017). Both the RWQ and the CDW are led by Health Canada, with representatives invited (though not always in attendance) from all provinces and territories in Canada (Health Canada, 2006; Health Canada, 2012; Health Canada, 2017). Representatives from Environment and Climate Change Canada (ECCC) and the United States Environmental Protection Agency (EPA) are also invited to take part (Health Canada, 2006; Health Canada, 2012; Health Canada, 2017). Both the RWQ and the CDW report to the Federal-Provincial-

Territorial Committee on Health and the Environment, who in turn report to the Advisory Committee on Population Health and Health Security and, for environmental issues, the Canadian Council of Ministers of the Environment (CCME) (Health Canada, 2006; Health Canada, 2012, Health Canada, 2017, Health Canada, 2020). The RWQ and CDW meet twice a year to review, add, remove, or change the recommendations made in these documents and update the information based on current scientific literature (Health Canada, 2006; Health Canada, 2012; Health Canada, 2017). Cyanotoxins are classified as a ‘*prioritized microbiological or radiological contaminant*’, which means the “parameters are reviewed on an ongoing basis or they have impacts on treatment processes that may indirectly impact human health” (GOC, 2020b, para. 10). As a result, the CDW regularly reviews new and updated information on cyanobacteria in order to protect human health (GOC, 2020b).

The GCRWQ (2012) has a chapter/section (6.0) on “cyanobacteria and their toxins” where the recommended recreational water values for cyanobacteria and their toxins can be found, which are: 100,000 cells/mL and 20 µg/L for Microcystin-LR (MC-LR), a common type of cyanotoxin. The document also provides information on the risks associated with cyanobacteria and their various cyanotoxins and the rationale for the levels listed in the document. The recreational water level for MC-LR is currently under review by the RWQ, with a new level of 10 µg/L for MC-LR and 50,000 cells/mL being proposed (Health Canada, 2020), however, the new document has yet to be formally published. Therefore, it is currently unknown if the provinces and territories will adopt the new ones proposed by Health Canada.

The CDWQG’s latest version (2017) by Health Canada contains a maximum acceptable concentration (MAC) for the cyanotoxin MC-LR in drinking water of 1.5 µg/L. In addition to the overarching guideline document, there are Guideline Technical Documents, which include one on cyanobacteria and their toxins (Health Canada, 2017). The MAC for MC-LR was developed using an adult male as reference, and while studies have shown that cyanotoxin guidelines are potentially less protective of infants, given their increased water consumption rates per kg body weight, a reference value MAC of 0.4 µg/L is recommended, especially for those on formula (Health Canada, 2017). The Canadian recommended MAC is higher than the MAC proposed by the World Health Organization (WHO) for MC-LR, which is 1.0 µg/L (WHO, 1998; Chorus and Bartram, 1999; Health Canada, 2017).

The two guidelines only have provisions for one cyanotoxin, MC-LR – a hepatotoxin that can promote liver tumour growth along with several other health problems – because it is the most commonly detected cyanotoxin in Canadian waters (Codd, 2000; Pick, 2015; O’Keefe, 2019). The level is also based solely on risk to human health (Health Canada, 2012; Health Canada, 2017) rather than geared towards the smallest lifeform impacted by the cyanotoxin concentration, which means it is unlikely to protect environmental, aquatic, or terrestrial health.

These water quality documents are recommendations only, which means the provinces and territories have a choice of whether or not to adopt all or portions of the guidelines into their own policies (CESD, 2005). What this means is that Canada does not have overarching water quality parameters that are legally enforceable resulting in variable standards across jurisdictions, with provinces having the ultimate responsibility for formulation and implementation (Dunn et al., 2014; Hill et al., 2008). Indeed, only 16 of the 94 water quality parameters listed within the CDWQG are implemented across the 13 Canadian jurisdictions, though some provinces regulate more than the 94 (Dunn et al., 2014). Therefore, standards for cyanobacteria and their toxins may vary across Canada.

2.3.2 Effluent Water Standards

Wastewater management is the collective responsibility of Federal, provincial, and municipal governing bodies (Mavinic et al., 2018). The Federal government specifies minimum effluent water standards using legislative or regulatory means, while provincial and territorial governments issue permits for WWTPs, thus governing their operations under a regulatory framework (Mavinic et al., 2018). Federally, there is no legislation directly addressing the discharge of municipal wastewater effluent although the Fisheries Act has a regulation – Wastewater Systems Effluent Regulation – which sets minimum effluent standards for pollutants discharged into waters frequented by fish (CCME, 2016; Mavinic et al., 2018; GOC, 2020a). Although virtually all natural surface waters have fish, the GOC is reluctant to extend its environmental authority to all inland waters. The regulation sets effluent standards for total suspended solids (TSS), carbonaceous biochemical oxygen-demanding material (CBOD), total residual chlorine, and un-ionized ammonia (NH₃), which must be achieved by secondary treatment or better (ECCC, 2020; Mavinic et al., 2018). Also, under the Federal Environmental Protection Act, WWTPs with discharge rates that exceed 10,000 m³/day are required to monitor,

meet thresholds, and report on the release of several substances, including P (Mavinic et al., 2018).

In 2003, the Federal, provincial, and territorial governments signed an agreement with the Canadian Council of Ministers of the Environment (CCME) to develop national wastewater effluent standards called the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* (CCME, 2016). The strategy required all municipal WWTPs adopt both National Performance Standards and site-specific Effluent Discharge Objectives for effluent waters in order to protect environmental and human health (CCME, 2009). The National Performance Standards are for TSS, CBOD, and total residual chlorine, matching the levels dictated by the Wastewater Systems Effluent Regulation (CCME, 2009; GOC, 2017). The site-specific objectives are to be determined by an Environmental Risk Assessment which might set more stringent levels than the National Performance Standards and identify other substances of concern (CCME, 2009), such as P. As part of the Canada-wide strategy, some provinces and territories signed bilateral agreements with the Federal government (GOC, 2020a). As of 2020, three provinces – New Brunswick, Saskatchewan, Quebec – and one territory – the Yukon – have bilateral agreements with the Federal government on wastewater effluent standards (GOC, 2020a). These bilateral agreements state that the provinces and territories in question have regulations deemed “equivalent in effect to the Wastewater Systems Effluent Regulations” (GOC, 2020a, para. 3). The Canada-wide strategy also provided funding to upgrade municipal WWTPs, installing treatment technologies necessary to meet the national standards (CCME, 2009).

As of 2017, 86% of Canadians were serviced by municipal WWTPs, with 71% provided secondary treatment or better (ECCC, 2020a). While the methods of P removal vary between plants and provinces, there are three main techniques used within Canada (Oleszkiewicz, 2015). Smaller communities (populations under 3,000) use lagoon systems, often without the pointed removal of P and N (Oleszkiewicz, 2015). Eastern Canada municipalities use conventional activated sludge with extended aeration (CAS EA) to remove organic pollutants, with most plants using chemical precipitation (Chem. P.) to actively remove P (Oleszkiewicz et al., 2015). Western Canada municipalities tend to utilize biological nutrient removal (BNR), which removes P and N from effluent water (Oleszkiewicz, 2015).

2.3.3 P in Detergents

Globally, P in detergents and cleaning supplies are not universally regulated, reduced, or removed, so detergents continue to be a source of P input to waterbodies and WWTPs (Hamilton et al., 2016). However, in Canada, P content in detergents and household cleaning products is regulated by the Federal Government because these products, and the P they contain, either end up in watercourses and waterbodies or they pose a major burden to WWTPs (Hamilton et al., 2016). Under the Canadian Environmental Protection Act (1999) there is the Concentration of Phosphorus in Certain Cleaning Products Regulations (SOR/89-501), which limits the amount of phosphates found in cleaning products in Canada (GOC, 2019). The purpose of the regulation is “to protect Canada’s environment from the release of phosphorus from certain products that could contribute to the over-fertilization of freshwater ecosystems, and the growth of harmful algae blooms that are proliferating in Canada’s lakes and rivers” (GOC, 2019, para. 1). The regulation applies to all manufacturers and importers of laundry detergents and household cleaning items (Table 2) sold for use in Canada (GOC, 2019). So, as of 2010, household cleaners, detergents, and dish-washing compounds are no longer allowed to have more than 0.5% concentration of P and commercial and industrial detergents are not allowed more than a 2.2% concentration of P, as decided by the % weight of P in the product (GOC, 2019).

2.3.4 NPS Nutrient Management Practices

PS nutrient loading was originally the main method of bloom management used in Canada (ECO, 2017b), Lake Erie being a prime example of the success limiting PS P loading into a waterbody can have for reducing blooms when PSs are the primary nutrient source (Schindler et al., 2016). However, since NPS nutrients are now the main source of P loading into waterbodies, BMP implementation is necessary for bloom management. Currently, in Canada, there are two main methods of implementing agri-environmental stewardship programs and their associated BMPs: enforcement and/or encouragement/incentivization, with these programs often used in combination (Rajsic et al., 2012).

Enforced stewardship programs are implemented by installing government legislation or regulations which set out environmental objectives and standards – generally centred around human health and safety (Vercammen, 2011) – that need to be met often under penalty of punishment, such as fines (Smithers and Furman, 2003; Morrison and FitzGibbon, 2014). Land-use planning processes (BMPs) and local governing statutes, like issuing building permits, are some of the means that can and have been utilized (Smithers and Furman, 2003). Installing

regulations is a more direct form of altering agricultural practices (Smithers and Furman, 2003). van der Vlist et al. (2007) found that strict agri-environmental practice regulations increased the technical efficiency of Dutch farmers when managing nutrients. Despite this, farmers perceive financial incentives as better for promoting conservation, though they recognize that in certain circumstances, regulatory approaches are more effective (Lamba et al., 2009).

Regulated nutrient management also requires more government oversight for monitoring, reporting, and enforcement (Harter, 2015), and is therefore costly and time consuming. It has been criticized for ignoring farmer heterogeneity and the influence interest groups seem to have on who is positively or negatively impacted by their installation and enforcement, which can result in the over or under regulation of certain agricultural practices (Vercammen, 2011). Additionally, policy effectiveness can be impacted by a lack of spatial targeting and poor distinctions between income support and agri-environmental objectives (van der Vlist et al., 2007).

Most provinces in Canada have some form of legislation that mandates the design of livestock operations and the storage and application of manure produced by these operations (Rajsic et al., 2012). However, the efficacy of reducing P exports is questionable since manure application rates target N as the limiting factor for crop production (Sharpley, 2015). The problem with N-based application is that most manure has high P content, with N being three to four times lower than the necessary uptake for crop production (Sharpley, 2015). Therefore, when manure is applied to meet crop N needs, P is applied in levels three to four times higher than annual crop needs (Sharpley, 2015). Provincial nutrient/livestock operation legislation and their associated regulations are also geared towards intensive livestock operations in provinces with significant crop and livestock farms, such as Alberta, Manitoba, Ontario, Quebec, and Saskatchewan (Rajsic et al., 2012). For example, Ontario has the Nutrient Management Act which regulates land application rates for agricultural source materials and requires a certified nutrient management plan or nutrient management strategy for the application of nutrients, but only if the farm is 300 animal units or greater (Rajsic et al., 2012). There is very little within the legislation/regulations that apply to all agricultural operations within the province (Rajsic et al., 2012), which is subject to alteration over time and fails to address cumulative effects. Despite the option of enforcement, most stewardship programs are either encouraged or voluntary or work

by providing financial incentives or the threat of future installment of regulations (Morrison and FitzGibbon, 2014; Liu et al., 2018).

However, the effectiveness and efficiency of regulating farming practices in Canada is impacted by provincial legislation around the “right-to-farm” (Vercammen, 2011; Rajsic et al., 2012). Legislation that protects a farmers right to employ agricultural practices that are consistent with current industry standards, thus preventing ‘nuisance lawsuits’ by local communities (Vercammen, 2011; Rajsic et al., 2012). While preventing nuisance lawsuits for things like farm operation smells is important, the right to farm has been cited as a major cause for the rapid expansion of industrial farming practices in Canada, increasing environmental degradation and cultural eutrophication (Rajsic et al., 2012).

Despite the option of enforcement, most stewardship programs work by providing either financial incentives, encouragement, or the threat of future installment of regulations (Morrison and FitzGibbon, 2014; Liu et al., 2018). Given that these programs are voluntary, various factors impact participation, which is why education and outreach, trust, and proof are integral for farmer participation. Farmers require and rely on the expertise/technical support of government agencies for understanding methods of BMP implementation (Yates et al., 2007). Trust in this information as well as commitment to the program improves participation, which can be longterm funding for education and outreach or funding for BMP implementation provided directly to farmers (Lamba et al., 2009). Proof that BMP implementation works for improving environmental conditions is also integral to participation in encouraged programs (Lamba et al., 2009; Liu et al., 2018; Niskanen et al., 2021). Studies have shown that farmers are more likely to adopt stewardship practices if they are proven to be effective (Atari et al., 2009; Lamba et al., 2009; Niskanen et al., 2021), which is tied to farmers ‘aversion to risk’. Then there is exposure and peer pressure. Exposure with the negative impacts of agricultural practices can effect farmer participation either by triggering a moral obligation to improve practices and/or it can be the result of impacts on production and therefore profits (Atari et al., 2009; Lamba et al., 2009; Yiridoe et al., 2010). Pressure from other farmers, society, international standards, NGOs, and government officials as to the benefits or costs can also elicit participation (Atari et al., 2009; Lamba et al., 2009; Yiridoe et al., 2010). Then there are economic considerations. “Economic concerns have been and continue to be the main drivers of BMP adoption” (Liu et al., 2018, p. 3)

with the benefits of BMP implementation needing to outweigh the costs to encourage their use (Liu et al., 2018; Niskanen et al., 2021).

Farmers' attitudes also affect proper implementation of BMPs. Optimizing application of fertilizers and manure to soils requires regular soil and manure testing, a BMP accepted by most farmers to reduce nutrient loading into waterbodies (Daxini et al., 2018). Yet, the successful adoption of soil testing, which is readily available in 'developed' countries, is significantly lower than it should be (Kelly et al., 2016; Daxini et al., 2018). Perhaps there is an insufficient incentive to adopt soil and manure testing (Daxini et al., 2018). "Farmers who do adopt soil testing often fail to fully translate these data into decision making surrounding fertiliser applications" (Daxini et al., 2018, p. 351). Therefore, incentivized stewardship programs are influenced by public policy, farmers behaviour, and the decision-making process (Atari et al., 2009).

2.3.5 Agri-Environmental Cost-Share Funding

Cost-sharing is the main method of promoting and incentivizing voluntary agri-environmental stewardship programs – where government agencies provide some percentage of funding for the implementation of BMPs, education and outreach, farm planning, and environmental assessments (Reimer and Prokopy, 2014; Vercaemmen, 2019; Zaga-Mendez et al., 2020). Cost-sharing is a means for governing bodies to apply administrative rules and control in the coordination of voluntary agri-environmental stewardship (Zaga-Mendez et al., 2020) with the voluntary nature of these programs "presented as more attractive, decentralized, and less bureaucratic, encouraging more engagement from producers than traditional command and control policies" (Zaga-Mendez et al., 2020, p. 296). However, it also means that the effectiveness of these programs is impacted by implementation mechanisms, unofficial and official rules, social norms, power relations, the range of participation, and local, national, and even international governance structures (Zaga-Mendez et al., 2020). Agri-environmental cost-sharing programs in the US and EU are the Environmental Quality Incentives Program (EQIP) and the Good Agricultural and Environmental Condition practices, respectively, programs that provide public funds for farming conservation practices (Rajsic et al., 2012; Reimer and Prokopy, 2014). In Canada, the current cost-sharing program is the Canadian Agricultural Partnership (CAP), "a \$3 billion five-year (2018-2023), investment by federal, provincial and territorial (FPT) governments to strengthen and grow Canada's agriculture and agri-food sector"

(Agriculture and Agri-Food Canada, 2021). The program is a 60:40 Federal-provincial funding split that coordinates agricultural business risk management initiatives (Ker et al., 2017; Agriculture and Agri-Food Canada, 2021), including agri-environmental stewardship practices (Vercammen, 2019).

Previously, CAP was known as Growing Forward (GF) and then Growing Forward 2 (GF2), and like its predecessors, completion of a provincial Environmental Farm Plan (EFP) program is often required to apply for BMP implementation funding (Rajsic et al., 2012; Vercammen, 2019), completion of an EFP being a means to control demand and ensure the proper allocation of funds to beneficiaries who will make effective use of them (Vercammen, 2019). An EFP is a voluntary, confidential, whole-farm assessment used to identify agro-environmental risks and the methods than can be used to address them (BMPs). Beyond a provincial EFP, there are a number of parameters that govern the cost-sharing program, which in turn regulate the total cost of the investment and the maximum sum that can be contributed to each project, known as the program “cap” (Reimer and Prokopy, 2014; Vercammen, 2019). “The program cap is particularly important because these limited-budget programs have historically been oversubscribed” (Vercammen, 2019, p. 16). The cap or funds provided are also how the Federal government controls which and how many practices to fund and promote, the major environmental problems to address, the number of proposals accepted, and the agreements made with state and/or provincial entities so program implementation can occur at a more local level (Reimer and Prokopy, 2014; Vercammen, 2019). As with most environmental initiatives in Canada, implementation of CAP is a provincial responsibility, as such the application methods, funding requirements (such as completion of an EFP), and funds available – minimum and maximum – for BMP implementation can vary between provinces (Vercammen, 2019). For example, CAP in Alberta is the *Environmental Stewardship and Climate Change – Producer Program* while in Ontario it is *CAP Environmental Stewardship Program* (Vercammen, 2019).

EFPs are often a requirement for funding, but since the program is voluntary, confidential, and whole-farm, funding cannot be based on farm-specific characteristics, such as size, debt, and age of the farmer (Vercammen, 2019). What this means is that funds are not allocated to those who might have the greatest need – young farmers with newly-established fields and greater debt, where funds from CAP could help set up the farm using environmentally friendly practices that would otherwise be economically unfeasible at this stage, versus a well-

established farm that could or would invest in the use of BMPs regardless of receiving cost-sharing funds (Vercammen, 2019).

Since the funds given under CAP and the previous funding programs are often for initial implementation, these programs allow for farmers to apply to other provincial or Federal funds to further subsidize the costs of BMP implementation (Rajsic et al., 2012). As a result, up to 90% of total costs can be covered by various provincial and Federal funding schemes, though this varies depending on eligibility, the province, and the BMP being implemented (Rajsic et al., 2012). Under GF2, approximately 28 different BMPs were eligible for funding (Rajsic et al., 2012), which may or may not still be the case under CAP. The number of BMPs funded also differ provincially depending the EFP program and their areas of assessment (Rajsic et al., 2012).

2.4 Summary of Key Findings

Cyanobacteria blooms are a wicked problem, with several known factors impacting bloom formation (sunlight, air temperature, thermal stratification, anoxia, and nutrient concentrations). However, cultural eutrophication is still believed to be the leading cause of bloom formation, principally in eutrophic and hypereutrophic systems. However, with the newly emerging problem of blooms in oligotrophic systems, it is clear that the cause is more complex, and redox reactions and the release of Fe^{2+} appear to play a role in bloom formation, especially in nutrient poor systems.

Cyanobacteria management can be split into three forms, prevention, control, and mitigation with the combination of the three needed for the successful management blooms, a known complex problem socially and environmentally.

Most management of blooms is focused on risk management, where source/drinking waters, and to a lesser extent recreational waters, are routinely or reactively monitored for cyanobacteria and their toxins. ALFs in combination with cyanotoxin threshold levels are used for public notifications, thus protecting public health from the risk's blooms pose. While there are a range of factors that can be used as threshold values, MC-LR is most commonly regulated for and therefore used.

NPS Nutrient management is largely encouraged and incentivized, reliant on proper funding and education and outreach initiatives to urge participation.

Water management in Canada is complicated by the myth of abundance and jurisdictional fragmentation, which complicates water management, let alone cyanobacteria management. Bloom management requires the coordination of efforts, which is where IWM may come in, as it is the form of water management used in Canada to coordinate water quality protection efforts.

Cyanotoxin threshold levels for the cyanotoxin MC-LR in drinking and recreational waters devised by the Federal government are recommendations only, making their adoption by provinces optional. Likewise, nutrient effluent standards are also recommendation, with agreements used to try and coordinate efforts between Federal and provincial governments.

Chapter 3: Methods

Policy analysis provides a means of understanding why and how governments choose to enact certain policies and the effects they have (Browne et al., 2019). The traditional, problem oriented, approach to policy analysis (Lasswell, 1970; Browne et al., 2019) is the scientific approach, where, a problem is identified and so too is a solution. This traditional orientation to “policy analysis involves deploying a rational comprehensive approach to problem solving, in a world that is objectively knowable” (Browne et al., 2019, p. 3). A positivist approach (objective and value-free) utilizes scientific understanding, free from political influence, to develop and apply an appropriate solution to the problem (Browne et al., 2019). However, cyanobacteria management is a wicked problem, so a policy analysis framework, similar to Real-Time Policy Evaluation (RTE), was developed and used to categorize and organize the data allowing for contrast and comparison (comparative analysis) (Hanberger, 2001). RTE allows for dynamic processes to be scrutinized and can distinguish uncertainty (Hanberger, 2001). RTE does justice to what is going on and is useful to practitioners for improving their practice because it takes into consideration policy change (Hanberger, 2001) with the framework (Figure 4) allowing for the policy analysed to be put in a societal context, making contrast and comparison possible (Mitchell et al., 2015).

| Problem/Situation | Policy | Implementation | Results/Consequences |
|---------------------|-------------------------|-------------------------|---------------------------|
| Context | Goals | Line of Action | Attained Goals |
| Actors/Stakeholders | Policy Theory | Organization/Competence | Unintended Results |
| Problem definitions | Policy Means | Resources | Effects |
| Relevant variables | Evaluation Intervention | Unexpected Problems | Values and order promoted |

Figure 4: Original RTE policy analysis framework seen in Hanberger (2001).

Rather than using Hanberger’s (2001) general RTE framework a more specific framework was developed combining aspects of IWM and “Ontario’s 12-point plan on blue green algal blooms” (Figure 5) with the research questions developed used to guide the data collection and input into the framework for comparative analysis. Seven main aspects were selected for the framework: (1) Communication, (2) Nutrient Management, (3) Risk Management, (4) Adaptive Management, (5) Monitoring, (6) Legislation and Regulations, and (7) Support, Funding, and Agreements (Figure 6).



Figure 5: The 12 points of “Ontario’s 12-point plan on blue green algal blooms”.

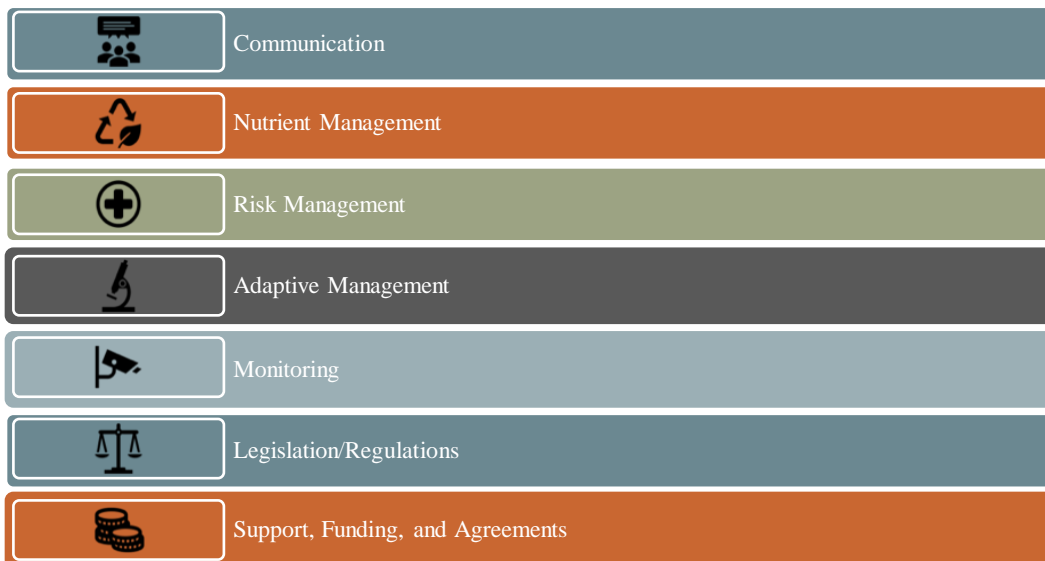


Figure 6: the framework developed for the comparative analysis used in this research

These seven points were then further broken down into cyanobacteria prevention, control, and mitigation. Control covered risk management, monitoring, legislation and regulations, and communication. Mitigation included adaptive management – research, remote sensing, chemical and physical treatments. Prevention integrated nutrient management – PS, NPS, and internal loading.

The research questions that guided the review were: (1) What is the response to the presence of blooms and is it consistent with the provincial policy surrounding bloom management? (2a) To what extent is NPS P loading regulated in each province? (2b) What is being done in each province to manage agricultural NPS P loading? (3a) What mechanism does each province have

for the transfer of scientific knowledge to the ministry staff and the management of blooms? (3b) Do provincial ministry personnel read or have access to the latest literature which may not be publicly available via open access? (3c) Is there any new science in recent years that staff think are management-relevant? (4) How and by whom is each province advised on the active management of cyanobacteria blooms? (5) Is what is being done in each province enough to partially mitigate (decrease) the size or frequency of blooms? (6) What are the gaps, if any, in bloom management? (7) Has any province seen a decrease in the occurrence of blooms after implementing a management strategy? (8a) Which ministries and agencies handle which specific actions in regard to implementing nutrient and risk management within a province? (8b) What is the division of responsibilities between Federal vs. provincial vs. municipal/local governing bodies?

Like Foulon and Rousseau (2019), the literature was selected using a rapid review, while a scoping and realist review was used to gather the relevant data. Primary and gray literature (primary literature, peer-reviewed reports and books, legislative materials, Federal and provincial policy documents, websites, and reports, and non-governmental organization (NGO) policy documents, websites, and reports) were reviewed for the 5 provinces of study – Alberta, Manitoba, Nova Scotia, Ontario, and Saskatchewan. Different databases (Google Search Engine, Google Scholar, JSTOR, Scholars Portal, Wiley Online), Government and NGO websites were rapidly searched to find the relevant literature using search terms like “drinking water guidelines”, “nutrient management”, “cyanobacteria management”, “Microcystins”, “Blue-Green Algae”, and more. The selection criteria included any information that fell within the scope of the research framework and related questions.

A rapid review is a form of knowledge synthesis in which components of a systematic review are excluded due to time constraints, but bias is still considered (VCU, 2021). So, the databases and webpages used and the documents selected were collected rapidly given the time constraints of the research. The methodologies used to review the documents and gather the relevant data to be entered into the framework were done using a scoping and realist review. A scoping review is a form of knowledge synthesis that “incorporates a range of study designs to comprehensively summarize and synthesize evidence with the aim of informing practice, programs, and policy and providing direction to future research priorities” (Colquhoun et al., 2014, pg.1291). Its scope is broad and aimed at mapping key concepts and approaches around a

research question (Foulon et al., 2020) or in this case a set of research questions. Since the policy review deals with a large range of topics, including a wicked problem, a realist review was also employed. A realist review has its roots in critical realism: a comprehensive philosophy of science that “helps researchers explain social events and suggest practical policy recommendations to address social problems” (Fletcher, 2017, pg.181). A realist review has an explanatory rather than judgemental focus and involves work that attempts to establish causal relationships (Pawson et al., 2005). Here, to infer a causal outcome the underlying mechanisms that link the cause to the context need to be fully understood (Pawson et al., 2005) making it ideal for evaluating a wicked problem (Foulon et al., 2019). A realist review was conducted using five main steps: (1) scope clarification, the search for evidence, (2) literature appraisal and data extraction, (3) evidence synthesis and the drawing of conclusions, and finally, (4) dissemination, implementation, and evaluation (Pawson et al., 2005).

Three case studies were also selected and comparatively analyzed to gain an understanding of the effectiveness of the policies in practice, outline guidance and cooperation between jurisdictional levels, establish any resource, policy, science, and management gaps/obstacles, determine local response at the lake level, and ascertain if any of these management strategies have been successful in reducing or preventing cyanobacteria blooms. The case studies selected were Lake Erie, Ontario, Lake Winnipeg, Manitoba, and Pigeon Lake, Alberta. The case study approach was used to explore a bounded system (the lake and its watershed) through a detailed, in-depth data collection pulled from a variety of sources (Creswell, 2013). A collective case study approach was employed to achieve a comparative perspective of management in practice between provinces (Cousin, 2005). This provided a better representation of variable management regimes in practice because “case research allows the researcher the opportunity to tease out and disentangle a complex set of factors and relationships” (Easton, 2010, pg.119). Each case study was also described in detail providing and exploring key themes for each case (Yin, 2017) using the framework. This allowed for cross-analysis between the case studies, searching for similarities and differences between them.

For both the provincial policy analysis and case studies approximately 500 documents and webpages were reviewed. The data collected then underwent descriptive analysis. Descriptive research depicts a phenomenon and its characteristics with a focus on how or why something has happened (Nassaji, 2015). Descriptive analysis allows for the “rigorous use and

integration of both qualitative and quantitative approaches” (Nassaji, 2015, p.131) which was important when considering the effectiveness of various management strategies in practice.

Finally, semi-structured interviews were conducted with key stakeholders from the selected case studies and provinces in order to provide a more contextual understanding of the successes or limitations implementation of these different provincial management strategies has had. Representatives from NGOs, federal, provincial, municipal, and regional governing bodies were interviewed for each of the provinces and case studies, for a total of 37 interviews.

All the stakeholders selected for interview actively take part in and have an affiliation with the bloom management processes within the province or for each of the lakes. Interviewees were selected using a combination of purposive and referral sampling. Purposive sampling is the deliberate selection of participants due to known the possession of known qualities (Etikan et al., 2016). It “involves identification and selection of individuals or groups of individuals that are proficient and well-informed with a phenomenon of interest” (Etikan et al., 2016, p. 2). Basically, certain individuals identified as working within cyanobacteria management either provincially or within the case studies selected were directly contacted due to the relevance of their position. The method of initial contact was predominantly via email, though some people were contacted over the phone. Referral sampling means just that, participants recommend others to interview or would share the interviewers contact information, allowing these individuals to volunteer to participate in the research. In some situations, a general inbox or phonenumber was contacted, and those tasked with responding or working the main switchboard would connect me with individuals in relevant positions.

The interviews were conducted over zoom or via email, depending on the availability of those who were willing to participate. Not all agencies or ministries were willing or able to provide information on the relevant programs, policies, and practices for a variety of reasons, such as the impacts of COVID-19. The majority of interviews (25) were conducted over Zoom or Teams, digitally recorded, and transcribed using NVIVO Transcription. The remaining interviews (8) were conducted via email, where the relevant questions were sent to the interviewee and the responses were sent back in a PDF document or an email response. In these cases, subsequent questions and answers occurred depending on the information provided. All interview data was thematically coded in NVIVO using the RTE framework for guidance. Thematic coding within NVIVO permitted for easily retrievable data for review. Analysis within

NVIVO also aided in the identification of common categories and themes within the interview data, supported the analysis during data collection, and allowed for ease of access to data during the writing phase (Leech and Onwuegbuzie, 2011).

Chapter 4: Cyanobacteria Management – A Case Study Approach

This chapter compares cyanobacteria prevention, control, and mitigation programs among the 5 provinces studied – Alberta, Manitoba, Nova Scotia, Ontario, and Saskatchewan. While cyanobacteria blooms are reported in parts of Canada, these five provinces have identified cyanobacteria as a risk to public health (Sask. MOE and SaskH2O, n.d.; NSE, 2009; ARD, 2016; GOS, 2017; HC, 2017; NSMOA et al., 2017; GOO, 2019) and have risk mitigative programs in place either for drinking water, recreational water, and/or water for agricultural use. These provinces also have nutrient management regulations and agri-environmental encouraged and incentivized programs to limit the overapplication of nutrients. However, these nutrient management regulations and programs are not geared towards cyanobacteria bloom management and instead are used to address a range of environmental issues. This chapter introduces the various provincial strategies to manage cyanobacteria blooms.

Only Ontario has officially adopted a province-wide response protocol for cyanobacteria management called “Ontario’s 12-point plan on blue green algal blooms” (GOO, 2019) The Ministry of the Environment, Conservation and Parks (MECP) in collaboration with other partners (e.g. conservation authority, municipalities, watershed associations) coordinate the implementation of the 12-point plan. The 12-point plan was a culmination of existing programs, focusing on nutrient management, drinking water standards, monitoring blooms, reporting health risks, scientific discovery, and public health guidelines (e.g., cyanotoxin concentrations). Ontario’s 12-point plan is useful framework for comparing cyanobacteria risk management strategies in the other provinces studied.

4.1 Bloom Control Programs: Cyanobacteria Risk Management

Most bloom events go unnoticed in the majority of Canadian lakes (approximately 2 million in total) because they are not routinely monitored for blooms (O’Keefe, 2019). As such, it is unknown how many blooms occur in Canada’s waters annually (O’Keefe, 2019). There is also no single strategy for monitoring bloom activity in Canadian waters, resulting in a variety of programs and practices used across provinces (O’Keefe, 2019). Given the number of lakes in Canada, there are too many to monitor routinely, so many provinces have to make a choice about mitigating risk to public health. Since drinking water and recreational waterbodies are two sources of possible cyanotoxin exposure. Provinces have established different monitoring

programs based on the local context and circumstances as health risks increase with higher concentrations of cyanotoxins.

Cyanobacteria risk management in all five provinces is geared towards mitigating the potential risks cyanobacteria blooms pose to the public in source/drinking waters and recreational waters, such as beaches. Only one province (Saskatchewan) currently has a cyanobacteria risk mitigation program dedicated to protecting the health and welfare of livestock from cyanobacteria blooms occurring in agricultural surface waters, which includes nutrient management education and outreach. All cyanobacteria risk management programs include water quality standards, monitoring, advisories, and education and outreach. Risk management is heavily dependent on bloom monitoring programs, with provinces using a combination of reactive and routine monitoring programs to respond to blooms in drinking, recreational, and sometimes, agricultural waters (Table 5). Advisory issuance, as a result of monitoring, uses risk assessments to determine the level of risk a bloom poses to the public, which varies depending on the means of exposure and therefore the waterbodies use (recreational and/or drinking).

Table 5: Cyanobacteria Bloom Monitoring Programs in Canada. All five provinces have routine bloom monitoring requirements for surface source water DWTPs. Routine recreational monitoring programs for blooms are the provincial beach monitoring programs, which in Alberta, Manitoba, and Saskatchewan are tied to their reactive monitoring programs. All provinces respond to public reports of bloom activity, though not all programs involve sampling.

| Province | Routine Recreational (Bloom) | Reactive (Bloom) | Routine Source Water (Bloom) | Agricultural Waters |
|---------------------|------------------------------|------------------|------------------------------|---------------------|
| Alberta | • | • | • | *a |
| Manitoba | • | • | • | *b |
| Nova Scotia | | • | • | |
| Ontario | | • | • | |
| Saskatchewan | • | • | • | • |

*a Alberta used to have a program for responding to farmer reports of blooms in dugouts where ministry personnel would help farmers manage risk to livestock and recommend BMPs to reduce occurrence. However, this program was shuttered in 2021.

*a Manitoba will, on a case-by-case basis help farmers respond to blooms in dugouts on farms. There is no formal mechanism for reporting blooms in dugouts and occurrences are not tracked.

4.1.1 Cyanobacteria Water Quality Standards

As previously mentioned, due to jurisdictional fragmentation, provinces have control over natural resources and therefore regulatory power over water quality standards. As a result, drinking and recreational water quality standards vary between provinces and territories in Canada. According to Dunn et al. (2014), 8 of the 13 jurisdictions in Canada have legally enforced drinking water standards while the other 5 have voluntary standards for Municipally managed Drinking Water Treatment Plants (DWTPs), which may or may not include cyanobacteria. However, all five provinces have adopted the Federal government's cyanotoxin MAC for MC-LR in treated drinking water (Table 6).

Table 6: Jurisdictional cyanotoxin (MC-LR) MACs and the related legislation and standards documents.

| Provinces | MAC | Drinking Water Legislation | Drinking Water Regulation | Water Quality Standards Document | Responsible Organization |
|---------------------|-------------------|---|--|--|--------------------------|
| Alberta | 1.5 µg/L MC-LR | 1. Environmental Protection and Enhancement Act 2. Public Health Act | 1. Potable Water Regulation (2003) 2. Nuisance and General Sanitation Regulation (2003) | Standards and Guidelines for Municipal Waterworks, Wastewater, and Storm Drainage Systems (2012) | AE |
| Manitoba | 1.5 µg/L MC-LR | Drinking Water Safety Act | Drinking Water Quality Standards Regulation (2007) | Manitoba Water Quality Standards, Objectives and Guidelines (2011) – Tier III | MCC ODW |
| Nova Scotia | 1.5 µg/L MC-LR | Environment Act | Water and Wastewater Facilities and Public Drinking Water Supplies Regulations (2005) | Guidelines for Monitoring Public Drinking Water Supplies: Part I - Municipal Public Drinking Water Supplies (2020) Guidelines for Monitoring Public Drinking Water Supplies: Part II – Registered Public Drinking Water Supplies (2020) | NSE |
| Ontario | 1.5 µg/L MC-LR | Safe Drinking Water Act | Drinking Water Quality Standards Regulation (2002) | Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines (2003) - archived | MECP |
| Saskatchewan | 1.5 µg/L MC-LR | The Environmental Management and Protection Act | The Waterworks and Sewage Works Regulations (2015) | Municipal Drinking Water Quality Monitoring Guidelines - Edition 5 (2020) | WSA |

Meanwhile, only 3 of the 5 provinces - Alberta, Manitoba, and Saskatchewan - have officially adopted the Federal government's recreational water guideline values for cyanobacteria and their toxins (Table 7).

Table 7: Provincial recreational water quality values for cyanobacteria and total microcystins. Manitoba and Alberta's recreational water values for cyanobacteria and total microcystins are legislatively backed, while Saskatchewan's are not.

| Jurisdiction | Threshold Levels | | Water Quality Guideline Document | Legislation and Regulations | Responsible Organization |
|---------------------|---------------------------------|--------------------------|--|--|--------------------------|
| | <i>Cyanobacteria Cell Count</i> | <i>Total Microcystin</i> | | | |
| Alberta | 100,000 cells/mL | 20 µg/L | Environmental Water Quality Guidelines for Alberta Surface Waters (2018) | The Environmental and Protection Enhancement Act | AH AHS |
| Manitoba | 100,000 cells/mL | 20 µg/L | Manitoba Water Quality Standards, Objectives and Guidelines (2011) | The Water Protection Act Manitoba Water Quality Standards, Objectives and Guidelines Regulation | ARD |
| Nova Scotia | N/A | N/A | N/A | N/A | AE |
| Ontario | N/A | N/A | N/A | N/A | MECP |
| Saskatchewan | 100,000 cells/mL | 20 µg/L | Canadian Recreational Water Quality Guidelines (2017) Surface Water Quality Objectives – Interim Edition (2015) | No legal standing | MOH SHA |

There are no other cyanotoxins regulated or monitored for in any of these provinces either for recreational or source waters, currently.

4.1.2 Source/Drinking Water Monitoring

Surface water is the dominant source of drinking water for most Canadian provinces and territories, save for PEI and the Yukon, with 4-5% of DWTPs identifying blooms as a risk to water quality (Giddings et al., 2012; O'Keefe, 2019). Municipal DWTPs are responsible for providing ~88% of Canadians with clean potable water (O'Keefe, 2019). The other 12% of Canadians are serviced by small drinking water systems (SDWS) or private water supplies (PWS) (O'Keefe, 2019).

Table 8: Drinking water routine monitoring, sampling, and testing methods for provincially managed DWTPs within five Canadian provinces.

| Province | Threshold Levels | Visual Inspection Frequency | | Timeframe | Water Sampling | | Sample Type | Analysis Method |
|--------------|---|--|-------------------------|--|---|---|--|---|
| Alberta | 1.5 µg/L MC-LR | Regulated | Weekly – required | Open Water Season * | Bloom visually confirmed | | Raw and Treated | PPI |
| | 12 µg/L TMC ^g | Unregulated | AHS Reactive Monitoring | Recreational Water Season * | | | | |
| Manitoba | 1.5 µg/L MC-LR 0.4 µg/L MC-LR ^h | Weekly – asked and required | | July to September (Suggested June start) | 1. Bloom visually confirmed 2. Test Kit positive (maybe) 3. Mid-August (only collected if no blooms observed) | | 1. Raw and Treated 2. Raw and Treated 3. Raw | 1. Field Test Kit ^e 1. Approved Lab 2. Approved Lab 3. Approved Lab |
| Nova Scotia | 1.5 µg/L MC-LR | Weekly – required | | May to October | Municipal | Bloom visually confirmed | Raw and Treated | Approved Lab |
| | | | | | Registered | Visually confirmed bloom dissipates | Raw | |
| Ontario | 1.5 µg/L MC-LR | Weekly – required (all surface source water DWTPs) | | June to October | Historic Blooms | 1. Weekly 2. Bloom visually confirmed | Raw and Treated | ELISA ^f LC-(ESI)MS/MS ^d |
| | | | | | No Historic Blooms | Bloom visually confirmed | Raw and Treated | |
| Saskatchewan | 1.5 µg/L MC-LR | Daily – recommended | | May to October | SDWS | Once in August | Treated | Approved Lab |
| | | | | | Large Plant | Monthly | Treated | Approved Lab |
| | | | | | All DWTPs | 1. Bloom Visually Confirmed 2. Test Kit Positive (maybe) | 1. Raw and Treated 2. Raw and Treated | 1. ELISA Test Kit 1. Approved Lab – likely LC-MS 2. Approved Lab |

* Open Water Season = May to September; Recreational Water Season = June to October

a SDWS = DWTPs services a population of 501 to 5000; b Large DWTPs = DWTPs services a population of 5001 or greater

c ELISA samples can be submitted to the MECPs Laboratory Services Branch (LaSB) (the MECPs provincial lab) or an approved laboratory

d Conducted when ELISA results for total microcystins meet or exceed 1.5 µg/L. This test can only be conducted by the MECP LaSB.

e ELISA field test kit used if available. Recommended that DWTPs with a history of blooms purchase these kits.

f ELISA is for total microcystin, and can be tested at an approved lab or LaSB

g Short-term MAC for TMC used for issuing drinking water advisories

h Threshold value used for infants on formula

As a result of adopting the MAC for MC-LR into provincial water quality standards, provincially managed DWTPs are required or recommended (Table 8) to conduct routine monitoring of surface water drinking water sources, as set out in the facilities' operating certificate. This means that all five provinces have routine monitoring of surface source waters to ensure that the MAC for MC-LR is not exceeded in treated water, thus protecting public health. However, the frequency of monitoring and sampling for routine bloom monitoring in source waters varies between provinces and the types of facility being managed (Table 8), though implementation is always delegated to the DWTP owner/operator. The timeframe monitoring is required or recommended, and the methods of water sample analysis also vary between provinces (Table 8).

Regulated routine monitoring and sampling of surface source waters is at various stages of implementation in all five provinces. Monitoring for blooms in Ontario surface waters by DWTPs was voluntary until in 2019, the province decided to issue monitoring requirements for all Municipal Residential Drinking Water Systems that use surface source waters in the facilities

license renewals. Implementation is still ongoing and slated for completion in 2022. Alberta DWTPs have been monitoring for blooms in surface source waters since 2007, even prior to the Federal guidelines. Although Alberta does not require that all surface source DWTPs routinely monitor for blooms, instead a preliminary assessment determines the monitoring requirements. If monitoring is deemed necessary by the assessment, the conditions are issued through the DWTPs approval license. Saskatchewan only adopted the MAC for MC-LR in 2020 and the province sets sampling requirements in the monitoring conditions of the DWTPs permit to operate waterworks (POW). These POWs and their monitoring requirements are directly linked with the population size serviced by the facility and the provinces municipal drinking water quality monitoring guidelines. DWTPs monitoring for blooms used to be voluntary in Manitoba as well, but since the province officially adopted the MAC for MC-LR in 2020 with implementation in 2021, monitoring forms have been or are being submitted to all DWTPs using surface source waters that have historic bloom issues. Though, it is mandatory for all surface source water DWTPs to now conduct visual inspections.

Table 9: Provincial reactive monitoring programs reporting, response, sampling, and analysis methods for cyanobacteria blooms and their associated toxins in surface source waters.

| Province | Method of Reporting | Responsible Group | | Field Assessment | Sampling Criteria | Sample Analysis Method |
|--------------|--|-------------------|-----|------------------|------------------------------|---|
| Alberta | Phone - Healthline - AHS - AE Local Offices | Regulated | AE | Bloom suspected | Visual confirmation of bloom | 1. Alberta Centre for Toxicology (microcystin) 2. UofA – Freshwater Diversity Lab (cell count) |
| | | Unregulated | AHS | | | |
| Manitoba | Online - ARD Bloom Reporting Webpage Phone - ARD number - MCC ODW | MCC ODW | | Bloom Suspected | Visual confirmation of bloom | Approved Laboratory |
| Nova Scotia | Phone - Regional or District NSE Office | NSE SAS Division | | Bloom Suspected | Visual confirmation of bloom | Approved Laboratory |
| Ontario | Phone - SAC - MECP DO - Local SDWB | MECP SDWB | | Bloom suspected | Visual confirmation of bloom | MECP Laboratory - LaSB (microcystin) - EMRB Lab (cell Count) Approved Laboratory |
| Saskatchewan | Online - Bloom Reporting Webpage Phone - Healthline - SHA District Office - WSA | WSA | | Bloom suspected | Visual Confirmation of bloom | Approved Lab |

*Not linked to advisory issuance, but is listed in the protocol as a monitored parameter

On top of the routine monitoring of municipal surface source waters, all five provinces have reactive source water monitoring programs, where blooms can be reported by the public, other ministries, NGOs, and more to the relevant ministries, using various means (Table 9). Once a report is received a response protocol is followed, triggering sampling protocols and assessing the risk to the DWTP and the public. That is, there is a set series of events that occur

when a cyanobacteria bloom is suspected in a source water, from confirming the bloom through visual inspection, sampling, and analysis, to notifying the DWTP and, if possible or necessary, initiating treatment protocols and/or issuing an advisory to inform the public that a contamination event has occurred and that there are possible health risks associated with the event (Figure 7; Figure 8; Figure 9; Figure 10; Figure 11).

These response protocols are a coordinated effort between various ministries, and linked with provincial cyanotoxin water quality standards and advisory issuance (Figure 7; Figure 8; Figure 9; Figure 10; Figure 11). While the response protocols for the five provinces are similar, the key differences are when notifications occur. Ontario conducts preliminary notifications, informing relevant parties of bloom presence and follow-up actions prior to receiving analysis results, while other provinces often wait for cyanotoxin exceedance confirmation before notifying Health Officials, outside of coordination with the impacted DWTPs. Nova Scotia is the only province to have set different response protocols for certain types of DWTPs within the province. Nova Scotia issues an advisory whenever a bloom is confirmed in a registered drinking water supply due to the known ineffectiveness of the facilities cyanotoxin treatment capacity. Meanwhile the other provinces and Municipal DWTPs within Nova Scotia, rely on analysis and risk assessment results for advisory issuance or, where applicable, the initiation of treatment protocols. Similar to Nova Scotia, Alberta has a set response protocol for SDWS within the province when blooms are reported in these source waters, however, this response protocol is entirely under the mandate of the provinces public health officials (AHS).

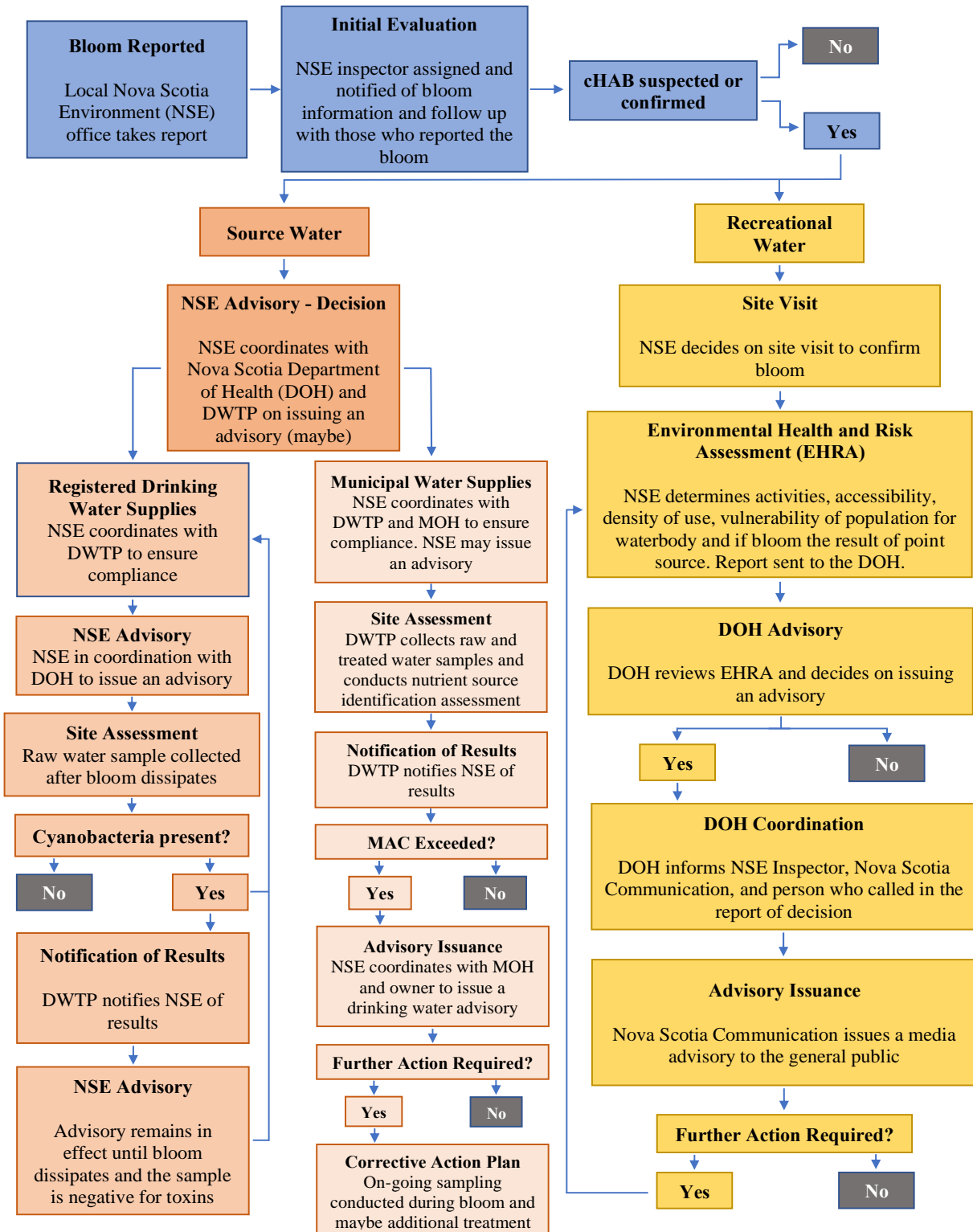


Figure 7: Nova Scotia Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters.

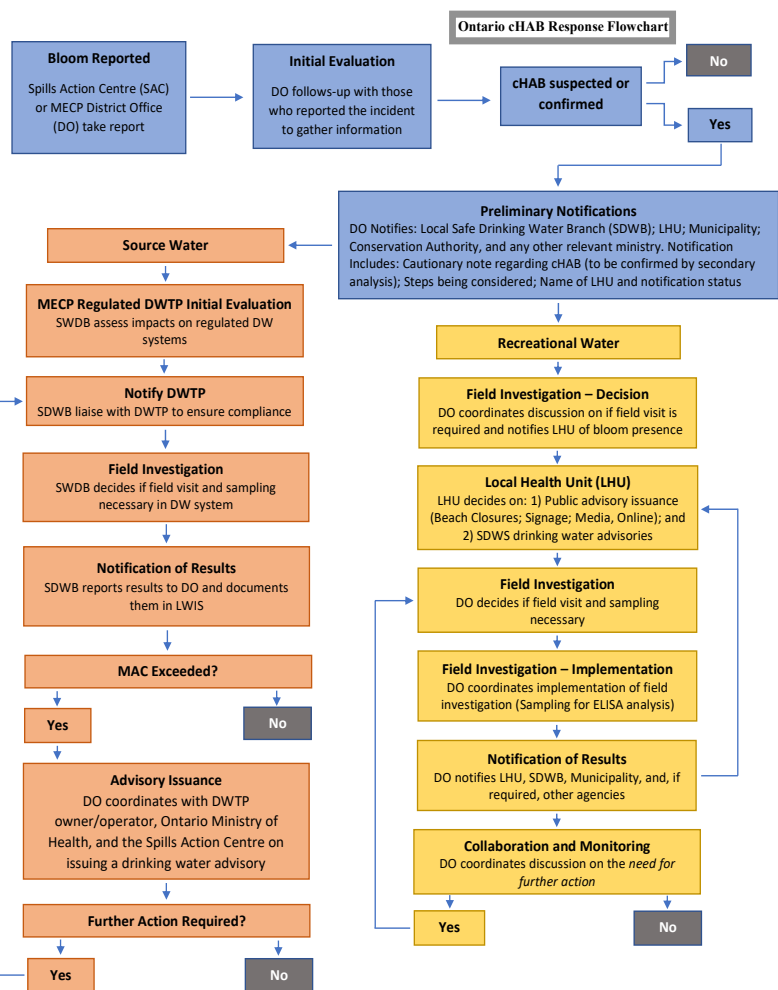


Figure 8: Ontario Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters.

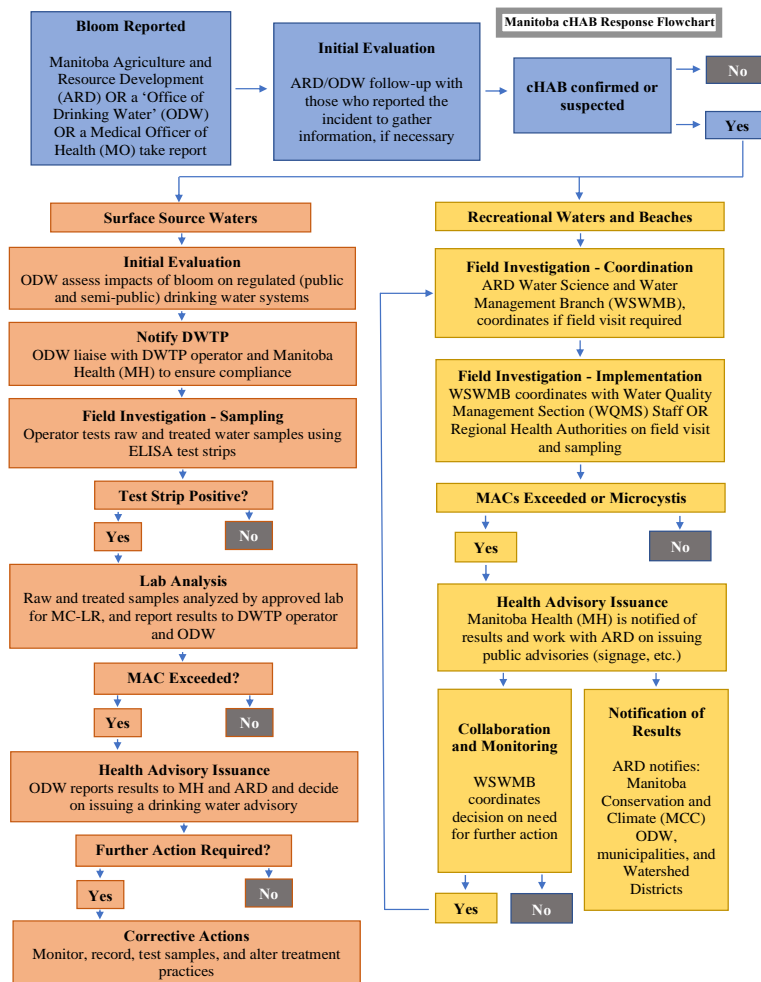


Figure 9: Manitoba Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters.

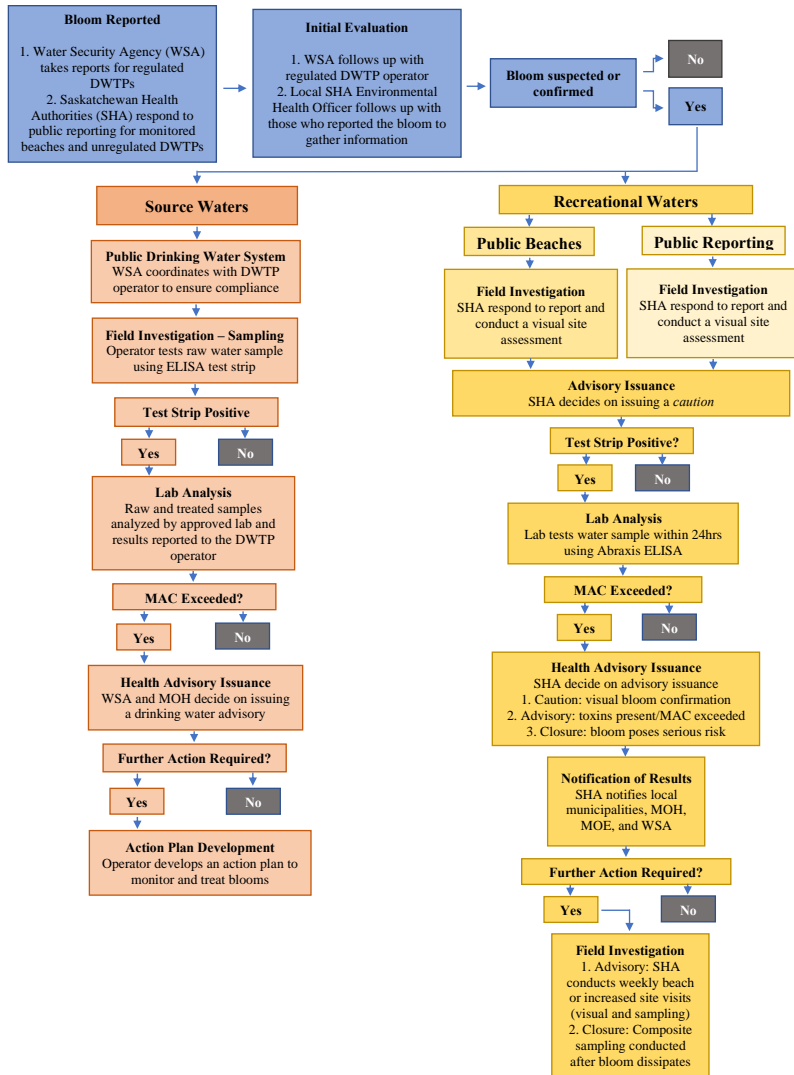


Figure 10: Saskatchewan Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters.

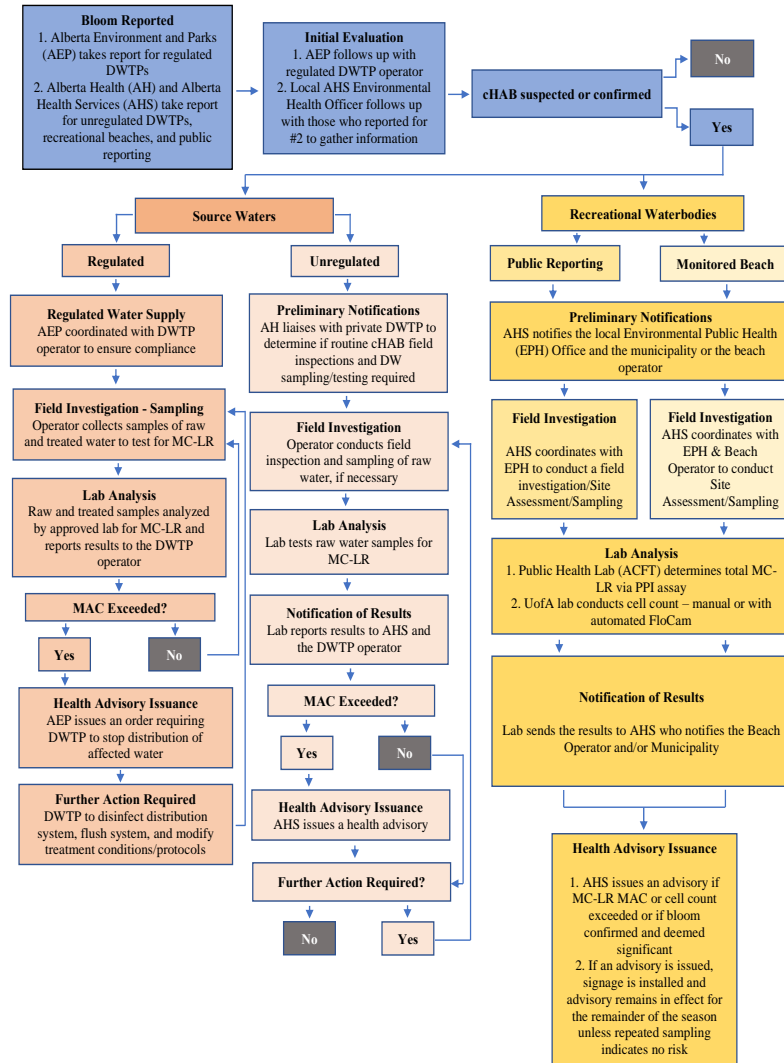


Figure 11: Alberta Cyanobacteria Bloom Response Protocols for Drinking (orange) and Recreational (yellow) Waters.

Given the variability in monitoring and analysis methods as well as the differences in longevity of these monitoring programs and their requirements, comparison of cyanotoxin levels in source waters between provinces and overtime would be and is difficult. A national framework for cyanobacteria monitoring would help track changes in cyanotoxin levels over time, which could aid in the scientific understanding of cyanotoxin production, thus helping with treatment methods and protocol development for DWTPs effected by bloom occurrence and bloom mitigation and prevention. Especially taking into consideration the increase in bloom occurrence throughout Canada.

4.1.2 Recreational Water Monitoring

As previously mentioned, only Alberta, Saskatchewan, and Manitoba have adopted the Federal recreational water quality guideline values for cyanobacteria and total microcystins. Coincidentally, these three provinces are the only ones to have routine recreational bloom monitoring/risk management programs, which are applied to public beaches (Table 10). All three programs are linked with provincial *E. coli* monitoring, which impacts site selection and monitoring frequency.

Table 10: Monitoring and sampling protocols for the provincial routine beach monitoring programs in Alberta, Manitoba, and Saskatchewan.

| Province – Program | No. of Beaches | Time Period | Visual Inspections | Frequency | Location | Sampling Criteria | Analysis Method |
|---|----------------|-------------------|--------------------|-----------------|----------------|---|--|
| Alberta – Safe Beach Protocol | 40 | May to August* | Yes | Weekly | Priority Sites | 1. Visual Confirmation of a bloom 2. When conducting a Field Visit | Approved Laboratory |
| Manitoba – Clean Beach Program | 60 | June to August | Yes | Weekly | Lake Winnipeg | Visual Confirmation of a bloom | Approved Laboratory |
| | | | | Biweekly | Site-Specific | | |
| | | | | Monthly | Site-Specific | | |
| Saskatchewan – Healthy Beach Program | 15-20 | June to September | Yes | Weekly | High Risk | 1. Visual confirmation of a bloom 2. When conducting a Field Visit 3. Positive Field Test Kit | 1. Field Test Kit 2. Field Test Kit 3. Approved Laboratory |
| | | | | Monthly | Moderate Risk | | |
| | | | | Once per season | Low Risk | | |

*Monitoring as part of the Safe Beach Protocol is conducted by the beach owner/operator. Beach may only be open from June to September; therefore, sampling would only be done when the site is open.

Each of the beach monitoring programs has a site selection cap (total number of beaches monitored annually) based on personnel, laboratory capacity, and program funding. As such, the number of beaches monitored varies both between provinces and annually within the provinces (Table 10). The public beach sites for Saskatchewan and Alberta are selected annually using a risk assessment tool before the monitoring season (the time period the program runs) begins, where parameters such as historical bloom occurrence, frequency of use, waterbody trophic status, and more are considered. Unlike Saskatchewan and Alberta, Manitoba monitors the same sites every year, with most sites monitored since the 1980’s or 1990’s. New sites have been

added over time as a result of repeated or extreme public health risk events, like fish die-off events, and some sites have been removed due to budgetary constraints.

Ontario and Nova Scotia do not have routine recreational monitoring programs for cyanobacteria blooms, and instead rely on reactive monitoring programs to mitigate the risks blooms in recreational waters pose to public health. Neither one of these reactive monitoring programs are linked with provincial recreational cyanobacteria water quality standards (Table 11; Figure 7; Figure 8). Out of the two provinces, only Ontario conducts cyanobacteria and cyanotoxin sampling as part of the reactive monitoring program. However, this may change in Nova Scotia after a recent incident on Shubenacadie-Grand Lake resulted in the death of two dogs and a woman was hospitalized (Lau, 2021).

Table 11: Provincial reactive monitoring programs response, sampling, and analysis methods and protocols for recreational waters.

| Province | Threshold Levels | Method of Reporting | Responsible Group | Field Assessment | Sampling | Sampling Criteria | Analysis Method |
|---------------------|---|---|-------------------|------------------|----------|------------------------------|---------------------------------------|
| Alberta | 100,000 cells/mL 20 µg/L MC-LR | Phone - Healthline - AHS | AHS | Bloom suspected | Yes | Visual confirmation of bloom | PPI |
| Manitoba | 100,000 cells/mL 20 µg/L total microcystins | Online - Bloom Reporting Webpage Phone - ARD number | ARD | Bloom Suspected | Yes | Visual confirmation of bloom | Approved Lab |
| Nova Scotia | N/A | Phone - Regional or District NSE Office | NSE | Bloom Suspected | No | No sampling done | No sampling done |
| Ontario | N/A | Phone - SAC - MECP DO | MECP DO | Bloom suspected | Yes | Visual confirmation of bloom | Cell Count ELISA LC-(ESI)MS/MS |
| Saskatchewan | 100,000 cells/mL* 20 µg/L total microcystins | Online - Bloom Reporting Webpage Phone - Healthline - SHA District Office | SHA | Bloom suspected | Yes | Visual Confirmation of bloom | ELISA Field Test Kit Abraxis ELISA |

*Not linked to advisory issuance, but is listed in the protocol as a monitored parameter

Saskatchewan, Manitoba, and Alberta also have reactive recreational monitoring programs for blooms, which are linked with their routine beach monitoring programs and recreational water quality standards (Table 11; Figure 8; Figure 9; Figure 10). These reactive monitoring programs rely predominantly on public reporting, however, other ministries, local public health officials, recreational water operators, NGO personnel, and more can also report sightings. And like reactive monitoring in surface source waters, there are a variety of means available for reporting bloom sightings, though telephoning in the sighting is often the main method utilized in each province (Table 11).

4.1.3 Monitoring Waters for Agricultural Use

Cyanobacteria is a risk to agricultural water in two ways: (1) cyanotoxins in agricultural surface waters can poison livestock and (2) crops irrigated with water containing cyanotoxins pose a risk to the public. Given these impacts, Saskatchewan has a program within the Ministry of Agriculture where farmers/producers can call in to report blooms in dugouts, sloughs, and/or shallow surface waters and any associated events such as livestock illnesses or death. Bloom events can also be reported by veterinarians if they believe a livestock death or illness is related to consumption of cyanotoxins. There are no advisories issued as part of this monitoring program, instead the primary goal is to protect animal welfare by working one-on-one with producers to manage blooms in agricultural waters, by implementing nutrient management practices and BMPs (Figure 12). When a bloom is reported in waters used for agricultural purposes, a set series of events are followed to ensure the health and safety of the livestock and manage the bloom occurring in the agricultural water (Figure 12).

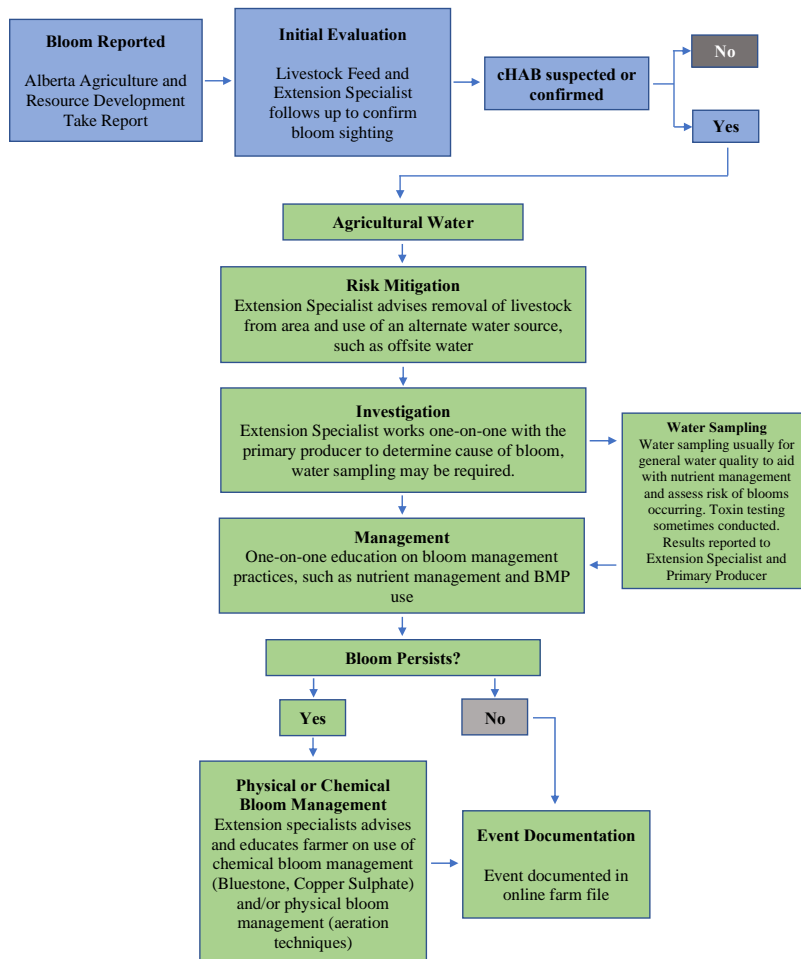


Figure 12: Saskatchewan Agricultural Water Cyanobacteria Response Protocol

Water sampling and analysis may be conducted as a part of this program; however analysis includes routine water quality standards (phosphorus) as opposed to identifying the cyanotoxins. If cyanotoxin sampling is conducted, it is done so to mitigate the risk of exposure to livestock and/or in response to livestock illness or death, and there does not appear to be an MAC/threshold for a particular cyanotoxin associated with this.

“I don’t know what their threshold is. I just know, like, there was one time when I got a call from the lab saying, you know, we haven’t sent the report out yet, but we feel like this producer should be contacted as soon as possible because this is what the number is, and I don’t know the number offhand, this was a couple years ago. So, just because they know that it’s a major concern and could be an issue. Maybe they do have a threshold, maybe it was just a “whoa, that’s too much, we need to be careful here”.” (Personal Interview, January 7, 2021, Saskatchewan)

When to collect water samples and what they are to be analyzed for (general water quality, cyanotoxin testing, or both) is under the discretion of ministry personnel. If cyanotoxin sampling is deemed necessary, collection is often delegated to the primary producer due to time, staff, and funding constraints (sizeable pasturelands over a large proportion of the province). The sample is submitted to an approved lab where recommendations are made based on the results which are reported to Ministry personnel and the primary producer, though, with no threshold values used, what levels are deemed a risk are unknown. All sightings and sample results are recorded; however, the data are stored in the individual farmers file, rather than being stored in a database specific to bloom events or by geographic location which makes the creation of or inclusion in a province-wide data base of blooms difficult. Instead, the data are stored for future educational and livestock safety purposes. It is not shared with any other ministry, but it is available to the primary producer upon request.

None of the other provinces have a program dedicated to responding to reports of blooms in agricultural waters; however, Manitoba Agriculture and Resource Development will, on a case-by-case basis, if informed of a bloom, work with farmers to implement BMPs to reduce the risk to livestock. And Alberta used to have a similar program, which was shuttered in 2021, where Alberta Agriculture and Forestry worked one-on-one with producers to help them manage blooms in dugouts and ponds used for consumption and small-scale irrigation. Management was achieved using education and outreach, promoting the use of BMPs for waterbody design and maintenance. The program also included water suitability assessments and treatment in the

dugout and at distribution, often using the *Rural Water Quality Information Tool*. This tool was available to producers to aid them in meeting their water quality requirements; however, it doesn't track cyanobacteria, cyanotoxins, TP, or chlorophyll-a in irrigation and/or livestock waters. The program was funded/part of CAP. Moving forward it is likely that only educational documents will be provided to producers to address blooms in dugouts rather than one-on-one guidance.

4.1.4 Advisories

Drinking Water Advisories

Both the reactive and routine monitoring programs for surface source waters are linked the response protocols and drinking water advisory issuance in each province.

In Canada there are three different types of drinking water advisories: (1) Do Not Use, (2) Do Not Consume/Drink, and (3) Boil Water. Do Not Use advisories are issued when the water supply is contaminated with something that cannot be removed by boiling and exposure can occur through physical contact or consumption (Galway et al., 2016). Do Not Consume advisories are issued when the water supply has contaminants that cannot be removed by boiling and exposure occurs through consumption (Galway, 2016). As such, the water is often deemed safe for uses other than consumption, such as washing dishes, showers, and/or more. What uses are acceptable are included in the advisory. A Boil Water Advisory informs the public that water is contaminated, however boiling the water is sufficient to remove the health risk (Galway, 2016). Only Do Not Use and Do Not Consume advisories apply to cyanobacteria blooms in surface source waters, because boiling water that contains cyanobacteria cells causes lysis, which would release the toxins contained within the cell. Several of the five provinces use these three advisories for drinking water, though Do Not Use and Do Not Consume are sometimes subsets for general water quality advisories (Table 12).

The criterion for advisory issuance due to the presence of cyanotoxins or a cyanobacteria bloom varies between provinces and facilities (Table 12), but it is always determined by a Medical Officer of Health (Ministry of Health Official or Public Health Official) in conjunction with a risk assessment, where the cyanotoxin level, size and treatment capacity of the DWTP, vulnerability and size of the population being serviced, and duration/severity of the event are considered. The risk assessment is conducted by the Ministry responsible for drinking water (Table 12) and the information is then shared with the Medical Officer of Health. And a drinking water advisory can only be rescinded by a Medical Officer of Health.

Table 12: Cyanobacteria Bloom Drinking Water Advisory Criteria in Canada.

| Province | Do Not Use | | Do Not Consume | | Closure |
|--------------|---|---|--|--|---------|
| Alberta | Regulated | Criteria: exceeds short-term exposure limit (12 µg/L total microcystins) OR exceeds the 1.5 µg/L MAC over a 12-month period | Regulated | Criteria: exceeds short-term exposure limit (12 µg/L total microcystins) OR exceeds the MAC over a 12-month period | N/A |
| | Unregulated | 1.5 µg/L MC-LR Exceedance or due to proximity to intake | Unregulated | 1.5 µg/L MC-LR Exceedance or due to proximity to intake | |
| Manitoba | Water Quality Advisory Criteria: based on consultation with MOH, facility treatment capacity, and toxin levels | | Drinking Water Avoidance Criteria: based on consultation with MOH, facility treatment capacity, and toxin levels | | N/A |
| Nova Scotia | Municipal Supply | Criteria: Consultation with MOH, site specific conditions, and Health Risks Present | Municipal Supply | Criteria: Consultation with MOH, site specific conditions, and Health Risks Present | N/A |
| | Registered Supply | Visual confirmation of a bloom and risk assessment | Registered Supply | Visual confirmation of a bloom and risk assessment | |
| Ontario | Drinking Water Advisory Criteria: Determined by local (public) health unit (LHU) in coordination with MECP | | Drinking Water Advisory Criteria: Determined by LHU in coordination with MECP | | N/A |
| Saskatchewan | Precautionary Drinking Water Advisory Criteria: level exceeds the permit level or inadequate treatment capacity | | Precautionary Drinking Water Advisory Criteria: level exceeds the permit level or inadequate treatment capacity | | N/A |

No province has officially mandated closure criteria for DWTPs and a closure event has never occurred in Canada due to a cyanobacteria bloom. Instead, provisions under Do Not Use or Do Not Consume advisories inform the public to use an alternate water source until the Medical Officer of Health rescinds the advisory.

For provincially managed DWTPs, when *treated water* either meets or exceeds the MAC for MC-LR, provinces will generally issue a drinking water advisory, though the type of advisory issued is still dependent on the risk assessment and Medical Officer of Health. Only Manitoba and Alberta have and use cyanotoxin levels outside of the Federal guideline MAC for MC-LR to issue advisories. Alberta uses a TDI for MC-LR of 12 µg/L. If this level is exceeded in two treated water samples (the initial sample and the follow-up sample), a drinking water advisory is issued. The 1.5 µg/L threshold level is a lifetime MAC, so an advisory is issued when the average MC-LR level over 12 months, including the resample, exceeds the MAC. In Manitoba, an advisory may be issued if the cyanotoxin concentration in treated water is 0.4 µg/L or higher if the serviced population is believed to be more vulnerable to exposure.

“The Medical Officer of Health is notified if we (the ODW) find microcystins in the treated water because the health-based value for infants is fairly low (0.4 µg/L MC-LR). So, basing off the national guideline, which is what we reference. So, there is potentially an advisory issued whenever there's microcystins found in the treated water or even in the raw water if we don't think that the treatment is adequate, if we don't think that there's adequate treatment in place. And that would be, again, be a drinking water avoidance advisory. And it's at the discretion of the medical officer. So, they're the ones. But they do have, you know, they do have their own processes for making those decisions.” (Personal Communication, January 26, 2021, Manitoba)

Manitoba and Nova Scotia will also issue an advisory if the treatment capacity of the DWTP is insufficient and the raw or treated water meets or exceeds the MAC for MC-LR. Saskatchewan may also do this, depending on the risk assessment.

If an advisory is deemed necessary, generally issuance is delegated to the DWTP owner/operator after being directed to do so by the/a Medical Officer of Health, unless the DWTP is unable or unwilling to do so in a timely manner. And any drinking water advisory that is issued can only be rescinded by a Medical Officer of Health.

Recreational Water Advisories

As a result of the reactive and routine recreational water monitoring programs, advisories are issued to warn the public of the risks blooms pose to public health (Table 13; Figure 7; Figure 8; Figure 9; Figure 10; Figure 11). Most provinces utilize a general Blue-Green Algae Bloom Advisory; however, Manitoba and Saskatchewan have two different advisories for bloom presence and toxin presence (Table 13).

Table 13: Recreational Water Advisories for Cyanobacteria Blooms and their criterion.

| Province | General Advisory | Bloom Present | Toxins Present | Beach Closed |
|--------------|--|---|--|---------------|
| Alberta | Blue-Green Algae Bloom Advisory Criteria: 1. Bloom visually confirmed (maybe) 2. Exceedance of cell count (maybe) 3. Toxin level exceedance | N/A | N/A | N/A |
| Manitoba | N/A | Algae Advisory Criteria: 100,000 cells/mL met or exceeded | Algae Toxin Advisory Criteria: 20 µg/L MC-LR met or exceeded | N/A |
| Nova Scotia | Blue-Green Algae Bloom in (location) Criteria: Bloom visually confirmed | N/A | N/A | N/A |
| Ontario | Blue-Green Algae Bloom Advisory Criteria: LHU Dependent | LHU Dependent | LHU Dependent | LHU Dependent |
| Saskatchewan | N/A | Caution Toxic Algae Criteria: Bloom Visually Confirmed | Toxic Algae Advisory Criteria: 20 µg/L total microcystin met or exceeded | N/A |

Like drinking water advisories, the criteria for issuing either general bloom advisories or bloom and toxin presence advisories varies between provinces (Table 13). Manitoba uses both recreational cyanobacteria threshold levels for issuing their advisories, with cell count linked with the “Algae Advisory” and the toxin level linked with the “Algae Toxin Advisory” (Table 13). Saskatchewan is similar to Manitoba, except that a caution is issued upon visual confirmation of a bloom sighting. All the other provinces tend to issue general advisories whenever a bloom sighting is suspected to be cyanobacteria and will reissue the advisory upon receipt of sample results that exceed the MAC for total microcystins. Which, in Alberta, Manitoba, and Saskatchewan is the Federal recreational MAC. In Ontario, if an MAC is used, it is under the discretion of the Local Health Unit (LHU). Nova Scotia is the only province to not

perform bloom water sampling for recreational waters, so advisories are only issued upon visual confirmation of a bloom. However, this may be subject to change due to the severe cyanotoxin exposure event on Shubenacadie-Grand Lake. Only Ontario issues beach closures due to cyanobacteria bloom presence, however, this is LHU dependent.

All five provinces use a variety of means to issue recreational water advisories, when one is deemed necessary, which vary between drinking and recreational water advisories.

Table 14: Advisory issuance methods utilized in each province to mitigate risk to public health. Not all methods used apply to drinking waters.

| Province | Signage | Public Announcements | Media | Advisory Webpage | Online Interactive Map | Social Media | Annual Reminder |
|---------------------|----------------|----------------------|-------|------------------|------------------------|--------------|-----------------|
| Alberta | • | • ^a | • | • ^a | | * | |
| Manitoba | • | • | • | | • | | |
| Nova Scotia | • ^c | • | • | • ^d | | | |
| Ontario | * | * | • | * | * | * | * |
| Saskatchewan | • | • | • | • ^b | | * | • |

*Advisory issuance under the mandate of LHUs. Some LHUs post signage, have an advisory webpage or interactive map, will use social media, and/or will have an annual reminder. All LHUs will issue a public advisory on their webpage and generally a local media advisory in coordination with the MECP reactive monitoring program.

a Advisory issuance and webpage run by AHS

b Healthy Beach Program Webpage

c Nova Scotia has advisory signage for drinking and recreational water advisories

d Cyanobacteria webpage upgraded in August of 2021, now lists all recreational water advisories within the province from 2009 to 2021.

Drinking water advisories in all five provinces have required notification methods, which are some combination of door-to-door notifications, newspaper publications, local media announcements (radio and television), posters, and any other methods dictated by the Medical Officer of Health. Only Nova Scotia posts signage for drinking water advisories.

For recreational water advisories, methods of notification are more variable, though all five provinces issue public announcements via media and online formats (provincial news webpages). Four out of the five provinces have provincial cyanobacteria bloom signage, with only Ontario not requiring signage (Table 14). Instead, the decision to have cyanobacteria signage is delegated to LHUs, with only certain ones adopting this practice. Only Alberta has cyanobacteria educational signage, with posting a requirement for all public beaches on a lake that historically have blooms (a public beach with two consecutive years of cyanobacteria bloom advisory issuance).

Four of the five provinces have dedicated cyanobacteria bloom advisory webpages for the entire province (Table 14). Nova Scotia's was updated in August 2021, again due to severe bloom event, and is a general list of all current and past advisories. Alberta's and Saskatchewan's are also lists, but only of active advisories. Manitoba's is an interactive map where the sample results (cell count and cyanotoxin levels) can be found. Ontario is the only province to not have some form of webpage where all provincial recreational water advisories can be found. Instead, certain LHUs have bloom advisory webpages, while others post advisories

as part of their beach monitoring programs for *E. coli*, and some have an interactive map. All LHUs post bloom advisories under news on their webpages.

None of the provinces have cyanobacteria bloom social media advisory ‘pages’, however, some of the LHUs in Ontario and provincial beach monitoring programs will use social media, Facebook or Twitter, to alert the public of an advisory. And only Saskatchewan issues a province-wide annual reminder via media and provincial webpages (MOH and SWA) for the public to be on the lookout for cyanobacteria blooms.

4.1.5 Education and Outreach

All five provinces have various forms of education and outreach regarding cyanobacteria blooms available to the general public in order to mitigate the risks posed by cyanobacteria blooms. However, the methods used tend to vary between provinces. The only consistency is that all five provinces have educational webpages and four out of five provinces have factsheets dedicated to cyanobacteria bloom risk management (Table 15).

Table 15: Education and outreach initiatives within each of the five jurisdictions.

| Province | Public Announcements | Signage Public Advisories | Annual Reminder | Factsheets | Website | Interactive Map | PowerPoint Presentations | Poster |
|--------------|----------------------|---------------------------|-----------------|----------------|---------|-----------------|--------------------------|--------|
| Alberta | • ^a | • | • | • | • | | | |
| Manitoba | • ^a | • | • | • | • | • | • | • |
| Nova Scotia | • ^a | | | | • | | • | |
| Ontario | • ^a | • ^b | • ^b | • | * | * | • | |
| Saskatchewan | • ^a | • | • | • ^c | • | • ^d | | |

a Public announcements are often waterbody type dependent. It is mandatory in all provinces for source water DWTP owners/operators to work with the relevant ministry to inform the public should there be exceedances in the treated drinking water for MC-LR and to inform the public for provinces who have adopted the Federal recreational water values for cyanobacteria and their toxins. If there is no provincial mandate, announcements are delegated to local authorities (see note b). Public announcements can be in newspaper articles (online or printed), news interviews (videos for TV or online), and via social media.

* These activities are Local Health Unit specific in Ontario. There is not overarching response protocol to manage risk within the province, so Local Health Units decide on their own methods, such as the use of signage and/or when to make public announcements (online, media, social media, etc.).

c Every year, Saskatchewan’s Ministry of Health holds a press conference reminding the public to be on the lookout for blooms in recreational waters, the risks associated with blooms, and what to do if a bloom is spotted. This notice is also posted online (Ministry of Health and Saskatchewan Water Security Agency).

d Cyanobacteria specific webpage run by the MOA. MOH has the Healthy Beach Program webpage which links to the General Information Factsheet on blooms.

While all five provinces have websites dedicated to providing information on cyanobacteria blooms, the information imparted is not consistent across provinces (Table 16). The only consistencies are general information on cyanobacteria bloom descriptions to aid in identification and that blooms are a potential health risk.

Table 16: Information on blue-green algae blooms provided by government websites

| Province | Provincial Plan | General Info. | Health Risk | Signs and Symptoms | Identif. | Cause | Bloom Prevention | Chem/Phys Treatment | Report Sighting | Report Symptoms | Risk Mitigation | Source Water |
|--------------|-----------------|---------------|-------------|--------------------|----------|-------|------------------|---------------------|-----------------|-----------------|-----------------|--------------|
| Alberta | | • | • | • | • | | | | • | • | • | |
| Manitoba | | • | • | | • | | • ^b | | • | | • | |
| Nova Scotia | | • | • | • | • | • | | | • | | • | • |
| Ontario | • | • | • | a | • | • | • | | • | | • | • |
| Saskatchewan | | • | • | | • | • | • | • | * | | | |

*Healthy Beaches Program website – which does not contain information on blue-green algae specifically (though it does provide a link to their BGA factsheet) but it lists all active advisories and provides the link to a BGA factsheet and the online reporting form for blue-green algae blooms.

a Most LHUs have webpages to educate the public on the health risks associated with blooms including the signs and symptoms of exposure

b N and P stated as cause of bloom formation and provide link to Lake Winnipeg bloom management webpage

The way blooms are described varies across these government webpages (Table 17), which could be due to the dominant species found in blooms frequently observed in the provinces or the fact that blooms can vary in colour depending on the species present. Still, it might be beneficial to provide more consistent information on the visual appearance of blooms and include more visual aids.

Table 17: Cyanobacteria bloom descriptions published on provincial webpages.

| Province | Bloom Description (Provincial Website) | Photos | Ministry |
|--------------|---|--------|----------|
| Alberta | “Appearing like scum, grass clippings, fuzz or globs on the surface of water, blue-green algae (cyanobacteria) can be blue-green, greenish-brown, brown, and/or pinkish-red, and often smell musty or grassy” | 0 | AHS |
| Manitoba | “Cyanobacteria can be blue, green or brown in colour and they range extensively in size and shape... Too much algae will form floating clumps or scums... During bloom conditions, the water sometimes looks like thick pea soup and may emit a strong, unpleasant odour” | 4 | ARD |
| Nova Scotia | “Despite the name, blue-green algae blooms can be turquoise, olive-green, or red. Blooms can look like fine grass clippings in the water or a large scum on the surface. They can be seen floating on the surface or suspended in the water. There may be algal mats at the bottom of clear shallow areas of lakes and rivers. They can be dark black, brown or green with a leathery texture and earthy, musty odour.” | 1 | NSE |
| Ontario | “Dense blue-green algae blooms may make the water look bluish-green, or like pea soup or turquoise paint. Very dense blooms may form solid-looking clumps. Fresh blooms often smell like newly mown grass, while older blooms may smell like rotting garbage.” | 1 | MECP |
| Saskatchewan | “Blue-green algae typically has a shimmering, blue-green colour. It may also have a foamy sheen-like appearance that looks like spilled paint floating on top of the water. Heavy blooms appear like a solid shimmering blue-green sheen across the water’s surface, or have an appearance and consistency similar to pea soup. The blooms are dispersed within the water column an unattached to solid objects unlike filamentous algae” | 2 | MOA |

Most provinces have three factsheets available regarding cyanobacteria blooms, with only Saskatchewan having two and Nova Scotia zero (Table 18). That is, prior to 2021, Nova Scotia did not appear to have any factsheets. However, due to the recent severe cyanotoxin event in August 2021 a “Advisory and FAQ for Shubenacadie-Grand Lake” is now available on the government’s cyanobacteria webpage, along with two webcasts.

Table 18: The number of factsheets found in each province dedicated to cyanobacteria blooms and their “type”.

| Province | No. of Factsheets | FAQ Drinking Water | Identification | General Information | Public Health |
|--------------|-------------------|--------------------|----------------|---------------------|---------------|
| Alberta | 3 | • ^a | | • | |
| Manitoba | 3 | | • | • | • |
| Nova Scotia | 0 | | | | |
| Ontario | 3 | | • | • | • |
| Saskatchewan | 2 | • ^a | | • | |

a Frequently Asked Questions factsheet for Alberta and Saskatchewan centred around risk management/mitigation

Like the provincial webpages on cyanobacteria bloom, the information imparted in these factsheets varies (Table 19). However, all factsheets provide general information on cyanobacteria, how/why they pose a health risk, the signs and symptoms of exposure, information on how to recognize a bloom or what they look like, methods of mitigating risk, that bloom infested waters should not be used for drinking, and that boiling cyanobacteria contaminated waters does not make the water safe for consumption (Table 19). And only

Ontario, Manitoba, Nova Scotia, and Alberta provide information on the risks posed by consuming fish caught during a bloom. Since provinces with Factsheets have more than one, one is often a General Information Factsheet while the other or others are more specific to drinking water or answering frequently asked questions (FAQs) about blooms (Table 18; Table 19).

Table 19: Information on blue-green algae blooms provided by government factsheets. Note: Not all information found on each factsheet.

| Province | General Health Info. | Health Risk | Signs and Symptoms | Identification | Cause | Bloom Prevention* | Report Sightings | Report Symptoms | Risk Mitigation | Do Not Drink | Do Not Boil |
|--------------|----------------------|-------------|--------------------|----------------|-------|-------------------|------------------|-----------------|-----------------|--------------|-------------|
| Alberta | • | • | • | • ^a | | • | • | • | • | • | • |
| Manitoba | • | • | • | • | | | • | • | • | • | • |
| Nova Scotia | | | | | | | | | | | |
| Ontario | • | • | • | • | • | • | • | | • | • | • |
| Saskatchewan | • | • | • | • | • | | | • ^b | • | • | • |

Nova Scotia created a factsheet in 2021 in response to a seriously bloom event

a AHS FAQ Factsheet includes photos of different types of blooms and other algal blooms that are often misidentified as cyanobacteria

b Told to report symptoms to physician

*Bloom prevention in provincial factsheets is generally “What You Can Do” – providing information on what the individual can do to limit nutrient loading, like keeping septic tanks in working order, limiting fertilizer application to lawns, using phosphate free cleaning products, and more.

Community engagement and education around cyanobacteria blooms is something that all five provinces do, however, the frequency with which this occurs has decreased in several provinces. That is, ministry employees used to engage in more outreach initiatives, giving presentations to cottage associations, communities impacted by blooms, and participating in conferences where provincial initiatives to manage blooms were presented, as was any current research. However, Ministry employees in several provinces reported that budgetary restraints had resulted in the decrease in community and conference engagement, with the publication of educational materials often taking the place of outreach initiatives.

4.2 Bloom Prevention Programs: Nutrient Management

Nutrient management is still the cornerstone of cyanobacteria bloom management because eutrophic lakes are high-risk for bloom formation. All five provinces have identified eutrophication as a risk to water quality and the leading cause of bloom formation, which is why PS and NPS nutrients are managed using a variety of regulated, encouraged, and incentivized programs, policies, and practices (Table 20; Table 21). However, despite nearly 50-years of PS and NPS nutrient management efforts in Ontario, reports of cyanobacteria blooms are increasing (Winter et al., 2016). Though, this is not to say that these nutrient initiatives haven’t successfully reduced nutrient exports from agricultural fields and nutrient loads in effluent waters, but rather, the reductions may not be enough to limit bloom formation in eutrophic systems, or there are other factors to consider. Especially given the increasing occurrence of blooms in mesotrophic and oligotrophic lakes.

Table 20: Regulated nutrient management programs and practices used across Canada

| Province | Wastewater Management | Manure Storage | Manure Application | Winter Manure Application Restricted | Urban Application Restricted | Golf Course Fertilizer Application | Buffer Zone Management | Wetland Protection | Setback Distance |
|--------------|-----------------------|----------------|--------------------|--------------------------------------|------------------------------|------------------------------------|------------------------|--------------------|------------------|
| Alberta | • | • | • ^a | • ^c | | | | | • |
| Manitoba | • | • | • | • | • | • | • | • | • |
| Nova Scotia | * | • | • | | | | | • | • ^d |
| Ontario | • | • | • | • | | | • | • | • |
| Saskatchewan | * | • | • ^b | | | | | | |

* Site-specific wastewater standards only

a Application rates triggered by exceedances to soil N and salinity

b Application rates triggered by soil N

c Farmers may apply to the Natural Resource Conservation Board to get approval for winter application

d Setback distances only apply to manure storage. No setback distances for manure application.

Table 21: Encouraged, Incentivized, or recommended nutrient management programs and practices.

| Province | EFP | 4R | BMP/CAP | Chemical | Physical | WQT |
|--------------|-----|----|----------------|----------------|----------------|-----|
| Alberta | • | • | • ^b | | | |
| Manitoba | • | • | • ^a | | | |
| Nova Scotia | • | | • ^a | | | |
| Ontario | • | • | • ^a | | | |
| Saskatchewan | • | • | • ^b | • ^c | • ^c | |

a BMP/CAP funding linked with provincial EFP program

b BMP/CAP no longer or minimally linked with EFP program (EFP assessment no longer a requirement to apply for CAP funding for BMPs)

c Chemical and physical recommendations linked with dugout monitoring/response program for agriculture. Encourage the use of Phoslock and aeration techniques to prevent blooms in dugouts, however these methods are not recommended for source and recreational waters

4.2.1 PS Nutrient Management

As of 2017, 86% of Canadians were serviced by municipal WWTPs, with 71% provided secondary treatment or better (ECCC, 2020a). While the methods of P removal vary between plants and provinces, there are three main techniques utilized within Canada (Oleszkiewicz, 2015). Smaller communities (populations under 3,000) use lagoon systems, often without the pointed removal of P and N (Oleszkiewicz, 2015). Eastern Canada municipalities use conventional activated sludge with extended aeration (CAS EA) to remove organic pollutants, with most plants using chemical precipitation (Chem. P.) to actively remove P (Oleszkiewicz et al., 2015). Western Canada municipalities tend to utilize biological nutrient removal (BNR), which removes P and N from effluent water (Oleszkiewicz, 2015).

Alberta, Manitoba, and Ontario all have provincially mandated total phosphorus (TP) effluent water standards that apply to municipally managed WWTPs (Table 22) to limit nutrient loading and protect water quality from eutrophication and algal blooms, along with other water quality concerns. However, while all three of the provinces apply the same TP effluent standard, the facilities the standard applies to varies between provinces (Table 22), altering their impact or contribution to cyanobacteria bloom management.

Table 22: Provincial Nutrient Wastewater Effluent Standards for Provincially Managed Wastewater Treatment Plants, listed best to worst for cyanobacteria bloom management.

| Province | TP Standard | TN Standard | Facilities Required to Meet the Standard(s): | Legislation | Regulations |
|---------------------|--------------|-------------|---|--|---|
| Ontario | 0.5-1.0 mg/L | N/A | <p>1. Lake Erie: All municipal and institutional sewage treatment works, regardless of nominal design capacity, discharging into the basin shall have effluents not exceeding the standard</p> <p>2. Lake Superior, Huron, Ontario, St. Lawrence and Ottawa River Basins: all municipal and institutional sewage treatment works with design capacities of 4,546 m³/day or more discharging into the aforementioned basins shall have effluents not exceeding the standard</p> <p>3. Recreational Waterways: all municipal and institutional sewage treatment works, regardless of capacity, discharging into recreational waterways shall have effluents not exceeding the standard. Specifically, but not limited to, the Trent-Severn River System, Rideau River System, Lake Nipissing drainage basin, selected areas of Lake Huron.</p> <ul style="list-style-type: none"> - Some treatment facilities have more stringent mean seasonal requirement of 0.5 mg/L TP from May-September. - Removal requirements for private communal sewage and municipal and institutional sewage discharging into waters not listed above are determined through receiving water assessments | <p>1. Water Resources Act (1990)</p> <p>2. Environmental Protection Act (1990)</p> | <p>1. <i>Ontario Regulation 129/04 Licensing of Sewage Works Operators</i></p> <p>2. <i>Ontario Regulation 215/95; Ontario Regulation 64/95; Ontario Regulation 562/94; Ontario Regulation 560/94</i></p> |
| Manitoba | 1.0 mg/L | 15 mg/L | <p>TP:</p> <ol style="list-style-type: none"> 1. All facilities discharging more than 820 kg TP/year (population is greater than 2,000 people or equivalent due to industry) 2. New or expanding facilities discharging less than 820 kg TP per year (population is less than 2,000 people or equivalent due to industry) OR a demonstrated nutrient reduction strategy <p>TN:</p> <ol style="list-style-type: none"> 1. All new or expanding facilities discharging more than 33,000 kg TN/year per year (population is greater than 10,000 people or equivalent due to industry) | The Water Protection Act | <i>Manitoba Water Quality Standards, Objectives and Guidelines Regulation</i> |
| Alberta | 1.0 mg/L | N/A | Tertiary treatment plants and aerated lagoons that treat water for populations > 20,000 | Environmental Protection and Enhancement Act | <p><i>Wastewater and Storm Drainage Regulation (119/93)</i></p> <p><i>Wastewater and Storm Drainage (Ministerial) Regulation (120/93)</i></p> |
| Saskatchewan | N/A | N/A | Effluent Discharge Objectives – standards set based on site-specific requirements when discharging into fish-bearing waters and/or “sensitive” waterbodies/watersheds | The Environmental Management and Protection Act | <i>The Waterworks and Sewage Works Regulations</i> |
| Nova Scotia | N/A | N/A | Facility Effluent Standards set based on site-specific requirements, which are determined by the condition of the receiving waterbody | Environment Act | <p><i>Water and Wastewater Facilities and Public Drinking Water Supplies Regulations</i></p> <p><i>On-site Sewage Disposal Systems Regulations</i></p> |

Ontario’s TP effluent standard applies to the greatest assortment of facilities and can be more stringent for specific facilities based on site-specific conditions or for certain waterbodies and watersheds (Table 22). The standard also takes into consideration seasonal differences, and so requires some plants to have a more stringent level to further decrease P loading during the warmer summer months (Table 22). Manitoba’s TP effluent standard applies to any facility that

meets a specific discharge level, regardless of location and treatment capacity (Table 22). Meaning that large polluters are all required to meet the TP standard, regardless of the discharge location. The standard also applies to any new or upgrading facilities. Manitoba is the only province to also have a total nitrogen (TN) effluent water standard, as N is believed to be contributing to bloom formation within the province. This is likely to substantially increase wastewater treatment costs and time and is unlikely to have an impact on cyanobacteria blooms due to certain cyanobacteria species ability to fix atmospheric nitrogen. Alberta is similar to Manitoba, in that large polluters are regulated; however, treatment capacity is also considered. Meaning that plants that service a population of 20,000 or more that aren't tertiary or aerated lagoons are not required to meet the standard, nor are tertiary or aerated lagoons that service a smaller population.

Neither Alberta nor Manitoba stated any plans make these effluent standards more stringent either overall or during the summer months when cyanobacteria blooms are more likely. This includes for facilities discharging into waterbodies that are known to have blooms. However, Manitoba is currently upgrading WWTPs within the province to include TN treatment methods and improve TP removal methods, so that WWTPs are in compliance with the current standards. However, the province has received some pushback due to the costs associated with TN removal.

“... For now, we're going with N and P and that decision has billions of dollars' worth of consequences. If you think, the City of Winnipeg and the North End Wastewater Treatment Plant that's frequency in the news, it's one of the largest treatment plants, WWTPs in Canada. And I believe it is the oldest. And we continue to ask them, you need to upgrade your facility so that you're meeting our effluent limits for nutrients. And they're one of the pushbacks for sure. “Well, the ELA research says we only have to remove P, so why are we worrying about N, you know, if we only have to remove P, then it's going to be a fraction of the cost of the upgrade.” And that's one of the reasons why it's been so delayed is trying to find the funding, first of all, for the 1.8-billion-dollar upgrade. But, you know, but there is a lot of, there is some pushback that we get on the N and P, but we will continue to make our decisions based on the best science that is available.” (Personal Communication, February 12, 2021, Manitoba)

Saskatchewan and Nova Scotia do not have overarching TP effluent limit standards, instead these provinces use facility operation licences to set site-specific effluent standards for WWTPs based on the results of a discharge waters site assessment (Table 22) (MRC and CCME,

2005; Mavinic et al., 2018). And since effluent limits are site-specific not all facilities have nutrient effluent standards. This means that the use of more stringent levels for WWTPs servicing large populations and consideration of cumulative effects on a waterbody or watershed are unknown and that algae blooms may or may not be a consideration for the setting of nutrient effluent standards for facilities. And neither province has set more stringent summer TP effluent standards for the warmer summer months.

4.2.2 Regulated NPS Nutrient Management

Manure and commercial fertilizer application to agricultural fields have contributed to the bulk of P export from agricultural activity. The long-term buildup of soil P increases nutrient loading to surrounding streams, rivers, and lakes, which can contribute to cyanobacteria bloom proliferation.

All five provinces have some form of legislation that manages the storage and application of manure to agricultural fields, which generally only applies to large livestock producers, Manitoba and Nova Scotia being the exception (Table 23).

Table 23: Provincial legislation and regulations for agricultural NPS nutrient management and the operations they apply to, listed best to worst for cyanobacteria bloom management.

| Province | Legislation | Regulation | Manure Management | P Threshold Values |
|---------------------|---------------------------------|--|--|--------------------|
| Manitoba | 1. The Environment Act | 1. Livestock Manure and Mortalities Management Regulation (LMMR) | 1. Triggered by: Size of operation – 300 Animal Units and new or expanding operations ^a | Yes |
| | 2. The Water Protection Act | 2. Nutrient Management Regulation (NMR) | 2. Triggered by: Small livestock Operation (< 300 Animal Units), Golf Courses and Driving Ranges, Urban and Rural Areas, Water Quality Management Zones | |
| Ontario | Nutrient Management Act (NMA) | 1. Ontario Regulation 267/03 2. Ontario Regulation 300/14 | 1. Triggered by: a) Size of operation – 300 Nutrient Units or greater b) Size of operation for new structures – 5 Nutrient Units or greater c) Within 100 m of a municipal well d) New or expanding operations 2. Triggered by: Greenhouse Operations | Yes |
| Nova Scotia | Fur Industry Act | Fur Industry Regulation | Applies to all licensed fur farms | Yes |
| Alberta | Alberta Operation Practices Act | Alberta Regulation 267/2001 | Triggered by: a) Size of operation – 500 tonnes of manure/annually b) Soil nitrate-nitrogen and salinity * | No |
| Saskatchewan | The Agricultural Operations Act | Intensive Livestock Provision | Triggered by: a) Storage of liquid waste b) 300 Animal Units c) 20-300 Animal Units if within 300 m of a watercourse * | No |

* Limited applicability to blooms as soil phosphorus not considered

^a Application rates based on soil nitrate-nitrogen limits where there is a regulated residual limit. Soil P is also to be tested for, with limits to manure application based on results. Regulation also has TP soil limits for manure applied to croplands.

Alberta, Ontario, and Manitoba’s legislation also regulate winter manure application and Alberta, Manitoba, and Ontario all regulate manure application and storage setback distances from watercourses (Table 20). Manitoba is the only province to regulate nutrient application to

golf courses and driving ranges, urban areas, and Water Quality Management Zones (WQMZs) where nutrient application limits are based on waterbody and watercourse vulnerability.

Most, though not all, regulated nutrient management requirements are geared towards large producers (Table 24), which means that cumulative effects are not well considered. Instead, the focus seems to be on preventing overaccumulation for operations that produce large amounts of manure annually. Nutrient management also is not cyanobacteria management focused, and instead is meant to manage a range of environmental concerns, such as coliform and N.

Table 24: Manure production rates that require the development of a provincially approved nutrient or manure management plan

| Province | Operational Unit | Definition |
|---------------------|--------------------------------|---|
| Manitoba | LMMR \geq 300 Animal Units | 1 animal unit = the number of livestock required to produce 73 kg (160 lbs) of nitrogen in a 12-month period |
| | NMR \leq 300 Animal Units | |
| Ontario | \geq 300 Nutrient Units | Calculations made for each type of animal on the farm and the given number of manure produced by each animal, which is added together to obtain the total Nutrient Unit generated by the farm |
| Saskatchewan | 20 – 300 Animal Units (Soil N) | A means of comparing different ages and species of livestock and the amount of nitrogen produced by one animal, so an animal unit is approximately the same across species. |
| Alberta | 500 tonnes of manure/annually | |

Only Ontario, Manitoba, and Nova Scotia have some limit to manure application based on soil P levels (Table 25), while Alberta and Saskatchewan’s nutrient management legislation and regulations consider soil salinity and nitrogen and nitrogen, respectively.

Table 25: Provincial Soil P and N Threshold Levels, listed best to worst for cyanobacteria bloom management.

| Province | Soil P Threshold Levels | Soil N Threshold Levels | Surface Water TP Threshold Levels |
|--------------------|--|---|---|
| Manitoba | <p>LMMR – If soil P levels (P_2O_5) in the top 0.15 m are:</p> <ol style="list-style-type: none"> < 60 ppm, manure application limited by soil N levels 60-120 ppm, manure application cannot exceed two times the crop removal rate 120-180 ppm, manure application cannot exceed one time the crop removal rate > 180 ppm, manure application is restricted <p>NMR – Soil P levels for WQMZs:</p> <ol style="list-style-type: none"> Zones N1, N2, N3: 2x the P removal rate if soil P levels < 120 ppm Zones N1, N2, N3: the P removal rate if soil levels > 120 ppm and < 180 ppm Zone N4: no nutrient application Zone N5: No application of fertilizer containing more than 1% P (P_2O_5) except: <ol style="list-style-type: none"> First year turf applied Soil P levels in proceeding 12 months are < 60 ppm, 30 ppm, and 18 ppm for different urban areas | <p>LMMR – Residual nitrate-N maximum soil limits in the top 0.6 m of soil:</p> <ol style="list-style-type: none"> Soil Class 1, 2, 3: 157.1 kg/ha Soil Class 3M, 3MW, 4: 101 kg/ha Soil Class 5: 33.6 kg/ha Soil Class 6, 7, and unimproved organic soils: no manure application <p>NMR – Soil nitrate-nitrogen concentrations cannot exceed (for WQMZs):</p> <ol style="list-style-type: none"> Zone N1: 157.1 kg/ha Zone N2: 101 kg/ha Zone N3: 33.6 kg/ha | N/A |
| Ontario | <p>NMP: Manure application based on agronomic and crop removal balance calculations</p> <p>NASMP: Crop removal + 390 kg/ha or less over a 5-year period</p> | <p>NMP: Manure application based on agronomic and crop removal balance calculations</p> <p>NASMP: Crop removal with application not to exceed 200 kg/ha within 12 months</p> | N/A |
| Nova Scotia | Management activities may be required if soil phosphate (P_2O_5) concentration is 800 kg/ha | N/A | Management activities may be required if surface water TP is 20 μ g/L |

NMP = Nutrient Management Plan; NASMP = Non-Agricultural Source Material Plan

None of the regulations and their nutrient management practices are based primarily on soil phosphorus levels or dissolved TP target levels in streams or lakes, i.e., P is not the primary nutrient of concern. As a result, these nutrient management regulations may or may not actively reduce P exports. Instead, often N is the main nutrient of concern because it is the primary limiting factor for crop production and a water quality concern itself. Soil P threshold values are exceedances (Table 25) to make sure that crop N requirements are met. Soil P is not always biologically available either, so the soil P thresholds are based on biologically available soil P levels (plant available phosphorus/biologically available phosphorus) rather than TP levels. Only Manitoba has determined soil P application limits based on soil P levels, that are to be adhered to in the absence of an approved plan (Table 25). This is something Ontario has defined as a limitation to provincial nutrient management programs and as a result, the province is currently looking to develop land-based P targets to be used as an environmental metric which would be BMP application focused. And only Nova Scotia has determined a dissolved TP level for surface waters that, when exceeded, may result in the required adoption of management activities to reduce NPS nutrient loading.

4.2.3 Encouraged, Voluntary, and Incentivized NPS Nutrient Management *Provincial EFP Programs and CAP*

A voluntary/encouraged environmental stewardship program that is used in all five provinces to help farms determine what BMPs would be most useful to reduce environmental harm is the Environmental Farm Plan (EFP) program. The definition for EFP varies between provinces (Table 26), as does implementation since each province is responsible for the development of their own EFP programs (Atari et al., 2009).

Table 26: Provincial definitions of EFP programs

| Government | Definition | Online Tool | Update Timeframe |
|---------------------|---|-------------|------------------|
| Alberta | “a voluntary, whole farm, self-assessment tool that helps producers identify their environmental risks and develop plans to mitigate identified risks. We are working together with farmers committed to environmental stewardship” (AEFP, 2021) | Yes | 5 Years |
| Manitoba | “a voluntary, confidential, self-assessment of a producer’s own farm or ranch delivered in partnership with Keystone Agricultural Producers (KAP). Environmental farm planning assists farm managers in identifying agri-environmental assets and risks in order to develop an action plan to address the identified risks.” (GoM, 2021) | No | 5 Years |
| Nova Scotia | “an educational program, delivered by the Nova Scotia Federation of Agriculture that helps farmers identify and assess environmental risks on their properties and enables farmers to incorporate environmental considerations into their everyday business decisions” (NSEFP, 2021) | No | 5 Years |
| Ontario | “assessments voluntarily prepared by farm families to increase their environmental awareness in up to 23 different areas on their farm. Through the EFP local workshop process, farmers highlight their farm’s environmental strengths, identify areas of environmental concern, and set realistic action plans with timetables to improve environmental conditions. Environmental cost-sharing programs are available to assist in implementing projects” (OMAFRA and GOC, 2021) | Yes | 5 Years |
| Saskatchewan | “free, online self-assessment tool designed to help producers identify environmental risks on their farm and create action plans to address those risks” (GoS, 2021a) | Yes | 10 Years |

What all Canadian EFP programs have in common, however, is that they are voluntary, confidential, whole-farm assessments that identify environmental risk and the corrective actions – BMPs – that can be used to address those risks (action plan). EFPs, therefore, are a form of environmental stewardship that identify agriculturally induced risks to the environment and the means farmers and/or producers can use to mitigate these risks. It is also a means of educating farmers on environmental risks posed by their operations.

Ontario, Alberta, and Saskatchewan now have online tools available to conduct the assessment. Ontario’s electronic EFP is to be used after attending the 2-day workshop or the 1-day refresher course. The EFP electronic tool is self-administered, which is why workshop attendance is recommended. Saskatchewan has farmers use the online tool to perform the EFP, which is then reviewed by a Ministry Agriculture Knowledge Centre specialist who coordinates with the farmer if/when necessary. Alberta’s EFP program is currently being ‘updated’ and outsourced. Currently, Alberta’s online EFP tool has farmers register for their own account. Once that is completed, a technician is assigned to the operation to help the farmer go through the workbooks and perform the assessment. Once the EFP is complete, it is reviewed by the assigned technician, approved, and the farmer receives a letter of completion.

Nova Scotia does not have an electronic form of the EFP assessment. Instead, the initial review consists of an on-farm visit by an EFP coordinator. Any follow-up, updating, and/or questions are then handled by the EFP coordinator. Manitoba also does not currently have an online tool or computer program to conduct the assessment. Manitoba, like Ontario, offers EFP workshops to help farmers work through the EFP workbooks. Keystone Agricultural Producers (KAP) then review the EFP workbook to maintain confidentiality and issue a *statement of completion* to the operation. Manitoba, Ontario, Alberta, and Nova Scotia recommend that EFPs be updated every 5 years while Saskatchewan recommends an update every 10 years.

Table 27: Provincial EFP Programs and their link to the CAP funding program

| Province | EFP Program | CAP Signatory | EFP required for BMP Funding | CAP Provincial Program |
|--------------|--------------------|---------------|------------------------------|--|
| Alberta | Alberta EFP | Yes | No ^a | Environmental Stewardship and Climate Change – Producer Program ^b |
| Manitoba | EFP | Yes | Yes | Ag Action |
| Nova Scotia | Nova Scotia EFP | Yes | Yes | Soil and Water Sustainability Program |
| Ontario | Canada-Ontario EFP | Yes | Yes | Environmental Stewardship Programming |
| Saskatchewan | Saskatchewan EFP | Yes | No ^a | Farm Stewardship Program |

^a EFP may be required to apply for funding for specific BMPs but is not an overall requirement for BMP funding under CAP within the province

^b BMP funding being revamped – so, this program may no longer exist and/or EFP will no longer be a requirement for funding under this program moving forward

All five provinces are signatories of the Canadian Agricultural Partnership (CAP) a Federal-Provincial-Territorial cost-share funding program that provides financial incentives for the adoption of BMPs by agricultural operations, thus limiting environmental risk (Table 27). CAP used to be linked to provincial EFP programs in all five provinces, however, Albert and Saskatchewan have both removed this requirement for BMP funding applications. The EFP programs in Ontario, Manitoba, and Nova Scotia are still linked with CAP, which means that funding for BMPs can only be applied for and awarded based on completion of an EFP, among other requirements which are BMP dependent (Table 27). Saskatchewan removed EFP as a requirement for CAP funding a number of years ago, while Alberta cut this requirement in 2021.

“I mean, the EFP program still exists, and it used to be a requirement to access BMP funding through the, through our department. It’s no longer a requirement. It’s part of the red tape reduction initiative. So, they felt it was too onerous on the producers to try and have an EFP in place before accessing the funds.” (Personal Communication, April 23, 2021, Alberta)

While the EFP programs still exist in both provinces – given that they are a requirement for the Canadian Dairy Farmers Association – their use either has or is predicted to wain due to their disassociation with funding.

“So, there's very limited uptake of the EFP and what we're seeing is that really, it's our dairy producers, because they're required to have one as part of their being part of the dairy sector. Right? It's a requirement under their supply management program. Right? So, that's where we're seeing the uptake. Aside from that, we're not seeing a lot of incentives to do the EFP. So, that was one component. We're seeing limited uptake of the EFP.” (Personal Communication, January 8, 2021, Saskatchewan)

“So, while the EFP Program exists, I think because that requirement to access our funds are lost, it will probably see less subscription. I mean, most of the people that were going to do it have already done it, so to get new people to do it without any sort of reason why, for some financial motivation to do it, I think there’s going to be a lot fewer EFPs annually issued than there have been historically.” (Personal Communication, April 23, 2021, Alberta)

This has implications for education for farmers. That is, there is less of an educational requirement for understanding the importance of using BMPs for limiting environmental impacts and what environmental risks certain BMPs address or would be best to employ for a particular agricultural operation to lessen their environmental impacts. To address this decrease in

participation in Saskatchewan, the EFP program is being updated to include international standards, which is something Manitoba has done as well. The idea being that in order to meet international agro-environmental standards, primary producers will use the EFP program, which will hopefully increase participation and improve education and outreach for agro-environmental stewardship.

EFPs are not specific to nutrient or P export reductions from agricultural fields, and it is unknown how well they address or lower nutrient loading. That isn't to say that P management isn't part of EFP or that BMPs that are used to reduce P exports from agricultural fields aren't identified within the education or a part of the program, but rather, these are just several of many environmental factors that are included in the EFP assessment. And since EFP programs are voluntary, confidential assessments, farmers can choose whether or not to employ BMPs that would reduce P loading.

“Well, EFPs are much, much, much more comprehensive than just phosphorous or even just nutrients, they deal with stuff like how you store your gas, your fuels, how you manage your pesticides, how you deal with farmyard runoff, silo seepage. So, in terms of aggressive, an EFP is more of a risk assessment than it is an actual plan, right? So, you would assess, say, your land application for many of the standards for phosphorus management. You're going to find a lot of the criteria that's in EFP is shared with nutrient management already, where it does overlap. So, the numbers tend to be more or less the same. And they align with our BMP approaches and with 4R, coincidentally enough, so it's a little tough to answer that because the individual farmer, when they're doing an EFP, they do all the sections that apply to them and then concentrate on the ones that they feel are the biggest impact on their operation. And that may or may not be a phosphorus based one. It may have to do with a well, they say, that is at risk and they want decommissioned, and it may be about putting bollards around their fuel storage. It may be about rerouting some of their catch basins that are collecting rainwater and not draining their property right. So, I don't know if I can say how aggressively it works. You do the assessment. You come up with sort of a plan to address things, to move them up levels in the EFP. And then typically there's a small amount of funding for you to take on a project or two as a result of that EFP. That's generally the way it works. So, I don't think it's particularly aggressive...” (Personal Communication, November 17, 2020, Ontario)

“...the goal of the EFP is to help producers identify agro-environmental risks that are specific to their operation. I, like, water quality, if it's one of the risks that producers identify, and we have programs to support and address that. Yes, it would be. But the EFP is quite a broad, like, whole farm program,

right? So, it could be used to address risks to their soil, their soil health as well, right? It's quite a broad range. So, it wouldn't be, I think, explicitly stated as here is the goal: the EFP is to address phosphorus runoff, right? But it would be addressing agro-environmental risks. Water quality being one of those.” (Personal Communication, January 8, 2021, Saskatchewan)

As all the EFP programs found in Canada are voluntary and confidential, farmers can choose to complete an EFP and whether or not to implement the BMPs identified by the assessment, often resulting in some rather than all BMPs identified being implemented. Therefore, the confidential nature of EFPs makes it impossible to know what BMPs have been adopted in a watershed in order to understand the efficacy of overall implementation, let alone the efficacy of BMPs implemented that are meant to reduce P exports from agricultural fields.

“...and the other thing about EFPs is that they are entirely voluntary, and they are confidential, currently. So, we don't know what's in an EFP. I wouldn't even have the data to know how many people are choosing phosphorus-based approaches.” (Personal Communication, November 17, 2020, Ontario)

There is also no timeframe for implementation of the BMPs identified and implementation is not tracked unless funding is granted, and this is an informal means of tracking. Which means that BMPs identified by EFP programs can only be tracked when CAP funding is applied for and awarded and only in provinces where completion of an EFP assessment is a requirement for funding. As such, most provinces have no way of knowing what environmental issue are addressed unless funding is applied for, and implementation is only tracked when funding is awarded.

“...From our perspective, the uptake through the incentive program, that's the only way that we can document with certainty that Practice A is being adopted by Farmer B, and that's, of course, because the program has provided cost-shared funding, it has provided financial support. And that's because the farmer has applied and revealed information about the operation and made a case for the funding, the funding is approved, and then the project, if things go well, is completed” (Personal Communication, May 21, 2021, Manitoba).

4R – Right Time, Right Rate, Right Source, Right Place

Another voluntary stewardship program used in Canada is the 4R Program, which alters farming fertilizer application methods in an attempt to lower nutrient runoff (Johnston and Bruulsema, 2014). 4R is an international fertilizer management strategy. The 4Rs are a set of BMPs – “the right source, right rate, right time, and right place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the

plant ecosystem” (Johnston and Bruulsema, 2014, p.366). The program uses a science-based approach to determine the optimal nutrient to select, the best rate of application for that nutrient, the ideal time for application, and the preferred placement (Johnston and Bruulsema, 2014) to limit nutrient runoff. 4R was developed by Fertilizer Canada, the Fertilizer Institute, and the International Plant Nutrition Institute (Bruulsema et al., 2009; Vollmer-Sanders et al., 2016) to provide a framework for an environmentally friendly, sustainable, and profitable crop systems goal (Vollmer-Sanders et al., 2016). The idea is that proper fertilizer management will increase crop yield while decreasing production costs and cultural eutrophication (Vollmer-Sanders et al., 2016).

The 4R program is used in Alberta, Manitoba, Ontario, and Saskatchewan. Nova Scotia is not currently a part of this international fertilizer management program, and it is unknown if the province will choose to be a participant in this industry lead program. The 4R principles used in this program are not unique to this program. That is, EFP uses these same principles when educating farmers on P or nutrient management, and it can be found in various provincial manure and nutrient management educational documents. Like other nutrient management practices, 4R is N rather than P-based, which means that P may still be overapplied and the programs contribution to reductions in P exports from agricultural fields is unknown. However, this program is international, and as such, agricultural operations that are part of 4R meet certain international certifications, which could help create uniform fertilizer management practices at the local, national, and international scales. Like all nutrient management programs, 4R is not cyanobacteria management specific, so it’s impact on limiting bloom formation is unknown. The program is also voluntary, which means that participation within each province is unknown.

4.2.3 Education and Outreach

Nutrient, Soil, and Manure Education and Outreach

The Ministry of Agriculture in all five provinces is tasked with education and outreach in each province, where BMP use is promoted by the ministry through their work with primary producers. That is, ministry personnel educate primary producers on agri-environmental farming practices using a range of methods, such as responding to inquiries (telephone or email) from primary producers, providing educational materials and/or software programs available to aid in BMP adoption – some of which is geared towards nutrient management practices – and informing producers of funding available for agro-environmental practices under CAP. Education and outreach initiatives also includes variety of webpages and documents on nutrient

management planning, soil nutrient management, and nutrient application management (Table 28). However, it should be noted that all education and outreach is for a suite of agri-environmental objectives, not just nutrient and cyanobacteria management.

Table 28: NPS education and outreach material available within each province.

| Province | Webpage | Nutrient Management PDF | Manure Management PDF | Soil Management PDF | Water Protection PDF | Software Programs | P-Based Software Program |
|--------------|---------|-------------------------|-----------------------|---------------------|----------------------|-------------------|--------------------------|
| Alberta | • | • | • | • | • | • | • |
| Manitoba | • | • | • | • | • | | |
| Nova Scotia | • | • | • | • | • | | |
| Ontario | • | • | • | • | • | • | • |
| Saskatchewan | • | | | | | | |

These, education and outreach initiatives do not include educating farmers on how P exports from agricultural fields can contribute to cyanobacteria bloom formation and the risks associated with them. If cyanobacteria blooms are mentioned, it is either in terms of their risk to livestock when occurring in agricultural waters, otherwise, the information is often only a brief mention of general algal blooms and how nutrient loading can contribute to their formation. The reason given in some provinces is that farmers are too far removed from cyanobacteria blooms occurring in waterbodies within the river watersheds where the farms are located. Therefore, the information is viewed as too specific or irrelevant to farmers. This speaks to a lack of consideration of cumulative effects – education does not include informing farmers of their combined ability to contribute to environmental risks like cyanobacteria blooms and their associated problems, which occur further down the river watershed in which their farm is located. Not to mention, research shows that farmers are more likely to invest in BMP implementation when they understand why it is important to do so. Educating farmers on the risks associated with cyanobacteria blooms is also important for irrigation waters and preventing the potential contamination of crops, as well as the risks posed in surface waters used by livestock for drinking.

4.3 Bloom Mitigation Programs: Chemical and Physical Treatment

Only Saskatchewan has a program that recommends the use of chemical or physical treatments for waterbodies to address cyanobacteria blooms. However, the program and its education and outreach initiatives are specific to agricultural dugouts, slews, and surface waters used for livestock or irrigation purposes. This program, run by the Ministry of Agriculture, is part of the reactive bloom monitoring program for agricultural waters (see section 4.2.2.4) that uses education and outreach initiatives to help farmers decrease the occurrence or risk of blooms in agricultural waters.

Education and outreach for this program includes teaching primary producers to recognize cyanobacteria blooms (bloom visual inspection training) and what BMPs would be most effective in reducing their occurrence or limiting exposure to livestock. Bloom visual inspection training is conducted annually in the summer, where primary producers are taken by ministry personnel to visit agricultural surface waters on pasturelands that are currently experiencing bloom activity. This is to aid in recognition and therefore reporting of bloom events so that livestock health can be protected. Nutrient management and BMP use are recommended whenever blooms are reported to reduce their occurrence and protect livestock health and safety under this program. In the event that a bloom persists or reoccurs in agricultural surface water, chemical bloom treatment is recommended using something like Registered Bluestone (copper sulphate). Physical bloom treatment is another recommendation made in cases of bloom reoccurrence, using techniques like aeration to prevent bloom formation.

4.4 Integrated Watershed Management

There is no single definition of IWM, and definitions vary between levels of government and the provinces (Table 29). Despite the variety of definitions found within Canada, the guiding principles remain the same: watershed based and informed by science; management of industry and human activity; coordination between government, non-government organizations (NGOs), and community management, policies and activities; stakeholder participation; accommodation and compromise; sustainable management; long-term objectives; wise and efficient use; local solutions; incorporates an adaptive approach; and considers the needs of the environment, economy, and society together (ARD, 1999; SWA, 2002; GOM, 2003; Carter et al., 2005; GOC, 2010; NSWAG 2010; GOA, 2015; CO, 2019).

Table 29: Canadian jurisdictions different definitions of IWM (SWA, 2002; GOC, 2010; NSWAG, 2010; GoA, 2015; CCME, 2016; Conservation Ontario, 2019; GoM, 2020).

| Government | IWM Definition |
|--------------------|---|
| Federal | “A multidisciplinary and iterative process that seeks to optimize the contribution of aquatic resources to the social, environmental, and economic welfare of Canadians, while maintaining the integrity of aquatic ecosystems, both now and into the future” (GOC, 2010) |
| Alberta | “Watershed management planning is a comprehensive, multi-resource management planning process involving all stakeholders within the watershed. The stakeholders identify the watershed’s resources, issues, and concerns and develop and implement a watershed management plan with solutions that are environmentally, socially, and economically sustainable” (GoA, 2015) |
| Manitoba | “A longterm action plan to manage land, water, and related resources on a watershed basis. IWMPs are developed cooperatively by watershed residents, all level of government and stakeholders.” (GoM, 2020). |
| Nova Scotia | “IWM is a comprehensive approach to managing water resources, including human activities and their effects on watersheds and ecosystems. It aims to ensure sustainability of water resources and their functions today and into the future.” (NSWAG, 2010) |
| Ontario | “The process of managing human activities and natural resources on a watershed basis, considering social, economic, and environmental issues, as well as community interests and to manage water resources sustainably” (Conservation Ontario, 2019) |

| | |
|--|---|
| Saskatchewan | “Sound management of watersheds and aquifers begins with planning and effective water management. Planning in the water management field can take many forms, ranging from a holistic approach whereby all aspects relating to water and the related ecological resources are evaluated and all issues are considered, to planning which is directed towards a specific issue or activity. With this range of perspectives, a planning model which is able to achieve a broad range of applications has been developed. Regardless of the scope, the model is designed to achieve consensus, collaboration and stakeholder involvement throughout the process.” (SWA, 2002) |
| Canadian Council of Ministers of the Environment (CCME) | “Integrated watershed management (IWM) is a continuous and adaptive process of managing human activities in an ecosystem, within a defined watershed. IWM involves the integration of environmental, social and economic decisions and activities through an inclusive decision-making process to manage the protection, conservation, restoration and enhancement of aquatic and terrestrial ecosystem features, functions and linkages. Governance is a collaborative approach appropriate to the watershed and issues at hand.” (CCME, 2016) |

IWM has been adopted in all five provinces and is endorsed at the Federal level, and while the guiding principles of IWM are the same, the method of implementation varies between provinces. That is, Alberta and Manitoba have created Integrated Watershed Management Plans (IWMPs) for all or some of their major river watersheds, whereas Nova Scotia, Ontario, and Saskatchewan have focused on the development of Source Water Protection Plans (SWPPs) for their surface water watersheds within the province (Table 30). While these source water plans in Nova Scotia, Ontario, and Saskatchewan are IWMPs, they were developed to protect surface water sources for human consumption. This is distinguishable from Alberta and Manitoba where the plans were created to protect all water sources, regardless of their use, although source water protection is one of the guiding principles of this, where applicable (GOA, 2003, 2008; MWS, 2011). Certain IWMPs and SWPPs are legislatively backed in all five provinces (Table 30), giving NGOs and/or DWTPs within each province the authority to manage/protect water resources at the river watershed scale.

Table 30: IWMPs link to cyanobacteria bloom management in five provinces. Eutrophication is listed as a risk to water quality in 62 of the 65 plans. Algae, algal blooms, or cyanobacteria were mentioned in 35 of the plans.

| Jurisdiction | Watershed Plans | Nutrient Loading a | Cyanobacteria/Algae a | Legislation | |
|---------------------|-----------------------------------|---|-----------------------|------------------|--|
| | Plans Reviewed/Total No. of Plans | problem/risk | problem/risk | | |
| Alberta | 1. WMPs 2. IWMPs ^a | 1. 5/7 2. 7/11 ^a | 1. 4/7 2. 6/7 | 1. 2/7 2. 3/7 | 1. The Water Act (2000) 2. Water for Life: Alberta’s Strategy for Sustainability (2008) |
| Manitoba | IWMPs | 19/27 ^b | 19/19 | 15/19 | Watershed Districts Act (2020) Water Protection Act (2006) Drinking Water Safety Act (2007) |
| Nova Scotia | 1. PWAs* 2. SWPPs | 24/24 ^d 9/75 ^c | N/A 9/9 | N/A 4/9 | 1. The Environment Act (1994-95) 2. Water for Life: Nova Scotia’s Water Resource Management Strategy (2010) |
| Ontario | SWPPs | 18/18 | 18/18 | 4/18 | Conservation Authorities Act (1990) Clean Water Act (2006) |
| Saskatchewan | SWPPs | 12/12 | 12/12 | 7/12 | The Water Security Agency Act (2005) The Watershed Associations Act (1978) |

Note: not all SWPPs or IWMPs were available for each province. Some of the reviewed plans listed algae as a potential risk rather than an active one (not necessarily indicative of bloom presence or absence).

*Protected Water Area’s

^aIWMPs are not legislatively backed and therefore have no regulatory powers. Established under the Water for Life strategy, they foster collaboration at the river watershed scale to elicit stakeholder participation, share resources, and develop solutions to water management problems. Not all IWMPs were developed the same way, some use source water protection plans while others have overarching IWMPs, with more detailed Lake Management Plans in place for individual waterbodies that are part of the watershed.

^bManitoba changed their IWMPs in 2020, so it is currently unknown if new IWMPs will be developed by the new Watershed Districts or if the old plans made under the Conservation Districts Act will remain or if all the plans are being updated under the new Watershed Districts Act. The IWMPs reviewed for this table were developed under the Conservation Districts Act.

^cNova Scotia has ~75 SSWPs either approved by Nova Scotia Environment or are being developed. Not all are for surface waters and not all could be found and reviewed for this table.

^dCertain PWAs have regulations that limit agricultural activities within the lake's watershed.

62 of the 65 IWMPs reviewed list nutrient loading as a risk to water quality, however, only 35 mention algal blooms, with even fewer specifically mentioning blue-green algae, and often simply as a consequence of nutrient loading/eutrophication, rather than as a current risk to water quality in the watersheds being managed (Table 30). The plans also aren't used to set P loading or concentration targets/nutrient targets for lakes experiencing cyanobacteria blooms, the exception being one IWMP in Saskatchewan where notional TP and TN percentile targets have been set for four waterbodies within the Lower Qu'Appelle (WSA and LQWS, 2013).

Only 3 of the provinces have developed or utilize the concept of maximum acceptable concentrations for waterbodies to prevent or reduce the occurrence of nuisance algae blooms. Manitoba and Ontario have both determined TP concentration targets for waterbodies within the province, to prevent or limit nuisance algae growth (Table 31). Alberta, rather than setting concentration targets, uses “narrative statements” for lakes, rivers, and waterbodies to protect aquatic life and prevent undesirable algae growth and aquatic macrophytes (Table 31) while maintaining a lakes natural trophic status.

Table 31: Provincial surface water nutrient concentration guidelines/targets to avoid excessive algae bloom growth

| Province | Nutrient MACs | Notes |
|---------------------|--|---|
| Alberta | No increase in TP or TN over existing conditions* | Lakes |
| | TP and TN levels to be maintained to prevent algae blooms* | Major Rivers |
| | TP and TN levels to be maintained to prevent algae blooms* | Other Waterbodies |
| Manitoba | ≤ 25 µg/L (expressed as 0.025 mg/L) | Applies to all ponds, reservoirs, and lakes, and tributaries at the point where the water enters them |
| | ≤ 50 µg/L (expressed as 0.05 mg/L) | Applies to “other streams” |
| Nova Scotia | N/A | N/A |
| Ontario | ≤ 20 µg/L | Lakes: Level to avoid nuisance algae blooms during the ice-free period |
| | ≤ 10 µg/L | Applied to lakes naturally below this level to ‘protect against aesthetic deterioration’ |
| | < 30 µg/L | For rivers and streams to eliminate excessive plant growth |
| Saskatchewan | N/A | N/A |

All levels subject to change based on site-specific trophic status

*Where priorities warrant, site-specific nutrient objectives, and management plans to be developed to manage nutrients and therefore algae blooms. Generally associated with man-made nutrient changes. Levels were previously 50 µg/L for TP and 100 µg/L for TN.

In Manitoba, these levels are legislatively backed and mentioned in the provincial IWMPs, where the 0.05 mg/L (50 µg/L) TP level for “other streams” is used as a target for the

managed river watersheds. For Ontario, these levels are not mentioned in the IWMP where they could be used as loading targets for managed watersheds and act as a means of evaluating the performance of these plans at reducing nutrient loading. Especially since nutrient loading is listed as a risk to water quality in 95% of the plans reviewed.

A majority of the IWMPs reviewed endorse the use of wastewater treatment and agricultural BMPs to lower nutrient loading. BMP use is promoted using education and outreach to encourage their use, rather than installing regulatory means. So, despite cyanobacteria blooms being a province-wide concern and a risk to water quality, these IWMPs do not appear to be used to mitigate blooms. Instead, they are used for education and outreach, encouraging BMP use to address eutrophication, while cyanobacteria blooms seem to be managed at the lake watershed scale even though the province has jurisdiction to take action.

4.5 Summary of Key Findings

All five provinces use the Federally recommended drinking water standard for the cyanotoxin MC-LR in treated drinking water, while only three of the provinces have adopted the Federally recommended recreational water standards for cyanobacteria and the cyanotoxin MC-LR. The only cyanotoxin regulated and therefore monitored for is MC-LR, and only in recreational and drinking waters.

All five provinces have routine and reactive monitoring programs for cyanobacteria blooms designed to mitigate the risks blooms pose to public health in treated potable water. While only three of the five provinces have routine monitoring programs for blooms in recreational waterbodies to mitigate risk. All five provinces have reactive monitoring programs for recreational waters.

While all five provinces have nutrient management legislation, none of the regulations and their requirements are specific to cyanobacteria blooms nor are they P-based. Only three provinces have requirements for limiting manure and fertilizer application that include P levels, though, these are over-application rates.

All five programs have voluntary, encouraged, and incentivized NPS nutrient management programs. EFP (voluntary program) and CAP (incentivized program) are employed in all five provinces to educate on and incentivize the implementation of BMPs, for nutrient management purposes. However, only three provinces still require the completion of an EFP to

obtain CAP funding, making education requirements different. 4R is also employed in four out of the five provinces, with Nova Scotia the only non-participant.

IWM is used to manage source or major river watersheds in all five provinces, however, they are not actively used to manage or monitor cyanobacteria blooms. And only three of the five provinces have nutrient targets to limit or prevent nuisance algal blooms, which are not really used as a measure of success or means of managing cyanobacteria blooms within provincial IWMPs.

Chapter 5: Case Studies

Three case studies were selected for more detailed description – Lake Erie, Ontario; Lake Winnipeg, Manitoba; and Pigeon Lake, Alberta. These lakes are considered high priorities by the provincial and federal governments because they are economically and politically important and because of increased frequency of cyanobacteria blooms over the last several years. The result has been the development of management strategies specific to these waterbodies to coordinate nutrient and cyanobacteria management. The management strategies discussed below are not representative of the management many lakes that experience blooms receive. However, the strategies described here could be used as models for which other lakes experiencing blooms, that do not currently have bloom management strategies, could be managed.

Cyanobacteria blooms in all three case studies have been attributed to cultural eutrophication, with only one lake considering and attempting to manage internal loading of nutrients - Pigeon Lake in Alberta. P is the main nutrient of concern for Lake Erie and Pigeon Lake, while Lake Winnipeg is concerned with P and N.

5.1 Background Information

Table 32: Waterbody Lake Characteristics and Nutrient Loading Sources

| Waterbody | Province | Avg. Depth | Max Depth | Lake Area | Watershed Area | No. of Basins | Blooms | Main Nutrient Source | Internal Loading |
|---------------|----------|------------|-----------|------------------------|---------------------------|---------------|--------|----------------------------|------------------|
| Lake Erie | Ontario | 19 m | 64 m | 25,744 km ² | 244,000 km ² | 3 | Yes | Agriculture-Urban | Yes |
| Lake Winnipeg | Manitoba | 12 m | 60 m | 25,000 km ² | 1,000,000 km ² | 2 | Yes | Agriculture-Urban | Yes |
| Pigeon Lake | Alberta | 6.2 m | 9.1 m | 97 km ² | 187 km ² | 1 | Yes | Internal-Agriculture-Urban | Yes |

5.1.1 Lake Erie, Ontario

Lake Erie is the smallest, shallowest, and warmest of the Great Lakes with an area of 25,744 km² and an average depth of 19 m (Watson et al., 2016; ECCC and MECP, 2018). The lake is divided into three basins: Main, East, and West. The Western Basin is the shallowest, with an average depth of 7.4 m and a max depth of 19 m (GLWQANAS, 2019). This is the basin that receives the largest influx of P due to inflows from two major rivers and their subwatersheds – Detroit and Maumee (Arhonditsis et al., 2019). The blooms in this portion of the lake are often the most prolific, typically occurring in the summer, and fall, detrimentally impacting the health of the lake (ECCC and MECP, 2018; Arhonditsis et al., 2019). While the western basin is deep enough to undergo thermal stratification, its shallow depth makes it susceptible to mixing under high wind and wave conditions so the thermal gradients are ephemeral (ECCC and MECP, 2018; GLWQANAS, 2019). The Central Basin has an average depth of 18.3 m and a max depth of 25

m (GLWQANAS, 2019). This portion of the lake is deep enough to undergo thermal stratification during the summer and it receives a large influx of P from the Sandusky River which contributes to hypoxic events in this portion of the lake – both of which promote cyanobacteria blooms (ECCC and MECP, 2018; Arhonditsis et al., 2019). The Eastern Basin is the deepest, with an average depth of 24 m and a max depth of 64 m (GLWQANAS, 2019). Like the central basin, the eastern basin is deep enough to undergo thermal stratification, however the P levels in this portion of the lake are often low, so attached blooms of nuisance *Cladophora* occur inshore rather than open water cyanobacteria blooms (GLWQANAS, 2019).

The Lake Erie watershed is part of the transboundary Great Lakes Basin and provides potable water and other water services to over 11 million people in Ontario, making it the most populated of all the Great Lakes (Watson et al., 2016; GLWQANAS, 2019). The watershed is split between Canada and the USA, covering one province (Ontario) and five states (Ohio, Michigan, Indiana, New York, and Pennsylvania) (GLWQANAS, 2019). Approximately three-quarters of the land on the Canadian side of Lake Erie is used for agricultural production; urban areas make up another 12%, followed by 13% for natural areas (GLWQANAS, 2019).

Lake Erie has been experiencing blooms since the 1960's, which were principally attributed to P loading into the lake (ECCC and MECP, 2018). In response to the presence of blooms, the Federal and provincial governments worked together to reduce PS loading of P into the lake (ECCC and MECP, 2018). Although major reductions in total PS loads were achieved by the 1980s (Baker et al., 2019), since the 1990's, blooms within the lake have been getting progressively worse (ECCC and MECP, 2018). The resurgence is believed to be the consequence of multiple stressors, namely, climate change, landscape alterations, and the presence of aquatic invasive species (AIS) (ECCC and MECP, 2018; Arhonditsis et al., 2019). In response, NPS nutrient loading controls were added to the management strategy for the lake (GLWQANAS, 2019) and may lower total loads as implementation proceeds.

Lake Erie is protected by several federal and provincial Acts and agreements that seek to manage blooms and hypoxic events within the lake,. Federal Acts that apply are: International Boundary Water Treaties Act, Canada Water Act, Canadian Environmental Protection Act, and the Fisheries Act (ECCC and MECP, 2018). Provincial Acts that apply are: Clean Water Act, Ontario Water Resources Act, the Great Lakes Protection Act, and the Nutrient Management Act (ECCC and MECP, 2018). Lake Erie has two agreements between Canada, the USA, and

Ontario, which are: the Canada-USA Great Lakes Water Quality Agreement (GLWQA), first signed in 1972 and last revised in 2012, and the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (COA), first signed in 1971 (Government of Ontario, 2019) and last revised in 2021. These acts and agreements allowed for the development of two bloom management strategies for Lake Erie: the Canada-Ontario Lake Erie Action Plan (COLEAP) and the Lake Erie Binational Phosphorous Reduction Strategy (BPRS) (ECCC and MECP, 2018; GLWQANAS, 2019). Both of these strategies have four main goals for Lake Erie: minimize hypoxic events in the lake, maintain algae presence below nuisance levels, maintain algal species that constitute a healthy ecosystem, and maintain cyanobacteria presence at a level where cyanotoxins pose a threat to human and ecosystem health (GLWQANAS, 2019).

Monitoring within the lake has been consistent, with monitoring and modelling data seen as an essential component to the management of blooms and hypoxic events (ECCC and MECP, 2018). The NOAA – Great Lakes Environmental Research Laboratory has a Harmful Algal Blooms (HABs) and Hypoxia Program that utilizes satellite images, remote sensing, buoys, a monitoring strategy, and genetic techniques to keep track of bloom events in Lake Erie (NOAA, 2016). Monitoring of the various stewardship programs is also occurring to track effectiveness of NPS nutrient controls (ECCC and MECP, 2018).

5.1.2 Lake Winnipeg, Manitoba

Lake Winnipeg is the 10th largest freshwater lake in the world, the 6th largest in Canada (ECCC and MWS 2011; ECCC 2018) is 436 km long (LWSB, 2006). The lake is split into two distinct basins, north and south, that are separated by a 2.5 km-wide channel, referred to as ‘the narrows’ (LWSB 2006). The north basin is the larger of the two, at 111 km-wide and contains 81% of the lake’s 284 km³ volume, whereas the south basin is only 40 km-wide and contains 10% of the lakes volume (ECCC and MWS, 2011; LWSB, 2006). Despite being a large lake, Lake Winnipeg is quite shallow, with an average depth of 12 meters (LWSB 2006; ECCC and MWS 2011). The north basin is deeper than the south basin, with an average depth of 19 meters to 13 meters, respectively (ECCC and MWS 2011; LWSB 2006). However, the deepest point in the lake is located in the south basin, measuring 60 meters in depth (LWSB 2006; ECCC and MWS 2011). Inflow into the lake occurs predominantly from three rivers: Winnipeg River, Saskatchewan River, and Red River. Outflow from the lake discharges into the Nelson River which is controlled by one of the world’s largest hydro-electric reservoirs (LWSB 2006; ECCC

and MWS 2011). The north and south basins have differing physiological, water quality, and biological characteristics, including abundance and composition of phytoplankton communities, such as cyanobacteria (LWSB 2006; ECCC and MWS 2011). These variations are the result of the differences in depth, turbidity and size of the basins, as well as the quantity and quality of waters flowing into them (LWSB 2006; ECCC and MWS 2011).

The Lake Winnipeg Watershed spans over four Canadian provinces (Saskatchewan, Alberta, Manitoba, and Ontario) and four American states (Montana, North Dakota, South Dakota, and Minnesota) (ECCC and MWS 2011; ECCC 2018).. 40% of the watershed area is composed of the Saskatchewan River sub-watershed, 31% the Red-Assiniboine sub-watershed, and 17% the Winnipeg River sub-watershed (LWSB 2006; ECCC and MWS 2011). Within Manitoba, Lake Winnipeg receives effluent water from ~200 small WWTPs and approximately 10 larger municipal and industrial facilities, not to mention runoff from a significant proportion of agricultural land (LWSB 2006; ECCC and MWS 2011). The watershed, is home to over 5 million people in Canada and around 1 million in the US – 80% of whom reside in urban areas (LWSB 2006; ECCC and MWS 2011). Lake Winnipeg is home to over 30 different local communities that contain ~23,000 permanent residents, supports a large commercial fishery, is used as drinking water for some communities, is a major source of hydroelectric power for the province, and is an area that supports numerous recreational activities (ECCC and MWS 2011; ECCC 2018).

Lake Winnipeg has been experiencing blooms with increasing severity, duration, and frequency over the last 30 years (Jones and Armstrong, 2001; Dibike et al., 2012) and in 2013 was named “the most threatened lake in the world” by the Global Nature Fund (CBC News, 2013). This increase is believed to be the result of two factors. First, the increase in industrial agricultural practices and urban development and second, the increased frequency and intensity of spring flooding resulting in increased P loading into the lake (climate change indicator) (Schindler et al., 2012). Both of these factors have caused the lake to become eutrophic to hyper-eutrophic, thus promoting the growth of blooms (Schindler et al., 2012).

Lake Winnipeg is protected by provincial legislation: The Save Lake Winnipeg Act (SLWA). The SLWA amended five provincial acts in order to reduce nutrient loading of P and N into the lake (POM, 2011). The five amended Acts are the Crown Lands Act, the Environment Act, the Mines and Minerals Act, the Planning Act, and the Water Protection Act (POM, 2011).

Federal Acts that apply to the lake are the Canada Water Act, the Fisheries Act, and the Canadian Environmental Protection Act (GOC and GOM, 2010).

Protection of Lake Winnipeg is a coordinated effort between the Federal Government and the province of Manitoba as the watershed crosses three provinces and four states (LWSB, 2009). In 2010, the Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin (MOU) was signed which details how the Federal government and the province of Manitoba will work together to protect the health, prosperity, and sustainability of Lake Winnipeg (GOC and GOM, 2010; ECCC, 2020).

In January of 2020, the Watersheds District Act (1987) reestablished Manitoba's conservation districts into 14 watershed districts, applying IWM to the province's watersheds (ARD, 2020a). Each district is charged with developing and implementing a program to protect watershed health (ARD, 2020a). Currently there are 26 plans in development and one plan under renewal (ARD, 2020a) – several of which will affect nutrient inflows into Lake Winnipeg.

Monitoring of the lake has been consistent since the 1990's, with two main programs that study water quality and quantity in the lake and its watershed (ECCC and ARD, 2020). The Lake Winnipeg Research Consortium (LWRC) was established in 1998; they conduct seasonal (spring, summer, fall) lake-wide surveys using a network of 65 monitoring stations (ECCC and ARD, 2020). The province of Manitoba, using 14 stations, conducts monitoring 4 times a year (one under ice and three in the open water season) (ECCC and ARD, 2020). Both keep track of nutrient and metal concentrations, DO, water clarity, pesticides, algal biomass and species composition, and algal toxin concentrations (ECCC and ARD, 2020; ARD, 2020a). Proper monitoring and sharing of information are part of the MOU between Environment and Climate Change Canada and the Manitoba Agriculture and Resource Development (ECCC and ARD, 2020).

5.1.3 Pigeon Lake, Alberta

Pigeon Lake is a popular, recreational, and shallow prairie lake located southwest of Edmonton (Teichreb, 2012; Teichreb et al., 2014). The maximum depth of the lake is 9.1 m with an average depth of 6.2 m (Teichreb et al., 2014). The lake is mesotrophic to eutrophic, oval shaped, and consists of one shallow main basin (AE, 1989; Teichreb, 2012). Several intermittent streams flow into the west and northwest portions of the lake (Teichreb et al., 2014). The outlet,

Pigeon Lake Creek, is located in the southeast and drains into Battle River which flows into the North Saskatchewan River (Teichreb, 2012; Teichreb et al., 2014; BRWA, 2021).

The Pigeon Lake Watershed is relatively small with the lake occupying 52% of the area (Teichreb et al., 2014). Contained within the main watershed, there are 15 subwatersheds (Teichreb et al., 2014). Over 60% of the watershed has been converted for human use: 2% for urban development and 58% for agricultural use (Teichreb et al., 2014). The remaining 40% is ‘undeveloped’ tributaries, ponds, wetlands, shrublands, and forests (Teichreb et al., 2014). The area around the lake that has been developed for recreational use consists of 10 summer villages, two provincial parks, and a large number of cottages and resorts occupying the shoreline (Teichreb et al., 2014). The watershed also has oil and gas developments (Teichreb et al., 2014). Recreational fishing, commercial fishing, and an Indigenous fishery are all located on the lake, which are dependent on the quality of the lake’s water (AE, 1989).

Pigeon Lake is susceptible to blooms because of its trophic status; however, blooms have been increasing in severity and duration over the last several decades (especially since 2002) negatively impacting water quality, aquatic life, and the recreational and social value of the lake (PLWMPSC, 2018). Bloom increase within the lake is largely attributed to increased inflow of P from NPS nutrient loading and internal P loading (Teichreb, 2014; PLWMPSC, 2018). The lake has a long residence time for water (>100 years), which means that increased inflows of P increase the amount of P stored in the sediment (Teichreb, 2014; PLWMPSC, 2018). Thermal stratification is predicted to occur on warm, calm days (Teichreb et al., 2014). Approximately 57% of phosphorus available for blooms comes from sediment release, with the remaining 43% the product of inflow into the lake (Teichreb, 2014).

Pigeon Lake has a municipal management plan to protect water quality called the Pigeon Lake Water Management Plan (PLWMP) (PLWMPSC, 2018). The main purpose of the plan is to “develop a comprehensive, science-based strategy to coordinate action for the protection and improvement of Pigeon Lake, its shore lands, and its watershed” (PLWMPSC, 2018). The PLWMP has three main goals: reduce the frequency and intensity of algal blooms, improve the health of the lake and watershed, and improve the recreational value of the lake and economic health of the surrounding area (PLWMPSC, 2018). Federal legislation that applies to the lake are The Canada Water Act (1970), The Fisheries Act (1985), and The Environmental Protection Act (1999). Provincial legislation that applies to the lake are the Environmental Protection and

Enhancement Act (2000) and the Water Act (2000). The province also has “Water for Life” guidelines, which are meant to promote three goals: first, safe and secure drinking water; second, promote healthy aquatic ecosystems; and third, reliable, quality water supplies for a sustainable economy (GOA, 2003, 2008). The province has also developed environmental quality guidelines for protection of surface water quality, which have similar goals to the “Water for Life” guidelines but includes land management planning for the protection of water quality (AESRD, 2014).

The Battle River Watershed and North Saskatchewan River are both managed river watersheds in Alberta. The Battle River Watershed is provincially managed via the Approved Management Plan for the Battle River Basin (MPBRB) (GOA, 2014). The North Saskatchewan River is managed by the North Saskatchewan Watershed Alliance, using IWM, which receives provincial funding (NSWA, 2016). It is also important to note that the North Saskatchewan River joins the South Saskatchewan River near Prince Albert, Saskatchewan (NSWA, 2016) and the South Saskatchewan River is provincially managed by the Alberta Government (AE, 2003). The Province of Alberta has regulations under the Water Act (2000) which protect the South Saskatchewan River – Bow, Oldman and South Saskatchewan River Basin Water Allocation Act (POA, 2007).

The Pigeon Lake Watershed Association (PLWA), Alliance of Pigeon Lake Municipalities (APLM), Pigeon Lake Watershed Management Plan Steering Committee (PLWMPSC), Alberta Lake Management Society (ALMS), Battle River Watershed Alliance (BRWA), Pigeon Lake Regional Chamber of Commerce (PLRCC), and the Government of Alberta (GOA) are all involved in the management of Pigeon Lake (PLWMPSC, 2018). The management plan also received input and funding from several NGOs, the Government of Canada (GOC), surrounding municipalities, the University of Alberta, and the Alberta Biomonitoring Institution (PLWMPSC, 2018).

Cyanobacteria monitoring has occurred regularly since 2010, with reports on the lake’s water quality published annually by Alberta Lake Management Societies (ALMS) LakeWatch program (ALMS, 2019; PLWMP, 2019). The Alberta Environment and Sustainable Resources Development (AESRD) and the ALMS collect weekly to bi-weekly water samples from the lake and rivers within the watershed from April to October (PLWMP, 2019). Pigeon Lake is also monitored by the Alberta Health Services Recreational Water Monitoring for beaches

(PLWMPSC, 2018; AHS). Weekly water samples are collected for select lakes during the open water season (May to November) (AHS, 2019). Samples are tested for cyanobacteria and their toxins for lakes where blooms have occurred in previous years (AHS, 2019).

5.2 Comparative Analysis/Results

Table 33: Cyanobacteria bloom management

| Waterbody | Bloom Management Strategy | Legislation/Regulations | Communi cation | Nutrient Management | Risk Management | Adaptive Management | Monitor ing | Agreeme nts |
|---------------|---------------------------|-------------------------|----------------|---------------------|-----------------|---------------------|-------------|----------------|
| Lake Erie | • ^c | • | • | • | • | • | • | • ^a |
| Lake Winnipeg | • | • | • | • | • | *a | • | • ^a |
| Pigeon Lake | • | * | • | • | • | | • | • ^b |

* Pigeon Lake does not have provincial legislation or regulations, however, using the Pigeon Lake Watershed Management Plan (2018) the municipalities have coordinated the creation of bylaws to limit nutrient loading and/or regulate development and activities within the lake's watershed.

*a Lake Winnipeg is currently developing an adaptive management framework to apply to the lakes current management strategy

a Lake Erie and Lake Winnipeg have Federal-provincial agreements to reduce bloom activity and improve the health of the Lake. However, Lake Erie also has an international agreement with the US, while Lake Winnipeg uses the IJC to try and coordinate efforts with the US.

b Pigeon Lake does not have any provincial agreements, however, the municipalities have banded together under the Pigeon Lake Watershed Management Plan to coordinate efforts to improve the health of the Lake and reduce cyanobacteria blooms.

c Lake Erie has two management strategies to reduce blooms, the Binational Phosphorus Reduction Strategy, and the Canada-Ontario Lake Erie Action Plan.

5.2.1 Scientific Understanding, Nutrient Targets, and Nutrient Management

Scientific Understanding – Nutrient Loading and Blooms

All three lakes have identified cultural eutrophication as the cause of blooms in these systems, the result of increased TP or TP and TN loads into the waterbodies. That is, TP concentrations in all three waterbodies have increased over time as have cyanobacteria blooms.

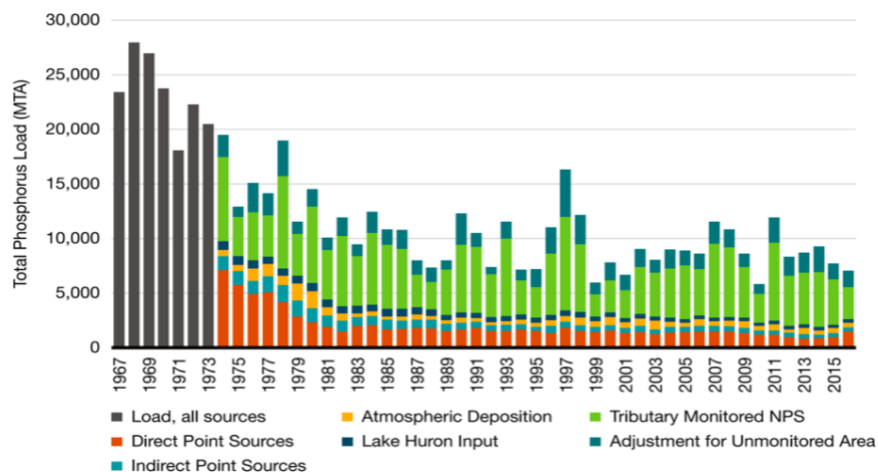


Figure 13: TP loads into Lake Erie from 1967 to 2013 [Source: QLWQANAS, 2019; modified from Maccoux et al., 2016].

Lake Erie was negatively impacted by blooms in the 1960's, which resulted in the adoption and implementation of TP reduction requirements for WWTPs discharging into Lake Erie (Han et al., 2012; Michalak et al., 2013; Jarvie et al., 2017). This tactic was successful in reducing P inputs and cyanobacteria blooms (Figure 13); however, a resurgence occurred in the 1990's where soluble reactive phosphorus (SRP) levels increased, an increase which has been

largely associated with rising agricultural activity (Figure 13) (Han et al., 2012; Michalak et al., 2013; Baker et al., 2014; Maccoux et al., 2016; Jarvie et al., 2017).

The GOC has stated that the long-term trend for Lake Erie TP levels are decreasing (1972-2019), with the offshore water quality listed as “poor” (ECCC, 2020). However, Maccoux et al. (2016) found that from 1999-2013 NPS loading showed a statistically significant increase of 4.7% per year ($p=0.026$). The dominant input is NPS from tributaries (Figure 13; Figure 14).

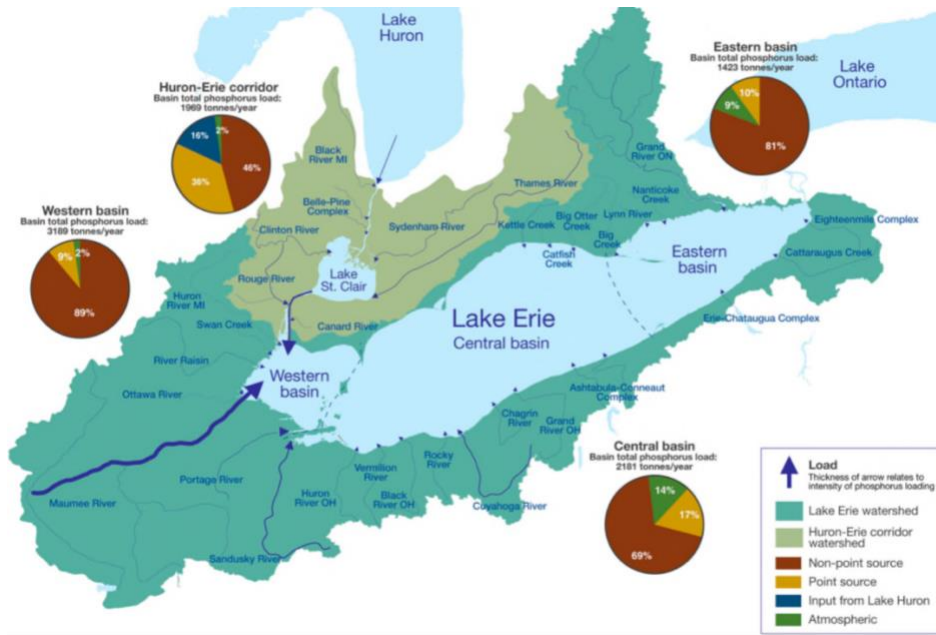


Figure 14: TP loads and sources into Lake Erie [Source: ECCC, 2020].

Lake Winnipeg has been suffering from worsening cyanobacteria blooms since the 1990’s, attributed to increased nutrient loading into the lake. TP levels have increased over time (Figure 15), despite several decades of nutrient management (ECCC, 2019). Lake Winnipeg is also concerned with TN levels in the lake and their contribution to cyanobacteria blooms, however, TN levels have been decreasing over time (Figure 15).

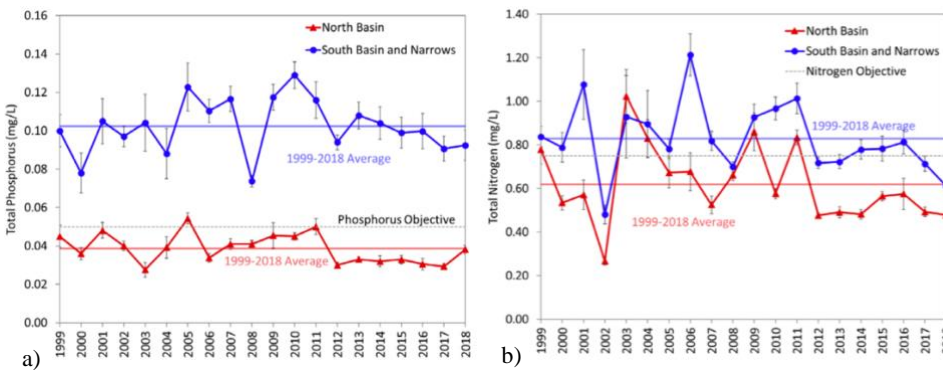


Figure 15: Lake Winnipeg TP (a) and TN (b) concentrations from 1999 to 2016 [Source: GOM, 2019]

Like Lake Erie, Lake Winnipeg's TP loads are subject to interannual and season variation due to changes in rainfall, overland and river flow, ice melt, flooding, and the presence of AISs (Figure 15). The predominant form of nutrient loading into the lake is also from NPSs, with the main source being the Red River (Figure 16).

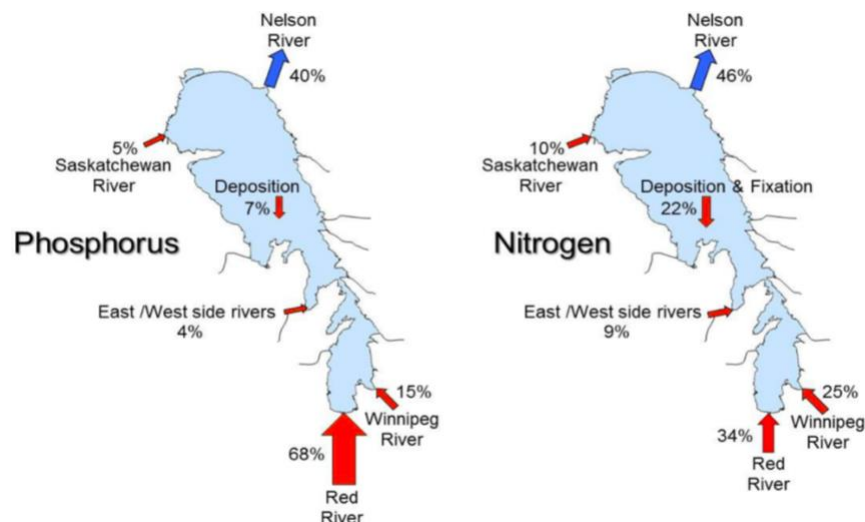


Figure 16: NPS TP (left) and TN (right) loading sources into Lake Winnipeg from the four major tributaries [Source: GOM, 2019].

In 2018, the South Basin had an average TP concentration of 0.092 mg/L (92 µg/L), while the North Basin was 0.038 mg/L (38 µg/L) making the lake hypereutrophic to eutrophic (ARD, 2020). The average TP concentrations for the North and South Basins from 1999-2018 were 0.039 mg/L (39 µg/L) and 0.102 mg/L (102 µg/L), respectively (ARD, 2020), all of which are above the historical natural state of the lake as determined by a paleolimnological study (Bunting et al., 2020).

There is some controversy around whether or not P loading into Pigeon Lake has changed over time, though it is widely accepted that cyanobacteria blooms in the lake have worsened over the last decade.

“That (the science) was actually more controversial than you would think. So, Pigeon Lake has a not too bad monitoring record. I think it goes back to the 80’s and 70’s in terms of water quality... But then there was a big gap when we had big funding cuts in the 2000’s. And then, of course, it picked up again in 2013, I think, or maybe a little earlier. Anyway, so we (AE) ran some trend analysis and we found there is no increase in phosphorus levels or chlorophyll-a. And so, it was actually really hard to get the government scientists to say there was a problem. They were like, well, we think that the residents are just, not that they’re making it up, but that they are, they’re more aware because there was a really bad bloom in 2006 that, you know, like I

said, the hyper critical nature of Pigeon Lake. And so, so there was big criticism of whether there was an issue. And we also looked at the data and they were like, well, it's been like 11 different labs or something like that over the course of the monitoring record, it could be, like there was lots of variation. So anyway, the government people kept coming back and saying, we need you to change the way that you want to present the information, so we switched to box plots, to make it, make those peaks and stuff look a little bit less dramatic, because people were also really frustrated and angry that on the ground, like a pitched like. And then Pigeon Lake the municipalities, commission, well selection of municipalities commissioned another consultant report that looked at Land SAT data to show that there was an increase in cyanobacteria blooms over time. And so that kind of got brought into the mix. So, it, all that controversy died down. And we did end up kind of coming up with agreed to statements, you know, that the algal blooms had been getting worse since the late 2000's and residents had been noticing it. Even though the phosphorus levels are not increasing, we still think we need to do something. So, what it did ultimately was change the way we formulated the objectives. So, instead of saying, oh, we want to have less phosphorus or, you know, giving a kind of like how Ontario or even in the States, how they have these numerical objectives, we totally went away from that 100 percent. And we used just a real broad, we want to see, which suits the residents, less frequency and duration of algal blooms" (Personal Communication, March 2, 2021, Alberta)

Using AE (2021) data, the TP concentrations for the lake show a slightly increasing trend (Figure 17).

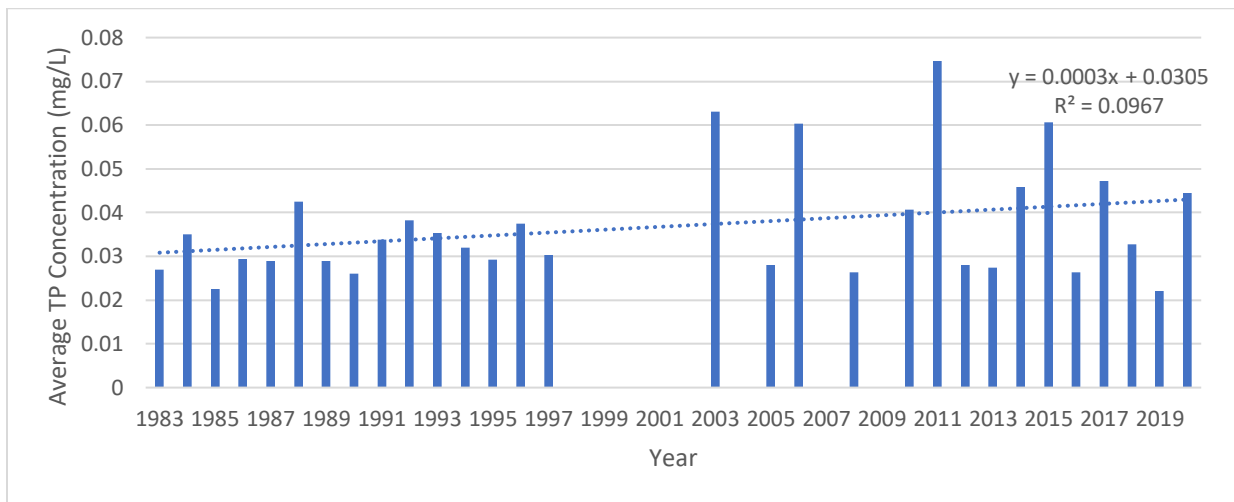


Figure 17: Open Water Season Average TP Concentrations (mg/L) for Pigeon Lake, 1983-2019 [Data Source: AE, 2021].

Note: data inconsistent between years with some years having no samples and others significantly more and analysis methods changed over time, therefore reliability and comparability is unknown.

In the 1980's the lake was classified as 'mildly eutrophic', with average P concentrations in 1983 and 1984 of 29 µg/L and 35 µg/L, respectively, though P concentrations tend to vary throughout the open water season (June to October) due to internal loading (AE, 1989).

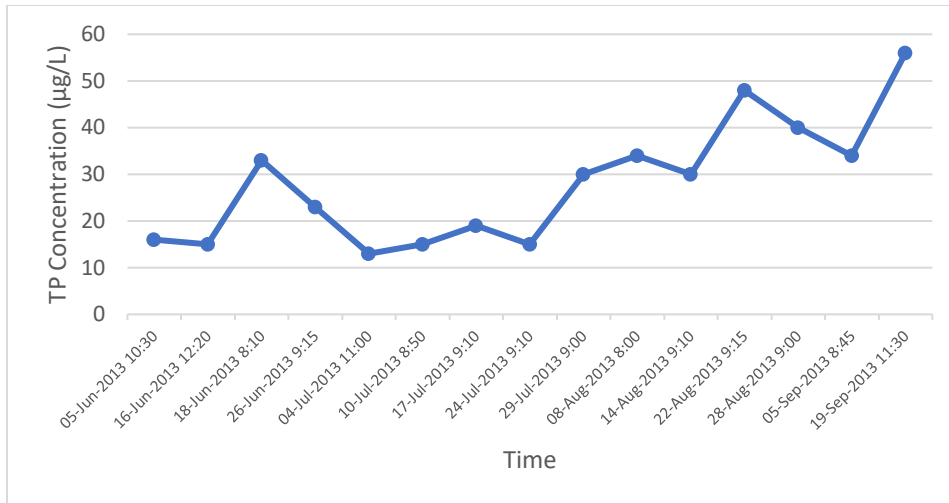


Figure 18: 2013 Pigeon Lake TP Concentrations from June to August [Data Source: AE, 2021]

By the GOC trophic status standards, this lake would be considered meso-eutrophic (20-35 µg/L) in 1983. However, in 2020, TP concentrations within the lake ranged from 0.013 mg/L (13 µg/L) in June to 0.076 mg/L (76 µg/L) in August, with an average TP concentration for the open water season (June to September) of 0.0445 mg/L (44.5 µg/L), making the lake classification eutrophic rather than meso-eutrophic. Some years the lake is even verging on hypereutrophic (Figure 17).

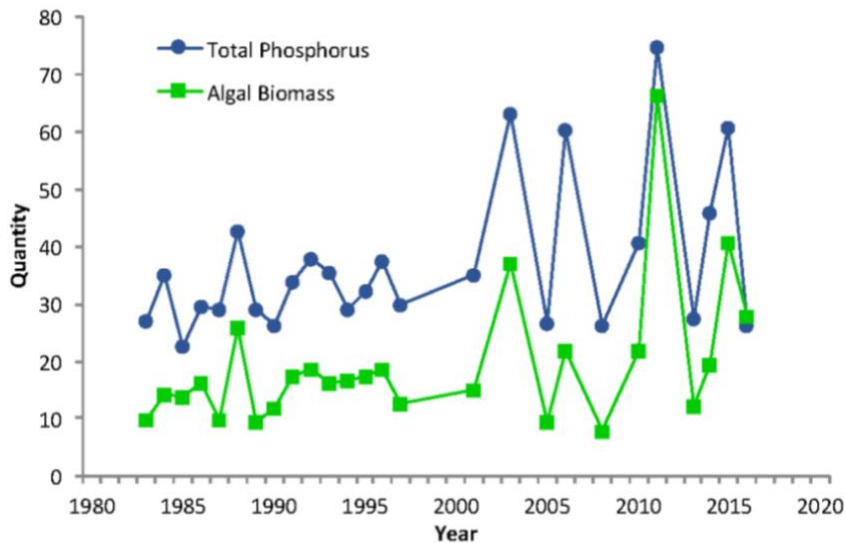


Figure 19: Pigeon Lake Annual Average TP concentrations and cyanobacteria bloom biomass from 1983 to 2016 (PLWMSC, 2018).

Not to mention, the years with significant cyanobacteria blooms correspond with the years where the open water season TP concentrations in the lake were the highest – namely, 2006, 2011, and 2015 (Figure 19), although blooms also occurred in other years.

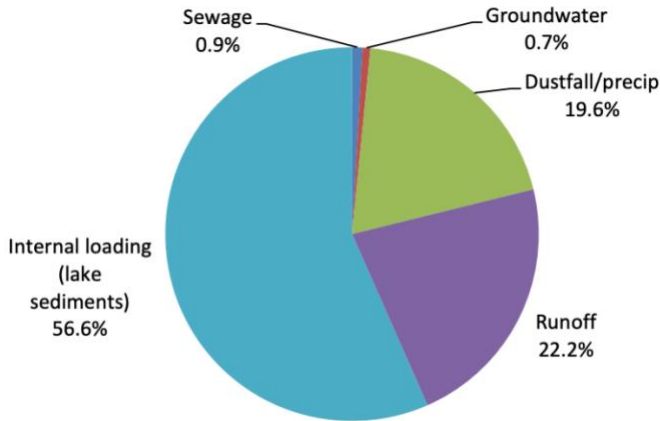


Figure 20: Pigeon Lake P loading sources [Source: Teichreb, 2014].

The main source of nutrient loading into Pigeon Lake is internal P loading (56.6%), with the second highest loading source NPSs (22.2%) (Figure 20). However, internal loading is innately linked with external loads, which means that reducing external P loading into the lake from PS and NPS would help reduce the amount of legacy P available for internal loading in future decades (Nürnberg and Lazerte, 2016).

Nutrient Targets

Setting annual nutrient loading targets first requires choosing a desirable long-term average lake concentration. The latter target may be higher than the pre-settlement concentration which might be unrealistic given modern-day populations and land use. Target concentrations are often based on a concentration that avoids highly undesirable characteristics like cyanobacteria blooms. Once a target concentration has been set, the effectiveness of various nutrient management strategies employed can be monitored based on changes in internal and external loads and lake concentrations,

All three lakes are currently attempting to reduce nutrient loading into the waterbodies using a variety of means, with Lake Erie and Lake Winnipeg concerned with NPS and PS loads, and Pigeon Lake concerned with internal P loading, NPS and PS loading. Lake Erie and Lake Winnipeg have installed nutrient loading and concentration targets in order to reduce nutrient loading and therefore cyanobacteria blooms, while Pigeon Lake has not (Table 34). (Table 34).

Table 34: Nutrient targets for the different waterbodies

| Waterbody | P Targets | N Targets |
|----------------------|--|---|
| Lake Erie | <p>Binational Phosphorus Targets (2019)</p> <ul style="list-style-type: none"> - 40% reduction in TP entering the Western and Central basins of Lake Erie from 2008 levels <ul style="list-style-type: none"> o Metric ton load reduction to the central basin <ul style="list-style-type: none"> ▪ Canada: 212 metric tons ▪ USA: 3,316 metric tons ▪ Total = 3,528 metric tons o Specific to anoxic zones - 40% reduction in spring TP and soluble reactive phosphorus (SRP) from the following watersheds <ul style="list-style-type: none"> o Canada: Thames River and Leamington Tributaries o USA: Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River, Huron River (Ohio) o Specific to algae - 40% reduction in spring TP and SRP loads from Maumee River in the USA <ul style="list-style-type: none"> o Specific to cyanobacteria biomass levels - Reductions compared to 2008 Levels <p>Canada-Ontario Lake Erie Action Plan (February 2018)</p> <ul style="list-style-type: none"> - 40% reduction (from 2008 levels) in Spring TP and SRP for the Maumee River to minimize cHABs in the western basin to minimize harmful algal blooms in the western basin - 40% reduction from 2008 levels in phosphorus loadings to the central basin, with a new binational loading target of 6,000 tonnes per year of total phosphorus - 40% reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for priority tributaries to minimize harmful algal blooms in the nearshore areas <p>Concentration Targets:</p> <ul style="list-style-type: none"> - East Basin: 6 µg/L - West Basin: 12 µg/L - Central Basin: 6 µg/L | N/A |
| Lake Winnipeg | <p>TP Concentration Target for the Lake: 0.05 mg/L</p> <p>TP Loading Targets for the four major tributaries:</p> <ol style="list-style-type: none"> 1. Red River: 2,800 tonnes/year 2. Dauphin River: 60 tonnes/year 3. Saskatchewan River: 340 tonnes/year 4. Winnipeg River: 1,050 tonnes/year | <p>TN Concentration Target for the Lake: 0.75 mg/L</p> <p>TN Loading Targets for the four major tributaries:</p> <ol style="list-style-type: none"> 1. Red River: 19,050 tonnes/year 2. Dauphin River: 4,550 tonnes/year 3. Saskatchewan River: 8,960 tonnes/year 4. Winnipeg River: 19,450 tonnes/year |
| Pigeon Lake | No Targets Available | No Targets Available |

Lake Erie has nutrient loading reduction targets for the lake’s major tributaries, and TP concentration targets for the Western and Central Basins, created and regulated under the COA and Binational Agreement (Table 34). These targets are split between Canada and the US, with each country responsible for different loading reduction targets (Table 34).

Lake Winnipeg has TP and TN concentration objectives for the lake (North and South basins), which are currently being adopted into provincial legislation - The Water Protection Act, the Nutrient Target Regulation - and load objectives for the four major rivers flowing into the lake (Table 34). Previously, the nutrient loading targets were percent reductions – 13% reduction in TN and 10% reduction in TP (LWSB, 2006; Zhang and Rao, 2012), with a TP concentration target of 0.05 mg/L TP for the North and South Basins. The TP target for the lake is the same, however, a TN target has been added.

Pigeon Lake has not set any phosphorus targets, as Alberta has moved away from the idea of setting external loading targets or nutrient concentrations for waterbodies within the province. The reason given for Alberta moving away from setting TP targets for waterbodies is that their soils are naturally high in P and N, as such the lakes are naturally eutrophic and therefore any attempts to reduce phosphorus would likely be going against the natural trophic status of lakes within the province.

“... the issue in, well, across most of the prairies is the nutrient issue is largely natural. So, the big, you got to recognize the lakes are functionally somewhat different between the provinces, and that makes managing them a little bit different when we have high nutrient levels. It's not as simple as looking at the activities in the watershed and saying, hey, you know, we got to change your activity or how you got to manage your activity better to reduce nutrient flow from what you're doing. That's not the case here. The geology here is very nutrient rich. It's large sedimentary bedrock deposits that Alberta sits on being that it was an inland sea in past geological time, so high in nutrients regardless. And I always say, yeah OK, we grow good crops in Alberta because of the soils are organic, but our lakes are organic too, unfortunately. So very different how you manage that compared to again, managing just issues in lakes that are derived from human impacts in the watershed. So, we recognize that we try to manage it around not having an increase in nutrients but maintaining natural condition.” (Personal Communication, December 15, 2020, Alberta)

This does not take into consideration land-use changes, the loss of natural/native tree and plant coverage around the lakes and in their watersheds, increased loads due to human activities in and around the lakes and in their watersheds, and the application and/or over application of P to soils for agricultural and urban purposes within the province and the lakes watershed. Even if the soils are naturally high in P, the activities mentioned above are enough to significantly alter natural overland flow and total external loading, increasing P export into watersheds and lakes thereby promoting bloom formation. The Pigeon Lake watershed is 58% agricultural, therefore, P imported into the watershed for grain and livestock production (Thormann et al., 2008) undoubtedly contributes to external loading.

Nutrient Management

All three waterbodies have provincially regulated nutrient management practices that apply to the lands surrounding the waterbodies (Table 34) and access to provincial encouraged, incentivized, and optional nutrient management programs (Table 36). That is, existing nutrient management programs and practices used to regulate or encourage NPS and PS nutrient loading

are utilized by these lakes, though their applicability and effectiveness are dependent on program specifics and the waterbodies use (see Chapter 4). For example, Alberta’s TP effluent standard for WWTPs does not apply to Pigeon Lake because wastewater around the lake comes from provincially approved pump-out tanks or septic fields (PLWMPSC, 2018).

Table 35: Provincially Regulated Nutrient Management for Lake Erie, Lake Winnipeg, and Pigeon Lake

| Waterbody | Nutrient Targets | Wastewater Management | Manure Storage | Manure Application | Winter manure application restricted | Riparian Zones | Wetland protection | Setback Distance |
|---------------|------------------|-----------------------|----------------|--------------------|--------------------------------------|----------------|--------------------|------------------|
| Lake Erie | • | • | • | • | • | • | • | • |
| Lake Winnipeg | • ^a | • | • | • | • | • | • | • |
| Pigeon Lake | | • | | | * | • | • | • |

^a Lake Winnipeg has TN and TP targets, and notional TN and TP targets have also been developed and are being put into legislation for the major river watersheds that flow into the lake.

Table 36: Encouraged and incentivized nutrient management programs and methods for Lake Erie, Lake Winnipeg, and Pigeon Lake

| Waterbody | EFP | 4R | CAP | BMP | Chemical | Physical |
|---------------|-----|----|-----|-----|----------------|----------|
| Lake Erie | • | • | • | • | | |
| Lake Winnipeg | • | • | • | • | | |
| Pigeon Lake | • | • | • | • | • ^a | |

^a A local community has secured Municipal/Provincial funding for an Alum application. It is being coordinated with the MOE and may or may not happen.

The cyanobacteria/nutrient management strategies created for these lakes have also resulted in more stringent or more specifically applied nutrient management practices. For Lake Erie in Ontario, WWTPs discharging 3.78 million L/day into Lake Erie are going to be required to meet a 0.5 mg/L TP effluent limit, though this was to be achieved by 2020. When speaking with the MECP in 2021, this did not appear to have been implemented, as the current 1.0 mg/L TP effluent standard was and is still the requirement for WWTPs discharging into the lake, with some variability for the summer months and specific facilities. On the NPS nutrient management side, farms within the Lake Erie watershed applying for funding to implement nutrient management BMPs under CAP that reduce nutrient export from agricultural operations are fast-tracked to receive funding, which requires the completion of Ontario’s EFP program. But, overall, the implementation plan for these nutrient targets is still under development, which means that existing nutrient management programs might be altered, more funding may become available for incentivized programs, and/or new programs may be developed to aid in achieving these targets. However, there have not been, nor do there seem to be any plans to increase nutrient management regulations. Instead, increased encouragement of existing nutrient management programs or participation in industry lead programs are likely to continue be the methods used to decrease NPS nutrient loading into Lake Erie.

“In terms of future regulatory amendments to increase the application of nutrient management. I’m not aware of any... So, but it would, I don’t believe there would be much of that on the horizon. And we frankly, we have a Conservative government that came in a little while ago and they will have their own priorities. Nutrient management was largely rolled out under a Liberal government. And, of course, the current government is wholly taken up with COVID response. So, I would be surprised to see any expanded approach to nutrient management right now, again, because I think a lot more effort is being put into the 4R and the industry focused developments.” (Personal Communication, November 17, 2020, Ontario)

For Lake Winnipeg, there has been increased and renewed investment in education and outreach and voluntary BMPs under CAP, called AgAction in Manitoba. This fund also provides participating farmers with cost-shared funding for BMP adoption. The Watershed Districts (formerly Conservation Districts) have access to this funding for increased education and outreach, where they provide information on why BMPs should be adopted, along with information on which BMPs have funding available for implementation. These Watershed Districts often promote the adoption of nutrient management BMPs to aid in reducing nutrient loading within the province, but specifically to Lake Winnipeg as well. The Watershed Districts are unsure how the new notional targets for the lake, once adopted into legislation, while not legally enforceable, will impact their initiatives and/or be achieved. The implementation strategy for these new targets is set to come out this year (2021). WWTPs are also being upgraded to remove TN as well as TP from effluent waters and research is currently underway to understand the impact of internal loading on nutrient availability within the lake.

For Pigeon Lake, agricultural operations are able to apply for BMP funding under CAP, though this is now separate from the provincial EFP program, reducing educational requirements for farmers. Using the PLWMP, municipal bylaws have been coordinated and installed which protect against shoreline development and agricultural practices within 800 m of the lake that would significantly increase P loading into the lake. The municipal bylaws installed prohibit development within the lakes riparian area – all areas within 800 m of the lake’s shore – or an approved construction permit or plan is required. A construction management plan is also required for any new developments within the watershed. New and expanding agricultural operations within the watershed now have land-use restrictions that apply to them in order to prohibit intensive livestock operations. Use of BMPs that reduce P loading are encouraged for all existing agricultural operations, recreational operations – such as golf courses and campgrounds

– and oil and gas operations within the watershed as well. These education and outreach initiatives are run by the PLWMA, where provincial documents and information on provincial programs are shared, as well as ones developed by the association to reduce fertilizer and land-use changes by the general public.

The PLWMP is the only plan that includes internal P loading in the management of cyanobacteria blooms, even though sediment released nutrients contribute to P levels and blooms in both Lake Erie and Lake Winnipeg (Nürnberg and LaZerte, 2016; Nürnberg et al., 2019). One of the communities around the lake is looking to pursue a chemical nutrient/bloom management method (Table 36). That is, the community has secured municipal/provincial funding, which they plan on using to buy and apply alum to the deepest part of the lake. The community is currently waiting on provincial approval before moving forward.

5.2.2 Agreements/Coordination

The Federal Government has initiated or signed onto several transboundary and trans-national water agreements which are meant to produce concerted, coordinated efforts that protect the quality and quantity of Canadian waters (GOC, 2019b; GOC, 2019a). These various agreements generally use committees to coordinate efforts and initiatives or they provide funding for research and support initiatives within the provinces that aim to protect, respond to, and/or monitor water quality issues (Table 37) (GOC and GoO, 2014; GOC, 2016; GLWQANAS, 2019). The agreements also tend to apply to transboundary/trans-provincial or transnational waters (Lake Erie and Lake Winnipeg watershed) or act to coordinate efforts under the mandate of protecting water quality for environmental and human health (IBWTA, 1985; CCME, 2008; GOC and GOM, 2010; GOC and GOO, 2014; GOC, 2017; GOC, 2019c; GOC, 2020c; GOC, 2020b).

Table 37: Agreements and MOUs between the Federal Government and provinces of Canada that are related to cyanobacteria management, directly and indirectly.

| Agreement | Purpose | Sub-Agreements/Strategies/Programs | Link to cHABs |
|--|--|--|---|
| Federal-Provincial-Territorial Agreement(s) on Water Quality Monitoring | “Achieve a longterm commitment for the acquisition of water quality data, to obtain comparable, scientifically sound water quality data that are reliable for the purposes of water resource management, and to disseminate timely information on water quality to the public, government agencies, industry and the scientific community” (GOC, 2021) | <ol style="list-style-type: none"> 1. Canada-British Columbia Water Quality Monitoring Agreement (1985) 2. Canada-Manitoba Water Quality Monitoring Agreement (1988) 3. Canada-New Brunswick Water Quality Monitoring Agreement (signed 1988, harmonized 1995) 4. Canada-Newfoundland Water Quality Monitoring Agreement (1986) 5. Canada-Prince Edward Island Water Agreement (1989, 2001) | Routine Water Quality Monitoring - Includes nutrients (N and P) |

| | | | |
|--|---|---|---|
| Canada-wide Strategy for the Management of Municipal Wastewater Effluent | <p>“This Strategy aims to ensure regulatory clarity in managing municipal wastewater effluent under a harmonized framework that is protective of human health and the environment” (CCME, 2009)</p> <p>Two main goals:</p> <ul style="list-style-type: none"> - Improve human health and environmental protection - Improve clarity on how municipal wastewater is managed and regulated | Site-Specific Effluent Discharge Objectives | <p>Effluent Discharge Objectives</p> <ul style="list-style-type: none"> - Standards set by Provinces - Nutrients <ul style="list-style-type: none"> - Total ammonia nitrogen - TKN (ammonia + organic N) - Total phosphorus |
| Canada-US Great Lakes Water Quality Agreement* | <p>“Agreement between Canada and the United States that identifies shared priorities and coordinating actions to restore and protect the chemical, physical and biological integrity of the waters of the Great Lakes”</p> | Lake Erie Binational Phosphorus Reduction Strategy | <p>Annex 4 – objective 4: maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the Waters of the Great Lakes</p> <p>General Objective VI: be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem</p> |
| Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health* | <p>“Agreement between Canada and Ontario that supports the restoration and protection of the Great Lakes basin ecosystem. Agreement outlines how the governments of Canada and Ontario will cooperate and coordinate their efforts to restore, protect and conserve the Great Lakes basin ecosystem. It is the means by which Canadian federal departments interact with the Ontario provincial ministries to help meet Canada's obligations under the Canada-US Great Lakes Water Quality Agreement (GLWQA)”</p> | Canada-Ontario Lake Erie Action Plan | <p>Annex 1: address the issue of excess nutrients and reduce harmful and nuisance algal blooms</p> <ul style="list-style-type: none"> - 40% reduction (from 2008 levels) in Spring TP and SRP for the Maumee River to minimize cHABs in the western basin - 40% reduction (from 2008 levels) in spring loads of total phosphorus and soluble reactive phosphorus for priority tributaries to minimize harmful algal blooms in the nearshore areas |
| Canada-Prairie Provinces Water Board Agreement on Water Quality | <p>“Governments of Alberta, Saskatchewan, Manitoba and Canada signed the Master Agreement on Apportionment (MAA) which provides for the sharing of water in eastward flowing streams that cross interprovincial boundaries and establish the PPWB board to oversee the Agreement”</p> | <p>Master Agreement on Apportionment</p> <ul style="list-style-type: none"> - Schedule A: An apportionment agreement between Alberta and Saskatchewan - Schedule B: An apportionment agreement between Saskatchewan and Manitoba - Schedule C: The Prairie Provinces Water Board Agreement describing the composition, functions and duties of the Board - Schedule D: A listing of Orders-in-Council for allocations of interprovincial waters - Schedule E: Water Quality Agreement | <p>Schedule E established water quality objectives for 12 PPWB eastward transboundary rivers</p> <ul style="list-style-type: none"> - Nutrient targets/objectives for 12 locations <ul style="list-style-type: none"> - TN and TP - Site-specific levels - 12 Locations <ul style="list-style-type: none"> - Cold Lake - Beaver River - North Saskatchewan River - Deer River - South Saskatchewan River - Battle Creek - Churchill River - Saskatchewan River - Carrot River - Red Deer River - Assiniboine River - Qu'Appelle River |
| Canada-Quebec Agreement on the St. Lawrence River | <p>Agreement between Canada and Quebec to “conserve, restore, protect, and enhance the St. Lawrence ecosystem and to participate in the maintenance and recovery of uses of the St. Lawrence”</p> | Action 2: Improving Water Quality | <p>Improving Water Quality 2011-2016</p> <ul style="list-style-type: none"> - Reducing agricultural sources of NPS pollution - Use the effects of harmful and toxic algae as indicators for monitoring the quality and eutrophication of the water <p>Improving Water Quality 2016-2021</p> <ul style="list-style-type: none"> - Reducing agricultural sources of NPS pollution - Effect of NPS pollution on human and ecosystem health |

| | | | |
|--|--|-----------------------------|---|
| Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin* | “The purpose of this MOU is to facilitate a cooperative and coordinated approach between the Parties in their efforts to understand and protect the water quality and ecological health of Lake Winnipeg and its basin, and achieve a healthy, prosperous and sustainable Lake Winnipeg for present and future generations.” (GOC and GoM, 2010) | Lake Winnipeg Basin Program | Goal of the Program: - Take action to reduce P and N loading in order to reduce the stress of large-scale algal blooms - Reduce TP to 0.05 mg/L (pre-1990 levels) - Reduce TN to 0.75 mg/L - Notional targets also developed for the lakes 4 main tributaries Key Stressors: - Nutrient loading (P and N) - Large scale algal blooms |
|--|--|-----------------------------|---|

*Agreements with specific provisions to deal with cyanobacteria blooms

Of the 7 agreements identified, only 3 have goals specific to the management of cyanobacteria blooms: the Canada-US Great Lakes Water Quality Agreement, The Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, and the Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin (Table 37), which are all lake-specific agreements. Reducing algal bloom biomass is a goal within these agreements for specific and significant waterbodies, so nutrient targets and monitoring programs have been developed to deal with blooms for these waterbodies. The rest of the agreements have an indirect effect either through monitoring of water quality (TP, chlorophyll-a levels) or the reduction of nutrient loads into river watersheds in order to protect general water quality (Table 37).

Pigeon Lake uses its management strategy to coordinate P reduction activities within the relevant municipalities, while Lake Erie has the Federal-provincial and international agreements to coordinate the nutrient reduction objectives. For Pigeon Lake, the PLWMP serves as an agreement between the relevant municipalities and Indigenous communities with the goal being the reduction of cyanobacteria blooms in the Lake. The management strategy has resulted in the coordinated development of nutrient management/P reduction strategies, education and outreach, monitoring, scientific research, and possibly, in-situ cyanobacteria lake treatment.

Lake Erie has two agreements to reduce P loading into Lake Erie, one is an international agreement, where Canada and the US have pledged to reduce nutrient loading into the lake’s major tributaries, in order to meet Lake level P goals. While the other is a provincial-Federal agreement, meant to coordinate nutrient management at the provincial scale in order to meet the goals of the international agreement.

Lake Winnipeg, while it has a Federal-provincial agreement, does not have an international and national agreement, even though the lake receives large nutrient inputs from rivers that flow through several provinces and states. Therefore, to coordinate the nutrient

reduction targets nationally, the Prairie Provinces Waterboard is used, and internationally the International Joint Commission (IJC) has been tasked with coordinating nutrient reductions from the US, with the hope that the states responsible for loading into the lake will agree.

5.2.3 Monitoring

Table 38: *Cyanobacteria bloom monitoring programs*

| Waterbody | Routine Recreational (Bloom) | Reactive (Bloom) | Source Water | Routine Phytoplankton | Cyanotoxin Testing | In-Situ | Remote Sensing | Routine Water Quality |
|---------------|------------------------------|------------------|--------------|-----------------------|--------------------|---------|----------------|-----------------------|
| Lake Erie | * | • | • | • | • | • | • | • |
| Lake Winnipeg | • | • | | • | • | | • | • |
| Pigeon Lake | • | • | | | • ^a | • | • | • |

* Routine recreational bloom waterbody monitoring is dependent on the Local Health Unit and therefore only certain LHUs perform routine visual inspections of Lake Erie beaches

^a The Pigeon Lake Watershed Association works with Lake Watch (a volunteer-based water quality monitoring program) that performs monthly cyanotoxin/microcystin testing

Lake Erie and Lake Winnipeg both have long-term monitoring due to increased blooms events. Monitoring for both lakes is a coordinated effort between the Federal and provincial governments, not to mention monitoring on the USA side for Lake Erie.

ECCC was recently (2020-2021) tasked with developing a new monitoring strategy for Lake Erie to aid with achieving the nutrient targets for the lake.

“We’ve (ECCC) been tasked to develop a monitoring program for Lake Erie going forward on how to measure lake response to this 40 percent reduction, so the policy has already been made and now I’ve been asked to advise and develop a plan for monitoring to look at lake response going forward to some of these managers, to some of these are nutrient targets that have been set. So, in that kind of capacity, I’m involved, but kind of formally at the decision-making level, that’s not really something I regularly participate in.” (Personal Communication, February 8, 2021, ECCC)

This has yet to be implemented. Outside of the routine and reactive drinking water monitoring programs and the reactive recreational monitoring program in Ontario, Lake Erie is routinely monitored under the Great Lakes Water Quality initiative by the ECCC, MECP, CAs, and various participating NGOs though this does not include regular phytoplankton monitoring. The ECCC has collected and stored samples for phytoplankton analysis, with ECCC researchers attempting to get the funding required to analyze them. Unfortunately, preserved phytoplankton samples degrade over time making stable long-term funding for sample analysis within a year or so of collection critical. Without sample enumeration, researchers must rely on remote sensing via satellite which only detects blooms within 1 m of the surface and can be obscured by cloud cover. Provincially, routine water quality monitoring of Lake Erie tributaries is delegated to Conservation Authorities (CAs) under the SWPPs, with the data shared with the MECP. The

MECP also has routine water quality monitoring programs, which have included nutrient and chlorophyll-a sampling of Lake Erie, and sometimes MC-LR testing for source waters, though not on a regular basis. The MECP is also currently conducting research on Lake St. Claire-Thames River, looking at their impacts on P loading into Lake Erie.

Lake Winnipeg has a comprehensive long-term monitoring program for lake water quality (nutrients, Secchi depth, chlorophyll-a, and more) and cyanobacteria bloom species composition, cell count, and toxin concentrations. This is a joint provincial-Federal monitoring program, which includes open-water season and winter sampling. The lake has 65 nearshore and offshore monitoring stations, which the ARD and the Lake Winnipeg Research Consortium (LWRC) use to collect data annually. In the summer, the LWRC research vessel is used to collect data from all 65 stations (if possible), with specific stations slotted for routine cyanobacteria and/or phytoplankton sampling. Any blooms visually confirmed while on the vessel are also sampled. All data is shared with the Federal government upon formal request. There is often a lag in data-sharing, with the provincial government keeping recent data for provincial research purposes.

Federally, Lake Winnipeg and Lake Erie are both monitored for blooms under the EOLakeWatch Program. EOLakeWatch is a Federal cyanobacteria bloom monitoring program that uses remote sensing via satellite to monitor bloom events on Lake Erie, Lake Winnipeg, and Lake of the Woods. The program is run by Environment and Climate Change Canada (ECCC). The program uses satellite imagery and an algorithm to monitor daily lake water colour/chlorophyll-a concentrations. Specific wavelengths are used to estimate the concentration of cyanobacteria-specific pigments and chlorophyll-a (which is an indicator of total phytoplankton bloom biomass) on the surface. Water sampling is used to calibrate the technology, with the samples collected by the ECCC or provincial ministries and NGOs upon request by the ECCC. The monitoring is almost real-time, with photos of water or bloom conditions available for analysis within a few hours of the satellite imagery being collected. However, imagery can be obscured by cloud cover and other environmental conditions, making the frequency of usable data inconsistent. Monitoring is conducted from June to October, and it tracks bloom extent, intensity, severity, and duration. All of the data are readily available online to the public, which can be viewed for all three lakes using the interactive map feature or

downloaded. Annual reports are also generated and available online, with reports available from 2002 to 2020.

Pigeon Lake has been relatively consistently monitored, with nutrient concentration sampling conducted almost every summer for almost 40 years by the province, along with chlorophyll-a and other water quality parameters of concern. However, there is a gap in the early 2000's due to budget cuts and a shift to river water and generalized water quality monitoring within the province. There are also years where budgets and short-term research funds resulted in increased sampling of Pigeon Lake. The sample analysis methods used over time differ due to changes in approved laboratories and analysis methods; as such, the comparison of sample results over time is tricky. In terms of cyanobacteria blooms, beyond the provincial routine and reactive recreational monitoring programs, Pigeon Lake is predominantly monitored by community efforts, where the PLWA has arranged for satellite monitoring of the lake for bloom activity and regular water quality monitoring to be conducted by ALMS. All data collected are shared with AE. The PLWA even purchased a buoy equipped with sensors to be part of the provincial governments new remote sensing water quality monitoring program. The buoy is able to track real-time water quality data throughout the water column, including DO concentrations, which is important for understanding internal P loading within the lake.

5.2.4 Funding

Lake Erie and Lake Winnipeg are both coordinated efforts with the Federal government, which means that federal funding is available for monitoring and research purposes. Lake Erie has Federal funds under the Great Lakes Protection Initiative. Provincially, there is the Great Lakes Local Action Fund, which is currently providing funding for a range of Lake Erie protection and research initiatives. The MECP is also currently researching Lake St. Claire-Thames River and their nutrient inputs into Lake Erie. This project has four years of funding with the end goal being long-term monitoring and contributions to nutrient reductions.

Lake Winnipeg has funding through the Lake Winnipeg Basin Program which is a cost-share program between the GOC and the province of Manitoba. The program funds various initiatives to protect the water quality of the lake. Nutrient management projects can and are funded under this program.

Pigeon Lake, since it is managed municipally, is reliant on provincially supplied provincial funding. The Watershed Group responsible for the management strategy also applies

to various Provincial and Federal funds/funding programs, for which they have to compete with other Watershed Groups within the province. Development of the PLWMP, the scientific research that made it possible, the various monitoring and education and outreach initiatives, and even the plans for in-lake treatment were all made possible by the interest of the surrounding communities and the willingness and ability to fund the various initiatives.

5.2.5 Risk Management

Risk management for all three waterbodies relies on existing cyanobacteria bloom risk management programs within the province (see Chapter 4). Pigeon Lake is part of the provincial routine and reactive beach monitoring programs (Figure 11), with educational and advisory cyanobacteria signage from these programs placed at public beaches around the lake.

For Lake Erie, there is only the provincial reactive monitoring program, where reports are followed up on by the MECP, with the LHUs deciding on beach advisory issuances or closures (Figure 8). The use of signage, educational or advisory, is dependent on the LHU, as are any other means of posting.

For Lake Winnipeg, the beaches are monitored by the Clean Beaches Program, with any advisories posted on the online interactive map and signage put in place on the beach.

Lake Winnipeg and Pigeon Lake are not surface source waters, so provincial routine drinking water monitoring does not apply. As such, both lakes only fall under the reactive and routine monitoring programs for recreational waters.

Lake Erie provides drinking water to a large number of Canadians and Americans. On the Canadian side, all DWTPs follow the provincial mandate for monitoring and reporting blooms in source waters (routine source water monitoring), with LHUs responsible for advisory issuance. All DWTPs follow the same protocols outlined in Chapter 4 (Figure 8). Point Pelee, on the north shore, follows a different protocol, having received special permission to use ELISA field test kits for preliminary testing of blooms in or around intake for the DWTP due to the frequency of bloom events in that area. This is the only DWTP approved to do so due to the unreliability of the test kits.

5.2.6 Adaptive Management

Lake Erie has requirements for adaptive management built into both the COA and Binational Agreement. New information regarding the cause of blooms and effective means of managing them are to be adopted into the management strategies for the lake. Currently Ontario is studying the cause of blooms in oligotrophic systems, with the idea of applying that

information to waterbodies within the province (see Chapter 6), including Lake Erie. However, the research is in its early phase, and it is unclear what impact this research will have on Lake Erie.

In 2017, Manitoba was tasked with developing an adaptive management framework for Lake Winnipeg, which was funded by the GOC. This framework is meant to “assess the effectiveness of management decisions intended to mitigate the effects of nutrient loading and multiple ecological stressors such as invasive species and climate change.” (GOC, 2018). This has yet to be implemented for the Lake as of 2020 but is a major consideration moving forward so that the best management strategies for the lake can be applied as new information becomes available. What changes, if any, might be the result of adopting this framework are currently unknown.

Pigeon Lake does not specifically list adaptive management within its cyanobacteria management strategy for the lake. However, investigation and research are part of the in-lake management goal and ongoing monitoring is another goal as well. But adapting to new scientific knowledge or other knowledge is not built into the plan itself, which could be a limitation as new information on management comes forward, such as the understanding around Fe^{2+} contribution to cyanobacteria bloom formation, especially in a lake known to experience internal loading.

Monitoring of sediment redox status because of the strong link between redox and bloom formation (Molot et al., 2014, 2021) has not been incorporated into any provincial monitoring programs nor have redox management policies for the management of cyanobacteria blooms been incorporated. On the risk management side, no cyanotoxins other than microcystin are monitored or controlled in drinking or recreational waters.

5.2.7 Education and Outreach

Lake Winnipeg and Pigeon Lake have developed educational documents for the public, which provide information on how the individual can reduce nutrient loading into the lakes. Lake Winnipeg has three documents that are available to view or for download online: The Water Protection Handbook, The Clean Water Guide, and Lake Friendly.

Pigeon Lake has the Alberta Clean Runoff Action Guide, which is also available to view or download online. The PLWA also has a range of webpages that educate on various BMPs that can be used to reduce loading around the lake, such as riparian zone maintenance or restoration, lawn care tips outside of fertilizer application, and more. The PLWA also arranges for summer

science-students to run youth education and outreach initiatives. Industry or scientific specialist are also arranged to come in the summer and discuss ways that individuals within the communities around the lake can improve environmental conditions and limit P loading and their impacts on the lake and the waters quality.

“... We have maybe a clean run off program will be selling rain barrels to support water retention lock. So, we have, or we might be bringing in native plant specialists to talk about ways in which you can naturalise your lot in different plants that you can use or low impact development landscape experts who will come and provide information for landowners so that each of the property owners can do something on their own lot. And I think really our programming, I know this happens around a lot of lakes, but it in particular around the area of clean runoff, which is a main objective for us, we developed the Alberta Clean Runoff Action Guide in partnership with ALIDT, that is the Alberta Low Impact Development Partnership, to look at basically green solutions to reduce runoff nutrients, the excess nutrients entering the lake. So, everything from rainwater harvesting, establishing rain gardens, adding swales in ditches, natural swales. So, you're, letting ditches grow and or planting. Other things include green roofs. You see that less in Alberta because most of our contractors here say you can't have a green roof, can't have a flat roof, there's too much snow. And then, other things, so, we have a whole guide. It's very expansive. It's a beautiful resource for our community. And I actually think in developing that program and through grants that we've had over the years, I think they've really changed the language. There's really a new lexicon here that, where our residents, whether they really know what runoff is, they can talk about that.” (Personal Communication, March 3, 2021, Alberta)

Ontario, provincially, has not developed any educational materials for the public on Lake Erie, outside of the two P reduction strategy documents, which are available online, though not linked too through the provincial Blue-Green Algae webpage.

5.3 Summary of Key Findings

The manner of setting nutrient targets for waterbodies is different between the case studies, with Lake Erie focusing on percent reductions in P from a baseline level (2008), while Lake Winnipeg has set concentration targets for the lakes basins and loading targets for the major tributaries.

Two out of the three waterbodies are focused on P only, trying to reduce biomass but reducing P, the main limiting source for aquatic biological production. Meanwhile, Lake Winnipeg is the only lake to include N in their management of the waterbody in order to reduce cyanobacteria blooms.

Whether the lakes have numerical nutrient targets (P or N and P) or not, nutrient reduction strategies are dependent on voluntary participation in NPS nutrient management programs rather than regulatory approaches to meet nutrient management goals for the waterbodies. This means that tracking of BMP adoption in order to understand success and/or the successful implementation of BMPs known to reduce nutrient or P loading into the lakes is relatively unknown.

Recent science on the importance of sediment redox contribution to bloom formation is not included in any of the management strategies for the three lakes. Instead, the focus is heavily on reductions of NPS and PS nutrient loads, with only Pigeon Lake considering internal P loading and attempting to mitigate this using an in-lake treatment. Sediment redox is also not included in monitoring programs for the lakes either.

The risk cyanobacteria blooms pose to public health is mitigated using a combination of monitoring programs and education and outreach initiatives, programs that are installed at the Provincial and sometimes municipal levels.

None of the management strategies have successfully reduced the occurrence of cyanobacteria blooms nor have they, where applicable, met their nutrient reduction targets. However, while NPS and PS nutrient management programs have been in place in several of the provinces (Manitoba and Ontario) for some time, which include P levels for limiting land application rates, the targets developed for these lakes are relatively newly installed. Not to mention, there is a understood offset time, where a lag is expected due to legacy P and/or nutrients stored within the lakes and their major tributaries.

The lakes selected are not representative of how most lakes within Canada are managed for blooms. That is, most lakes experiencing blooms are not actively managed, and instead rely on the patchwork of control and prevention programs currently in place within each of the provinces.

Chapter 6.0: Interviews

The aim of the interviews was to use multiple sources of evidence to assess provincial efforts to manage cyanobacteria blooms. By speaking with provincial and NGO personnel who work in the selected case studies and provincial programs (directly and/or indirectly related to cyanobacteria management) a comparison could be made between the policies, programs, and practices real-world applications versus what was outlined in the documents. The interview questions were semi-structured, which allowed for respondents to answer based off their experiences and opinions. It also allowed for follow-up questions based on the responses. The answers were organized using the policy analysis framework developed, where three key themes were identified. First, the controversy around the cause of blooms. Second, the effect funding, capacity, and regime changes have on cyanobacteria management in practice. Third, that cyanobacteria management is focused on risk control over bloom mitigation and/or prevention.

6.1 Science, Research, and Blooms in Oligotrophic Systems

6.1.1 P vs. N and P

The review of provincial cyanobacteria policies and programs showed that Alberta and Ontario are focusing on P reductions, while Manitoba has included N in cyanobacteria bloom management. The rationale is that reducing TN into the lake will decrease bloom toxicity while the TP reduction target is stringent enough to reduce non-N fixing cyanobacteria species (ARD, 2020b).

“So, since about 2011 Manitoba has followed this approach, this dual approach of, it's important, believing it's important to remove nitrogen and phosphorus together. And that's kind of contrary to some of the early research that was done kind of in the 60's, 70's, and 80's, especially at the experimental lakes area. But over the last two decades there has been a lot more literature come out suggesting that nitrogen and phosphorus together work synergistically to create these algal blooms. And don't get me wrong, the ELA research is great, certainly some lakes can improve their water quality or reduce algal blooms by just removing phosphorus alone, other ones by nitrogen alone. I think it's New Zealand that has, up until recently, only been focusing on nitrogen alone. But, certainly over the last well, especially over the last decade anyway, the literature is showing that it's critical to remove both. We know that nitrogen and phosphorus is increasing in our waterbodies, so it doesn't hurt in the beginning just to remove them both. But that ratio is so critical for determining the composition of the bloom. Like when you have a cyanobacteria bloom people think, oh, you know, that's just one species. But in fact, that's completely untrue. And these blooms could be made up of a number

of different things. And they can, whether it's non-nitrogen fixing species or nitrogen fixing species. You know, from our standpoint, it's very important that we a) try to reduce the blooms, but we're also very concerned with the toxins and the recent research shows that nitrogen concentration and speciation are having a huge influence on the production, initiation, development, and release of algal toxins. So, that right there, that's probably where we have the most credence for the argument of "nitrogen is important". Because although there has been 70 years of eutrophication research people still argue "is it phosphorus only? Is it nitrogen and phosphorus?" If you read the literature, it's gotten more, it has turned into more of a personal argument, where people are writing papers to try and disprove other people. And the research at ELA has been great with the phosphorus only approach, but we believe it's both. And the US EPA in 2015 came out with a policy document that stated that they believe it's both. The European Union about, a number of the countries in the European Union have also come out with, stating that nitrogen and phosphorus is important. And even China, recently, is now starting to publish papers on the importance of N and P, as opposed to the P only. So, it's been a slow transition, and certainly the N and P argument isn't as strong as the P only because the P only was the focus for so many decades. We just didn't have, the N and P just isn't as well studied as the P only." (Personal Communication, February 12, 2021, Manitoba)

The adoption of N into cyanobacteria management in Manitoba also influenced the Lower Qu'Appelle Integrated Watershed Management Plan upstream in Saskatchewan, where four lakes have N and P percentile targets meant to reduce cyanobacteria blooms. The WWTP discharging into that watershed has also been upgraded to include TN effluent standards, increasing the cost of water treatment. The adoption of these targets and the TN effluent wastewater removal is meant to reduce algal bloom formation within the watershed.

Question: The nutrient balance report was tied to cyanobacteria, but the P and N targets for those 4 waterbodies are not meant to address that?

Answer: In this case (Regina WWTP); reduction in concentration of nutrients in effluent was undertaken in part due to consideration of effects in downstream lakes and with knowledge that nutrient decreases may decrease risks associated with duration/frequency/intensity of algal blooms. Nutrient targets through the planning process were set as being notional and designed to be updated once more information was available. Interest in nutrients by members participating in the planning process did relate to algal blooms.

Question: When you say nutrients, do you mean both P and N? and when you say algal blooms, are you referring to cyanobacterial blooms or other forms of phytoplankton?

Answer: N&P. Generally, nutrients that can affect species biomass and/or composition, so N&P. Blooms. Yes, concern is principally around surface blooms of cyanobacteria.

While research has shown that reducing N and P can impact toxin production, N reduction does not have the same impact on bloom intensity, meaning that bloom occurrence and density are not altered under N reduction regimes due to a shift in species composition to N-fixing cyanobacteria (see Chapter 2). This means that dead zones can form as these blooms decompose, which can also feed into a positive feedback loop of bloom formation as nutrients are released from sediment under anoxic conditions. It is possible that the targets proposed for the lake, especially under climate change conditions, might not be enough to decrease cyanobacteria blooms.

6.1.2 Blooms in Oligotrophic Systems and Internal Loading

All five provinces have had and/or responded to reports of blooms in mesotrophic or oligotrophic lakes. However, several provinces described these blooms as a surprising and new problem, that, in some cases, was occurring later into the open water season (October).

“Yeah, we’re starting to and some of them also, like, I’ll get calls from waterbodies that I wouldn’t be expecting to have algal blooms, let’s say, especially in the North. This year, I’ve received a number of calls this past summer. Yeah, even into October I was getting calls of waterbodies that I was under the assumption were oligotrophic, so, yeah, it’s definitely starting to occur.” (Personal Communication, December 14, 2020, Manitoba)

Despite this, Ontario is the only province currently conducting research into the cause of these blooms, with the end goal of including the findings in provincial management of cyanobacteria blooms.

“So, there isn't a specific program. There are programs that are monitoring based, and research based that are more generally awarded around monitoring. So that monitoring of inland lakes and trying to understand how multiple environmental stressors impact water quality impact the ecology of lakes... So, one of the things that we're interested in more recently is why are we seeing more reports of algal blooms in lakes with low levels of nutrients.” (Personal Communication, December 15, 2020, Ontario)

The research being conducted is focusing on the link between increasing sediment anoxia and internal loading using paleo-ecological techniques.

“A lot of the work... has been paleo-ecological studies and so we would reconstruct bottom water oxygen. I won’t get into the details, but we could try and build a history of past deep water offshore concentrations and I would say that that seems to be a common thing we’re seeing is a worsening in the bottom water oxygen in recent years, which seems to be associated with climate

change. And that, we think, is a key driver. In some of these lakes that are oligotrophic, or we call them, mesotrophic... they tend to be this, I don't want to generalize, but they tend to have pretty small... hypolimnion... So, they have small kind of bottom sections to the lake that become isolated from the air and so oxygen is depleted through the season. And so, because they're small in volume the oxygen is depleted quite quickly through the season, but we think it's getting worse. And it's these lakes with small hypolimnia that we think are, seem to be the most susceptible to these kinds of blooms. So, yeah, there's, we think there's a link to internal loading for sure. (Personal Communication, December 15, 2020, Ontario)

While the topic is being researched in Ontario, it is currently ongoing, and so no information on the cause of blooms in these systems has been included in the provincial cyanobacteria management strategy.

“I don't think there is really, at this stage, really sufficient information to understand exactly what the drivers of those (oligotrophic system) blooms are so, it's kind of, it's a little bit early to be making management decisions.” (Personal Communication, April 27, 2021, Ontario)

As a matter of fact, internal loading and the connection with sediment redox and the release of Fe²⁺ or P has not been included in the provincial management of blooms in any province, to date.

Question: And is the province adapting at all to new scientific information about blooms that form in nutrient-poor systems?

Answer: “No, I wouldn't say not on the oligotrophic systems yet. It's kind of all newer work, newer research coming out. We've adapted in a sense that, we don't know or we don't, we no longer just look at the eutrophic and hypereutrophic systems as the major risk, you know, we now look at any lake can potentially be a risk depending on how the lake is used, it can be a risk. And so, I guess we're adapting that way to what we're learning. That was something, you know, for drinking water, for instance. You could say if you have a municipality taking water out of an oligotrophic system, there is still a risk that you could bring microcystin into a system from metalimnetic blooms down at depths if that's where the drinking water intake is, you're pulling in microcystin. So, yeah, it's there's no kind of formal recognition. It's we're adapting kind of on the fly and trying to learn from what we're seeing. Right.” (Personal Communication, December 15, 2020, Alberta)

Though, some provinces are starting to recognize the significance internal P loading has on bloom formation. For example, in Alberta, internal P loading is considered a key factor contributing to eutrophication and cyanobacteria blooms in lakes because soils in the province are generally high in P.

“We recognize that if you're going to really want to understand, of course, the, how a lake functions, you need to know what, how much nutrients coming from the sediment. And unfortunately, in Alberta, internal loading of phosphorus is the primary load in lakes on an annual basis.” (Personal Communication, December 15, 2020, Alberta)

However, the work of understanding internal P loading, the link to blooms, and pushing for in-lake treatments is the responsibility of Lake Stewardship Groups, with support from the provincial government, rather than provincially led.

“It (internal P loading) has in the past (been assessed) on a case-by-case basis. And that was some of the research, the early research in Alberta in the late 80s and 90s, looking at some recreational lakes that had major issues with bloom activity. So, there were phosphorus budgets conducted on a handful of lakes that was all conducted within the department at the time. More recently, we're looking at phosphorus budgets and understanding phosphorus, internal phosphorus loading more so through the work of the Lake Stewardship Groups. So, it's stewardship groups that want to further lake management planning, lake watershed management planning for their lake. That would be something that we would then support or help them assess. That's where some consultants are still used potentially, looking at data and conducting future monitoring activities to, again, budget nutrients in lakes and having an understanding of the nutrient loading.” (Personal Communication, December 15, 2020, Alberta)

Certain lakes in Manitoba and Nova Scotia have also had internal loading assessed, though this is not standard practice for managing eutrophication or cyanobacteria blooms in either province. To date, four lakes in Manitoba have been assessed, and a mass-balance report for the selected lakes produced. The research and reports generated were all completed by individual consultants and technical advisors, though the work often received provincial and sometimes Federal funding. In Nova Scotia, two lakes have been assessed. However, the reason internal loading was quantified for these lakes was because they both have dedicated research funds and the research efforts were supported by local NGOs and municipalities.

“It (internal loading) has been looked at in two systems that have been studied most intensely, but those are certainly not representative of the standard provincial approach. Both of those have dedicated research funds... So, both of those have looked at internal loading and the municipality also considered internal loading” (Personal Communication, January 13, 2021, Nova Scotia)

Bloom prevention, when it occurs, is still focused on limiting PS and NPS nutrient loading, which is important in eutrophic and hypereutrophic systems; however, this strategy is

less applicable to mid-nutrient systems, and not applicable to nutrient-poor systems experiencing blooms. And no evidence had been found that a nutrient-poor lake experiencing blooms is being actively managed in Canada, at this time. This could be due to the lack of applicability of nutrient reduction-based strategies, or more likely, because this is an emerging problem, cyanotoxins do not pose a public health risk, and/or the blooms are in a location where they are not seen to pose a serious risk to human health.

As for the believed cause of blooms in these nutrient-poor systems in the other provinces, Alberta attributes them to nutrient loading and climate change, while Manitoba and Nova Scotia attribute it to nutrient loading/cultural eutrophication, with the understanding that blooms are a complex problem. No information was found or provided from Saskatchewan on the cause of blooms in these systems. Again, this could be due to these blooms being a newly emerging problem, so in time more provinces might conduct research into the cause of blooms in these systems, or turn to primary literature to manage or understand the problem, especially if they pose a risk to human health.

Question: And is the province adapting at all to new scientific information about blooms that form in nutrient-poor systems?

Answer: Let's put it this way, I'm not aware of any adaptation to that, principally because of our hands off approach to management, the absence of effectively resources and mandate to do more. So, you know, it's always a case of learning what that new information is. And in the context of our mandate, and our resources, what can we do with this? Do we basically just keep it on hand and sort of, like, remember to refer to this if opportunities provide for that in the future? But I don't know what, of any instances where we have specifically made an adaptation. (Personal Communication, January 13, 2021, Nova Scotia)

In most provinces blooms in oligotrophic lakes are reported by the public through provincial monitoring programs for recreational waters. However, in Alberta, these blooms were observed using the regular water quality monitoring program. A discovery attributed to the fact that water quality monitoring is not focused on any one problem, which allows for a range of lake trophic scales to be monitored.

“Research activities and the fact that we're on the landscape, we're out there, data comes in and, you know, the fact that we put a blanket protocol for all of our lake monitoring in place helps because I'm not just targeting microcystin analysis for eutrophic and hypertrophic systems. We do it in all of our systems. And that's, you know, we've been doing it since 2005, basically. So, I've seen early on that, OK, we are getting cases, especially on these mesotrophic lakes,

it can be quite, microcystin can be quite prevalent depending on how warm the summer is. So, I definitely got a sense that, you know, potential climate change could have a major impact on mesotrophic lakes. And then you see odd occurrences happen. While even in my own research back in the mid 90's at the University, low nutrient systems have Planktothrix periodically blooming in, at the metalimnion and typically not at the surface. So, you never witness it at the surface but Microcystins everywhere to some extent. But typically, in those oligotrophic lakes, the microcystin has been at minute levels, basically trace levels for the most part. But it's yeah, long, 20-some years of research has shown me that it's showing up everywhere. So, we're aware of it, of course. And that's part of the reason why we wanted to focus our provincial lake program away from the recreational lakes and into those headwater lake areas, those small, lower, typically lower nutrient foothills and mountain kind of areas to gain data, more data on just the overall prevalence of cyanobacteria. What species occur periodically and, of course, microcystin levels. So, yeah, we're definitely on top of that.” (Personal Communication, December 15, 2020, Alberta)

Lake nutrient reduction strategies to control blooms in mesotrophic and oligotrophic systems should consider internal loading. Alternatively, monitoring DO concentrations near lake sediments can help predict bloom events. This could also inform when mitigative efforts that could help prevent or limit bloom intensity or duration should be undertaken. For example, aeration techniques can maintain oxygenated water near the sediment-water interface, thus preventing the release Fe²⁺ and P from the sediment, limiting the occurrence of bloom events. For bloom targets, understanding internal loadings contribution to P within a waterbody could also help determine the offset time for meeting nutrient loading targets.

6.1.3 Cyanobacteria Research Programs

None of the five provinces have a research group dedicated to conducting cyanobacteria research. Instead, like Ontario, the other provinces tend to conduct research on a case-by-case basis, when there is funding available, centred around an area of interest or concern. In Alberta, MOUs with universities and academics are often used to coordinate any research conducted on topics of interest, where the agreement facilitates an ease of data sharing between the parties involved. Academics will use the monitoring data obtained by the government for research, the end product being publications and information that can be applied within the province. In Manitoba, as mentioned, blooms are attributed to nutrient loading, so research programs tend to focus on accessing nutrient loading reductions, mainly of P but N is included as well. A lot of this research is centred around Lake Winnipeg and involves collaboration with universities and NGO's. In Nova Scotia, some interest has been expressed in studying the cause of non-toxic

blooms in provincial waterbodies because they are viewed as an unknown risk. However, this has yet to be approved or initiated, and is not centred around the cause of blooms in low nutrient systems. In Saskatchewan, BMP effectiveness for reducing NPS nutrient loading in Buffalo Pound Lake is currently underway, a lake that serves as a primary water source within the province that experiences regular bloom activity.

As research is done on a case-by-case basis around an area of provincial interest, depending on funding availability, most provincial ministries are not currently conducting cyanobacteria bloom specific research. Though, as mentioned, several provinces are conducting nutrient management/BMP research. So, instead, primary literature is reviewed, and the information can or is incorporated into management, if approved.

*“Yeah, we don't do a lot of research-based things right now, so we're reviewing literature that is done by academics and incorporating that information into our program and modifying our sampling accordingly.”
(Personal Communication, December 14, 2020, Manitoba)*

“There's no formal program that is geared strictly to that topic (cause of blooms). There's ongoing research and but that's largely dependent on kind of and who's employed and who's involved in the work we're doing. We do a lot of collaboration with our data to academics across the country and even in the U.S., so all along we know we've been collecting in terms of microcystin data, we've got probably one the longest histories of data collection for that parameter. And we've shared that data, you know, to numerous universities. So, there is, I mean, we're ah, my job is not to conduct research. It's about managing a monitoring program and, you know, looking at emerging issues and a number of topics, you know, not just cyanobacteria. But all along I've been sort of dabbling in the research areas with not just with the universities, but I do conduct some of my own as far as we can. So, yeah, yeah. We're actively engaged in research. We did hire a postdoc a couple of years ago from the U. Of A. And we hired them on for about a year and a half and to look at the historical data set and to do some novel statistical methods to kind of determine spatially across the province how microcystin levels change our lakes different across the province. And then we also tacked on to that phytoplankton trait assessment. So, we want to actually look at environmental factors and traits of different cyanobacteria species and to see how they relate to what we see in our lakes in terms of cyanobacteria numbers and toxins. So, yes, we do research, just not formally.” (Personal Communication, December 15, 2020, Alberta)

All five provinces have some form of access to scholarly literature through their provincial ministries; however, this access is variable depending on journal subscriptions

purchased and the means of access. So, not all primary literature is obtainable, depending on the subscriptions chosen and the methods of access to these subscriptions. For example, in Manitoba, provincial employees have to request access to primary literature through legislative librarians, who are able to access most publications for them. Provincial employees can also request access to literature that is outside of provincial subscriptions, which may be purchased if the request is approved. And provincial scientists with adjunct professor status at universities have access to those universities' libraries.

Review of primary literature is often encouraged or expected, especially for ministry personnel who are employed as scientists or public health officials.

“As a scientist, in our performance agreements, we identify annually, you know, kind of goals, professional goals for ourselves. And part of that is maintaining an understanding of the current state of our areas of expertise. We're encouraged definitely to read and produce peer reviewed literature.”
(Personal Communication, December 15, 2020, Alberta)

In other cases, it is seen as more of an expectation due to the nature of the work. So, while it isn't stated as an outright requirement, it is supported within the ministry. In cases where reading the literature isn't an expectation and/or access to literature is limited there can be some reliance on “others”, described as a network of willing collaborators, to bring attention to the literature, such as NGO personnel or local community members with access to research or sometimes researchers in the field.

Question: Are you encouraged to read the latest literature?
Answer: I, well, let's put it this way, not directly. But, I guess, we, we're encouraged to do whatever it is that we can do to fulfill our mandate. So, let's just say it's supported.
(Personal Communication, January 13, 2021, Nova Scotia)

Where this is an expectation, it can be made difficult by time constraints. Often, it is expected that science personnel will conduct this literature review in the “slower” winter months. However, employees find that this time can quickly get filled with other work duties, leaving little time for literature review.

Another means of obtaining new information on cyanobacteria blooms and their management is by attending conferences, provincially, nationally, or internationally. Ontario has IFHAB – Interdisciplinary Freshwater Harmful Algal Blooms Workshop – an annual conference on cyanobacteria bloom management that is spearheaded by the MECP and ECCC.

Representatives from Alberta, Nova Scotia, and Ontario, in the past, have participated in the North American Lake Management Society (NALMS) and Alberta representatives also attended an all-day cyanobacteria conference in Quebec several years ago.

Question: So, what mechanism does the province have for the transfer of new scientific knowledge on blooms and new information on bloom management to the different ministry departments?

Answer: Well, different ways. We have speaker series. I think I mentioned before. We have we have a speaker series. So that can be, that's a technical speaker series that anyone can tune into. And it's broadly advertised across the ministry. We have, we also have a couple, we have a group in our ministry that deals with the inland water policy. And so, we interact with them on many files. So, for example, we're interacting with them on the Lake of the Woods file so that is an algal bloom related file for sure. So, it's often there's lots of different ways. Often, it's up through management and then across and then down. And so, there are some staff level, the staff level conversations that go on. But first, all of those connections have to be made so that everybody's in the loop.

(Personal Communication, December 15, 2020, Ontario)

Incorporating any new information on cyanobacteria blooms into policy can be tricky because it involves communicating scientific data to those working within policy in a manner that is understandable to decision-makers who might not have a scientific background and is limited by the methods of managing water quality within the province.

“It’s challenging because really our policy is developed because of the lack of resources that we have to do anything proactive. So, any new information would probably be developed more so in terms of what information that we share about blooms that might be different than we share now. So, I can’t think of a good example right now, but, you know, I suspect that it’s going to be mostly background and maybe it will drive new research projects or maybe it will, you know, to further investigate the risk that we didn’t understand or maybe it would drive more things on, like change more on the drinking water side than it would on the recreational side.” (Personal Communication, January 13, 2021, Nova Scotia)

For other provinces, it’s the research and time it takes to get any new information included in active management programs. Discussing the research and presenting the means of implementation, and then getting approval to do so.

“We do, you know, we have active areas of policy development, more pertaining around managing lakes, because, again, I think we have a good handle on the issue now. It's we're at that point, the next step of, it's not just us, but there's lake stewardship groups that are pretty mature in their monitoring activities at a given lake. They've done activities in the watershed to reduce the

load of nutrients from cottages and other developments around in a lake basin. However, the next step is, is breaching the topic of in-lake treatment. You know, do we now allow or go down the road of actually trying to change a lake from what it is now to some other state. So, there is those areas that, it's been a challenge. But that's an active area of discussion and policy development currently going on in the province right now. We definitely have some areas that we need to follow here.” (Personal Communication, December 15, 2020, Alberta)

This is further complicated by the disconnect between science and practice, with political, economic, environmental, and scientific factors not weighed equally in the policy development decision-making process. Political and economic factors are often chosen over scientific understanding and environmental considerations, resulting in the failure to adopt science into practice. For example, cultural eutrophication is the known cause of blooms in eutrophic waterbodies in all five provinces, making the adoption of nutrient limitations methods necessary for addressing blooms. Yet, NPS nutrient management is largely unregulated, not P-based, and BMP implementation is either not or informally tracked. Furthermore, nutrient management is not required in watersheds negatively impacted by bloom formation.

The provinces seem to be generally unaware of how cyanobacteria management occurs in other provinces. Various Ministry employees expressed an interest in finding out about other provincial cyanobacteria management programs stating that there was very little knowledge shared about management between provinces. Though, provincial employees are interested in finding out about other programs, especially if there are successful or new practices that can be incorporated into their own programs.

“Are you going to be, or are you going to distribute your findings? ...What I was just going to say is that, man, if we can steal, like we're big on stealing ideas, we're all about that” (Personal Communication, January 7, 2021, Saskatchewan)

“... It (cyanobacteria drinking water monitoring and control) is an evolving process and if there's thing that you're learning from other jurisdictions, we are a pretty small jurisdiction, so I know there's tons of other work going on in larger provinces like Ontario that have a lot more resources. Our water systems, so, I guess that's the other context, our water systems compared to other jurisdictions are typically quite small, maybe more comparable to Saskatchewan. But, if you're looking at comparing to Ontario or Alberta, our systems are typically quite small, so we're trying to manage the program, keeping in mind the size of our systems and the resources that are available to

them, and we're always trying to learn from other jurisdictions.” (Personal Communication, January 26, 2021, Manitoba)

6.2 Funding, Capacity, and Regime Changes

Cyanobacteria management control and prevention programs are impacted by funding, capacity, and government regime changes. Regime changes are important because they are often what impacts funding and capacity; the result of changes to goals or areas of interest newly elected governments or officials have and the resources they are willing to devote to programs not seen as essential to achieving these goals. As such, regime changes can and have resulted in budget cuts, especially for environmental protection and research.

“...We have a Conservative government that came in a little while ago and they will have their own priorities. Nutrient management was largely rolled out under a Liberal government.” (Personal Communication, November 17, 2020, Ontario)

Legislative reviews and the changes associated with them are also often conducted post-election, as part of the regime change. For example, right now, Alberta is undergoing a “red-tape reduction”, where environmental legislation is being reviewed to “streamline it” under the regime of newly elected officials.

“We really look at legislation every three to five years, and we're sort of in the phase right now. Even though we talk about it yearly, we really don't do, you know, hard work until every three to five years. That's sort of our legislative review window. So, right now, we just did one on some of the regulations and made some changes. And we're just looking at the act (NPS nutrient management) right now through red tape reduction and trying to streamline, make it work better and make sure some of the things that we missed in the act, which may actually add to the red tape. But some of the things that we missed with the act are plugged in. So, unfortunately, we haven't really done a full provincial rollout of that. (Personal Interview, April 14, 2021, Alberta)

Depending on the programs' cuts are being made to, the impacts on cyanobacteria management change. For example, budget cuts to monitoring efforts impact data collection, research capabilities, and risk management, limiting the effectiveness of public health protection efforts. While on the nutrient management side, budget cuts impact BMP funding, education and outreach, non-compliance monitoring, and therefore enforcement, and research efforts, all of which impact the adoption and implementation of BMPs.

6.2.1 Routine Recreational Beach Monitoring

Cyanobacteria risk management programs are dependent on monitoring for their effectiveness. However, monitoring and sampling for cyanobacteria and their toxins, let alone coordinating advisories and ensuring public understanding of the risks posed, requires time, money, and expertise. Most provincial employees within bloom risk management programs stated that their budgets had either remained static (without consideration of inflation or increased bloom occurrences), while others found that funding had fluctuated, or decreased, often depending on the party in power within the province and how long the program has been in place.

Question: Has funding for bloom monitoring increased or decreased?

Answer: Definitely decreased. This is the way of government, reducing budgets all the time.

Question: Has this impacted the monitoring or sampling of blooms?

Answer: Definitely. The price of the analysis costs of algal bloom samples continues to increase, the funding that we get continues to decrease. So, it's a difficult position to be in.

Question: Has this impacted risk management or how has this impacted risk management?

Answer: And so, that's where we are having to rely on the education piece and partially why the Factsheet and the poster were developed. We're in the process of revising our current advisory signs and maybe that's where, we are waiting on new management to be able to look at these new policy changes, so that maybe some further education pieces can be developed, maybe some permanent signage can be put at beaches informing about algal blooms. But those things are all on hold at the moment.

(Personal Communication, December 14, 2020, Manitoba)

While some provinces have seen an increase in focus on education and outreach initiatives, especially when monitoring decreases, other provinces have also seen education and outreach initiatives cut. For example, in Alberta there is/was an education and outreach program called "Respect our Lakes", which published and updated publications on cyanobacteria blooms, such as the cyanobacteria factsheet. But, as of 2021, funding was significantly reduced, and the program appears to have been shuttered, associated with a lack of governmental interest.

"The resources under the Respect our Lakes program are dwindling and there isn't a strong desire to reinvigorate the program beyond what's already available." (Personal Communication, February 22, 2021, Alberta)

Funding also impacts program monitoring capacity, affecting the number of lakes and/or samples routine monitoring programs can analyze and the frequency with which they can be collected.

“Most of them (beaches) have been with the program since the early 90’s or even 80’s... But that’s not to say that new beaches can’t be added. And in recent years, we’ve had budget cuts. We’ve had to reassess a lot of the program. And so, beaches that had 10 years of good, no exceedances of E. coli, no exceedances of algae, we’ve had to drop them, just from a budgetary perspective.” (Personal Communication, December 14, 2020, Manitoba)

For reactive monitoring programs, the ability to respond to all reported sightings, or to repeated sightings, is also impacted by funding and capacity, capacity in this case being the personnel to respond to all the sightings, and the equipment and funds to analyze the samples collected.

“So, we do respond to all reports of potential blooms. The only time that there, maybe we don’t go out routinely is if we’ve been out there numerous times. The lake is known to have blooms and most importantly, the public health unit has permanent signage. That also, it can happen that, where there’s been blooms reported, like the City of Kingston at the public boat launch every summer, there’s always blue green algae sign there. So those are the only few cases where an environmental officer won’t go out and obtain samples.” (Personal Communication, April 27, 2021, Ontario)

Question: Does the MECP respond to multiple reports for the same lake, or is it just once?

Answer: “...They go out, kind of, on an on-needed basis and that’s also really inconsistent, because sometimes it takes them days, if not weeks, to get out to the lake. Or if the conditions aren’t right, they won’t go out. And some lake residents get a little upset because they call it in and then by the time the ministry staff get out there, the thing is gone because it’s been a few days. And then in other cases, they’re excellent. They’re out there, like, that day checking it out. So, I think it’s just a question of resources and you know, what their volume is like, what else they’re dealing with.” (Personal Communication, January 8, 2021, Ontario)

So, the number of sightings on a particular lake, the history of bloom events on the lake, the popularity of the waterbody, and the number of reported sightings being called in within the province are often a consideration for response or response times, particularly for recreational waters.

6.2.2 General Water Quality Monitoring

General water quality monitoring within provinces is important for understanding the risk or cause of bloom formation within a variety of systems, so that the blooms can be addressed in an effective manner. Like monitoring for risk management (control) programs, funding for general water quality monitoring within all provinces has fluctuated or decreased over time, often with renewed interest being tied to specific research programs or problems within lake systems.

“Yeah, it’s (water quality monitoring) varied over the years. So, we’ve, you know, there’s been program changes, partly for budget reasons, partly for resources, partly partnerships, so it’s varied a bit. We’ve had, collectively over those decades back to the 80’s, we’ve had some changes. And, as I say it might have been the LICA program, at one time in the Beaver Hill Area was a partnership with industry and so we got to focus on the lakes in the Beaver Hill area. So, that lead to some pretty extensive data for those lakes. So, it was a bit of a spatial gap in our program. So, part of it is a bit opportunistic. You won’t necessarily see data over many years.”

(Personal Communication, February 24, 2021, Alberta)

These budgetary cuts are also often the result of regime changes and the changing government interests.

“... Alberta Environments operating budget, in terms of their ability to fund new equipment, establish monitoring locations or just fund all of the parameters that they analyze in air and water quality is reduced. So, they’ve had to prioritize a lot on which monitoring stations they need to keep, and which parameters are essential for their quality monitoring.” (Personal Communication, April 23, 2021, Alberta)

General water quality monitoring never includes routine phytoplankton sampling, largely a result of the costs associated with this. Though, some monitoring programs have resulted in sporadic phytoplankton or cyanotoxin monitoring within provinces. And not all provinces analyze samples for the same suite of parameters. For example, water quality monitoring in Manitoba does not include chl-a, save for the case of Lake Winnipeg, while chl-a is a regular parameter for lakes and rivers monitored in Alberta.

New technologies have or are being researched and possibly invested in within various provinces. For example, Ontario is researching the use of remote sensing techniques for bloom monitoring in northern Ontario. Alberta is launching a remote sensing program using buoys with sensors attached to monitor water quality in real time in approximately 6 lakes across the

province, which includes DO monitoring throughout the water column. However, there incorporation into provincial cyanobacteria management programs has yet to be determined.

6.2.3 NPS Nutrient Loading

Funding/budgetary changes have also impacted investment in NPS nutrient management programs. For example, Alberta has recently cut funding for one-on-one education and outreach for primary producers, which is centred around BMPs, the EFP program was removed as a requirement for CAP funding, and even water research programs focused on studying the means of limiting nutrient exports from agricultural fields have been closed. The last program was a significant one, as the group conducting this research was the primary coordinating group with AE, which means that data-sharing and coordinating responses will be more difficult moving forward.

“...Particularly in the last year and a half to two years, just with our current suite of elected officials have really upended a lot of things, and so, and budgets have been reduced a lot. Albert Agriculture departments have cumulatively seen, like, a 23 percent reduction in staff, mostly due to a large reduction in budget. And a lot of our budget is through, on the agricultural side of Agriculture and Forestry, most of our budget is staff. So, we’ve seen a lot of staff reduction; a lot of that staff was research scientist and extension (education and outreach) folks... So, there used to be the Irrigation Promoter Branch and the Environmental Stewardship Branch, they we’re basically cut in half and merged together. So, the Environmental Stewardship Branch administers the CAP programs for nutrient management and environmental stewardship issues, and those programs have all but been eliminated. They have been revamped into something else, but the classic BMP funding for environmental matters is no longer. It’s just, they’re into more efficiency and economic-type CAP programs. But as I said, I mean, some of those would still realize environmental benefits, it’s not explicitly environmentally motivated”
(Personal Communication, April 23, 2021, Alberta)

Cutting funding to NPS nutrient management programs and education and outreach initiatives are not a practice adopted in all provinces, with Nova Scotia and Manitoba investing in new initiatives and existing programs to reduce agriculturally induced environmental risks with an added goal to meet international agri-environmental standards.

“You know, it's this additional funding really made a huge difference. So, the, this GROW Program is just kind of a dream come true or, you know, it's hard to believe that the province did something like that. That's really changed the game. It's doubled our budget, you know, doubled our impact with producers on the number of programs we can deliver, the amount of impact we can have,

how many BMPs can be implemented. That's been a real game changer... ”
(Personal Communication, January 7, 2021, Manitoba)

But, as always, these programs, while they promote BMPs that reduce P exports from agricultural fields, are not P-based nor are they specific to cyanobacteria blooms. Not to mention, in Manitoba specifically, the province is looking to expand pig livestock operations, which are a known large contributor to NPS nutrient loading in the province.

6.3 A Focus on Cyanobacteria Control Over Mitigation or Prevention

All five provinces stated that cyanobacteria management is focused on control rather than mitigation or prevention. That is, cyanobacteria specific programs are all geared towards adaptive measures specifically meant to protect human health, rather than strategies meant to reduce the occurrence of blooms themselves.

Question: And is risk management and adaptation the greater focus over mitigation?

Answer: Yes. Yes, yeah. Yeah. By far. So, it's so widespread in Alberta, compared to other places, just given the nature of, again, the geology and our lakes here, blooms are extremely common that we have to first and foremost manage the risk around that versus the mitigation. And again, mitigation is a difficult thing because of the laws around that. With the Water Act, Provincial Water Act and the Environmental Protection Enhancement Act and other various pieces of legislation, and Federal legislation for that matter. Definitely, there's a lot more hoops that you would have to jump through to get to the mitigation into place.

(Personal Communication, December 15, 2020, Alberta)

While this can vary depending on the mandate of the program being discussed, information obtained from interviewees supported the fact that regulated and unregulated NPS nutrient management programs are not cyanobacteria bloom specific, which is discussed below, along with PS nutrient management limitations for cyanobacteria management.

6.3.1 NPS Nutrient Management

During interviews with personnel that work in nutrient management, when asked what their role in in cyanobacteria management, the response was almost always the same:

“We're not, I wouldn't say necessarily focused on algal blooms and that sort of thing, but nutrient management for sure falls under this (EFP) program.”
(Personal Communication, February 2, 2021, Nova Scotia)

Nutrient management programs within all provinces are designed to address a range of environmental problems while maintaining crop production rates. As such, NPS nutrient

management is geared towards crop production and soil nutrient application rates to limit overapplication to agricultural fields rather than reducing nutrient loading into waterbodies.

“Management plans, be they formal documents demanded by regulation and submitted to regulatory authorities or voluntarily created by farmers or their professional advisors for their exclusive use and not shared with government can only be expected to achieve better management of phosphorus as an essential nutrient in crop (fertilizer) and livestock (feed) production, resulting in reduced P loading to land (i.e., the soils upon which or into P is applied) or the agronomically justified accumulation on land, not necessarily directly achieving reduced P loading to surface waters. The latter would require intensive monitoring and/or research to establish solid links between the management of phosphorus by a farm at a given location or farms in a given area and P loading to surface waters.” (Personal Communication, January 7, 2021, Manitoba)

This isn't to say that these programs don't reduce P exports from agricultural fields given that limiting overapplication of nutrients does reduce legacy build-up in soils, and therefore loading. But rather, this is not the main purpose. As a matter of fact, neither cyanobacteria nor algae are included in the goals for provincial NPS nutrient management programs, nor are they terms found within any of the legislation for the regulated programs. That being said, ministry personnel are tasked with conducting research to reduce nutrient exports from agricultural fields, to aid in developing nutrient management plans for specific waterbodies impacted by blooms, and to help promote the use of BMPs to reduce environmental risks, such as cyanobacteria blooms.

“... In Ontario the need for cyanobacteria response would reside with the Ministry of the Environment, Conservation and Parks and we (OMAFRA) would generally be seen as a supporting role, where the nutrient source is related to agriculture, rural, or food-based production. And because Ontario has a substantial amount of farmland, very frequently, in watersheds, agriculture is a primary driver of nutrient loading, so we are often asked to participate, to look at measures to help reduce nutrient loading from farms in Ontario, right? So, that would primarily be through BMP implementation, best management practices, and so, I would, part of my role would be to sit on these committees, if there is water management plans. But I would also work individually with farmers, to promote management practices, say on an individual farm. I'd also work with some of our policy people to implement a more structured approach, some of which are regulatory, to implement programs, say under the Nutrient Management Act, of which OMAFRA is supportive, or responsible for doing approvals, for farms that have substantial quantities of nutrients to manage. We would also be a key partner in larger

scale initiatives, like the Lake Erie Action Plan, or the Canada-Ontario Lake Erie Action Plan, I should say. So, that's the protective document that's looking to reduce the algal blooms in western basin Lake Erie, primarily. And we would also have a role, I would have a specific role, when it came to a number of different funding programs that OMAFRA might help administer, including the Canada-Ontario Agreement, or what's called, COA, and the other major provincial-Federal agreement called the Canadian Agricultural Partnership, or CAP program.” (Personal Communication, November 17, 2020, Ontario)

As seen, nutrient management is also not P-based or P export reduction specific, nor are practices intensified or required in systems where blooms are occurring, and cultural eutrophication believed to be the leading cause.

“There isn't, to my knowledge, a prioritization for areas that are more vulnerable versus less vulnerable, if that's what you're looking at. We do have with some of our funding programs approaches that prioritize the Lake Erie basin for some of the dollars that we roll out. But, to my knowledge, there isn't different regulatory requirements if you're in a large, or small, watershed that is phosphorus impaired versus one that is not, right? Our requirements regulatory under nutrient management are based more on size of the operation. Whether or not it has expanded recently. So, we tend to implement measures when you're expanding because we figure if you've got money to build a new barn, you've got money to do it right. As opposed to implementing things retroactively. And, the other thing that phases, we use phase-in basically. As we impose rules based on certain site-specific issues. So, there's a regulation under nutrient management that permits greenhouses specifically to land apply what's called greenhouse nutrient feed water under a different set of regulatory rules to protect surface water from excess phosphorus accumulation. So, there isn't a geographic or a watershed-based-criteria that I am aware of for us.” (Personal Communication, November 17, 2020, Ontario)

Saskatchewan and Alberta do not currently have land application rates or P threshold levels for regulated nutrient management. In Saskatchewan, every several years the ministry assesses whether or not to update the legislation to include P. But, despite blooms increasing in frequency, including in a source water that provides the province with 25% of their drinking water – Buffalo Pound Lake – legislation has not been updated to include P. Alberta has also chosen to not include P requirements in their legislation, focusing instead on soil salinity and N.

Question: Are there any plans to install legislation to limit phosphorus loading into waterbodies or watersheds?

Answer: That's a good question, first and foremost, that would be tackled through WPACs, I think, on the, for the major rivers and whether that trickles down then broad scale to lakes... It's an interesting idea. It would be a difficult

one to tackle. Can you really? It's easy to put laws around Industry and point sources, it's much more difficult to deal with one of the largest industries in Alberta, being agriculture. That's a tough one. And how you go and legislate that? I'd like to see someone try because this is the Wild West and who knows what's going to happen. People, it's difficult. That's a difficult question. I can't see that happening any time soon.

(Personal Communication, December 15, 2020, Alberta)

A limitation that was consistent across provinces was/is the deficiency of NPS nutrient management specific to cyanobacteria blooms. Either NPS nutrient management regulations are not stringent enough to limit P levels in watersheds and waterbodies and/or enforcement is an issue, especially for illegal dumping into lakes.

“... We've got a few problem areas where there are operations that will dump into nearby bodies of water on the regular, so that causes problems every year and we know who the frequent flyers are, and they don't care. So, the runoff from those operations are an ongoing challenge for which I believe Environment and Agriculture both have been not successful in convincing these folks that they need to do things differently” (Personal Communication, January 7, 2021, Saskatchewan)

6.3.2 PS Nutrient Management

None of the provinces require WWTP tertiary treatment to meet nutrient effluent standards, with provinces, at most, requiring secondary treatment or equivalent.

Question: And are all wastewater treatment plants of any size required to install tertiary treatment?

Answer: No, our minimum requirement is secondary treatment. And then it depends again on the site-specific treatment and discharge location on whether nutrient removal is required.

(Personal Communication, February 1, 2021, Saskatchewan)

Aggressive oxidative steps beyond required secondary treatment are not an obligation for WWTPs, though some plants may adopt oxidative methods in order to meet provincial effluent standards.

Question: Are all WWTPs required to have aggressive oxidative steps?

Answer: It depends on the proposed design of the WWTF (Wastewater Treatment Facility). The majority of facilities in Manitoba are facultative wastewater treatment lagoons with intermittent discharge. Most of the aerated lagoons keep their DO level to 2 mg/L either throughout the water column or in the top 2 metres of the liquid in each cell. Wastewater treatment plants may have oxygen limits for specific processes.

(Personal Communication, January 4, 2021, Manitoba)

Only Ontario requires that certain WWTPs reduce their TP effluent standard in the warmer summer months. None of the other provinces have this requirement, nor are there currently any plans to make it a requirement either within existing legislation or site-specific assessments.

Question: Are P reductions increased during certain times of year, for example, during peak bloom periods or springtime?

Answer: No.

Question: Any plans to do this?

Answer: No.

(Personal Communication, January 4, 2021, Manitoba)

6.4 Summary of Key Findings

All provinces attribute cyanobacteria bloom formation to cultural eutrophication, with provinces using a patchwork of nutrient management programs to address cultural eutrophication. While four of the provinces are focused on P controls, some provinces have decided to adopt a dual N/P approach – Manitoba and certain IWMPs in Saskatchewan.

All provinces have had reports of blooms in mesotrophic and/or oligotrophic systems. Currently, these blooms are also attributed to cultural eutrophication, though it is understood that cyanobacteria blooms are a complex/wicked problem. Monitoring sediment redox and the importance of Fe^{2+} to bloom formation are not currently considered or actively a part of bloom prevention and mitigation in any province.

Cyanobacteria management is impacted by funding, capacity, and regime changes. With changes in government representatives/elected officials (Liberal vs. Conservative) impacting funding and capacity (technological and personnel) for control and prevention programs.

Provincial cyanobacteria management is focused on mitigating public health risks (control) after a bloom forms, rather than on prevention or mitigation. All cyanobacteria specific programs are for monitoring bloom activity and source and recreational waters in order to protect public health. Mitigation programs and their applicability to cyanobacteria management vary between PS and NPS programs. PS prevention programs (nutrient management) often include the pointed reduction of P while NPS nutrient management is often not P-based nor is it meant to limit nutrient loading into watercourses.

Limitations to control and prevention programs have been identified in several provinces; limitations that are variable between provinces based on program specifics.

Chapter 7: Discussion and Conclusions

This chapter highlights key findings grouped within each of the three objectives listed at the end of Chapter 1:

1. Describe and assess provincial cyanobacteria prevention (e.g., nutrient management), risk control (e.g., bloom monitoring, public reporting, public communication), and mitigation (e.g., in-lake chemical and/or physical treatments) plans and programs.
2. Assess the provincial scientific understanding of cyanobacteria bloom formation and its incorporation into policy.
3. Explore cyanobacteria management practices in different provinces using selected case studies.

7.1 Assessment of Provincial Cyanobacteria Management Programs

7.1.1 Provincial Health Risk Control Programs

The provincial cyanobacteria control programs are highly variable, which means they all have advantages and limitations. This makes an assessment of “best” or “worst” program difficult. That being said, some limitations that could be addressed are the cyanotoxins monitored for and the criteria used, national-scale monitoring and the methods of analysis for toxin levels, advisory issuance protocols and their ties to MACs, and the effectiveness of education and outreach.

More than one cyanotoxin should be monitored. Cyanotoxins include hepatotoxins, neurotoxins, and dermatotoxins, yet only a single hepatotoxin is monitored. Saxitoxin and anatoxin-a(s) are both more toxic than microcystins (Table 1), and while not currently as prevalent in the environment, this could change, especially under global warming conditions and a poor understanding of the cause of toxin formation. By not monitoring for other toxins, a shift in dominant toxin species or an increase in prevalence would be unobserved if not monitored for, which poses a risk to public health.

The MACs for MC-LR monitored for in recreational and drinking waters are lifetime values that only apply to humans, though blooms pose a threat to a wide variety of wildlife, livestock, and domesticated animals. Under the CCME (2007) guiding principles for the protection of aquatic life, water quality guidelines should protect “all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term, from the negative effects of anthropogenically altered environmental parameters or exposures to

substances via the water column” (pg.2). As such, MACs should protect aquatic life, not just human. While the CCME has recommended levels for a range of environmental parameters, like mercury and arsenic, none exist for cyanotoxins. Therefore, a better understanding of the risks cyanotoxins pose to aquatic life and their development should be determined so that life beyond humans can be protected. Cyanotoxins are also a possible risk when consuming fish that are caught during a cyanobacterial bloom. So, there should also be a better understanding of the risks cyanotoxins pose in consumable fish, which should be imparted to the public in all provinces via education and outreach documents and be a monitoring consideration for fisheries.

Monitoring should be Canada-wide, with data on bloom occurrences and toxicity shared between provinces and all data available to the general public on one platform. However, a national database would require cooperation from all provinces and territories to work. Having a national database would serve to improve education and outreach initiatives and therefore the protection of public health. Information on advisories would be easier to find and the information on the risks blooms pose and how to recognize them would be uniform across the country, which could also aid in reporting efforts. Creating a national database would require that identification methods and laboratory analysis of toxins across provinces be comparable. As provincial methods of analysis are different, interpretation and comparison of cross-Canada data would be more complicated, though not impossible.

Blooms reported in waters used for agricultural purposes should be tracked in all provinces. Currently, only Saskatchewan has a program meant to respond to reports of blooms in waters used for agricultural purposes. However, this data is not shared or included in provincial bloom monitoring data. Monitoring blooms in eutrophic agricultural surface waters has important implications for livestock health, as well as the risks these waters pose to humans when used for irrigation purposes, so occurrences should be monitored. Knowledge transfer from monitoring these blooms could also be used to help educate farmers on the importance of implementing BMPs to protect water quality on a larger scale, possibly improving BMP implementation rates.

Advisory issuance should be more consistent across provinces and not just issued to protect human health or adult human health. For drinking waters, a TDI level should be used as well as the lifetime MAC to protect against acute exposure. Only one province, Alberta, has a TDI level for MC-LR in drinking water that is used for issuing advisories and only Manitoba

uses the federally recommended 0.4 µg/L MAC for infants. These are practices/methods that should be adopted in other provinces in order to better protect public health. Advisory issuance is also based on a risk assessment, where the weight of an MAC exceedance in treated drinking water on issuance is variable between provinces. The risk assessment method could be combined with an ALF for greater transparency in decision-making around advisory issuance. For recreational waters, each province should distinguish between a confirmed cyanobacteria bloom and a confirmed toxic bloom; methods used in Saskatchewan and Manitoba. Though Manitoba's advisories are directly linked with both provincial recreational threshold levels for cyanobacteria cell count and toxins. Distinguishing between toxic and non-toxic blooms would improve public understanding of the risk's blooms pose to public health and therefore create a greater understanding of the risks undertaken when consuming water versus in-water or on-water activities when a bloom is present. Recreational water advisories should also be issued to mitigate risks to domestic pets and education and outreach extended to provide a greater understanding of the risks posed to them. Take dogs for example; cyanotoxin toxicity levels for dogs are considerably lower than for humans (Table 3), i.e., they are more sensitive, which means that a toxic bloom advisory using the 20 µg/L MAC for MC-LR does not extend protection to domesticated pets, putting them at greater risk for illness or death when exposed.

For the provinces with routine recreational monitoring programs, site selection should not be coupled with the bacterial coliform *E. coli*. This is not to say that routine monitoring should not be conducted with *E. coli* monitoring, rather that coupling the two parameters when selecting sites to protect public health could and likely does limit the appropriateness of some selected sites both for *E. coli* and cyanobacteria blooms. Often cyanobacteria monitoring is secondary to *E. coli*, where visual inspections are only conducted when required water samples for *E. coli* are collected, making bloom observations incidental rather than purposive. While public reporting would provide some remedy for this, reactive monitoring response times impact the effectiveness of this form of monitoring for protecting public health.

All provinces should have routine monitoring of high-risk recreational waterbodies that have a history of bloom formation. Currently, Ontario and Nova Scotia do not, relying solely on the reactive monitoring programs, which, as mentioned, have a time delay that impacts effectiveness. Having both routine and reactive monitoring programs reduces the risks posed to public health.

For reactive monitoring programs, hotlines and/or webpages for reporting bloom sightings should be easy to find and accessible. Given that public reporting is essential for Canadian waters, the public should know where to share that information. Wait-times and inaccessibility are a hinderance to participation.

All provinces should have cyanobacteria specific advisory signage, such as those used in Saskatchewan and Manitoba. Both provinces having signage distinguishing between confirmed cyanobacteria blooms and toxic cyanobacteria blooms, which are posted at waterbodies' public beaches when either advisory is issued. Educational signage for high-risk waterbodies, such as used in Alberta, should also be an adopted practice in all provinces.

In the absence of a national website for bloom advisories and/or visual confirmations, bloom advisory and observational data should be available in each province in a single, easy to find location. Listing current/annual advisories in a single location is done in Alberta, Manitoba, Saskatchewan, and now Nova Scotia, while Ontario has delegated this to the LHUs. As such, bloom advisories are posted on individual LHU webpages using a variety of methods to share the data. However, the extent to which the public are aware of the availability of bloom advisories on LHU webpages is unknown, further bringing into question the effectiveness. Therefore, it would be beneficial for Ontario to coordinate/consolidate a recreational cyanobacteria bloom response protocol for the LHUs and consolidate advisory issuance to a single webpage where, at least, all current bloom advisories could be found. This would make the data easier to find and public health risk management more effective and far-reaching. This would require the allocation of resources and coordination of data transfer from LHUs to a provincial reporting agency, such as the MECP or MOHLTC.

Historic data on cyanobacteria bloom observations and advisories should be available in all provinces, as it would also aid public health risk mitigation. Despite this, long-term data on bloom observations or advisories are not available in any of the five provinces, Nova Scotia now being the exception, as of August 2021. Ontario does maintain a list of historical public bloom reports, but the data are not available online, nor are they likely to be made available.

The effectiveness of current education and outreach initiatives within each province should be assessed. Are the general public actively aware of this water quality issue and do they understand the risks posed to their health? Do people actually know what cyanobacteria blooms look like in order to avoid exposure or report sightings? This second question is important as

Canadian bloom monitoring programs are reliant on public reporting. Provinces should also have cyanobacteria bloom information available in multiple languages, Nova Scotia being the only exception with educational materials available in French and English. Blooms, especially in recreational waters, pose a risk to tourists and residents not fluent in English as well as local populations. This should apply to signage (advisory and educational) as well.

7.1.2 Provincial Nutrient Control (Indirect Bloom Mitigation) Programs

In terms of NPS nutrient management, Manitoba is the only province that regulates smaller livestock producers, golf courses, urban areas, and activities in watersheds deemed sensitive to impacts from nutrient loading (Water Quality Management Zones), as well as large livestock producers. Manitoba is also the only province to have soil P limits that must be met, should the operation not have an approved plan in place. Manitoba is also the only province to have WQMZs, where high-risk waterbodies have been identified and activities that contribute to nutrient loading are regulated, which is an important step for limiting P loading enough to address blooms in eutrophic and hypereutrophic systems. Other provinces could and should adopt similar regulations into their own nutrient management acts in order to limit nutrient loading. Though more stringent requirements are still necessary to address cyanobacteria blooms in high-nutrient waterbodies.

There should be less reliance on voluntary, encouraged, and incentivized NPS nutrient management programs in all five provinces and more on mandated measures, and implementation of BMPs should be properly tracked. This would make assessment of effectiveness possible and/or it would also allow for a ‘hot spot’ approach to be employed.

For PS nutrient loading, the regulations in Ontario are the best for addressing cyanobacteria blooms. This is because the regulations cover a broader range of parameters and are not dependent on human population size or treatment capacity. For example, all WWTPs discharging into Lake Erie are required to meet the provincial TP effluent standard of 1 mg/L or a more stringent standard in some locations, regardless of capacity. While PS nutrients are no longer the main or largest source of loading into many systems, their on-going regulation is still important for maintaining low nutrient loading and addressing blooms.

7.1.3 Provincial In-Lake Prevention Programs

In-lake treatments are not in wide-spread use in Canada, likely due to financial and environmental considerations. Saskatchewan is ahead of the other provinces in this regard due to the existence of the agricultural waters cyanobacteria bloom education and outreach program.

This was the only program identified in this study that promotes the use of in-lake treatments, likely due to the small size of the surface waters and their containment on private land.

In-lake treatments are not common but could be employed strategically in important waterbodies to limit cyanobacteria bloom formation. For example, aeration techniques could be used to prevent internal loading of P and Fe²⁺ by maintaining oxidized sediments (i.e., high redox). Studies have shown that oxidized sediments prevent bloom formation. Understanding the combination of events that lead to low sediment redox could be used to identify the best times to aerate these waters. These methods could also be employed in and around intake areas for DWTPs, preventing bloom formation in locations where they might be a nuisance or risk to the facility.

7.2 Provincial Scientific Understanding of Blooms

Cyanobacteria blooms are attributed to cultural eutrophication in all five provinces, with the understanding that blooms are a complex problem and other environmental factors contribute to bloom formation. Phosphorus is known to be a clear risk factor for bloom formation and is strongly correlated with bloom size but our understanding of the key pre-conditions that allow bloom onset is insufficient. This understanding is based on research conducted primarily on eutrophic and hypereutrophic systems, which means phosphorus management is limited to these same systems but is not always as effective as desired. Moreover, it is clear that P-based management approaches for eutrophic waterbodies will not be practical or effective in oligotrophic systems with low P concentrations.

There is a clear recognition within each province that phosphorus management must be a key element of bloom control programs but newer ideas surrounding sediment anoxia have not been incorporated into policies and programs. There is also an understanding that all blooms, regardless of size, are possibly toxic and therefore pose a risk to public health. Given these understandings, policymaking is focused on the development and maintenance of control (public risk management) and prevention (nutrient management) programs, though control is given greater priority. Blooms in low nutrient lakes are recognized as a problem but management plans have yet to be developed, let alone implemented.

7.3 Assessment of Case Studies

The case studies chosen, while they provided valuable data for how cyanobacteria blooms are managed, are for economically significant, large waterbodies, and they are not representative of how the majority of lakes in Canada are managed for blooms. However, they

do provide valuable information on how cyanobacteria blooms could be managed for other, less intensively studied and managed eutrophic and hypereutrophic waterbodies experiencing blooms. Below are aspects that could be adopted more widely throughout Canada.

For high-nutrient waterbodies experiencing blooms, loading targets for the major tributaries and associated lake phosphorus concentration targets should be determined based on emerging ideas that identify previously overlooked key pre-conditions which allow adjustment of targets as the climate changes. Setting science-based targets is beneficial for two reasons. First, the targets developed, based on current and historical data, would allow for the development of P reduction targets that could address the frequency and severity of cyanobacteria blooms. Second, the targets could act as a measure of success. Often implementation of nutrient reduction strategies does not always achieve the desired impact on bloom formation. Meeting and maintaining phosphorus as well as bloom size goals could act as measures of success. Lake Winnipeg used modelling to determine the necessary load targets for the major tributaries in order to meet the concentration targets for the lake. The lake concentration targets were developed using paleolimnological and historical data, in order to return the lake to its trophic status during the early 1990's. Similar methods could be employed for lakes where there is limited historical data.

The nutrient targets developed should include inputs from internal loads and mechanisms of controlling internal loading, where feasible and necessary. While nutrient targets have not been developed for Pigeon Lake, the nutrient budget did include contributions from internal loading, so that in-lake treatments could be used along with methods of limiting external loading, the only case study to do so of the three selected. Application of the chemical alum is being proposed for the lake, and while this means of in-lake mitigation available, it comes with certain impacts and limitations (see Chapter 2, Section 2.2.2).

An adaptive management framework should always be included, such as the one developed for Lake Erie. Adaptive management also helps promote continued and consistent monitoring efforts, research, and as assessment of the effectiveness of the plan in practice. As a result, this framework should allow for the adoption of new scientific information and techniques into the management strategies over time. So, similar to Lake Erie, plans developed for other lakes would undergo regular assessments over a pre-determined time period, which are based on

a series of performance measures, such as the extent to which nutrient targets have been achieved for high nutrient systems.

All three case studies have satellite monitoring of blooms, which aids in the monitoring and tracking of bloom events for the lakes. This is not likely economically feasible for the majority of lakes, especially the smaller, less popular and economically significant lakes where other tools are needed to detect blooms. Pigeon Lake has organized a citizen bloom monitoring program in association with an NGO and various research initiatives.

Education and outreach documents should be made available to the general public, where information is shared on actions the individual can take to limit their impact on water quality and contributions to bloom formation. Lake Erie and Pigeon Lake both have documents available to the public, which, if effective, could help reduce loads from urban and rural contributions. This would also likely help with monitoring efforts and public health risk mitigation efforts, as those in the communities around the lake would be better informed on cyanobacteria blooms and the risks they pose.

7.4 Conclusions

All five provinces have cyanobacteria risk management and nutrient management programs, however, there is an obvious focus on ‘after the fact’ risk management to mitigate the risks to public health with programs aimed at bloom mitigation or prevention receiving much less emphasis.

All threshold levels used for risk management purposes are for the cyanotoxin MC-LR in treated drinking water and recreational waters, with routine and reactive monitoring programs applying to the associated waterbodies. No other toxins have threshold levels, nor are they monitored for. And the threshold levels in place for MC-LR are human specific, which means the risk of exposure to native wildlife, aquatic species, livestock, and domesticated animals are unknown. Cyanobacteria visual monitoring and sampling is also limited to areas around intake pipes, treated waters, and shoreline areas, and is largely representative of only surface level blooms.

In terms of nutrient management programs, PS nutrient reductions are often more stringent in waterbodies or watersheds where cyanobacteria blooms are occurring, should these waterbodies be discharge sites, or the watersheds be defined as sensitive/at-risk. This means that PS nutrient loading can and is often geared towards mitigating bloom size. In contrast, NPS

nutrient management programs, whether regulated, encouraged, or incentivized, are not necessarily P-based nor are they meant to reduce cyanobacteria blooms. Instead, NPS nutrient management programs are meant to deal with a host of environmental problems, including but not limited to eutrophication. As a result, P reductions are often not aggressive enough to decrease bloom occurrences in eutrophic and hypereutrophic systems.

The adoption of P-limiting BMPs for NPS nutrient management is not mandatory in the watersheds experiencing cyanobacteria blooms. Instead, there is heavy reliance on incentivized or encouraged voluntary programs, with no formal means of tracking implementation outside of CAP awarded funding. Education and outreach initiatives for NPS nutrient management have been reduced in Alberta and Saskatchewan, due to the removal of EFP as a requirement for CAP funding. This has also resulted in less one-on-one work with producers, where they could and would be educated on the environmental risks associated with nutrient loading and the benefits of adopting BMPs that reduce loading. Finally, farmers are often not educated on how P export from agricultural fields or livestock contributes to cyanobacteria bloom formation. Instead, more general information is provided because it is believed that often farmers are too far removed from the bloom problem to feel that the information is relevant to them or that general nutrient management is enough to address cyanobacteria blooms.

While IWMPs for source waters and major river watersheds are used in all five provinces to protect water quality, cyanobacteria management is not often an explicit component. So, while several provinces have nutrient targets developed to prevent the occurrence of algae blooms in lakes and rivers and nutrient loading is listed as a risk to water quality with algae blooms often listed as possible result of loading, these plans have not been utilized to mitigate cyanobacteria blooms either preventatively or actively for systems experiencing blooms.

Cyanobacteria blooms in all five provinces are attributed to cultural eutrophication, with an understanding that they are a complex problem with risk of occurrence and bloom magnitude fueled by excessive nutrient loading. What bloom management strategies do exist are focused on reducing anthropogenic NPS and PS nutrient loading which indirectly address blooms by attempting to starve them to some extent. Nutrient loading targets are often based on achieving desirable chl-*a* levels (which are associated with lower risk of blooms and smaller bloom sizes) or ensuring oxygenation of deep-water fish habitat and sometimes prevention of internal P loading. None of the provinces consider preventing anoxic conditions in sediments, a recently

identified pre-condition for bloom formation, as a means of preventing blooms or when setting nutrient targets although some target internal P loading which requires ensuring oxidized sediments. And while limits to PS nutrient loading are regulated, NPS nutrient management programs are predominantly voluntary, not monitored, and not usually specific to bloom management. In addition, nutrient reduction strategies are not applicable to the emerging problem of blooms occurring in nutrient-poor systems. While the latter is a cyanobacteria problem, it is not a eutrophication problem.

Most lakes experiencing cyanobacteria blooms are not actively managed for blooms. That is, most lakes experiencing blooms do not have cyanobacteria management strategies, P reduction targets (where applicable), and the cause of blooms in these systems are not always well studied but are usually attributed to excessive P or N and P. As such, most lakes are managed using province-wide programs centred around ‘after the fact’ risk control and the adoption of adaptive behaviours, such as finding an alternative drinking water source or limiting recreational activities in the event of a bloom. For the few lakes that are being actively managed for blooms, P and/or N and P reduction strategies have been adopted, where coordinated efforts are used to promote encouraged and incentivized provincial NPS nutrient management programs and practices, sometimes with extra funding available in these watersheds. PS nutrient management from WWTPs is always regulated for these systems if the waterbodies or their major tributaries are discharge sites, though, depending on provincial policy, this does not always apply to all facility types discharging into these systems.

It is clear that current efforts are not enough to mitigate let alone prevent cyanobacteria blooms in most Canadian waters and that greater efforts are needed to address nutrient export from point and non-point sources. This is particularly important given predictions that frequency of cyanobacteria blooms will worsen in the future, especially under climate change and global warming scenarios. Until then, Canadians will have to rely on risk management programs based on public reporting, monitoring of drinking and recreational waters, and public advisories to protect their health.

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