Towards democratizing water quality monitoring processes for the lower Grand River and nearshore Lake Erie

by

Elaine Ho

A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Social and Ecological Sustainability (Water)

Waterloo, Ontario, Canada, 2021

Examining committee membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner	**BRENDA PARLEE** Associate Professor and Canada Research Chair Department of Resource Economics and Environmental Sociology University of Alberta
Supervisors	**SIMON C. COURTENAY** Professor and Director School of Environment, Resources, and Sustainability University of Waterloo
	ANDREW J. TRANT Assistant Professor School of Environment, Resources, and Sustainability University of Waterloo
Internal Members	**DAN MCCARTHY** Associate Professor School of Environment, Resources, and Sustainability University of Waterloo
	ROBERT B. GIBSON Professor School of Environment, Resources, and Sustainability University of Waterloo
Internal-external Member	**MARK SERVOS** Professor Department of Biology University of Waterloo

Author's declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of contributions

In the School of Environment, Resource and Sustainability, two forms of presentation of the doctoral dissertation are permitted: (1) a standard dissertation monograph, and (2) a manuscript option centered on three or four published or publishable learned journal-type manuscripts on related matters, packaged with introductory and concluding chapters that integrate the purposes/ research agenda and findings/implications, with the required result forming a conceptual whole. This thesis uses the manuscript option. Specific requirements relating to the manuscript option, which have been met, are as follows:

- The manuscript-based dissertation must reflect a consistent overall conceptual foundation and research agenda and the parts must be integrated to form a coherent package. The whole must be related to the overall purposes of the School of Environment, Resources and Sustainability (SERS) doctoral program, and the individual components of the dissertation must originate from the doctoral research.
- The manuscripts must be dominated by the intellectual effort of the student. While members of the advisory committee and others involved in the research may, as appropriate, be listed as secondary authors on individual manuscripts, the manuscripts must be written by the student, and the student must be the first author on each manuscript.
- Where multiple authorship occurs, there must be a preface statement in the thesis outlining the roles of the respective authors and clarifying the extent and nature of the contribution of the student. Co-authors must sign the statement to indicate that they agree with the evaluation of the roles and contributions of the various authors.
- In no case can a co-author serve as an external examiner for the thesis.

Findings from this dissertation research are reported in five co-authored manuscripts (Chapters 3, 4, 6, 7, and 8) and one sole author manuscript (Chapter 5). Chapters 3 and 5 are published in peer-reviewed journals, while the other four chapters have not yet been submitted. References are provided below, and a list of summary reports is in Appendix A. All research was conducted at the University of Waterloo under the joint supervision of Dr. Simon Courtenay and Dr. Andrew Trant.

Chapter 3

Ho, E., Trant, A., Gray, A., and Courtenay, S. C. (2020). Comparison of freshwater monitoring approaches: strengths, opportunities, and recommendations. *Environmental Monitoring and Assessment* 192: 614. DOI: 10.1007/s10661-020-08570-1.

This manuscript is published. The student (E. Ho) identified 'best programs' and criteria used to review these programs from literature, consultations with practitioners and researchers (e.g., at Global Water Futures), and as part of key informant interviews; assessed information availability (for scoring) and performed the scoring/analysis; drafted the first manuscript; and edited the manuscript based on feedback from co-authors. Dr. Andrew Trant, Dr. Simon Courtenay, and Dr. Mark Servos offered insights into the list of programs to be reviewed. Dr. Andrew Trant, Dr. Simon Courtenay, and Dr. Michelle Gray provided extensive comments for editing the manuscript before and during the journal submission process. I also acknowledge the contributions of Scott Kidd, who provided input into the paper's structure, and Georgina Kaltenecker, who provided information about the Provincial (Stream) Water Quality Monitoring Network.

Chapter 4

Ho, E., Courtenay, S. C., and Trant, A. J. *In preparation*. Freshwater quality monitoring in Ontario: Strengths, weaknesses, opportunities, threats, and recommendations. *Not yet submitted*.

The student undertook all interviews, coding, analyses, and the drafting of an independent summary report as well as the first draft of a manuscript. Navjot Dhaliwal and Kelly-Ann Wright contributed to the drafting of the summary report (Appendix A). Aalia Khan and Siobhan Mullally transcribed interviews. Dr. Mark Servos made a few introductions with the Grand River Fisheries Management Plan Implementation Committee to begin/encourage interview recruitment. Dr. Simon Courtenay and Dr. Andrew Trant contributed to drafting the interview questions and the ethics approval process. The first versions of the manuscript were overhauled after extensive feedback from Dr. Simon Courtenay and Dr. Andrew Trant, followed by a new manuscript being drafted by the student. Dr. Mark Servos provided feedback on this second version, which was then revised by the student.

Chapter 5

Ho, E. (2018). Criteria-based ranking (CBR): A comprehensive process for selecting and prioritizing monitoring indicators. *MethodsX* 5: 1324-1329. DOI: 10.1016/j.mex.2018.10.015.

This methods paper is published and was written to accompany a preceding co-authored paper (Ho, Eger, & Courtenay, 2018)[1]. All content regarding the CBR process in Ho, Eger, and Courtenay (2018) was designed, implemented, and written by the student. The student collaboratively designed the research

[1] Ho, E., Eger, S., and Courtenay, S. (2018). "Assessing current monitoring indicators and reporting for cumulative effects integration: A case study in Muskoka, Ontario, Canada". *Ecological Indicators*, 95: 862-876.

with Dr. Sondra Eger, Dr. Simon Courtenay, Christy Doyle, and Rebecca Willison, and implemented all aspects described in the methods paper (e.g., practitioner workshop, ranking activity). This methods paper was drafted after an invitation to submit to *MethodsX* during the proofing stage of Ho, Eger, and Courtenay (2018).

Chapter 6

Ho, E., Courtenay, S. C., Miller, R., McLeod, C., and Trant, A. J. *In preparation*. Knowledge co-creation through arts-based engagement: Diversity in freshwater quality monitoring and management. *Not yet submitted*.

The student collaboratively designed and carried out the research. The Great Art for Great Lakes portion of the case study was undertaken in partnership Waterlution, with support from Chris McLeod and Karen Kun. Waterlution organized, promoted, paid for, and convened the events (i.e., the events occurred independently of this research), and modified the workshop questionnaires in collaboration with the student. The Grand Expressions portion of the case study was co-created by Indigenous partners Paul General (former) and Richelle Miller, with the participation of youth in the Music for the Spirit & Indigenous Visual Arts program as supported by their parents/guardians. The student followed the recommendations of Paul engagement regarding how to engage the perspectives of the community and the lead of Richelle Miller to design the process for engaging with Indigenous youth. The student guided the youth collaboratively with Richelle Miller as they created artworks and offered stories to accompany them. While the student drove the research process, Richelle Miller and Tayler Hill liaised with community members and followed up with students to ensure the process was being implemented. The student compiled the virtual exhibit, prepared the in-person exhibit for display, coded and analyzed all questionnaires and the Grand Expressions virtual exhibit, wrote two summary reports (Appendix A), and drafted the manuscript. Promotion of the in-person event was led by the student, who also pursued extensive non-academic dissemination (Appendix A). Dr. Simon Courtenay, Dr. Andrew Trant, Dr. Dan McCarthy, Dr. Mark Servos, Chris McLeod, and Richelle Miller provided feedback on the manuscript, which the student used to revise prior to submission.

Chapter 7

Ho, E., Ding, Z., Trant, A. J., and Courtenay, S. C. *In preparation*. Cumulative effects monitoring in the lower Grand River and nearshore Lake Erie (Ontario, Canada): Recommendations for implementation. *Not yet submitted*.

The student undertook interviews as described above (under Chapter 4 heading) and co-supervised a senior student in Biology (Ziyuan Ding) with Dr. Simon Courtenay to collaboratively design and carry out an exploration of cumulative effects monitoring in the study area. The student (E. Ho) led the organization and execution of an online workshop with practitioners, including collaboratively identifying potential invitees, sending out invites, tracking responses, creating and sending out pre- and post-workshop materials, collaboratively delivering a presentation at the workshop, leading the collaborative completion of the ethics approval process, and following up with workshop participants after the event. Ziyuan Ding and Dr. Simon Courtenay contributed to the development of the workshop and its materials, as well as the ethics review process. Navjot Dhaliwal took notes during the workshop and contributed to the drafting of the summary report, in collaboration with Ziyuan Ding and the student (E. Ho). The student (E. Ho) compiled and analyzed pre- and post-workshop activities and drafted the first draft of the manuscript. Dr. Chris Jones provided extensive feedback on a manuscript restructure, which the student then used to restructure the draft. Further comments by Ziyuan Ding, Dr. Andrew Trant, Dr. Mark Servos, and Dr. Simon Courtenay were also addressed by the student.

Chapter 8

Ho, E., Courtenay, S. C., Ford, G., and Trant, A. J. *In preparation*. Ideals, values, and practice: A framework for collaboration to design and implement cumulative effects monitoring in the lower Grand River and nearshore Lake Erie. *Not yet submitted*.

All methods contributed to this culminating chapter, for which the student's contributions are outlined above. In addition, the student organized an online workshop to receive practitioner and scientist feedback on the draft framework for collaboration in water quality monitoring. Nancy Goucher and Kirsten Grant contributed to the formation of the discussion questions, potential invitees, and workshop structure. Marta Veenhof, Kelly-Ann Wright, Navjot Dhaliwal, and Ana Carolina Esteves Dias were note-takers during the event (Kira Cooper was on standby); Navjot Dhaliwal contributed to the summary report, which was drafted primarily by the student. Gregary Ford provided draft content regarding the Niagara Coastal Community Collaborative. Feedback from Dr. Simon Courtenay, Dr. Andrew Trant, and Dr. Mark Servos contributed to the student's further revision.

I testify that I am the primary author of the manuscripts in my dissertation, and that the work was dominated by my intellectual efforts.

Elaine Ho

I testify that Elaine Ho is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.

Simon Courtenay (Co-advisor)
University of Waterloo

Andrew Trant (Co-advisor)
University of Waterloo

Abstract

Freshwater quality issues are among the most pressing challenges of our time. Such issues are increasingly complex and tend to recur when we fail to acknowledge the interacting stressors that influence them. One example of a recurring issue is the prolific growth of *Cladophora* (a benthic nuisance alga) in the eastern basin of Lake Erie. Water managers thought they had corrected the issue by controlling nutrient loading from the 1970s to the1990s; however, the *Cladophora* issue returned in the mid-2000s and has persisted due to new factors changing the way the ecosystem works. The Grand River in Southern Ontario remains Lake Erie's largest contributor of nutrients in Canada, and so is the focus of current management efforts. Problems like this, which are caused by several interacting factors in a given space over time, are known as cumulative effects.

Much of the literature on cumulative effects and/or water quality monitoring in this dissertation reflects conventional practice focused on the perspectives of water scientists and managers; however, this dissertation does not replicate this approach. Instead, the social-ecological context surrounding freshwater quality monitoring in the study area is critically considered by incorporating diverse community perspectives alongside conventional perspectives. In the study area, Indigenous communities have treaty rights to participate in the governance of the watershed (which sits entirely within the Haldimand Tract), but these communities – like others – have not been engaged as partners in water quality monitoring or management. One reason for this is that community and Indigenous knowledges often come in different formats than conventional scientists are used to dealing with, and so these forms of community 'data' are not easily integrated with conventional data. As Canada moves towards a mandate for reconciliation with Indigenous communities, ignoring the challenge of bringing together different 'ways of knowing' is no longer acceptable. Inspired by the *Cladophora* challenge and the need to diversify monitoring practice, this research strives to answer the following question: How can cumulative effects water quality monitoring be enabled and involve diverse perspectives in the Grand River-Lake Erie interface?

This research encourages the democratization of water quality monitoring to ensure more diverse persons can participate in the gathering of water quality information and that their diverse ways of knowing may supplement conventional science in management and decision-making. In other words, this dissertation explores approaches for diversifying perspectives that contribute to our understanding of freshwater quality in the study area. A multimethod approach to research was undertaken to explore what may be done differently. Methods used in this research include a systematic review of monitoring programs (Chapter 3), key informant interviews (Chapter 4), in-person and online workshops (Chapters 5, 7, and 8), and artistic research (Chapter 6) – a new approach in the context of water quality monitoring

and management in the study area. First, the systematic review of monitoring programs highlighted aspects of current monitoring to maintain and improve upon. Then, key informant interviews raised 106 strengths, weaknesses, opportunities, and threats, as well as 51 recommendations. I also discuss a culture shift towards more holistic thinking and more collaborative water governance, which study participants deemed necessary to develop a strong and resilient cumulative effects monitoring program. To enable this culture shift, two examples of artistic research were implemented to demonstrate potential approaches for diversifying practice. Following, eight recommendations are provided for implementing cumulative effects monitoring in the study area.

The multimethod approach results in a framework for collaboration (i.e., organizational structure and process framework) to enable more diverse and collaborative water quality monitoring in the study area that contributes to our ability to understand and address cumulative effects. The proposed framework is community-led (whether catalyzed by community members or invited by government) and incorporates equal weighting of Indigenous and western priorities and monitoring indicators – a unique and potentially transformative contribution to literature and practice. The use of artistic research as an equitable means of community involvement is also new in the study area. Finally, because involving diverse persons to contribute their perspectives demanded the development of different approaches than currently practiced, the research process and its process-related lessons and recommendations may contribute to raising the standard for future research and practice in water quality monitoring.

This research also has implications that extend beyond strengthening the practice of water quality monitoring. The core outcomes of the later chapters – e.g., recommendations towards collaborative and community-based monitoring processes coupled with a culture shift regarding the creation and application of knowledge – would, if practiced, support at least three broader transformations in society: a formal sharing of responsibility over natural resources, increased collaboration that is mindful of diversity, and systemic changes in support of Canadian-Indigenous reconciliation. While many aspects of the future scenarios described in the concluding chapter are likely a generation away (or longer) and are far beyond the scope of any one thesis project, my hope is that possible actions catalyzed by this research and other efforts like it will collectively move society in a different, more equitable direction.

Acknowledgements

This research, the University of Waterloo, and my residence during this study are all situated on the Haldimand Tract – land that was promised to the Haudenosaunee of the Six Nations of the Grand River to steward and enjoy in perpetuity. The land is also the traditional territory of the Neutral, Anishinaabe, and Haudenosaunee peoples. I am grateful for the support and contributions of many Six Nations individuals, including Paul General, Richelle Miller and the inspiring youth that contributed to this research – nia:wen kowa and/or chi miigwech to all.

Many individuals were instrumental in the making of this work. First, I want to recognize and thank all study participants and those who consulted on the research, including Sandra Cooke, Dr. Chris Jones, Mark Anderson, Janet Ivey, Ryan Hamelin, Gerald Tetreault, Dr. Kelly Munkittrick, Dr. Brad Bass, Dr. Barb Veale, Christy Doyle, Rebecca Willison, Christopher McLeod, Karen Kun and many others. I wish to acknowledge those whose work preceded my own, including the late Dr. James Kay.

Second, many faculty and staff provided valuable guidance, resources, coordination, networking and dissemination throughout dissertation administrative processes and research. Faculty in the School of Environment, Resources, and Sustainability (SERS) provided regular expertise and guidance on literature, methods, and resources, whereas faculty in the Collaborative Water Program (delivered by The Water Institute) delivered a fantastic, interdisciplinary educational experience that influenced the development of this research. Support staff at The Water Institute, including Lake Futures and Global Water Futures staff, included Allie Dusome, Nancy Goucher, and Kirsten Grant. SERS administrative staff Jennifer Nicholson and Amanda Campbell provided constant support through every aspect of the administrative process from degree start to finish.

Third, my dedicated committee members – Dr. Simon Courtenay, Dr. Andrew Trant, Dr. Dan McCarthy, Dr. Mark Servos, Dr. Robert (Bob) Gibson, and Dr. Linda McCarthy (former) – provided extensive, thoughtful guidance and personal mentorship over the five years, as well as extremely useful feedback throughout the research process and on many pieces of writing. I could not ask for a better committee to challenge me constructively and support my development as an individual, an academic and emerging professional. I would like to thank my external examiner, Dr. Brenda Parlee, as well for her time and thoughtful consideration, especially given the extent of this work and the relatively short timelines we operated within.

The guidance of my dissertation committee, my colleagues (including my peers in the School of Environment, Resources and Sustainability as well as in the Collaborative Water Program), and my research participants have motivated me to continue developing community-led research related to water quality in Ontario. I was inspired by the dedication and willingness to share personal experiences from community members and experienced practitioners, with whom I am proud to have built what I hope will be long-term working relationships. The opportunities I gained from this research – supported or provided by the University of Waterloo, Waterloo Global Science Initiative, the Water Institute, Canadian Water Network, Canadian Rivers Institute, Global Water Futures, and others – have provided me with a rich understanding of broader sustainability issues (including those related to freshwater quality) and the opportunities to influence meaningful change within them. For this, I will be forever grateful.

Fourth, this research was funded as follows:

- Graduate student funding provided by the University of Waterloo in the following ways: Dean's Doctoral Initiative, University of Waterloo Graduate Scholarship, Environmental Studies Graduate Experience Awards, University of Waterloo Graduate Scholarships, and a Faculty of Environment Graduate funding top-up.
- Funding through the Lake Futures group (part of Global Water Futures) in the form of University of Waterloo Graduate Research Studentships (Global Water Futures is funded largely by the Canada First Research Excellence Fund).
- An Ontario Graduate Scholarship jointly funded by the Province of Ontario (two thirds) and the University of Waterloo (one third).
- Additional funding to support conferences from University of Waterloo's Faculty of Environment and from Dr. Simon Courtenay's lab.
- An *Our Water – Our Life – The Most Valuable Resource* award from the Canadian Water Resources Association.

Finally, and most importantly, completion of this work would never have been possible without the incredible support and patience of my fiancé Sam Tassone, the most amazing partner I could have. For the countless hours I spent hiding away at my desk, the final months you spent single-handedly maintaining the household *and* rearing our 1-year-old, the self-care you encouraged and the inspiration you provided (and so much more) this work belongs to you as much as it does to me.

Dedication

This dissertation is dedicated first to my son, Cosmo Christopher Tassone, and to my stepdaughter, Gabriella Rose Tassone, for whom the world is a rapidly changing place that will soon be theirs to steward. It is my hope that the shortcomings of today's society are addressed through works like this research so that you may be more effective in building a bright and healthy future for all things.

I also dedicate this dissertation to my fiancé, Sam Tassone. While many of us wish to make this world a better place – and some of us strive to make incremental change through research like this – you make peoples' lives better every single day. Whether volunteering with the fire department, guiding troubled youth, going out of your way to help our neighbors, carrying out little gestures to let others in our community know they are thought of, or any of the many other things you do in kindness, I hope our children and others who steward our futures honor your efforts to 'do good'.

My mother, Ann Alimi, my stepfather, Fabrice Alimi and my sisters, Olivia Goldstein and Emma Alimi were immensely supportive of my 13-year journey (arguably longer) through post-secondary education – thank you for everything you have done! My father, Gilbert Ho, also instilled in us a responsibility for others (human or not). I especially thank my mother, who raised me with a keen awareness of the wellbeing of the natural world and all that live in it, and a belief that I could (and must) change the world. For all those times you showed me newspapers or shared someone's experience, followed by "Do something!" or "You have to fix it," this work is also for you.

Table of Contents

List of figures

List of tables

List of abbreviations

CA	Conservation Authority (or authorities)
CBR	Criteria-based ranking
CCME	Canadian Council of Ministers of the Environment
CEA	Cumulative effects assessment
COVID-19	Coronavirus disease 2019
CWRA	Canadian Water Resources Association
CWRC	Canadian Watershed Research Consortium
EEM	Environmental Effects Monitoring
GWF	Global Water Futures
MWC	Muskoka Watershed Council
OCAP®	Ownership, Control, Access, and Possession
PWQMN	Provincial (Stream) Water Quality Monitoring Network
SDG(s)	Sustainable Development Goal(s)
SRDP	Slave River and Delta Partnership
SWEEP	Slave Watershed Environmental Effects Program
SWOT(R)	Strengths, Weaknesses, Opportunities, Threats (Recommendations)
VEC(s)	Valued ecosystem component(s)

Quote

"It is perhaps the defining question of our time: How to tackle the complex interrelated challenges of the 21st century in a coherent and effective way? The answer, I am convinced, lies in what I call the diplomacy of knowledge, defined as our ability and willingness to work together and share our learning across disciplines and borders. When people achieve the right mixture of creativity, communication and co-operation, remarkable things can happen."

~ The Right Honourable David Johnston
Former Governor General of Canada (2010-2017)
Former President of University of Waterloo (1999-2010)

PART 1 – INTRODUCTION

Chapter 1
About this research

Much of the literature on water quality monitoring cited in this dissertation reflects conventional practice in its focus on western scientist-derived information. The research presented in this dissertation deviates from this convention and may therefore require additional explanation and context regarding its direction, purpose, and approach. Although some readers may feel this explanation is unessential, it is included to ensure each reader is provided with a common frame of mind with which to review the manuscript chapters. Chapter 1 focuses on the less conventional approach taken in this research, though a more conventional description of the study context is presented in Section 1.4. The methodology is then described in Chapter 2, followed by six manuscript chapters (Chapters 3-8) and a concluding synthesis and reflection in Chapter 9.

1.1 Researcher positionality

Although the research methodology (described in Chapter 2) emerged primarily from early consultations with local practitioners, my personal experiences (described in Appendix B) influenced research in three ways: my understanding of society's problems, my preferred methodological approach to research, and the way in which I define 'information'. First, I view society's 'big, hairy, audacious' problems (i.e., impactful, little understood, and collectively important problems) as integrated and inseparable social-ecological challenges (e.g., one cannot adequately address the ecological aspects without in some way addressing the social aspects). This 'holistic' understanding of the issues and the social-ecological system (i.e., the watershed) is represented throughout the dissertation, both directly and indirectly. Second, my experiences resulted in a drive to make the world a better place for all things, which manifests as a methodological preference towards some form of applied research (e.g., as opposed to research that has little relevance to the real-world context of the study). Finally, the way in which I value different perspectives is a critical aspect of this dissertation that is relevant to the focus on diversity in practice.

This research was developed through a review of the literature and consultations with practitioners at the Grand River Conservation Authority to identify opportunities to contribute to literary gaps while providing value to practitioners. In these early consultations, practitioners described financial and human capacity challenges exacerbated by the large size of the Grand River and its watershed (where the study area is situated – see Sub-section 1.4.1). Practitioners were generally satisfied with their abilities to implement 'the science', but integration of information between freshwater quality monitoring agencies (see Sub-section 1.4.2) was problematic in part due to the lack of personnel to carry out the task. In previous years, the capacity issue had been mitigated somewhat by infrequent engagements with local community members and/or grassroots organizations by facilitating the detection of issues, contributing to water quality monitoring efforts, or participating in/encouraging adoption of local management solutions. Practitioners also highlighted two related challenges that were reinforced by the results of Chapters 3 (a review of monitoring programs) and 4 (key informant interviews), and which steered the rest of this dissertation:

1. Community members are usually not deeply engaged in water quality monitoring or management and are not viewed as collaborators in existing water quality monitoring processes.
2. Indigenous knowledge could not easily be integrated with existing water quality monitoring data and so was not included despite recognition that Indigenous communities should be – and have legal/treaty rights (see Sub-sections 1.4.1 and 6.2.1) to be – meaningfully involved.

As Canada moves towards a mandate for reconciliation with Indigenous communities (Truth and Reconciliation Commission of Canada, 2015; ECCC, 2020a), ignoring the challenge of bringing together different ways of knowing is no longer acceptable. It is worth noting that this dissertation was not originally proposed to focus on either community-derived data or the bringing together of Indigenous and non-Indigenous forms of knowledge; however, ignoring the challenges raised by consulted practitioners would not only reduce the useful contributions of this work, but would serve to maintain a history of poor or lacking relationships between Canadian society and local Indigenous communities (this history is outlined briefly in Sub-section 6.2.1). Therefore, the multimethod approach applied in this research was steered by water managers and scientists in the study area to address the challenge of contributing diverse perspectives and ways of knowing to our water quality.

Unfortunately, initializing a relationship between Indigenous and non-Indigenous entities in the form of research is automatically linked, to some, with imperialism, colonialism, bad memories, and distrust (Smith, 1999). It is often viewed as something non-Indigenous – especially White/Western researchers – do *to* Indigenous persons, so conventional research approaches are often met by the colonized with silence (Smith, 1999). Changing this perception requires relationship building, which in turn requires changes to existing social structures and power dynamics (e.g., critical pedagogy: Denzin, Lincoln, & Smith, 2008). As I am a non-Indigenous researcher, the portion of this research involving Indigenous persons was co-created with them to ensure an Indigenous research framework was applied, rather than subsuming Indigenous methods under a Western way of knowing (Kovach, 2009). Thus, Chapter 6 of this dissertation sets itself apart from other, more conventional chapters, as a demonstration of decolonizing methods.

1.2 Underlying assumption

The research presented in this dissertation accepts the assumption, based on decades of literature (cited throughout this dissertation) and practitioner experience, that the practice of freshwater quality monitoring and its application to management and decision-making are imperfect and may lead to an incomplete understanding of complex social-ecological phenomena (e.g., cumulative effects). This assumption explains, in part, the reason for existing disconnects between the production of freshwater quality monitoring data and their application – or lack thereof – in management and decisions (i.e., reflects historical contentions between science and policy: Funtowicz & Ravetz, 1990; Bradshaw & Borchers, 2000; Stevens et al., 2007; Howlett, Ramesh & Perl, 2009; Hulme, 2009; Lindenmayer & Likens, 2009; McFadden et al., 2009; Holmes & Scott, 2010; Ball et al., 2012; Glasgow et al., 2012).

Further, the production of data is a goal of water quality monitoring as a means by which to understand watershed health. The exploration of ways of knowing – whether through conventional freshwater quality monitoring (e.g., Part 2) or from alternative approaches (e.g., Part 3) – is central to the arguments and recommendations presented throughout this dissertation. The multimethod approach described in Chapter 2 strives to demonstrate potential approaches for engaging with more diverse persons. The reason for taking this approach is supported by Funtowicz and Ravetz (1993), who stated:

> The triumph of the scientific method, deploying the technically esoteric knowledge of its experts, has led to its domination over all other ways of knowing; this applies to our knowledge of Nature, and of much else besides. Commonsense experience and inherited skills of making and living have lost their claim to authority… The activity of science now encompasses the management of irreducible uncertainties in knowledge and in ethics, **and the recognition of different legitimate perspectives and ways of knowing** [emphasis added]. In this way, its practice is becoming more akin to the workings of a democratic society, **characterized by extensive participation and toleration of diversity** [emphasis added]. As the political process now recognizes our obligations to future generations, to other species and indeed to the global environment, science also expands the scope of its concerns. We are living in the midst of this rapid and deep transition, so we cannot predict its outcome (p.741, 754).

Similarly, the premise of this research and its assumption – i.e., conventional science and management practice may be inadequate in their current state to address cumulative effects, therefore, diverse persons and their knowledges may need to supplement existing monitoring and management activities – is supported by Funtowicz and Ravetz (2003): "…new problems are characteristic of 'complex systems'… In such complex systems, **there can be no single privileged point of view for measurement, analysis and evaluation** [emphasis added] (p.1-2)".

1.3 Study objectives

This dissertation explores approaches for diversifying perspectives that contribute to our understanding of freshwater quality. Rather than design a water quality monitoring program specific to the study area, this dissertation aspires to *enable the design* and implementation of monitoring by diverse persons. The type of monitoring I strive to enable would (1) have improved connections to management and decision-making (e.g., maintains relevance to current priorities), (2) engage local communities in meaningful and consistent ways (e.g., addresses the capacity issue described by practitioners), and (3) support the pursuit of cumulative effects assessment via social-ecological knowledge contributions.

Current practitioners (i.e., western scientists) steered the research to focus on more effective knowledge sharing and cross-cultural (e.g., Indigenous) collaboration. The information collected through this research is used to achieve three objectives:

1. Confirm and describe opportunities for improvement in the practice of water quality monitoring (refer to Part 2, Chapters 3 and 4).
2. Explore ways to involve more diverse persons in water quality monitoring (refer to Part 3, Chapters 5 and 6).
3. Propose a strategy for enabling cumulative effects monitoring in the study area (refer to Part 4, Chapters 7 and 8).

These objectives address consulted practitioners' views that the science of water quality monitoring is regularly reviewed/discussed and is currently being built upon in the study area, but that the social constructs – who should be involved, in what roles, and through what processes – are rarely reviewed with the same attention. Thus, the social constructs require dedicated study to ensure water quality monitoring serves current societal (including management) interests and needs.

1.3.1 Why diverse perspectives are needed

For more than 20 years, the International Water Association's annual World Water Forum frequently returned to the same conclusion: the world's water problems are not simply a matter of science and technology, or they would have been fixed a long time ago (Beck, 2016). The role of good governance and social and political processes have been a focus of the World Water Forum in recent years. So, to, has the way we think about social-ecological systems, resulting in an outreach paper (Beck, 2016) by the International Water Association to facilitate the application of systems thinking to the science of ecosystem services and water-related engineering infrastructure.

Conventional science is objective and truth-seeking, applied to society to describe what 'is' and determining what 'should be' (Kay & Schneider, 1994); however, scientists are increasingly recognizing that environmental monitoring is (and must be) inherently value-laden in the questions of what we choose to monitor and in what decisions or outcomes follow (Kay & Schneider, 1994; Jones, 2016; Larson, 2011; Stephenson et al., 2017). Larson (2011) suggests that the two questions – 'what is' (e.g., state of the watershed, based on monitoring data) and 'what ought to be' (e.g., that some state should be different than it is, requiring a management intervention) – are characterized as statements of fact (the former) versus ethics (the latter). This discourse was first explored in great depth by English philosopher David Hume, who brought the 'is-ought problem' to mainstream epistemology. Hume's method contradicted what scientists before him accepted: that facts discerned from independent empirical observations can be connected (e.g., causal inference) simply by knowing each individual fact. Rather, Hume (1739; 1978) suggested that the way in which we interpret or understand facts, and determine what to do with the information, is a judgement based on a chain of reasoning. This reasoning is usually based on some combination of experience and interpretation, which inevitably results in subjectivity. Further, Hume (1978) suggests some connecting principle (e.g., principle of association) is necessary to make inferences between past experience and future conditions – for example, that the future will be the same as the past, which Hume calls the uniformity principle. Hume suggested – and most scientists today would agree – that the uniformity principle is unjustifiable, except perhaps by using probable arguments rather than an objective guarantee of future conditions.

This inevitable subjectivity in the creation of knowledge – including how we observe, interpret, and report upon water quality and related phenomena – is one of many justifications for diversity in water quality monitoring personnel as well as for the multimethod research approach described in Chapter 2. Subjectivity in the way we collect, interpret, and act upon information has been studied by scientists across disciplines (Larson, 2011). These studies have concluded with the same arguments put forward by researchers such as Kay & Schneider (1994), Jones (2016), Stephenson et al. (2017) – that there is no science that is entirely value-free. Larson (2011) uses an example of declining Great Lakes health to illustrate different value systems inherent to the definition of healthy lakes and assessment of health moving forward. Thus, the state of a watershed – though premised on what 'is' – is interpreted and applied to management on a basis of perspective and the vision of a particular person or group regarding what 'should be.' Any change away from that vision is considered undesirable; however, in complex ecosystems, change is not inherently bad. Examples of 'natural' change are ecological succession (a change in the habitat and collection of species over time, e.g., from a grassland to a forest) and range shifts (changes to the geographic distribution of a species, e.g., in response to climatic change). Further, change is the heart of the adaptive cycle that underlies much of ecology (Sundstrom & Allen, 2019).

When applying water quality monitoring information to management, the key questions are what changes exist, which are important (e.g., versus changes that are within the natural variability of the system being managed), and how do we respond to them? These questions imply value-based judgements that require recognition of whose priorities are represented. Management of water must recognize that ecosystems are diverse. They are comprised of physical domains, biota, and interactions between them; they are complex, open, adaptive, hierarchical, and integrated, characterized by non-equilibrium (Kay, 1999; Funtowicz & Ravetz, 1993; Jones, 2016). The need to incorporate systems thinking in the science and management of complex social-ecological systems (Funtowicz & Ravets, 2003) implies a need to understand the potential influences and roles each of us may have in problem creation, identification, and solution. Therefore, this dissertation consciously considers value systems and diverse perspectives as part of its pursuit to diversify the practice of water quality monitoring; however, the implications of this pursuit may be further reaching than influencing water quality monitoring practice in the study area alone. Funtowicz and Ravetz (1993) stated:

> The reductionist, analytical worldview which divides systems into ever smaller elements, studied by ever more esoteric specialism, is being replaced by a systemic, synthetic and humanistic approach… based on the assumptions of unpredictability, incomplete control, and a plurality of legitimate perspectives… With mutual respect among various perspectives and forms of knowing, **there is a possibility for the development of a genuine and effective democratic element in the life of science** [emphasis added] (p.731-741).

The above quote and preceding sections highlight a need to consider diverse perspectives and ways of knowing to propose approaches – e.g., regarding the production of freshwater quality monitoring information and its application to policy, management, and/or decisions – that will be effective in today's complex social-ecological systems. A grander hope is that the proposed changes to existing social structures, power dynamics, and government-community relations could one day catalyze more democratic science endeavors across disciplines.

1.4 Study context

1.4.1 Study area

This research focuses on the interface of the Grand River and Lake Erie (Ontario, Canada). The Grand River – named O:se Kenhionhata:tie ("Willow River") in the Mohawk language – drains Southern Ontario's largest and most populated watershed, at approximately 6,800 km^2 (roughly the size of Prince Edward Island). Its headwaters are in Dufferin County, from which the Grand River's waters run approximately 310 km[2] to Port Maitland in the eastern basin of Lake Erie – named Erielhonan in the Iroquois language, meaning "long tail". The watershed is home to roughly 1 million residents who primarily reside in Kitchener, Waterloo, Guelph, Cambridge, and Brantford. The watershed consists of 39

[2] The combined length of all contributing rivers and streams is closer to 11,000 kilometers.

municipalities located at least in part within its boundaries, in addition to two First Nations territories. First Nations communities are the Six Nations of the Grand River First Nation—Canada's largest Indigenous community by population, and the only place in North America where all six Iroquois nations reside—and the Mississaugas of the New Credit First Nation. In addition, about 80 species at risk are found in the watershed, which also boasts a world class fishery; more than half the fish species in Canada are found in the watershed (GRCA, nd).

As the research was conceived from concerns of nutrients and algae (*Cladophora)*, the interface's boundaries are based largely on a plume study conducted by the Grand River Conservation Authority (He et al., 2006; Loomer & Cooke, 2011). Other sources that influenced the delineation of our study area include the area described by the Grand River-Lake Erie Working Group (2012; Kuntz, 2008; MacDougall & Ryan, 2012), and a review of long-term (>40 years) algae monitoring in Lake Erie (three studies: Higgins et al., 2005; Malkin et al., 2008; Stewart & Lowe, 2008). Long-term studies showed *Cladophora* was nearly always found at ≤10 m depths (Higgins et al., 2005; Malkin et al., 2008; Stewart & Lowe, 2008). In addition, the study area described below is not just relevant to issues of nutrients and algae. This is the area of river-lake influences (hereon referred to as 'the interface'), which includes influences of nutrients and other factors on algae growth, but which is not defined entirely by those interactions.

From upstream to downstream, the study area (Figure 1) includes the lower 32 km of the Grand River from Talbot Road/ON-3 in Cayuga, to the river's mouth in Port Maitland, and out into Lake Erie to the 10 m bathymetry line[3] (which varies from 1.5-5 km distance from the shore: Higgins, 2005b). This section of the Grand River is a high order stream (Strahler classification 7) that presents immense logistical challenges for monitoring. The nearshore boundary extends from Evan's Point about 18 km west of the river's mouth to Mohawk Point and about 10 km east. The extent and direction of the area of Lake Erie's nearshore affected by Grand River discharge (e.g., the plume) varies with the current. The study area generally aligns with the Grand River Conservation Authority's watershed management boundary, which includes Lake Erie's waters within 5 km of the shoreline; however, many of the dissertation's results and discussions (including implications) apply beyond the study area.

---

[3] The extent to which the study area reaches into Lake Erie is not important to its delineation for the purpose of this dissertation as monitoring sites are not determined; however, the range for *Cladophora* is included as a recommendation for defining this boundary in future research that strives to design a monitoring program based on the recommendations and conclusions of this work. Also, the aquatic area was included to offer context for collaborations with local communities who were asked to describe their relationships with the waters of the Grand River and Lake Erie.

Figure 1. The study area (red solid and dashed lines) and its position within the Haldimand Tract (e.g., treaty territory: green dotted line). The dashed line is approximately 1.5 km offshore as a minimum estimated location of the 10 m bathymetry line.

The interface is limited in normal estuarine ecological function by human settlements (e.g., removal of wetlands) and the Dunnville dam (and its fishways), which impedes movement of commercial species like Walleye (*Sander vitreus*) and Species-at-Risk like Lake Sturgeon (*Acipenser fulvescens*). Land use in the lower watershed is largely rural, though urban areas and mixed industry use – e.g., aquaculture, mining, manufacturing – exist as well (McSweeney, 2017). The study area is geographically defined by one municipality, Haldimand County, and is situated within the Haldimand Tract (the green dotted line in Figure 1). The Haldimand Tract is a land grant of 10 km on either side of the river, from its headwaters to Lake Erie, that was given to the Six Nations peoples by King George III in the Haldimand Treaty of October 25, 1784, for their alliance with Britain during the American Revolution (Six Nations Council, 2008). To recognize the Six Nations' historical authority of the waters and surrounding lands, of which only 5% remains in their hands via Federally titled lands (Reserve No. 40), the community is incorporated into the study area.

The Six Nations are comprised of Iroquois (Haudenosaunee and Neutral) peoples of the Mohawk, Oneida, Onondaga, Cayuga, Seneca, and Tuscarora (Six Nations Council, 2015). The village of Ohsweken (the reserve's main economic area) is about 200 m above sea level and covers an area of about 75 km^2. The Reserve is about 183 km^2. There are about 12,271 people living on-reserve, though full Band membership is approximately 25,660 people (Six Nations Council, 2013). Elected members of the Six Nations Band Council govern the Reserve, alongside the Grand Council of the Haudenosaunee Confederacy. In addition, the New Credit Reserve (Reserve No. 40A and 40B) is a 25.13 km^2 sub-section of the Six Nations Reserve, offered to the Mississaugas by the Six Nations after attempts to relocate elsewhere failed (MNCFN, nd). New Credit Band membership consists of about 2,295 Ojibwa people, of which nearly two-thirds live off-reserve (MNCFN, nd).

Downstream of the Six Nations Reserve is Haldimand County. Haldimand County has a population of approximately 46,000 people (about 5% Aboriginal) in an area approximately 1,252 km^2. Its six urban centers are Cayuga, Caledonia, Dunnville, Hagersville, Jarvis and Townsend. Caledonia is the furthest upstream, followed by Cayuga, and then Dunnville at the interface; Hagersville, Jarvis and Townsend are within the County but are not located on the Grand River. Compared to other areas of Ontario, a larger percentage of the resident labor force work in water-dependent industries like agriculture, forestry, fishing, and hunting (McSweeney, 2017). Tourism in the region also thrives on recreation and leisure opportunities that come with clean, usable watercourses. The Dunnville Mudcat Festival is the area's biggest event, attracting about 60,000 visitors each year – many of whom consider the town's mascot a highlight of their visit. Muddy, a 50-foot-long channel catfish (*Ictalurus punctatus*) is a symbol of the region's rich fisheries and of the value placed on aquatic ecosystems by County locals (Dunnville Mudcat Festival, 2017).

1.4.2 Water governance in Ontario and Canada

In Canada, waterways situated within a province or territory are the jurisdiction of that region, except waterways in Nunavut and the Northwest Territories, which are governed by Indigenous Services Canada (often co-managed with local Indigenous communities). Authority related to commercial fisheries, navigation, water on federal lands, international relations (e.g., transboundary waters), and creation and management of protected areas lies with the Government of Canada, primarily through Environment and Climate Change Canada (ECCC, 2020a). Federal lands include National Parks, federal facilities (e.g., office buildings, labs, penitentiaries, and military bases), and First Nation reserves. Some responsibilities are shared between national and subnational authorities, such as agriculture and human health. Certain aspects of environmental protection are also shared. For example, while each of the provinces and territories have pollution control powers, Federal legislation sometimes overlaps in this authority – e.g., the *Canadian Environmental Protection Act, 1999* and the *Fisheries Act, 1985* both contain lists of deleterious substances related to water resource protection; in Ontario, the Ministry of Environment and Energy's *Policies and Guidelines of Water Management* document also governs pollutants (MOEE, 1994).

After the Canadian federal election in October 2019, the mandate letter provided to the Minister of Environment and Climate Change included the following: "With the support of the Minister of Agriculture and Agri-Food, create a new Canada Water Agency to work together with the provinces, territories, Indigenous communities, local authorities, scientists and others to find the best ways to keep our water safe, clean and well-managed (Trudeau, 2019)." Development of the Canada Water Agency demonstrates national prioritization of fresh water in Canada, as well as for interagency cooperation at all levels of government (including Indigenous; ECCC, 2020a). A discussion paper published by Environment and Climate Change Canada in December 2020 also highlighted the opportunity for the Canada Water Agency to help the Government of Canada advance reconciliation with Indigenous peoples (ECCC, 2020a). The Government of Canada also launched PlaceSpeak, an online engagement platform, to provide information and take consultations regarding the creation of the Canada Water Agency. Public input was accepted via emails and participation in consultation events, a series of national and regional Policy Forums from January 27-February 18, 2021 (ECCC, 2020b). From this feedback, 10 objectives for the federal government and eight main themes (or, 'areas of convergence') emerged, which are described in-depth in the government's *What We Heard* report (ECCC, 2021). Both this report and the mandate letter focus on the Great Lakes and other large lakes (e.g., Simcoe, Winnipeg); however, at the time of dissertation writing, Indigenous consultations were ongoing and general comments were still being accepted through a study of federal policies and legislation relating to freshwater by the Standing Committee on Environment and Sustainable Development (Freshwater).

Provincial and territorial governments are responsible for most management roles regarding fresh water in Canada. These roles include authorization for water use within their borders, governing drinking water, and managing inland fisheries, aquatic species at risk, and invasive species (ECCC, 2020a). In some regions, as in Ontario, operational responsibility for drinking water and wastewater is delegated to municipalities. Ontario is also unique in that it has watershed-scale management agencies called conservation authorities. Conservation authorities (CAs) are non-profit organizations legislated by the provincial *Conservation Authorities Act, 1990* as of 1946 (note, the original *Conservation Authorities Act, 1946*, was replaced with the more recent Act). They are funded by diverse sources, including municipal levies, provincial and federal grants, and other sources (Conservation Ontario, 2013). The provincial allocation has not increased since the 1990s and has generally decreased until today (Orr, 2019). Ontario has 36 CAs, of which 31 are in southern Ontario.

Until June 2019, their roles were to protect/safeguard, manage, and restore natural areas, develop, and maintain programs to protect life and property from natural hazards like flooding or erosion, provide opportunities for public education, and allow for the respectful enjoyment of both private and shared natural areas (Conservation Ontario, 2013). The Minister of Environment, Conservation, and Parks is responsible for all aspects of the *Conservation Authorities Act, 1990* except for its natural hazard clauses (per Order In Council 1149/2018), which are the powers of the Minister of Natural Resources and Forestry (per OIC 1158/2018).

Legislation passed in June 2019 greatly reduced the scope of mandatory programs and services delivered by conservation authorities to four basic management functions: risk of natural hazards (which includes permitting for development), lands titled to conservation authorities, source water protection, and other endeavors per the regulations (to be prescribed). In addition to these mandatory programs and services (determined by the Province) CAs may advise that other programs and services be implemented (determined locally). Non-mandatory programs and services that address community priorities are determined by a CA's Board of Directors. Services provided to non-CA member municipalities, e.g., services related to the *Clean Water Act, 2006* are determined by agreements with those municipalities and are to be funded by municipal levy (Fox, 2020).

As of December 2020, the Province has now implemented mandatory permit issuance for development meeting their criteria, and the Minister of Natural Resources and Forestry is now able to override permit decisions by CAs. Developers can appeal administrative fees for services provided by conservation authorities, which limits programming that municipalities and Cas may wish to pursue for the interest and benefit of local communities (e.g., assisting landowners to improve broader environmental quality through actions on their property).

Announced in December 2020, a Working Group was assembled in early 2021 to help implement changes these changes. This Group is chaired by Hassaan Basit, President and CEO of Conservation Halton, and will provide input to help the province develop regulations on:

- The mandatory core programs and services CAs would be required to provide,
- The agreements between municipalities and CAs and the transition period associated with non-mandatory programs and services, and
- How local members of the community can participate in their CAs through community advisory boards.

In addition to this Working Group, public feedback on regulatory and governance proposals was gathered through the Environmental Registry from May 13 to June 21, 2021. As the water management situations in Ontario (re: conservation authorities) and in Canada (re: the Canada Water Agency) are still evolving, research implications discussed in this dissertation may differ from actual outcomes.

The Grand River Conservation Authority is the management agency responsible in the study area (originally organized as the Grand River Conservation Commission in 1934, which amalgamated with the Grand Valley Conservation Authority in 1966 to form the present-day CA); however, decision-making powers lie almost exclusively with the Province of Ontario. Local municipalities and community groups (e.g., Friends of the Grand River, Trout Unlimited) help to monitor and advocate for the waters and their organisms (especially fish), educate the public, and implement restoration projects. Further, most of the area surrounding the lower Grand River is either First Nation Reserve or private property (residential, agricultural, or industrial), and so certain decisions lie with these stakeholders.

In Lake Erie, the main Federal and Provincial authorities are Environment and Climate Change Canada, Fisheries and Oceans Canada, the Ontario Ministry of Environment and Climate Change, and the Ontario Ministry of Natural Resources and Forestry. Other ministries like the Ontario Ministry of Agriculture, Food, and Rural Affairs also have important roles in keeping the water system functional (e.g., regarding nutrients and other contaminants from agriculture). Municipalities along the shore have some decision-making powers, though these are typically more restricted than in the Grand River due to binational agreements and responsibilities.

Binational agreements governing the Lake include the Great Lakes Water Quality Agreement, the Lake Erie Lakewide Action and Management Plan, and the Lake Erie Binational Nutrient Management Strategy. In 2014, the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health was implemented to support integrated and collaborative achievement of commitments under the Great Lakes Water Quality Agreement (primarily related to nutrient reductions). A new Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health has been drafted and will replace the 2014 Agreement once finalized in 2021. Further, the Drinking Water Source Protection Plan for the Grand River Source Protection Area is a mandate from the Federal government following binational commitments related to Lake Erie.

It is worth noting that dozens of other initiatives exist in support of water monitoring in Ontario. For example, the Ontario Stream Monitoring and Research Team (SMART) networks provide a forum for exchange of ideas, data, knowledge, and science about flowing waters. There are three regional networks of partners: Southern Ontario Stream Monitoring and Research Team (SOSMART), Western Ontario Stream Monitoring and Research Team (WeSMART), and Stream Monitoring and Research Team Eastern Region (SMARTER). DataStream, by Gordon Foundation, is a citizen science database that collaborates with regional authorities to utilize the data and covers two-thirds of Canada's water quality data (with plans to increase dramatically in upcoming years). Similarly, non-profit organizations like Swim Drink Fish and Water Rangers strive to empower community members to collect water quality data, providing easy-to-use apps and databases for standardized entry, verification, and sharing of citizen data. Academia and the private sector also do significant research and contribute to many initiatives (including on-the ground action and community-based[4] water monitoring; ECCC, 2020a).

Indigenous persons and communities also have fresh water-related rights under many historic and modern treaties and self-government agreements. Section 35 of the *Constitution Act, 1982*, recognizes and affirms existing aboriginal and treaty rights of Indigenous peoples, which can be affected by freshwater management decisions. Although First Nations, Métis, and Inuit peoples have different relationships with water, there is a common sense of urgency to address a multitude of challenges (e.g., drinking water) due to water's socio-economic, political, and cultural importance (ECCC, 2020a). Indigenous peoples also contribute to local, regional, and transboundary freshwater management in various ways (e.g., sitting on management, steering, or advisory boards).

1.4.3 Introduction to conventional water quality monitoring

The main objectives of most water quality monitoring programs are to assess current states, identify change, predict risks from potential effects, and/or to inform a management response (Anderson et al., 2003; Brack et al., 2009; Jones, 2016). Two approaches to assessment are commonly used to understand environmental change: stressor-based and effects-based. Stressor-based assessments first identify potential causes of environmental stress, then address potential effects (Dubé et al., 2013). Monitoring undertaken by industry, perhaps as part of an environmental assessment or permitting process, is usually an example of a stressor-based approach. Effects-based assessments first identify effects/impacts, typically by measuring responses in indicators relative to reference conditions, then work to identify related stressors (Dubé et al., 2013).

The basic questions of any monitoring program are what to monitor and why (e.g., an effect has been observed or a stressor identified, providing motivation to monitor water quality), followed by where, when, and how to monitor (Lindenmayer & Likens, 2009; Ball, Noble, & Dubé, 2012; Greig & Prickard, 2014; Arciszewski & Munkittrick, 2015). Some monitoring, particularly programs tied to environmental assessment processes, answer the questions of what to monitor which indicators to use through identification of valued ecosystem components (VECs), also known as valued components (Bidstrup, Kørnøv, & Partidário, 2016; Ball, Noble, & Dubé). These are defined as aspects of ecosystems that have "scientific, social, cultural, economic, historical, archeological, or aesthetic importance (CEAA, 2016)." These may be identified by community or stakeholder groups, or within managerial groups. A recommendation from Dubé et al. (2013) to generate standardized, regional VECs for monitoring

[4] "Community-based" and "community-led" are used interchangeably in this dissertation to described monitoring undertaken and driven by local community members and organizations. Chapter 8 and 9 offer further definitions and discussion.

purposes may not be possible, or ecologically relevant on a local scale. Due to differences in regulatory requirements, water quality standards, land use, and a variety of other biophysical and social dimensions, water management and monitoring must be tailored to the locality (Behmel et al., 2016).

1.4.4 Water quality issue of concern: *Cladophora* in Lake Erie's eastern basin

The Laurentian Great Lakes have experienced decades-long challenges with water quality, including eutrophication – unbalanced nutrient cycles resulting in algal blooms and hypoxia (areas of low oxygen; initially in Lake Erie, now across the Great lakes). Eutrophication has been attributed to many factors, including nutrient cycling, land use changes (e.g., urbanization), increases in agricultural activity, climate change, and population increases (Vollenweider, 1968; Vitousek et al., 2009; Liu et al., 2012; Jeppesen et al., 2005). Phosphorus, the main nutrient involved in eutrophication, is a biologically active element that typically acts as a biological limiter, as it does not naturally occur in high quantities (Schindler, 1974). In aquatic systems, phosphorus is measured in different forms: particulate, dissolved (soluble reactive), and the sum of both (total phosphorus). Phosphate (PO_4^{3-}) is a dissolved ion that is formed by the enzymatic hydrolysis (i.e., digestion/use) of dissolved and particulate organic phosphorus by microorganisms. Phosphate is the only form of phosphorus consumed/used by bacteria, phytoplankton, and macrophytes (Correll, 1998). Historical[5] contributors of phosphorus to Lake Erie included agriculture (56,000 t/yr), municipal discharge (7,900 t/yr), industrial discharge (2,000 t/yr), septic systems (<2,000 t/yr), and aquaculture (500 t/yr) (Carey, 2007).

In the late 1960s and 70s, an influx of phosphorus in Lake Erie's western basin caused an overproduction of algae (e.g., *Anabaena* spp., *Aphanizomenon* spp., *Microcystis* spp., and *Cladaphora* spp.), often followed by hypoxic 'dead zones' (Hartig et al., 2007; Scavia et al., 2014; Watson et al., 2016). *Cladophora* is the most abundant alga in alkaline streams worldwide and is widely regarded as the most important harmful filamentous alga of inland waters (Burkholder, 2009). The first formal report regarding nuisance *Cladophora* in the Great Lakes was published in 1848, though references to the algae in Lake Erie exist as early as 1820 (Higgins et al., 2008). Worsening eutrophication resulted in the implementation of initiatives encouraging the collaboration of binational stakeholders to restore lake conditions. These included the Great Lakes Water Quality Agreement in 1972, Lake Erie Region Source Protection Committee in 2007, and the Lake Erie Binational Nutrient Management Strategy in 2011.

By the 1990s, many sources of phosphorus were thought to have been eliminated after reductions were made in laundry detergents and sewage treatment plant effluents across the Great Lakes (Nicholls & Hopkins, 1993). In the decade prior, a decline in *Cladophora* biomass in Lakes Ontario and Huron were

[5] t/yr figures presented here are from 1996 data (Carey, 2007).

measured at up to 80%; however, there is no biomass reduction data for Lake Erie. Then, invasive zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) took hold across the Great Lakes, altering their ecology (Hartig et al., 2007; Higgins et al., 2008; Watson et al., 2016).

Starting in 1995, there has been a resurgence of *Cladophora* in Lakes Erie, Ontario, and Michigan, coupled with an increase in complaints from residents (Higgins et al., 2008). In the early 2000s, *Dreissena* near the shores of Lake Erie were found to trap phosphorus, concentrating it (>10μg/L) in colonized areas (Carey, 2007). This concentrated phosphorus was later released as soluble reactive phosphorus in a phenomenon known as the "nearshore shunt" – exacerbating the effects of other pre-existing sources of soluble reactive phosphorus and other nutrient forms (Hecky et al. 2004; Carey, 2007). Resulting *Cladophora* proliferation, although non-toxic (compared to cyanobacteria), caused a diversity of social and economic problems. For example, nuisance benthic algae foul beaches. The decomposing material is aesthetically displeasing, causes odours, creates breeding sites for biting flies, and incubates microbes like *Escherichia coli* and *Clostridium botulinum* (Lake Erie Millennium Network, 2016). As these issues worsened, hydrological monitoring in Canada had been decreasing, creating a void of data needed to understand biogeochemical exchanges that occur between land, water, and air (Shiklomanov, Hammers, & Vorosmarty, 2002). Today's prioritization of water quality is motivated in part by worsening nutrient conditions in the Great Lakes. For example, the record harmful algal bloom of 2015 in western Lake Erie left roughly half a million people without drinking water for days to weeks (Seewer, 2017; NOAA, 2017). In autumn of 2017, Lake Erie's algal blooms were the worst seen in years (Seewer, 2017; NOAA, 2017).

Quantification of *Cladophora glomerata* in northeast Lake Erie has been pursued by few due to the complex factors involved. Higgins et al. (2005), who monitored the area from 1995 to 2002, concluded that midsummer areal coverage in shallow areas (up to 5m in depth) ranged from 4-100% coverage, with a median coverage of 96%. Algae production began in early May and peaked in mid-July, growing to a maximum seasonal biomass of 940 g/m^2 dry mass (DM), with a median DM of 171 g/m^2 (Higgins et al., 2005). A mid-summer die-off followed the biomass peak, which reduced aerial coverage to <10% and mean biomass to <1 g DM/m^2. The length of filaments averaged 33 cm in the peak period, then decreased to <1 cm following (Higgins et al., 2005). More recently, biomass densities have reached only 700g DM/m^2, with the greatest biomass occurring at depths of 0.5-2 m (Lake Erie Millennium Network, 2016). While *Cladophora* dominates the shoreline, it is not the only nuisance benthic alga found in the Lake; *Lyngbya wollei* can be locally abundant at times. *Chara*, *Spirogyra,* and others are also common (Lake Erie Millennium Network, 2016).

A study using the Great Lakes *Cladophora* Model in Lakes Huron and Michigan concluded phosphorus controls implemented under the Great Lakes Water Quality Agreement were effective in offshore waters, though nearshore areas were not much improved (Tomlinson et al., 2010). Past research may provide some insight: the Canale and Auer Model (Auer, 2005 – their conceptual framework was developed in 1982 for *Cladophora* in Lake Huron) suggests a nonlinear response of *C. glomerata* growth to reductions in phosphorus loading, in part due to so-called luxury phosphorus uptake (Burkholder, 2009). Luxury uptake is the storage of phosphorus in living things in the form of either acid-soluble or acid-insoluble polyphosphate (Powell et al., 2008). Acid-soluble polyphosphate is used actively in an organism's metabolism, whereas acid-insoluble polyphosphate is stored for times when external/environmental sources of phosphorus become limiting.

Up to 30% of Lake Erie's shoreline – including nearly the entire eastern basin – is affected by benthic algae (Lake Erie Millennium Network, 2016). The lack of improvement in nearshore waters was partially attributed to ecosystem perturbation by *Dreissena* colonization, resulting in conditions of increased photic (light) penetration (Tomlinson et al., 2010). Now, algal overproduction across all three basins in Lake Erie has resulted in the lake's re-eutrophication, driving authorities to look 'upstream' to its tributaries to restore water quality. The Canada-Ontario Lake Erie Action Plan (ECCC, 2018) highlights phosphorus reductions in the Grand River watershed as the primary strategy for addressing algal issues in Lake Erie's eastern basin. Of the two main nutrient contributors to Lake Erie – the Thames and Grand Rivers – only the Grand River empties directly into Lake Erie. Further, phosphorus from the Thames contributes to cyanobacteria and hypoxia in the central basin, while phosphorus from the Grand contributes to *Cladophora* in the eastern basin. An average of 340-373 metric tonnes per annum (MTA) of total phosphorus – 35% of the eastern basin's total loading – came from the Grand River between 2003 and 2013, with an increase in nutrient contributions of approximately 3.1% ($p > 0.1$) (Maccoux et al., 2016; ECCC, 2018). This makes the Grand River the fourth largest contributor of total phosphorus to all of Lake Erie – the largest contribution of Canadian tributaries – followed by the Thames River, which contributes an average of 323 MTA (Maccoux et al., 2016). Sources of nutrients, especially phosphorus, in the Grand River watershed include wastewater discharges from municipalities, industry, and small septic systems, urban and rural (including agricultural) runoff, and invasive species like *Dreissena*. The impacts of invasive species are not fully understood, though current research continues to improve our understanding of their influence. Much of the research considering nutrient-algae-invasives relationships is focused on dreissenids. The Canale and Auer Model mentioned previously was later modified as the *Cladophora* Growth Model to consider effects of mussel invaders (Burkholder, 2009; Higgins, 2005a). The model was also used to estimate the total phosphorus taken up by *Cladophora*, and its significance to nearshore and overall phosphorus dynamics in the eastern basin of Lake Erie.

In addition to the release of soluble reactive phosphorus, the presence of dreissenid mussels provides additional 'substrate' for algae to attach to (Dayton, Auer, & Atkinson, 2014). Dreissenids clarify the water, extending the reach of the photic zone (Auer et al., 2010; Dayton, Auer, & Atkinson, 2014). Higgins et al. (2005) quantified the impact of dreissenids on *Cladophora*, concluding the increased photic zone increased depth-integrated biomass by a factor of 1.3. Further, Malkin et al. (2008) estimated that dreissenids in Lake Ontario extended the maximum depth of *Cladophora* growth from 5.2 m in 1972 to 10.4 m in 2005. In that study, biomass increase due to dreissenid presence was a factor of about 2.5 (Malkin et al., 2008).

Despite many knowledge gaps, we know that multiple factors contribute to the phenomenon of *Cladophora* proliferation in Lake Erie's eastern basin. Higgins et al., (2005) suggested levels of phosphorus and sunlight, both affected by dreissenid colonization, were determining factors. Lake Erie Millennium Network (2016) concluded production is greatest in shallow, clear, nutrient-rich waters where appropriate substrate is available. Lake Erie was found to have considerable amounts of suitable substrate (including masses of dreissenids) and nutrients to support high biomass. Historic research has connected greater phosphorus storage in organisms (in the form of acid-insoluble polyphosphate) to increased ambient pH levels in the environment (Terry & Hooper, 1970; González et al., 1989; Powell et al., 2008). Despite the above examples of research, relationships between nutrients and multiple stressors in the river-lake interface are not well understood (Watson et al., 2016; Annex 10 Task Group, 2016). Also, *Cladophora* growth in Lake Erie is a result of non-point source, basin wide soluble reactive phosphorus concentrations (Lake Erie Millennium Network, 2016). As a result, applying ecosystem-based, watershed-based approaches to research and practice have been increasingly prioritized, as they acknowledge that environmental effects occur across spatial and temporal scales (Carey, 2007).

1.4.5 Current state of knowledge

In the study area for this research, environmental factors (e.g., the waterway's physiography and changing weather patterns) and biological and chemical processes act cumulatively with multiple stressors (Scavia et al., 2014; Watson et al., 2016). Such cumulative relationships contribute to challenges experienced across Lake Erie and the Great Lakes, (Lake Erie LaMP, 2011; Scavia et al., 2014; Watson et al., 2016). For this reason, the Grand River watershed was one case study in the Canadian Watershed Research Consortium (CWRC) (CWN, 2016). The CWRC was convened by the Canadian Water Network to provide a basis for exploring cumulative effects assessment in water monitoring and management using seven case studies from across Canada. As a result of the CWRC, which designed and tested regional cumulative effects assessment frameworks in each node from 2010-2015, there are now insights regarding how conventional monitoring may be adapted to consider cumulative effects on a watershed scale. However, it is worth noting that Consortium research conducted in the Grand River (Servos et al., 2015;

Servos, 2016) focused on the upper and middle sections of the watershed, not the lower portion that is the focus of this research. This dissertation strives to address this gap.

Recognizing the need to align priorities between the Grand River and Lake Erie, the Grand River Conservation Authority convened the Grand River-Lake Erie Working Group. The Group included members from the Conservation Authority, Environment Canada, Ontario Ministries of Environment, Natural Resources and Agriculture, Food and Rural Affairs, and other members whose organisational mandates recognized directives set out in the Great Lakes Water Quality Agreement and the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA). Members met monthly from November 2011 to March 2012. A report by the Grand River-Lake Erie Working Group (2012) identified a Lake Effect Zone comprised of two interacting areas with unique physical, chemical, and biological processes: the river-lake interface (e.g., how far up the river and how far out into Lake Erie) and the portion of Lake Erie's nearshore influenced by the plume of the Grand River (e.g., distance of shoreline east/west of the river's mouth). Uncertainty of river-lake interactions is high in this area; processes that influence its ecology are poorly understood, as are the mechanisms and sources of variability from the Grand River. Knowledge gaps such as these preclude application of a systems approach to identifying linkages between water quality and limiting resource conditions in the Lake Effect Zone (Grand River-Lake Erie Working Group, 2012). However, that phosphorus is a key determinant of ecosystem health in the Lake Effect Zone is clear (Ryan et al. 2003; Higgins et al. 2005; Charlton, 2009).

Based on the limited knowledge available at the time, the Grand River-Lake Erie Working Group (2012) described a framework for identifying indicators applied to the Lake Effect Zone. 'Aquatic Species of Interest' were identified for their ecological importance, underperformance, or potential for rehabilitation or reintroduction; all were limited directly or indirectly by water quality. These species, which functioned as a tool to identify critical water quality needs of the aquatic community (i.e., were not indicators themselves), were Walleye (*Sander vitreus*), Yellow Perch (*Perca flavescens*), Muskellunge (*Esox masquinongy*), Lake Sturgeon (*Acipenser fulvescens*), River Redhorse (*Moxostoma carinatum*), and three species of at-risk freshwater mussels (Mapleleaf or *Quadrula quadrula*, Threehorn Wartyback or *Obliquaria reflexa*, and Fawnsfoot or *Truncilla donaciformis*). Six water quality indicators relevant to the Aquatic Species of Interest were then selected for monitoring: phosphorus, turbidity (or total suspended solids), temperature, dissolved oxygen, flow regime, and macrophyte community (Grand River-Lake Erie Working Group, 2012). Further, information compiled as part of the systems approach for indicator identification in this framework also highlighted the ecological importance and sensitivity of the Grand River's coastal wetlands – most of which are in an area of five individual wetlands referred to as the Dunnville marsh complex. They are designated as provincially significant and are collectively one of the last remaining large river mouth marshes in Southern Ontario. Improvements to the ecological health and function of these areas and adjacent floodplains would likely result in improvements to other areas.

The upper Grand River research (Servos et al., 2015; Servos, 2016), conducted from 2012-2014 as part of the CWRC, produced a biomonitoring framework for assessing cumulative effects. Servos' (2016) study examined biological indicators of four categories – (1) nutrients (e.g., nitrate) and stream metabolism (via oxygen concentrations and isotopes), (2) macroinvertebrate community composition, (3) fish diversity and abundance, and (4) fish responses (e.g., relative gonad and liver sizes, fish condition) – to detect ecological change across the Upper Grand River and assess and manage cumulative effects at the watershed scale. Ecological change was possible to discern by comparing the biological indicators against their contexts of natural variability. The biological measures included in the study demonstrated that each endpoint measured different ecological processes at different scales. Therefore, multiple indicators with known spatial and temporal variability and biological complexities should be used (Servos, 2016).

Although each of the CWRC nodes were focused on cumulative effects, each node has its own issues of priority to monitoring agencies. In the Grand River watershed, nutrients are a focus of local, regional, and national water managers, which the Grand River CWRC work by Servos et al. (2015) contributed to. Nutrients and dissolved/suspended solids from the Grand River enter Lake Erie's eastern basin via a plume of river water that influences biogeochemical processes in the nearshore around the Grand River's mouth (He et al., 2006). Plume movement is primarily controlled by wind-driven coastal currents. Southwesterly winds at 10-15 km/h (up to 25 km/h) are common; however frequent reversals in these currents may limit the extent of the plume and may result in continuously turbid waters/resuspended sediment in the vicinity of the river's mouth (Higgins et al., 2005; He et al., 2006). Nutrients from the plume contribute to the growth of benthic green algae like *Cladophora glomerata* (Loomer & Cooke, 2011, p.iv; He et al., 2006).

From 2015-2018, Greenland Technologies Group (GREENLAND®) and the University of Guelph were retained by the Government of Canada to undertake an "Evaluation of Policy Options to Achieve Phosphorus and Nutrient Reductions from Canadian Sources to Lake Erie (Greenland, 2020)." As part of this evaluation, they completed a review of efforts previously undertaken to understand the influence of the Grand River on Lake Erie's eastern basin to support Lake Erie's remediation. Efforts identified in this review include (*The Project*, nd):

- Ongoing work related to the Grand River Simulation Model, first developed in 1978, for water quality forecasting and water management planning.
- Ongoing stormwater management planning that looks at sediments and associated nutrients.

- State of Water Quality in the Grand River watershed study by the Grand River Conservation Authority (2011) – updated monitoring data from the 2003-2008 report
- Haldimand Rural Water Quality Program (2012) – projects include livestock access restriction, erosion control structures, tree planting/stream buffers, sediment basins/wetland creation, etc.; targeted at rural landowners, mostly farmers.
- Agricultural best management practices review by the Great Lakes Nutrient Initiative (Environment Canada, completed in 2013) – incorporated climate change scenarios for use in the Grand River Water Management Plan to identify representative scenarios in which to evaluate best management practices.
- Cost/benefit analysis of phosphorus management alternatives in the Grand River watershed by Environment Canada (completed in 2013) – developed the Phosphorus Management Decision Support Tool, which went beyond a conventional cost/benefit analysis to also consider distribution among stakeholders, forecasting benefits and costs over a 20-year planning horizon.
- Two updates of the Grand River Water Management Plan, which had not been updated since 1982:
    - Grand River Water Management Plan (Appendix A in 2012 report) presents a framework for identifying indicators of water resource conditions in the interface (report by the Grand River-Lake Erie Working Group).
    - Grand River Water Management Plan (Appendix C in 2014 report) presents a cost-benefit analysis of improved phosphorus management using and ecological goods and services approach.
- Numerous engagements of diverse stakeholders over the years (especially in the last decade).

Improving the knowledge base related to nutrients and algae in Lake Erie was one category of action per the Canada-Ontario Lake Erie Action Plan (ECCC, 2018). Two of the action groups within this category are to conduct monitoring and modelling, and to conduct research to better understand nutrient dynamics in the Lake Erie basin. Regarding monitoring, the Grand River was highlighted as a priority for understanding river-lake dynamics. Ontario's Great Lakes Nearshore Monitoring Program and Canada's Great Lakes Nutrient Initiative were implemented (and are still developing) in response to the need for more information (ECCC, 2018).

1.4.6 Research gaps

1.4.6.1 Gaps identified through initial practitioner consultations

Water managers and subject matter experts, who represented different organizations and governance levels in Ontario, collectively suggested there is a need to explore approaches for generating, sharing, and applying knowledge about the state of the river-lake interface ecosystem. Some individuals suggested there is little work being carried out due to logistical challenges (e.g., large, fast-moving river), while others suggested there is likely enough work being carried out but not coordinated or shared between government agencies and other organizations (e.g., Grand River Conservation Authority). Further, one consulted water manager recognized the importance of the First Nations communities in the watershed and the lack of monitoring from non-Indigenous agencies on reserve – a result, in part, due to solely Federal jurisdiction and apparent lack of action. The same manager (and others thereafter) confirmed there was little, if any, engagement of these communities in water quality monitoring, management, and decision-making, except for the inclusion of an Indigenous representative (e.g., the Wildlife Manager) at regular Western-centric meetings.

1.4.6.2 Gaps identified from the literature

The previous sections outlined clear theoretical and applied gaps this research might address, including needs to:

1. overcome capacity limitations through coordination of monitoring efforts (Arciszewski & Munkittrick, 2015),
2. assess the state of knowledge (e.g., regarding nutrients and *Cladophora*) in the river-lake interface,
3. recognize the subjectivity of data (and/or knowledge) interpretation (Greig and Prickard, 2014),
4. address value systems and subjectivity in monitoring and management questions and processes (e.g., what to monitor, what does it mean, what should we do about it – e.g., Hume 1739; 1978; Kay & Schneider, 1994) and share examples of how improved processes were operationalized (Stephenson et al., 2017),
5. consider how First Nations communities may be more involved in water quality monitoring and management, which requires the use of decolonizing methodologies and recognition of different ways of knowing (Funtowicz & Ravetz, 1993; Smith, 1999; Funtowicz & Ravetz, 2003),
6. generate knowledge regarding river-lake interactions – including identifying linkages between water quality and limiting resource conditions in the Lake Effect Zone,
7. generate knowledge regarding relationships between nutrients and multiple stressors in the river-lake interface (Watson et al., 2016; Annex 10 Task Group, 2016), and
8. prioritize an understanding of non-point sources of basin wide soluble reactive phosphorus concentrations in the Grand River watershed (Lake Erie Millennium Network, 2016; ECCC, 2018).

The dissertation narrative was built on these needs in two ways: first, by characterizing current practice to identify potential areas of improvement and recommendations for acting on those opportunities (e.g., needs #1 and 2 in the list above – addressed in Part 2 of the dissertation), and second, by explicitly discussing the subjectivity of water quality monitoring (e.g., needs #3-5 – discussed in Part 2 but addressed primarily in Parts 3 and 4 of the dissertation). The dissertation narrative is then pulled together to determine a potential way forward in Part 4. The dissertation narrative focuses on needs #1-5 in the list above, as extensive collaborative work by practitioners to address needs #6-8 was already underway during the formation and execution of this research, e.g., Grand River Conservation Authority Fisheries Management Plan revisions (including priority areas called 'best bets'), Ontario's Great Lakes Nearshore Monitoring Program implementation, and Canada's Great Lakes Nutrient Initiative pilot program (Smith & Wright, 2001; ECCC, 2018).

By addressing the gaps described above, the research is expected to make timely contributions by way of:

- Building on knowledge and practice from across Ontario and Canada to recommend improvements in the practice of water quality monitoring and its connection with management.
- Focusing on processes for collaboration and coordination within monitoring, rather than on monitoring itself.
    - Note: early consultations and literature review suggested monitoring protocols are generally well-established and the need to address them is secondary to the need to determine a process for working together in monitoring and management.
- Demonstrating potential approaches for engaging with diverse persons and what may come out of such collaborations.
- Proposing a framework for moving the practice of water quality monitoring forward to involve more diverse persons and their knowledges.

1.5 Introducing this research

1.5.1 Purpose

The purpose of this dissertation is to enable the participation of more diverse persons in the gathering of water quality information, and to encourage managers to supplement their science-based evidence with the diverse ways of knowing that emerge from such participation. Water monitoring and management practitioners continue to rely primarily on standard scientific methods that do not always capture the complexity and diversity of the social-ecological systems that are our watersheds (Kay & Schneider, 1994; Becht, 1974; Weber & Schmid, 1995). Kay and Schneider (1994) highlighted the need to evolve conventional science and management. Stephenson et al. (2017) recommend participatory decision-making that recognizes diversity and power dynamics. Soon after, Stephenson et al. (2018) addressed the lack of social considerations in a marine fisheries context by proposing a framework that requires governance to adopt a social-ecological system worldview – likely the greatest impediment for its implementation. They recommended a participatory approach involving expertise reflecting each of the sustainability pillars to achieve success. To address these calls to action, this dissertation presents a philosophical consideration of "whose concerns are evident… [and] whose objectives are paramount (Stephenson et al., 2017, p.1985)."

1.5.2 Aspirations

In this research, I strive to: (1) meaningfully engage with stakeholders and rightsholders throughout the research process (e.g., co-creation); (2) influence improved use of water monitoring data and information in decision making and management; (3) update local priorities (e.g., VECs) for the Grand-Erie interface, many of which have not been updated since the 1990s (Smith & Wright, 2001); and (4) explore approaches for increasing diversity in water quality monitoring. Two of the four aspirations are pursued in specific ways in this research: Aspiration #2, by connecting monitoring to management and decision-makers (e.g., to inform decisions), and Aspiration #4, by involving Canadian and Indigenous community members in water quality endeavors.

The connection of water monitoring to management and decision-making in this dissertation is focused on a recognition of value systems and subjectivity (e.g., what effects are observed and which effects matter for management). Jones (2016) highlights the importance of recognizing subjectivity in the assessment and management of cumulative effects. Kay and Schneider (1994) used systems theory and thinking to describe how social-ecological systems function (i.e., as self-organizing holarchic open systems). Stephenson et al. (2017; 2018) argued sustainability should be embedded into fisheries management. This dissertation does not specifically address water management, as that is beyond the scope of this dissertation; however, water management is recognized as part of a system of generating *and acting upon* knowledge (i.e., monitoring is pointless if no action follows; action refers to management or decision-making). As such, management is necessarily discussed throughout the dissertation chapters, but should be viewed only in terms of its relevance to the broader monitoring process and in consideration of value systems.

1.5.3 Theoretical foundation and research questions

Literature cited throughout this chapter (and this thesis) demonstrates a need to implement systems thinking to understand the potential influences and roles of social, ecological, economic, and governance factors in water quality problem creation, identification, and solution-building (Beck, 2016). Examples of systems thinking applied to freshwater management are emerging (Hipel et al., 2008; Tasca et al., 2019; Dzwairo, Otieno, & Ochieng, 2010), though applications to water quality monitoring remain sparse. Instead, monitoring practitioners in my study area and elsewhere in Canada are working to develop an understanding of cumulative effects (Jones, 2016; CWN, 2016). Each of these developments is important and each presents an opportunity to contribute to theory and practice in PhD research; however, there may be missed opportunities if these trends or needs are only considered independent of one another. As this research developed, it became clear that systems concepts, integration of diverse knowledges with management, and sustainability are inextricably linked and may be most effectively addressed together. This is perhaps best described in the words of Kay and Schneider (1994), who highlighted the importance of social aspects ecosystem science (e.g., monitoring water*sheds*, not just waters), as discussed earlier in this chapter:

> The question on everyone's mind is "what does ecosystem science identify as the main, simple, basic, universal laws which will allow quantitative prediction of ecosystem behaviour and what are the resulting rules for ecosystem management?"
>
> … systems theory suggests that ecosystems are inherently complex, that there may be no simple answers, and that our traditional managerial approaches, which presume a world of simple rules, are wrongheaded and likely to be dangerous.
>
> … If we are going to deal successfully with our biosphere, **we are going to have to change how we do science and management. We will have to learn that we don't manage ecosystems, we manage our interaction with them** [emphasis added] (p.49).

More than 25 years later, we have yet to focus water monitoring and management *interactions* rather than *resources*. Extensive work by the Canadian Fisheries Research Network identified common water quality monitoring and management shortfalls: fragmented and uncoordinated management practice, little integration of social-economic factors, insufficient consideration of cumulative effects, lack of transparency and participation in management, and a lack of process for routine integration of sustainability concepts (Stephenson et al., 2017). The Network then developed a framework for Canadian fisheries to operationalize four pillars of sustainability: ecological, economic, social (including cultural), and institutional (or governance: Stephenson et al., 2018). These pillars – and the people who make up our communities – are implicit in Kay's and Schneider's (1994) emphasis on managing our interactions with ecosystems.

To manage social-ecological interactions, Dr. Henry Lickers – the International Joint Commission's first Indigenous Commissioner – presented a worldview in which recognition of diverse values, sustainability, and the application of holistic thinking are preceded and, thus, contextualized by the pursuit of reconciliation, or improving our relationships with one another (Lickers, 2020). In other words, managing our interactions with the ecosystem requires improved interactions with one another. Lickers (2020) continued this discussion with the suggestion that "science and traditional knowledge need each other to be a whole knowledge system (p.2)." Similarly, Tengö et al. (2014) and others at the Stockholm Resilience Centre suggest Indigenous, local, and Western knowledge systems are different manifestations of knowledge that parallel and complement one another, but are distinct (Bartlett, Marshall, & Marshall, 2012; Tengö et al., 2014; Goodchild et al., 2021). In this spirit, this research effort to promote diversity in study and practice do not imply the presented approaches should replace conventional science, but rather that they should be undertaken in parallel.

This research builds on the works of Funtowicz and Ravetz (1993), Kay and Schneider (1994), and the Canadian Fisheries Research Network (Stephenson et al., 2017; 2018), as well as past work from the Canadian Watershed Research Consortium (CWRC), e.g., Servos et al. (2015), Servos (2016). In addition, as early consultations pointed out, the social dimensions of sustainability[6] are not usually well-implemented despite legislative and policy supports (Stephenson et al., 2017; 2018).

1.5.3.1 Research question and sub-questions

Recognizing the dissertation's four aspirations (Section 1.5.2) and its focus on diversity, the question this research originally set out to answer was: How can current water quality monitoring in the Grand River-Lake Erie interface be strengthened to consider cumulative effects, be co-created by diverse stakeholders and collaborators, be feasible for implementation post-research, and which informs decisions? This question was later modified as follows:

How can cumulative effects water quality monitoring be enabled and involve diverse perspectives in the Grand River-Lake Erie interface?

This question is addressed through discussion about the monitoring design process, its assumptions and underlying philosophical limitations, and exploration of approaches that may contribute to stronger practice. There are three sub-questions within this research question, each of which is tackled by two chapters in this dissertation:

1. What does current monitoring in the interface look like, and what are opportunities for improvement? What can we learn from best practices?

[6] In this dissertation, sustainability is the integration of social (including cultural), economic, ecological, and institutional (including governance) priorities in the pursuit of a better and more just world (Kemp, Parto, & Gibson, 2005; Stephenson et al., 2017).

    a. Chapter 3 (a review of best monitoring practices)
    b. Chapter 4 (interview results about the current state of monitoring)
2. Whose values matter for determining what we measure, and how do we ensure diverse values are considered?
    a. Chapter 5 (the first iteration of a monitoring indicator ranking process)
    b. Chapter 6 (public and Indigenous engagement – arts-based approaches)
3. (How) would cumulative effects monitoring differ from current practice, and what would a strategy for implementation look like in the Grand-Erie interface?
    a. Chapter 7 (a strategy for cumulative effects monitoring in the study area)
    b. Chapter 8 (proposed collaboration framework)

The first and third questions were determined pragmatically – i.e., one could not propose improvements without knowing the current state, and a collaboration framework considerate of cumulative effects requires an understanding of what cumulative effects assessment looks like in the context of monitoring. The second question was posed by Stephenson et al. (2017) and collectively supported by those who consulted on the research and study participants. Thus, the research concept was co-created from the start and evolved due to engagement with diverse parties throughout the five years, from 2016 to 2020.

1.5.3.2 Conceptual framework and epistemological progression

The problems discussed in this research are complex social-ecological challenges that require both applied and theoretical discussions to address (Figure 2):

- **Social**: The social dimension involves the challenge of engaging with community members as identified by practitioners, in addition to acknowledging a complex watershed governance context – which includes three levels of government, binational targets, and Indigenous government and treaties.
- **Ecological**: The recurring ecological issue of prolific *Cladophora* growth in Lake Erie impacts oxygen levels in the process of eutrophication, recreation via the fouling of beaches and boat propellors, and animal and human health when bacterial growth occurs.
- **Applied**: The research has implications for practice as it strives to address the need to better connect water quality science with decision making while also improving capacity, coordination, and collaboration across and within the various agencies involved.
- **Theoretical**: Theoretical components of this work include exploring how to bring Indigenous and western knowledges together, for example practicing "Etuaptamuk" or Two-Eyed Seeing,

understanding how to assess cumulative effects, and developing ways to meaningfully engage with diverse community members.

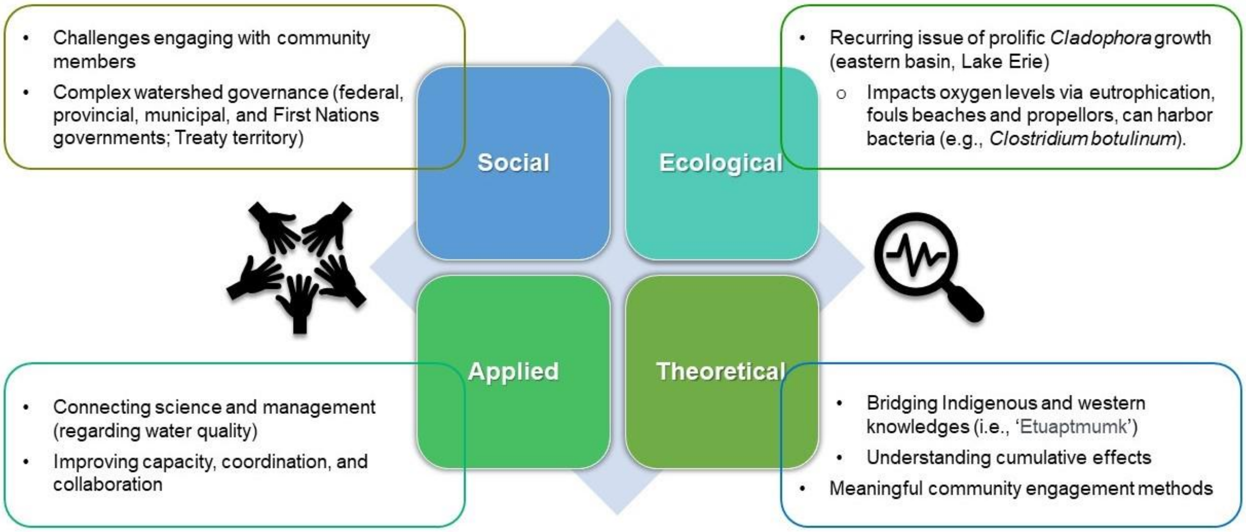


Figure 2. Conceptual framework of the research.

The epistemological concepts regarding water quality monitoring, described throughout this chapter, progress in future chapters to support the final proposed approach presented in Chapters 7-9. This epistemological progression is described in Figure 3.

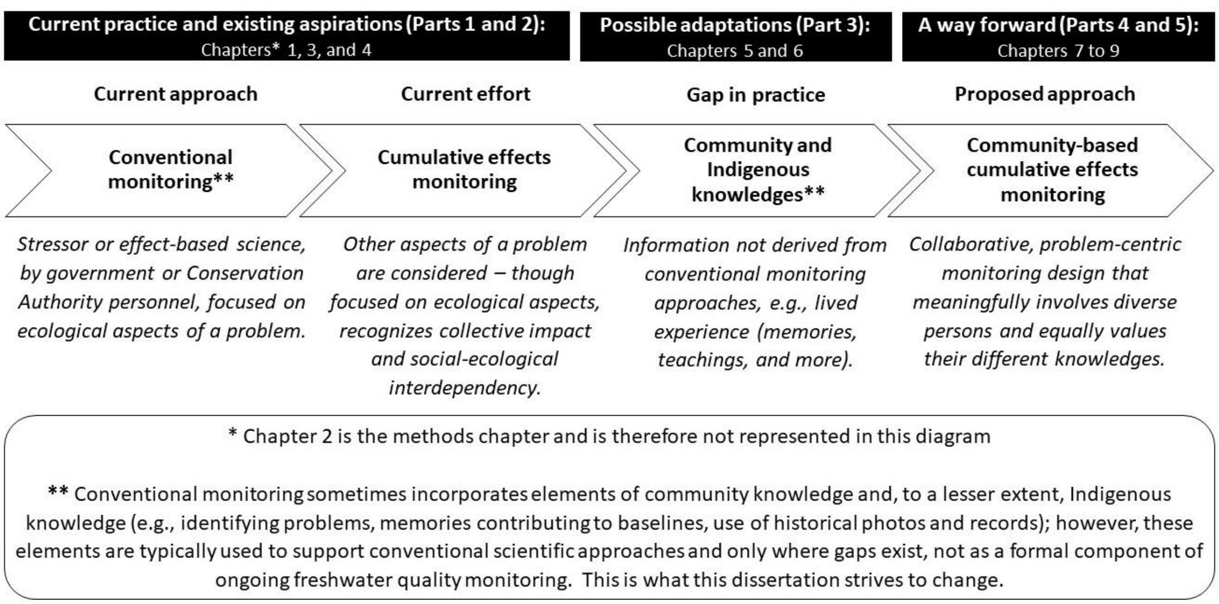


Figure 3. Progression of epistemological concepts throughout the chapters.

1.6 Chapter overview

This dissertation consists of two introductory chapters (Part 1), six manuscripts chapters (Parts 2-4), and a concluding chapter (Part 5). The manuscript chapters are organized into three sections: assessing current practice (Part 2 – two chapters), adapting current practice (Part 3 – two chapters), and a proposed way forward (Part 4 – two chapters).

The first two manuscripts (Chapters 3 and 4, Part 2) consider the ideals of monitoring program design, assess the current state of monitoring practice in Ontario, and present opportunities for improving monitoring in the study area. The next two manuscripts (Chapters 5 and 6, Part 3) consider different adaptations to current practice – first, a small adaptation that incorporates different perspectives when determining what to monitor, and second, a larger adaptation that considers a different approach for more meaningful engagement of diverse perspectives. The final two manuscripts (Chapters 7 and 8, Part 4) consider how cumulative effects monitored may be implemented in the study area and how previous chapter discussions contribute to a proposed framework for collaboration in the design and implementation of water quality monitoring in the study area.

Not all manuscripts represent an entirely unique contribution, e.g., Chapters 3, 4, and (to a lesser degree) 7 primarily assess which aspects of the literature are active considerations in today's context (e.g., there are challenges we have experienced for a long time, but are they all relevant to today, or do certain ones apply more than others?). Chapters 5, 6, and 8 represent novel contributions. A final chapter (Chapter 9, Part 5) synthesizes this dissertation's collective insights, considers questions that emerged from the research, and discusses potential future research. The sub-questions are addressed in Parts 2-4, while the main research question is also addressed in Part 4. Each of the sections and the chapters therein are described in greater detail below.

Part 1: Introduction

Chapter 1 provided context and rationale for the research. This chapter also discussed the research question, and sub-questions, incorporating the themes of sustainability, applying systems approaches, and recognizing diversity (of stakeholders and rightsholders). Chapter 2 presents an introduction to the multimethod approach and each of the methods used within the methodology.

Part 2: Assessing current practice

- *Research sub-question: What does current monitoring in the interface look like, and what are opportunities for improvement? What can we learn from 'best practices'?*

The first manuscript in this dissertation (Chapter 3) defines what 'good monitoring' looks like. The same manuscript highlights opportunities for improvement based on ideals raised by practitioners and the literature. Recommendations from this paper support earlier literature in the suggestion to incorporate more diverse knowledge sources (e.g., Indigenous knowledge) into water quality monitoring program. Chapter 4 builds on the principles described in Chapter 3's recommendations to provide a discussion of the current state of monitoring practice in the study area and across Ontario (i.e., many aspects of monitoring are standardized across the province). Recommendations for improving water quality monitoring and how holistic thinking (e.g., considering different aspects of sustainability) may contribute to positive change are discussed.

Part 3: Adapting current practice

- *Research sub-question: Whose values matter for determining what we measure, and how do we ensure diverse values are considered?*

This section considers how more meaningful engagement might be adapted from existing practice. Chapter 5 presents a process for implementing a relatively small adaptation to current practice that may facilitate the consideration of broader value systems to assess what should be measured in a monitoring program. While the approach may ensure more diverse perspectives are at least acknowledged, other more significant ways to engage such perspectives exist. Although the literature provides support for broader societal goals and inclusion in resource management, there is little guidance on how to move from conventional consultation to more meaningful engagement and collaboration. As this research was co-created, we explored with community partners how to bring the voices of different demographics to water monitoring and management persons. Arts-based engagement is one approach that is accessible to a broader subset of society than is conventional science. This kind of engagement can be implemented or applied in unique and effective ways but is not often used in watershed monitoring programs. Chapter 6 presents two examples of arts-based engagement (e.g., through artistic research) that provide insights into how this approach may serve broader watershed monitoring and management objectives.

Part 4: A way forward

- *Research sub-question: (How) would cumulative effects monitoring differ from current practice, and what would a strategy for implementation look like in the Grand-Erie interface?*
- *Overall research question: How can cumulative effects water quality monitoring be enabled and involve diverse perspectives in the Grand River-Lake Erie interface?*

Parts 2 and 3 of this dissertations provide a standard of monitoring and highlight strengths to maintain, gaps and opportunities for improvement, and different approaches that can be used to adapt current practice. Part 4 builds on these sections to provide recommendations for real-world implementation. First, Chapter 7 provides a discussion of how cumulative effects monitoring may be practiced. Then, Chapter 8 describes a framework for collaboration during monitoring program design and implementation. The framework is designed to provide organizational and methodological structure for designing monitoring programs in the future. It recommends ways to bring people, adaptive processes, and practice together to effectively address complex problems like cumulative effects (e.g., *Cladophora* proliferation) in the Grand River interface and elsewhere. The framework also differentiates itself from conventional monitoring and summarizes lessons learned from the research.

Part 5: Synthesis and conclusion

Chapter 9 summarizes the contributions and limitation of this research. Implications of the research are discussed, followed by reflections of the research and recommendations for future study. This chapter (and the dissertation) concludes with final thoughts about my experience carrying out this research and how future research can build on this work.

Chapter 2
Multimethodology

This dissertation was informed by multimethod research (Brewer & Hunter, 1989; 2006 – explained in Section 2.1), which was preceded by an exploratory study. The exploratory study, undertaken in 2016, built on work by the Canadian Watershed Research Consortium, focusing on the Muskoka River Watershed. A colleague (Dr. Sondra Eger) and I conducted a review of monitoring and reporting by the Muskoka Watershed Council for opportunities to improve as well as to incorporate climate change. The review was published in Ho, Eger, and Courtenay (2018) and, from this, a new method for indicator selection was developed, described in Ho (2018). The indicator selection process is described and built upon in Chapter 5 of this dissertation.

2.1 The multimethod research approach

Although inspired by early works (e.g., Weber, 1949; Campbell & Fiske, 1959), multimethod research was first described in-depth as a distinct methodology by sociologists Brewer and Hunter (1989); however, the approach arguably has roots in practice, in a series of 1920s management studies known as the Hawthorne studies, reported by Roethlisberger and Dickson (1939) – one of four 'early exemplars' described by Brewer and Hunter (2006). The definition of multimethod research is inconsistent in the literature, as some focus on triangulation as its original and sole purpose (e.g., Campbell & Fiske, 1959); others consider it an extension of mixed method research, in which qualitative and quantitative approaches serve to validate results (e.g., Goertz, 2016; Seawright, 2016); and still others differentiate it entirely from mixed method research, suggesting multimethod research must be either entirely qualitative or entirely quantitative (Creswell, 2015; Mik-Meyer, 2020).

One common element of all interpretations of the multimethod approach is that the use of single methods leaves gaps in knowledge due to inevitable biases and/or limitations, regardless of which method is used. The multimethod 'strategy' is described by Brewer and Hunter (2006) as the attack of a research problem "with an arsenal of methods that have nonoverlapping weaknesses in addition to their complementary strengths (p. 4)." The concept is simple: that the convergent findings can be accepted with greater confidence, while the divergent findings signal opportunities for further investigation (Campbell & Fiske, 1959; Brewer & Hunter, 1989; 2006). Multimethodology is not so much about the mixing of quantitative and qualitative methods, although this may certainly be the case; rather, the methods used are determined by the demands of a particular problem. Brewer and Hunter (2006) highlight four imperfect yet useful 'principle methods' used in social sciences, which they recommend be considered in a multimethod research approach: fieldwork (firsthand observation of people and events in their natural settings), surveys (interviews or questionnaires of a statistically representative sample of a given phenomenon), experiments (controlled conditions that test a causal hypothesis), and nonreactive research (a non-intrusive form of observation that prevents reactive error, e.g., by studying artifacts, archives, statistics, and other social 'by-products'). These four complimentary methods aside, other methods exist and may be considered.

This dissertation explores approaches for diversifying perspectives that contribute to our understanding of freshwater quality (e.g., by democratizing monitoring and management processes). There are three reasons why the multimethod research approach (Brewer & Hunter, 1989) is used in this work. First, the research objectives imply a need to speak with current water quality monitoring and management practitioners about existing shortfalls to overcome, as well as community members who may provide insights as to how the practice of water quality monitoring can be made more conducive to their participation. Existing water quality practitioners are familiar with the subject matter and generally know what to expect from conventional, scientific approaches like interviews and brief workshops; however, power dynamics and knowledge discrepancies between conventionally excluded persons and those with authority or expertise in freshwater science call for methods that are shaped for these persons' participation. Second, this research is premised on a need for more diverse perspectives and practice. As such, the research is intentionally designed to cross discipline-specific approaches and it strives to demonstrate possible alternative methods that may apply to both research and practice. Third, supplementing expert perspectives with community member perspectives (e.g., Chapter 6) affirms the underlying assumption of this research – that current practice is imperfect and potentially incomplete. All three rationales are supported by early practitioner consultations, in which practitioners recognized other approaches to practice were possible (perhaps preferable) but so far not feasible for them to explore.

For these reasons, this dissertation applies the strategic bringing together of multiple distinct methods within a multimethod research approach. Further, as this dissertation's focus is on *enabling* change, rather than designing a new practice, an exploratory multimethod approach is most appropriate. As such, interdependence between methods is planned (e.g., methods are applied to supplement or enhance the conclusions of one another rather than to independently cross-validate each other) and contrasts in the results were sought (e.g., to determine whether different perspectives would emerge from different persons being involved and in different ways than they currently are) (Brewer & Hunter, 2006). Although methodological interdependence is considered a shortcoming in multimethod studies where cross-validation is the goal, influences via the investigator/researcher is an intent of exploratory studies. In exploratory multimethod research (e.g., this dissertation), different ways of knowing demonstrated by the different methods used force the researcher to understand the collected information in different ways based on their contexts (Glaser & Strauss, 1967). For these reasons, the research process and its process-related lessons and recommendations are as important as its other, more direct results.

2.1.1 Data validation in multimethod research: a postmodern pedagogy

In the multimethod approach, different data collection techniques form a set of indicators that point to the same social phenomenon (e.g., in the case of this dissertation, changes in water quality monitoring practice), but which also minimize the risk of overlapping methodological biases (Brewer & Hunter, 2006). If more than one method points to the same phenomenon, the result is likely valid, assuming they are unlikely to suffer from a common source or error (Brewer & Hunter, 2006). Although true triangulation requires the social situations of each method to be at least similar, if not identical, there is no strict criteria to determine the qualifying level of similarity (Campbell & Fiske, 1959; Brewer & Hunter, 2006).

Given the diverse contexts of my research participants – as described in Chapter 1 – their social-economic situations are quite different. They are geographically similar and experience many of the same ecological contexts, though their social contexts influence differences in their experiences of ecological situations (e.g., the lack of clean drinking water on First Nations reserves is a factor of social-economic inequities that persist in the study area, which means surface water pollution impacts them differently than those who have access to clean drinking water). The methods used in this research, described in Section 2.2, were selected with limited triangulation in mind, but were more intentionally selected to ensure a more 'complete' understanding of the different community perspectives that exist as they relate to understanding water quality and cumulative effects in the study area. The latter purpose is supported by multimethod scholars, who suggest the ability to ensure multiple perspectives permits multifaceted analyses that comply with the complex dynamics of the social world (Mik-Meyer, 2020).

Although the multimethod approach is an appropriate methodology for this research, triangulation as defined by Campbell and Fiske (1959) is not likely an appropriate means by which to validate the data, for the reason described above (note: a different definition of triangulation is provided later in this section, per Nakkeeran & Zodpey, 2012). The alternative, then, recognizes that multimethod research addresses the classical questions of science (e.g., regarding the measurement validity of data, generalizable sampling, questions of causation in testing hypotheses) from a postpositivist point of view (Brewer & Hunter, 2006). As such, validation of data in this dissertation's context most appropriately follows a postmodern pedagogy. A "soft" postpositive evaluation of multimethod data involves reflection on three major themes: "the ideas of narrative, rhetoric, and the social construction of scientific facts (Brewer & Hunter, 2006, p. 152)." The 'narrative' refers to an understanding of what combination of events, experiences, and insights contributed to the creation of a certain knowledge over time –

essentially, the knowledge's personal history. The 'rhetoric' refers to how this story is told, e.g., by using a passive voice to imply objectivity, and how rhetoric affects the use of certain research methods. Finally, the 'social construction of scientific facts' refers to a pleasant debunking of the 'myth of objectivity' (Gould, 2003) to recognize and celebrate that facts are the product of social negotiation, and that acceptance of a given fact is at least partly determined by differences in power, prestige, and positions in social networks (Brewer & Hunter, 2006).

Recognizing that a postpositive, qualitative approach for examining the context of water quality monitoring will be unfamiliar to many in this field, research standards are briefly outlined below to provide a basis upon which to judge the quality of this dissertation. Validity is typically applied in quantitative research to assess the extent to which the results were accurately measured; however, judging postpositive, multimethod research on validity can be problematic if the individual(s) assessing validity is/are entrenched in empirical science (e.g., if assessment uses empirical criteria: Punch, 1998). Maher et al. (2018) suggest that rigor in qualitative research is determined by the research process (including appropriateness of method for the research objectives – addressed above) and trustworthiness, as defined by Lincoln's and Guba's (1985) four criteria: credibility, transferability, dependability, and confirmability.

There are common pitfalls to avoid when practicing and evaluating postpositive, multimethod research. For example, a review of 397 postpositive science publications concluded that normal science is often misapplied to complex policy issues that are better suited to postpositive analyses (König, Børsen, & Emmeche, 2017). Further, Nakkeeran and Zodpey (2012) suggest the tendency to quantify qualitative data is a common pitfall where methods were not designed for quantification. They also highlight the problem of treating group-derived responses (e.g., workshops in this dissertation) as individual responses, which is often misleading; rather, group responses should be presented as collective discussion rather than capturing individual perspectives (note: the collective approach was taken throughout this research, evidenced by the summary reports listed in Appendix A). According to Nakkeeran and Zodpey (2012), the quality, or rigor, in qualitative research is determined by:

1. A systematic yet flexible study design, beginning with a clear stage of conceptualization (e.g., co-creating the research agenda in this dissertation with practitioners and study participants).
2. Dedicated rapport building and activities to get to know the study context (e.g., participant observation in this dissertation, and the 1.5 years spent building relationships with Indigenous persons).
3. Staggered data collection (e.g., the phased data collection implemented in this dissertation),
4. Methodical selection of informants, events, and data domains (e.g., this dissertation's use of key informant interviews).

5. Careful selection of informants, events, or data domains. A prescriptive sample size is usually inappropriate; sample size is less important than the criteria used to select who contributes, e.g., ensuring the relevant cultural domains are selected is important. Interviewing until saturation is achieved (Nakkeeran & Zodpey, 2012) and seeking out alternative means of engagement, like through artistic research, are examples from this dissertation.
6. Systematic data archiving (e.g., the use of multiple formats of recording and dissemination in this dissertation).
7. Triangulation and/or 'member checking' – returning to research participants to ensure the interpretation of the researcher was what was intended to be portrayed – e.g., in this dissertation, draft summaries and other reports were provided to research participants and corrected per their feedback prior to publication).
8. Beginning analysis as early as possible and keeping it concurrent (e.g., analyzing each phase of this research as data were collected, rather than leaving it until the end).

Given the multimethod approach and above criteria for evaluating its quality, individual methods that comprise this study's multimethodology are described below. These methods are divided into two categories: first, methods that contributed to research design (but which did not result in data collection), and second, methods that contributed to data collection. As a reminder, an exploratory study preceded this research, which is built upon during this work, but which is not included as one of the methods within this study's multimethodology.

2.2 Methods that contributed to research design

Early methods that informed the multimethod approach were a literature review, participant observation, and practitioner consultations. A probe into literature on systems theory (to support cumulative effects) and social-ecological sustainability was carried out from September 2016 to April 2017. As part of participant observation, I participated in meetings of the Grand River Fisheries Management Plan Implementation Committee (a committee within the Grand River Conservation Authority) on January 10, March 7, and May 2, 2018, where I presented my initial research plan, discussed gaps in knowledge, and recruited many of my interviewees. Further, I co-led a stakeholder engagement workshop at the Canadian Water Resources Association's National Conference on May 26, 2019 (Collingwood, Ontario). Participant observation was not incorporated into the dissertation but helped to familiarize me with the study context and provided networks from which to recruit research participants (e.g., expert interviewees).

Practitioner consultations began during research conceptualization in 2016 and continued until the 2019 Global Water Futures Annual Science Meeting (May 15-17, 2019, Saskatoon, Saskatchewan).

Current water monitoring practitioners and water scientists at the Grand River Conservation Authority, University of Waterloo, and in Global Water Futures were consulted to ensure this work would be relevant to today's needs. Consultations took the form of one-on-one meetings, email conversations, casual 'buffet line' conversations at large, organized meetings (e.g., via Lake Futures and/or Global Water Futures), and phone calls or email communications via PhD committee members/advisors. From these consultations, and from further engagement as part of the research, the multimethod approach was developed using the methods introduced below.

2.2 Methods that contributed to data collection/knowledge creation

Knowledge[7] in this research is sourced from individuals whose social, professional, or political role and/or experience determines their authority to address the question(s) being explored (e.g., an '*authoritarian'* method to knowledge creation, not a representative, '*scientific'* method: Frankfort-Nachmias & Nachmias, 1996).

2.2.1 Systematic review of monitoring programs: May 2018-May 2019

This method falls within 'nonreactive research' – one of four methods recommended by Brewer and Hunter (2006). I reviewed documents and websites of nine monitoring programs and frameworks recommended as exemplary by practitioners. Programs were scored per criteria that were selected from literature and consultations with practitioners. Common strengths and weaknesses were identified, along with five recommendations. Refer to Chapter 3.

2.2.2 Key informant interviews: February-May 2019

This method falls within 'surveys', another of Brewer's and Hunter's (2006) recommended methods. Recruitment began in January 2018, after which I conducted 21 semi-structured interviews with Canadian practitioners and subject matter experts. A summary report (Ho, Dhaliwal, & Wright, 2021) describes 106 issues and 51 recommendations that were collated from this method. Refer to Chapter 4.

2.2.3 Artistic research: June 2019-March 2020

Although this method does not clearly fit within the four common methods outlined by Brewer and Hunter (2006), it may either be considered as one of 'other' approaches or can be considered an adaptation of 'fieldwork' given its conception is rooted in natural/preferred community behaviours. The

[7] The use of the term 'knowledge' is intentionally used in this dissertation until partway through Chapter 6 (as noted in the chapter) to contrast conventional interpretations of 'data' in quantitative study.

Vienna Declaration on Artistic Research defines artistic research as "practice-based, practice-led research in the arts" that "addresses key issues of a broader cultural, social, and economic significance (Vienna Declaration on Artistic Research, 2020)." Art, or creative expression and/or creation, is not the subject of scientific research (i.e., 'art research'); instead, the arts are the means through which research participants are engaged and data are collected (Borgdorff, 2012; Lilja, 2015). Artistic research took two forms in this dissertation, both of which are described further in Chapter 6:

1. **Partnership with Great Art for Great Lakes: June-September 2019**

Waterlution, a national non-profit organization, commissioned six artists to engage over 1,000 members of the public artistic workshops focused on building awareness of Lake Erie issues. I spoke at workshops about the Grand River and Lake Erie and collected 133 anonymous questionnaires about the public's watershed priorities.

2. **Partnership with Music for the Spirit & Indigenous Visual Arts: August 2019-March 2020 (relationship building began in July 2018)**

Indigenous youth in an after-school program at Six Nations of the Grand River were engaged to create water-themed artwork and write accompanying stories that would be part of a traveling art exhibit. These creations comprised the *Grand Expressions* art exhibit (Ho & Miller, 2020), which was on public display from August 2020 to January 2021 (in addition to other forms of dissemination, e.g., industry journals).

2.2.4 Workshops: October 5 and December 7, 2020

Like the last method described, the workshops do not fit clearly within the four methods outlined by Brewer and Hunter (2006); however, they can be defined as a hybrid between 'fieldwork' and 'surveys'. I first led a sense-making exercise (via a 3-hour online workshop on October 5, 2020) through which past research participants could verify or revise their contributions to the work and all participants could contribute to reorganizing the proposed framework in a more feasible and meaningful way. This workshop was a major contributor to shaping the current version of the proposed framework. Refer to Chapter 8. Then, I co-led a second workshop (also 3 hours in a virtual format) in which practitioners and subject matter experts considered how cumulative effects monitoring might be implemented in the study area. An activity that built on the exploratory work (explained in Chapter 5) was also undertaken in this workshop. Refer to Chapter 7.

2.3 Ethics review

A University of Waterloo Research Ethics Committee reviewed and approved three methods in this research: key informant interviews, artistic research, and the December 2020 cumulative effects indicators workshop. Participant observation and the monitoring program review did not require ethics approval. The October 2020 workshop was not used to collect any data or formally capture knowledge; instead, workshop discussions reshaped my thinking regarding the proposed framework.

2.4 Dissertation roadmap

Each of the research questions, corresponding dissertation chapters and their methods are included in a dissertation roadmap in Figure 4.

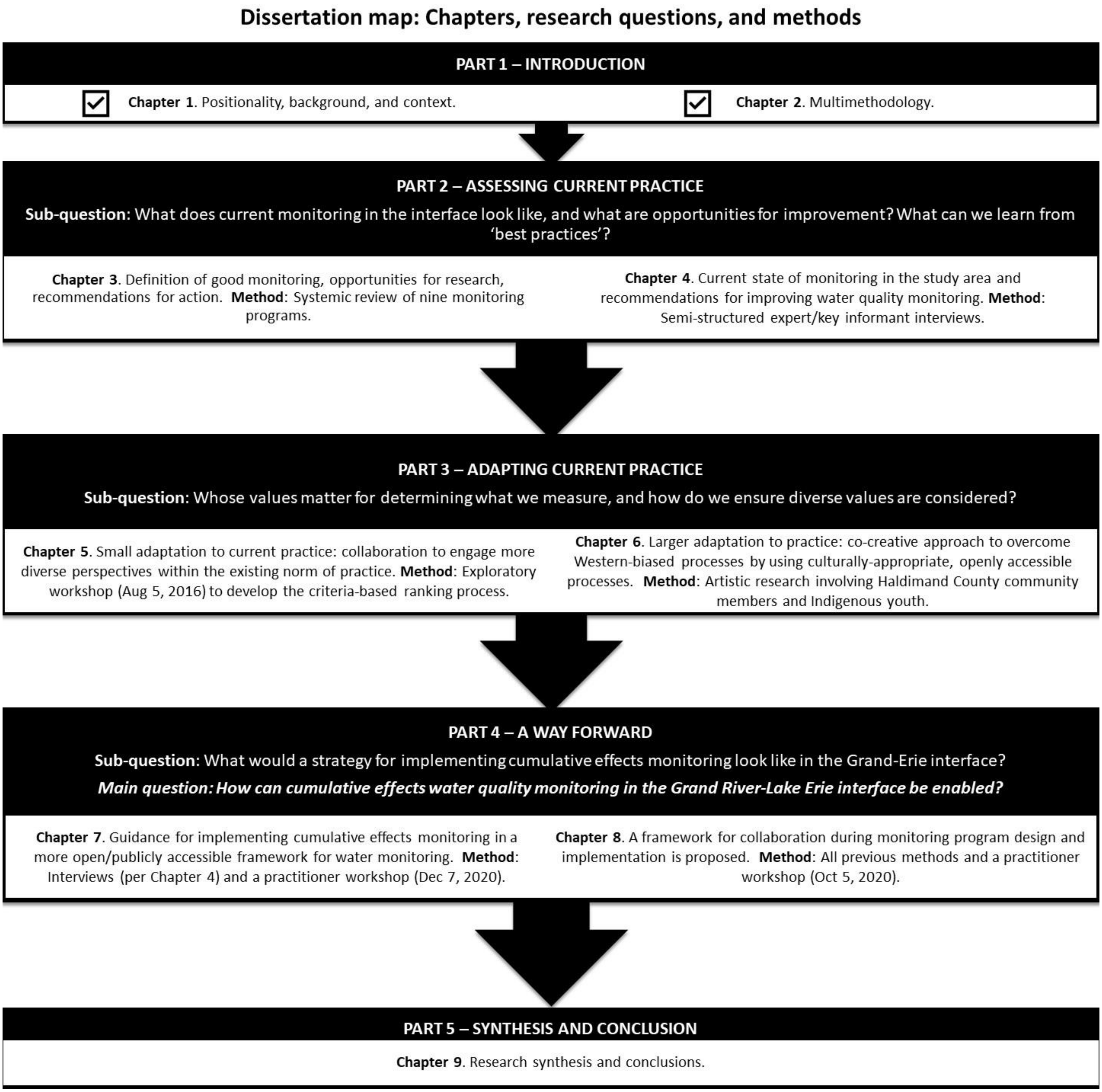


Figure 4. Summary of dissertation content (chapters, research questions, and methods)

PART 2 – ASSESSING CURRENT PRACTICE

Chapter 3

Comparison of freshwater monitoring approaches: strengths, opportunities, and recommendations

Citation: Ho, E., Trant, A., Gray, A., and Courtenay, S. C. (2020). Comparison of freshwater monitoring approaches: strengths, opportunities, and recommendations. *Environmental Monitoring and Assessment* 192: 614.

3.1 Acknowledgements

We would like to thank Scott Kidd for helping to shape the early iterations of this work and for his valuable feedback throughout the editing process. Kelly Munkittrick reviewed and contributed to introductory information regarding types/structures of monitoring programs. Further, Georgina Kaltenecker provided feedback on content related to the Provincial Water Quality Monitoring Program.

3.2 Introduction

Water monitoring is the repeated observation and measurement of indicators related to water quality, water quantity and/or specific biota over a given time, usually at multiple locations within the area of interest. Greig and Pickard (2014) describe a variety of approaches to monitoring and analyzing aquatic ecosystems in the context of industry projects, including:

- before-after designs (monitoring a site over time, e.g., monitoring a stretch of a given stream before and after sewage treatment upgrades are implemented);
- paired before-after control-impact (comparing a site to multiple local/regional sites over time, e.g., monitoring multiple sites across a watershed with multiple sewage treatment plants in which only some plants upgrade while others are maintained);
- control-impact designs (comparing a site to another local site at the same time, e.g., comparing reference upstream and downstream conditions surrounding a single sewage treatment plant upgrade);
- multiple control-impact designs (comparing a site to multiple local/regional sites at the same time, e.g., multiple reference sites compared to a single downstream site); and
- regional reference design (Bailey, Norris, & Reynoldson, 2004), a predictive approach in which biotic assemblages are collected from reference sites, followed by identification of organism groupings (using multivariate statistical tools) that are associated with nonbiological variables.

The variables identified as being important drivers of biotic assemblages in references conditions are used to predict assemblages at exposure sites.

The Canadian Council of Ministers of the Environment (CCME), an intergovernmental forum of 14 member governments partnered to develop nationally consistent environmental standards and practices, outlines five steps for designing water quality monitoring programs: (1) goal and objectives; (2) monitoring design; (3) data collection and quality; (4) data analysis, interpretation and evaluation; and (5) communication and interpretation (CCME, 2015). The CCME highlighted the need for monitoring programs to become more effective and cost-efficient, better-coordinated and more consistent in practice across jurisdictions (CCME, 2006; 2015). Regarding monitoring design (step two), a unique approach suggested by the CCME is to base the selection of monitoring variables, spatial and temporal frequency on economic analyses that evaluate space-time trade-offs (CCME, 2015).

Key attributes of a monitoring program include iterative study designs, relevant and effective monitoring indicators and the consideration of multiple scales (Therivel & Ross, 2007; Arciszewski & Munkittrick, 2015). A variety of water monitoring frameworks and approaches have been implemented across Canada, including monitoring that informs integrated watershed management (Conservation Ontari,o 2016), adaptive monitoring (Lindenmayer & Likens, 2009), monitoring within environmental impact assessment or strategic impact assessment (Bidstrup, Kørnøv, & Partidário, 2016), and monitoring for the purpose of characterizing and assessing in a state-of-the-watershed report (Government of Alberta, 2008). These approaches are aimed at better understanding cause and effect relationships, on which the politics of sustainable water management and decision-making are often based (Red'ko, Prokhorov, & Burtsev, 2004).

Because of this dependence on cause and effect relationships, current water management systems are largely reactionary in their approaches to identifying and addressing problems/undesirable effects (Duinker & Greig, 2006). However, monitoring data can be used to inform decisions or actions before effects occur by using computer models that predict future conditions. In these cases, the main objectives of monitoring programs are to assess change and predict the risk of effects that may occur to inform management decisions or responses (Anderson et al., 2003; Brack et al., 2009; Jones, 2017). For example, the Grand River Conservation Authority in Ontario uses historic flood data to inform road closures or send out flood/high water messages to residents ahead of an expected weather event, which allows the community to relocate property or reroute traffic before property damage, injury or loss of life occurs.

Iterative, adaptive monitoring and management frameworks enable the evolution of monitoring programs and management regimes based on emergent information and changing research questions (Lindenmayer & Likens, 2009; MNRF, 2016). The recent increase in focus towards fair and equitable consultation, transparent data collection and integration of Indigenous knowledge/perspectives in environmental monitoring calls attention to the relevance of past monitoring and management approaches (Diver, 2017; Ho & Runnalls, 2018; SSHRC, 2018; Government of Canada 2019a; Thomson, 2019). Considering societal shifts, together with recommendations for adaptive practice, reviews of environmental monitoring programs are timely.

3.2.1 Study management context

This paper brings monitoring, management and decision-making together to make freshwater monitoring more meaningful and actionable. The paper contributes to a larger study developing an integrated monitoring-management design framework for the freshwater interface of the Grand River at Lake Erie. The need for a new framework emerged after management efforts in the 1990s failed to reduce long-term phosphorus contributions from rivers like the Grand into Lake Erie (Carey, 2007). Increased algae blooms exacerbated by climate change and invasive mussels raised fears of repeated eutrophication, last seen in the 1960s and 1970s (Watson et al., 2016). Despite the Grand-Erie focus, the findings presented here are also more widely applicable. The Grand River watershed (Ontario, Canada) is the largest watershed in Southern Ontario, which presents many complex and accumulating water management challenges across a very diverse social-ecological system. The goals of this paper are to: (1) identify common elements of 'best practices' for monitoring programs, identified through water manager consultations and 21 key informant interviews, and (2) discuss how to strengthen monitoring programs.

Water management in the Province of Ontario is unique. The Grand River watershed is managed by the Grand River Conservation Authority, one of 36 Conservation Authorities in highly populated watersheds which have legislated managerial mandates but little decision-making authority. Decision-making largely rests with two provincial government ministries – the Ministry of Natural Resources and Forestry and the Ministry of Environment, Conservation and Parks – as well as the municipalities that make up each Conservation Authority. Conservation Authorities have dedicated staff and currently have the following general abilities or roles, per Section 21(1) of the *Conservation Authorities Act*: acquire land for recreation and conservation, regulate that land for community safety, and provide opportunities for public education and enjoyment while maintaining watershed health. However, following amendments made in 2019, these abilities will soon be changed to the following: deliver programs and services related to the risk of natural hazards, the conservation and management of lands owned or controlled by the CA (i.e., no new acquisitions), and any duties, functions and responsibilities prescribed by the regulations of this Act or related to source water protection under the Clean Water Act.

The selection of monitoring programs in this paper was the result of consultation with water managers and researchers in the Global Water Futures collaboration, as well as recommendations from key informant interviews. Key informants – who represented various sectors of expertise, from academia to water management – were asked to identify water monitoring programs that exemplified the best in today's practice. Criteria were gleaned in part from key informant interviews (i.e., regarding what those best practices are), supported by the literature. This review identifies strengths and weaknesses of current monitoring approaches to propose a more effective, holistic way to address complex water monitoring and management problems. In addition, this paper includes discussion on connecting monitoring, management, and decision-making. We recognize existing monitoring programs are imperfect, but being the best models identified, they provide case studies for building improved models – especially when reviewed collectively.

3.3 Method

This study reviewed documents and websites of a variety of monitoring programs and frameworks (hereon collectively called 'programs' for brevity). Nine programs were selected for review through consultation and interviews with monitoring practitioners, water managers and subject matter experts. Researchers affiliated with the Global Water Futures research programme (a Canada-wide research initiative representing the single largest investment in university-led water research in history; Wilfred Laurier University, 2019) were consulted at the first Global Water Futures Annual Science Meeting (June 3-6, 2018 at McMaster University and Six Nations of the Grand River). The 21 semi-structured key informant interviews contributed to this monitoring review by asking experts/key informants to describe best practices, identify exemplary programs and share perspectives on how to strengthen (and better integrate) water monitoring and management. In other words, this study was designed to evaluate programs considered by experts to be of high quality.

In this review, the concept of a monitoring program was intentionally defined more loosely than in the literature for the purpose of identifying potentially new, innovative approaches to implementing the act of water monitoring (i.e., seeking lessons from conventional approaches alone may not yield as many insights). Monitoring programs reviewed in this study include several local/regional programs that align with the conventional definition (described in the Introduction), in addition to a provincial network of local and regional monitoring organizations, and two broader frameworks with monitoring mandates. One framework, the Global Action Agenda (under the Brisbane Declaration 2018), was designed specifically for the goal of sustainable water allocations for both human and ecological purposes (Arthington et al., 2018). The other framework, the Statistics Canada Sustainable Development Goals Data Hub, incorporates targets related to water monitoring within the United Nations Sustainable Development Goals (Government of Canada, 2019b).

Recommended programs were assessed for available information in a review of online sources and documents provided by those consulted; those programs that did not have information available on all criteria were excluded from the review, resulting in the final nine programs (Table 1). The following programs were reviewed:

Table 1. Programs evaluated and their descriptions.

Program (location)	Scale and leadership	Description
Blair Creek Subwatershed monitoring program (Ontario, Canada)	Subregional/local subwatershed, led by the Grand River Conservation Authority	The Blair Creek Subwatershed was used as a case study to explore a multi-scale pre-, during and post-development monitoring program within a cumulative effects assessment framework. This case study was a partnership between the City of Kitchener, where the Subwatershed is located, the Grand River Conservation Authority and the Ontario Ministry of the Environment and Climate Change. Objectives included: improve characterization of land-use change and water quality, increase the awareness of the importance of cumulative effects monitoring, and enhance the understanding of different scales of monitoring (GRCA, 2017).
Canada's Environmental Effects Monitoring Program (Canada-wide)	National program of local or project-based monitoring, led by the Government of Canada, legislated under the Fisheries Act for Canadian metal mines and pulp and paper mills	EEM is an adaptive monitoring program originally designed in the 1990s to assess the adequacy of industry-specific regulations for protecting aquatic receiving environments by monitoring the status of fish, fish habitats (as indicated by benthic invertebrate communities) and use of fish (as indicated by relevant contaminant levels in fish and reports of tainting). It is an industry-funded, adaptive monitoring program, currently required for pulp and paper and metal mining industries. EEM studies include water quality monitoring, effluent chemical characterization, and effluent sublethal toxicity testing as supporting measurements (Government of Canada, 2017). The requirement for conducting an EEM program is part of the compliance requirements under permit given to discharge deleterious substances. Environment and Climate Change Canada is responsible for the coordination, development, and implementation of EEM in consultation with diverse stakeholders and Indigenous rights-holders (Walker et al., 2003).
Grand River watershed monitoring program (Ontario, Canada)	Regional/watershed monitoring, led by the Grand River Conservation Authority	The Grand River Conservation Authority works with the Ontario government, municipalities, and other groups to monitor surface and ground water in the Grand River watershed. Surface water levels are monitored for water quality and flood forecasting and management. Groundwater quality and quantity are both monitored. One of several local projects, GRCA has partnered with the Canadian Water Network and University of Waterloo to develop a framework for monitoring in support of cumulative effects assessment to quantify benefits of upgrades to municipal wastewater treatment plants.
Muskoka River Watershed monitoring program (Ontario, Canada)	Regional/watershed monitoring, led by the District Municipality of Muskoka	The Muskoka Watershed Council (MWC) aquatic monitoring program was redesigned between 2016 and 2018. The program now reports on only eight indicators: four health indicators and four that measure potential threats. Health indicators are total phosphorus, calcium, benthic macroinvertebrates, and interior forest cover. Threat indicators are climate change, species at risk, invasive species and (habitat) fragmentation. Cumulative impacts are discussed with the community, although not necessarily measured through monitoring. For example, for the species at risk indicator, MWC points to multiple interacting stressors to answer the question "Why are these species at risk?" The response includes various types of habitat loss and fragmentation, competition from introduced species, traffic mortality, illegal harvesting, disease, pollution, and other stressors. Similarly, for climate change, multiple potential impacts from climate change as a stressor are discussed, including potential flood, drought and fire risk, habitat degradation and warmer waters,

		which cumulatively result in impacts like lower fish spawning rates (and other impacts mentioned).
Slave Watershed Environmental Effects Program (Northwest Territories, Canada)	Regional/watershed monitoring, led by the Slave River and Delta Partnership	The Slave Watershed Environmental Effects Program (SWEEP) is one of three community-based water monitoring programs that were developed as part of the Northwest Territories Water Stewardship program hosted by the Government of Northwest Territories in partnership with Canadian and Indigenous communities. Funding is provided by the Government for community monitoring and youth engagement grants, and data from these programs are shared with the Government for decision-making purposes. On the program website, any jargon is explained either via an information icon next to the term or on a glossary page (often both). There are clear communications about who the site is for, how it can be used and what resources are available (i.e., maps of monitoring sites, explanations of 119 Action Items and 54 Performance Indicators, datasets and more). Monitoring priorities are based on community concerns about water quality, hydrology, sediment load, wildlife, air, climate, vegetation, fish, and insects. Two types of indicators were measured in a Canadian Water Network project that helped to develop this program: Type 1 are measured by the community and include direct biological measurements and observations (including traditional knowledge); Type 2 are a scientific baseline assessment of river conditions, including measures of water quality, bottom-dwellers, hydrology and fish health. A Bayesian Belief Network was used to integrate qualitative and quantitative information and to identify where uncertainty lies, and where more data are required (Canadian Water Network, 2020).
Healthy Land and Waters program (South East Queensland, Australia)	Regional/watershed monitoring, independent organization	The Ecosystem Health Monitoring Program (EHMP) was established in 2000 as one of the first monitoring and reporting programs in Australia. The creation of this program was inspired by the eutrophication of Moreton Bay, fed by the Brisbane River (parallels this study, in which Lake Erie experiences nutrient challenges fed in part by the Grand River). After municipal wastewater treatment plant upgrades proved ineffective to reduce nitrogen and phosphorus discharges, further exploration revealed the bigger problem was episodic discharge from rivers flowing into Moreton Bay after large rainfall events (also similar to the Grand-Erie context in this study). European colonization resulted in the removal of bank vegetation, causing erosion that brought an influx of soil nutrients into Moreton Bay. Part of the solution is revegetation, which is what supports the EHMP program. Financial support is generated through a nutrient offset program in which polluters contribute to revegetation of the upper watershed to reduce the cumulative impact of nutrients on the watershed and Moreton Bay. EHMP provides a regional assessment for each of South East Queensland's major catchments, river estuaries and Moreton Bay zones. This catchment-scale monitoring and reporting program is designed to achieve a management response. The high level goal (which has four aims within it) is to manage waterways in South East Queensland to "enhance community quality of life by fostering stewardship to protect and restore waterway health (Healthy Land and Waters, 2020)."
Provincial (Stream) Water Quality Monitoring Program (Ontario, Canada)	Provincial network of local and regional monitoring organizations, led by the Ontario Ministry of Environment, Conservation and Parks	The Provincial (Stream) Water Quality Monitoring Network (PWQMN) measures water quality in rivers and streams across Ontario. This dataset provides stream water quality monitoring data for a number of parameters, including total and dissolved nutrients, metals, and chlorophyll. Spatial information for stream monitoring locations across Ontario are also available. Over 400 locations are monitored in partnership with Conservation Authorities, provincial parks and municipalities. Partners collect water samples on a monthly basis, on average, and deliver them to the ministry's laboratory where they are analyzed for a suite of water quality parameters. Water quality data are shared freely between the partners and with the public.

		Recent data (2002-2009) are available for download on the ministry's Data Download page. The program has been operating since 1964, providing a valuable database for tracking changes in water quality over time. More recently, special studies have been implemented in agricultural and urban watersheds to collect additional information in support of source protection planning, nutrients, road salts and pesticides management.
Statistics Canada Sustainable Development Goals Data Hub (Canada-wide)	Canadian targets within a global framework, led by the Government of Canada, includes targets under Goal 6 for clean water and sanitation	Launched by Statistics Canada in 2018 as an online resource to allow Canadians to monitor progress toward the United Nations 2030 Sustainable Development Goals and targets. Statistics Canada is responsible for the collection, collation, analysis, presentation and dissemination of data for regular monitoring of Canadian progress against the global indicators and has developed this online data hub for disseminating Canada's SDG data (Government of Canada, 2019b).
The Brisbane Declaration and Global Action Agenda on Environmental Flows (Brisbane, Australia but global in scope/application)	Global framework created at the 2007 10th International *Riversymposium* and revised at the 2017 20th International Environmental Flows Conference, respectively	This framework was designed by scientists and practitioners working in environmental water management including science, practice, and policy around environmental flows in rivers. Water allocations for human and ecosystem requirements are defined and protected to include considerations of biodiversity and ecosystem services within integrated water resources management. Thirty-five recommendations were made in 2018 under the Global Action Agenda on Environmental Flows through legislation, regulation, water management and research. These recommendations, linked by partnership arrangements involving diverse stakeholders, take into consideration social and cultural elements in addition to the more traditional ecological/biophysical considerations. Attention is paid to active participation of people of all cultures including in decision-making processes. The Declaration and the Global Action Agenda revised the definition environmental flows to "describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being (Arthington et al., 2018)." Together, the Declaration and the Agenda provide a framework of principles that represent the insights of global practitioners and evolving or emerging trends in freshwater monitoring, management, and decision-making.

Criteria were used to score each monitoring program independently. These criteria were selected in part from recommendations related to best practices in the literature as well as general consultations with water managers, researchers and subject matter experts regarding ideal monitoring. The criteria used here were also influenced by outcomes of our exploratory study in the Muskoka River Watershed (Ho, Eger & Courtenay, 2018). The exploratory study, which took place from January to August 2016, considered implications of integrating cumulative effects assessment and monitoring with the existing monitoring program of the District Municipality of Muskoka, which forms part of the Muskoka Watershed Council. The Council's watershed reporting program was reviewed, and the assessment and selection of monitoring indicators was discussed. A new Criteria-based Ranking method was developed for selecting and/or short-listing monitoring indicators (Ho, 2018).

It is important to acknowledge there are challenges in comparing monitoring programs that operate at different spatial and temporal scales and with different goals or objectives. Two methodological design approaches were used specifically for this reason. First, contrary to the monitoring review completed in our exploratory study (Ho, Eger, & Courtenay, 2018), indicators measured and the communication of information across reporting years were not compared as part of this review. Instead, we compared high-level qualities (e.g., whether more than one reporting type was used). Second, scores for each program were calculated using only those criteria that were applicable to each program (e.g., different total possible scores per program). A 'grade' for each program was calculated as a percentage using the score achieved divided by the total applicable possible score. In this way, incomparable and inapplicable criteria were not forcefully reviewed or unfairly scored, while final percentage grades were comparable between monitoring programs. Also, many programs exist as part of a suite of complementary programs that address most to all criteria; so, even if a particular program falls short of one or more criteria, there may be other programs in place to account for those criteria which were not reviewed in this study. We did not review complementary programs for aggregate scores, as evaluating suites of programs and policies was beyond the research scope.

Of the 22 criteria used, two were scored on a 'yes/no' basis (i.e., score of 1=yes, 0=no) while the rest were scored on a 'yes/somewhat/no' basis (i.e., 2=yes, 1=somewhat, 0=no). Not all criteria related to every program. For example, the Environmental Effects Monitoring Program was designed to be carried out by industry, and so the criterion related to funding for community monitoring is inapplicable. As such, each program had a different total possible score. A final percentage grade was used for comparison purposes, calculated as the total score divided by the total possible score, multiplied by 100. The 22 criteria used were as follows:

- Western knowledge (i.e., western science) forms at least some evidence
- Indigenous Knowledge and/or ways of knowing (i.e., Traditional Ecological Knowledge, including cultural ways of inferring change and cultural values informing what is desirable) is recognized and ideally forms at least some evidence
- The program is well-coordinated internally and connected with decision-makers and/or key stakeholders and rightsholders (partnerships may be formed to carry out monitoring or to make it actionable)
- Monitoring indicators are identified by diverse stakeholders and rightsholders, and are relatable to the community
- Program reporting (e.g., outcomes of monitoring) and related resources are easily understood by the lay person
- Program reporting is provided in multiple reporting formats (e.g., conventional report, interactive maps, blogs, videos, community papers, etc.) – YES/NO
- High-level/regional summaries are supplemented with local/sub-regional reporting
- Most or all indicators that are measured are reported upon

- Long-term continuous data (10+ years) are part of the program
- Mid-term continuous data (5-9 years) are part of the program
- Short-term continuous data (1-4 years) OR 'snapshot' data are part of the program
- A database is accessible or a metadatabase is provided
- Details about the parameters measured are shared and/or explained in lay terms (e.g., what does a high level of calcium mean?)
- Methods, approaches or protocols used in monitoring are explained
- Management and monitoring roles (i.e., who does what) are clear
- Interim progress is reported for long-term plans or goals
- Community-based monitoring or citizen science is incorporated in some form
- Funding is provided to the community for monitoring purposes
- Cumulative effects are considered
- Whole-watershed approach is taken, which considers all three of the following: water quality monitoring, monitoring of water quantity and biomonitoring
- Contact person(s) or information is/are provided – YES/NO
- Monitoring is linked to watershed management, project management, or decision-making

Key informant interviews were used to collect perspectives on the strengths and weaknesses of water monitoring programs (including fisheries) as well as to discuss interviewee experience with water management, decision-making, cumulative effects, and/or integrating science with policy. Interviewees completed a routing questionnaire using SurveyMonkey (Appendix C) prior to being interviewed so that a short-list of questions relevant to their unique experience could be selected from a larger pool of questions (Appendix D).

Key informants were recruited to represent diverse perspectives: federal government, provincial government, academia (e.g., professional researchers – government, university, or private), water managers and monitors (e.g., Grand River Conservation Authority), key representatives from the public (including community associations, non-profit groups and advocacy organizations, e.g., Trout Unlimited) and the Six Nations of the Grand River. Individuals were identified from the literature and through consultation with those who work in the study area (i.e., scientists and water managers). The interview phase was reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee.

3.4 Results

When all final scores were calculated, the top five monitoring programs, ordered by descending score, were as follows (note: totals are different become some criteria were inapplicable to all programs reviewed):

1. Slave Watershed Environmental Effects Program (Slave Lake and Delta, Northwest Territories, Canada) – 93% (score 39/42)
2. Government of Canada Environmental Effects Monitoring Program (specific to Canadian mining and pulp and paper industries, on a per-project basis) – 72% (score of 26/36)
3. Healthy Land and Waters (Queensland area, Australia) – 71% (score of 30/42)
4. District Municipality of Muskoka (Muskoka River Watershed, Ontario, Canada) – 64% (score of 27/42)
5. Provincial (Stream) Water Quality Monitoring Program (Ontario, Canada) – 61% (score of 23/38)

All five of these programs made use of western science, stakeholder-driven indicators and all three durations of data (short-term or snapshot data, mid-term data, and long-term data). Further, all five programs provided a contact person and/or general contact information in case readers had questions or requests, and four of the five programs reported on all indicators that they measured. As this review is part of a larger study in the Grand River watershed, it is important to note the Grand River Conservation Authority monitoring program placed 6th overall with a score of 52%. Table 2 summarizes the criteria scores and total scores for each of the top five monitoring programs.

Table 2. Scores of the top five monitoring programs evaluated.

Monitoring program	Slave Watershed Environmental Effects Program	Canada's Environmental Effects Monitoring Program	Healthy Land and Waters	District Municipality of Muskoka	Provincial Water Quality Monitoring Program
Indigenous knowledge	2	0	1	0	0
Multiple reporting formats (YES/NO)	0	0	1	1	1
Community-based monitoring	2	N/A	1	0	N/A
Funding provided to community for monitoring purposes	2	N/A	0	1	0
Cumulative effects	1	1	1	1	0
Database or metadatabase available	2	0	1	0	2
Management and monitoring roles (who does what) are clear	2	1	0	1	1
Progress (interim) reported on for long-term plans or goals	2	2	0	1	N/A
Contact person(s) or information provided (YES/NO)	1	1	1	1	1
Whole-watershed approach; water quality, quantity and biomonitoring	2	1	2	1	0

Monitoring is linked to management, project, or decision-making	2	2	1	1	0
Subwatershed breakdowns	2	N/A	2	2	1
Coordination and/or partnerships with key decision-makers and stakeholders	2	1	2	1	2
Easily-understood reporting and/or resources	2	2	1	2	1
Most or all indicators measured are reported on	2	2	2	2	0
Long-term continuous data (10+ years)	2	2	2	1	2
Mid-term continuous data (5-9 years)	2	2	2	1	2
Parameters and data sheets shared and/or explained	2	1	2	2	2
Methods or approaches explained	1	2	2	2	2
Western knowledge	2	2	2	2	2
Relatable or stakeholder-driven indicators	2	2	2	2	2
Short-term continuous data (1-4 years) OR 'snapshot' data	2	2	2	2	2
Total possible score	42	36	42	42	38
Total score	39	26	30	27	23
Grade	**93%**	**72%**	**71%**	**64%**	**55%**

For these top-scoring programs, the 22 criteria were placed in ascending order based on percentage grade (total score divided by total possible score), demonstrating the areas most in need of improvement for these five programs as follows:

1. Recognizing Indigenous Knowledge or ways of knowing (done well or somewhat by 2 programs, score of 30% from applicable programs)
2. Incorporating community-based monitoring (done well or somewhat by 2 programs, score of 50% from applicable programs)
3. Providing funding to the community for monitoring purposes (done well or somewhat by 2 programs, score of 38% from applicable)
4. Using multiple reporting formats (done well or somewhat by 3 programs, score of 60% from applicable programs)
5. Clarity regarding management and monitoring roles (done well or somewhat by 4 programs, score of 50% from applicable programs)
6. Consideration of cumulative effects (e.g., in reporting) (done well or somewhat by 4 programs, score of 40% from applicable programs)
7. An accessible database or a metadatabase is available (done well or somewhat by 3 programs, score of 50% from applicable programs)

8. Interim progress is reported for long-term plans or goals (done well or somewhat by 3 programs, score of 63% from applicable programs)
9. A whole-watershed approach is taken (measuring water quality, quantity and biomonitoring indicators) (done well or somewhat by 4 programs, score of 60% from applicable programs)
10. Monitoring is linked to water management, project management, or decision-making (done well or somewhat by 4 programs, score of 60% from applicable programs)

When the 22 criteria were ordered according to their cumulative grades from all nine programs reviewed (total score divided by total possible score), criteria showed a gradual decrease from western science (used across all nine programs) to those least addressed (community-based monitoring and funding for these programs), per Figure 5.

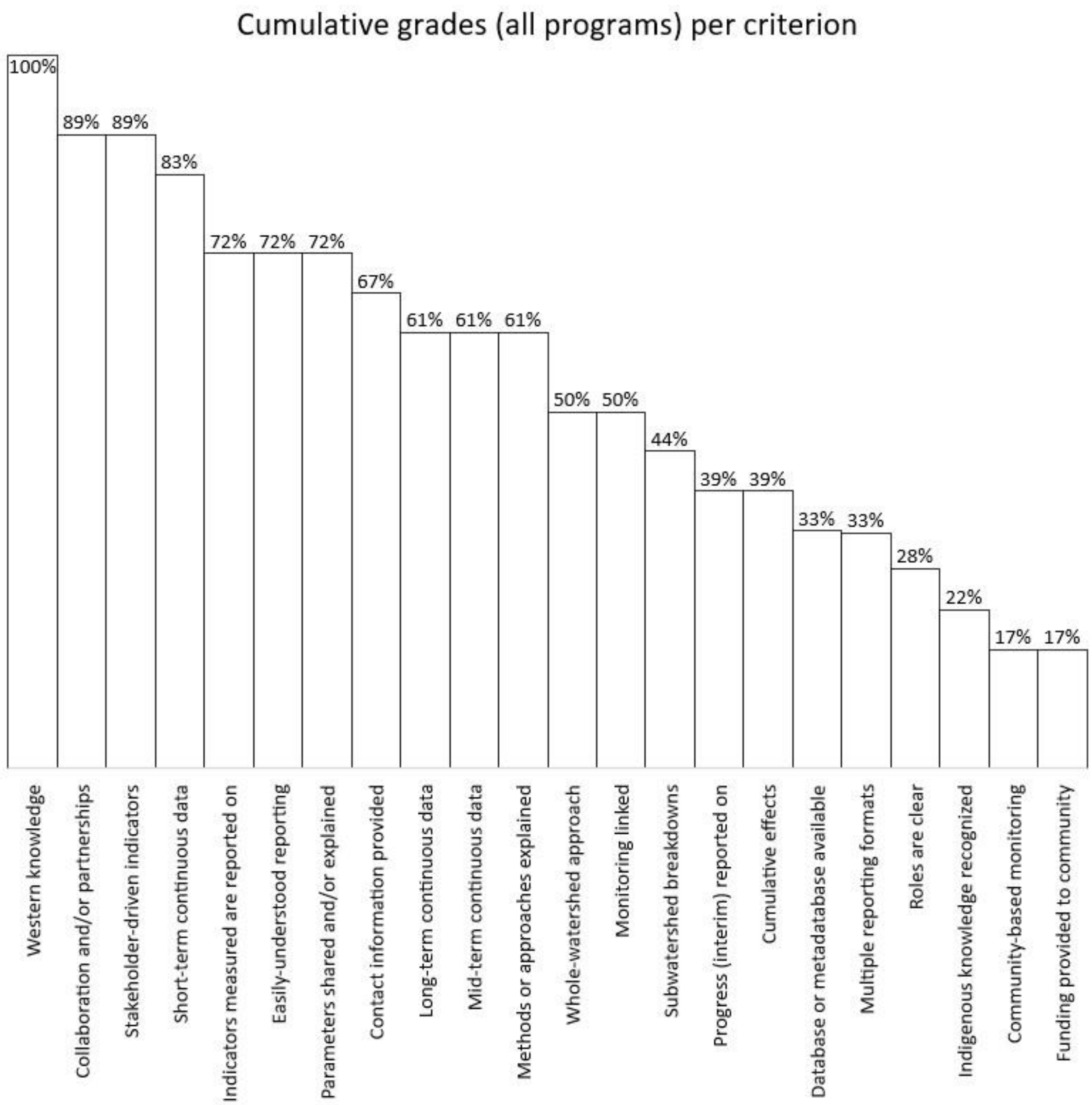


Figure 5. Criteria grades in descending order (sum of program scores divided by total possible score).

3.5 Discussion

Through a monitoring review and key informant interviews, we identified positive aspects of current monitoring programs and opportunities for improvement. Aspects of monitoring programs to celebrate and maintain moving forward are summarized in three key points, as follows:

- All monitoring programs reviewed were based heavily on western science, while the top-scoring programs had datasets that spanned all three criteria timeframes (short, mid, long-term). Key informants generally shared the view that science-based approaches are needed (though are not always well-used – see Recommendation 5 below) and that varying durations of data collection are important to maintain if we are to continue addressing emerging questions.

- Collaboration was well-implemented with some partners or stakeholders (not as well with rightsholders) who are often engaged in shaping priorities and/or monitoring indicators; however, collaboration evidently does not imply coordination. Key informants unanimously stated coordination among and between monitoring and management bodies is a major challenge to address.
- Although contact information was provided for the top-scoring programs, this was not the case with many others. Key informants suggested that basic information like program goals, contact information and descriptions of what is measured are basic tenets of open, understandable monitoring. Also discussed were issues of accessibility and transparency related to the idea of building relationships for data-sharing, collaboration and coordination. While this aspect of the criteria is to be celebrated and maintained by those already performing, those who do not meet the criterion are encouraged to address it.

Results of this study and our exploratory research support outcomes of previous reviews (Veale, 2010; Mesner & Paig,e 2011), as described in Ho, Eger and Courtenay (2018). Results from a study on Best Management Practices in water monitoring and management undertaken by the University of Wyoming (Mesner & Paig,e 2011) highlight nearly identical opportunities for improving monitoring compared to the recommendations we have described. The three most common mistakes in developing a water monitoring program are described (Mesner & Paige, 2011) alongside related recommendations from this study in Table 3.

Table 3. Previously identified common mistakes in developing water monitoring programs (Mesner & Paige 2011), evolved to demonstrate high-level outcomes of this study.

Previously identified failure	**Description**	**Related recommendation in this paper**
Consider alternate methods for demonstrating impact	Considering non-linear, complex responses	Recommendation 1: Consider cumulative effects and incorporate other knowledge approaches (e.g., Indigenous Knowledge)
Carefully consider project objectives	Assuming someone will use monitoring at some point, without directing the act of monitoring to a project or objective	Recommendations 2, 3 and 5: Use multiple reporting formats, clarify goals and roles of all parties, and link monitoring to decision-making
Understand the dynamics and transport processes of the pollutant of concern in a particular watershed	Context-specific dynamics, transport, and transformation	Recommendation 4: Take a context-specific, whole-watershed approach. Indicators should be driven by diverse local persons, perspectives and organizations

The three failures identified by Mesner and Paige (2011), described in Table 3, are supported by monitoring indicator selection frameworks from Niemeijer and de Groot (2008) and van Oudenhoven et al. (2018). These frameworks and the work by Mesner and Paige (2011) collectively address how relatable, relevant or understandable monitoring information is for managers and decision-makers.

Niemeijer and de Groot’s (2008) framework connects water monitoring with management by suggesting indicator selection criteria that consider the ‘policy and management dimension’. This dimension defines the following criteria for monitoring indicators: comprehensible, linkable to social and management domains, relevant, and user-driven (among other criteria).

Similarly, Oudenhoven et al.’s (2018) framework includes salience as a criterion for selecting monitoring indicators, which incorporates relevance to decision-makers and how understandable the information is. Key informants also emphasized that an important part of connecting monitoring to decision-making is to ensure the goals of monitoring are co-created with or designed to address the needs and interests of decision-makers. In addition, a recent (2019) proprietary monitoring review in Canada concluded there is very little pre-planning/coordination of what is being reported on in ‘State of the Environment’ Reports compared to pre-determined desired outcomes/objectives for the watershed/ecosystem (S. Kidd, pers. com.[8]). That study recommended that management objectives should drive what is assessed and reported on (e.g., have we made progress on improving these aspects of water quality?).

There were two ‘opportunities for improvement’ lists generated from the monitoring review: one from the top five-scoring programs and one from all nine. We considered those lists alongside results from the key informant interviews and other recent or current monitoring reviews, in addition to current priorities of local key informant practitioners. Once similarities were highlighted, five key recommendations were identified for improving water monitoring. These recommendations are summarized in Table 4.

Table 4. Recommendations emerging from opportunities for improvement of monitoring programs.

Recommendation	Criteria and/or opportunities for improvement that inform the recommendation
Recognize different knowledge approaches	From criterion: Indigenous Knowledge and/or ways of knowing is recognized and ideally forms at least some evidence.
Use multiple reporting formats	From multiple criteria: understood by lay person, reported in multiple formats, indicators measured are reported upon, accessible datasets or metadata. Also relates to Key Informant discussion on transparency and usability of data, as well as introductory content about indicator criteria (e.g., Niemeijer & de Groot, 2008; van Oudenhoven et al., 2018). Supported by exploratory research (Ho, Eger and Courtenay, 2018).
Clear roles for monitoring and management	From criterion: Management and monitoring roles (i.e., who does what) are clear. Also relates to coordination criterion.
Consider a whole-watershed approach	From criterion: Whole-watershed approach is taken, which considers all three of the following: water quality monitoring, monitoring of water quantity and biomonitoring. Also relates to criterion relating to cumulative effects.
Link monitoring to management and decision-making	From criterion: Monitoring is linked to watershed management, project management, or decision-making. Relates to coordination and defining roles. Supported by the independent monitoring reviews.

[8] S. Kidd: 109 Ferndale Avenue, Winnipeg, MB R2H 1T9

Improving the connection between monitoring, management and decision-making requires effort and systemic/institutional change from parties across all three groups of water resource personnel. The collective experiences of key informants demonstrated that efforts by water researchers, monitoring personnel and/or water managers to engage with decision-makers were often ineffective due to bureaucratic systems (i.e., no direct access to decision-makers due to strict and somewhat convoluted chains of command) or were left unanswered by inaccessible decision-makers. There is essentially no structure or process to facilitate coordination between different government departments, both within and between federal and provincial bureaucracies. As such, the role of governance cannot be overstated. We must rethink our governance structures and the motivations of water authorities to fully realize the integration, coordination, and/or alignment of monitoring with management and decision-making at multiple levels. Network gaps identified during and after an industry workshop (described as part of Recommendation 1) support this conclusion.

This paper provides a foundation for developing a new monitoring framework in the study area (i.e., the interface of the Grand River and Lake Erie in Ontario, Canada), to be further developed in later stages of the research. The recommendations below discuss our results in more detail, along with implications of addressing the issues raised. We conclude this paper with a summary of key points that form a foundation for moving forward with an improved monitoring framework.

Recommendation 1: Recognize different knowledge approaches

The monitoring review and some key informant interviews highlighted the need to incorporate multiple lines of evidence in water monitoring and management. These include conventional sources of information – e.g., academia, more collaboration among government science divisions, and monitoring partners – as well as less conventional sources like citizen science and Indigenous persons and communities. Indigenous knowledge and ways of knowing include observations/data, the process of monitoring and interpretation or use of data, i.e., traditional ways of inferring change (e.g., customary practice) and cultural values informing what kind of ecosystem or watershed is desirable. When designing a monitoring program, recognizing perspectives and values of the Canadian public alongside those of Indigenous rightsholders is imperative for meeting diverse needs and addressing issues affecting all groups of stakeholders or rightsholders.

A workshop at the 2019 National Conference of the Canadian Water Resources Association (CWRA) highlighted the importance of incorporating diverse knowledge approaches (E. Ho, personal communication, May 26, 2019). The workshop, which took place on May 26, 2019, involved a rightsholder/stakeholder mapping activity. A speaker at the workshop described how our mental models (i.e., internal representations of reality) define the roles, possibilities and limitations of those with whom we engage – whether in-person or within computer-based decision-support tools. For example, in agent-based modeling, the relationships and potential responses of each agent are defined for the context or question we are analyzing; in reality, those agents (e.g., people) are more complex and dynamic than the limited set of actions and responses we have coded into the software. Yet, a decision will be based on a model in which limited coding is all the individuals can ever do. Recognizing this, engaging with the 'agents' early on to define the context and confirming their roles within that context can facilitate more realistic and meaningful decision support tools. Early engagement allows the 'agent' (or stakeholder, rightsholder) to define his or her own role according to individual abilities, context, and interests – as opposed to agent roles being defined by the interpretation or biases of the person coding. Early, meaningful engagement becomes more important the more distinct each person or group's perspectives, needs and/or function are from our own.

Recommendation 2: Use multiple reporting formats

The monitoring review and key informants both raised the need to offer multiple reporting formats beyond conventional state-of-the-watershed report cards and pages-long, jargon-filled, issue-based reports. Reporting in multiple formats promotes the accessibility (including physical access and comprehension) and usability of information produced from monitoring data for stakeholders, rightsholders, and especially decision-makers. Four other criteria can also be addressed through this recommendation: reporting on measured indicators, providing open/accessible datasets or metadata and explaining the methods/approaches of monitoring and implications of parameters measured (note: explaining methods and explaining parameters were two separate criteria).

Transparency about how data are produced results in a demystified process and trust-building – two points highlighted by key informants as imperative to collaboration and creating a source of information sought by decision-makers. Key informants also stressed the importance of reporting on user-driven data in formats preferred by the user (e.g., decision-makers). An exemplary case study from the programs reviewed is the the Muskoka Watershed Council (MWC) Watershed Health Report Card, which communicates information using data collected from the District Municipality of Muskoka's aquatic monitoring program. The Report Cards program was redesigned between 2016 and 2018 as a result of our exploratory study (Ho, Eger, & Courtenay, 2018). The revised program was included in this review.

The 2018 Report Card communicated information regarding four health indicators and four indicators that measure potential threats – a total of eight indicators within two categories. Health indicators are total phosphorus, calcium, benthic macroinvertebrates and interior forest cover. Threat indicators are climate change, species at risk, invasive species and (habitat) fragmentation. The Report Card also includes two formats: infographics and story boards. Infographics are created for each indicator, which are then compiled into one general Report Card in addition to subwatershed Report Cards – all of which are designed to be accessed online. There is a general story board navigation, which includes pages defining watersheds and watershed report cards, justification for reporting, and an interactive map for locating oneself in one of the quaternary subwatersheds, in addition to individual story boards per indicator. These storyboards incorporate text, interactive maps with color-coded areas of vulnerability, videos and photographs. These format changes were designed and implemented by many of the same people who collect the data and who will use the data with specific decisions in mind (i.e., the District Municipality). This is a key link for successfully connecting monitoring and management or decision-making.

Recommendation 3: Clear roles for monitoring and management

This recommendation is rooted in the criterion regarding clear management and monitoring roles, although aspects of this discussion are relevant to the criterion on coordinated, collaborative efforts. The explicit clarification of roles among different partners or collaborators was the fifth greatest opportunity for improvement across top-scoring monitoring programs and among the top opportunities across all programs (tied for second place, along with multiple reporting formats and recognizing Indigenous Knowledge). This issue was first identified during our exploratory study in the Muskoka River Watershed (Ho, Eger, & Courtenay, 2018). The Muskoka Watershed Council was initially a partnership between the District Municipality of Muskoka and the Muskoka Heritage Foundation (which evolved and renamed over time). As part of our exploratory study, we held a workshop on August 5, 2016 to engage the Council in answering questions such as, "Does the method/format of communication work for what we are trying to achieve?" – which addressed one of our review criteria and Recommendation #2, above.

Implicit in this discussion on achieving communication goals was a question around what the intended goal actually was (e.g., changing community behaviour, influencing decision-makers, or simply raising awareness). Different goals require different communication/reporting strategies. It was soon apparent there were conflicting views on what the Council should strive to accomplish, calling into question its organizational structure and whether evaluation of the monitoring program would be feasible given the lack of clear goals and roles. Today, the Muskoka Watershed Council is a collaboration between the District Municipality of Muskoka and the Muskoka community, while the Heritage Foundation has merged into the Muskoka Conservancy. The present role of the Council is to provide information to decision-makers, managers and the general public on ways to protect and restore the watershed.

Recommendation 4: Consider a whole-watershed approach

The criterion regarding a whole-watershed approach considers all three of the following: water quality monitoring, monitoring of water quantity and biomonitoring. Although social dimensions are not included in this criterion, we acknowledge that humans are a key component (if not 'the' key component) of watershed management. Most monitoring programs addressed this criterion at least in part (i.e., measured 2-3 indicator types), while one did not address it (i.e., measured only one indicator type). This criterion was inapplicable to the Statistics Canada Sustainable Development Goals Data Hub.

The Slave Watershed Environmental Effects Program (SWEEP) in the Northwest Territories (Canada) is an example of a community-based, whole-watershed monitoring approach. It was also our top-scoring program in this review, having addressed all criteria in part or in full except for providing multiple reporting formats. SWEEP was developed according to the capabilities of local (Canadian and Indigenous) communities to establish a whole-watershed monitoring program for the Slave River and Delta, and administered through the Slave River and Delta Partnership (SRDP). Both western and Indigenous knowledge are incorporated into this program, which brings members of both western and Indigenous communities together to identify program priorities and indicators to measure. Monitoring indicators monitor cumulative effects through two indicators types. Type 1 indicators, measured by the community, included biological measurements and local observations. Type 2 indicators, which provided a baseline condition assessment, included numerous water quality, hydrological, and biological indicators. Fish health, wildlife abundance, water quality and quantity, aquatic invertebrates, ice dynamics and Traditional Knowledge were all part of the monitoring program, which incorporated indicators common to western science (e.g., contaminant levels) and Indigenous experience (e.g., fish taste). In total, SWEEP considered 41 indicators corresponding to nine indices based on the three guiding questions (Jones, 2015).

To identify multiple potential stressors affiliated with cumulative effects, identify where uncertainty was greatest and whether more data were required, qualitative and quantitative indicators were integrated into a blended computer model. The model, a Bayesian Belief Network, was designed to balance Traditional Knowledge and western science indicators (Jones 2015). A conceptual depiction of the Bayesian Belief Network is provided in Jones (2017). In this visual, a combination of western science and Indigenous Knowledge indicators contribute to each of nine indices (water quality, fish health, wildlife health, water quantity, food web, wildlife population, ice regime, social, and livelihood), which contribute to the same three underlying questions of the SRDP: is the water safe to drink, are the fish and wildlife safe to eat, and is the ecosystem healthy?

Recommendation 5: Link monitoring to management and decision-making

Key informant interviews highlighted the disconnect between monitoring, management and decision-makers (especially links with decision-makers) as one of the greatest challenges to address, alongside funding for monitoring and response. However, funding is largely allocated by decision-makers, so addressing the connection between them and monitoring/management personnel could, in theory, address other challenges. Top performing programs in this review addressed this criterion at least in part, though it remains one of greatest opportunities for improvement. Only two programs were determined to satisfy the criterion well: the Slave Watershed Environmental Effects Program (described in the previous section) and Canada's Federal Environmental Effects Monitoring Program.

The Environmental Effects Monitoring program (EEM) is an adaptive monitoring program originally designed in the 1990s to assess the adequacy of industry-specific regulations for protecting the receiving environment by monitoring the status of fish, fish habitats (as indicated by benthic invertebrate communities) and use of fish (as indicated by relevant contaminant levels in fish and reports of tainting). It is an industry-funded adaptive monitoring program, currently required for pulp and paper and metal mining industries. EEM studies include water quality monitoring, effluent chemical characterization, and effluent sublethal toxicity testing as supporting measurements (Government of Canada, 2017). The requirement for conducting an EEM program is part of the compliance requirements under permit given to discharge deleterious substances. Environment and Climate Change Canada is responsible for the coordination, development and implementation of EEM in consultation with diverse stakeholders and Indigenous rightsholders (Walker et al., 2003).

There are several benefits of the regulatory approach taken with EEM. It is evidence-based and is a nationally consistent monitoring approach for determining the potential effect of effluent on aquatic ecosystems (Walker et al., 2003). The cyclical, adaptive monitoring process – detection and confirmation of the presence of effects, determination of spatial extent and magnitude of effects, and investigation of the cause of effects – allows for adaptation to changing contexts and improvement, as necessary. There are long-term data from projects across Canada, generating a spatial characterization of potential mine and mill effluent effects in receiving waters over time, permitting an effective adaptive management approach. The EEM program has successfully balanced scientific approaches for monitoring with decision-maker needs like legal certainty and ability to enforce monitoring requirements within a regulatory context (Walker et al., 2003).

3.6 Conclusion

The management of freshwater resources is critical for understanding changes in water quality, water availability, and targets species that depend on water resources. While there are many approaches to achieve successful water management, they should all integrate: 1) aims and objectives, 2) appropriate monitoring design, 3) data collection, 4) data analysis, interpretation and evaluation and 5) communication and interpretation. Using an iterative, adaptive, and scale-appropriate framework with cultural and ecologically relevant indicators will allow for meaningful and emerging questions to be answered. To evaluate how effectively freshwater is managed in Canada, we reviewed nine freshwater monitoring programs and used 21 key informant interviews to identify best practice elements of existing management frameworks and identified opportunities to strengthen monitoring programs. All monitoring programs were evaluated on 22 criteria that addressed knowledge/evidence used, indicators, methods, data quality and extent, communication, and decision making. The top five ranked programs ranged in overall effectiveness from 61% to 93%, with recognizing Indigenous Knowledge or ways of knowing and incorporating community-based monitoring programs being the top two areas identified as needing improvement. In terms of program strengths, we found that most programs were evidence-based (in most cases, western science) often integrating multiple temporal scales. Another strength identified were strong collaborations with partners and stakeholders in setting program priorities. Our results also indicate a desire for programs to have accessible and transparent goals, methods, and contact information.

Ultimately, discussion around institutional barriers and management-driven monitoring goals relate to human relationships and understanding the context(s) of roles that need to better connect. For example, monitoring personnel should strive to understand and meet the needs/interests of decision-makers, while decision-makers require an understanding of the context and relevance of information provided by monitoring. Further, understanding who is at the table, and why, may result in more targeted monitoring goals, watershed priorities more representative of the general public and Indigenous rightsholders, new ideas or approaches for addressing challenges, and more coordinated messaging to, or influencing of, decision-makers. A variety of tools and approaches exist, like the CWRA network analysis example, that may facilitate a common understanding of different roles, their contexts and pressures, and potential opportunities for improved collaboration (Cooperrider & Srivastva, 1987; Reed et al., 2009; Rousseau & Billingham, 2018). Recent work from the Canadian Water Network has also concluded that, in addition to integrative structures or processes facilitating coordination among government bodies, there is an emerging role for knowledge brokers who can facilitate the connection between knowledge producers (e.g., anyone or any group collecting monitoring information) and knowledge consumers (e.g., managers and decision-makers; Holgate, 2012).

From our work, we made five recommendations for freshwater management programs: 1) recognize and integrate different knowledge approaches to avoid biasing certain types of evidence; 2) improve reporting communication to be more assessable and wider reaching; 3) clarify management and monitoring roles and responsibilities to enhance effectiveness and ensure all important aspects are being addressed; 4) consider a whole-watershed approach that addresses cumulative impacts; and 5) make evidence-based decisions inferred from monitoring outcomes.

Chapter 4
Freshwater quality monitoring in Ontario: Strengths, weaknesses, opportunities, threats, and recommendations

Citation: Ho, E., Courtenay, S. C., and Trant, A. J. *In preparation*. Freshwater quality monitoring in Ontario: Strengths, weaknesses, opportunities, threats, and recommendations. Not yet submitted.

4.1 Introduction

Although nearly 20% of the world's current freshwater resources and 7% of the world's renewable fresh water exist in Canada, it is not a water secure country (Schuster-Wallace, Sandford, & Merril, 2019). Extreme weather, climate change, distribution (geographic and commercial), and contamination all impact water availability and use in Canada. Ecological pressures – including water/natural resource crises – are among the most pressing political and economic risks facing the world today (World Economic Forum, 2020; 2021 – see also *Global Risks Reports* published in previous years). As such, freshwater quality is a central focus of economic and social development at local and global scales (WWAP, 2017).

Despite the importance of water quality monitoring programs, capacity for water monitoring in Canada decreased by the early 2000s, creating a void of data regarding biogeochemical exchanges between land, water, and air (Shiklomanov, Hammers, & Vorosmarty, 2002; Turner, 2013). In addition, shifting political priorities and budgetary constraints can impact the viability of consistent, long-term data collection (Lindenmayer & Likens, 2009). Finer, more detailed data are usually needed to account for effects across scales and are one of the main deficiencies in monitoring analysis (Bidstrup, Kørnøv, & Partidário, 2016). The high cost of data collection and analysis is the most significant hurdle faced by monitoring organizations, though it is a hurdle that can be reduced through coordination of monitoring efforts with other organizations (Arciszewski & Munkittrick, 2015). Even exemplary monitoring programs have their shortcomings. Our recent review of nine water monitoring programs, determined to be of high quality by Canadian water managers and scientists, resulted in five recommendations: (1) recognize different knowledge approaches (e.g., Indigenous), (2) use multiple reporting formats to satisfy the needs of end users, (3) clarify roles for monitoring and management, (4) consider a combination of water quality, quantity, and biomonitoring, and (5) strengthen linkages between monitoring, management, decision-making (Ho et al., 2020).

While monitoring, management, and decision-making can be most effective when designed for one another, implementation is wrought with challenges (Stevens et al., 2007; Hulme, 2009; Ho, Eger, & Courtenay, 2016). These challenges include: (1) anticipating research needs, communicating between disciplines, and applying research (e.g., translating monitoring into action); (2) equalizing risk tolerances and definitions in terms of uncertainty, and standardizing priorities; and (3) willingness to change (Quevauviller, nd; Glasgow et al., 2012; Holmes & Scott, 2010; McFadden et al., 2009; Hulme, 2009; Stevens et al., 2007). These challenges are partially due to uncertainty around how, when, where, and to what extent potential social-ecological impacts may be experienced, and what an appropriate response looks like (Stevens et al., 2007; Hulme, 2009; Holmes & Scott, 2010).

The consideration of social-ecological (and economic) impacts is of great relevance to policy and decision-making; however, monitoring – which ideally informs management and decisions (Jones, 2016) – has conventionally focused on biophysical impacts. The literature in natural resource science and management has long demanded consideration of sustainability, arguing that conventional science should do more to reflect complexities in social-ecological environments (Kay & Schneider, 1994; Kemp, Parto, & Gibson, 2005; Jones, 2016; Stephenson et al., 2017 and 2018). Sustainability is defined as the integration of social (including cultural), economic, ecological, and institutional (including governance) priorities in the pursuit of a better and more just world (Kemp, Parto, & Gibson, 2005; Stephenson et al., 2017). Frameworks for sustainability recognize that resources are limited, and that social, economic, ecological, and institutional aspects are codependently linked and should be managed together (Rocktsröm et al., 2009; Raworth, 2012; Steffen et al., 2015; Raworth, 2017).

In practice, the concept of sustainability has been developing since the early 1970s, as humanity's impacts on Earth's physical and biological systems – impacts so severe they are geologically observable (e.g., the anthropocene: Crutzen & Ramanathan, 2000) – were increasingly recognized (Sachs, 2015). Agenda 21 – a global plan for sustainability – was adopted at the United Nations Conference on Environment and Development in 1992, followed by development of the ecosystem approach at the Convention on Biological Diversity in 1995. Various agencies of the Government of Canada have since adapted and applied the ecosystem approach to the management of forests (Natural Resources Canada; McAfee & Malouin, 2008), national parks (Parks Canada, 2017), and fisheries (Fisheries and Oceans Canada; DFO, 2007).

This dissertation explores approaches for diversifying perspectives that contribute to our understanding of freshwater quality. In this chapter, we argue that improving freshwater quality monitoring involves consideration of integrated priorities in the pursuit of sustainability; otherwise, existing shortcomings in monitoring and management are likely to be maintained. For example, social-ecological problems predicted 50 years ago have only intensified today, in part because we have failed to integrate pillars of sustainability – e.g., social, ecological, economic, and institutional considerations – in science and management (Meadows et al., 1972; Sachs, 2015; Stephenson et al., 2017). Research can be designed to provide timely, relevant information to leaders and decision makers who are currently reshaping, even completely transforming, approaches to science and regional management (Schuster-Wallace, Sandford, & Merril, 2019). In this study, we describe the state of current monitoring – e.g., strengths, weaknesses, opportunities, and threats – and recommendations for improvement.

4.1.1 Study context

The study area is the interface of the Grand River and nearshore Lake Erie (described in Sub-section 1.4.1). Decision-making regarding freshwater quality in the study area is primarily within the mandates of two Ontario ministries – Ministry of Natural Resources and Forestry (MNRF) and Ministry of Environment, Conservation, and Parks (MECP) – except for the Lake Erie portion, which is primarily the jurisdiction of Environment and Climate Change Canada. Other authorities, depending on the issue, include the Ontario Ministry of Agriculture, Food, and Rural Affairs and Fisheries and Oceans Canada. The study area also falls within the management boundaries of the Grand River Conservation Authority, which manages water quantity and quality throughout the watershed and into Lake Erie 5km from the shore.

4.2 Method

Semi-structured key informant interviews were undertaken to assess aspects of current practice that should be maintained in future monitoring and what shortcomings exist. A key informant is someone with expertise on the subject or challenge at hand, with specialized knowledge of certain characteristics (Tremblay, 1957; Marshall 1996). The informant's professional role, knowledge (per consultations), willingness (assessed during recruitment) and communicability (per consultation, publications, and recruitment discussions) were considered in the selection of interviewees, per the criteria laid out in Tremblay (1957). Individuals who consulted on the project or who participated as interviewees also recommended other participants. Between February 27 and May 16, 2019 (inclusive), 21 semi-structured interviews were conducted in person or via telephone. Individuals were identified from the literature and through consultation with those who work in the study area (e.g., scientists and water managers). Participants (Appendix E) represented federal and provincial government agencies, the local Conservation Authority, the local Indigenous community, local, regional, and national community groups or non-profit organizations, a regional industry association, and an independent scientist. Participants spoke about water monitoring programs (water quality and fisheries), water management, decision-making, cumulative effects, and/or integrating science with policy. In some cases, citizen-science and the integration of western and Indigenous knowledge were discussed.

Before each interview, participants completed a routing questionnaire using SurveyMonkey (Appendix C) so that a short-list of questions relevant to their unique experience could be selected from a larger pool of questions (Appendix D). In addition to name and general comments, participants were asked to describe their familiarity with the study area, and whether they wanted to review interview questions prior to the interview. Interview questions were selected from a pool of 16 questions related to general water monitoring (6 questions), cumulative effects (3 questions), and decisions and coordination (7 questions), in addition to three concluding questions. Interviews were audio recorded for transcription purposes and, if requested, each interviewee's custom question list was provided before each interview.

Francis et al., (2010) recommend four principles for assessing saturation of interviews in qualitative research: (1) meeting a minimum number of interviews (in the literature and in this study this was determined to be 10 interviews), (2) delivering a maximum number of 'redundant' interviews (Francis et al., 2010, suggested three), (3) ideally more than one coder would analyze the data, and (4) findings would be reported back so participants can evaluate the evidence. This research implemented principles 1, 2, and 4; however, rather than coding/analysis by multiple individuals (principle 3), multiple individuals transcribed interviews and contributed to synthesizing the information. Redundancy of content was noticed as early as the 17th interview, and no new names of experts specific to the monitoring/management in the study area were raised by the final (21st) interview. One interview with an Indigenous person was the exception, as the content for that interview was designed differently than others; the interviewee was engaged to provide insights for Indigenization of water monitoring and management processes, not to provide specific expertise on water monitoring or management. As such, the new content/ideas and referred individuals from that interview are recognized but were not considered in the assessment of saturation. Doing so would result in immense scope creep of this research project.

To ensure consistency, one researcher performed all interviews and analysis. Interview audio was first transcribed using an auto-transcription software, Transcribe Wreally. Following auto-transcription, transcripts were manually edited. Interviews were analyzed using NVivo 12 and were coded into seven high-level categories ('nodes') with subcategories beneath them (Figure 6). Files that were analyzed included 21 transcripts and one written response. The written response was the typed notes from interviewee 2, which was included due to not having enough time to complete the interview. Once coded, a 'Coding Summary By Code' report was exported from NVivo 12. All coded content beneath each parent node was then recoded/reorganized into topic areas, as opposed to transcript number.

Nodes

Name	Files	References
1 - Strength of monitoring	17	37
Examples of programs	13	24
2 - Weakness of monitoring	20	96
Challenges	20	136
3 - Collaboration	16	52
Who are decision-makers	9	14
Who's involved	17	51
4 - Coordination and use of data	21	148
5 - Cumulative effects	13	34
Definition	10	14
Different from regular monitoring	7	7
Examples of CE in practice	11	15
What can CE monitoring do	5	9
6 - Other	20	83
Citizen science	9	31
Decision support tools	16	30
Knowledge integration	10	26
7 - Recommendations	17	50
Ideal monitoring program	14	38
Priorities and values	20	82

Figure 6. Coding categories, or nodes, in NVivo 12. Parent categories do not include aggregate codes from child nodes.

A synthesis was written from the coded content, which was then used to create a modified SWOT analysis: SWOTR (e.g., recording Strengths, Weaknesses, Opportunities, and Threats in the left column of a table, and Recommendations in the right column) – described more below. SWOT issues that were relevant to one another were grouped together in the SWOTR analysis, which resulted in main-level issues and sub-issues for each SWOT category row, alongside recommendations (as applicable). Recommendations were often matched to SWOT issues by the researcher, not by the interviewee, as recommendations were discussed separately from SWOT issues and, therefore, were not necessarily directly attributed to (or limited by) the issues that study participants raised.

4.2.1 SWOTR: theory and rationale

The SWOT analysis is likely the most widely used management technique in the process of decision-making, normally in the context of business (Panagiotou, 2003). The approach was originally developed as a first step in a process of organizing interview responses into categories based on organizational roles or mandate (e.g., administration, finance…), which would be followed by commitments by individuals in each role to address issues, in turn followed by a planning process to determine what should be done (Humphrey, 2005). This study uses a modified SWOT analysis as a first step for identifying and grouping what issues exist in water monitoring. We have modified the SWOT model to enable the linking of recommendations with the SWOT issues identified by interviewees (e.g., SWOT categories in rows in the left column of a page, with associated recommendations in the right column). Thus, the resulting SWOTR analysis identifies issues and integrates a high-level analysis regarding what actions may follow. Managers and other end users of this research might apply additional analyses – e.g., Multiple Criteria Decision Support method (Kajanus et al., 2012) – to strengthen the utility of SWOTR for their needs.

Recognizing the steps initially proposed by Humphrey (2005) – sorting, categorizing based on commitments, and planning to rectify issues – our modified method of SWOTR was completed using the following steps:

(1) Initial SWOT analysis is carried out. Issues are identified by informants (e.g., stakeholders, experts, etc.) and are sorted into separate pages or rows.

(2) Optional: If required, a review of mandates and commitments is done separately. In the context of resource management in Canada, authority and commitment are legislated, regulated, and mandated with (usually) a high amount of detail/specificity. Thus, categorization to achieve agreement and commitment (part of the original SWOT analysis process) is irrelevant in a context where both are determined by legislated jurisdiction and policy mandates. Most informants would be aware of designated roles, inherent to many of the recommendations provided; however, for areas of overlap or unclear jurisdiction (e.g., some aspects of freshwater monitoring in estuaries of the Great Lakes), a review of jurisdiction and mandates may be warranted.

(3) Recommendations are categorized according to the issue they address. Incorporating the recommendations into the SWOTR analysis ensures Humphrey's third step – planning to rectify issues – is integrated with the identification of issues. This provides a basis for further analysis to facilitate management or decision-making and a blueprint for planning and action.

4.3 Results

Interviewees identified 106 issues and 51 recommendations. Issues were grouped into 23 main issues and 83 sub-issues within the four SWOT categories. The number of issues and recommendations in each category are as follows:

- Strengths: 15 issues (4 main issues, 11 sub-issues) and 11 recommendations.
- Weaknesses 53 issues (10 main, 43 sub) and 24 total recommendations.
- Opportunities:12 issues (5 main, 7 sub) and 5 total recommendations.
- Threats: 26 issues (4 main, 22 sub) and 11 total recommendations.

The main issues and their associated (numbered) recommendations are summarized in Table 5. The full list of 106 issues and 51 recommendations is presented and described in more detail in the interview summary report (Ho, Dhaliwal, & Wright, 2020).

Table 5. Summary of 23 main issues, 13 recommendations, and priorities (indicated by asterisk and bolded) from 21 practitioner interviews. Only main-level issues and associated recommendations are listed below. Sub-issues (83) and their associated recommendations (38) are acknowledged in parentheses. Numeration is preceded by letters that represent SWOT categories: Strengths ("S"), Weaknesses ("W"), Opportunities ("O"), and Threats ("T"). More information is provided in Ho, Dhaliwal, and Wright (2020).

Issues	Recommendations
S1. 60+ years of comprehensive data (sub-issues: 7)	S1. *No main-level recommendation* (sub-recommendations: 5)
S2. Collaborative inter-agency and stakeholder relationships (sub-issues: 3)	***S2. Collaboration is critical; consult with all parties from the start and design together (including United States re: Great Lakes) (sub-recommendations: 3)**
S3. Standardized sharing of data (sub-issues: 1)	S3. *No main-level recommendation* (sub-recommendations: 1)
S4. Regional, accessible data repositories (*no sub-issues*)	S4. Monitoring data should feed into a coordinating agency (for communication, efforts); stipulate there are no limitations on data use (*no sub-recommendations*)
W1. Limited operational capacity (sub-issues: 6)	W1. Review what makes sense to complete in-house, and what can be carried out by partners (note: for community partners, recognition and purpose should be provided to maintain involvement, and capacity provided for analysis and dissemination); capacity-building should be done using both western and Indigenous approaches (sub-recommendations: 1)
***W2. Knowledge capacity gaps exist (e.g., cumulative effects assessment) (sub-issues: 6)**	W2. *No main-level recommendation* (sub-recommendations: 1)
W3. Good scientific indicators are not necessarily the best indicators to answer management or decision-maker questions (sub-issues: 2)	***W3. Decision-makers and scientists co-design monitoring, translate decisions into viable questions (sub-recommendations: 1)**
W4. Monitoring design needs improvement (sub-issues: 5)	W4. *No main-level recommendation* (sub-recommendations: 2)
***W5. Communication needs improvement in every way (sub-issues: 5)**	W5. Determine the purpose, objectives of monitoring early and collaboratively (sub-recommendations: 2)
W6. Coordination is severely lacking (sub-issues: 5)	W6. Improve communication; implement redundancy in roles, not activities (sub-recommendations: 2)
W7. Programs and processes are exclusive (sub-issues: 4)	W7. It is critical to engage with the right people, at the right time, and that they represent diverse backgrounds (sub-recommendations: 2)

W8. Management culture does not support meaningful action (sub-issues: 4)	W8. *No main-level recommendation* (sub-recommendations: 1)
W9. Cumulative effects are not well-considered (sub-issues: 4)	W9. *No main-level recommendation* (sub-recommendations: 3)
***W10. River-lake dynamics are highly variable and not well documented (sub-issues: 2)**	***W10. Grasp the relative influence of the river and lake on each other, and track change over time (including the interface's importance to Species-at-Risk) (sub-recommendations: 2)**
O1: Advances in technology have increased capacity to investigate complex issues (sub-issues: 2)	O1: *No recommendations*
O2: Open data practices are becoming the norm (and are increasingly expected; sub-issues: 1)	O2: *No recommendations*
O3: Reconciliation provides a mandate for meaningful Indigenous collaboration (sub-issues: 1)	O3: Indigenous communities should be considered end users of information; implement a strong, accessible, two-way knowledge mobilization strategy (sub-recommendations: 1)
O4: Legislated and policy mandates determine whether and how decisions are made (they are clearly defined and comprehensive; sub-issues: 1)	O4: Knowledge producers who know the mandates of their decision makers and tailor their information to them may be more successful at negotiating desirable outcomes (*no sub-recommendations*)
O5: Knowledge and practice are co-evolving and becoming more dynamic (sub-issues: 2)	O5: *No main-level recommendation* (sub-recommendations: 2)
T1: Capacity deficiencies (sub-issues: 4)	T1: *No main-level recommendation* (sub-recommendations: 1)
T2: Limiting regulatory/legislative processes, policy mandates, and jurisdiction (sub-issues: 8)	***T2: Community groups and other partners may collaborate to fill gaps in mandates or jurisdiction (sub-recommendations: 3)**
T3: Misinterpretation may undermine progress (sub-issues: 4)	***T3: Be transparent (e.g., how information was created, not passing political opinions off as fact) (sub-recommendations: 2)**
T4: Other systemic gaps (sub-issues: 6)	T4: *No main-level recommendation* (sub-recommendations: 3)

A potential process for designing monitoring programs was also outlined from collective responses from interviewees. The most detailed proposal by a participant was used as a base process and other participants' suggestions were added by the researcher in a logical position without duplicating steps. The collectively proposed process is as follows:

(1) Identify who the end users/decision-makers are.

(2) Identify who will do monitoring.

(3) Identify any other persons who should be engaged in some capacity.

(4) Assess needs/priorities of end users and what decisions need to be made.

(5) Convert decisions and needs into monitoring questions.

    a. Both sides should be involved in this so all understand.

    b. Be transparent about what can and cannot be said, what level of certainty is likely.

(6) Determine how data will be analyzed, identify capacity (i.e., who will do this, when, and with what funds?).

(7) Confirm what format the evidence should be in.

(8) Design and implement monitoring (including funding).

(9) Analyze, interpret data, produce information in a format per step 7.

a. Engage with professional communicators or specialist technical experts.

(10) Annual check-in/status review.

a. Bring in knowledge brokers to facilitate communication and to bring the information to where it needs to go.

4.4 Discussion

4.4.1 Current state of freshwater quality monitoring: is change possible?

Although water quality monitoring in the study area is highly collaborative, there is no question that improvement is needed. Three quarters (74.5%) of the insights provided by practitioners highlighted deficiencies: weaknesses comprised 53 (50%) of 106 issues, and threats comprised another 26 (24.5%). However, despite an obvious need to reconceptualize existing practice, early consultations with some practitioners and academics raised the question of whether a practice established for decades would be accepting of change. We suggest that current evolutions in freshwater quality monitoring can be integrated with past objectives that maintain relevance today. The merging of new developments with existing systems has been successful in the past. For example, in the 1990s, the ecosystem approach was promoted by then-Ontario Ministry of Environment and Energy (presently split into the Ministry of Environment, Conservation and Parks and the Ministry of Energy, Northern Development and Mines) through its *Policies and Guidelines of Water Management (s.1.4)*, which stated:

> The ecosystem approach views the ecosystem as composed of air, water, land and living organisms, and the interactions among them. It is the basis for environmental protection and resource management. It requires consideration of the cumulative effects on the environment, the inter-dependence of air, water and living organisms, and the relationships among the environment, the economy and society. Within the context of water resource management, ecosystem management includes the physical, chemical and biological components and their inter-relationships (MOEE, 1994, p.2).

Cumulative effects and ecological interdependencies continue to be recognized, expressed in today's Statements of Environmental Values – policies that guide Minister decisions on the environment, which go through Ontario's Environmental Registry (i.e., public consultation) prior to adoption – from the relevant provincial ministries (Government of Ontario, 2021). Although the governing ministries were reorganized, then-new developments to consider an ecosystem approach and cumulative effects remained present and were accepted as approaches that should be used (though their implementation has yet to be established: CWN, 2016). The above statement also demonstrates an early and implicit mandate to consider integrated social, ecological, and economic priorities that we have defined as the pursuit of sustainability (discussed further in Sub-section 4.4.3).

Although interviewees celebrated the immense collaborations that exist in water quality monitoring across Ontario – more than anywhere in Canada, they collectively prioritized continued local, regional, and binational collaboration as a recommended action for the study area. This recommendation included four sub-recommendations: (1) determine personnel roles on more than knowledge and monitoring capacity (e.g., flexibility/adaptability was raised as a critical criterion), (2) apply social network analyses (Prell, Hubacek, & Reed, 2009; Salpeteur et al., 2017); or other similar approaches to identify common areas of influence or authority, (3) implement a stakeholder assessment exercise (e.g., who is missing, who is redundant: Reed & Curzon, 2015) to ensure the right people are engaged at the right times, and (4) stakeholders/end users can be engaged collaboratively to design and use predictive models. Thus, although current monitoring is highly collaborative, these collaborations can be more focused and coordinated.

In addition to continuing collaboration, study participants praised the immense amount of data produced through current monitoring practices across Ontario; however, data are less comprehensive in the study area. Study participants and scientists who were consulted in this work highlighted the lower 30 km of the Grand River and the nearshore area of Lake Erie (e.g., our study area) as a space in which knowledge is largely being developed 'from scratch' as of the last 20 years. The information we have gained in this time has shown that river-lake dynamics are highly variable and not well documented; more recent research (i.e., since 2015) may provide insights into questions around influences of the river in the lake's nearshore, but in many cases our study participants noted that these studies have not yet been published and may – in some cases – never emerge as published information. Such knowledge gaps exist for many reasons, including staffing turnover and a lack of strong data and information management. For example, sharing and integration of information from different monitoring agencies does not happen as easily or efficiently as community members might think. Limited capacity to analyze data and produce information was shared as a reason data are often not even looked at for years after collection.

4.4.2 Recommended improvements

To address the knowledge gap highlighted in the previous section, study participants recommended that a dataset of baseline data – cross-sections of vertical depths, longitudinally, every three to four weeks, over several years – should be created and maintained. Such an effort would be collaborative and coordinated among monitoring agencies, which would allow monitoring objectives to align between different levels of monitoring agencies while decreasing overlaps in monitoring efforts. Consistent funding would be required, as "funding deficiencies result in piecemeal monitoring or interrupted continuous monitoring as a best-case scenario (Ho, Dhaliwal, & Wright, 2020, p.14)." In addition to capacity, legislated mandates/jurisdiction also limit the production of knowledge. Most interviewees were concerned about the limitations presented by jurisdiction and siloed water management agencies. Staff in these agencies may have expertise on their part of the watershed, but the problem is that few have the whole watershed/ecosystem in mind. Jurisdiction also limits the activities each agency can undertake, despite shared benefits and common goals. To address this issue, study participants suggested that community groups and other non-government partners may collaborate with current monitoring agencies to fill gaps in mandates or jurisdiction. The river-lake interface is one example of an area in which such a gap exists, as neither the Province nor Federal agencies overlap their jurisdictions beyond the boundary of the river (Province) or lake (Federal). The Grand River Conservation Authority's management boundary extends from the river 5 km into Lake Erie and along the shore in the vicinity of our study area; however, the Conservation Authority has little decision-making power, does not implement biological monitoring (per Chapter 3 recommendations), and does not define monitoring objectives according to VECs (though, some monitoring considers the 'best bets' of the Grand River Fisheries Management Implementation Plan Smith & Wright, 2001).

As part of filling the knowledge gap, interviewees discussed the consideration of other knowledge – especially community-derived information. For example, although there were some comments about an inability to measure historical improvements to the watershed, other interviewees provided information that counters this perspective. Interviewees recalled intergenerational memories that tracked and described the state of the water system since the 1960s. Observations included the color and smell of the river, the presence or lack of certain species (e.g., bald eagles – *Haliaeetus leucocephalus*, rainbow trout – *Oncorhynchus mykiss*, lake sturgeon – *Acipenser fulvescens*), and the impact of human development (e.g., dams). Nearly all interviewees who shared memories of river improvement commented on how it has changed from an unusable water system to a much-loved resource with significant economic value. A handful of interviewees recommended this 'generational model' to ensure future generations can enjoy what we currently or previously enjoyed, while maintaining long-term memories (i.e., records) of how conditions changed.

On the topic of generational knowledge, most interviewees recognized the importance of engaging with local Indigenous communities to recognize their knowledge and experiences as well. Historical relationships between governments and the Six Nations community contribute to today's challenges with knowledge sharing and their applications to management. Recent changes to government requirements (e.g., to include First Nations in certain approval processes) and changing data availability (e.g., Ontario's open data approach) are positive steps towards Canadian-Indigenous reconciliation; however, implementation is challenging when there is little guidance on how to operationalize the necessary changes. The fundamental question of how to bring Indigenous knowledge into conventional databases raises the issue that inclusivity is sometimes not the ideal. One interviewee suggested the notion of inclusivity needs to be replaced with shared, equitable, and just spaces. Inviting new perspectives into a space and processes not designed for them—inclusivity—is not an effective way to engage or co-create. For those conventional spaces that are being improved for co-creative purposes, decolonizing strategies (e.g., Freire, 1970; Smith, 1999; Kovach, 2009) create spaces that are not just equitable for Indigenous representation, but for other demographics as well. We also need to recognize that inclusivity often comes with a demand to amalgamate, which results in a trade-off between being engaged and maintaining one's identity. This is where justice comes into play.

Another priority of participants is communications. Study participants first suggested that the purpose and objectives of monitoring should be determined early and collaboratively – with stakeholders and rightsholders where feasible, but especially between monitoring personnel and managers/decision-makers. In addition, the ways in which knowledge is disseminated should be carefully considered. Visuals like color-coded maps are visually pleasing and easy to comprehend, but they often oversimplify data and do not capture variability, uncertainty, or seasonality. Probabilistic language is not used where it should be, e.g., stating there is an 80% chance we are not overfishing at any given time (as an example). Expectations of evidence provided by monitoring can therefore be misinterpreted and, where actual effects differ as a result, can result in monitoring information to no longer be used in decisions. In addition, "when monitoring does not reflect actual conditions, the whole practice of monitoring is devalued and more likely to be defunded (Ho, Dhaliwal, & Wright, 2020, p.16)."

4.4.3 Holistic thinking and sustainability

In 1994, the Grand River Conservation Authority produced *The Grand Strategy*, a 25-year watershed management plan for managing the Grand River as a Canadian Heritage River, developed after about seven years of extensive community engagement (GRCA, 1994). This Plan was significant and innovative for its emphasis on the social-cultural well-being of watershed residents. Holism was a principle of the Plan, described as "using approaches to research and resolve issues which recognize social, environmental, and economic interdependencies and to include others in research, planning, decision-making, and implementation (p. 13)."

Despite the call for what we now describe as sustainability and systems thinking, the ten-year report (Veale, 2004) began to shift focus towards justifying the conservation of natural and human heritage in economic terms. The 20-year report (GRCA, 2014) was primarily informed by Grand River Conservation Authority publications, reports, website pages, and staff members, while community engagement was reduced to two years of recreation and heritage surveys in addition to a local action registry. While the conservation authority's heritage activities remained strong at the time of interviews, it was clear that there has been a shift away from holistic thinking. Capacity limitations, political and legislative uncertainties, and more complex problems – e.g., growing populations and demands exacerbating existing social-ecological challenges – appear to have contributed to a more 'focused,' siloed/disciplinary approach to research and practice.

As the local management trend evolved away from holism, ecosystem-based/watershed-based approaches were recommended at the federal level to address non-point cumulative effects, e.g., excessive growth of benthic *Cladophora* algae, in the eastern basin of Lake Erie (Carey, 2007). Though the watershed management approach (i.e., more holistic and integrated than water management, which excludes the cultural purview) is generally supported in the study area today, interviewees highlighted imperfections in its execution. For example, today's practitioners struggle to motivate many of their colleagues to even consider interdisciplinary or cross-sectoral (or even inter-agency) collaboration and coordination.

Interviewees commented on the lack of research in the interface of the Grand River and Lake Erie since limited Federal-Provincial collaboration in the 1980s and 90s. The lack of research contributes to a lack of knowledge and tools for assessing cumulative effects, and a lack of understanding coastal water quality in the study area. Interviewees suggested funding deficiencies not only affected water quality monitoring in recent years, but also the capacity for engaging with community members. As such, community-driven solution-building processes were out of the scope of actions that can be undertaken by conservation authorities – despite a recognized need for them (per study participants). Interviewees recommended improvements to communications, coordination, and engagement with members of local communities. As part of communications and engagement, knowledge mobilization was suggested to be a two-way process, which invites community members – including Indigenous persons – to contribute to the watershed knowledge base.

The consideration of social-cultural, economic, ecological, and governance (e.g., policy) aspects of the watershed remains a goal of 'the heritage folks' in the conservation authority; however, this broad consideration of sustainability is not reflected in water quality monitoring. In more than 25 years, holism – i.e., sustainability, systems thinking, addressing value systems, and respecting and applying local Indigenous knowledge systems – has remained the domain of a siloed department of watershed management and decision-making. Interviewees identified the problems this approach creates, e.g., uncoordinated monitoring activities, disparate professional cultures, and a lack of knowledge transfer between/within monitoring agencies. These problems not only impact the ability of monitoring to inform management, but also the ability of either scientists or managers to assess cumulative effects. Thus, both the literature and the collective experiences and perspectives of interviewees suggest that reconciling with one another – scientist, policymaker, Canadian communities, local First Nations – is a critical component to addressing complex watershed problems effectively (Kay & Schneider, 1994).

We recommend a culture shift towards holistic thinking that brings diverse persons together for knowledge sharing and co-creation. Further, consideration of sustainability and systems thinking implies more than recognizing interdependencies between the pillars described at the start of this paragraph (e.g., Stephenson et al., 2017). Such consideration demands action to better coordinate monitoring (i.e., clearly identify roles of monitoring and management), improve communications (e.g., recognize the information needs and formats of end users), and unite different knowledge, customs, and values (i.e., for a unified purpose, while respecting distinct identities).

4.4.4 Adaptive monitoring process

Practitioners who contributed to this research echoed the literature (e.g., Lindenmayer & Likens, 2009) in their support for an adaptive monitoring process. Adaptive monitoring is somewhat piecemeal in the study area in that some components are practiced while others are not. For example, a formal stakeholder analysis is not usually undertaken, in part due to time constraints, whereas it is the first step in our proposed adaptive monitoring cycle (Figure 7). Currently, the conversion of upcoming decisions into monitoring questions is done by monitoring practitioners independently of decision makers with the assumption that the information will be accessed and applied during decision making; however, practitioners suggested including decision makers in the process of determining monitoring questions to ensure their needs are met and to ensure there is a commitment to apply the information in decision making later on. Further, data use is usually determined during or after the collection period, which can cause issues if data end up not usable in certain analyses that are later deemed important for a decision. So, practitioners suggested determining the use of data collaboratively and prior to implementing the monitoring program. Another unique aspect to our proposed framework is the recommendation to involve knowledge brokers (e.g., communications specialists, knowledge mobilization specialists, or other individuals who are positioned to bring information to end users) in the dissemination of data and information.

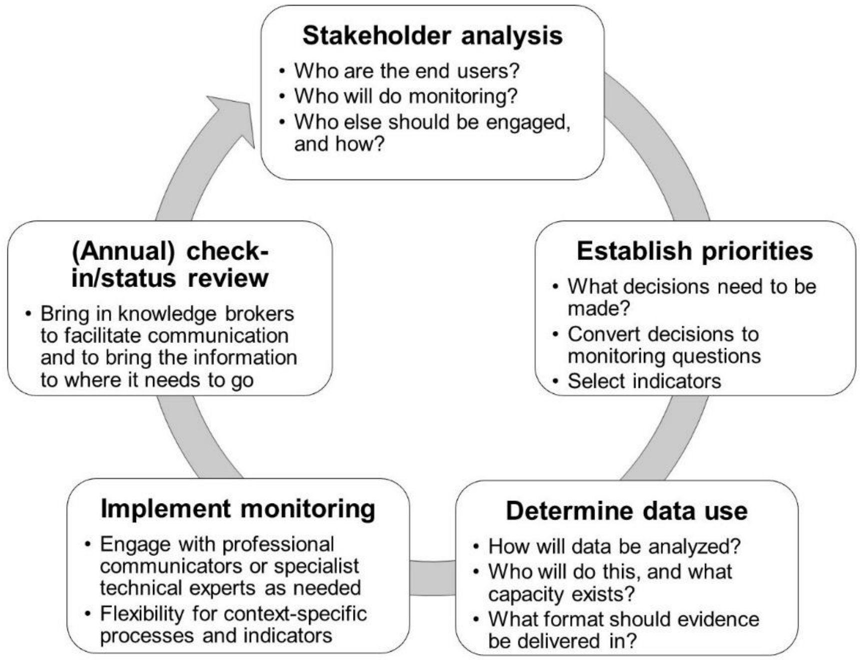


Figure 7. Recommended adaptive freshwater quality monitoring cycle.

Recognizing the above differences, the process proposed by our study participants is generally like other approaches that use an adaptive cycle (Holling, 1992; Carpenter et al., 2001). For example, the adaptive monitoring framework proposed by Lindenmayer and Likens (2009) encompasses four key themes: early development of tractable questions, rigorous statistical design, based upon a conceptual ecosystem model, and be driven by a management need. Our adaptive monitoring cycle is similar in that it involves early, collaboratively developed questions of relevance to management and/or decisions, incorporates holistic thinking about the ecosystem, and is based on evidence; however, an important difference is in the definition of evidence. Our process is meant to be flexible enough to include multiple forms of knowledge, which are disseminated in different ways (e.g., not always in the form of a conventional database, technical report, or peer-reviewed publication).

This process, although proposed to be broadly applicable, is meant to be amenable to whichever context it is implemented within. In the Grand River context, 'stakeholders' would be redefined as 'end users' to include the two First Nations communities in the watershed – Six Nations of the Grand River First Nation and Mississaugas of the Credit First Nation. The establishment of priorities would likely be driven by decisions as well as Indigenous management/stewardship interests. The determination of data/knowledge use would involve conversations on ownership, control, access, and possession (e.g., OCAP® principles: FNIGC, 2021). Implementation of monitoring in the study area may involve community groups like Trout Unlimited, which currently engages in some monitoring activities upstream of the study area (in the middle Grand River section). In addition, the process is meant to be implemented with four 'enabling conditions' – capacity, collaboration, coordination, and various forms of knowledge – to support a monitoring program.

4.4.5 Legislative changes in the study area

Changes in legislation have occurred since interviews were undertaken and, therefore, the state of monitoring and recommendations shared were not considerate of the new monitoring and management context. The roles and powers of conservation authorities and Ministers have shifted, first from legislative changes in June 2019 via the *More Homes, More Choice Act, 2019,* and second, in December 2020 via the *Protect, Support and Recover from COVID-19 Act (Budget Measures), 2020*. The 2019 legislative changes greatly reduced conservation authorities' mandate to four basic management functions: risk of flooding, lands titled to conservation authorities, source water protection, and other endeavors per the regulations (e.g., permitting for development; *More Homes, More Choice Act, 2019*). In 2020, further changes – implemented contrary to clear public opposition – undermined conservation authorities' independent, science-based watershed management approach for protecting human life, property, and natural resources (*Protect, Support and Recover from COVID-19 Act (Budget Measures), 2020)*.

The Province has now implemented mandatory permit issuance for development meeting Provincial criteria, and the Minister of Natural Resources and Forestry is newly able to override permit decisions by conservation authorities. Developers can appeal administrative fees for services provided by conservation authorities, which can no longer participate in appeals under the Planning Act, and conservation authority boards of directors must now be comprised solely of municipalities (representing no other – e.g., community – interests). Further, the Province now determines any 'other endeavors' conservation authorities may undertake, which limits programming that municipalities and conservation authorities may wish to pursue for the interest and benefit of local communities (e.g., assisting landowners to improve broader environmental quality by subsidizing mitigating actions on their property). The impacts these changes will have on our watersheds and local/regional monitoring and management are yet to be seen but are not expected to change the perspectives shared in this paper.

4.5 Conclusion

In this paper, we described strengths, weaknesses, opportunities, and threats or freshwater quality monitoring, and discussed recommendations for improvement. Semi-structured key informant interviews provided a basis for our discussion. In our discussion, we described the current state of freshwater quality monitoring in Ontario as highly collaborative and productive, though somewhat uncoordinated, and not as well-funded as is sometimes needed. Despite much data generated from across the Province, there is a knowledge gap in the study area that may benefit from involvement by community members and non-governmental organizations. Engaging with these groups – including Indigenous communities – and their knowledge may require a reconceptualization of our current data/information systems and the ways in which we identify and apply 'evidence' to management and decisions. Communication – between monitoring personnel and managers/decision-makers (e.g.., determining monitoring questions) as well as in the dissemination of information – was among the priority areas identified by study participants for improvement.

We argued that improving freshwater quality monitoring involves consideration of integrated social, ecological, and economic priorities in the pursuit of sustainability. We described a trend away from holistic thinking since the 1990s in the study area and recommended that siloed approaches to sustainability should be avoided. Broad reconciliation and a culture shift towards holistic thinking were recommended to unite diverse persons together for knowledge sharing and co-creation. In addition, our study participants recommended an adaptive process for freshwater quality monitoring that should be implemented along with the enabling conditions – capacity, collaboration, coordination, and various forms of knowledge – to improve existing practice.

One way forward to implement our recommendations is to explore different engagement approaches, since collaboration is an important aspect of current monitoring program design (despite limited applications in practice). Whether small adaptations (e.g., changing how we choose what to monitor – Ho, 2018, dissertation Chapter 5) or larger ones (e.g., integrating Indigenous knowledge into reconceptualized 'databases' using processes like the ones described in dissertation Chapter 6), we suggest it is possible to influence incremental changes in the current water quality monitoring system over time. By integrating monitoring and sustainability, longstanding limitations in capacity, coordination, and linkages with management and decisions may be overcome in ways that enable society to move towards a new vision of collaborative water stewardship.

PART 3 – ADAPTING CURRENT PRACTICE

Chapter 5

Criteria-based ranking (CBR): A comprehensive process for selecting and prioritizing monitoring indicators

Citation: Ho, E. (2018). Criteria-based ranking (CBR): A comprehensive process for selecting and prioritizing monitoring indicators. *MethodsX* 5: 1324-1329. DOI: 10.1016/j.mex.2018.10.015.

Published as a supplementary methods paper to accompany the following: Ho, E., Eger, S., and Courtenay, S. (2018). Assessing current monitoring indicators and reporting for cumulative effects integration: A case study in Muskoka, Ontario, Canada. *Ecological Indicators*, 95: 862-876.

5.1 Acknowledgements

The author wishes to acknowledge colleagues Sondra Eger and Dr. Simon Courtenay, who co-authored a larger study (Ho, Eger, & Courtenay, 2018) that provided the context for hosting the August 5 workshop, where this method was tested. In addition, special thanks to individuals from the University of Waterloo Faculty of Environment, Canadian Water Network, Muskoka Watershed Council, Chris Jones, Barb Veale, and Christy Doyle who supported the larger project within which this study occurred. This work was supported by Muskoka Watershed Council, Canadian Water Network, and University of Waterloo. In-kind donations (use of room for the workshop, provision of snacks and a/v equipment) were provided by Muskoka Watershed Council.

5.2 About the Criteria-based Ranking method

Resources allocated to natural resource management often fluctuates. As a result, the types and numbers of parameters (e.g., indicators for ecosystem health) being measured in monitoring programs are frequently reassessed according to management (or political) priorities and limits on budgets and human resources. This periodic need to refocus monitoring conflicts with the need to maintain consistent, long-term indicators which demonstrate changes to ecosystem health or define ‘abnormal’ indicator measures. To mitigate the conflict between updating monitoring indicators according to current needs or limitations and maintaining long-term indicators, a new process for selecting and prioritizing indicators is needed. This new process should make shortlisting indicators possible and relevant while ensuring continuity of long-term indicators. Further, the process of selecting indicators should be robust and comprehensive enough to represent broad perspectives representative of diverse decision-makers, technical experts (e.g., scientists) and local stakeholders to improve resilience against changing political regimes.

Conventional processes for selecting or short-listing environmental monitoring indicators generally involve two steps: identify Valued Ecosystem Components (VECs) – things people care about (e.g., swimmable waters, fishing opportunities) – and discussing which indicators and methods should be used to measure them. VECs create a scope for the selection of indicators. For example, a VEC may be edible fish (e.g., something of importance to the community), and an indicator may be levels of lead in fish tissue (e.g., a way to measure impacts on that important thing). VECs may be identified by community or stakeholder groups, or within managerial groups. Indicators for each VEC are then selected through group discussion and are sometimes a standard measure of the VEC (e.g., measuring nitrogen is common to achieve the VEC of swimmable waters due to its influence on algae). Discussions on indicator selection are highly-dependent on who is present in the room, especially when the monitoring program is long-standing with a consistent group of discussants from year to year. A new process for selecting or prioritizing monitoring indicators was synthesized in the context of watershed management from existing approaches in environmental assessment, rooted in management studies.

In management studies, Multiple Criteria Decision Making (MCDM) is the closest approach to the new method presented here. MCDM was first formally discussed in the 1970s by management scientist Dr. Stanley Zionts and colleagues (International Society on MCDM, nd). Generally, MDCM methods outline the following three steps (Triantaphyllou, 2000): determine relevant criteria and alternatives, attach numerical measures to relative importance of criteria and impact of alternatives, and process numerical values to determine a rank. A more recent approach, the Pugh matrix/decision matrix (Tague, 2004), uses a similar process for determining priorities: determine criteria, weight criteria, evaluate each alternative per criteria, and multiply each rating by the criterion weight before summing up a final score per alternative. Delving deeper into the purpose and methods within each approach from the management literature, high-level concepts satisfied the needs of water managers looking to improve their monitoring programs while the idea of 'alternatives' and certain aspects of value hierarchies were inapplicable. Thus, there was a need to explore management-focused ecological literature for tools or processes that would generate the desired outcome (e.g., comprehensive shortlists of monitoring indicators).

The Criteria-Based Ranking (CBR) process presented in this paper borrowed design aspects from Simple Weighted and Leopold matrices used in environmental assessment. Both matrices score criteria that together calculate a rank. A Simple Weighted matrix places environmental components down the left column, project actions (stressors) along the top row, and a score of impact in each intersecting box (positive or negative, from no impact to severe/permanent impact). In Simple Weighted matrices of environmental assessment, ecosystem components are weighted so each score is multiplied by the weight and summed up at the end of each row (Noble, 2006); weighting was not applied in this study. In a Leopold matrix (Leopold et al., 1971), which is a more comprehensive and commonly-used magnitude matrix, environmental considerations are also along the left column with actions/stressors along the top row. However, components are not weighted, and the intersecting boxes are split (diagonally) into two numbers – magnitude (strength and positive/negative) and importance of the impact (as opposed to importance of the component in Simple Weighted matrices).

Since the CBR process aims to prioritize indicators rather than quantify stressors and impacts, the process used in this research used a modified table (Table 6). The process includes environmental components along the left column, and criteria for assessing each indicator along the top row. Like in Simple Weighted matrices, a single score is placed in each intersecting box, which is summed at the end of each row (the indicator's total score). Criteria incorporate basic principles of Leopold matrices – importance (of the component) and magnitude of impact – in addition to other principles relevant to the watershed management context (e.g., ease of monitoring).

Table 6. Sample prioritization matrix adapted from environmental assessment tools.

Criteria (score: 1-5)	**Indicator**		
	Secchi depth	Algae biomass	Calcium
Cost-effective	4	2	3
Ease of measuring	5	1	4
Important to me	2	4	3
TOTAL SCORE	**11**	**7**	**10**

As the CBR process aims to be inclusive of diverse perspectives, participation and co-creation are encouraged where possible. First, the list of Valued Ecosystem Components (VECs) would ideally be co-created with representative stakeholders (e.g., seasonal and year-round community members, local Indigenous communities, youth). Second, a 'long list' of monitoring indicators should be generated by diverse key stakeholders/subject matter experts and decision-makers (e.g., of differing political positions and scientific expertise). The reason for including decision makers in this process, especially of differing political positions regardless of who is leading at the time, is that monitoring indicators should be aligned with the general direction and high-level priorities of decision-making to ensure monitoring outcomes (e.g., reports on a certain change, Report Cards) are relevant to those who are able to make decisions about the aspects being measured. Without this relevance, monitoring and reporting are likely to be completed without much action resulting from them, as is commonly the case.

The monitoring program in the Muskoka River Watershed (Ontario, Canada) was used as a case study to assess whether using the CBR process would have any effect on the process and outcome of short-listing monitoring indicators. This study was narrowly scoped since engaging with stakeholders for assessing VECs, a long list of indicators and criteria for short-listing would have required large amounts of resources (time, human resources, funds) to implement. As such, the first question was to test the final CBR process to assess whether spending resources to implement it full-scale would provide value.

A workshop was held on August 5, 2016 with members of the Muskoka Watershed Council to discuss monitoring indicators and communication of monitoring outcomes. The Muskoka Watershed Council is a multi-stakeholder group concerned with monitoring, reporting on and championing the health of the Muskoka River Watershed. At the time of the workshop, Muskoka Watershed Council was made up of members from the District Municipality of Muskoka and Muskoka Heritage Foundation. Since the workshop, the Council is made up of the District Municipality of Muskoka in partnership with diverse members of the community (e.g., residents, researchers, community organizations).

Because the purpose of this study was to test the efficacy and impact of the CBR process, not to implement the process full-scale, the study used Muskoka Watershed Council's existing monitoring framework (e.g., VECs, indicators, current priorities and limitations) as its context. Similarly, criteria were provided to workshop participants rather than co-created with them, as the concept of criteria co-creation was not to be tested at this stage in method development. Criteria were designed by the researcher to incorporate multiple needs (e.g., from ecological monitoring, social and policy perspectives). Criteria were weighted equally, since recent research concluded that applying weights to individual indicators did not significantly change the results of scoring (Attari & Mojahedi, 2009). As such, the standard unweighted methods were recommended, especially for single-community purposes. However, since each context is different, future iterations should consult with key stakeholders as to whether unequal weighting is warranted. Similarly, criteria for indicator ranking were provided in this case study, though in future iterations these criteria will be designed by the stakeholders.

Workshop participants walked through a simple exercise to reduce a list of six indicators to a list of five. The starting list consisted of one new/proposed indicator (reflecting a change in management priorities) and five existing ones. Existing indicators were chosen by the group from those reported in previous Report Cards and Background Reports. The five existing indicators selected for this exercise were Secchi depth, algae growth, calcium, land use and wetland cover. The new indicator would relate to Muskoka Watershed Council's recent decision to consider climate change in future watershed monitoring and communications. Participants decided upon carbon footprint as the climate-specific indicator for this exercise.

SurveyMonkey was used to collect scores for each indicator from each workshop participant, which was then summed up into the matrix exemplified in Table 6. SurveyMonkey was used for ease of response by participants, as well as to ensure participants could not easily track scores across criteria to manipulate scores to individual interests. Each question on the survey was dedicated to each indicator. The following is Question 2 of the survey, with the seven criteria that were used to assess all indicators:

- *Rank the indicator 'secchi depth' on a scale of 1 (least) to 5 (most) based on the criteria below.*
    - *I would include this indicator, by this or other name, in the Report Card (e.g. not just in the Background Report)*
    - *This indicator is measurable given reasonably expected resources (tools, people, funds, time...)*
    - *We have control over changes to this indicator*
    - *We have effective mechanisms for correcting CURRENT unwanted changes to this indicator*
    - *We have effective mechanisms for correcting FUTURE unwanted changes to this indicator*
    - *Unwanted changes to this indicator would result in serious impacts (directly or indirectly) on ecological and human systems*
    - *This indicator is important to me*

Like environmental assessment matrices, this process is transferrable to other contexts. For example, the criteria used for scoring indicators, and whether weighting is applied (to criteria or components), can be determined for each context. Further, though this process was designed for ranking indicators, the same process can be applied for short-listing a lengthy list of VECs as well. Greater numbers of stakeholders engaged in this process, especially if they are representative of the communities managed, will produce more meaningful and relevant results. The process used for this first iteration of the ranking method for indicator selection are outlined in Figure 8.

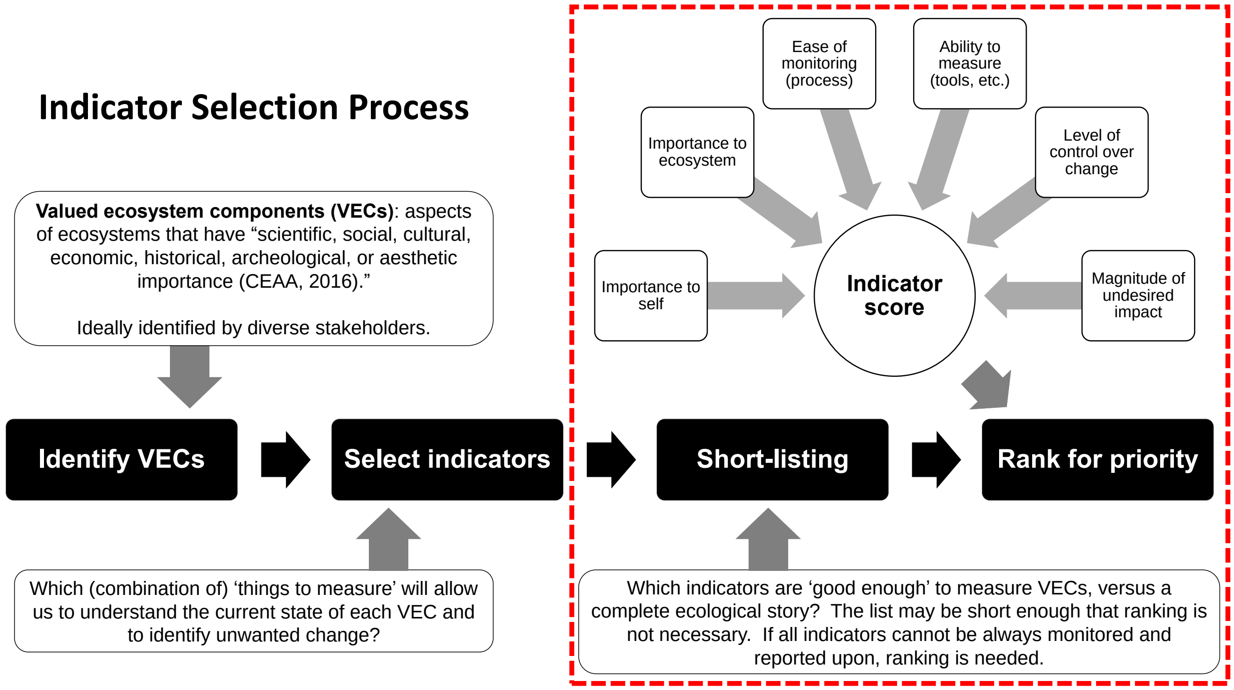


Figure 8. Criteria-based ranking (CBR) process for indicator selection, highlighted in the box. Criteria in the figure are examples of what may be considered and can be tailored to specific contexts.

The first two steps follow conventional approaches. The difference here is that, leading up to the CBR process in step four, stakeholder engagement is recommended in a broader, more comprehensive and inclusive way than typically occurs. In the third step, criteria are developed for ranking indicators, though stakeholder engagement in this step is more targeted to a core group of water monitoring, management and decision-making stakeholders. Finally, the criteria are ranked for each indicator, which sum up to a final score. These scores prioritize the list of indicators from highest (high score) to lowest (low score), ensuring effective and meaningful shortlisting when monitoring capacity changes. A standard process of including or excluding indicators ensures degree of consistency despite regular fluctuations in capacity.

Although workshop participants agreed that consistency and a standardized practice improves the quality of monitoring, an unforeseen challenge at the workshop was achieving acknowledgement from participants that not all indicators were possible to address each year (as evidenced by different numbers of indicators having been reported year-to-year). Participants also discussed the challenge of balancing indicator quantity and quality. The general view from science-oriented participants was that ecological systems are complex and so indicators should not be simplified or reduced. Participants with a more political point of view, and those concerned with the economics of the monitoring program, generally agreed that maintaining a consistent set of indicators for ongoing monitoring would require refining and, likely, reducing the number of indicators currently used. The idea of keeping current indicators, and finding ways to maintain current capacity (people, funds, technology), was briefly discussed before a consensus was reached: the current set of indicators needed revision.

Workshop participants not only identified new potential indicators to address recent challenge or priorities, but also assessed existing indicators for efficacy and relevance to current priorities (e.g., how well they address/contribute to our understanding of impacts from climate change). This is especially necessary in contexts like the Muskoka River Watershed where there is no regulatory structure to ensure consistent human and financial capacities (e.g., funding and personnel likely change year-to-year). The question going into the workshop was whether the CBR process would be an effective way to assess monitoring indicators moving forward. This study confirmed that when a common set of criteria was used to assess indicators, a different set of indicators emerged than the set created without common principles to guide assessment. During discussions, Secchi depth was the one indicator workshop participants felt was sure to top the list as a key indicator. However, after assessing the indicators using the CBR process, results for the top five indicators were land use, wetland cover, carbon footprint, algae growth, and calcium; Secchi depth did not even make the list (Table 7).

Table 7. Results of the indicator prioritization exercise.

Criteria	**Indicator***					
	Secchi Depth	Algae	Calcium	Land Use	Wetland cover	Footprint (new)
I would include this indicator, by this or other name, in the Report Card (e.g. not just in the Background Report)	17	31	23	33	32	27
This indicator is measurable given reasonably expected resources (tools, people, funds, time...)	33	22	25	30	25	20
We have control over changes to this indicator	18	20	18	27	24	23
We have effective mechanisms for correcting CURRENT unwanted changes to this indicator	16	19	16	25	19	20
We have effective mechanisms for correcting FUTURE unwanted changes to this indicator	20	21	17	27	21	20

Unwanted changes to this indicator would result in serious impacts (directly or indirectly) on ecological and human systems.	22	31	27	31	28	30
This indicator is important to me	24	31	25	34	31	28
TOTAL SCORE	**150**	**175**	**151**	**207**	**180**	**168**
Rank – short-listed?	**6 – No**	**3 – Yes**	**5 – Yes**	**1 – Yes**	**2 – Yes**	**4 – Yes**

In assessing the efficacy of this process to produce a list of meaningful, comprehensive and robust monitoring indicators, there are related points to consider. In the same way indicators may need to be prioritized in times of fewer resources, monitoring practices may need to be assessed so that data collection sites are coordinated with prioritized indicators. For example, an indicator may not be ideal to measure the way it currently is (e.g., method and locations); however, another indicator studied at strategic locations may still provide desired insights. Alternatively, some monitoring programs use a consistent set of indicators but will do a rotation of sites across years. For example, in the Northumberland Strait estuaries (Gulf of Saint Lawrence in eastern Canada), eelgrass is measured in five estuaries per year on a five-year rotation so that the 25 estuaries are covered in a five-year period (van den Heuvel et al., 2016). Considering changing indicators and sites together may improve cost-effectiveness and encourage the addressing of cumulative effects.

In addition, bias exists from individuals who are at the table to determine which indicators will be measured, but who do not represent all stakeholders in the watershed. Thus, the selection of what to sample may hinder the program's ability to detect effects, though this risk may not even be recognized consciously (Greig & Pickard, 2014). The CBR indicator prioritization method is one way of many ways to address this bias. By ensuring indicator assessment criteria represent diverse perspectives, the representativeness of individuals assessing/selecting indicators is less important. This is not to say the criteria that were used were perfect. Rather, using broad (e.g., ecological, socio-political, economic) criteria agreed-upon by diverse watershed stakeholders is more likely to result in a list of indicators that responds to multiple needs and addresses multiple issues than without assessment criteria. Similarly, it is possible these criteria may direct monitoring to produce information more relevant to decision-makers; confirming this was outside the scope of this study.

Finally, the indicator prioritization process should be further developed in other contexts. Future iterations may assess whether weighting of criteria is warranted in specific contexts. Further, whether criteria should be standardized or specific to individual cases may also be explored. Of the criteria used in this study, the author suggests also incorporating 'measures of success' – for example, incorporating the criterion of ‘efficacy’, ‘reach’, or ‘influence’, evaluating whether the target audience (e.g., decision-makers) is reading or considering information reported from the monitoring program. Having considered the above points, the CBR process for indictor selection was found to be an effective way to prioritize which monitoring indicators would be consistently used and which would be addressed as capacity permitted.

5.3 Since publication: further development of this method

The CBR process described in this chapter emerged from the exploratory study of this research, in the Muskoka River Watershed, not from the study area of the lower Grand River and nearshore Lake Erie. It is likely useful for general water quality characterization and ‘early warning’ monitoring undertaken to identify problems; however, whether it would be a good approach for decision-specific monitoring is uncertain as the process focuses on incorporating diverse perspectives and priorities, not on developing a narrative to inform a given decision. Regardless of its application, this method is meant to be used to support widespread collaboration on indicator selection even when people are not able to be in the same room.

The CBR process described above was further developed for use in a cumulative effects workshop described in Chapter 7. A key difference between the exploratory process and the process used in Chapter 7 is the revised CBR process used scoring criteria defined by workshop participants, rather than criteria provided by the researchers. While participants of the exploratory study completed the survey after the workshop, this study permitted participants to complete it the weekend before, during, or after the workshop, depending on their time constraints and the information they had available.

Chapter 6

Knowledge co-creation through arts-based engagement: Diversity in freshwater quality monitoring and management

Citation: Ho, E., Courtenay, S. C., Miller, R., McLeod, C., and Trant, A. J. *In preparation*. Knowledge co-creation through arts-based engagement: Diversity in freshwater quality monitoring and management. Not yet submitted.

6.1 Acknowledgements

Early iterations of our research were inspired by Paul General (Six Nations of the Grand River). We thank Richelle Miller and Tayler Hill, coordinators for Music of the Spirit & Indigenous Visual Arts, for their immense commitment during our partnership for Grand Expressions. We recognize Chris McLeod and Karen Kun for adapting the 2019 delivery of Great Art for Great Lakes to serve the goals of this research.

6.2 Introduction

The theoretical underpinnings and practice of water quality monitoring, e.g., which questions should be asked of monitoring and whether data are being collected in the right way for the questions being asked, are ongoing discussions since at least the 1950s (Ho, Dhaliwal & Wright, 2020; Ho, Ding, & Dhaliwal, 2020). Although literature has provided useful discourse to guide improvements to monitoring practice (e.g., CWN, 2016; Stephenson et al., 2017), there seem to be some areas in which little progress has been made. For example, collaboration is essential for addressing complex problems (Head, 2010; Head & Alford, 2015), but Brown (2017) suggested that meaningful collaboration with diverse peoples remains an optimistic idea hindered by government's push to act on matters quickly. Further, Ho et al. (2020 – dissertation Chapter 3) evaluated nine water monitoring programs and frameworks that practitioners identified as high-standard examples based on criteria compiled from literature and practitioners. Few programs used multiple reporting formats (e.g., other than scientific journals or technical study reports), recognized other sources of knowledge (e.g., Indigenous), or incorporated community-based or community-led monitoring. Current practitioners and subject matter experts supported these conclusions and reiterated the need for a culture shift in terms of how information is defined, produced, accessed, and used (Chapter 4).

A recent (2017) gathering of Canadian Scientists and Indigenous knowledge keepers highlighted the importance of broadening the sources of information we use to make decisions in the following statements:

1. Empirical science's strength comes partly from its ability to apply analytical tools and techniques on a part of nature, but this fragmentation hinders the whole from being anticipated and removes important context from study (Miller, 2020).
2. "…for all the knowledge and truly amazing technologies that science has provided, we have failed so far to prevent serious damage to our environment… We need better approaches to planning and decision-making – for the long term… and we need to be able to link our actions together with outcomes through more holistic, critical thinking (Dr. Nancy Turner, Professor Emeritus at University of Victoria, quoted in Miller, 2020, p.12)."

Criticisms of science-only approaches to resource management are not new. Kay and Schneider (1994) suggested that ecosystem science is limited in its ability to quantitatively predict ecosystem behavior, requiring the introduction of human elements (e.g., social, economic, institutional factors per Stevenson et al., 2017) to mitigate our relationships with the natural world. Ho et al. (2020) highlighted the inclusion of Indigenous ways of knowing as particularly important for diversifying water quality monitoring and broadening the approaches of management in Canada. In the roundtable described above, one participant stated, "As a scientist, I started to see that science was failing to see the big picture… Science looks at a small piece of the puzzle, while Indigenous knowledge is a way of looking at the whole picture (Dr. David Suzuki, Professor Emeritus at University of British Columbia, quoted in Miller, 2020, p.12)".

This dissertation explores approaches for diversifying perspectives that contribute to our understanding of freshwater quality. In this chapter, we build on two recommendations from Chapter 3 (Ho et al., 2020): (1) recognizing different knowledge forms from diverse sources, especially Indigenous, and (2) facilitating action by managers and decision-makers. We acknowledge the need to diversify approaches to water science (described above) and recognize that capacity challenges are inevitable in Canada, which has thousands of freshwater systems distributed over millions of square kilometers. The root of our study is the question, how might diverse perspectives contribute to better water quality monitoring? A related question posed by the literature is "whose concerns are evident… whose objectives are paramount (Stephenson et al., 2017, p.1985)?" The purpose of our study was to explore the utility of a co-created approach for information gathering that is not commonly practiced in freshwater monitoring in the study area. We structured our approach to identify community priorities, understand community views and interactions with the watershed, and determine a vision for freshwater monitoring and management from persons who may not normally be involved in these processes and practices. We aimed to apply the approach and evaluate its potential contributions to monitoring and management.

We have previously explored possible adaptations to current monitoring practice by recommending a criteria-based ranking process that integrates priorities from multiple sources to determine what is measured in the monitoring program (Ho, 2018 – dissertation Chapter 5). While the approach may ensure more diverse perspectives are at least acknowledged, we posit that other more significant ways to engage such perspectives exist. This study not only explore how to enhance water monitoring by incorporating diverse perspectives, but also exemplifies one approach to engage with watershed stakeholders and rightsholders more meaningfully for this purpose. We address a context-specific challenge, that applying such approaches to water science may result in the delivery of information in ways we are not used to incorporating – e.g., intergenerational memories, stories, song, and traditional teachings. As action from managers or decision-makers ideally follows water quality monitoring, we conclude by suggesting potential ways in which diverse perspectives and unconventional data formants may be applied in freshwater quality monitoring and management.

6.2.1 Canadian-Indigenous context in the study area

The study area is the interface of the Grand River watershed, the largest watershed in Southern Ontario (Canada). Three Indigenous treaties apply to this area:

1. Two-Row Wampum (a wampum is a beaded belt; the Two-Row Wampum is known in the Mohawk language as Gä•sweñta') is one of the oldest treaty relationships between the Onkwehonweh (original people) of Turtle Island (North America) and European immigrants, originally made in 1613 (Onondaga Nation, 2021). It symbolizes Indigenous and settler ways of life existing alongside one another without interference.
2. The Dish With One Spoon is a treaty between the Anishinaabe, Mississaugas and Haudenosaunee — and later, Europeans and all newcomers — that bound all parties to share and protect territory and its resources. Its three simple rules are to take only what you need, leave some for everyone else, and keep the 'bowl' (our environment) clean (Nandogikendan, nd). Although commonly referring to the treaty signed in Montreal in 1701, the Dish with One Spoon was an Indigenous covenant dating as far back as 1142 (Mann & Fields, 1997).
3. The Haldimand Proclamation of 1784 designated 6 miles (~10km) on either side of the Grand River – from headwaters to Lake Erie – as permanent Six Nations territory due to their displacement for allying with the British during the American Revolution. Originally 950,000 acres, about 48,000 acres remain due to growing settlements dating as far back as 1798 (Six Nations Council, 2008).

Collectively, these treaties represent three historical promises to share the Grand River watershed and surrounding areas with Indigenous peoples: (1) to collaboratively maintain the health of lands, waters, and wildlife; (2) to recognize distinct but equally valued cultures living together but separately, without interference from each other; and (3) a declaration designating the land to the Six Nations. Today, none are fulfilled. Figure 9 shows the study area with the extent of the Haldimand tract overlain.

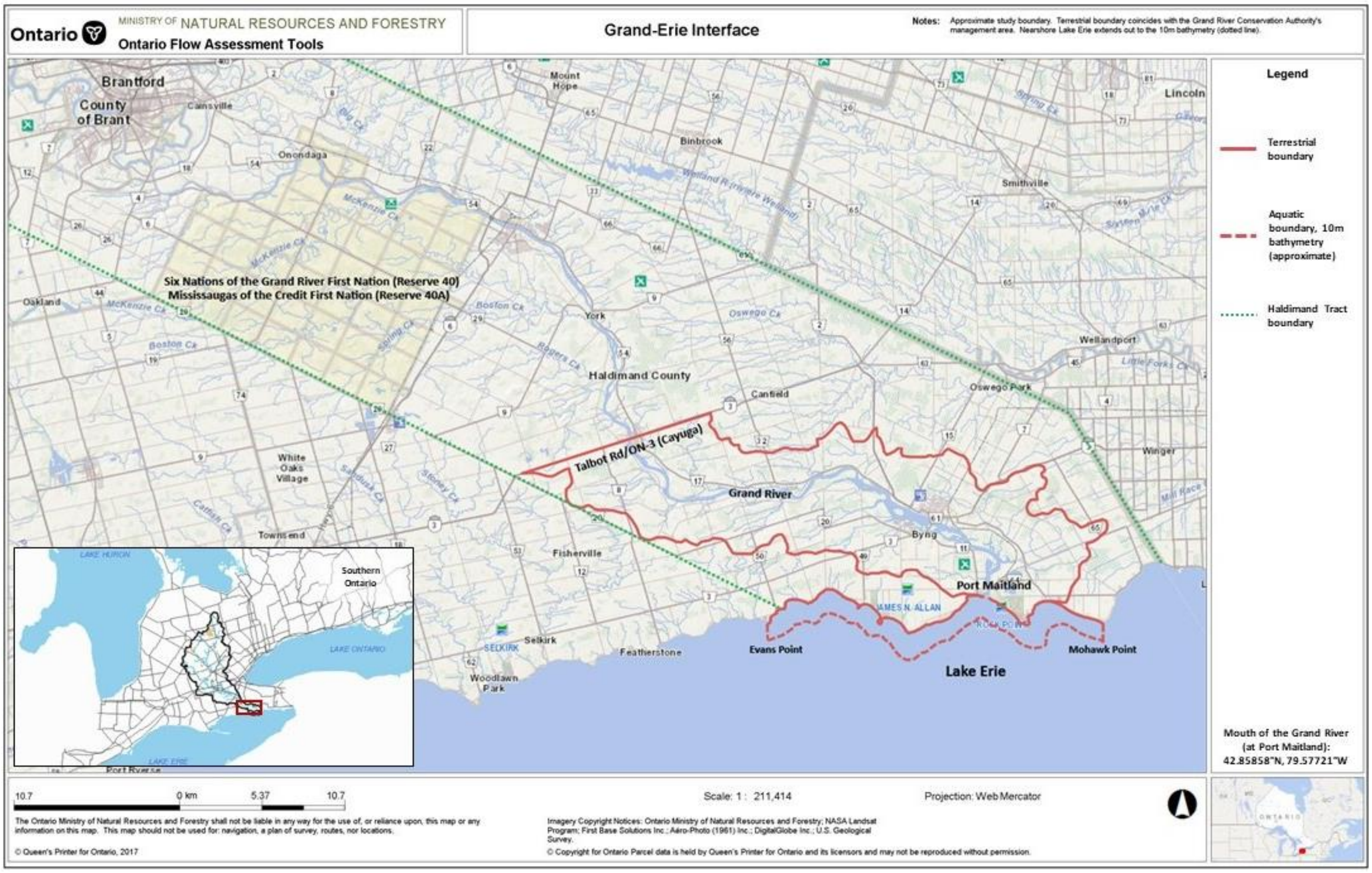


Figure 9. The study area (red solid and dashed lines) and its position within the Haldimand Tract (green dotted line), downstream of two First Nations communities. The dashed line is approximately 1.5km offshore, within which the 10m bathymetry line is located.

As Indigenous peoples were largely removed from decision-making institutions, they have been put in a position to succumb to the interests of the majority while their own needs and interests have been either secondary, ignored, or strategically inhibited for assimilation[9]. This goal to assimilate Indigenous

[9] This statement emerged from discussions at the Generation SDG Summit, convened by the Waterloo Global Science Initiative, in which 40 Canadian and Indigenous youth, experts, and knowledge keepers collaborated to lay a path for Canada's implementation of the Sustainable Development Goals.

children into British/Canadian Christian society resulted in unimaginable physical, emotional, and spiritual abuse experienced in Canada's Indian residential school system. The abuse or neglect resulted in an average child mortality rate as high as 60% in Indian residential schools across Canada (Reconciliation Canada, nd; based on a 1907 report by Canadian Medical Inspector Dr. Bryce). Upstream of the study area, the Mohawk Institute in Brantford, Ontario was the oldest continuously operated Indian residential school in Canada, and is one of the last two standing in Ontario. Established as the Mechanic's Institute (for native boys) in 1828, the school's recognized founding came three years later when the school took in boarders (The Anglican Church of Canada, 2008). Girls were admitted as of 1834, and in later years Indigenous children from other reserves – New Credit, Moraviantown, Sarnia, Walpole Island, Muncey, Scugog, Stoney Point, Saugeen, Bay of Quinte and Caughnawaga – were increasingly enrolled; only 23 Six Nations students were in attendance by the time the school closed in 1970 (The Anglican Church of Canada, 2008).

Although this study considers involvement of local Canadian community members, we focus on collaboration with Indigenous community members (in our case, members of the Six Nations of the Grand River). This is due to unique challenges in our context in Canada, as historical colonial relationships between Indigenous communities and Canadian entities (e.g., institutions, state authorities) have been characterized by conflict and confrontation throughout living memory (Natcher, 2001). Given worsening relationships between Britain/Canada and Indigenous communities through centuries of successive generations, scientists and managers must recognize the impacts these relationships have had on communities and community members – and must act on their responsibility to promote healing and trust – to facilitate a cooperative and collaborative future for all communities. Chief Dr. Robert Joseph, a Hereditary Chief of the Gwawaenuk First Nation (British Columbia, Canada) has expressed this sentiment most eloquently: "Let us find a way to belong to this time and place together. Our future, and the well-being of all our children rests with the kind of relationships we build today (Reconciliation Canada, nd)." Unequal power dynamics (e.g., residual effects of colonization), a severe (but justified) lack of trust, and respect must first be addressed through relationship-building (Ho & Runnals, 2018). What's more, strong personal relationships – not systemic/institutional approaches – were determined to be the core of collaboration between policymakers and Indigenous community members in the study by Brown (2017).

An established approach for building relationships between colonizers and the colonized is Paulo Freire's critical pedagogy (also known as the pedagogy of the oppressed; Freire, 1970). Freire's pedagogy sets up a social environment in which excluded peoples are formally encouraged to question and act against dominant systems of power (Chevalier & Buckles, 2013). One method that addresses power sharing is co-creation, e.g., collaborative value creation through interactions with some category of end users (Ramaswamy & Gouillart, 2010). Although co-creation originally defined relationships between customers and companies, it has been adapted for a variety of contexts, including change-making for ecological sustainability (Mauser et al., 2013). All parties involved collaborate to shape their own experiences, processes, and outcomes, rather than have a decision or solution imposed upon them (Ramaswamy & Gouillart, 2010). Canadian examples of Indigenous co-creation regarding resource management are beginning to emerge. For example, the Laurentian Forestry Centre was motivated to explore co-creation as part of Canada's commitment to reconciliation with Indigenous communities (Truth and Reconciliation Commission of Canada, 2015; Théberge et al., 2019). After the Centre developed an approach for co-creation of land management strategies on Canada's east coast (Théberge et al., 2019), the Canadian Forest Service has committed to reimagine management practice collaboratively with Indigenous communities across the country (Government of Canada, 2020). The method described in this study was developed using a co-creative process.

6.3 Methods

At the turn of the 21st century, immense disruptions occurred regarding ways of knowing, with Indigenous scholars demanding their institutions decolonize scientific practice (Denzin & Lincoln, 2008). Like the Laurentian Forestry Centre, we, too, recognized our responsibility to address Canadian-Indigenous history in the study area by honoring treaty rights to be involved in shared resource management activities (e.g., water quality monitoring). This dissertation research applies a Western methodology (e.g., multimethodology) for knowledge production and does not attempt to situate Indigenous methods within a non-Indigenous methodology. Indigenous methodologies are distinct and comprised of methods rooted in relational tribal epistemologies (Kovach, 2009; Smith, 1999). These methodologies developed alongside other discourses in critical theory and pedagogy that intertwined postcolonial, anti-oppressive approaches (e.g., seminal works by Deloria Jr., 1969, and Freire, 1970).

On the relationality of knowledge, Smith (1990) states the following: "What makes ideas 'real' is the system of knowledge, the formations of culture, and the relations of power in which these concepts are located (p.48)." For this reason, early relationship building between the Western researcher (E. Ho) and the local Indigenous community (Six Nations of the Grand River) made clear that the identities of research contributors would be preserved, not assimilated, and that participants would have the authority to steer the research direction as it relates to their participation and contributions (via the partner organization, Music for the Spirit & Indigenous Visual Arts). The importance of this approach is supported by Smith (1999):

> Self-determination in a research agenda …is expressed through and across a wide range of psychological, social, cultural and economic

> terrains. It necessarily involves the processes of transformation, of decolonization, of healing and of mobilization as peoples. The processes, approaches and methodologies - while dynamic and open to different influences and possibilities - are critical elements of a strategic research agenda (p.116).

Co-creation was used to ensure this study was relevant and meaningful to the participating community and to guide the integration of ways of knowing that might be applied in future iterations of water quality monitoring design and implementation. In this way, this study may inspire a deeper dive into the integrated knowledge translation of Indigenous and community knowledge in water quality monitoring (Giles & Graham, 2017). Three main steps of a co-creation framework include (1) co-design of the research agenda, (2) co-production of knowledge, and (3) co-dissemination of the results (Mauser et al., 2013). In the first step, co-designing the research agenda, we began discussing potential ways to engage with the Six Nations community with their Wildlife Manager at the time, in July 2018. From our discussions came the suggestion to pursue artistic research as a culturally appropriate way to initiate conversation about the watershed with community members. Artistic research (also known as art-based research, research in the arts, and many other names) is research in which knowledge is produced and disseminated through the arts (definition condensed from Lilja, 2015). It is distinct from art-science collaborations, in which artists are visitors or participants in scientific practice (Borgdorff, 2012). There is an established and growing literature to support the use of art to engage with community members. For example, one seminal work states the following:

> …the production of art as an instrument for change... may be thought of as encompassing three types of work. One is emblematic: objects or actions that embody the social problem or make a political statement and by their presence in a public setting hope to inspire change. A second is supportive: works conceived and created by the artist that, upon presentation, are designed to be linked to others, ultimately feeding back into an actual social system… A third type is participatory, whereby the concept of the work and perhaps its actual production come out of a collaborative process. It aims to make a lasting impact on the lives of the individuals involved, be of productive service to the social network, or contribute to remedying the social problem (Jacob, 1995, 53-54).

From discussions held as the first step in co-creation, artistic research emerged as the preferred method of community engagement. We recognize this is an unconventional approach in the study of water quality monitoring; however, this dissertation methodology was designed to facilitate the emergence of different ways of knowing (i.e., use of multimethodology that supports the postmodern Multiple Evidence Base Approach: Tengö et al., 2014). Artistic research was implemented in this study to build relationships, hold conversations, provide social context for the larger research project (to develop a framework for improved monitoring), and make science communication more accessible to and by community members. To put it simply: we applied artistic research in this portion of the research because that is what our Indigenous community partners determined would be an equitable and appropriate collaboration. After our initial discussion in July 2018, we had periodic meetings with the Six Nations Wildlife Manager to organize a community art project over the next eight months; however, given our limited resources and recognizing strong synergies, he introduced us to the Great Art for Great Lakes (GAGL) project at the end of February 2019. In August 2019, we connected with a new contact from the Six Nations community via GAGL (as the Wildlife Manager had retired), from which an Indigenous youth art exhibit was conceived. Both these partnerships and their methods are described below.

6.3.1 Great Art for Great Lakes (GAGL)

GAGL is led by Waterlution, a Canadian non-profit organization that actively works to listen, understand, and look to participatory collaborative models unique to the community they are working to serve. The GAGL project has impacted over 6,000 community participants across Ontario, in various watersheds connecting to the Great Lakes, over its three years (2018-2020) of project implementation. The project commissioned artists ('makers') to engage with at least 250 members of the public each through workshops aimed at skill-building, educating, showcasing the grandeur of the Great Lakes, and co-creating a permanent art installation in their communities. Local artists also benefited from expanding their practice with a focus on socially engaged participatory art.

A distinct feature of this work is the factoring of the audience into the process of creating the final product, which activates the viewer as a participant with ownership of the creation. Civic engagement and the creation of inclusive spaces for discussion around our connections to water, water-related challenges, and our ability to express and share these discussions visually and experientially, are the foundation of the socially engaged, participatory art projects that comprise GAGL. Artists involved in the 2019 season, and dates workshops were held are as follows:

- Michael Barber (wood burning): June 8, 9, July 10, 13; unveiled September 24
- Suzanne Earl and Holly Anderson (beach clean-up and mosaic tiles): beach clean-up July 15; workshops August 1, 10, 14, 15, 17; unveiled October 8
- Lacie Williamson (graffiti art): June 15, 22, July 6, 20; unveiled September 17
- Logan Staats and Rob Lamothe (musical composition): July 8, 9; unveiled October 18

Participants in each workshop were invited to complete a questionnaire to contribute to future planning of the program and, if they permitted, to contribute to this research. This questionnaire, which was used in the previous year of GAGL delivery to collect feedback on the project, was redesigned collaboratively with the Creative Director of GAGL to ensure relevance to the research and the GAGL team – i.e., the second step of co-creation per Mauser et al. (2013). The ten questions used in this research were open-ended (e.g., no options or sample answers were provided), allowing for complete freedom and unguided personal/individual responses. All responses were anonymous. A total of 133 (of 135) questionnaires were used; omissions were due to responses being irrelevant to the study area, e.g., visiting for the first time as opposed to living in the area. Questions asked of workshop participants were as follows:

1. How are you connected to Lake Erie/Grand River?
2. What activities do you enjoy on/in Lake Erie/Grand River?
3. Who do you feel is responsible for the health of Lake Erie/Grand River?
4. Do you feel Lake Erie/Grand River are healthy? If no, why not?
5. Why are you interested in learning how to [workshop activity]?
6. Has this experience impacted the way you feel about Lake Erie[10]? Please explain.
7. Moving forward, will you do anything differently regarding Lake Erie? Please explain.
8. Do you think participatory arts projects like these are effective for bringing the community together? [Note: some workshops had an earlier version of the questionnaire that did not have this question on it]
9. What do you care most about, or what do you think is most important regarding the Grand River and/or Lake Erie (including their wetlands, ponds, creeks, etc.)?
10. Imagine you have a chance to speak to those who make decisions about the Grand River and/or Lake Erie, and you have only minutes to raise your priorities with them. What are…
    a. Issues or challenges you have identified that you feel should be prioritized?
    b. Your ideas or recommendations about how we should address the issues/challenges?

The final step of co-creation (co-dissemination of the information) was not implemented in this partnership because the Great Art for Great Lakes program had been designed and implemented prior to the research partnership being formed (i.e., this research partnership was formed in Year 2 of a three-year implementation). The hand-written responses were scanned and imported as PDF files into NVivo 12 software, which was used for coding and analysis. An adapted grounded theory approach (Bryant et al., 2011) was used for data analysis, in which themes and categories slowly emerged as responses were coded. First described by Glaser and Strauss (1967) – with some foundation in Gallie (1956), the grounded theory approach has evolved to become the pre-eminent qualitative research method and is making headway in quantitative analyses as well (Bryant et al., 2011). The method is adapted in our study because we are exploring what may be discerned from applying unconventional approaches to

[10] Questions 7 and 8, regarding personal impact and potential future action, were focused exclusively on Lake Erie as the art project themes and, therefore, most discussion of issues were focused only on the Lake.

water science and management; as such, the requirement to achieve saturation through a representative sample (Stern, 2011) was not a design consideration here. Instead, we sought to begin the process of raising new information, in new ways, rather than collect all new information that exists in the community. A grounded theory method remained the most relevant and useful method for analysis because it is one of the only qualitative approaches that embraces the experiences of real people, does not force the data into an existing, known framework (i.e., theories are developed directly from the data), and although it is context-specific, there are components (e.g., some elements of process, or principles of practice) that may be abstracted for application outside the research context (Stern, 2011).

Although our questionnaire questions provided a loose framework under which the responses could be categorized, the themes were not finalized until after all questionnaires were coded. There were six final themes: VECs (i.e., 'valued ecosystem components' – things people care about), public engagement (i.e., why they are participating in the workshop and whether they will do anything as a result), perception of health (i.e., whether participants thought the river and/or lake is a healthy system), responsibility (i.e., whose role is it to manage watershed health?), problems identified, and solutions proposed.

6.3.2 Indigenous youth (via Music of the Spirit & Indigenous Visual Arts)

Music of the Spirit & Indigenous Visual Arts (MFTS) is an after-school cultural program for on- and off-reserve youth of Six Nations of the Grand River. In August and early September 2019, discussions took place regarding how to engage the youth to share their perspectives with local Canadian communities and water managers (i.e., the first step of co-creation – co-designing the research agenda – per Mauser et al., 2013). By September, the *Grand Expressions* art exhibit (untitled at the time) was planned. Soon after, from October 2019 until early March 2020, the youth created their pieces and wrote their interpretative text to guide readers' understanding of their messages (i.e., the second step of co-creation – knowledge co-production – per Mauser et al., 2013). Two after school program days were attended in January and February 2020 to get to know the youth, build relationships with their parents (i.e., answer any questions), and to record the story of one youth whose preference was to share her story orally as would be tradition. This youth's dictation was then written as text to accompany her artwork by the researcher, who sent the draft write-up to the young artist for approval.

To build capacity within the youth group to capture and express stories using photography, a professional photographer was bought in to lead a photojournalism workshop in Ohsweken, Ontario, Canada (on reserve) on January 20, 2020. Then, a one-day art camp was held on February 15, 2020, where youth came together to work on their pieces, share their progress, and contribute to group creations. In addition, while developing the plan for *Grand Expressions*, the MFTS Coordinator was asked how youth involvement in the research could be reciprocated by the researcher. The sharing of youth voices with local communities was of primary interest. Efforts were then made to seek opportunities for the youth to share their contributions publicly, which were discussed with the MFTS Coordinator before communicating a vision to the venues (i.e., the third step of co-creation – co-dissemination of results – per Mauser et al., 2013). Most conversations with venues occurred between December 2019 and March 2020.

The *Grand Expressions* art exhibit was originally scheduled to rotate between nine events at eight prominent venues across five cities over six months; however, due to closures resulting from the COVID-19 pandemic, the exhibit was launched only at its first location at The Carolinian Café (Cayuga, Ontario). All venues shut down and the exhibit was promptly converted to a virtual tour made available via the research website. The first version was launched online on Monday March 2, 2020, followed by a second version on Monday August 3, 2020. This second version was viewable on a tablet on the third floor of THEMUSEUM in Kitchener from the end of August 2020 to January 2021, where an estimated 5,000 patrons had the opportunity to view it. A final version of the exhibit (Ho & Miller, 2020), with minor edits and examples of dissemination included, was published to the research website on October 20, 2020[11].

In addition to exhibit opportunities, other opportunities to promote the youths' work were pursued to support our commitment of reciprocity. Nearly 200 undergraduate students studying Field Ecology (ENVS 200) at the University of Waterloo reviewed and reflected on the exhibit as part of their course in May 2020. Several feature write-ups were provided to different departments within the University of Waterloo, including a story for one of our lab groups and write-ups for the Lake Futures group, Global Water Futures, and The Water Institute. The Water Institute's August 2020 story was also featured by the University of Waterloo on the homepage banner, where it was the highest-performing story of the week. In mid-September, *Grand Expressions* was featured in the Canadian Water Resources Association's Fall 2020 issue of *Water News* (Ho, 2020b), which included a cover page highlight, full-page centre spread and a full-page feature on the rear cover of the issue. Shortly after, a story about building new ways to improve the diversity of community water management was published in the Nov/Dec 2020 issue of *Water Canada* magazine (Ho, 2020c). In November, the Canadian Rivers Institute published a blog story about implications of research on communities, which featured *Grand Expressions* (Ho, 2020d). Further, a feature article was invited to *The Conversation*, published on March 18, 2021, ahead of World Water Day. The article (Ho & Miller, 2021) in *The Conversation* received about 2,500 reads from a dozen countries in the first month of publication.

[11] Link to virtual exhibit: www.GrandErieStudy.ca/tour

The youths' written stories in *Grand Expressions* were analyzed using NVivo 12 and a grounded theory approach was used. The perspectives shared within each code were then compiled into a summary report, from which several common themes emerged. High-level recommendations and values were summarized into a list of principles and values to support action in local water science and management. A list of principles and values to underlie a new monitoring framework were gleaned from the exhibit. This list was supplemented by key informant interviews undertaken as part of the larger study. Between February 27 and May 16, 2019, 21 semi-structured interviews were conducted in person or via telephone. When interviewed, individuals represented federal and provincial government, the local Conservation Authority, Six Nations of the Grand River, independent scientists, and local or regional community and non-profit organizations. The principles and values shared by these practitioners were integrated with the principles and values that emerged from *Grand Expressions*.

6.4 Results

The questionnaires distributed during Great Art for Great Lakes workshops provided insights regarding Lake Erie, Grand River, or either/both from Canadian and Indigenous participants in local communities. Most questions are summarized in Table 8; however, three more general questions (i.e., were not relative to a specific water body) provided insights as follows:

- *Question 5 – participant's interest in the workshop*: learning or experiencing something new (19); looking for ways to participate in the community (17); wanted to do their part or 'do good' (16)
- *Question 8 – is participatory arts engagement effective?* Yes (74); it can be (1).
  - Also: 2 participants stressed the importance of the educational component; 1 highlighted that multiple cultures and age groups (i.e., generations of the same family) could participate in and understand the issues.
- *Question 10(b) – proposed solutions*: education, awareness, and advertising (31); community clean-ups (16); legislate the reduction of pollution (13).

Table 8. Dominant themes and their numbers of respondents regarding relationships with Lake Erie, Grand River, or both. Questions 5, 8, and 10b were not split according to water system and are included above.

Question asked of participant	**Lake Erie dominant themes (# aggregate respondents)**	**Grand River dominant themes (# aggregate respondents)**	**Unspecified or both dominant themes (# aggregate respondents)**
(1) How are you connected…? (2) What activities do you enjoy…? (9) What do you care most about, or what do you think is most important…?	Recreation (114); community and culture (42); wildlife and functional ecosystems (6)	Recreation (66); community and culture (28); wildlife and functional ecosystems (3)	Wildlife and functional ecosystems (80); community and culture (26); recreation (6)

(3) Who do you feel is responsible for the health of Lake Erie/Grand River?	Everyone, including community members (9); government (2)	Conservation authority (2); government (1); the city (1); Canadian people (1)	Everyone, including community members (111); government (22)
(4) Do you feel Lake Erie/Grand River are healthy? If no, why not?	Unhealthy (21); healthy or somewhat healthy (13)	Unhealthy (10); healthy or somewhat healthy (2)	Unhealthy (48); healthy or somewhat healthy (44)
(6) Has this experience impacted the way you feel about Lake Erie? Please explain.	YES responses (64): Learned something new (64); felt closer to the water than before (4); felt more involved in community issues (2)	Not applicable (activities were focused on Lake Erie, so these evaluative questions are irrelevant to the Grand River)	Not applicable (activities were focused on Lake Erie, so these evaluative questions are irrelevant to the Grand River)
(7) Moving forward, will you do anything differently regarding Lake Erie? Please explain.	YES responses (93): Reduce waste/littering/garbage (themselves or encourage others – 27); spread awareness (16); reduce single-use plastics (14)	Not applicable (activities were focused on Lake Erie, so these evaluative questions are irrelevant to the Grand River)	Not applicable (activities were focused on Lake Erie, so these evaluative questions are irrelevant to the Grand River)
(10)(a) …What are issues or challenges you have identified that you feel should be prioritized?	Pollution or contamination (9), algae (4)	Pollution or contamination (9)	Pollution or contamination (85); top three types of pollution were garbage or litter (35), plastics (15) and agricultural or chemical runoff (15)

Analysis of the *Grand Expressions* virtual exhibit resulted in a list of 16 summary recommendations:

- Recognize the fundamental nature of water; we begin our lives in water, it nourishes us throughout our lives, and it provides sustenance for every other organism on the planet.
- Recognize that impacts are shared by all, though not equally.
- There is a unique connection between women and water. We should celebrate this and empower female champions of the community.
- The interconnectedness of our world means what we put into the watershed returns to us in one form or another; we need to acknowledge this and act as if it matters.
- We should not shy away from encouraging love and gratitude for each another and for the water, which we all depend on. We need to openly acknowledge that we are all sentient, equal and co-dependent in many ways.
- We should celebrate the gifts we enjoy from the water, making gratitude a regular part of the way we think about the water.
- There needs to be much more accountability for the lack of drinking water on reserves.
- While open dialogue is a great start, action must surpass dialogue towards restoration and prevention; a proactive approach is preferred.
- Managers should strive to measure and enhance community experiences as part of their assessment of watershed health.

- Nation-to-nation histories must be openly acknowledged, and efforts made to reconcile (i.e., too many Grand River residents do not know what the Haldimand Tract is).
- Intercultural and intergenerational knowledge should be captured and shared.
- Diverse perspectives are necessary to succeed with making our watershed healthy and equitable for all.
- Managers and community members need to understand and accept the diverse relationships that exist between different peoples and the water (i.e., including spiritual, emotional, and physical).
- Precautionary management should be implemented.
- Positive framing may make the community more receptive to messages about riverine health.
- More of us need to be engaged to collectively work together towards shared goals.

In addition, the youth identified several priority challenges facing the community: chemical spills and other pollution, lack of drinking water on reserve, undrinkable surface water (Grand River), unknown cumulative effects, and two mentalities that need changing (dilution fallacy and removing ourselves from the 'big picture' interconnectedness of nature).

Value statements provided in key informant interviews (as part of the larger research) were integrated with the youths' list above. Once synthesized, 10 principles emerged:

1. Water is essential and finite.
2. What we put into the watershed returns to us in one form or another.
3. Impacts are shared but unequally distributed.
4. We are inextricably embedded within ecosystems and are co-dependent in many ways.
5. Partnerships and collaboration are the foundation of program implementation.
6. We openly acknowledge diversity, histories and strive to reconcile. We recognize and value diverse relationships between water and people.
7. Data, knowledge, and communication are open, transparent, and accessible. In the remainder of this dissertation, cultural and intergenerational (and other forms of community and/or Indigenous) knowledges are recognized as data.
8. We will manage as stewards. Waters are treated as living, sentient beings – with love, respect, and gratitude.
9. We recognize that iterative, adaptive processes do not fail (they improve). Proactive, precautionary approaches are applied when feasible.
10. Managers should strive to measure and enhance community experiences as part of their assessment of watershed health.

6.5 Discussion

The purpose of our study was to explore the utility of a co-created approach for information gathering that is not commonly practiced in freshwater monitoring in the study area. At the start of this paper, we recognized the need to improve freshwater monitoring and build on two recommendations from Ho et al. (2020): (1) recognizing different knowledge forms from diverse sources, especially Indigenous, and (2) facilitating action by managers and decision-makers. From this, we posed the question, how might diverse perspectives contribute to better water quality monitoring in the Grand River interface? A co-creative process led us to use artistic research to shed light on community priorities, interactions with the watershed, and a vision for collaborative watershed monitoring and management moving forward. As we are considering methodological contributions for monitoring, we have organized this discussion into three sub-sections that are adapted from the three steps of co-creation (Mauser et al., 2013): (1) implications for monitoring program design ('the agenda'), (2) knowledge co-production with diverse people ('the data'), and (3) sharing and applying unconventional knowledge ('the outcome').

6.5.1 The agenda: implications for monitoring program design

Six implications of this research emerged for the design of future water quality monitoring programs. These are described below.

1. **Our co-created, arts-based approach can be effective for engaging diverse community members.**

From this study we recognize that the expression of information is sometimes best provided in alternative formats – e.g., visual arts, song, dance, theatre, stories, photographs – especially when experiences, connections, and values are of interest. Demographics who do not normally contribute to water monitoring or management processes – e.g., youth, Indigenous community members – were able to engage with the subject matter (i.e., what constitutes watershed health?) and provide insights towards the creation of a water monitoring framework. GAGL questionnaire responses suggested that people did not engage with the project because of the artistic expression, but because they wanted to be involved in their communities (about 63.5% of responses; remaining responses related to learning something new). In our study, the arts provided a platform for conversation, like public forums currently being held as part of national consultations for the creation of a Canada Water Agency, or the purpose behind the Environmental Registry of Ontario – a place to learn about what is going on in your community and provide input to influence management or decisions (except the arts are perhaps a more widely accessible format).

Further, in both examples of engagement provided in this paper, some form of capacity building was included (e.g., awareness-raising and science-based talks at GAGL workshops, photojournalism workshop and art camp as part of *Grand Expressions*). A monitoring program that intends to engage with community members – whether in the ways we engaged or for community-based monitoring purposes – should ensure that capacity-building and/or training is provided. Such capacity building would have benefited our participant community members, as their questionnaire responses demonstrated a lack of clear understanding about water governance. The question of whether the river and/or lake is healthy was also a matter of some debate; 79 (57%) suggested one or both water bodies were unhealthy, while 59 (43%) suggested they were at least somewhat healthy. Increased awareness, education, and advertising (e.g., public service announcements) were the most proposed solutions in the area (31 participants).

2. In research, there are often ethical dilemmas that should not be accepted as just another systemic limitation.

Research ethics systems provide an immense opportunity to decolonize science and research. An example from our study was that written consent to participate was preferred, which required participants to read, understand, and sign a 4-page information and consent form. Two problems with this approach are (1) that signed agreements have not historically been upheld by the non-Indigenous party in the past (and these agreements may represent colonial contracts to some community members), and (2) that the building of trust, by developing meaningful, personal relationships, is largely absent (compared to the verbal contract approach). We adjusted our approach to ensure verbal and implied consent were possible. In addition, we completed two review processes: one at the University of Waterloo (reviewed by a university ethics committee), and one at Six Nations of the Grand River (reviewed by an Indigenous ethics committee).

3. Reciprocity must be within the program scope.

The idea of reciprocity must not only be within the scope of the monitoring program but must also be within the scope of any collaborators in that program. For example, in our study, one of the monitoring agencies that is an end user of this research was asked to acknowledge the *Grand Expressions* exhibit in some form (e.g., host the exhibit temporarily or highlight it in a newsletter). Unfortunately, support for giving space to the Indigenous youths' voices was not provided, despite immense support for other (western) aspects of the project. In addition, all program commitments (e.g., open data sharing) must be transparently discussed and followed through. Finally, as part of co-creation and building reciprocal relationships, monitoring parties should be flexible to adjust activities or expectations. For example, if the initial plan was to monitor two sites in a Subwatershed but the local community is interested in an addition two sites at the confluence of another Subwatershed, the request should be considered if community monitoring support – including access to Indigenous lands – is provided.

4. Co-create shared spaces and incorporate co-solutions.

Co-creation is different than inclusivity, because inclusivity involves inviting groups who were not previously engaged into a social environment that was not designed for their involvement. This can impede their full participation and prevent innovations from happening, diminishing benefits shared by all. We recommend just, shared spaces, which we define as entirely new social environments designed to ensure all parties can meaningfully contribute to shared goals. *Grand Expressions* is an example of a shared space for communicating priorities and values in mutually meaningful ways. Also, where possible, community members should be involved in collaboratively developing solutions for issues affecting or influenced by their community.

5. Investigate existing models.

Throughout the broader research, conversations with water managers and monitoring personnel have demonstrated to us there is a real challenge of not having the processes or know-how to consider diverse values despite individual appreciation for them. Fortunately, frameworks and guidance papers for addressing these challenges exist. Like our set of guiding principles, frameworks can be developed from Indigenous and other community knowledge as well. A recent example is the Two-Eyed Seeing framework for fisheries, developed by Reid et al. (2021). Another set of guiding principles developed specifically for research contexts, 10 Calls to Action to natural scientists (on behalf of Indigenous communities) working in Canada, is described in Wong et al. (2020).

In addition, examples like the Slave Watershed Environmental Effects Program (SWEEP) exist across Canada. SWEEP reflects principles of both co-management and co-creation. Guiding questions of the monitoring program were co-created and are whether fish and wildlife were safe to eat, whether water was safe to drink and whether the ecosystem was healthy (Jones, 2015). The program engages community members, integrates Indigenous Traditional Knowledge, and supports a regional government partnership with local peoples and academia (Jones, 2015). SWEEP builds capacity for its communities to collect, interpret and use a system of aquatic environmental indicators based on a Two-Eyed Seeing approach. Watershed indicators were developed through a co-creative process.

6. Ensure the logistical infrastructure is present.

Operationalized information flow channels (e.g., agreed-upon data sharing, expectations that outputs/outcomes of the research will be received by the managers, a mandate for cross-sectoral and interdisciplinary collaboration, and more) are a critical requirement of an improved monitoring framework. This was described directly or indirectly by the community members that participated in our two arts-based processes, e.g., a GAGL comment that one of the biggest problems facing the watershed is the lack of communication and awareness building from local water managers to community members and was touched upon by key informant interviews (see Ho, Dhaliwal, and Wright, 2020).

6.5.2 The data: knowledge co-production with diverse people

Water quality data can be supplemented or augmented using different forms of knowledge, e.g., Indigenous, traditional, or local knowledge systems. An example from the larger research is beach monitoring by community members to record the approximate biomass of washed-up algae near the study area in the eastern basin of Lake Erie. Other examples have proven (empirically) that traditional knowledge can effectively inform management, especially where reference conditions or knowledge of wildlife movements are lacking (e.g., Polfus et al., 2013). Traditional Indigenous knowledge and other community knowledge forms are "built by cumulative wisdom, practical knowledge, and place-based communities (Chevalier & Buckles, 2013, p. 24)."

The results from GAGL provide several insights useful for the collection of monitoring data. The most dominant themes for people's relationships, activities, and values regarding Lake Erie and/or the Grand River are (1) recreation, (2) community and culture, and (3) wildlife and functional ecosystems. Two of three dominant themes relate to people's experiences in the watershed – their quality and the kinds of experiences available. This is interesting from a monitoring point of view because little, if any, existing water quality monitoring is connected to community member experience in the study area (other than whether waters are safe to swim in at beach/park areas). However, community members also demonstrated an appreciation for more conventional water quality parameters in their prioritization of pollution (primarily plastics – not currently assessed in the study area), contamination (e.g., metals, hydrocarbons), and algae-related issues (e.g., nutrients). Further, four recommendations for the way we view 'data' emerged from this study, described below.

1. **Recognize the validity of other knowledge forms.**

Artistic research permitted us to collaboratively consider what constitutes good monitoring data – a question also raised in critical Indigenous pedagogy of good science (Denzin & Lincoln, 2008). While there is concrete evidence supporting traditional and community knowledge – e.g., photographs, maps, evidence of settlements and tools, beadwork – concerns around validity and reliability of orally transmitted wisdom remain (Chevalier & Buckles, 2013). We suggest these concerns, although often grounded in a genuine desire to understand different ways of knowing, are somewhat misguided. First, we do not suggest replacing one form of knowledge with another, which would imply the need to assess the superior approach for our purpose; as discussed in our introduction, western science and other kinds of information (e.g., Indigenous cultural teachings, community intergenerational stories and records) should complement one another in a Two-Eyed Seeing approach, enabling a more complete understanding not only of certain aspects of the watershed, but of the relationships between those aspects and the broader social-ecological contexts surrounding them. Using the Two-Eyed Seeing approach, a value comparison does not contribute to the way in which we understand watershed health.

Second, much like natural history and ecology often begin with field observations, Indigenous knowledge is also experimental by nature. It is time-tested and triaged over generations, as what does not work tends not to be useful information to pass on, and oral transmission is known to have survived complex social, cultural, spiritual, and political systems (Simpson, 2004). Verification is valued in these knowledge systems, as oral stories and histories are told with citational practice as scientists cite the authors of other studies to support their claims. When a story is told, its origins are told, as is how the teller acquired the story (e.g., who told it to them). The common demand to justify applying Indigenous knowledge is underpinned by the assumption that more empirical knowledge results in better management of natural resources (Simpson, 2004). Arguments equating the apparent 'loss' of Indigenous knowledge to the suggested fragility of the knowledge form fail to recognize the dominant role of western society in the destruction of Indigenous knowledge through assimilative methods like Canada's residential school system. This reality reinforces an understanding that oral traditions are not more vulnerable than are empirical approaches to knowledge; rather, continuing colonial mentalities of scientists affect ongoing efforts to build effective relationships (Simpson, 2004). A growing literature supports this discussion, e.g., Berkes' (2018) evolving discussion on traditional knowledge systems in practice.

As with co-creation, management frameworks conducive to Two-Eyed Seeing exist across Canada. For example, adaptive co-management of natural (e.g., fresh water) resources, most prevalent in Canada's North, provides dozens of examples in which Indigenous knowledge and western science work together (Kristofferson & Berkes, 2005). Numerous definitions collectively describe adaptive co-management as an organized network of actors sharing management power and responsibility, self-organized in an iterative process of learn-by-doing (Holling, 1978; Walters, 1986; Folke et al., 2002). Adaptive co-management systems are community-based, localized (e.g., tailored) and engage with different levels of people and organizations (Kristofferson & Berkes, 2005). These management structures represent institutionalized cross-scale social-ecological and procedural linkages between communities, resource managers and decision-makers. Fundamentally, co-management is more about managing relationships than managing resources (e.g., mitigating our relationships with ecosystems per Kay & Schneider, 1994).

As such, it is less an organizational model as a process and structure for Indigenous negotiation of power (Natcher et al., 2005).

2. Constant engagement is not necessary.

Guiding water quality monitoring using a community-generated set of values is one approach for ensuring the community's priorities are being addressed without having to constantly re-engage with everyone. It is important to note that the list of principles produced in this research was synthesized from independent engagements with Indigenous youth and current practitioners as a proof of concept to demonstrate what values could emerge in this type of exercise; however, if a set of values were to be determined for application to the study area, the process of generating the list of principles should be collaborative between the end users and community members directly (i.e., not through a researcher's synthesis). We must also acknowledge that although we describe this approach as emerging in this paper, this practice is not a new concept (e.g., the Grand River Conservation Authority produced 'best bets' – priorities for fisheries management – from broad engagement in the early 1990s to guide the following 20 years of management); however, the approach is still considered emerging as they are still not yet widely recognized or implemented in management practice.

An international example is the Dublin Statement on Water and Sustainable Development, which represents the perspectives of more than 500 United Nations conference participants including government-designated experts from 100 countries and representatives of 80 international, intergovernmental, and non-governmental organizations (ICWE, 1992). The four guiding principles of the Statement, which were followed by an Action Agenda, demonstrate clear overlaps in the calls for action or a change in attitude presented by the 10 principles in our results:

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognized as an economic good.

On a regional scale, agencies (e.g., municipalities) and the private sector may take our approach further by formalizing community principles and values (e.g., a community management charter), exemplified in the Dublin Statement.

3. Do not undertake collaborative data production to only serve the needs of western science.

Building on our mention of shared spaces versus inclusive spaces, practitioners should be aware of their intentions for engaging with other knowledge forms. The co-creation of knowledge should serve mutual, co-created goals and not be a situation in which western science is missing data so identifies and dissects knowledge from elsewhere to fill its gap. The recognition of data sources is also important, as cultural appropriation of heritage and practice is a risk to be carefully mitigated (Posey, 1996). It is also worth noting that bringing Indigenous knowledge into existing resource management programs is not just a matter of including an additional indicator or adjusting the narrative. The Principles of OCAP® (Ownership, Control, Access and Possession), established by the First Nations Information Governance Centre, set standards for how First Nations data should be collected, protected, used or shared (First Nations Information Governance Centre, n.d.).

4. **Appreciate the continued evolution of scientific practice and embrace opportunities to co-develop potentially useful knowledge.**

The practice of science (including water monitoring) has evolved over time. Recognizing this, we recall a quote from Putnam (1995): "You won't, for example, tell us, nor could you possibly tell us, what the criteria are by which we know which uses of 'know' in the future will be legitimate or rational… (p.32)." This discourse on what the future will constitute as acceptable data or knowledge is recognized here since the larger research strives to consider the assessment of cumulative effects in water monitoring. Cumulative effects are "changes to the biophysical, social, economic, and cultural environments caused by the combination of past, present and 'reasonably foreseeable' future actions (Northwest Territories, 2015)." Complementary data of diverse sources and formats may contribute to our understanding of cumulative effects now and in the future. In particular, the ability of diverse knowledge forms to augment commonly accepted data regarding past and potential future effects (e.g., reference conditions and developing predictive models) may be a major factor as to whether they are incorporated into future monitoring practice.

6.5.3 The outcomes: sharing and applying unconventional knowledge

This study explored the potential utility of unconventional, diversity-driven knowledge approaches for freshwater quality monitoring. As such, the concepts and results presented in this study are yet to be tested in a management context (we identify this as a next step for future research). Still, we can suggest that using universal forms of expression to celebrate and collect different lines of evidence, e.g., the arts, can effectively disseminate information important to the watershed context. For example, nearly 200 university ecology students reviewed and reflected on *Grand Expressions*, with many expressing surprise and dismay at the water challenges facing the Six Nations community. Per our introduction, recognizing such issues facilitates more open and effective relationship-building that can impact the continued sharing of data, knowledge, and other resources needed for a water quality monitoring program. Potential behavioural changes inspired by increased awareness may also have eventual positive impacts on watershed health.

Further, from both GAGL and *Grand Expressions*, individuals may be (or have been) personally impacted to a point where they seek opportunities to be involved in the creation or dissemination of further knowledge. Citizen science initiatives – e.g., community monitoring, surveying, and crowdsourcing observations (e.g., using web-based or smartphone apps like iNaturalist and EDDMapS) – may be useful data sources and have the potential to fill capacity gaps (e.g., WWF-Canada, 2020). These initiatives engage community members in problem identification and can reinitiate the co-creation process by providing a basis for co-created or community-led solutions.

6.6 Conclusion

The results and discussion of this paper demonstrate examples of co-created artistic research for incorporating diversity into freshwater quality monitoring. Interpreted collectively, the results of this study demonstrate that Two-Eyed Seeing is not only possible using creative approaches like artistic research or arts-based engagement, but that community members view it as a mandatory if more collaborative monitoring and management processes are to be implemented. While the challenges of bringing different forms of knowledge together may seem daunting, we suggested some ways unconventional knowledge formats may be collected and applied to existing monitoring and management practice. We conclude there are three core ingredients for considering a similar approach to ours, which were highlighted throughout the discussion:

- Relationship-building: e.g., our process required over a year of relationship-building and co-creative processes.
- Capacity-building (which reinforced relationships and built trust): e.g., intercultural competency on the part of the researcher, skill-building on the part of the artist, and knowledge on the part of the community member.
- Reciprocation: e.g., seeking opportunities for the youths' voices to be shared increased participant motivation and commitment, empowered the youth, and increased the support of community members while also raising the profile of the research project.

We built on past work (Ho, 2018; Ho et al., 2020) to consider diverse knowledge sources – especially Indigenous – and facilitate action by managers and decision-makers. Though this paper focuses on water monitoring, we considered potential applications to management and/or decisions throughout the discussion. Our six implications for monitoring program design and four recommendations for knowledge co-production complement usable information for future monitoring programs, e.g., characterizing community priorities; identifying unclear community knowledge in water governance and understanding watershed health; and synthesizing a list of 10 principles from community and practitioner values.

The impacts of the co-created approach described in this paper reach beyond the design of future monitoring programs. GAGL participants stated they learned something from the experience, felt a closer connection with the watershed, and/or felt more involved in their community. Most of these individuals expressed their intent to implement or influence behavioural changes as a result. If enough of the community is reached, the collective impact of behavioural change may result in shared improvements to our water bodies.

PART 4 – A WAY FORWARD

Chapter 7

Cumulative effects monitoring in the lower Grand River and nearshore Lake Erie (Ontario, Canada): Recommendations for implementation

Citation: Ho, E., Ding, Z., Trant, A. J., and Courtenay, S. C. *In preparation*. Cumulative effects monitoring in the lower Grand River and nearshore Lake Erie (Ontario, Canada): Recommendations for implementation. Not yet submitted.

7.1 Acknowledgements

We thank Dr. Chris Jones for his extensive and thoughtful feedback on the first iteration of this paper, which resulted in extensive edits that shaped the current version.

7.2 Introduction

In Canada, cumulative effects assessment (CEA) has largely been implemented as part of environmental impact assessment – evaluation of industry projects for their potential ecological, social, and economic impacts before major decisions and commitments related to projects are made (Cashmore 2004; Glasson, Therivel, & Chadwick, 2013; Jones 2016). Cumulative effects are incremental and accumulating environmental changes caused by one or more natural or human activities in a region over a specified time (CWN, 2016; GRCA, 2010). More specifically, these effects are defined as "changes to the biophysical, social, economic, and cultural environments caused by the combination of past, present and 'reasonably foreseeable' future actions" (Northwest Territories, 2015). CEA is defined by Dubé (2015) as "the process of monitoring, tracking and predicting accumulating environmental change relative to established limits (p.1)." Dubé et al. (2013) suggested there are four key components required for CEA in watersheds: (1) local scale monitoring consistent with regional scales, (2) watershed planning, (3) assessment of accumulated watershed state, and (4) development and use of modelling to predict future states based on multiple project trajectories.

The study of cumulative effects recognizes that geographic and temporal scales influence biophysical interactions. For example: in a watershed, the combined effect of temperature, nutrient runoff, water clarity (i.e., light penetration), and the presence of invasive species (e.g., quagga mussels, *Dreissena bugensis*) affects the proliferation of nuisance benthic algae like *Cladophora* (Jones, 2016; Duinker & Greig, 2006; Therivel & Ross, 2007; Li et al., 2021; Vanni, 2021). Management following CEA may incorporate the following courses of action: avoidance, mitigation (minimizing impact), compensation (no-net-loss, e.g., creating new wetland when one is lost); and/or revision of rules at the strategic level (e.g., rather than focus on changes to specific projects, to change legislative or regulatory rules for siting, phasing, and managing projects: Therivel & Ross, 2007).

Jones (2016) outlined seven steps for implementing CEA. The last four steps involve monitoring and predicting cumulative effects, which remain challenging to implement in any actionable way (CWN, 2016). To consider different aspects of cumulative effects monitoring (CEM) – e.g., use of terminology, indicators, and practice; issues of scale and reference conditions; accumulated state assessments; stressor-response linkages – the Canadian Watershed Research Consortium was convened by the Canadian Water Network in 2010 (Dubé et al., 2013; CWN, 2016). Seven case studies were implemented across Canada between 2010 and 2015 (though the initial pilot study began in 2008: Dubé et al., 2013). A special series of nine articles published in *Integrated Environmental Assessment and Management* present interim discussion of this work, beginning with Dubé et al. (2013). The Canadian Water Network then published a culminating summary report (CWN, 2016).

In our study, the Consortium's results are paired with discussion from the literature (especially Jones, 2016) to support practitioner-derived recommendations for implementing CEM in the study area. We focus on the steps involved in monitoring for cumulative effects to propose recommendations for CEM. We build on the work of Jones (2016), CWN (2016), and others to understand the principles and process of CEM. In addition, public engagement is said to be critical throughout the CEM process, with maximum benefits occurring when engagement is substantive and begins early (Jones, 2016; Eimers, 2016). This suggestion is also considered in our study.

7.3 Methods

The study area, described in Sub-section 1.4.1, is the interface of the lower Grand River and nearshore Lake Erie. We collected perspectives on cumulative effects from recent and current water scientists and management practitioners. First, we interviewed 21 practitioners from February to May 2019. Though interviews focused on the general practice of freshwater quality monitoring, a subset of questions (Appendix D) were about cumulative effects. Interviews were analyzed in a 'SWOTR' analysis – Strengths (e.g., Ontario has decades of data to work with), Weaknesses (e.g., there is little coordination of monitoring efforts), Opportunities (e.g., technological advances have increased our ability to investigate complex issues), Threats (e.g., systemic/jurisdictional silos prevent most decision-makers from integrating priorities outside their mandates), and Recommendations; Chapter 4 provides more details on the interview process and results.

Second, on December 7, 2020, we led an online practitioner workshop attended by three of our interviewees and five other experts. An additional nine practitioners were not able to attend the workshop but provided their contributions by email (i.e., 17 workshop contributors). In total, 35 current or recent practitioners provided insights for this study. All study contributors represented Environment and Climate Change Canada, Parks Canada, four Provincial ministries, the Grand River Conservation Authority, Haldimand County (the municipality at the mouth of the river/in the study area), or were non-government (e.g., academic, non-profit).

Before the workshop, we compiled two lists from participants: (1) indicators that participants currently measure to assess causes of *Cladophora* growth, and (2) criteria participants would (or do) use to evaluate indicators for CEM. During the workshop, we discussed the theory and limited practice of CEM, focusing on potential indicators for addressing prolific *Cladophora* growth in the nearshore of Lake Erie's eastern basin. As part of the workshop, participants were asked to score the compiled list of indicators according to the compiled list of criteria in an exercise with two goals: (1) to further develop an indicator ranking process designed and tested during our exploratory study (Ho, 2018), and (2) to short-list a set of potential indicators for CEM of *Cladophora* in the study area. Participants had the option to complete the activity from three days prior to one week after the workshop).

A key difference between the exploratory method (Ho, 2018 – dissertation Chapter 5) and the approach used in this study is this study used scoring criteria defined by workshop participants, rather than criteria provided by the researchers. In addition, our current indicator selection process supports widespread collaboration and was designed to enable people to be involved even when they are not able to be in the same room. Workshop participants scored each indicator/parameter on each criterion using a scale of 1-5. A score of "1" meant the indicator did not meet the criterion at all, while a score of "5" meant the indicator fully met the criterion. Participants were asked to complete the activity individually and were instructed to only score those indicators and criteria they felt were relevant to the cumulative effects monitoring of nutrients and/or *Cladophora*. Seven activities were returned, with varying degrees of completion (i.e., some were partially completed due to time constraints).

First, scores from all participants were averaged and summed for each indicator. Second, a weighted average score was calculated by multiplying each indicator's average by the percentage of people who scored it. A weighted average was necessary to reflect actual indicator preferences; otherwise, indicators that had more responses were likely to carry higher scores regardless of whether they were preferred. Participant insights were organized into summary reports from interview transcripts and detailed workshop notes, emailed comments, and workshop activity submissions. The interview summary report (Ho, Dhaliwal, and Wright, 2020) was organized thematically – e.g., strengths of monitoring, weaknesses, and sections according to commonly discussed themes like coordination of monitoring – and concluded with a summarized SWOTR analysis (e.g., Strengths, Weaknesses, Opportunities, Threats in the left column of each page, and associated Recommendations in the right column). The workshop report (Ho, Ding, and Dhaliwal, 2021) was organized according to the steps of workshop execution: pre-workshop contributions, three discussions, final thoughts, and the workshop activity.

We synthesized relevant practitioner insights from the interview SWOTR analysis and workshop summary report, and we present our results in the form of eight recommendations. These eight recommendations were determined based on the subject matter of the interview results (i.e., comments provided in the context of cumulative effects or applying holistic/systems thinking in monitoring). The description of each recommendation is comprised entirely of relevant practitioner comments, per the above paragraph. It is important to note that several of the recommendations raise the need for broader and more meaningful engagement and/or collaboration; however, implementation of engagement approaches in support of monitoring is outside the scope of this paper (see Chapter 6 for a deeper discussion on this topic).

7.4 Results: Recommendations for CEM in the study area

1. Establish a common definition of cumulative effects/CEA before implementing CEM.

Variation among interviewed professionals regarding their conceptualizations of *cumulative effects* and *cumulative effects assessment* demonstrates a need to define a CEM program's use of the term(s) before implementation (e.g., so that all parties involved have a common understanding of the program). For example, some definitions of cumulative effects included only human-induced changes in the environment, while others also included changes resulting from natural processes or stressors. Also, different spatial and temporal boundaries were recommended (e.g., whether the watershed is an appropriate boundary for all VECs, whether short-term or long-term monitoring is needed to understand variability – e.g., participant recommendations varied from 3 to more than 10 years). These examples have implications for monitoring practice e.g., our analyses of stressor-effect pathways may be influenced by these differences in how we understand and identify effects. Too short of a timeframe may not accurately capture phenomena.

Emerging approaches (e.g., remote sensing) applied to CEA continue to be assessed for their applicability to monitoring, and those that are applied to monitoring (e.g., remote sensing of the spatial extent of algae growth in Lake Erie's eastern basin) are so new they have limited predictive abilities. As such, there is little operational expertise surrounding cumulative effects. Efforts should be made to establish a common understanding of CEM amongst all involved (e.g., monitoring personnel as well as managers and decision-makers). There should also be clarity about what the CEM program can offer (and what it cannot). Finally, monitoring should be undertaken to verify or improve the efficacy of emergent innovations (e.g., in-person verification of remote sensing data/trends).

2. **Ensure diverse 'others' are meaningfully involved early and throughout the design and implementation of CEM.**

More attention must be devoted to ensuring the right people, of diverse perspectives, are engaged in the right way (e.g., their way) and at the right time(s) (e.g., not everyone needs to be always involved). The right people are often described as 'end users' – e.g., watershed managers and decision-makers; however, local Indigenous communities have a role in governing activities in their territory of the watershed, and so should be identified as end users as well. Collectively, these end users should all be involved meaningfully, e.g., must be able to fully participate, or empowered to do so, to define monitoring questions and VECs, and to determine how information will be analyzed and presented.

A formal stakeholder and rightsholder identification exercise should be undertaken at the start to ensure the right people have been identified and have been or will be engaged. On monitoring questions: good scientific indicators are not necessarily the best indicators to address management or decision-maker needs, which reinforces the need to ensure appropriate levels of engagement if monitoring is to be actionable (e.g., to ensure a management or decision-making response, or a behavioural change in local communities, follows the provision of monitoring information). In other words, to ensure CEM is actionable, there should be a mandate for action (e.g., legislated) that the program serves in some way. Monitoring partners and/or agencies must also coordinate their efforts to avoid redundant monitoring and must ensure the transfer of knowledge between them (e.g., this strengthens everyone's knowledge base and removes the need for one agency to monitor what another agency already has).

3. **Develop adaptive, innovative processes for assessing and understanding both stressor and effect-based indicators (collectively).**

A combination of stressor and effect-based indicators may be required to assess the condition of VECs studied in CEM (e.g., monitoring treatment plant outflows together with biological effects); however, the increased complexity of combining the two monitoring approaches may affect scientists' abilities to identify meaningful information. The more indicators are measured, the more likely we are to observe trends that are unimportant for the question(s) asked and the more likely we are to experience erroneous interpretations of data. An adaptive monitoring process is imperative for validating the results of such a program and, when needed, to adjust indicators or monitoring protocols.

Analytical approaches for bringing together both stressor and effect-based monitoring in a CEM context – i.e., understanding potential stressor-effect pathways – may need to be further developed to be useful for end users. Study participants stated 'further' developed because this recommendation has already been adopted at Federal and Provincial levels (especially Federal); however, this has not been done well in the study area as we are still developing basic ecological knowledge of how the river-lake interface functions. Data analysis should be determined according to end users' intended use of the information *prior to* data collection, since specific analyses may have different requirements of data that may need to be considered in the design of the monitoring program. Thus, end users should be involved early.

4. Select indicators co-operatively with end users (defined in Recommendation #2).

Following recommendations by Jones (2016), Eimers (2016), and others (e.g., Ho et al., 2020 – Chapter 3; interviewees in Chapter 4; Head, 2010; Head & Alford, 2015) we adapted the Criteria-based Ranking (CBR) process as a tool for engaging in a collaborative process to determine what might be monitored in a CEM context. This activity required a problem context that CEM could respond to. As such, our collaborative workshop process was contextualized by discussion about what stressors cumulatively contribute to the prolific growth of *Cladophora* in Lake Erie's eastern basin.

Federal and Provincial governments and the Grand River Conservation Authority monitor indicators relevant to this study. For example, Environment and Climate Change Canada currently measures phosphorus concentrations at the mouth of the Grand River and in transects in the eastern basin of Lake Erie. Both federal and provincial agencies monitor *Cladophora* biomass indirectly, while the Niagara Coastal Community Collaborative – a pilot community-based monitoring program initiated by Environment and Climate Change Canada – directly assesses beach washup of *Cladophora* biomass. In total, participants identified 16 existing indicators related to nutrients and/or *Cladophora* biomass. These indicators were then ranked in the workshop activity using a decision matrix-style tool adapted from Ho (2018) to determine the top 10 indicators for monitoring cumulative effects of conditions lading to *Cladophora* growth. We compiled 22 potential criteria from participants to use in the ranking process, which are listed in Ho, Ding, and Dhaliwal (2021). Below we highlight a subset of ten of these criteria.

The indicator:

- responds predictably (for modelling) so the value of the indicator can be interpreted.
- reflects a known or hypothesized mechanism by which a stressor or natural feature, or multiple stressors and/or natural features influence a valued ecosystem component (VEC).
- is related to one or more VEC or priority (i.e., is relevant) and is backed by research to be a good indicator of each VEC/priority.
- is conceptually simple enough for broad dissemination (i.e., interpretable by non-technical audience).

- is associated with known variability and desired conditions.
- processes that determine the condition of the indicator (i.e., influence change in the indicator) are understood.
- is ordinal (has magnitude and defined units of measurement) or binary.
- can measure multiple effects coinciding in the same space or time.
- measures the VEC directly or, if no direct measurement is possible, influences the direct VEC.
- is responsive to change.

Based on the workshop activity, the top 10 ranked indicators (Figure 10), listed from most to least likely to be used to determine which combination of stressors cumulatively contribute to *Cladophora* growth, are: total phosphorus (score of 73.71), dissolved oxygen (73.5), water temperature (67.5), *Cladophora* biomass (63), nitrate (58.44), soluble reactive phosphorus (56.67), total suspended solids (53.5), total ammonia nitrogen (47.5), turbidity (47), and conductivity (43.17). Although *Cladophora* biomass/growth is the VEC of discussion and so would be assumed to be the #1 indicator *Cladophora* monitoring program, its score reflects uncertainties captured by the scoring criteria. These include the subjectivity with which it is currently measured (i.e., visual estimations of quantity using transects) and that we are still developing knowledge of the environmental conditions that influence change in this algae's growth.

Three other indicators had close scores to the lowest indicator in the top 10 list: *Cladophora* via remote sensing (42.67), benthic macroinvertebrates (42.5), and fish condition (42.17). Participants highlighted that although remote sensing of algae has been a useful method elsewhere, its application in the study area is limited due to the area's natural turbidity. In addition, fish condition was used to respond to a different nutrient-related question than the one we posed. Thus, if we were to design a monitoring program today, using the indicators that are currently measured by workshop participants, the likely candidates would be those in the top 10 as well as benthic macroinvertebrates (e.g., mussels).

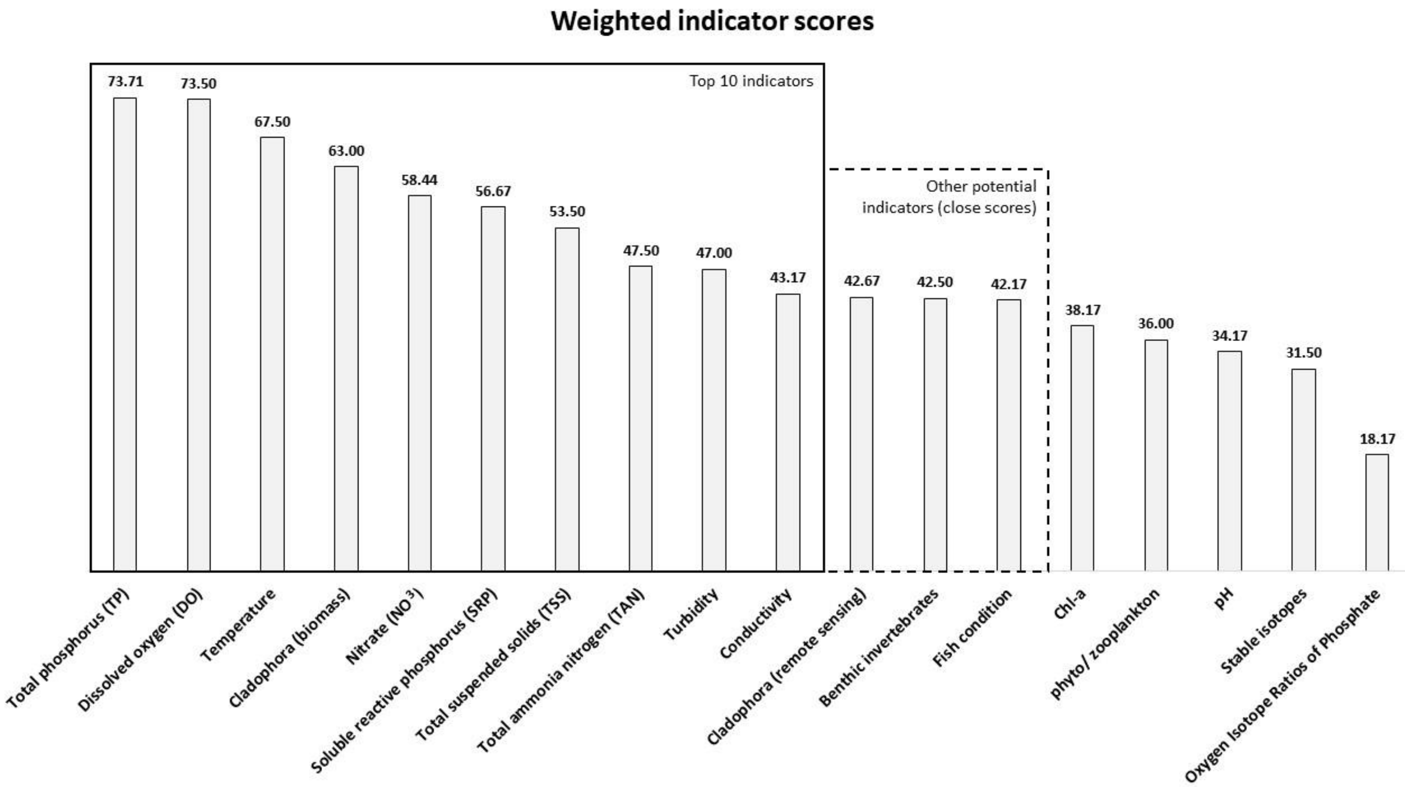


Figure 10. Indicators ranked according to a weighted score. Top ten indicators are outlined by the solid box, other potential indicators due to similar scores) are outlined by the dashed box. Potential indicators represented the collection of existing (i.e., currently monitored) indicators that workshop participants identified as potentially relevant to the workshop topic.

Our VEC, *Cladophora* biomass, should be measured as directly as possible. Although Chlorophyll a (Chl-a) is often used to assess phytoplankton abundance, study participants suggested Chl-a is likely not a good way to monitor *Cladophora*. In addition, there are many factors that influence the state of *Cladophora*, with much work currently underway. Participants suggested it is not feasible to consider effects from all stressors without the active, vested involvement of those who control them. Thus, broader collaboration (e.g., in addition to current managers and scientists) may enhance CEM design and implementation by increasing the ability to monitor a comprehensive set of potentially relevant indicators using collective capacity and/or resourcing. Further, inherent to engaging conventionally unengaged peoples is the opportunity to consider diverse sources of evidence/information that may complement existing knowledge. While this discourse is too large to fairly incorporate into this paper, our study participants stressed the importance of ensuring our scientific and managerial practices moving forward can bring together different kinds of knowledge contributions for the benefit of all contributors.

5. **Endeavor to understand the relative influence of the Grand River and Lake Erie on each other and track changes through time. This should be a priority for monitoring in the study area.**

River-lake dynamics are highly variable and not well documented. A baseline dataset for the lower Grand River and nearshore Lake Erie should be generated by sampling a collaboratively determined set of indicators in a series of cross-sections of vertical depths, longitudinally, every three to four weeks, over several years. Depending on the question being addressed, some monitoring (e.g., of nutrient concentrations) can only be done within a few kilometers along the nearshore, from the mouth of the Grand River to Rock Point, due to erratic and inconsistent dilution rates of the lake. The rate of change in the study area is so variable that effects may not be appropriately assessed if only a single definition of 'normal' is accepted; therefore, we may need to identify more than one range of variability (e.g., in different seasons, or under different lake and river conditions – e.g., high/low river flows and lake levels). We need continued research, e.g., determining how the volume of water discharged from the Grand River influences the Lake's (nearshore) circulation regime. Once variability is characterized and the nearshore circulation regime is better understood (e.g., as it relates to the river), management responses can be developed.

6. **Use collaborative watershed analysis and supportive methods and tools.**

Workshop participants suggested that conceptual models of all pathways that affect the effect (e.g., in our context, the effect is the prolific growth of *Cladophora*) would be needed to most accurately pinpoint the indicators to measure and manage. In some cases, pathways are well-established, so little work is needed, but others are quite dynamic, requiring deeper analysis. Rather than look at which indicators should or should not be measured, a recommendation was to start by considering which could be grouped together to understand how changes in one indicator would influence or represent changes in other indicators and our VEC(s). This kind of an exercise should be done with experts who know the organism (*Cladophora*) and the system well, in collaboration with end users of the information (e.g., managers). Collaborative watershed analysis is a proposed approach for understanding complex interactions and their resultant cumulative effects using visuals that are designed and utilized in collaboration with diverse persons – partners, end users and/or stakeholders and rightsholders (e.g., if they are not already considered as end users) – as required by monitoring program questions and VECs[12]. It is a way for a diverse group of people to contribute a collective understanding of how the watershed functions, what is causing observed

[12] While all other recommendations were entirely derived from practitioner contributions, the name and definition of collaborative watershed analysis are proposed by the authors based on practitioners' suggestions of what should be implemented. We suggest further development of this concept together with practitioners and others.

effects, and to strategize on potential actions that should follow monitoring. Watershed maps and/or other visuals – e.g., hypothesis-of-effect or impact-hypothesis diagrams (Robinson, Duinker, & Beazley, 2010), Ishikawa/fishbone diagrams (Ishikawa, 1968; 1976), causal loop diagrams (Bala, Arshad, & Noh, 2017), bow-tie analyses (BowTieXP, 2015; Creed et al., 2016) – are at the center of this approach as their development provides a stage for collaboration and their use enables informed discussion or action by diverse individuals.

Development of a full collaborative watershed analysis process was beyond the scope of this study, but participants collectively proposed the following steps:

(1) The problem (e.g., an undesired effect that has been observed and which has not been effectively managed) is verified in a discussion of the indicators that collectively demonstrate or confirm the undesired effect on a VEC.

(2) Recognize that the social-ecological system being addressed is defined by the observed effect (on the VEC) and is not automatically assumed to be the watershed (e.g., the watershed boundaries are defined by the drainage basin; however, human activities influencing change in the watershed may come from outside this drainage basin). Then, define the system's spatial and temporal boundaries according to the VEC and observed effect.

(3) The whole watershed, or other delineation of the system, is studied as the group considers which combination of interactions (e.g., stressor-effect relationships, influences of environmental conditions) may be behind the observed effect. Stressors and environmental conditions that influence change in the discussed indicators are identified.

(4) Visuals are developed to depict the processes and pathways that result in the observed effect. Ideally, similar pathways would be included to demonstrate how potential management responses would result in the desired effect.

(5) Visuals are modified over time as complex interactions in the watershed are better understood and/or to enable their continued use in management and/or decision-making.

(6) Predictive modelling (discussed below in Recommendation #7) may benefit from a collaborative watershed analysis process and may be developed/adapted/used alongside the visuals created from this process.

7. Use modelling tools but recognize limitations of their use.

Even with a collaborative process such as the one described above, models are needed to achieve explanatory power of how (for example) phosphorus and nitrogen contribute to *Cladophora* biomass. A broad base of data is required to inform a modelling tool that can identify relationships and generate predictions. Potential stressors and their influences on the indicators should be modelled to see what combination of stressors results in the issue being observed. If none sufficiently fit observations, return to the first step to see what information may have been missed, as perhaps we have misunderstood what the actual dynamics of the system are. Some examples of recommended modelling and related tools included scenario modelling, Bayesian networks, and value of information analyses. Scenario analyses can help to fill gaps in research, including how much nutrient the Grand River contributes to Lake Erie's eastern basin under different flow regimes. Though modelling tools were strongly recommended by study participants as potentially powerful and effective tools for informing proactive management and decision-making, challenges were identified and should be considered during model development and use. Because models may consider many predictors, a process should be in place for selecting an appropriate number. This process may require engagement with different parties to determine what the appropriate number of predictors is.

CEM may contribute to stronger models over time as predictions are verified or models corrected (note: we suggest that the improvement of models does not rely entirely on verification by monitoring, but also on collaborative processes like the one described in Recommendation #6 which strive to understand social-ecological relationships used by the model). In addition, time lags (e.g., the time it takes an ecosystem to recover from a disturbance/stress of some kind) affect decision-making; therefore, although they add complexity to models, they should be considered if predictions are to be useful. Finally, we may not always have all the data or expertise required for modelling. Still, there is usually a point at which data are 'good enough' to permit a model to provide insights, even if predictions are not entirely reliable yet. In this way, participants suggested we should not let imperfect data prevent the use of good science.

8. Share and receive knowledge in various ways.

Two-way knowledge sharing and mobilisation implies conventional data collection is coupled with equitable ways of engaging local peoples to share their knowledge about the watershed and of effects being observed. In addition to enhancing the knowledge generated by monitoring, two-way knowledge mobilization is an opportunity for community members to be involved and to reconnect with the land and water (and each other). A two-way knowledge mobilization strategy would support nation-to-nation relationships and facilitate cultural and ecological healing (e.g., Canada-Indigenous reconciliation: Truth and Reconciliation Commission of Canada, 2015).

Ethics are an important part of this recommendation, though acknowledged by only a few study participants. Ethics for conventional data collection (e.g., animal handling, agency proprietorship over data – recently shifting to open data policies in Canada and in Ontario, etc.) are well-established and are often internally recognized by practitioners; however, the ethics involved in collecting, recording, interpreting, and applying different forms of community and Indigenous knowledge are less universally-known. There needs to be an overriding philosophy that everything is freely shared and that everyone can use it for any purpose. Still, we recognize the importance of incorporating principles of respect when accessing and using data (e.g., access and use should recognize the source of information and respect the context from which it was produced). One participant suggested Indigenous data should be collected and used in accordance with the OCAP® principles (Ownership, Control, Access, and Possession; First Nations Information Governance Centre, n.d.); others acknowledged OCAP® in their examples of practice. We expand on research and data ethics further in the discussion.

7.5 Discussion: Implications of recommendations

Our results very closely reflect the principles and conclusions presented in Jones (2016) and the lessons learned from the Canadian Water Network's Canadian Watershed Research Consortium (CWN 2016). Here, we discuss possible implications of our recommendations for the practice of CEM. Following, we initiate a brief discussion of broader implications for governance.

7.5.1 Implications for cumulative effects monitoring

Although different definitions of cumulative effects and CEM exist, our first recommendation (establish a common understanding of the concept prior to implementing it) is likely to facilitate a more common definition – or at least make known different iterations of CEM in specific contexts – to be developed over time. The indicator selection process described in our fourth recommendation (selecting indicators co-operatively with end users) may facilitate a more standard understanding of CEM and may make expectations of such programs more consistent across Ontario. In environmental impact assessment, from which CEA emerged, the management perspectives, scope of stressors, spatial and temporal boundaries, criteria for evaluating effects, and rationale for monitoring (e.g., the 'hallmarks' of assessment) are all centred on mitigating ecologically significant effects of past, present, and future project stressors within a project's vicinity for the purpose of regulatory compliance (Jones, 2016); however, recent iterations of CEA demonstrate increasing recognition of social-cultural, economic, and institutional effects (e.g., *Impact Assessment Act*, *S.C. 2019*). Monitoring undertaken as part of impact assessment, e.g., as part of CEA, has similar objectives.

Conversely, while water quality monitoring in a watershed management context reflects most of the above hallmarks, it does not focus on a specific project; rather, it strives to answer a water quality question. Conventional freshwater quality monitoring often focuses on singular VECs within management and/or watershed boundaries for characterization and to identify potential problems as they arise. Our participants collectively suggested that CEM can build on conventional practice in some ways – e.g., that CEM would also strive to answer a question, monitor indicators to assess the state of one or more VECs, and would reflect the hallmarks of CEA/impact assessment described earlier in this paragraph – but likely requires changes to the ways in which we work together (or do not) and understand and/or use monitoring data, which we described in our recommendations and discuss further below.

Our second recommendation to engage diverse 'others' – e.g., end users (including Indigenous communities in the Grand River watershed) – addresses one part of conventional monitoring that should change should CEM be implemented. Literature suggests collaboration can result in effective management of complex problems that are beyond the management ability of a single organization, as cumulative effects often are (CWN, 2016); however, collaborators must be involved from the outset, and aspects of program design, e.g., monitoring vision, VECs, values, and partner roles, should be co-created with collaborators to explicitly reflect their values and ethics (Jones, 2016; CWN, 2016) - hence our fourth recommendation to select indicators co-operatively with end users. Freshwater management is not a purely rational/objective practice, so explicitly recognizing and addressing values (e.g., whose values are represented in what we measure and what we do once we have information) is important for future practice (Jones, 2016; Stephenson et al., 2017). Further, CWN (2016) recommended regular communication and coordination to ensure the right people remain engaged.

In addition to the end users described in our recommendations, Jones (2016) suggested that public involvement in CEA is essential. Earlier chapters in this dissertation delved more into how to engage with broader stakeholders and rightsholders as part of CEM, which reflect calls for wider and more meaningful engagement from both the literature and our study participants. Regarding who should be involved, one of our workshop participants also suggested an early-process stakeholder mapping/social network analysis exercise in which current practitioners follow a process (e.g., Prell et al., 2008; Reed, 2009; Walker, Bourne, & Shelley, 2008; Reed & Curzon, 2015) to analyze their professional networks of people and organizations to identify overlaps and gaps in monitoring activities and engagement.

Overlaps and gaps may both represent opportunities to collaborate; yet, although more and better collaboration is clearly called for by our study participants (and the larger research project, e.g., Ho et al., 2020), there are downsides in monitoring where labor is distributed (e.g., where community monitoring and/or monitoring by other organizations are included). For example, where there are many different people involved in field work, there may be issues with standardization as there is often insufficient auditing of field or lab procedures (pers. comm., Chris Jones[13]). There is usually less control over the program since there are multiple priorities and multiple 'owners' that must come together. As such,

[13] Comments provided during manuscript review, January 27, 2021: f.chris.jones@ontario.ca

adapting the monitoring program's coverage to respond to a specific environmental issue may be challenging. These concerns are raised not to imply collaboration should not be done, but rather that there are trade-offs to acknowledge and address.

Our third recommendation suggests existing integration of stressor and effect-based monitoring at higher levels of government should be replicated at the local level. In addition, although many practitioners support the idea that data use should be determined before data collection, this practice is still not common. We recommended an adaptive monitoring process to address anticipated data challenges. For example, the complexity of bringing together stressor and effect-based data requires extensive knowledge of the data context, which can be gradually generated through iterations of collaborative monitoring. The need to validate results over time (e.g., as effect are realized *in situ*) and issues with standardization also contributed to the recommendation for an adaptive CEM process. Such a process would be accepting of incomplete or evolving knowledge and approaches. Although the challenges described here can impede the development of required knowledge, an increasing amount of data being collected and made widely available in recent months and years may be sufficient to begin understanding stressor-effect phenomena (e.g., data currently being collected by practitioners – those who participated in our workshop as well as their colleagues – may be enough to better determine what influences *Cladophora* biomass at different times of the year or in its different life stages).

Our fifth and sixth recommendations highlight the potential importance of collaboration as we strive to understand river-lake influences (which was a recommended priority for our study participants). Though a collaborative watershed analysis process was proposed, our practitioners were unsure how to begin the relationship-building process that would get diverse peoples, e.g., Indigenous communities, to the table to begin with. The value of Indigenous Knowledge is currently a main discussion in the Great Lakes area (e.g., the theme of 64th annual Conference on Great Lakes Research in 2021, hosted by the International Association for Great Lakes Research, is "Bridging: Knowledges • Seven Generations • Land to Lake": IAGLR, 2021) as "science and traditional knowledge need each other to be a whole knowledge system (Lickers, 2020, p.2)."

Lickers (2020) recommended that relationship-building should be premised on the Great Law of Peace, taught in the story of Hiawatha and the Peacemaker (e.g., Robertson & Shannon, 2015) and represented in the Hiawatha Wampum (e.g., a Wampum is a beaded belt that often serves as a treaty, or record of some agreement). The Great Law of Peace, which is the "science of relationship that the Haudenosaunee have been practicing for hundreds of years (Lickers, 2020, p.3)," is based on three principles: (1) respect (which incorporates the 'tools' of understanding, communication, consensus, mediation, and honor), (2) equity (focusing on knowledge, networks, and social/political power), and (3) empowerment (e.g., sharing authorship of papers, other ways of acknowledging the contributions of

Indigenous peoples through *action*: Lickers, 2020). Lickers (2020) also proposes these principles can be used to analyze failed efforts to build relationships.

Our sixth recommendation and, to some degree, our seventh raise the question of how systems thinking applies to CEM. In this paper (e.g., the context of CEM), we define systems thinking as a three-step process: (1) the process of identifying the roles of and relationships between people, other organisms, biophysical processes, and environmental features as they relate to observed water quality effects; (2) the process of identifying what influences change in how these people, organisms, etc. function or behave (e.g., what causes a change in an indicator); and (3) determining what actions should be pursued to influence a desired outcome in the VEC (e.g., reducing the biomass of *Cladophora* in Lake Erie's eastern basin). Ecosystems are characterized by complex, non-linear interactions and multiple stressor-effect pathways, influenced by factors within and external to the system (e.g., some stressors exist within watershed boundaries, others do not) that are too complex to be fully considered in the scope of conventional monitoring or CEA (Kay et al., 1999; Jones, 2016). As such, collaboration may facilitate an understanding of the effects of multiple stressors (singly and together).

Consensus among our study participants was that current monitoring approaches are good but not sufficient for addressing cumulative effects and developing stressor-effect pathways in our study area. While the ability to discern whether effects are present (e.g., versus observing natural variability) is important, much of the data and information raised by study participants were only recently produced or are still being compiled/analyzed. For example, the most recent systems mapping exercise as of December 2020 occurred in March 2019 and aimed to describe processes that influence algae (including *Cladophora*) across Lake Erie; however, the data and information are still being compiled. The Great Lakes Nutrient Initiative is a promising program that integrates biotic and abiotic indicators in nearshore areas; however, its data are also largely still being analyzed (as of the workshop in December 2020). The Nearshore Monitoring Framework, developed under Annex 2 of the Great Lakes Water Quality Agreement, has been collecting data directly and through spin-off programs that have yet to be disseminated publicly. Despite numerous complementary and promising initiatives, published information remains sparse pending further data collection, analysis, and discussion on applications for decision-making. As such, we are still characterizing natural variability in the river-lake interface area.

As highlighted in our participant recommendations (e.g., Recommendation #7), visualizing these system features (e.g., people, stressors, effects, potential pathways) may be key to being able to effectively discuss and understand what drives the issue (e.g., *Cladophora* proliferation) and what would be effective in managing it. Past studies provide examples of such diagrams: a *Cladophora* growth model (Higgins 2005a), an adapted DPSIR model (e.g., drivers, pressures, state, impact and response) for eutrophication and organic pollution (Kristensen, 2004), and an ISO 31000-2009 risk analysis bow-tie by

Creed et al. (2016). Similarly, our recommendation to use modelling tools where appropriate has recently begun to be explored in the literature, e.g., applying the Soil and Water Assessment Tool (SWAT) to model the hydrology, sediment, and nutrients from the Grand River to Lake Erie (Liu et al., 2016; Hanief & Laursen, 2017).

Our final recommendation (share and receive knowledge in various ways) highlighted the need to handle data and research in ethical ways. We raised the OCAP® principles (First Nations Information Governance Centre, n.d.) raised by participants, but other guidelines are increasingly available to western scientists who strive to bring Indigenous knowledge into their work (e.g., Wong et al., 2020). As part of ethical practice, and related to the first and second principles of the Great Way of Peace (respect and equity), western scientists must strive to understand what Indigenous ways of knowing are, what they offer, and how western and Indigenous knowledge complement one-another (versus Indigenous knowledge being collected to enhance western science).

Implications of bringing together different knowledge forms may include a need to rethink the ways in which we organize, store, and access knowledge, e.g., knowledge transferred in oral form (e.g., as stories or memories, whether from Indigenous or Canadian communities), may not be appropriate to include in conventional monitoring databases. This, in turn, suggests managers and decision-makers should recognize that such databases are not the only source of useful, credible information. Further, since incorporating community information and data implies addressing their unique priorities, the questions asked of monitoring are unlikely to be consistent across the Province of Ontario (e.g., the scale at which legislated decision-making occurs). In this case, a process would be required to understand the common and related high-priority questions that exist within the decision-maker's scope to tweak local monitoring programs to ensure these priority questions can be answered (e.g., especially where stressors exist outside a watershed). Thus, the incorporation of diverse knowledge and practicing ethics in this pursuit may require both systemic/institutional adjustments and an evolution in the culture/thinking of conventional water quality science (e.g., monitoring), management, and decision-making.

7.5.2 Implications for governance

The Canadian Water Network (CWN, 2016) concluded that operationalizing monitoring frameworks within CEA requires links to governance regimes and other decision infrastructures, as well as targeted communication of the value of monitoring (CWN, 2016). An example from our interviews is the prioritization of efforts to conserve wetlands and assess nearshore cumulative effects on habitat described in Annex 7 of the Great Lakes Water Quality Agreement. However, study participants highlighted the challenge that the planning/regulatory connections and processes required by CEA/CEM often do not exist yet. Stephenson et al. (2017) supported this conclusion that there is a lack of process for integration of the four pillars of sustainability – ecological, economic, social (including cultural), and institutional considerations – in resource management (in their case, fisheries). They recommended revising governance to address diverse objectives and provide possible scenarios for constructing a governance system that integrates the four pillars across different temporal and spatial scales. In all cases, integration requires a systems approach with explicit consideration of strategic and operational aspects of management (among other requirements, such as interdisciplinarity and participation: Stephenson et al., 2017).

To improve buy-in from key partners and decision-makers, one interviewee described a decision matrix that was used to consider which management objectives were present, and what monitoring design would provide feedback regarding whether objectives were achieved. This matrix inspired discussion on what the long-term effects are of cumulative stressors on the whole system. Another interviewee proposed the use of *value of information analysis* – a tool for assessing whether new information would influence a decision. We explored a similar approach in this study through the criteria-based ranking process we further developed (originally from Ho, 2018). The process engaged practitioners in developing potential indicators to consider in a CEM context as well as potential criteria for selecting or short-listing those indicators; however, beyond a conclusion of which indicators may be used to address the problem of *Cladophora* proliferation, this exercise provided a basis for discussion on what practices are currently implemented, by whom, and whether the indicators or criteria are appropriate to guide effective management. Finally, when developing management responses to monitoring, we suggest that this (like other aspects of CEM) should be determined collaboratively. The principles of the Great Law of Peace would apply – especially the third principle of empowerment, which involves power-sharing and validating the contributions of Indigenous communities through action.

7.6 Conclusion

Study participants represented diverse perspectives from multiple levels of government, academia, industry, communities, and independent science. Collectively, they provided a recent (e.g., February 2019 to December 2020) snapshot of efforts to monitor cumulative effects related to multiple stressors and *Cladophora* growth in the eastern basin of Lake Erie. As our results very closely replicate or complement the findings of Jones (2016) and CWN (2016) – multi-year Canada-wide studies that considered extensive research and practice – we suggest these replicated demonstrate that broad principles and recommendations for CEM can be discerned.

This study furthered discussion on cumulative effects by building on recent work to catalyze conversations on the design and implementation of CEM in the study area. Eight practitioner-derived recommendations provide a broad guide for developing a CEM framework. Within these recommendations, we explicitly and intentionally positioned systems thinking and collaborative approaches as part of CEM design and implementation. Such approaches (e.g., the collaborative watershed analysis approach proposed in Recommendation #6) help us understand the complexities of ecosystems or problems being managed; however, they can also provide a foundation for building collaborative relationships, facilitating meaningful discussion, and developing targeted communications. Systems methodologies should inform modelling and should make identifying redundancies or gaps in monitoring easier, contributing to more efficient programming and effective adaptive processes (for CEM program design).

Participants also outlined potential criteria for selecting monitoring indicators for CEM, from which the CBR process may be tailored to other areas. We noted that *Cladophora* was not scored first among potential indicators for a *Cladophora*-focused monitoring program due to uncertainties captured by scoring criteria (explained under Recommendation #4). As such, the CBR ranking process should be viewed as a tool to facilitate discussion for indicator selection and is not meant to determine indicators based exclusively on scoring outcomes.

We also highlighted the need to ensure a common understanding of the principles and purpose of CEM prior to implementation and demonstrated the importance of diversity and collaboration between monitoring personnel and end users – which, in our study area, include Indigenous communities. As such, although this study was undertaken in the context of *Cladophora* in Lake Erie's eastern basin as influenced by the Grand River watershed, our results and discussion represent broader experiences that may be useful if developing monitoring for CEM elsewhere.

Finally, we recognize synergies between the objectives of monitoring and sustainability (e.g., social-cultural, economic, and institutional). Integrating these objectives is implicit in the vision of effective watershed management. Building on this connection (i.e., between monitoring and management via sustainability objectives) may be the key for evolving practice from conventional monitoring to CEM while developing collaborations and knowledge that also serve the sustainability goals of broader society.

Chapter 8

Ideals, values, and practice: Collaboration to enable cumulative effects monitoring in the lower Grand River and nearshore Lake Erie

Citation: Ho, E., Courtenay, S. C., Ford, G., and Trant, A. J. *In preparation*. Ideals, values, and practice: A framework for collaboration to design and implement cumulative effects monitoring in the lower Grand River and nearshore Lake Erie. Not yet submitted.

8.1 Introduction

Water resource management and long-term decision-making are increasingly complex. As such, approaches to address today's challenges require a comprehensive, integrative approach that considers the relationships between various aspects of society (Kay & Schneider, 1994; Kemp, Parto, and Gibson, 2005; Stephenson et al., 2018). In the late 1970s, the term 'cumulative effects' was first mentioned in the guidelines of the Council on Environmental Quality (1978) for the practice of environmental impact assessment. Cumulative effects were defined as individually minor, but collectively significant impacts on the environment resulting from incremental impacts of an action when added to other past, present, and reasonably foreseeable future actions, regardless of who undertakes those other actions (Council on Environmental Quality, 1978). Chapter 7 considered what implementation of cumulative effects monitoring might involve in the study area to gain a better understanding of *Cladophora* growth and how to manage it. This chapter translates recommendations from all previous chapters into a collaboration framework that may enable a community-led, cumulative effects monitoring program to be developed and implemented in the lower Grand River and nearshore Lake Erie.

Despite existing theory on complex problem-solving, real-world applications of integrative, comprehensive approaches are not well documented. Checkland (1981) highlighted a need to recognize the importance and roles of knowledge and perception if we are to address problems that involve the social world. The Sustainable Impact Assessment framework presented by the Canadian Institute for Environmental Law and Policy (Elwell, 2002) incorporate facets of culture and ethics as well. Kay and Schneider (1994) pointed out that the standard scientific method works well in simple, predictable, and controlled situations; however, they suggested that "…ecosystems are inherently complex, that there may be no simple answers, and that our traditional managerial approaches, which presume a world of simple rules, are wrongheaded and likely to be dangerous (Kay & Schneider, 1994, p.49)." Despite decades of theory and practice, Jones (2016) highlighted that environmental impact assessment and its sub-discipline, cumulative effects assessment, have historically lacked consistent, conceptually linked components. Concurrently, seven case studies from across Canada tested regional cumulative effects assessment frameworks from 2010-2015 under the Canadian Watershed Research Consortium (convened by the Canadian Water Network; CWN, 2016).

One of these case studies by Servos et al. (2015) produced a biomonitoring framework for assessing cumulative effects. In this case study, which focused on the upper and middle sections of the Grand River, agricultural non-point sources and urban sources of nutrients (namely wastewater treatment plants) were found to have dramatic influences on the river throughout the watershed. A clear shift in macroinvertebrate taxa was observed in the urban areas of the watershed, from Ephemeroptera, Plecoptera, and Tricoptera to primarily Diptera (which are more pollution-tolerant); however, Servos (2016) recommended also measuring functional measures to detect specific pollution effects more clearly. Fish assemblage and population endpoints were concluded to be not sensitive enough to use in a cumulative effects program in the Grand River; however, fish responses were found to be effective. Among other responses, rainbow darters (*Etheostoma caeruleum*) sampled in the Grand River showed a high occurrence of intersex in urban areas, especially in areas downstream of wastewater treatment. Fish lab bioassay studies followed this study to further understand the mechanisms of fish responses (Servos, 2016). Overall, the study concluded there can be no single indicator for assessing cumulative effects in the Grand River watershed.

More recently, Stephenson et al. (2017; 2018) identified several imperfections to the way in which complex problems are addressed in marine fisheries – e.g., fragmented and uncoordinated management practice, little integration of social-economic factors, insufficient consideration of cumulative effects, lack of transparency and participation in management, and a lack of process for routine integration of sustainability concepts – which were addressed through development of a framework for sustainable fisheries. The framework is cognizant of systemic integrations for operationalizing four pillars of sustainability in Canadian fisheries: ecological, economic, social (including cultural), and institutional (or governance; Stephenson et al., 2018). These pillars are implicit in Kay's and Schneider's (1994) emphasis on managing our interactions with ecosystems, rather than the ecosystems themselves.

Since efforts to address complex social-ecological challenges have largely not achieved full success in their implementation, many of these challenges persist. The Laurentian Great Lakes have experienced decades-long challenges with water quality, including eutrophication – excessive loading of nutrients resulting in algal blooms and hypoxia. A recognized cumulative effect, eutrophication has been attributed to many factors, including nutrient cycling, land use changes (e.g., urbanization), increases in agricultural activity, climate change, and population increases (Vollenweider, 1968; Vitousek et al., 2009; Liu et al., 2012; Jeppesen et al., 2005). Historically, the Grand River was the greatest Canadian contributor of nutrients to the eastern basin of Lake Erie, and it remains one of Canada's priority watersheds for tackling phosphorus loading reductions to the eastern basin (ECCC, 2018). Although current management efforts attempt to address multiple challenges through collaborative measures – e.g., a binational (Canada-US) agreement to reduce phosphorus loading to Lake Erie by 40% – implementation is still fragmented, with the various working groups tackling their allocated issues relatively independently from one another.

The Grand River watershed has a unique history and mix of Indigenous and Canadian communities. The Grand River is Southern Ontario's largest watershed, at approximately 6,800km^2 (roughly the size of Prince Edward Island). The watershed is also Ontario's most populated, home to roughly 1 million residents who reside in 39 municipalities and two First Nations territories. This population is expected to increase to about 1.4 million people by 2041 (Region of Waterloo, 2020). First Nations communities are the Six Nations of the Grand River First Nation – Canada's largest Indigenous community by population, and the only place in North America where all six Iroquois nations reside – and the Mississaugas of the Credit First Nation. In 1784, six miles (~10km) on either side of the Grand River from its headwaters to Lake Erie (the 'Haldimand Tract') were designated as permanent Six Nations territory in the Haldimand Proclamation.

Although the initial land grant was held 'in trust' by the Crown for the sole use and benefit of the Six Nations, in many cases this responsibility was not upheld (Six Nations of the Grand River, 2015). In 1794 – only a decade after the Treaty was proclaimed – Lieutenant-Governor John Graves Simcoe reaffirmed the land grant after removing more than a quarter of it (about 275,000 acres) to allow for settlers to move into the territory. The first non-Six Nations settlers moved into the territory as early as 1798 (Six Nations Council, 2008). Over the next 30 years, nearly 90% of the original land grant had been expropriated, often without the knowledge, consent, or benefit to the Six Nations peoples (Six Nations of the Grand River, 2015). Today, less than 5% of the original 950,000 acres remain designated for the community's use. The 48,000 acres that remain exist in the form of Federally owned and controlled Indian Reserve lands (i.e., the Six Nations reserve is Reserve No. 40, and the section that was later separated for the Mississaugas is Reserve No. 40A).

This unique context inevitably results in diverse interests and priorities across the watershed. As demonstrated by at least 40 years of literature – e.g., Checkland (1981), Kay and Schneider (1994), Kemp, Parto, and Gibson (2005), Jones (2016), Stephenson et al. (2017; 2018) – conventional science (e.g., freshwater quality monitoring) and management have failed to utilize broad perspectives and address diverse priorities. In other words, conventional science alone is incomplete and, in many cases, not as comprehensive as needed for management responses. The first-ever national assessment of freshwater ecosystems across Canada showed there is a lack of sufficient data in most sub-watersheds (the smaller, secondary river systems that feed into the main unit of watersheds) to determine where threats like climate change and habitat loss are having the greatest impact on watershed health (WWF-Canada, 2020). The report also suggested that an increase in community-based water quality monitoring programs – e.g., through organizations like Water Rangers, Swim Drink Fish, Living Lakes Canada, etc. – and the emergence of large open data platforms (e.g., the new Great Lakes DataStream, provincial and national benthic biomonitoring databases, and others) are filling gaps in monitoring at the local level. Current practitioners and subject matter experts also suggested that community-led monitoring groups may contribute to closing a knowledge and capacity gap in the study area (per Chapter 4). Thus, coordinated approaches that recognize local knowledge contributions in a standardized national monitoring system were recommended to support evidence-based decisions (WWF-Canada, 2020).

Water quality data can be supplemented or augmented using different forms of local knowledge, including Indigenous, traditional, intergenerational, and local knowledge. These knowledge forms can (and arguably should) complement one another in a Two-Eyed Seeing approach (Reid et al., 2021) – mandated in the results of Chapter 6 – to enable a more complete understanding not only of certain aspects of the watershed, but of the relationships between those aspects and the broader social-ecological contexts surrounding them. Further, Lickers (2020) suggests "science and traditional knowledge need each other to be a whole knowledge system (p.2)."

The above context demonstrates that solving complex social-ecological challenges requires systems concepts (including cumulative effects), integration of different approaches to knowledge, and a sustainability lens (integrating four 'pillars': social-cultural, ecological, economic, and institutional considerations). In many cases, there is an increasing urgency to address such challenges: ecological pressures are globally recognized as among the most pressing political and economic risks we will face in the next decade, and water crises have been identified as a 'top five' risk for the last ten years (World Economic Forum, 2020). Research can be designed to provide timely, relevant information to leaders and decision makers who are currently reshaping, even completely transforming, approaches to science and regional resource management (Schuster-Wallace, Sandford, & Merril, 2019).

This study builds on past work from Kay and Schneider (1994), Jones (2016), Stephenson et al. (2017; 2018), the Canadian Watershed Research Consortium (CWN, 2016), and others to propose an organizational structure and process framework (collectively referred to hereon as 'the framework') for cumulative effects monitoring in the lower Grand River and nearshore Lake Erie. The proposed framework focuses on improving freshwater quality water monitoring and attempts to merge with current practice to catalyze potential transformations in the future. Literature, current or recent water monitoring and management practitioners, and other research participants (including local Indigenous youth) collectively provided insights. Although this study focuses on the Grand River interface and nearshore

Lake Erie (see study area description in Sub-section 1.4.1), the insights gleaned from the literature and from practitioners were often not specific to the study area. As such, many aspects of this study, including components of the proposed framework, are expected to be applicable in broader contexts.

8.2 Method

This study took place over five years from January 2016-August 2020. We implemented a variety of methods, including ongoing consultations with practitioners from the earliest stages of research design, participant observation, key informant interviews, two different formats of arts-based community engagement, and two online practitioner workshops (held virtually to comply with local COVID-19 restrictions). These methods are briefly outlined in Table 9 and are described further in previous chapters.

Table 9. Summary of methods (more detail in previous chapters).

Method	Months	Brief description
Exploratory study with Muskoka Watershed Council	January-August 2016	We conducted a review of monitoring and reporting in the Muskoka River Watershed. The review of practices was published in Ho, Eger, and Courtenay (2018) and a new method for indicator selection was published in Ho (2018). Refer to Chapter 5.
Monitoring program review	May 2018-December 2019	We reviewed documents and websites of nine monitoring programs and frameworks recommended as exemplary by practitioners. Programs were scored per criteria that were selected from literature and consultations with practitioners. Common strengths and weaknesses were identified, along with five recommendations. Refer to Chapter 3.
Key informant interviews	February-May 2019	We conducted 21 semi-structured interviews with Canadian practitioners and subject matter experts. A summary report (Ho, Dhaliwal, & Wright, 2021) describes 106 issues and 51 recommendations. Refer to Chapter 4.
Community engagement with Great Art for Great Lakes (hosted by Waterlution)	June-October 2019	Waterlution, a national non-profit organization, commissioned six artists to engage over 1,000 members of the public artistic workshops focused on building awareness of Lake Erie issues. We spoke at workshops about the Grand River and Lake Erie and collected 133 anonymous questionnaires about the public's watershed priorities. Refer to Chapter 6.
Community engagement with Music for the Spirit & Indigenous Visual Arts	August 2019-March 2020	Indigenous youth in an after-school program at Six Nations of the Grand River were engaged to create water-themed artwork and write accompanying stories that would be part of a traveling art exhibit. These creations comprised the Grand Expressions art exhibit (Ho & Miller, 2020), which was on public display from August 2020 to January 2021 (in addition to other forms of dissemination, e.g., industry journals). Refer to Chapter 6.
Practitioner workshop: framework proposal and revision	October 5, 2020	We led a sense-making exercise through which past research participants could verify or revise their contributions to the work and all participants could contribute to reorganizing the proposed framework in a more feasible and meaningful way. This workshop was a major contributor to shaping the current version of the proposed framework. Refer to Chapter 8.

Practitioner workshop: cumulative effects monitoring	December 7, 2020	We invited practitioners and subject matter experts to consider how cumulative effects monitoring might be implemented in the study area. Refer to Chapter 7.

Conclusions from each of the above methods were published in peer-reviewed journal articles (e.g., Chapters 3 and 5) and summary reports (cited in Appendix A). These conclusions contributed to the development of the framework presented in this paper. To develop this framework, the main results of each method were summarized. Then, duplicative concepts (e.g., overlaps in perspectives and recommendations) were removed. After, the remaining ideas were organized into two main themes: (1) people (e.g., who should be involved and in what roles), and (2) process (e.g., relationship building, monitoring design and implementation). A third theme – products (e.g., data, descriptions of approaches used) – was originally separated but later amalgamated into the 'process' theme as part of knowledge dissemination. The proposed framework and the two themes of content are described below.

8.3 A proposed organizational structure and process framework

Here, we propose an organizational structure and process framework (collectively referred to as 'the framework') for collaboration during monitoring program design and implementation. The proposed framework strives to facilitate improved working relationships between more diverse personnel, while also providing a blueprint for the ways in which these personnel may collaborate. In other words, this framework strives to demonstrate how diverse people and groups can work better together (across sectors and disciplines, integration across government) in a cumulative effects monitoring program. It does not assess specific monitoring protocols, nor does it attempt to determine how science should be implemented (e.g., specific methods) as current practitioners are well-versed in these areas. Our discussions with practitioners were contextualized by a recurring issue in Lake Erie's eastern basin – prolific *Cladophora* growth (a benthic nuisance algae) – for which the Grand River is a major source of nutrients; however, the framework does not specifically address *Cladophora*. Instead, the framework provides organizational and methodological structure for collaboration in the design and implementation of a cumulative effects monitoring program, regardless of the issue(s) it strives to address.

Collaboration underlies the 'people' theme, in which community champions (e.g., passionate, dedicated community members who are typically engaged in some aspect of watershed science, management, and/or advocacy) initiate the process and bring others together to design and implement the framework (e.g., the *who* of monitoring). Sufficient capacity and coordination are required in the 'process' theme, which focuses the monitoring design, implementation, and review (e.g., *what* to measure, *how*, *where*, and *when*). Quality, open data and information are also important to process, including how data/information are organized, stored, made available, interpreted, and shared. Further, this proposed framework looks beyond *what* results emerge from monitoring to ask *why* they are important and *how* to (collectively) understand and apply them.

8.3.1 People

Participants in this research strongly recommended that the framework focus on communities (e.g., priorities, activities, and relationships), as government mandates to pursue anything beyond existing initiatives are limited. In addition, leadership by government agencies may hinder progress due to approvals processes. Further, participants suggested establishing community-level relationships would incentivize larger organizations and government agencies to collaborate. Therefore, a main conclusion of our discussions with practitioners is that any additional water quality monitoring programs in the study area should be community-led.

A consistent group of community champions is proposed to drive the whole process/program. Study participants agreed that community relationships would be most effective if initiated by the communities involved, especially in the case of Indigenous communities. Approaches for engaging with each community would be determined and led by its champions. Community champions may emerge from existing collaborations – e.g., the Grand River Fisheries Management Plan Implementation Committee or the Southern Ontario Stream Monitoring and Research Team – or may assemble from a new interest to collaborate (e.g., from a session at the annual conference convened by the International Association of Great Lakes Research, or from some event held to celebrate community-based monitoring and/or Indigenous-western knowledge approaches). Or they may emerge from grassroots organizations like cottagers associations, angler clubs, issue-based social groups (e.g., dam removal advocacy group), or communities. Alternatively, a community-based monitoring program may be initiated/invited by a government agency (e.g., Sub-section 8.4.1). The common element is an identified problem or concern that requires some form of knowledge and/or action to address.

The core team consists of community champions (described above), the steering team, and the coordination team. In addition to driving the process, champions act as overseers or project managers to ensure required capacity is provided, collaborations are effective, and to verify priority areas or objectives are being achieved. There is likely to be overlap between individuals who are a community champion and those who sit on the other core groups. The steering team guides the process and is a diverse group representative of monitoring collaborators, interests, and 'end users' of the monitoring information (e.g., managers, decision-makers, Indigenous stewards). This team includes at least one ethics overseer, likely an Indigenous person, to ensure interactions and practices are respectful and ethical. Ethics are based on cultural or standard practice, as well as a list of principles and/or values developed during conceptualization with all collaborators. For example, reciprocity (Kirkness & Barhardt, 2001) should be within the scope of partner commitments even if not directly related to the monitoring program. Also, collaborative data production should not be undertaken to serve the needs of western science (e.g., to support investigations), and the OCAP® principles (Ownership, Control, Access, and Possession: FNIGC, 2021) should be followed. The coordination team ensures there are minimal gaps, duplications, and miscommunications in collaborative activities. Ideally, this team includes specialized members of collaborating groups, or dedicated staff (depending on the size of the collaboration), who can interpret and organize public-derived data.

In addition to the core team, personnel may take on a capacity building role or a knowledge-producing role. Program capacity involves funds, training, equipment, and expertise; however, most are managed internally by collaborating parties. The resourcing committee is the only designated group related to program capacity, which is primarily responsible for identifying and pursuing sources of funding (or other capacity, e.g., in-kind contributions from municipalities or the conservation authorities) to ensure the program can continue. Knowledge producers are primarily comprised of individuals and organizations involved in monitoring and/or the collection of data and information. If needed, a data team may be assembled from monitoring partners and the coordination team (e.g., specialists) to ensure the timely organization, analysis, and interpretation of data/information. Regardless of whether a data team is assembled, a single manager (person or organization) is identified to curate the data/information – including maintaining an openly accessible database. Knowledge brokers facilitate the sharing of knowledge between collaborators (e.g., at interim reviews) and help ensure information gets to the people it needs to reach. Consultants may be involved for certain things outside the collective abilities of collaborators, e.g., to guide a stakeholder analysis exercise, GIS and mapping, statistics, and modelling, or facilitating the collation of datasets. Figure 11 illustrates a possible organizational chart for the proposed framework.

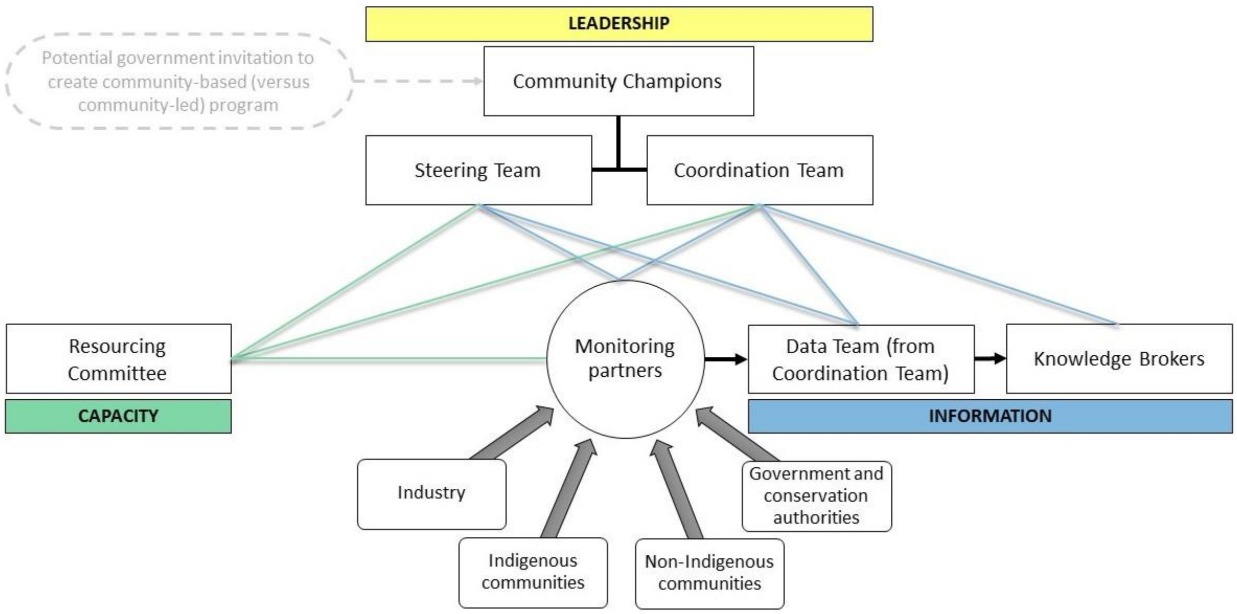


Figure 11. Organization of main/consistent parties in the monitoring collaboration, divided into three categories that broadly define their role. Other roles (e.g., contracted consultants) may exist outside of this structure.

8.3.2 Process

A 10-step design and implementation process emerged from the perspectives, recommendations, and criticisms shared by our research participants. The process is catalyzed by a group of community champions who would convene to address related concerns or a common broad purpose, e.g., residents and cottagers may be concerned about nuisance benthic algae along their Lake Erie shorelines near the mouth of the Grand River, anglers may be concerned about the effects of runoff on fish populations, and the local Indigenous community may be concerned about drinking water and fish consumption. As these peoples assess synergies and begin to form a collaborative, others with related interests may be engaged in some capacity, e.g., for simple informing purposes, data sharing, or monitoring implementation. In the context described here, these 'others' may include scientists and government agencies that seek to understand cumulative stressor-effect pathways originating from the Grand River watershed that influence prolific *Cladophora* growth in Lake Erie's eastern basin.

Our study participants recommended completing a stakeholder analysis exercise as part of these early stages to identify potential collaborators. Examples of questions to ask as part of this exercise include: Who makes decisions that affect the issue, or a mandate to do so (e.g., authority)? Who has control over stressors (e.g., sources of nutrients)? Who is impacted (positively or negatively) by effects? Who has knowledge of the ecosystem, issue, and/or stressor-effect pathways? Once potential collaborators are identified, the 10 steps of monitoring design and implementation can be followed, described below.

1. Develop a common worldview[14].

This first step of the process focuses on *why* the parties wish to collaborate. Participants recommended beginning with basic meetings to familiarize each of the collaborators with one another, e.g., 'this is what we do and how we do it,' followed by identifying shared goals and determining a common understanding of the issues to be addressed. A common understanding includes what the issue is, how we know it is an issue (e.g., based on what evidence or observation), and – to whatever degree is possible with current knowledge – what we know about potential stressors that could be influencing the problem (e.g., develop a hypothesis). As part of this early relationship building and worldview development, collaborators should develop a plan with "if-then" scenarios for keeping discussions or the monitoring process moving if there is disagreement (e.g., recognizing that differences in worldviews will be part of the process). This exercise may make use of risk assessment approaches for mitigating anticipated issues in relationships or implementation. The focus of resolutions may be on long-term outcomes that are desired and shared by all collaborators, regardless of whether short-term outcomes are not, recognizing that all parties may be vested in different ways and their paths to mutual success may be different.

2. (a) Visioning and conceptualization; (b) develop an inventory of relevant information and list of questions.

The visioning and conceptualization stage is where the collaborators determine *what* they wish to accomplish (e.g., what monitoring will achieve). Now that everyone has a common understanding of the issues and who is at the table, monitoring priorities can be established by converting end user needs into questions to address. In addition to end user priorities, community priorities should also be considered. Although end user and community priorities are often similar at their foundation, collaborative approaches are important since the two groups tend to articulate their priorities in different ways. For example, the following are responses we received from community questionnaires compared to practitioner interviews and workshops:

- *Community*: we care about recreation, community/culture, wildlife/ecosystems; urgent issues to address include pollution/contamination (incl. agricultural runoff), and algae.
- *Practitioners*: there is a gap in knowledge about river-lake dynamics; we need adaptive, innovative processes for assessing and understanding both stressor and effect-based indicators (collectively).

[14] Defined in Poonwassie and Charter (2001)

By collaboratively determining monitoring questions, collaborators will confirm a common definition of key concepts, e.g., cumulative effects, cumulative effects monitoring, what success looks like (e.g., what is 'good' water quality), etc. The first time this process occurs, all members are involved; however, once roles have been determined, the steering team leads this process (e.g., adjusting questions as monitoring provides information) in future iterations. Also, participants stated that clear objectives must be set regarding what data are collected and why they are being collected early on to reduce situations in which data are collected but not used. Social infrastructure is also put in place during this first step, e.g., a Terms of Reference for clear communication during engagement, a Memorandum of Understanding for data management and intellectual property, and a co-created list of guiding principles (some that all agree upon, some that have mixed reviews but which everyone can collaborate towards in some way). Funding opportunities will be discussed here as well but pursued more formally as part of planning (the next step).

As soon as the monitoring questions have been determined, an inventory of relevant information is compiled (or, in future iterations, is updated) by some members of the collaboration (in future iterations, led by the coordination team and knowledge brokers). This step is likely to be challenging and time consuming but allows collaborators to 'check the pulse' of uncoordinated regional efforts that may collectively support effective action. In addition to the inventory of relevant information, this pulse check includes compiling a list of all the questions being asked of water quality monitoring across the region (however collaborators define this – in our context, likely watershed-wide with involvement from Federal agencies who are responsible for Lake Erie). Even if not relevant to the program being designed, knowledge of other questions provides context for any future collaboration and allows monitoring partners to situate their efforts among broader water quality objectives (e.g., there may be complementary efforts worth coordinating).

3. Plan the program and organize collaborators.

The planning stage is where the collaborators determine *how* they are going to do what they outlined during visioning. Our study participants provided several recommendations for this step, including implementing adaptive monitoring and management, applying the Tamarack Institute's (2021) collective impact model, and to clearly outline how data will be used to answer what questions before data collection occurs (e.g., how data will be analyzed or interpreted – which may affect methods of data collection). Planning should incorporate multigenerational thinking to recognize how past activities contributed to today's state of water quality and to consider potential capacities and needs of future generations (e.g., data needs, analysis abilities). Our collective data and knowledge contribute to explaining the history, current state, and desired future state of the watershed/area being monitored. Collating this knowledge early in the process supports later efforts to determine stressor-effect pathways.

As one of our goals is to connect monitoring to management and decision-making, planning should consider how to make information useful for these purposes. Approaches, tools, or methods for communicating data and information (e.g., modelling, mapping, grading or scoring certain characteristics or areas) should be determined along with data analyses to ensure the appropriate data will be collected to make these tools meaningful. Decision-making tools/exercises like decision matrices (e.g., the criteria-based ranking approach outlined in Ho, 2018 – Chapter 5) and value of information analyses may help inform decisions but can also be used in monitoring program design (e.g., planning) and evaluation. Study participants suggested these tools have been effective for grounding potentially contentious discussions and ensuring everyone is aligned regarding potential stressors to investigate and what the monitoring program will tell us. A criteria-based ranking process (Ho, 2018) may be applied to determine the indicators to be measured. For example, in cumulative effects monitoring, a criterion may be that indicators should satisfy multiple priorities or questions. Study participants also highlighted the importance of recognizing that different indicators may be used to measure different metrics that demonstrate different pathways to achieving the effects observed. Or, in some cases, an effect may look different for different VECs (e.g., edible fish and healthy fish populations are related, but the effects are different).

Finally, planning requires the determination of roles for each of the various parties involved. People or organizations may have multiple roles (e.g., may carry out data collection and sit on the coordination team) and these roles may change as iterations of monitoring design progress. Each partner/collaborator is involved in determining his/her/its own role based on collective needs identified by community champions and the steering team as well as qualifying criteria, e.g., whether the partner has the capacity to carry out the role; whether he/she/it is flexible or adaptable enough to make changes midway through a process should the circumstances require a change. Although all partners are expected to discuss potential contributions or funding opportunities during conceptualization, those who join the resourcing committee will be responsible for acquiring funds as part of planning. Contribution agreements (e.g., either formal or informal agreements regarding cash or in-kind contributions; research agreements with Universities) should be put in place during planning; however, the role of fund acquisition is ongoing throughout the monitoring process.

4. Implement pilot programs as training opportunities for monitoring personnel.

This step is implemented for two reasons: first, to ensure a common capacity to carry out the program across all partners, and second, to demonstrate that the expected data will be produced through the program as planned. Our study participants and the literature suggested training where parties have different approaches or skill levels to ensure standardization across practitioners (especially for community participants who may not have any background knowledge or skill in monitoring practice). Further, study participants called for some mechanism to assess whether data are telling us what we want to know before implementing a full, multiyear program. We propose implementing short pilot programs (e.g., less than one year, possibly a single season in duration, potentially comprised of smaller pilot projects if needed) that are limited in scope (e.g., perhaps focused on characterization so the data may contribute to later assessments of natural variability; or, a project may focus on developing an innovative engagement approach alongside a conventional monitoring program). Pilot programs/projects provide opportunities to achieve both goals of training and confirmation. Pilots may also support familiarization with study sites (e.g., identifying potential hazards or impediments to monitoring continuity – which may include other people) and identification of reference conditions [e.g., if a reference condition approach is used (Bailey, Norris, & Reynoldson, 2004; Ball et al., 2012) – recommended in our context to align with current practice]. Finally, where additional community relationships need building, or engagement processes refined (e.g., methods for collecting traditional Indigenous knowledge), a pilot project provides an opportunity to develop these requirements before monitoring is implemented.

5. **Implement monitoring and data collection (including community and Indigenous data/knowledge).**

Planning is executed in this step, which focuses on the collection of monitoring data and information. Community champions lead data collection; however, the coordination team oversees all parties, including champions, and ensures the collective vision is executed effectively and efficiently (e.g., in this step, the coordination team not only addresses redundancies and gaps as they arise, but they act as a form of quality control for monitoring practice). Study participants suggested a conversational approach to data collection is likely the best start in any community setting, especially in Indigenous contexts, to co-create a data collection approach with the community (e.g., participatory processes are strongly recommended). Ideally, this step will have been completed as part of the pilot projects implemented in the previous year. Where data from Indigenous and non-Indigenous sources appear disconnected from one another (e.g., if it is not clear what the narrative is), the context in which the information was acquired should be considered and, where possible, experienced firsthand to improve understanding of lived knowledge. This highlights the importance of community champions who are already culturally integrated and who can interpret (e.g., who have lived experience with) the meaning of the data or information collected. All community champions should be celebrated as the drivers of the collaborative, exemplifying their successes in relationship building alongside their data contributions. Also, regardless of the source of data/information, methods of acquisition should be well-documented.

6. Interpret and disseminate information.

Interpretation and dissemination of information should be done collaboratively and in ways that are relevant to the end user, defined as managers, decision-makers, government agencies (e.g., policymakers at any level of relevant government) and Indigenous communities (who are recognized to have a governance role in their territories). Study participants suggested that approaches for collaborative interpretation and dissemination should involve the creation of useful visuals (e.g., descriptive but comprehensible) that illustrate stressor-effect pathways and position the data/information within them. The collaborative watershed analysis process proposed in Chapter 7 is one example of a potential exercise to implement, but there are other approaches across literature and practice to explore (e.g., our participants highlighted community mapping and the collaborative creation of hypothesis-of-effects diagrams: Robinson, Duinker, & Beazley, 2010).

Our study participants also recommended independent dissemination – e.g., by community champions to their own communities – that represents the collective integration of knowledge but is presented in a format that is appropriate for specific end users. There may be specific institutional or social requirements to consider, e.g., public consultations required by government agencies prior to decision-making (which requires certain types of dissemination). In our study area, there is a Notification Agreement in place between the local First Nations, the Grand River Conservation Authority, the Region of Waterloo, and others that is renewed every 5 years, which ensures everyone is kept informed on management and decisions in the Haldimand Tract. Mechanisms such as this may address the common issue of little capacity to 'do anything' with the data collected. In addition, shared dissemination, and the proposed organizational structure (i.e., a dedicated data team) may also address this issue.

Study participants recommended the framework strive to produce at least one long-term outcome desired by all partners in addition to other outcomes in the interest of a subset of partners. These other goals should relate to two or three core indicators and, therefore, be agreed upon by partners regardless of whether they have a personal interest in the other outcomes. 'Outcomes' may include decisions, partnerships, openly accessible databases, and/or benefits achieved through the monitoring process (e.g., capacity building, recognition, etc.). Information should be presented in ways that align with end users' normal ways of accessing information to satisfy their information needs. These may include publications, grey literature (e.g., quarterly, biannual, or annual reports), conference or meeting proceedings, financial reporting, communication material generated by the coordination team, community outreach (e.g., newsletters, social media), presentations (e.g., to community, stakeholders, and partners), and/or news releases related to the project).

7. Response to monitoring – management, decisions, community-led solutions.

Although reactions to monitoring are not within the scope of a monitoring program – e.g., we do not control the actions of managers, decision-makers, or policymakers – we recognize this action as part of the process as it influences prior and further steps taken by monitoring. This highlights the interdependence of monitoring and management/decision-making, as discussed by our study participants. Prior steps regarding data collection, interpretation, and dissemination are guided largely by the needs of end users for the purpose of informing management and decisions. Also, further steps in adaptive monitoring are influenced by management/decision-maker reactions and feedback to ensure continued relevance to their needs as more data/information is produced.

8. Monitoring review (interim or full cycle).

Monitoring reviews are data-driven evaluations and revisions based on *both* Indigenous and western standards and information. Indigenous and western ways of thinking and doing are viewed as unique and equally valued/important within our framework. Interim reviews, or ‘status checks’, occur at the end of each cycle of data collection, interpretation, and dissemination (e.g., every other year) and involve all parties engaged in collaboration. Interim data are discussed, adaptations to the program are made as needed, and any challenges or disagreements on the purpose, process, or practices of the collaboration are dealt with. These interim reviews are also an opportunity to invite others to provide a sense of work being done outside the collaboration that may be of interest.

Full cycle reviews occur at least every 5 years – or 4 years to coincide with every other interim review – and involve leadership of the collaboration (e.g., champions, steering committee, coordination committee), the resourcing committee, and others as needed (e.g., perhaps knowledge brokers or some monitoring partners). Collaborators are assessed (e.g., to identify those who are no longer relevant, any new persons or groups who should be invited to join the collaboration), the efficacy of existing relationships and collaborator satisfaction/vestment are discussed, and collaborators are engaged either during or after the review to ensure everyone still has the same understanding of what is being achieved through this collaboration. The metadabase and list of relevant questions being addressed across the region are reviewed and updated as needed, and the questions asked of monitoring are checked against current priorities and needs (e.g., of community members, managers, and decision-makers). Everyone’s roles are reviewed and adjusted as needed, and any training that is requested – either of new partners or existing collaborators who wish to refresh skills or knowledge – is provided. Then, a new interim cycle of monitoring begins.

9. Determine whether objectives have been achieved.

Achievement of goals should be assessed as part of iterative monitoring reviews to revise the program as needed. The full cycle review looks at those goals that were determined to have been achieved to ensure collaborators are satisfied all objectives within those goals – e.g., ecological, social, economic, and institutional (e.g., policy) objectives. For example, while the indicators demonstrate a VEC has been brought to the desired state (e.g., fish are now safe to eat and populations are stable enough to support a broader fishery), there may be relational objectives that have fallen short of some partners' expectations. Some of these objectives, e.g., if a desired certain species has not recovered despite others doing well, may be within the purview of the collaborative to address; however, others, e.g., traditional rights to fish outside regulated seasons or limits are not recognized, may not be within the scope of the collaborative. These objectives should be validated and reported upon in a way that informs the relevant parties these perspectives are present. The question of scope (e.g., what is within/outside the expected narrative of this monitoring program) highlights the importance of ensuring the early visioning and conceptualization stage is fully implemented.

10. Assess the need for continued collaboration in the current form.

The final step in the process, led by the original group of community champions that first convened to develop the monitoring program, is to determine whether any other knowledge needs to be produced to serve the original purpose of the program. If so, a monitoring review occurs and the adaptive process continues; if not, the existing collaborative is ended/closed, though the relationships and approaches developed are likely to be maintained (e.g., in collaborations led by other champions for a different purpose). As part of the closing process, champions will determine if ongoing monitoring is required to identify whether the collaborative needs reassembling (e.g., if the issue recurs). If ongoing monitoring or regular surveys are required, the partners will collaboratively determine where this may best fit/who will be responsible for this activity.

These 10 steps are illustrated in Figure 12. Once community champions determine the collaboration is no longer needed in its existing form, the monitoring cycle is either completed (e.g., Steps 5 through 8) or ended (if ended, all data must be interpreted and shared prior to ending the collaboration).

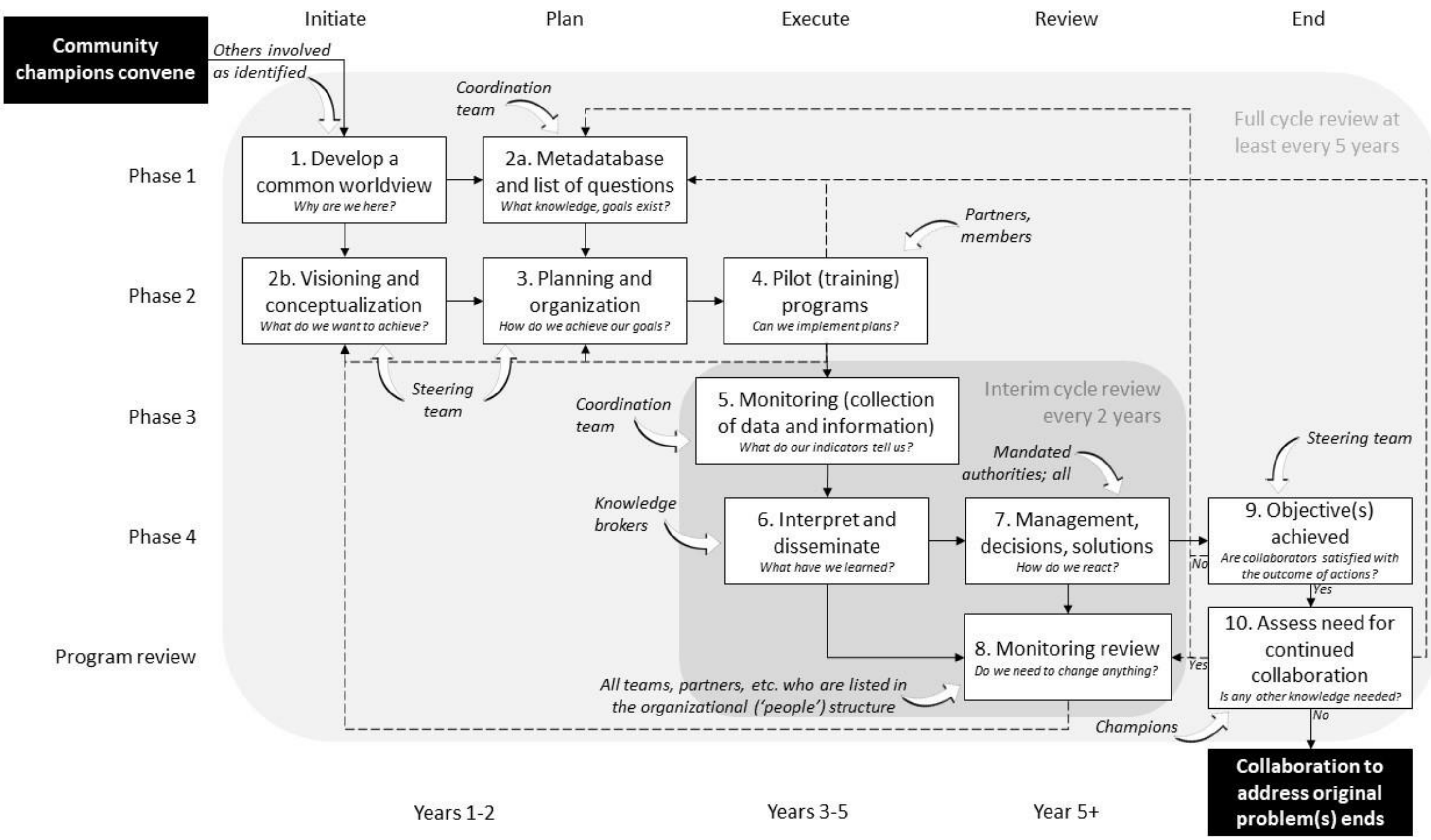


Figure 12. Process for monitoring program design (#1-4), implementation (#5-6), response (#7), and review (#8-10). Black boxes are start and end points and white boxes are sequential steps between them. Two shaded boxes in the background represent nested adaptive process cycles (e.g., full, and interim cycle reviews). Solid black arrows show the linear (numbered) sequence of the process from first convening to ending the collaboration, while the dotted black arrows show iterations within the process. White shadowed arrows and accompanying text demonstrate the main people/organizations involved in each step (note: #1 and the first iteration of #2-3 are led by champions, as roles are not determined for others until the first iteration of #3). Implementation phases are titled at right, associated with the project's life cycle at top and estimated timeline at bottom.

The framework is proposed to be implemented in four phases as part of a nested adaptive cycle (per the background shaded boxes in Figure 12). In Phase 1, community champions and other potential members meet to discuss their motivations for assembling (e.g., what effects have been observed and/or what other interests exist), listen to each other's understanding of how the river-lake system works, and come to a consensus on what problems and/or needs are being addressed. Then, two efforts may begin concurrently: first, as part of Phase 1, an inventory of relevant information is compiled to take stock of all the available data, knowledge, and what questions are prioritized (relevant to the initially identified problems/needs); and second, visioning (e.g., monitoring objectives, guiding principles for practice) and conceptualization (e.g., identifying what will need to be done to set the program up) begin Phase 2. Phase 2 continues with planning the program and organizing the various people and organizations into their roles, followed by pilot monitoring programs less than a year in duration. These pilot programs serve two purposes: training for members to ensure consistency in collection methods, and a proof of concept to demonstrate whether the planned roles and approaches are likely to work (including assessing whether the data are going to tell us what we hope they will tell us).

Phase 3 is where monitoring – including the collection of community and Indigenous data and knowledge – is implemented. This phase is also the start of the 2-year interim monitoring program cycle (e.g., the nested adaptive cycle). Phase 4 is comprised of knowledge interpretation and dissemination, (co-)design and implementation of solutions, and an assessment of whether the collaboration's objectives have been achieved. Management responses and decisions are outside the control and scope of this monitoring program, which highlights the importance of engaging with the relevant agencies as advisory members (e.g., in steering or coordination roles) or partners in monitoring. If the collaboration's objectives have been achieved, community champions will assess the need to continue the collaboration in its current form and will either proceed to review the program or end it. If objectives have not been achieved, the group will proceed to carry out a monitoring program review – described in detail under Step #8, above.

8.4 Discussion

The proposed framework represents a shift in responsibility for freshwater resources, from being entirely the domain of government agencies to being a responsibility shared with empowered community members and organizations. The collaborative and community-led features of the proposed framework are a direct result of demands from practitioners and community members alike. Community-based water (quality) monitoring is defined as a type of citizen science that directly engages or mobilizes community volunteers as well as community organizations in program design and data collection (Castleden, 2015; Allen, Colwell, & Curran, 2018). While most literature and global organizations commonly define community-based monitoring as community-led and/or driven (e.g., Castleden, 2015; Allen, Colwell, & Curran, 2018; Wilson et al., 2018; Reed, Brunet, & Natcher, 2020; TheGlobalFund, 2020), other examples from within and outside of Canada describe the practice as more of a partnership between leading or coordinated government agencies and community members and groups (e.g., EMAN Coordinating Office & the Canadian Nature Federation, 2003). In this research, we have not differentiated between community-led and community-based water quality monitoring programs, as our participants did not do so; however, given the strong recommendation to implement a community-driven program, the terminology should be agreed-upon by any potential implementers.

Though roles within our proposed framework are to be determined in collaboration with the partners, our study participants discussed examples of how collaboration may be set up within a community-based water quality monitoring program. Existing government-University partnerships may be examples to replicate in the context of our framework. Universities have the capacity to organize, interpret, analyze, and report on community data, which would benefit the collaborative; however, students at these institutions will also benefit from free access to current data and a network of people they can connect with to further investigate their questions. Government agencies or the Grand River Conservation Authority may open a space for community engagement by publicizing their interest in a particular issue or a set of objectives and inviting community groups to address it with them (e.g., not just through funding applications). Our study participants from government agencies suggested government's role would be more of a broader stakeholder advisory role, though participation would be dependent upon confirmation that the collaboration would not duplicate existing efforts in the river, lake, and nearshore. A focus on the interface (as proposed through our study) was recommended to be maintained, largely due to the knowledge gaps that exist in this area.

Aspects of our framework have been implemented previously and have worked well. For example, the Provincial (Stream) Water Quality Monitoring Network (PWQMN) is driven by provincewide partners who collaboratively determine a common vision (e.g., which indicators should be monitored) and implement that vision in whatever way is appropriate in each watershed. The Ontario Benthos Biomonitoring Network (OBBN) – a biological complement to the PWQMN – is comprised of five components: (1) standard sampling procedures (Jones, 2005), (2) training and certification, (3) database, (4) analytical software, and (5) a collaborative, applied research program (Jones et al., 2006). A Terms of Reference outlines the network's objectives, deliverables, development schedule, and implementation plan, while a separate manual outlines its standard protocol (Jones et al., 2007). Aspects that contribute to success in PWQMN and OBBN that are relevant to our framework include standardized protocols, accessible databases, dependence on collaboration, and flexibility of implementation (e.g., each partner determines where to sample and how frequently). In addition, PWQMN recognizes a broader vision without requiring all indicators be always measured by all partners, while OBBN provides field training to ensure partners from diverse disciplinary backgrounds are able to contribute to the database and, thus, to a shared interest.

While capacity building is explicit in Step #4 (pilot programs), it begins from the first step and continues as partners establish a common worldview of the issues and discuss what knowledge means to them (e.g., how is it accumulated, what data are collected, how they should be used). Participants in our study suggested training opportunities should be included in in-kind agreements (e.g., where gaps exist in the pilot program training). There are also other training opportunities – e.g., webinars, courses, event series (many of which are free of cost) that are often not considered as part of capacity building; however, there are several potentially helpful frameworks and approaches that are relevant to our proposed framework – each accompanied by its own resources. For example, the Tamarack Institute (2021) offers resources and training on the collective impact approach. The First Nations Information Governance Centre offers resources on the First Nations Principles of OCAP® (FNIGC, 2021) and A First Nations Data Governance Strategy (FNIGC, 2020). BetterEvaluation offers an online platform (betterevaluation.org) with over 300 methods and processes for measuring success. One of the approaches in the platform is empowerment evaluation, a community-collaborative approach for evaluating programs and projects (Fetterman, 2019).

Determining what to monitor, what evidence will support conclusions, and what actions should follow, are likely to pose challenges due to their subjectivity (e.g., they are based on value systems more than 'fact': Jones, 2016). Further, interpreting evidence in a complex area like the Grand River-Lake Erie interface presents additional challenges – especially when attempting to define natural variability. One approach to consider may be a 'Venn diagram' approach in which riverine variability above the Lake Effect Zone/river-lake interface is described, as well as variability in the nearshore (lake) areas outside the immediate interface. From this, we can monitor the interface (e.g., the interface of the river and the lake) to achieve a better understanding of potential overlaps in any phenomena observed. The approach applied by Servos et al. (2015), which discerned ecological change by studying multiple biological endpoints in relation to their contexts of natural variability (e.g., stream metabolism, fish diversity, condition, etc. – described in Sub-section 1.4.5 and in Servos, 2016), is strongly recommended to be carried forward from the upper and middle sections of the Grand River into the lower reach and nearshore Lake Erie. One question may be whether assessments of endpoints in Servos (2016) would be repeated in biomonitoring studies in nearshore lake environments (e.g., fish assemblages were not sensitive enough in the upper and middle Grand River, though fish responses were effective; would this be true for a large lacustrine ecosystem like Lake Erie?). A key conclusion from Servos (2016), reflected in the recommendations that emerged from Chapter 3, is that multiple indicators (including bioindicators) are likely required for assessing cumulative effects in the study area; however, given Servos et al.'s (2015) approach to compare trends against their natural variability, we reiterate the need highlighted by interviewees in Chapter 4 to address a knowledge gap in river-lake influences (including natural variability of ecological conditions) in the Grand-Erie interface.

In our proposed collaboration framework, Indigenous and western monitoring indicators are equally weighted to enhance our understanding of such phenomena. We recognize that understanding complexity requires different data sources and practitioners must be conscious of biasing one form of evidence over another. Evidence that informs decision-making must be defined more broadly than it currently is (e.g., limited to western science, validated by western methods). This highlights the need for a culture shift in how we understand and value information, as described in our introduction – a need we expect may be addressed by collaborations like the framework we have proposed. A study participant suggested engaging with different parties by asking ‘How do you think we should achieve the outcome you want?’ – rather than, ‘How can we work with you for the outcome we want?’ The culture shift extends to how we interact with each other as well. For example, study participants suggested minimum commitments should be established (e.g., a minimum duration of collaboration) to reduce turnover; however, we are cautious to propose minimum commitments during the first iteration(s) of monitoring design as it may deter engagement from some partners and may undermine trust-building in the early stages. Intercultural and intergenerational knowledge should be captured and shared, and managers should strive to measure and enhance community experiences as part of their assessment of watershed health. Since Indigenous knowledge is more difficult to record and interpret (e.g., it is lived experience, not simply learned information), we also need to reconsider our data use and storage. Managers and decision-makers should recognize that conventional databases are not the only source of useful, credible information.

Recent research (Wilson et al., 2018; Reed, Brunet, & Natcher, 2020) has also determined that Indigenous peoples’ engagement in community-based water quality monitoring is not limited to knowledge input. Instead, community-based water quality monitoring should be understood as an emerging expression of Indigenous governance (Wilson et al., 2018). Thus, community-based monitoring programs in Indigenous contexts can be considered a decolonizing approach to practice – a recommended approach discussed in Chapters 3 and 6. Community-based monitoring programs may therefore help accomplish multiple goals discussed throughout this dissertation, including filling knowledge gaps, providing a more holistic understanding of cumulative effects, and creating a shared space in which Canadian and Indigenous persons and organizations can meaningfully and equitably collaborate to achieve shared goals.

8.4.1 Real-world example

A nearby community-based monitoring program exemplifies many aspects of this framework. The Niagara Coastal Community Collaborative (NCCC) uses a collective impact approach (Cabaj & Weaver, 2016; Tamarack Institute, 2021) to water governance. In this approach, environmental non-governmental organizations, educational institutions, citizen groups, and municipal, provincial, and federal governments coordinate activities and collaborate to achieve a common goal. In the NCCC’s case, that goal is to optimize and expand local capacity and action to build a healthy and resilient Lake Erie coastal ecosystem. A healthy Lake Erie coastal ecosystem supports the community’s economic, recreational, and spiritual needs. Through the development of shared performance indicators, progress tracking, and sharing data, information, and plans, the NCCC is focused on improving collaborators’ understanding of the health of Lake Erie’s shoreline. The health of Lake Erie’s nearshore depends on good water quality, beaches free from nuisance algae, and naturalized shorelines that provide habitat for locally significant species. The NCCC has five main aspirations:

- Local stakeholder groups have a venue for collaboration to contribute to a healthy and resilient Lake Erie coastal ecosystem.
- The actions of local stakeholder groups are mutually reinforcing towards building a healthy and resilient Lake Erie coastal ecosystem.
- Local stakeholder groups have sufficient technical and scientific information to identify causes of impairment and take effective action.
- Community members are aware of the importance of a healthy and resilient Lake Erie coastal ecosystem, potential threats, actions underway, and opportunities for involvement.
- Activities of the local stakeholder groups are aligned with broad Lake Erie basin wide ecosystem management.

Environment and Climate Change Canada conceived the NCCC to address needs identified in its nearshore monitoring program. After reaching out to local community groups, community champions stepped up to lead the pilot program. Community volunteers follow NCCC's protocol monitor beaches for *Cladophora* wash-up. These volunteers place transects along their local beaches in specific distance increments, estimate the volume of algae (e.g., equivalent to a Ziploc bag, barrel, pickup truck, etc.), describe the appearance of the algae (i.e., color denotes how fresh the wash-up is, while the look and texture offer a quality control feature for confirming whether it is likely *Cladophora* being recorded), and take photos of the algae (also for quality control) and the area surveyed.

To help make the data from this program more accessible, a new tool – Niagara's Visual Assessment Survey Tool (VAST) – is currently (March 2021) under development. VAST is a scalable one-year pilot demonstration that brings the NCCC community surveys/data together with aerial drone surveys. Results and information will be shared with the public through annual reports, a live updated ESRI™ StoryMap, and web-based mapping services. Live updates and engagement of citizen data will create a near real-time tracking of coastal changes throughout the project duration. This initiative is the first step in the development of an adaptive management-based coastal decision support tool. Observations are expected to be used by coastal managers to inform restoration, policy, and strategic direction of coastal decisions.

It is important to recognize that examples of community-led monitoring across Canada are not new. For example, the Canadian Community Monitoring Network was an early example of attempts to coordinate local community-based monitoring efforts on a national scale in 2003 (EMAN Coordinating Office & the Canadian Nature Federation, 2003; Whitelaw et al., 2003), followed by the Community-Based Environmental Monitoring Network based at St. Mary's University in Halifax in 2004. The more recent advent of mobile applications and online map-based monitoring platforms – e.g., iNaturalist, EDDmapS, DataStream, Canada's Citizen Science Portal, and through organizations like Living Lakes Canada, Water Rangers, and Swim Drink Fish – has since made citizen science and community-based monitoring mainstream practice, though their integration into management and decision-making remains questionable. The NCCC program is exemplified in this study because of its proximity to our study area, it is a current program, and it provides a real-world demonstration of many of the aspects described in our proposed framework. We therefore recommend a program modelled after the NCCC may be implemented in the study area, provided that the other aspects of our proposed framework (e.g., integration of Indigenous knowledge) are also recognized.

8.5 Conclusion

At the start of this paper, we highlighted the need to consider broader evidence in support adaptive monitoring to address complex social-ecological issues. We summarized conclusions from this dissertation research, a five-year Canadian study, to propose a framework for collaboration in the design and implementation of a community-based cumulative effects monitoring program. Features of this framework include:

- Led by local community members and organizations
- Nested adaptive processes
- Coordination and alignment of multiple activities in support of common objectives
- Early, meaningful engagement with end users (including Indigenous communities)
- Interagency integration of ecological knowledge and relationships (through coordinated dissemination)
- Accountability via ethics overseer(s), monitoring reviews, and a community-driven process
- A mandate to implement systems thinking (e.g., considering sustainability – ecology, society, economy, and institutions – and use of visuals to represent potential stressor-effect pathways) to understand cumulative effects and address multiple priorities
- A focus on understanding river-lake dynamics (e.g., influences on natural variability from the river to the lake, and vice versa) to support the biomonitoring portion of cumulative effects monitoring (e.g., Servos et al., 2015; Servos, 2016) – not currently practiced in the study area
- Equal valuation of western and Indigenous knowledge approaches
- A non-linear, cyclical adaptive process that utilizes and normalizes community-based approaches in ways that contribute to governance of freshwater in Ontario and across Canada.

Insights provided by study participants were organized into two themes: people (e.g., organizational structure/guide for collaboration) and process (e.g., four phases of implementation, monitoring review). We discussed potential roles for different monitoring partners in our study context and considered the feasibility of our framework compared to two existing collaborative monitoring programs. While collaborative monitoring exists in Ontario, these programs are often government-led and do not address questions that involve cumulative river-lake interactions. As such, the various examples of existing approaches that may be applied to this framework should be carefully considered and adapted for the specific context of the Grand River-Lake Erie interface. Finally, as demonstrated throughout the paper, a culture shift is required in the way we view knowledge and how we pursue knowledge production. It is our hope that by implementing a framework like the one proposed here, meaningful collaborations may enhance current practice and catalyze lasting relationships that inspire a collective worldview for actionable cumulative effects monitoring in the future.

PART 5 – SYNTHESIS AND CONCLUSION

Chapter 9
Thesis summary and conclusion

Recurring, cumulative effects – e.g., prolific growth of nuisance algae *Cladophora* in Lake Erie's eastern basin – demonstrate that conventional water monitoring and management in the Grand River-Lake Erie interface need strengthening to enable managers to better track, understand, and address such issues. The design and implementation of cumulative effects monitoring (CEM) has been limited in Canada, though recent initiatives (e.g., Canadian Watershed Research Consortium: CWN, 2016) have begun to develop this research and practice across Canada. This dissertation research was undertaken to explore approaches for diversifying perspectives that contribute to our understanding of freshwater quality in the study area. I assessed the current state of freshwater quality monitoring in the Grand River-Lake Erie interface, considered underlying value assumptions of that monitoring, explored different approaches that monitoring in the area might consider implementing, and proposed a framework for community-based CEM that is better equipped to address cumulative effects like the *Cladophora* issue. Early consultations and the literature review suggested that the science of monitoring is generally well established, although implementation of monitoring is often uncoordinated and exclusively western in its approach. Thus, processes for broader and more diverse collaborations and coordination in monitoring are the focus, rather than monitoring protocols and planning.

9.1 Research questions and objectives

The research question addressed in this dissertation is: "How can cumulative effects water quality monitoring be enabled and involve diverse perspectives in the Grand River-Lake Erie interface?" Aspirations of the research were to:

1. Meaningfully engage stakeholders and rightsholders in the process of designing the monitoring framework (e.g., co-creation).
2. Influence improved use of water science (e.g., monitoring) in decision-making and management.
3. Update local priorities (e.g., VECs) for the Grand River-Lake Erie interface.
4. Explore approaches for incorporating different ways of knowing into water quality monitoring.

To translate these aspirations into research objectives, I consulted with water managers and subject matter experts from different organizations and governance levels in Ontario to collaboratively determine my study direction. The final three research objectives were as follows:

1. Confirm and describe opportunities for improvement in the practice of water quality monitoring (Chapters 3 and 4).
2. Explore alternative processes to support water quality monitoring that may be more conducive to bringing together of different ways of knowing (Chapters 5 and 6).
3. Propose a strategy for enabling cumulative effects monitoring in the study area and outline an organizational structure and process framework for the design and implementation of a cumulative effects monitoring program (Chapters 7 and 8).

Practitioner consultations supported two of the original sub-questions (below); however, they steered the second sub-question and, as a result, the direction of the research, to focus on the context of water quality monitoring rather than the monitoring itself (described in Section 1.1 and below). The three sub-questions are:

1. What does current monitoring in the interface look like, and what are opportunities for improvement? What can we learn from 'best practices'?
2. Whose values matter for determining what we measure, and how do we ensure diverse values are considered?
    a. Note: The original sub-question was: "How can monitoring data be more useful to managers and decisions makers, and what would motivate them to use it more?" This question changed to better align with core questions in the literature, focus on monitoring (rather than addressing management practice as well), and to address recommendations from those with whom I consulted, some of whom suggested there is a greater need to consider how managers and others can *work better together* – rather than how to *monitor better* (i.e., practitioners generally felt the science is solid and protocols well-established).
3. (How) would cumulative effects monitoring differ from current practice, and what would a strategy for implementation look like in the Grand-Erie interface?

The proposed organizational structure and process framework, co-created by diverse stakeholders and collaborators, was simplified after feedback from practitioners to ensure feasibility and was designed to apply to existing and emerging methods of informing decisions; however, changes to current approaches are also needed and were acknowledged. Further, the process framework was simplified to allow for broader applications outside the study area, which current practitioners suggested was feasible after reviewing its new and simplified form.

9.2 Main results

While the main results are presented in this dissertation, more information can be found in the related summary reports and other literature that were produced as part of this research (i.e., to disseminate information more widely, using different formats). These reports and literature are listed in Appendix A. The results in this dissertation are summarized below according to the affiliated research sub-question.

9.2.1 Sub-question 1: What does current monitoring in the interface look like, and what are opportunities for improvement? What can we learn from 'best practices'?

The monitoring review (Chapter 3) identified three aspects of current monitoring to maintain: the availability of short-, medium-, and long-term scientific information, collaboration with many partners, and (for some programs) contact information is available (a component of transparency and accountability). Five recommendations followed: (1) recognize different knowledge approaches, (2) use multiple reporting formats, (3) ensure clear roles for monitoring and management, (4) consider a combination of water quality, quantity, and biomonitoring, and (5) link monitoring to management and decision-making. Chapter 4 demonstrated practitioner support for these recommendations, as their 106 'SWOT' issues (e.g., Strengths, Weaknesses, Opportunities, Threats) and 51 recommendations overlapped concepts discussed in the previous chapter. These concepts include highlighting strong collaborations, identifying the need to better coordinate monitoring activities, raising challenges integrating western and Indigenous approaches (despite a recognized need to do so), and recommendations for connecting monitoring with management and decision-making (e.g., via mandates). Also, Chapter 4 recommends improvements to practice, outlines the importance of considering integrated sustainability goals and holistic thinking in monitoring and management, and presents an adaptive monitoring process for future monitoring.

9.2.2 Sub-question 2: Whose values matter for determining what we measure, and how do we ensure diverse values are considered?

A Criteria-based Ranking (CBR) process is introduced in Chapter 5, which was further developed in Chapter 7 (described more in Sub-section 9.2.3). Regardless of implementation nuances (e.g., approaches used in Chapter 5 versus a more user-driven approach in Chapter 7), the CBR process demonstrates a relatively minor modification to current practice that both standardizes indicator selection (or short-listing) and provides an opportunity to address diverse perspectives or priorities by using criteria to score and select monitoring indicators. Chapter 5 demonstrates that a different set of indicators may emerge when using an approach like the CBR process, versus the conventional method of a handful of practitioners determining monitoring indicators. Chapter 6 then explores a more significant modification to current practice, exemplifying community engagement and co-creation via the arts – an approach that has not previously been used in the study area. Co-creation and arts-based engagement presented opportunities to not only engage with the public to identify their priorities and perspectives (e.g., whether the public feels the river/lake are healthy, what they feel the priority issues are), but these methods provided a space in which to understand community member relationships with the watershed and the values that emerge from those stories. Youth at Six Nations of the Grand River shared their values through artwork and storytelling. A preliminary list of principles and values was then synthesized with value statements from practitioner/subject matter expert interviews. The following example[15] of 10 principles emerged to guide water monitoring (e.g., to consider when determining the narrative that monitoring indicators will tell), management, and decision-making:

1. Water is essential and finite.
2. What we put into the watershed returns to us in one form or another.
3. Impacts are shared but unequally distributed.
4. We are inextricably embedded within ecosystems and are co-dependent in many ways.
5. Partnerships and collaboration are the foundation of program implementation.
6. We openly acknowledge diversity, histories and strive to reconcile. We recognize and value diverse relationships between water and people.
7. Data and communication are open, transparent, and accessible. Cultural and intergenerational knowledge are recognized as data.
8. We will manage as stewards. Waters are treated as living, sentient beings – with love, respect, and gratitude.
9. We recognize that iterative, adaptive processes do not fail (they improve). Proactive, precautionary approaches are applied when feasible.
10. Managers should strive to measure and enhance community experiences as part of their assessment of watershed health.

In the discussion, six conclusions and recommendations for using co-creation and arts-based approaches were highlighted for designing water monitoring: (1) our co-created, arts-based approach can be effective for engaging diverse community members; (2) in research, there are often ethical dilemmas that should not be accepted as just another systemic limitation; (3) reciprocity must be within the program scope; (4) co-create shared spaces and incorporate co-solutions; (5) investigate existing models; and (6) ensure the logistical infrastructure is present. Four recommendations for broadening our understanding of 'data' were also discussed: (1) recognize the validity of other knowledge forms; (2) constant engagement is not necessary; (3) do not undertake collaborative data production to only serve the needs of western

[15] An example only, as an implemented set of principles should be collaboratively generated and not synthesized independently by a researcher (per Recommendation #2 in Sub-section 6.5.2).

science; and (4) appreciate the continued evolution of scientific practice and embrace opportunities to co-develop potentially useful knowledge. Three key ingredients contributed to success in this part of the research: relationship-building (including co-creative collaboration), capacity-building, and reciprocity (e.g., meaningful actions undertaken in return for community member participation in the research). Finally, one of the more important conclusions from Chapter 6 is that Two-Eyed Seeing is not only possible using creative approaches like artistic research or arts-based engagement, but that community members view it as a mandatory if more collaborative monitoring and management processes are to be implemented.

9.2.3 Sub-question 3: (How) would cumulative effects monitoring differ from current practice, and what would a strategy for implementation look like in the Grand-Erie interface?

Chapter 7 presents eight recommendations for cumulative effects monitoring: (1) establish a common definition of cumulative effects/cumulative effects assessment before implementing cumulative effects monitoring (CEM); (2) ensure diverse 'others' are meaningfully involved early and throughout the design and implementation of CEM; (3) develop adaptive, innovative processes for assessing and understanding both stressor and effect-based indicators (collectively); (4) select indicators co-operatively with end users; (5) endeavor to understand the relative influence of the Grand River and Lake Erie on each other and track changes over time (e.g., importance of river-lake dynamics to species-at-risk and invasive species); (6) use collaborative watershed analysis and supportive methods and tools; (7) use modelling tools but recognize limitations of their use; and (8) share and receive knowledge in various ways. Collaborative watershed analysis was proposed as a new/different approach developed from the collective feedback of research participants. The process is proposed as follows:

1. The problem is verified in a discussion of the indicators that collectively demonstrate or confirm the undesired effect on the valued ecosystem component (VEC).
2. Recognize that the social-ecological system being addressed is defined by the observed effect (on the VEC) and is not automatically assumed to be the watershed. Then, define the system's spatial and temporal boundaries according to the VEC and observed effect.
3. The whole watershed, or other delineation of the system, is studied as the group considers which combination of interactions (between stressors and environmental conditions) may be behind the observed effect.
4. Visuals are developed to depict the processes and pathways that result in the observed effect (and, ideally, potential management responses).

5. Visuals are modified over time as complex interactions in the watershed are better understood and/or to enable their continued use in management and/or decision-making.
6. Predictive modelling may benefit from a collaborative watershed analysis process and may be developed/adapted/used alongside the visuals created from this process.

The final proposed organizational structure and process framework (collectively referred to as the collaboration framework) is introduced in Chapter 8. The collaboration framework is described in two sections: people (Figure 11) and process (Figure 12). The cumulative effects monitoring program proposed in this research is catalyzed and driven by community champions, facilitated by others with specialized knowledge, in collaboration with managers, decision-makers, and knowledge producers. Leadership consists of the community champions, a steering team, and a coordination team. A resourcing committee ensures adequate capacity, while information is developed by monitoring partners with support from a data team (e.g., for analyses or interpretation) and knowledge brokers (who help disseminate information to the intended audience and more generally connect end-users with the information they need to better do their jobs). Other persons (e.g., consultants with specialized knowledge or for a specific purpose) may be engaged ad hoc. The process consists of 10 iterative steps:

1. Develop a common worldview.
    a. Why are we here?
2. Concurrently:
    a. Visioning and conceptualion (e.g., what do we want to achieve?)
    b. Develop an inventory of relevant information and list of questions (e.g., what knowledge, goals exist?)
3. Plan the program and organize collaborators.
    a. How do we achieve our goals?
4. Implement pilot programs as training opportunities for monitoring personnel.
    a. Can we implement plans?
5. Implement monitoring and data collection (including community and Indigenous data/knowledge.
    a. What do our indicators tell us?
6. Interpret and disseminate information.
    a. What have we learned?
7. Respond to monitoring (e.g., management, decisions, community-led solutions).
    a. How do we react?
8. Review monitoring (interim or full cycle).
    a. Do we need to change anything?
9. Determine whether objectives have been achieved.

a. Are collaborators satisfied with the outcome of actions?

10. Assess the need for continued collaboration in the current form.

a. Is there any other knowledge (e.g., monitoring) needed?

These steps are proposed to be implemented in four iterative phases that occur over five or more years (including a relatively extensive 1–2-year phase at the beginning to develop relationships and a common worldview). The collective recommendation to implement collaborative and community-based (i.e., community-led) approaches to water quality monitoring – e.g., the collaborative watershed analysis tool described in Chapter 7 and the framework outlined in Chapter 8 – reflect a broader shift in recognition that Canada's vast watersheds require a sharing of responsibility for monitoring with the communities that reside in them.

9.3 Contributions

First, the dissertation presents an updated (as of 2020) characterization of the state of freshwater monitoring practice in the study area (and Ontario), including common strengths and weaknesses of 'good practice', potential criteria with which to evaluate practice, and 157 strengths, weaknesses, opportunities, threats, and recommendations (Part 2, Chapters 3 and 4). Recent literature representing years of development in theory and practice – Jones (2016), CWN (2016), Stephenson et al. (2017; 2018) – underlie and guide theoretical exploration throughout this dissertation. The literature was brought together and built upon to investigate assumptions behind freshwater monitoring in the study area and to propose the final organizational structure and process framework.

Second, a Criteria-based Ranking process was developed and applied in the exploratory research (Chapter 5) and further developed as an activity in the cumulative effects workshop (Chapter 7). This process addresses inherent biases and potentially completely changes the way in which practitioners may understand and implement freshwater monitoring indicators by introducing (collaboratively generated) criteria that are used to identify or short-list the indicators. While practitioners may choose to determine criteria for indicator selection independently (e.g., informed by literature and/or experience) as we (the researchers) did during the exploratory study, collaboratively generated criteria provided an opportunity for our practitioners to consider and discuss each person's expectations of monitoring and their unique understanding of cumulative effects. These discussions contributed to the building of theory behind cumulative effects monitoring.

Third, Chapter 6 explored the utility of a co-created approach using visual arts and written storytelling for information gathering that has not previously been practiced in freshwater monitoring in the study area; therefore, its application to the study is itself a methodological contribution. Co-creation provided multiple insights into both monitoring and into the research process and challenged the researcher's own assumptions of how freshwater monitoring is viewed and understood by the watershed's communities. It proved to be a culturally relevant means by which to engage with the local Indigenous community and identify potential values and principles to guide monitoring and management in the area. The approach also highlighted issues with western research ethics (discussed in Section 9.6) and important factors that lead to success. Collectively, the third and fourth contributions (Part 3, Chapters 5 and 6) enhanced the investigation into underlying assumptions of monitoring, asking epistemological questions and catalyzing theoretical discussions that may influence the shaping of future knowledge production by freshwater monitoring.

Fourth, this dissertation contributes to the development of literature in CEM – a concept that has existed in theory for decades as part of cumulative effects assessment, but which has not yet taken shape as an established and common practice (at least in Canada: Jones, 2016; Duinker & Greig, 2006). Chapter 7 separates discussion of CEM from its conventional context in Environmental Impact Assessment and cumulative effects assessment, providing recommendations for developing a CEM framework as part of freshwater quality monitoring. In addition, a new approach for analyzing monitoring data – collaborative watershed analysis – began to emerge. Both this contribution and Chapter 8's contribution (explained below) collectively encourage implementation of systems thinking in ways that are broadly accessible and which result in more effective management and decisions (Part 4, Chapters 7 and 8). Chapter 7 also explicitly applies holistic, systems thinking to freshwater *monitoring* (as opposed to more conventional application to *management*), which contributes to currently limited discourse on this topic.

Finally, Chapter 8 presents an organizational structure and process framework to enable implementation of CEM in the study area (which may be relevant for broad applicability) that challenges conventional monitoring practice by shifting responsibility for water monitoring from being the sole responsibility of government agencies to being shared with community members. The community-led feature of the proposed collaboration framework (whether catalyzed by community members or invited by government) and its equal weighting of Indigenous and western priorities and monitoring indicators are unique and potentially transformative. The discussion highlighted the need for a broader cultural shift in how we understand and value information, which may be catalyzed by implementing frameworks like the one proposed (which provide formal space to address culture and challenge assumptions). Though focused on monitoring, the collaboration framework addresses necessary changes in management and decision-making to also recognize conventional databases are inadequate on their own for informing decisions.

9.4 Limitations

There are important limitations of the methods used in this research. First, co-creation is a place-based and people-focused methodology. As such, its methodological design and implementation are always tailored to the unique needs and norms of the place and community (or communities) being studied. While this is a strength for providing recommendations and solutions that are likely to work in the study area, broader applicability can sometimes be a problem. To address this issue, this research incorporates a multimethodology that permits both a top-down and bottom-up approach to data collection and interpretation. Perspectives shared by current managers, practitioners, and subject matter experts were often not specific to the study area, which allows for more relevance of our discussion outside the study area. This was balanced by community perspectives that are specific to the study area, ensuring relevance to those whose section of the watershed was being studied.

Second, like the first limitation, the core activity of relationship-building is always unique to the people involved and can never be truly replicated by others. This does not have to be problematic, as it is an opportunity to build trust in unique ways that play to the strengths of those involved. Still, relationship-building should not be undertaken unless those involved are prepared to follow through to deliver on commitments made. This is a major shortfall of practice, which was overcome in this research by openly asking the research partners what form of reciprocation would be desired and collaborating to ensure our research process satisfied the needs of both parties (e.g., the researcher and the research partner).

Third, the methods applied in this research were not intended to provide a representative sample of perspectives, but instead strived to explore new approaches for understanding and implementing freshwater monitoring in the study area. Community participants were (intentionally) not screened or selected in the same way key informant interviewees were to bring forward a range of potential perspectives – especially those that have not been commonly incorporated into water quality monitoring in the study area. As such, the views and recommendations presented in this dissertation should only be considered a partial truth of the perspectives that exist and *not* a consensus of 'what should be'. To address this limitation, Ross et al. (2010) recommend considering ways to identify and incorporate the risks, needs, and perspectives to/of community members and end users who did not participate in the research. This highlights an assumption of research, that we often judge the validity of participants' contributions based on authority, which is usually defined by the dominant society (more on this in Chapter 6). Thus, researchers and practitioners must both consider power imbalances and personal biases that influence the selection of those who develop knowledge with them (Ross et al., 2010; Hotze, 2011).

Finally, the need for this research was defined using literature that emerged from western science and verified by consultations with western practitioners. This is inherently limiting as it focuses on the knowledge and experiences of some end users to the exclusion of Indigenous end users (i.e., would water stewards at Six Nations of the Grand River have expressed a need for this research if they had been engaged during early consultation?). Opportunities to achieve a holistic and lived understanding of the watershed were therefore diminished early in the research process. Co-creative approaches to research design may address this limitation if diverse views (e.g., collaboration with Indigenous persons in our study area) are considered from the start of research design. Further, identifying areas in which to improve research practice should be formally explored, including ethics processes, recognizing guiding principles and values, and exploring existing critical discourse (e.g., *10 Calls to Action to natural scientists working in Canada*: Wong et al., 2020).

9.5 Implications of this research

As the research progressed, hints of potential long-term, institutional implications were observed. For example, the Honourable Bardish Chagger, Canada's Minister of Diversity, Inclusion, and Youth, expressed interest in meeting with the youth artist who participated in the creation of *Grand Expressions* (however, the meeting did not occur due to COVID meeting restrictions and the lack of internet connectivity on reserve). In addition, an opportunity to influence coordination between monitoring agencies at the Provincial level arose in early 2021 because of the exploratory research and interview results (discussion with a Provincial agency is currently ongoing). As coordination is too big a task for any one agency at any level – demonstrated by past failed efforts for individual offices to assess the current state of knowledge across and within levels of government – a metadatabase of what is being measured and what data are available is being discussed. This would be a first step for assessing redundancies and gaps in monitoring across Ontario and would be a starting point for determining a subset of indicators (e.g., an exercise we carried out at a smaller scale during our cumulative effects workshop, per Chapter 7).

As discussed throughout the dissertation (especially in Chapters 6 to 8), successful implementation of the proposed recommendations and collaboration framework would require a cultural shift from monitoring personnel and western end users. The framework can be integrated into current practice, especially given shifts in current practice, e.g., Ontario and Canada moving towards open datasets and government recognition of community-science databases like Gordon Foundation's DataStream. Still, aspects of the collaboration framework and our recommendations – e.g., bringing together different forms of knowledge (e.g., braiding western and Indigenous data and knowledge), moving beyond conventional databases to inform decisions with alternative formats of repositories and/or information – require systemic changes to how we understand and support knowledge production. Given interviewees' emphasis on designing knowledge dissemination according to end user needs (including the format of dissemination), there may be opportunities to influence the needed changes from different angles of research and practice (e.g., from the data collection point of view as well as the dissemination point of view).

Related to our view of knowledge is how to operationalize systems thinking – not just in our water managers and decision-makers, but in our communities as well (given their core role in the proposed collaboration framework). The concept of systems thinking need not be complicated, though its complexity should not be understated, and the concept should be demystified by knowledgeable practitioners, educators, and subject matter experts. Systems thinking should be accessible and applicable by anyone engaging in watershed/freshwater quality monitoring and management. In our study area, deferring to the expertise and experience of local Indigenous communities would likely prove beneficial for everyone and would improve nation-to-nation relationships, as a holistic view of social-ecological ecosystems, collective thinking, shared responsibility, consideration of impacts of current decisions on future generations, and consensus decision-making are well established in Haudenosaunee (Iroquois) customary practice (Delormier et al., 2003). In other words, we have experienced systems thinkers living as stewards upstream with historical knowledge of our study area, who promote a holistic and interdependent understanding of social-ecological systems to all members of their community as a way of common life (i.e., not just for the academic or decision-making elite). Thus far, conventional monitoring and management practices have been remiss by not fully engaging with these experts. Of course, engaging with these communities should not be undertaken to simply tap into an additional source of knowledge. Dissertation chapters addressed additional important reasons, e.g., treaty/cultural rights, shared responsibility as stewards in the watershed, and a national mandate for Indigenous reconciliation; however, implications for operationalizing systems thinking should not be overlooked.

Thus, this research has implications that extend beyond strengthening the practice of water quality monitoring. The core outcomes of the last chapters – recommendations towards collaborative and community-based monitoring processes coupled with a culture shift regarding the creation and application of knowledge – would, if practiced, support at least three broader transformations in society. First, a formal sharing of responsibility over natural resources, as described in the earlier sections, would dramatically change the dynamics of decision-making, and could potentially empower communities to manage or steward local waters directly (as opposed to being affected by top-down decisions). If coordinated on a national scale (but managed locally), this in turn could ensure that many more of our waters, lands, and natural resources across Canada receive the attention they require to help them thrive and conserve their diversity and function for future generations. Shared responsibility would also remove accountability for failed management from the Federal and regional governments exclusively, which is likely to result in a more collaborative and iterative approach of continual improvement in which all persons and organizations involved share accountability.

Second, increased collaboration mindful of diversity would require a change in how we gauge the validity, trustworthiness, and/or value of knowledge. While rigorous science would likely maintain a similar authority to what it enjoys today, it would not necessarily be considered the most relevant way of producing knowledge given the cumulative and unreliable qualities of real-live scenarios. Rather than using the immense knowledge generated by science as factual statements as we often do today, the knowledge of science might be presented *and accepted* in a way that is more transparent (and likely preferred by many of the knowledge producers) – e.g., followed by statements of uncertainty, or other statements like "in scenarios like this", "if organisms respond the same way they did in the lab", or "we expect this to be true for approximately 20% of the scenarios", etc. While decreasing the factual authority of conventional science may be threatening to some researchers and practitioners, this kind of transparency may serve to improve the public's trust in scientific knowledge and may be one factor determining the use – or lack thereof – of science by decision-makers (as was suggested by some of our interviewees). This practice does, however, require a certain comfort level with uncertainty that we are generally not trained to appreciate.

Third, the systemic changes described in this dissertation collectively support an existing priority in Canada's governance and, largely, its society: Indigenous reconciliation. Changes to how we perceive different ways of knowing can foster respect for cultural knowledge and practice, while collaborative approaches lay the groundwork for inclusivity and new models of shared governance of natural resources. Respect for a people may be coupled with improved recognition of past transgressions if focused on building relationships in a good way moving forward. Although there are conflicts between the practices of management and stewardship, humility in our acceptance of diverse ways of knowing and doing can permit us to overcome such challenges. Beyond nation-to-nation relationships, it is perhaps more important that the shifts described in this research may improve personal agency/self-determination in Indigenous communities in the long-term. These changes may also support a gradual recognition of traditional Indigenous leadership as distinct governments, and a broader understanding of Indigenous 'communities' as sovereign nations within our borders.

While many aspects of the future scenarios described here are likely a generation away (or longer) and are far beyond the scope of any one thesis project, my hope is that possible actions catalyzed by this research and other efforts like it will collectively move society in a different, more equitable direction.

9.6 Reflections and future research

Reflecting on this research, I am left with more questions than I set out to answer. For example, research participants celebrated that monitoring agencies in Ontario monitor in collaboration with more organizations than anywhere in Canada. If we accept this statement as fact, I wonder why this is the case – e.g., why do we collaborate more than elsewhere? Is the population density in Ontario higher than other areas of Canada, requiring more intensive monitoring across the province and resulting in greater numbers of water-related initiatives with which to partner? Or are conservation authorities (e.g., watershed-scale government-mandated organizations) the key to this phenomenon, as the only legislated watershed-focused organizations in Canada? Regardless of the reason, does this higher degree of collaboration result in more effective monitoring and management (as suggested by the literature)? Another question that arose during the research is how recent and developing changes to freshwater quality monitoring theory and practice changes the findings of this research. For example, will any of the following change the conclusions of our SWOTR analysis in the next five years: changes to Provincial legislation (e.g., regarding conservation authorities); a shift in practice towards open data; changes to the ways in which society works and functions because of COVID-19 (e.g., the Ontario Benthos Biomonitoring Program is currently suspended); the creation of a Canada Water Agency; or a growing appreciation for and interest in bringing Indigenous knowledge forward?

Before this research, I underestimated the importance of carefully considered ethics guidelines (whether applied to research or practice). Ethics had not been raised in most discussions in the monitoring and management literature reviewed, nor did any consulted practitioner or most study participants consider ethics beyond recognizing a lack of knowledge of cultural etiquette for Indigenous collaborations. The exception was study participant Dr. C. Jones, who explicitly discussed ethical considerations throughout his paper (Jones, 2016) and who furthered this discussion in his feedback following his review of Chapter 7. Further, although the University research ethics review process was discussed as an impediment experienced during the research (Chapter 6, supported by literature in Chapter 7), there may be opportunities to improve ethics review processes to encourage increased Indigenous collaboration and consideration of Indigenous knowledge where relevant. Granting/funding bodies across Canada appear to recognize this in their more recent ethics requirements and guidelines (e.g., Interagency Advisory Panel on Research Ethics, 2018). In recognition of the importance of ethics, the proposed organizational structure includes at least one ethics overseer (Chapter 8).

Future research can build on this work to explore a variety of topics and questions – some of which were described above in this section. Seven future potential research topics include:

- Consider how Indigenous knowledge can facilitate broader/community systems thinking, as described in the previous section.

- Evaluate the potential role of research ethics to support reconciliation and equity-based action and research (per above). This may involve a collaborative process to generate a set of principles for application to local water quality monitoring and management.
- Implement a proof of concept for the organizational structure and process framework, e.g., to build on the arts/public engagement process or delve deeper into the potential role of citizen science in monitoring (i.e., to replicate the Niagara Coastal Community Collaborative in the Grand River-Lake Erie interface).
- Assess whether water governance in Ontario should be changed to distribute responsibility for stewardship/management (also differentiating between the two) and allow for more power sharing.
- Explore the potential role (per community desires) of Indigenous peoples in water monitoring and/or management. This involves further relationship-building with the broader community and exploring how to bring together Indigenous and western knowledge approaches.
- Apply participant-recommended data analysis approaches (e.g., collaborative watershed analysis, or established approaches like bow-tie, value of information, Bayesian analyses) and developing decision support tools from existing data.
- Study river-lake dynamics in the context of biomonitoring for cumulative effects, extending the work of Servos et al. (2015; summarized in Servos, 2016) and considering whether lacustrine ecosystem influences would change the conclusions of indicator assessments).

In addition, study practitioners recommended seven priority topics for future study:

- Evaluate nearshore cumulative effects on wetland habitat—primarily, those described in the Great Lakes Water Quality Agreement, Annex 7 – within or outside the context of climate change mitigation/adaptation.
- Research aimed at verifying implications of the Dunnville Dam – e.g., using keep or remove scenarios – on invasive species.
- Understand the effects of emergent and legacy pollutants – e.g., plastics, Neocotinoids, mercury, chloride – on wildlife, including expounding on limited bioaccumulation knowledge in the Grand River.
- Policy-focused research on fish passage and biodiversity (e.g., focusing on species of interest to commercial and recreational fisheries), as well as on species at risk. This research would ideally consider implications for Indigenous culture (e.g., the impediment of fish passage is symbolic of colonization given the cultural importance of some species like lake sturgeon – a species at risk).
- Cost-benefit analyses on invasive species as well as economic and cultural valuation of the Grand River-Lake Erie interface/interface.

- Build on existing efforts to understand cumulative effects and address other knowledge gaps in the nearshore of Lake Erie's eastern basin.
- Understand and document highly variable river-lake dynamics, e.g., the relative influence of the river and lake on each other and tracking changes over time (including the interface's importance to species at risk).

Future research should also recognize that knowledge in the study area is quickly developing. Our knowledge of the *Cladophora* issue – e.g., what really drives changes to algae biomass or growth – has grown immensely over the last 15 years (per Sub-section 1.3.5), which is a relatively short period of time considering most of the studies reviewed span at least a 3 to 4-year period. Conditions are known to have changed as well, as expected of cumulative effects. For example, the colonization of Lake Erie's nearshore by dreissenid mussels increased the maximum depth at which *Cladophora* grows by a factor of about 1.3-2.5, from about 7m maximum depth before pre-dreissenids to about 10m after their colonization (Higgins et al., 2005; Malkin et al., 2008). The study area in this work was based on the more recent estimation of a 10m maximum depth; however, future work on *Cladophora* should seek to confirm the relevance of this delineation prior to determining a study area.

Finally, the results of this work can be used to propose more transformational approaches or frameworks; however, the methods would likely need to be adjusted. This research relied heavily on current practitioners and subject matter experts. Although this approach provided insights into current practice and helped ensure the research outcomes would be more broadly applicable (as opposed to relying entirely on community perspectives), current perspectives should likely not be the sole source of ideas to consider. New, different sources – e.g., western and Indigenous community members (and youth in particular), environmental grassroots/non-governmental organizations, elders and retired persons who may shed insight into why current processes evolved in the ways they did – should be considered to raise unique, unconventional ideas for testing.

9.7 Final thoughts

This research has shaped my thinking about water quality monitoring, management, and 'meaningful' engagement. I have learned that water quality monitoring is not as simple as responding to management questions, as it may once have been. Rather, it is about creating a foundation of knowledge – however defined – to inform decisions, management, and to influence community behaviour (e.g., the latter is relevant in the context of a watershed approach, versus water only). It is also about value systems, systems thinking, and diverse perspectives that collectively determine how we understand, assess, and respond to the state of the social-ecological system that is our watershed. The design of monitoring and management should reflect the features of this system. This would mean implementing nested, iterative processes and considering different perspectives, as well as the roles of relevant people, organizations, organisms, and biophysical features that collectively contribute to an observed phenomenon.

Moving forward, I would challenge researchers and practitioners to consider a problem-centric approach in which neither monitoring nor management is at the center of discussion. The problem that arises is a conflict that I identified from practitioner comments regarding who should have the onus to coordinate or cater to the needs of the other – i.e., two perspectives, that monitoring should be designed to serve the needs of managers and decision-makers, versus that managers and decision-makers should act according to what the monitoring and characterization data tells us. In a problem-centric approach, disciplinary and sectoral hierarchies are disregarded and replaced with identities determined by the roles each agency (or organization, partner, etc.) may have in the resolution of an issue at the center of monitoring and management activities. An approach such as this would facilitate the cultural changes recommended throughout this thesis that are needed to ensure freshwater quality monitoring processes and resulting management are more sustainable, equitable, and more effective at addressing cumulative effects in the future.

WORKS CITED

Allen, K., Colwell, R., & Curran, D. (2018). *Community-Based Water Monitoring and Decision Making*. An ELC Clinic report prepared for Living Lakes Canada and The Gordon Foundation. Online: https://elc.uvic.ca/wordpress/wp-content/uploads/2018/10/UVic_ELC_CBM_Final_2018Oct26-1.pdf

Anderson, B. S., Hunt, J. W., Phillips, B. M., Nicely, P. A., Gilbert, K. D., … and Tjeerdema, R. S. (2003). Ecotoxicologic impacts of agricultural drain water in the Salinas River, California, USA. *Environmental Toxicology and Chemistry*, 22, 2375–2384.

Annex 10 Task Group. (2016). *State of Knowledge of Cladophora in the Great Lakes Workshop – Executive Summary*. Conference held at NOAA-Great Lakes Environmental Research Laboratory, January 26-28, 2016. Summary compiled for the Annex 10 Task Group by the Lake Erie Millennium Network Workshop Co-convenors: Paul Horvatin, Ram Yerubandi, Jan Ciborowski, Craig Stow, Russell G. Kreis, Jr. Online: https://yosemite.epa.gov/sab/sabproduct.nsf/F0511648B656303F85257FB800739B4E/$File/Cladophora+Workshop+Executive+Summary+-+May+10+2016+(final).pdf.

Arciszewski, T. J., & Munkittrick, K. R. (2015). Development of an Adaptive Monitoring Framework for Long-Term Programs: An Example Using Indicators of Fish Health. *Integrated Environmental Assessment and Management*, 11(4), 701-718.

Arthington, A. H., Badhuri, A., Bunn, S. E., Jackson, S. E., … & Ward, S. (2018). The Brisbane Declaration and Global Action Agenda on Environmental Flows (2018). *Frontiers in Environmental Science*, 6, 45.

Attari, J., & Mojahedi, S. A. (2009). *Water Sustainability Index: Application of CWSI for Ahwaz County*. Conference proceedings of the World Environmental and Water Resources Congress 2009, Great Rivers, May 17-21, 2009. Kansas City, Missouri, 1664-1670.

Auer, M. (2005). Modeling Cladophora growth: A review of the Auer-Canale framework. In: *Cladophora Research and Management in the Great Lakes* (pp. 57–61). Proceedings of a Workshop Held at the Great Lakes WATER Institute, University of Wisconsin-Milwaukee, December 8, 2004. Great Lakes Water Institute, Wisconsin Aquatic Technology and Environmental Research, UW Milwaukee.

Auer, M. T., Tomlinson, L. M., Higgins, S., Malkin, S. Y., Howell, E. T., & Bootsma, H. A. (2010). Great Lakes *Cladophora* in the 21st Century: Same Algae-Different Ecosystem. *Journal of Great Lakes Research*, 36(2), 248-255.

Bala, B. K., Arshad, F. M., & Noh K. M. (2017). Causal Loop Diagrams. In B. K. Bhala, F. M. Arshad, & K. M. Noh, *System Dynamics*, (pp. 37-51). Springer.

Ball, M. A., Noble, B. F., & Dubé, M. G. (2012). Valued Ecosystem Components for Watershed Cumulative Effects: An Analysis of Environmental Impact Assessments in the South Saskatchewan River Watershed, Canada. *Integrated Environmental Assessment and Management*, 9(3), 469-479.

Ball, M. A., Somers, G., Wilson, J.E., Tanna, R., Chung, C., … & Seitz, N. (2012). Scale, Assessment Components, and Reference Conditions: Issues for Cumulative Effects Assessment in Canadian Watersheds. *Integrated Environmental Assessment and Management*, 9(3), 370-379.

Bailey R. C., Norris R. H., & Reynoldson T. B. (2004). The Reference Condition Approach. In R. C. Bailey, R. H. Norris, & T. B. Reynoldson, *Bioassessment of Freshwater Ecosystems*, (pp. 145-152). Springer.

Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies and Sciences*, 2, 331-340.

Basu, N. (2017). *Lake futures: Enhancing adaptive capacity and resilience of lakes and their watersheds*. Proposal by University of Waterloo Principal Investigator (N. Basu), Co-Investigators, and collaborators, to the Global Water Futures initiative.

Battagello, D. (2018). *Group to test solutions for Lake Erie algal blooms*. Windsor Star. https://windsorstar.com/news/local-news/funds-donated-to-study-lake-erie-algal-bloom-troubles.

Becht, M. (1974). Systems theory, the key to holism and reductionism. *BioSience*, 24(10), 569-579.

Beck, M. B. (2016). *Understanding the Science of Ecosystem Services: Engineering Infrastructure for Urban Water Services – An introduction to the Science and Technology of Contemporary Practice*. Applying Systems Thinking: An Outreach Paper prepared for the International Water Association. https://iwa-network.org/wp-content/uploads/2016/03/1453725763-IWA_Ecosystem_Services_web_publication.pdf.

Behmel, S., Damour, M., Ludwig, R., & Rodriguez, M.J. (2016). Water quality monitoring strategies – a review and future perspectives. *Science of the Total Environment*, 571, 1312-1329.

Berkes, F. (2018). *Sacred Ecology [4th Edition]*. Routledge.

Bidstrup, M., Kørnøv, L., & Partidário, M. R. (2016). Cumulative effects in strategic environmental assessment: The influence of plan boundaries. *Environmental Impact Assessment Review*, 57, 151-158.

Borgdorff, H. (2012). *The Conflict of the Faculties: Perspectives on Artistic Research and Academia*. Leiden University Press.

BowTieXP. (2015). *BowTieXP: The next generation BowTie methodology tool – Bowtie Methodology Manual*. RPS. https://bowtierisksolutions.com.au/wp-content/uploads/2019/08/BowTieXP-User-Manual-V9.2-Rev-39.pdf.

Brack, W., Apitz, S. E., Borchardt, D., Brils, J., Cardoso, … & Hein, M. (2009). Toward a holistic and risk-based management framework of European river basins. *Integrated Environmental Assessment and Management*, 5, 5-10.

Bradshaw, G. A., & Borchers, J. C. (2000). Uncertainty as Information: Narrowing the Science-Policy Gap. *Ecology and Society*, 4(1), 7.

Brewer, J., & Hunter, A. (1989). *Multimethod research: A Synthesis of styles*. Newbury Park, CA: Sage.

Brewer, J., & Hunter, A. (2006). *Foundations of Multimethod Research*. Thousand Oaks, CA: Sage Publications, Inc.

Brown, P. R. (2017). Attempting to cultivate mindsets for boundary spanning in remote Indigenous policy. *Research and Evaluation*, 76(4), 412-425.

Bryant, A., Casper, M., Charmaz, K., Henwood, K., Mitchell, R. G., … & Wittgenstein, L. (2011). Introduction: Grounded theory research: Methods and practices. In A. Bryant & K. Charmaz (Eds.), *The SAGE Handbook of Grounded Theory,* (pp.1-28). http://methods.sagepub.com.proxy.lib.uwaterloo.ca/base/download/BookChapter/the-sage-handbook-of-grounded-theory/d5.xml.

Bryman, A. (2012). *Social Research Methods (4th Ed.)*. Oxford University Press.

Burkholder, J. M. (2009). Harmful Algal Blooms. In G. E. Likens (ed.), *Encyclopedia of Inland Waters*, (pp. 264-285). Academic Press.

Cabaj, M., & Weaver, L. (2016). *Collective Impact 3.0: An evolving framework for community change*. Tamarack Institute. https://cdn2.hubspot.net/hubfs/316071/Events/CCI/2016_CCI_Toronto/CCI_Publications/Collective_Impact_3.0_FINAL_PDF.pdf.

Campbell, D. T., and Fiske, D.W. (1959). Convergent and discriminate validation by the multitrait-multimethod matrix. *Psychological Bulletin* 54 (1959):297–312.

Carey, J. (2007). *Mr. John Carey (Director General, Water Science and Technology, National Water Research Institute) at the Environment and Sustainable Development Commit*tee. Statement to the Environment and Sustainable Development Committee on June 12th, 2007. OpenParliament. https://openparliament.ca/committees/environment/39-1/64/john-carey-1/only/.

Carpenter, S., Walker, B., Anderies, J. M., and Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, 4(8), 765–781.

Cashmore M. (2004). The role of science in environmental impact assessment: process and procedure versus purpose in the development of theory. *Environmental Impact Assessment Review*, 24(4), 403–426.

Castleden, H. (2015). *Connecting community-based water monitoring with environmental management and stewardship in Canada*. Canada Water Network, online: https://cwn-rce.ca/wp-content/uploads/2018/07/CWN-EN-Castleden-2015-6Pager-Web.pdf

[CCME] Canadian Council of Ministers of the Environment. (2015). *Guidance manual for optimizing water quality monitoring program design*. Canadian Council of Ministers of the Environment. https://www.ccme.ca/files/Resources/water/water_quality/Guidance%20Manual%20for%20Optimizing%20Water%20Quality%20Monitoring%20Program%20Design_1.0_e.pdf.

[CCME] Canadian Council of Ministers of the Environment. (2006). *A Canada-wide Framework for Water Quality Monitoring*. Canadian Council of Ministers of the Environment. https://www.ccme.ca/files/Resources/water/water_qua l i ty /wqm_framework_1.0_e_web.pdf.

[CEAA] Canadian Environmental Assessment Agency. (2016). *Glossary*. Canadian Environmental Assessment Agency. http://www.ceaa.gc.ca/default.asp?lang=En&n=B7CA7139-1&offset=3#v.

Center for Community Engagement. (2017). *Differences Between Community-Based Research, Community-Based Participatory Research, and Action Research*. Sonoma State University. http://web.sonoma.edu/cce/faculty/differences_cbr_cbpr_ar.html.

Charlton, M. (2009). *Status of Nutrients in the Lake Erie Basin.* Prepared by the Lake Erie Nutrient Science Task Group for the Lake Erie Lakewide Management Plan, presented at the Lake Erie Millennium Network 5th Biennial Conference, April 29-May 1, 2008, University of Windsor, ON. vi + 34 p.

Checkland, P. (1981). *Systems Thinking, Systems Practice*. John Wiley.

Chevalier, J. M., & Buckles, D. J. (2013). *Participatory Action Research: Theory and Methods for Engaged Inquiry*. Routledge.

Conservation Ontario. (2012). Working Together: Protecting natural resources & their functions. Conservation Ontario. https://conservationontario.ca/fileadmin/pdf/policy-priorities_section/IWMFactSheet_PP.pdf.

Conservation Ontario. (2013). *Conservation Authorities of Ontario*. Conservation Ontario. http://conservationontario.ca/about-us/conservation-authorities.

Conservation Ontario. (2016). *Nearshore monitoring: A protocol for assessing lake environments*. Conservation Ontario. https://conservationontario.ca/fileadmin/pdf/policy-priorities_section/GreatLakes_NearshoreMonitoringProtocol.pdf.

Cooperrider, D. L., & Srivastva, S. (1987). Appreciative Inquiry in Organizational Life. In W. A. Pasmore & R. W. Woodman (Eds.), *Research in Organizational Change and Development (Vol. 1)*, (p.p 129-169). Jai Press Incorporated.

Correll, D. L. (1998). The role of phosphorus in the eutrophication of receiving waters: A review. *Journal of Environmental Quality*, 27(2), 261-266.

Council on Environmental Quality, *National Environmental Policy Act – Regulations.* Federal Register Vol. 43, No. 230, November 29, 1978, pp. 55978-56007.

Creed, I. F., Cormier, R., Laurent, K. L., Accatino, F., Igras, J., … & Trick, C. G. (2016). Formal Integration of Science and Management Systems Needed to Achieve Thriving and Prosperous Great Lakes. *BioScience*, 66(5), 408–418.

Creswell, J. W. (2015). *A concise introduction to mixed methods research*. Thousand Oaks, CA: Sage.

Crutzen, P. J., & Ramanathan, V. (2000). The Ascent of Atmospheric Sciences. *Science,* 290(5490), 299-304.

[CWN] Canadian Water Network. (2016). *Synthesis of learnings of the Canadian Watershed Research Consortium*. Canadian Water Network. https://cwn-rce.ca/wp-content/uploads/2018/07/CWN-CanadianWatershed-EN-2016-Web-updated.pdf.

[CWN] Canadian Water Network (2020). *SWEEP – The Slave Watershed Environmental Effects Program*. Canadian Water Network. https://cwn-rce.ca/project/sweep-the-slave-watershed-environmental-effects-program/.

Dayton, A. I., Auer, M. T., & Atkinson, J. F. (2014). Cladophora, mass transport, and the nearshore phosphorus shunt. *Journal of Great Lakes Research*, 40, 790-799.

Deloria Jr., V. (1969). *Custer died for your sins*. Macmillan.

Delormier, T., Cargo, M., Kirby, R., McComber, A., Rice, J., & Potvin, L. (2003). Activity implementation as a reflection of living in balance. *Pimatisiwin: A Journal of Aboriginal and Indigenous Community Health*, 1(1),142–63.

Denzin, N. K., & Lincoln, Y. S. (2008). Introduction: Critical methodologies and Indigenous inquiry. In N. K. Denzin, Y. S. Lincoln, & L. T. Smith (Eds), *Handbook of Critical and Indigenous Methodologies,* (pp. 1-20). Sage Publications Inc.

Denzin, N. K., Lincoln, Y. S., & Smith, L. T. (Eds). (2008). *Handbook of Critical and Indigenous Methodologies*. Sage Publications Inc.

[DFO] Fisheries and Oceans Canada. (2007). *A New Ecosystem Science Framework in Support of Integrated Management*. Communications Branch, Fisheries and Oceans Canada.

Diver, S. (2017). Negotiating Indigenous knowledge at the science-policy interface: Insights from the Xáxli'p Community Forest. *Environmental Science & Policy*, 73, 1–11.

Dubé, M. (2015). *Assessing Cumulative Effects of Canadian Waters*. Canadian Water Network. http://www.cwn-rce.ca/assets/End-User-Reports/Monitoring-Frameworks/Dube/CWN-EN-Dube-2014-5Pager-Web.pdf.

Dubé, M., Duinker, P., Greig, L., Carver, M., Servos, M., . . . & Munkittrick, K. (2013). A framework for assessing cumulative effects in watersheds: an introduction to Canadian case studies. *Integrated Environmental Assessment and Management*, 9(3), 363-369.

Duinker, P.N., & Greig, L. (2006). The impotence of cumulative effects assessment in Canada: ailments and ideas for redeployment. *Environmental Management*, 37(2), 153-161.

Dunnville Mudcat Festival. (2017). *About the Festival*. Dunnville Mudcat Festival. http://dunnvillemudcatfestival.ca/aboutmudcat/.

Dzwairo, B., Otieno, F. A., & Ochieng, G. M. (2010). Making a case for systems thinking approach to integrated water resources management (IWRM). *International Journal of Water Resources and Environmental Engineering*, 1(5), 107-113.

[ECCC] Environment and Climate Change Canada. (2018). *Canada-Ontario Lake Erie Action Plan.* Environment and Climate Change Canada. https://www.canada.ca/content/dam/eccc/documents/pdf/great-lakes-protection/dap/action_plan.pdf.

[ECCC] Environment and Climate Change Canada. (2020a). *Toward the Creation of a Canada Water Agency*. Discussion paper. Environment and Climate Change Canada. https://www.placespeak.com/uploads/6321/Canada_Water_Agency_Discussion_Paper.pdf.

[ECCC] Environment and Climate Change Canada. (2020b). *Protecting Canada's Fresh Water*. PlaceSpeak platform for the creation of the Canada Water Agency. Environment and Climate Change Canada. https://www.placespeak.com/en/topic/6321-protecting-canadas-fresh-water/

[ECCC] Environment and Climate Change Canada. (2021). *Toward the creation of a Canada Water Agency: Stakeholder and public engagement: What we heard*. Online: https://www.canada.ca/en/environment-climate-change/services/water-overview/protecting-freshwater/canada-water-agency-stakeholder-public-engagement-what-we-heard.html

Eimers, C. (2016). Cumulative effects assessment and monitoring in the Muskoka Watershed. Canadian Water Network. https://cwn-rce.ca/report/cumulative-effects-assessment-and-monitoring-in-the-muskoka-watershed/.

Elo, S., Kääriäinen, M., Kanste, O., Pölkki, T., Utriainen, K., & Kyngäs, H. (2014). Qualitative Content Analysis: A Focus on Trustworthiness. *SAGE Open*, 4: 1-10.

Elwell, C. (2002). *Sustainability Impact Assessment of the Earth Summit @ 10 – A Canadian Perspective*. Canadian Institute for Environmental Law and Policy. http://cielap.org/pdf/sia.pdf.

[EMAN Coordinating Office & the Canadian Nature Federation] Ecological Monitoring and Assessment Network Coordinating Office & the Canadian Nature Federation. (2003). *Improving Local Decision-Making through Community Based Monitoring: Toward a Canadian Community Monitoring Network*. Online: https://publications.gc.ca/collections/collection_2014/ec/En40-883-2003-eng.pdf

Fetterman, D. (2019). Empowerment evaluation: a stakeholder involvement approach. *Health Promotion Journal of Australia*, 30(2), 137-142.

[FNIGC] First Nations Information Governance Centre. (2021). *The First Nations Principles of OCAP®*. First Nations Information Governance Centre. https://fnigc.ca/sites/default/files/docs/ocap_path_to_fn_information_governance_en_final.pdf.

[FNIGC] First Nations Information Governance Centre. (2020). *A First Nations Data Governance Strategy*. First Nations Information Governance Centre. https://fnigc.ca/wp-content/uploads/2020/09/FNIGC_FNDGS_report_EN_FINAL.pdf.

Frankfort-Nachmias, C., & Nachmias, D. (1996). *Research Methods in the Social Sciences (5th Ed.)*. Edward Arnold Publishers Ltd.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L. H., Holling, C.S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio*, 31, 437-440.

Fox, B. (2020). *Recent Changes to the Conservation Authorities Act and Moving Forward Together*. Presentation as part of the Latornell Leadership Project, October 6, 2020, online: http://www.latornell.ca/professional-development/

Freire, P. (1970) *Pedagogy of the Oppressed*. Continuum International Publishing Group.

Funtowicz, S. O., & Ravetz, J. R. (1990). *Uncertainty and Quality in Science for Policy (eBook)*. Kluwer Academic Publishers (Springer).

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures* 25(7), 739-755.

Funtowicz, S., & Ravetz, J. (2003). *Post-normal Science*. International Society for Ecological Economics Internet Encyclopaedia of Ecological Economics. http://isecoeco.org/pdf/pstnormsc.pdf.

Gallie, W. B. (1956). Essentially contested concepts. *Proceedings of the Aristotelian Society*, 167–198.

Giles, J. J., & Graham, I. D. (2017). Community-based participatory research and integrated knowledge translation: Advancing the co-creation of knowledge. *Implementation Science*, 12, 150.

Glaser, B., & Strauss, A. L. (1967). *The Discovery of Grounded Theory*. The Aldine Press.

Glasgow, R. E., Green, L. W., Taylor, M. V., & Stange, K. C. (2012). An Evidence Integration Triangle for Aligning Science with Policy and Practice. *American Journal of Preventive Medicine*, 42(6), 646-654.

Glasson, J., Therivel, R., & Chadwick, A. (2013). *Introduction to environmental impact assessment [4th Edition*]. Routledge.

Goertz, G. (2016). Multimethod research. *Security Studies*, 25:3-24.

González, F., Muñoz, J., Arias, J. M., & Montoya, E. (1989). Polyphosphate and orthophosphate content during the life cycle of *Myxococcus coralloides* D. *FEMS Microbiology Letters*, 65(1-2), 105-108.

Goodchild, M. (2021). Relational Systems Thinking: That's How Change is Going to Come, From Our Earth Mother. *Journal of Awareness-Based Systems Change*, 1(1), 75-103.

Gould, S. J. (2003). *The hedgehog, the fox and the magister's pox*. New York: Harmony Books.

Government of Alberta. (2008). *Handbook for State of the Watershed Reporting: A Guide for Developing State of the Watershed Reports in Alberta*. Government of Alberta. http://aep.alberta.ca/water/programs-and-services/water-for-life/partnerships/documents/8044.pdf.

Government of Canada (2017). *Environmental Effects Monitoring*. Government of Canada. https://www.canada.ca/en/environmentclimate-change/services/managing-pollution/environmentaleffects-monitoring.html.

Government of Canada. (2019a). *Monitoring water quality in Alberta oil sands*. Government of Canada. https://www.canada.ca/en/environment-climate-change/services/oil-sands-monitoring/monitoring-water-quality-alberta-oil-sands.html.

Government of Canada (2019b). Goal 6 – Clean water and sanitation. Sustainable Development Goals Data Hub. https://www144.statcan.gc.ca/sdg-odd/goal-objectif06-eng.htm.

Government of Canada. (2020). *When western and Indigenous science and knowledge come together: Collaborative research centred on knowledge co-creation*. Government of Canada. https://www.nrcan.gc.ca/when-western-and-indigenous-science-and-knowledge-come-together-collaborative-research-centred/22929.

Government of Ontario. (2021). *Statements of Environmental Values*. Environmental Registry of Ontario. https://ero.ontario.ca/page/sevs.

Grand River-Lake Erie Working Group. (2012). *A Framework for Identifying Indicators of Water Resource Conditions: Support of Ecological Health by Water Resources in the Grand River-Lake Erie Interface*. Grand River Watershed Water Management Plan, Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/resources/Documents/WMP/Water_WMP_Report_EcoHealth.pdf.

[GRCA] Grand River Conservation Authority. (nd). *Our Watershed*. Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/Our-Watershed.aspx.

[GRCA] Grand River Conservation Authority. (1994). *The Grand Strategy for Managing the Grand River as a Canadian Heritage River*. Prepared for the Canadian Heritage Rivers Board. Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/resources/Documents/CHRS/CHRS_1994_GrandStrategy.pdf.

[GRCA] Grand River Conservation Authority. (2010). *Cumulative Effects Assessment (Water Quality and Quantity) Best Practices Paper for Below-Water Sand and Gravel Extraction Operations in Priority Subwatersheds in the Grand River Watershed*. Grand River Conservation Authority. https://www.grandriver.ca/en/Planning-Development/resources/Documents/Planning_AggregateBestPractices.pdf.

[GRCA] Grand River Conservation Authority. (2014). *Canadian Heritage Rivers System Ten Year Monitoring Report 2004-2014*. Prepared for the Canadian Heritage Rivers Board. Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/resources/Documents/Final-CHRS-10-Year-Monitoring-Report-2004-2014.pdf.

[GRCA] Grand River Conservation Authority. (2017). *Blair Creek Monitoring Program Summary: 2006 – Present*. Prepared by C. Irvine and J. Ivey. Cambridge, ON.

Great Lakes Commission. (2018). *Concerned citizens can now directly invest in improving Lake Erie water quality*. Press release, Great Lakes Commission. https://www.glc.org/news/EriePMarket-091918.

Greenland. (2020). *Canadian Watershed Evaluation Tool (CANWET™)*. Greenland. https://www.grnland.com/Greenland-Technologies-Group/CANWET/CANadian-Watershed-Evaluation-Tool-CANWET.html.

Greig, L., & Pickard, D. (2014). *Environmental Monitoring Triggers: Workshop Report*. Report to Kelly Munkittrick, Canada's Oil Sands Innovation Alliance, Calgary, Alberta. https://www.yumpu.com/en/document/view/35323119/cosia-monitoring-triggers-workshop-report-final/3

[GWF] Global Water Futures. (2020a). *About GWF*. Global Water Futures. https://gwf.usask.ca/about-contact/about-us.php.

[GWF] Global Water Futures. (2020b). *Global Water Futures – Solutions to Water Threats in an Era of Global Change*. Global Water Futures. https://gwf.usask.ca/.

Hanief, A., & Laursen, A. E. (2017). SWAT modeling of hydrology, sediment and nutrients from the Grand River, Ontario. *Water Quality Research Journal*, 54(4), 243-257.

Hartig, J. H., Zarull, M. A., Ciborowski, J. J. H., Gannon, J. E., Wilke, E., … & Vincent, A. (Eds.). (2007). *State of the Strait: Status and Trends of Key Indicators*. Great Lakes Institute for

Environmental Research, Occasional Publication No. 5, University of Windsor, Ontario, Canada. ISSN 1715-3980.

He, C., Rao, Y. R., Skafel, M. G., & Howell, T. (2006). Numerical Modelling of the Grand River Plume in Lake Erie during Unstratified Period. *Water Quality Research Journal of Canada,* 41(1), 16-23.

Head, B. W. (2010). How Can the Public Sector Resolve Complex Issues? Strategies for Steering, Administering and Coping. *Asia-Pacific Journal of Business Administration*, 2, 8-16.

Head, B. W., & J. Alford. (2015). Wicked Problems: Implications for Public Policy and Management. *Administration and Society,* 47, 711-739.

Healthy Land and Waters. (2020). *Ecosystem Health Monitoring Program*. Healthy Land and Waters. https://hlw.org.au/project/ecosystem-health-monitoring-program/.

Hecky, R. E., Smith, R. E., Barton, D. R., Guildford, S. J., Taylor, W. D., … & Howell, T. (2004). The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 61(7), 1285-1293.

Higgins, S. N. (2005a). The Contribution of *Dreissena* to the Resurgence of *Cladophora* in eastern Lake Erie. In *Cladophora Research and Management in the Great Lakes,* (pp. 63–71). Proceedings of a Workshop. UW Milwaukee Great Lakes WATER Institute Special Report No. 2005–01, University of Wisconsin Milwaukee.

Higgins, S. N. (2005b). *Modeling the growth dynamics of Cladophora in eastern Lake Erie*. Ph.D. thesis, University of Waterloo. UWSpace. http://hdl.handle.net/10012/1274.

Higgins, S. N., Howell, E. T., Hecky, R. E., Guildford, S. J., & Smith, R. E. (2005). The wall of green: the status of *Cladophora glomerata* on the northern shores of Lake Erie's Eastern basin, 1995–2002. *Journal of Great Lakes Research,* 31, 547–563.

Higgins, S. N., Howell, E. T., Guildford, S. J., Campbell, L., Hiriart-Baer, V., & Hecky, R. E. (2008). An ecological review of *Cladophora glomerata* (Chlorophyta) in the Laurentian Great lakes. *Journal of Phycology*, 44(4), 839-854.

Hipel, K. W., Obiedi, A., Fang, L., & Kilgour, D. M. (2008). Adaptive Systems Thinking in Integrated Water Resources Management with Insights into Conflicts over Water Exports. *INFOR: Information Systems and Operational Research*, 46(1), 51-69.

Ho, E. (2013). *Mapping Youth-led Engagement: Impacts of Youth-led Engagement in English Canada over the Last 35 Years*. Master’s thesis, University of Waterloo. UWSpace. http://hdl.handle.net/10012/7974.

Ho, E. (2018). Criteria-based ranking (CBR): A comprehensive process for selecting and prioritizing monitoring indicators. *MethodsX*, 5, 1324-1329.

Ho, E., Dhaliwal, M., & Wright, K.-A. (2021). *Grand-Erie Study Practitioner Insights for stronger monitoring in the Grand River interface*. Interview summary report.

Ho, E., Ding, D., & Dhaliwal, N. (2021). *Indicators for assessing cumulative effects of nutrients on Cladophora (December 7, 2020)*. Workshop summary report.

Ho, E., Eger, S., & Courtenay, S. (2016). *Building Stronger Social and Ecological Communities in the Muskoka Watershed*. Report to the Muskoka Watershed Council.

Ho, E., Eger, S., & Courtenay, S. (2018). Assessing current monitoring indicators and reporting for cumulative effects integration: A case study in Muskoka, Ontario, Canada. *Ecological Indicators*, 95, 862-876.

Ho, E., & Runnalls, J. (2018). *Blueprint: Generation SDG*. Waterloo Global Science Initiative. Waterloo Global Science Initiative.

Ho, E., & Miller, R. (Eds). (2020). *Grand Expressions – A Self-guided Tour*. The Grand-Erie Study. www.granderiestudy.ca/tour.

Ho, E., & Miller, R. (2021). Indigenous youth are playing a key role in solving urgent water issues. *The Conversation*, March 18, 2021, online: https://theconversation.com/indigenous-youth-are-playing-a-key-role-in-solving-urgent-water-issues-157251

Ho, E., Trant, A., Gray, A., & Courtenay, S. C. (2020). Comparison of freshwater monitoring approaches: strengths, opportunities, and recommendations. *Environmental Monitoring and Assessment*, 192, 614.

Ho, E., Clarke, A., & Dougherty, I. (2015). Youth-led social change: Topics, engagement types, organizational types, strategies, and impacts. *Futures*, 67, 52-62.

Holgate, S. A. (2012). Emerging Professions: Knowledge Broker. *Science (Careers Articles)*. https://www.sciencemag.org/careers/2012/06/emerging-professions-knowledgebroker.

Holling, C. S. (1978). *Adaptive Environmental Assessment and Management*. John Wiley and Sons.

Holling, C. S. (1992). Cross-Scale Morphology, Geometry, and Dynamics of Ecosystems. *Ecological Monographs*, 62(4), 447-502.

Holmes, J., & Scott, A. (2010). Bridging the Gaps between Science and Policy: A Review of the Evidence and some Principles for Effective Action. In P. Quevauviller (Ed.), *Water System Science and Policy Interfacing*, (pp. 15-34). RSC Publishing.

Hotze, T. (2011). Identifying the Challenges in Community-Based Participatory Research Collaboration. *American Medical Association Journal of Ethics*, 13(2), 105-108.

Howlett, M., Ramesh, M., & Perl, A. (2009). *Studying Public Policy: Policy Cycles and Policy Subsystems [3rd Edition]*. Oxford University Press.

Hulme, M. (2009). The Performance of Science. In M. Hulme, *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*, (pp. 72-108). Cambridge University Press.

Hume, D. (1978). *A treatise of human nature (Reprint).* L. A. Selby-Bigge and P. H. Nidditch (Eds.). Oxford University Press.

Hume, D. (1739). *A treatise of human nature (Vol. 1)*. Longmans Green and Co.

Humphrey, A. (2005). *SWOT Analysis for Management Consulting*. SRI Alumni Association Newsletter, December 2005. SRI International. https://www.sri.com/sites/default/files/brochures/dec-05.pdf.

[IAGLR] International Association of Great Lakes Research. (2021). *Join us online*. Conference homepage. International Association of Great Lakes Research. http://iaglr.org/iaglr2021.

[ICWE] International Conference on Water and the Environment. (1992). *The Dublin Statement on Water and Sustainable Development*. International Conference on Water and the Environment, Dublin, 26-31 January 1992. http://www.un-documents.net/h2o-dub.htm.

Interagency Advisory Panel on Research Ethics. (2018). *TCPS 2 (2018) – Chapter 9: Research Involving the First Nations, Inuit and Métis Peoples of Canada*. Government of Canada. https://ethics.gc.ca/eng/tcps2-eptc2_2018_chapter9-chapitre9.html.

International Society on MCDM. (nd). *Short MCDM History*. International Society on MCDM. https://www.mcdmsociety.org/content/short-mcdm-history-0.

Ishikawa, K. (1968). *Guide to Quality Control*. JUSE Press Ltd.

Ishikawa, K. (1976). *Guide to Quality Control*. Asian Productivity Organization. ISBN 92-833-1036-5.

Israel, B. A., Schulz, A. J., Parker, E. A., & Becker, A. B. (1998). Review of Community-based Research: Assessing Partnership Approaches to Improve Public Health. *Annual Review of Public Health,* 19, 173-302.

Jacob, M. J. (1995). An Unfashionable Audience. In E. Lacey (Ed.), *Mapping the Terrain*, (pp. 50-59). Bay Press.

Jeppesen, E., Soendergaard, M., Jensen, J. P., Havens, K. E., Anneville, O., ... & Winder, M. (2005). Lake responses to reduced nutrient loading–an analysis of contemporary long---term data from 35 case studies. *Fresh water Biology*, 50(10), 1747-1771.

Jones, C. (2005). *OBBN-Implementation Survey: September 2005*. Ontario Benthos Biomonitoring Network Report Download Page. Saugeen Valley Conservation Authority. http://www.svca.on.ca/download/benthos/OBBN_Participants_Survey_Sep_2005.pdf.

Jones, F. C. (2016). Cumulative Effects Assessment: Theoretical Underpinnings and Big Problems. *Environmental Reviews*, 24, 187-204.

Jones, F. C., Baird, D., Browman, M. F., Cameron, G., Craig, B., … & Whitelaw, G. S. (2006). Performance of Ontario's Benthos Biomonitoring Network: Impacts on Participants' Social Capital, Environmental Action, and Problem-solving Ability. *Environments Journal*, 34(1), 37-53.

Jones, F. C., Somers, K. M., Craig, B., & Reynoldson, T. B. (2007). *Ontario Benthos Biomonitoring Network: Protocol Manual*. Queen's Printer for Ontario. ISBN 978-1-4249-2121-8. PIBS 5816e.

Jones, P. (2015). SWEEP – *The Slave Watershed Environmental Effects Program*. Canadian Water Network. http://cwn-rce.ca/project/sweep-the-slave-watershedenvironmental-effects-program/.

Jones, P. (2017). Slave Watershed Environmental Effects Program. Canadian Water Network. http://cwn-rce.ca/wp-content/uploads/2018/07/CWN-EN-SlaveRiver-2016-7Pager-Web.pdf.

Kajanus, M., Leskinen, P., Kurttila, M., & Kangas, J. (2012). Making use of MCDS methods in SWOT analysis—Lessons learnt in strategic natural resources management. *Forest Policy and Economics*, 20, 1-9.

Kay, J. & Schneider, E. (1994). Chapter 4 – Embracing complexity: the challenge of the ecosystem approach. In L. Westra & J. Lemons (Eds.), *Perspectives on Ecological Integrity, (*pp.49-59). Springer.

Kemp, R., Parto, S., & Gibson, R. B. (2005). Governance for sustainable development: moving from theory to practice. *International Journal of Sustainable Development*, 8(1/2).

Kirkness, V. J. & R. Barnhardt. (2001). First Nations and Higher Education: The Four R's – Respect, Relevance, Reciprocity, Responsibility. In R. Hayoe & J. Pan (eds.), *Knowledge Across Cultures: A Contribution to Dialogue Among Civilizations*. Comparative Education Research Centre, The University of Hong Kong.

Kønig, N., Børsen, T., & Emmeche, C. (2017). The ethos of post-normal science. *Futures*, 12-24.

Kovach, M. (2009). *Indigenous Methodologies: Characteristics, Conversations, and Contexts*. Toronto, ON: University of Toronto Press Inc.

Kristensen, P. (2004). *The DPSIR Framework*. Paper presented at the 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya. http://wwz.ifremer.fr/dce/content/download/69291/913220/file/DPSIR.pdf.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. University of Chicago Press.

[Lake Erie LaMP] Lake Erie Lakewide Management Plan. (2011). *Lake Erie Binational Nutrient Management Strategy: Protecting Lake Erie by Managing Phosphorus*. Prepared by the Lake Erie LaMP Work Group Nutrient Management Task Group.

https://www.epa.gov/sites/production/files/2015-09/documents/binational_nutrient_management.pdf.

Lake Erie Millennium Network. (2016). *State of Knowledge of Cladophora in the Great Lakes Workshop: Executive Summary*. Workshop summary compiled for the Annex 10 Task Group. Held at NOAA-Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, USA, January 26-28, 2016. https://yosemite.epa.gov/sab/sabproduct.nsf/F0511648B656303F85257FB800739B4E/$File/Cladophora+Workshop+Executive+Summary+-+May+10+2016+(final).pdf.

Larson, B. (2011). *Metaphors for environmental sustainability: Redefining our relationship with nature*. Yale University Press.

Leopold, L. B., Clarke, F. E., Hanshaw, B. B., & Balsley, J. R. (1971). *A Procedure for Evaluating Environmental Impact*. United States Geological Survey, Geological Survey Circular No. 645, Washington, US. https://pubs.usgs.gov/circ/1971/0645/report.pdf.

Levine, C. R., Yanai, R. D., Lampman, G. G., Burns, D. A., Driscoll, C. T., … & Schoch, N. (2014). Evaluating the efficiency of environmental monitoring programs. *Ecological Indicators*, 39(2014), 94-101.

Li, J., Ianaiev, V., Huff, A., Zalusky, J., Ozersky, T., & Katsev, S. (2021). Benthic invaders control the phosphorus cycle in the world's largest fresh water ecosystem. *Proceedings of the National Academy of Sciences of the United States of America*, 118(6), 1-9.

Lickers, H. (2020). *A letter from Henry Lickers*. IAGLR LAKES Letter, Fall 2020. http://iaglr.org/ll/2020-4-Fall_LL7.pdf.

Liljia, E. 2015. *Art, Research, Empowerment*. Stockholm: Elanders Sweden AB.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage.

Lindenmayer, D. B., & Likens, G. E. (2009). Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology & Evolution*, 24(9), 482-6.

Liu, W., Li, S., Bu, H., Zhang, Q., & Liu, G. (2012). Eutrophication in the Yunnan Plateau lakes: the influence of lake morphology, watershed land use, and socioeconomic factors. *Environmental Science and Pollution Research*, 19(3), 858-870.

Liu, Y., Yang, W., Leon, L., Wong, I., McCrimmon, C., … & Fong, P. (2016). Hydrologic modeling and evaluation of Best Management Practice scenarios for the Grand River watershed in Southern Ontario. *Journal of Great Lakes Research*, 42(2016), 1289-1301.

Loomer, H. A., & Cooke, S. E. (2011). *Water Quality in the Grand River Watershed: Current Conditions & Trends (2003 – 2008).* Grand River Conservation Authority, Cambridge, ON.

Lost Rivers of Toronto Project. (nd). Disappearing Rivers interactive map. A partnership between the Lost Rivers of Toronto Project and Geohistory/Géohistoire, the Canadian Historical GIS Partnership Development Project. http://www.lostrivers.ca/disappearing.html.

Maccoux, M. J., Dove, A., Backus, S. M., & Dolan, D. M. (2016). Total and soluble reactive phosphorus loadings to Lake Erie: A detailed accounting by year, basin, country, and tributary. *Journal of Great Lakes Research*, 42(6), 1151-1165.

MacDougall, J. D., & Ryan, P. A. (2012). *An Assessment of Aquatic Habitat in the Southern Grand River, Ontario: Water Quality, Lower Trophic Levels and Fish Communities.* Lake Erie Management Unit, Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Port Dover, Ontario.

Maher, C., Hadfield, M., Hutchings, M., & de Eyto, A. (2018). Ensuring Rigor in Qualitative Data Analysis: A Design Research Approach to Coding Combining NVivo With Traditional Material Methods. *International Journal of Qualitative Methods*, 17(1), 1-13.

Malkin, S.Y., Guildford, S.J., & Hecky, R.E. (2008). Modeling the growth response of Cladophora in a Laurentian Great Lake to the exotic invader Dreissena and to lake warming. *Limnology and Oceanography*, 53(3), 1111-1124.

Mann, B. A. & Fields, J. L. (1997). A sign in the sky: dating the League of the Haudenosaunee. *American Indian Culture & Research Journal*, 21(2), 105–163.

Marshall, M. N. (1996). The Key Informant Technique. *Family Practice*, 13(1), 92-97.

Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., … & Moore, H. (2013). Transdisciplinary global change research: the co-creation of knowledge for sustainability. *Current Opinion on Environmental Sustainability* 5, 420-431.

McAfee, B., & Malouin, C. (2008). *Implementing ecosystem-based management approaches in Canada's forests. A science-policy dialogue*. Natural Resources Canada, Canadian Forest Service, Headquarters, Science and Programs Branch, Ottawa.

McFadden, L., Priest, S., Green, C., & Sandberg, A. (2009). *Report: Basic Principles of Science and Policy Integration.* Coastal Systems Approach Framework. http://www.coastal-saf.eu/All_PDFs/Basic_Principles_of_Science_and_Policy_Integration.pdf.

McSweeney. (2017). *Haldimand County Economic Development Strategy*. Report prepared by McSweeney for Haldimand County. https://www.haldimandcounty.on.ca/uploadedFiles/Business/Economic_Development/Haldimand%20ED%20Strategy%20-%20final.pdf.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). *The Limits to Growth*. Universe Books.

Merton, R. K. (1973). *The normative structure of science. The sociology of science: Theoretical and empirical investigations*. University of Chicago Press.

Mik-Meyer, N. (2020) Multimethod qualitative research. In: D. Silverman (ed.) *Qualitative Research*. London: Sage, pp. 357-374.

Miller, J. (2020). *Feeding the sacred fire: Highlights from the spiritual and ceremonial gathering at the Turtle Lodge*. Reconciling Ways of Knowing: Indigenous Knowledge and Science Forum. https://www.waysofknowingforum.ca/reports.

[MNCFN] Mississaugas of the New Credit First Nation. (nd). *Community Profile*. Mississaugas of the New Credit First Nation. http://www.newcreditfirstnation2015.com/community-profile/#mississauga.

[MNRF] Ministry of Natural Resources and Forestry. (2016). *Technical Bulletin: Maintaining Water Management Plan*s. Ministry of Natural Resources and Forestry. https://www.owa.ca/wp-content/uploads/2017/01/NEW-Maintaining-Water-Management-Plans.pdf.

[MOEE] Ministry of Environment and Energy. (1994). *Water Management: Policies – Guidelines – Provincial Water Quality Objectives of the Ministry of Environment and Energy*. Queen's Printer for Ontario.

Nakkeeran, N., & Zodpey, S. P. (2012). Qualitative research in applied situations: Strategies to ensure rigor and validity. *Indian Journal of Public Health*, 56(1), 4-11.

Nandogikendan. (nd). *Dish With One Spoon*. Nandogikendan. https://nandogikendan.com/dish-with-one-spoon/.

Natcher, D. (2001). Land use research and the duty to consult: a misrepresentation of the Aboriginal landscape. *Land use policy*, 18, 113–122.

Natcher, D., Davis, S., & Hickey, C. (2005). Co-management: managing relationships, not resources. *Human Organization*, 64, 240–250.

Nicholls, K. H. & Hopkins, G. J. (1993). Recent changes in Lake Erie (North Shore) phytoplankton: cumulative impacts of phosphorus loading reductions and the zebra mussel introduction. *Journal of Great Lakes Research*, 19(4), 637–647.

Niemeijer, D., & de Groot, R. S. (2008). A conceptual framework for selecting environmental indicator sets. *Ecological Indicators*, 8, 14–25.

[NOAA] National Oceanic and Atmospheric Administration. (2017). *NOAA, partners predict significant summer harmful algal bloom for western Lake Erie*. National Oceanic and Atmospheric Administration. http://www.noaa.gov/media-release/noaa-partners-predict-significant-summer-harmful-algal-bloom-for-western-lake-erie.

Noble, B. (2006). *Introduction to Environmental Impact Assessment: A Guide to Principles and Practice*. Oxford University Press.

Noble, H. & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-Based Nursing*, 18, 34-35.

Northwest Territories. (2015). *2016-2020 Action Plan*. Northwest Territories Cumulative Impact Monitoring Program. Northwest Territories. http://www.enr.gov.nt.ca/sites/enr/files/press_pdf_cam_nwtcimp_nwt_cimp_action_plan_2016-2020_designed_30_september_2015.pdf.

Onondaga Nation. (2021). *Two Row Wampum - Gä•sweñta'*. Onondaga Nation. https://www.onondaganation.org/culture/wampum/two-row-wampum-belt-guswenta/.

Orr, E. (2019). *Preserving the integrity of Ontario Conservation Authorities*. Public Sector Digest. https://publicsectordigest.com/article/preserving-integrity-ontario-conservation-authorities.

Panagiotou, G. (2003). Bringing SWOT into focus. *Business Strategy Review*, 14(2), 8-10.

Parks Canada. (2017). *Ecosystem management and ecosystem models*. Parks Canada. https://www.pc.gc.ca/en/pn-np/ab/banff/info/gestion-management/enviro/approche-eco-mgmt.

Polfus, J. L., Heinemeyer, K., Hebblewhite, M., & Taku River Tlingit First Nation. (2013). Comparing traditional ecological knowledge and western science woodland caribou habitat models. *Wildlife Management*, 78(1), 112-121.

Poonwassie, A., & Charter, A. (2001). An Aboriginal worldview of helping: Empowering approaches. *Canadian Journal of Counselling*, 35, 1.

Posey, D. A. (1996). *Traditional Resource Rights: International Instruments for Protection and Compensation for Indigenous Peoples and Local Communities*, IUCN.

Powell, N., Shilton, A. N., Pratt, S., & Chisti, Y. (2008). Factors influencing luxury uptake of phosphorus by microalgae in waste stabilization ponds. *Environmental Science & Technology*, 42, 5958-5962.

Prell, C., Hubacek, K., & Reed, M. (2009). Stakeholder Analysis and Social Network Analysis in Natural Resource Management. *Society and Natural Resources*, 22, 501-518.

Prell, C., Hubacek, K., Quinn, C., & Reed, M. (2008). 'Who's in the network?' When stakeholders influence data analysis. *Systemic Practice and Action Research*, 21, 443-458.

Professional Institute of the Public Service of Canada. (2014). *Vanishing science: The disappearance of Canadian public interest science*. Professional Institute of the Public Service of Canada. http://www.pipsc.ca/portal/page/portal/website/issues/science/vanishingscience.

Punch, K. F. (1998). In*troduction to Social Research: Qualitative and Quantitative Approaches*. Sage Publications.

Putnam, H. (1995). *Pragmatism*. Blackwell.

Quevauviller, P. (nd). *Science and policy integration – The ultimate challenge*. Presentation to the IMPRINTS Consortium. http://www.crahi.upc.edu/imprints/final/images/stories/pdf/imprints_pdfs/presentations/IMPRINTS_Philippe.pdf

Ramaswamy, V., & Gouillart, F. (2010). Building the Co-Creating Enterprise. *Harvard Business Review*. https://hbr.org/2010/10/building-the-co-creative-enterprise.

Raworth, K. (2012). *A Safe and Just Space for Humanity: Can We Live Within the Doughnut?* Oxfam Discussion Paper. Oxfam.

Reconciliation Canada. (nd). *Background*. Reconciliation Canada. https://reconciliationcanada.ca/about/history-and-background/background/#:~:text=Quick%20Facts%20on%20Residential%20Schools&text=150%2C000%20Indigenous%20children%20were%20taken%20from%20their%20families.&text=90%20to%20100%25%20suffered%20severe,%2C%20emotional%2C%20and%20sexual%20abuse.&text=There%20was%20a%2040%20%E2%80%93%2060,rate%20in%20Indian%20residential%20schools.&text=Residential%20schools%20date%20back%20to%20the%201870s.

Reed, M. S., Graves, A.,… & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management,* 90(5), 1933-1949.

Reed, G., Brunet, N. D., & Natcher, D. C. (2020). Can indigenous community-based monitoring act as a tool for sustainable self-determination? *The Extractive Industries and Society*, 7(4): 1283-1291.

Region of Waterloo. (2020). *2021 GRCA Draft Budget*. Online: https://www.regionofwaterloo.ca/en/regional-government/resources/Budget/2021-GRCA-Draft-Budget---Region-of-Waterloo.pdf

Reid, A., Eckert, L., Lane, J-F., Young, N., Hinch, S. G., … & Marshall, A. (2021). “Two-Eyed Seeing”: An Indigenous framework to transform fisheries research and management. *Fish and Fisheries*, 22(2), 243-261.

Robinson, C., Duinker, P. N., & Beazley, K. F. (2010). A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads. *Environmental Reviews*, 18, 61-86.

Rocktsröm, J., Steffen, W., Noone, K., Persson, Å, Chapin, F. S… & Foley, J. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society,* 14(2), 32.

Roethlisberger, F. J. & Dickson, W. J. (1939). *Management and the worker*. Cambridge, MA: Harvard University Press.

Ross, L. F., Loup, A., Nelson, R. M., Botkin, J. R., Kost, R., … & Gehlert, S. (2010). The challenges of collaboration for academic and community partners in a research partnership: points to consider. *Journal of Empirical Research on Human Research Ethics,* 5(1), 19-31.

Rousseau, D., & Billingham, J. (2018). A systematic framework for exploring worldviews and its generalization as a multipurpose inquiry framework. *Systems*, 6(3), 27.

Ryan, P. A., Knight, R., MacGregor, R., Towns, G., Hoopes, R., & Culligan, W. (2003). *Fish-community goals and objectives for Lake Erie*. Great Lakes Fishery Commission Special Publication 03-02.

Sachs, J. D. (2015). *The Age of Sustainable Development*. Columbia University Press.

Salpeteur, M., Calvet-Mir, L., Diaz-Reviriego, I., & Reyes-García, V. (2017). Networking the environment: social network analysis in environmental management and local ecological knowledge studies. *Ecology and Society*, 22(1), 41.

Scavia, D., Allan, J. D., Arend, K. K., Bartell, S., … & Zhou, Y. (2014). Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia. *Journal of Great Lakes Research,* 40(2): 226-246.

Schindler, D. W. (1974). Eutrophication and recovery in experimental lakes: implications for lake management. *Science*, 184(4139), 897-899.

Schuster-Wallace, C. J., Sandford, R., & Merril, S. (2019). *Water Futures for the World We Want*. University of Saskatchewan, Saskatoon, Canada.

Seawright, J. (2016). Better multimethod design: the promise of integrative multimethod research. *Security Studies*, 25:42-49.

Seewer, J. (2017). *Lake Erie algae in 2017 matches third-most severe on record*. AP News. https://apnews.com/article/fa0cb7455f5c4b21802274d62efa7d9a.

[SERS] School of Environment, Resources and Sustainability. (2016). APPENDIX 3 – PhD Program Overview for the School of Environment, Resources and Sustainability. In, Oelbermann, M.: *Student Guide to Graduate Studies: How to Prepare for your Master's and Ph.D. Degrees and Beyond*, (5th Edition).

[SERS] School of Environment, Resources and Sustainability. (2017). *Research*. School of Environment, Resources and Sustainability. https://uwaterloo.ca/environment-resources-and-sustainability/research.

Servos, M. (2016). *Monitoring and cumulative effects assessment of the Grand River*. Summary report prepared as part of the Canadian Watershed Research Consortium. Canadian Water Network. https://cwn-rce.ca/wp-content/uploads/2018/07/CWN-EN-GrandRiver-2016-7Pager-Web-Revised.pdf.

Servos, M., Dhiyebi, H., Tetreault, G., Schiff, S., Venkiteswaran, J., Yates, A. J., & Van Der Kraak, G. (2015). *A Regional Monitoring Framework for Supporting Cumulative Effects Assessment and Adaptive Management in the Grand River*. Research Progress Report Prepared for the Grand River Research Consortium Meeting April 13, 2015. 71 p.

Shiklomanov, A.I., Hammers, R. B., & Vorosmarty, C. J. (2002). Widespread Decline in Hydrological Monitoring Threatens Pan-Arctic Research. *Eos*, Transactions American Geophysical Union, 83(2), 13-17.

[SSHRC] Social Sciences and Humanities Research Council. (2018). *Toward a successful shared future for Canada*. Social Sciences and Humanities Research Council. https://www.sshrc-crsh.gc.ca/society-societe/community-communite/ifca-iac/03-aboriginal_peoples_in_Canada_report-les_peuples_autochtones_en_Canada_rapport-eng.aspx.

Shore, N., Ford, A., Wat, E., Brayboy, M., Isaacs, M-L., … & Seifer, S. D. (2015). Community-Based Review of Research Across Diverse Community Contexts: Key Characteristics, Critical Issues, and Future Directions. *American Journal of Public Health*, 105(7), 1294-1301.

Smith, L. (1999). *Decolonizing methodologies: Research and indigenous peoples*. Zed Books.

Smith, N. & Wright, J. (2001). *Technical background report for the Grand River Fisheries Management Plan*. Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/resources/Documents/Fishery/Fishery_ManagementPlan_TechReport.pdf.

Six Nations Council. (2008). *The Haldimand Treaty of 1784*. Six Nations of the Grand River. http://www.sixnations.ca/LandsResources/HaldProc.htm.

Six Nations Council. (2013). *Community Profile*. Six Nations of the Grand River. http://www.sixnations.ca/CommunityProfile.htm.

Six Nations Council. (2015). *Six Nations of the Grand River*. Six Nations of the Grand River. http://www.sixnations.ca/SNLands&ResourcesBooklet2015Final.pdf.

Six Nations of the Grand River. (2015). *Six Miles Deep: Land Rights of the Six Nations of the Grand River*. Six Nations of the Grand River. http://www.sixnations.ca/SixMilesDeepBooklet2015Final.pdf.

Steffen, W., Richardson, K., Rockström, J., Cornelle, S. E., Fetzer, I… & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science Express online*, 347(6223), 1259855.

Stephenson, R. L., Benson, A. J., Brooks, K., Charles, A., Degnbol, P., … & Wiber, M. (2017). Practical steps toward integrating economic, social and institutional elements in fisheries policy and management. *ICES Journal of Marine Science*, 74(7), 1981–1989.

Stephenson, R. L., Paul, S., Wiber, M., Angel, E., Benson, A. J., … & Sumilia, U. R. (2018). Evaluating and implementing social–ecological systems: A comprehensive approach to sustainable fisheries. *Fish and Fisheries* 19, 853-873.

Stevens, C.J., Fraser, I., Mitchley, J., and Thomas, M.B. (2007). Making ecological science policy-relevant: issues of scale and disciplinary integration. *Landscape Ecology*, 22, 799-809.

Stewart, T. W. & Lowe, R. L. (2008). Benthic Algae of Lake Erie (1865-2006): A Review of Assemblage Composition, Ecology, and Causes and Consequences of Changing Abundance. *Ohio Journal of Science*, 108(5), 82-94.

Sundstrom, S. M., & Allen, C. R. (2019). The adaptive cycle: More than a metaphor. *Ecological Complexity* 39, 100767.

Tamarack Institute. (2021). *Collective Impact: The Collective Impact Compendium Series*. Tamarack Institute. https://www.tamarackcommunity.ca/collective-impact-compendium-series-resouces.

Tasca, F. A., Goerl, R. F., Michel, G. P., Leite, N. K., Sérgio, D. Z., …& Finotti, A. R. (2020). Application of Systems Thinking to the assessment of an institutional development project of river restoration at a campus university in Southern Brazil. *Environmental Science and Pollution Research*, 27, 14299-14317.

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. *Ambio*, 43(5), 579-591.

Terry, K. R., & Hooper, A. B. (1970). Polyphosphate and Orthophosphate content of *Nitrosomonas europa* as a function of growth. *Journal of Bacteriology*, 103(1), 199-206.

[*The Project*]. nd. *"The Project" Evaluation of Policy Options to Achieve Phosphorus/Nutrients Reductions from Canadian Sources to Lake Erie*. Online: https://buyandsell.gc.ca/cds/public/2014/12/16/b253b04c8fcb5e4833c0f9e010bc1a68/english_phosphorus_and_nutrients_reduction_project_-_background_document.pdf.

The Anglican Church of Canada. (2008). *The Mohawk Institute — Brantford, ON*. Truth and Reconciliation. https://www.anglican.ca/tr/histories/mohawk-institute/.

TheGlobalFund. (2020). *Community-based monitoring: An overview*. Online: https://www.theglobalfund.org/media/9622/core_css_overview_en.pdf

Therivel, R., & Ross, B. (2007). Cumulative effects assessment: Does scale matter? *Environmental Impact Assessment Review*, 27, 365-385.

Tomlinson, L. M., Auer, M. T., Bootsman, H. A., & Owens, E. M. (2010). The Great Lakes *Cladophora* Model: Development, testing, and application to Lake Michigan. *Journal of Great Lakes Research*, 36, 287-297.

Thomson, J. (2019). Indigenous knowledge and the future of science. *The Walrus*. https://thewalrus.ca/indigenousknowledge-and-the-future-of-science.

Tremblay, M.-A. (1957). The Key Informant Technique: A Nonethnographic Application. *American Anthropologist*, 59(4), 688-701.

Triantaphyllou, E. (2000). *Multi-Criteria Decision Making Methods: A Comparative Study*. Springer.

Trudeau, J. (2019). *Minister of Environment and Climate Change Mandate Letter*. Government of Canada. https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-environment-and-climate-change-mandate-letter.

Truth and Reconciliation Commission of Canada. (2015). *Truth and Reconciliation Commission of Canada: Calls to Action*. http://nctr.ca/assets/reports/Calls_to_Action_English2.pdf.

UN-Water. (2017). *Advance Briefing: SDG 6 Synthesis Report on Water and Sanitation*, High-level Political Forum on Sustainable Development 2018. UN-Water Technical Advisory Unit: Geneva, Switzerland.

van den Heuvel, M., Macguarrie, K., St-Hilaire, A., & Courtenay, S. C. (2016). *Cumulative Impacts Assessment in the Northumberland Strait: Linking Land Use, Sediment, and Nutrients With Stream and Estuarine Health*. Canadian Water Network. https://cwn-rce.ca/report/cumulative-impacts-assessment-in-the-northumberland-strait/.

van Oudenhoven, A. P. E., Schröterb, M., Drakoud, E. G., Geijzendorffere, I. R., Sander Jacobs, S., van Bodegoma, P. M., … & Albert, C. (2018). Key criteria for developing ecosystem service indicators to inform decision making. *Ecological Indicators*, 95, 417-426.

Vanni, M. J. (2021). Invasive mussels regulate nutrient cycling in the largest fresh water ecosystem on Earth. *Proceedings of the National Academy of Sciences of the United States of America*, 118(3),1-3.

Veale, B. J. (2004). *A Decade in the Canadian Heritage Rivers System: A Review of The Grand Strategy 1994-2004*. Prepared for the Canadian Heritage Rivers Board. Grand River Conservation Authority. https://www.grandriver.ca/en/our-watershed/resources/Documents/CHRS/CHRS_10YearReport.pdf.

Veale, B. J. (2010). *Assessing the Influence and Effectiveness of Watershed Report Cards on Watershed Management: A Study of Watershed Organizations in Canada*. PhD thesis, University of Waterloo. UWSpace. http://hdl.handle.net/10012/5610.

Vienna Declaration on Artistic Research. (2020). Vienna Declaration on Artistic Research. A policy paper, published June 22, 2020, co-authored by AEC, CILECT / GEECT, Culture Action Europe, Cumulus, EAAE, ELIA, EPARM, EQ-Arts, MusiQuE and SAR. Online: https://aec-music.eu/userfiles/File/Newsitems/2020/Vienna_Declaration_on_AR_final_version_24_June_20.pdf

Vitousek, P. M., Naylor, R., Crews, T., David, M. B., Drinkwater, L. E., ... & Zhang, F. S. (2009). Nutrient imbalances in agricultural development. *Science*, 324(5934), 1519.

Vollenweider, R. A. (1968). *Water management research: Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication*. OECD Tech Rep DAS/CS/68.27.

Walker, S. L., Ribey, S. C., Trudel, L., & Porter, E. (2003). Canadian environmental effects monitoring: experiences with pulp and paper and metal mining regulatory programs. *Environmental Monitoring and Assessment*, 88, 311-326.

Walker, D. H. T., Bourne, L. M., & Shelley, A. (2008). Influence, stakeholder mapping and visualization. *Construction Management and Economics*, 26(6), 645-658.

Walters, C. J. (1986). *Adaptive Management of Renewable Resources*. Macmillan.

Watson, S. B., Miller, C., Arhonditsis, G., Boyer, G. L., Carmichael, W. … & Wilhelm, S. W. (2016). The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. *Harmful Algae*, 56, 44-66.

Weber, M. (1949). *The methodology of the social sciences.* New York: Free Press.

Weber, M., & Schmid, B. (1995). Reductionism, holism, and integrated approaches in biodiversity research. *Interdisciplinary Science Reviews*, 20(1), 49-60.

Whitelaw, G., Vaughan, H., Craig, B., & Atkinson, D. (2003). Establishing the Canadian Community Monitoring Network. *Environmental Monitoring & Assessment*, 88: 409-418.

Wilfred Laurier University. (2019). *Global Water Futures*. Northern Water Futures. https://researchcentres.wlu.ca/northern-water-futures/about/global-water-futures.html.

Wilson, N. J., Mutter, E., Inkster, J., & Satterfield, T. (2018). Community-Based Monitoring as the practice of Indigenous governance: A case study of Indigenous-led water quality monitoring in the Yukon River Basin. *Journal of Environmental Management*, 210: 290-298.

Wong, C., Ballegooyen, K., Ignace, L., Johnson, M. J. (G.), & Swanson, H. (2020). Towards reconciliation: 10 Calls to Action to natural scientists working in Canada. *Facets*, 5(1), 769-783.

World Economic Forum. (2020). *The Global Risks Report 2020*. World Economic Forum Global Risks Initiative. https://www.weforum.org/reports/the-global-risks-report-2020.

World Economic Forum. (2021). *The Global Risks Report 2021*. World Economic Forum Global Risks Initiative. http://reports.weforum.org/global-risks-report-2021/.

[WWAP] World Water Assessment Programme. (2017). *The United Nations World Water Development Report 2017 - Wastewater: The Untapped Resource*. UNESCO.

WWF-Canada. (2020). *2020 Watershed Reports: A national reassessment of Canada's fresh water*. Paquette C. Hemphill L. Merante A. Hendriks E. World Wildlife Fund Canada. Toronto, Canada.

APPENDICES

Appendix A: Grey literature produced as part of this research

Summary reports:

- Community engagement – Great Art for Great Lakes: Ho, E. 2020. *Summary of results: GAGL Feedback For*ms. Ayr, Ontario, February 9, 2020.
- Community engagement – Music for the Spirit & Indigenous Visual Arts: Ho, E. 2020. *What does it mean? Implications of Grand Expressions for Canadian water managers*. Bruce Mines, Ontario, September 1, 2020.
- Workshop – framework review: Ho, E., and Dhaliwal, M. 2020. Workshop Summary: *A Grand-Erie Interface Monitoring Framework*. Bruce Mines, Ontario, October 20, 2020.
- Interviews: Ho, E., Dhaliwal, M., and Wright, K.-A. 2021. *Grand-Erie Study Practitioner Insights for stronger monitoring in the Grand River interface*. Bruce Mines, Ontario, January 4, 2021.
- Workshop – cumulative effects: Ho, E., Ding, D., and Dhaliwal, N. 2021. *Indicators for assessing cumulative effects of nutrients on Cladophora*. Bruce Mines, Ontario, January 4, 2021.

Other publications and literature:

- *Grand Expressions* virtual exhibit: Ho, E., and Miller, R. (Eds). 2020. *Grand Expressions Self-guided Tour (Version 3)*. Bruce Mines, Ontario, October 20, 2020.
    - This publication was viewable on a tablet alongside the ALARM exhibit at THEMUSEUM in Kitchener, Ontario, from August 2020 to January 2021.
- Article in *Water News*: Ho, E. 2020. Grand Expressions: Perspectives from First Nation youth. Special feature in *Water News*, official magazine of the Canadian Water Resources Association (Fall/Winter 2020).
- Article in *Water Canada*: Ho, E. 2020. Overcoming social challenges: Building new ways to improve the diversity of community water management. *Water Canada*, November/December 2020.
- Canadian Rivers Institute blog: Ho, E. 2020. *Does research matter to those we study?* Canadian Rivers Institute blog, November 25, 2020. Online: https://www.canadianriversinstitute.com/blog/2020/11/16/does-research-matter-to-those-we-study

- Invited feature in *The Conversation*: Ho, E., and Miller, R. (2021). Indigenous youth are playing a key role in solving urgent water issues. *The Conversation*, World Water Day feature (published March 18, 2021). Online: https://theconversation.com/indigenous-youth-are-playing-a-key-role-in-solving-urgent-water-issues-157251

There are dozens of other online feature stories, presentations, webinars, and posters that were produced from this research as well.

Appendix B: Researcher vignette

I was born to Canadian immigrants in Toronto, Ontario. The city sits on one of the largest freshwater lakes in the world, fed by several rivers that run through Toronto. As an elementary school student, I came up with my own ways to try and understand the water at our local park, even rationalizing my DIY 'instruments' to random passersby who wondered what a pre-teen in Toronto was doing with containers and a stopwatch, standing in a stream. During high school, I visited a repurposed former quarry and industrial site in the Don River Valley – the Evergreen Brickworks (formerly the Don Valley Brickworks) – for the first time. In the Brickworks Welcome Court, there is an art installation[16] by Ferruccio Sardella, titled *Watershed Consciousness* by the artist, but known locally as the Flourishing Green Watershed Wall. The installation is a 30' x 50' x 4' work of steel, copper, brass, green wall infrastructure, plants, and water. This was the first time I had seen a map of Toronto with only the river systems and freeways represented (e.g., no other roads or human-made landmarks). The extent of the waterways, and how they appeared as veins of the city, were astounding to me. Waters reach nearly every part of the city, as seen in the Toronto and Region Conservation Authority's watershed mapping tool (Figure 13), and if Toronto's lost rivers are recognized – watercourses that were covered, diverted, or drained during urban development – waters reach every part of the city (Lost Rivers of Toronto Project, nd). I began to understand how privileged we were. Potable water always flowed from our taps and it was a given that it would continue to be present without effort and at little cost. Though I had always had an interest in/draw to water, experiencing Sardella's artwork was the start of a more focused interest to study water in more formal ways.

[16] View the artist's blog, including a description of the work and photographs, at https://ferrucciosardella.wordpress.com/watershed-consciousness/

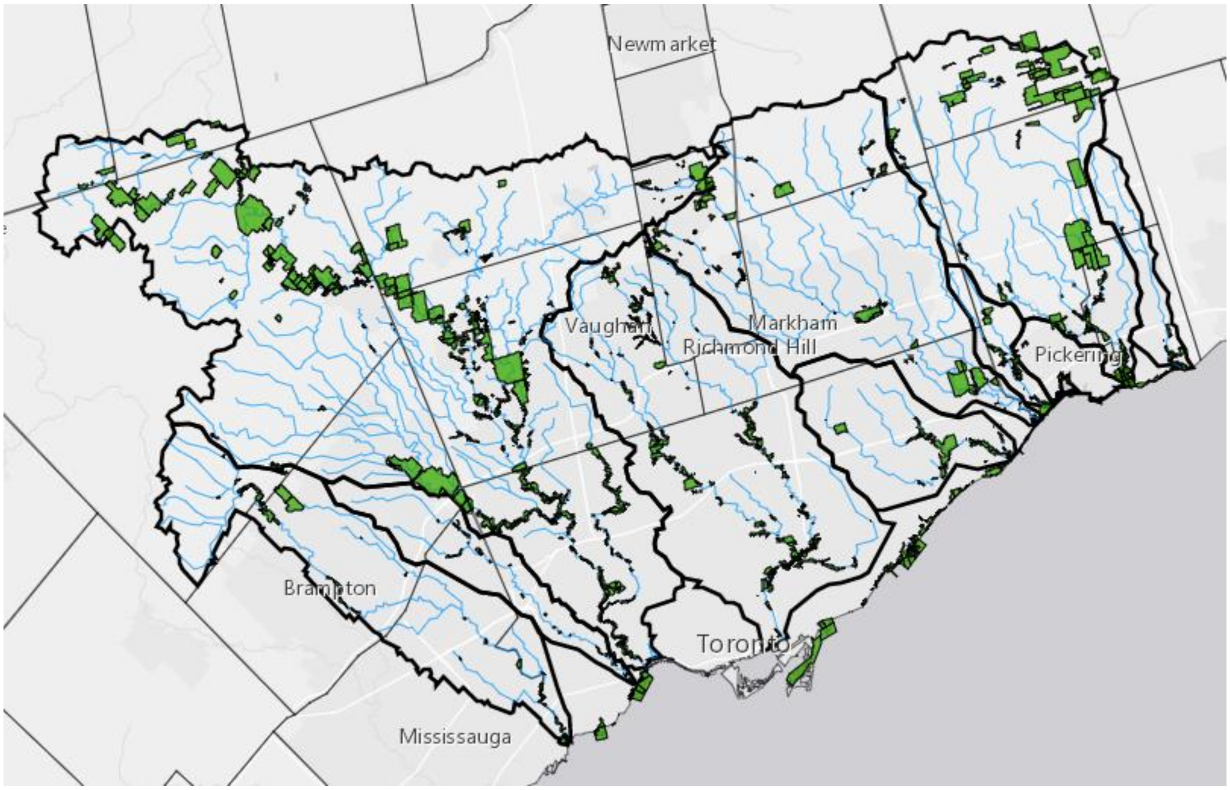


Figure 13. Toronto's vein-like watercourses. Map created by the Toronto and Region Conservation Authority's GIS tool.

Growing up in Toronto also meant being exposed to and normalizing diverse people from various ethnic groups, cultures, religions, and with different health conditions, physical, and cognitive abilities. This experience was a bit of a paradox: on the one hand, I grew up recognizing that each person was important, and each had their own knowledge and ways of approaching societal problems; on the other hand, I was also exposed to people who had not normalized diversity or who viewed certain demographics in inequitable ways. These individuals reacted to me – a mixed-race female raised in a mixed-faith household – with exclusion, racism, harassment, and more. Further, my childhood in a single-parent, low-income household taught me what it was like not to have access to things everyone else around me had access to. Thus, my circumstances led me to value people according to their character and what they bring to the world, not according to identifying features or what they have; yet I also gained a first-hand understanding of how inequity is reinforced and what the personal/human implications of those actions are. As a result, by the time I finished elementary school, I directed much of my extra-curricular professional/academic development activities into pursuits of advocacy and transformation towards a better society for all. This personal mission was integrated with my interest in water during my studies at University of Waterloo (and, to some extent, my short experience at Ryerson University with Faculty who were a part of Ryerson Urban Water).

When I began my undergraduate studies at University of Waterloo in 2008, I was exposed to numerous water issues for the first time (e.g., I had never before known anyone who relied on ground or well water). I recognized consciously for the first time that my childhood reality was not in any way reflective of the rest of the world—or even Ontario. In 2009, I was privileged (thanks to the support of many individuals in my circle and my parents' networks) to participate in the inaugural Redfish School of Change, an action-oriented field school to both educate and inspire positive and transformative societal change. There, I was deeply moved and influenced by several individuals, including Indigenous persons whose cultures I was exposed to (and temporarily immersed into) for the first time. This experience peaked my interest of Indigenous communities and their connections to the world around them. Later, in 2012, I was formally adopted into the Memiri Losho community[17], a rural Maasai (Indigenous) community in Kenya, after beginning what would be a years-long collaboration to empower the community's women and girls, diversify the community's income, and conserve their traditional, pastoral way of life. At around the same time, I lived with an Indigenous woman and social worker from Northern Ontario who spared no time in educating me regarding my (expected) ignorance towards Indigenous communities and their challenges and oppression here in Canada.

Collectively, these experiences strengthened my desire to advocate for positive change – a desire I indulged in my Masters research, studying the impact of 35 years of youth-led engagement in Canada (Ho, 2013; Ho, Clarke, & Dougherty, 2015). As my studies and the global policy agenda focused more on social-ecological sustainability, complexity, and systems thinking, this desire to advocate for change diminished somewhat to make room for a new purpose: to directly instigate much-needed change. As I sought to understand what this would mean for my dissertation (e.g., how to make this research meaningful and actionable for current and future practitioners), the summer of 2019 brought a combination of clarity and direction to both my life and my research. Before then, I had never truly understood how gendered water issues really are (though I thought I did). In May 2019, the Global Water Futures Annual Science Meeting was held in Saskatoon, Saskatchewan. One of the keynote addresses was delivered by an Indigenous elder, who spoke of how the treatment of women reflects our treatment of water. He spoke of our beginnings in our mothers' waters (in the womb), and how important waters are for our whole health (body, mind, and spirit). This resonated strongly with me, as I was five months pregnant at the time and I was constantly evaluating whether the food and drink would be safe for my child anywhere I went (e.g., I relied on bottled water anywhere that was not home). The elder's talk, which was reinforced by communications with many persons in the days, months, and years that

[17] Formal adoption entails meetings of the community's elders to determine whether an individual has contributed to the community in ways that justify adoption into the community, and then the selection of a Maa (the Maasai language) name. The name given to me is Reto, which does not have a true equivalent in English but which roughly translates into 'philanthropist'.

followed, made me realize something that would heavily influence the second half of my dissertation research: that I could not possibly have understood how real the connections described by the elder really are – between women, water, and society – without having been pregnant at the time I heard his talk, despite having lived my life identifying as a woman. In other words, at least in some cases, there is no substitution for lived experience.

Research mandate

This research is part of a larger project, Lake Futures, based at University of Waterloo. In turn, Lake Futures is one of 39 projects in six core teams at 15 Canadian universities that comprise the Global Water Futures (GWF) research programme. GWF, based at University of Saskatchewan, organizes its projects into three pillars that collectively seek solutions to water threats in an era of global change: diagnosing and predicting change in cold regions (Pillar 1), developing big data and decision support systems (Pillar 2), and designing user solutions (Pillar 3). Lake Futures (and this research) falls under Pillar 3. GWF strives to improve disaster warning, prediction of water futures, and our abilities to manage and adapt to water related risks. The main question all projects answer in some way is "How can we best forecast, prepare for and manage water futures in the face of dramatically increasing risks (GWF, 2020a)?" GWF's goal is described as follows:

> The overarching goal of the program is to deliver risk management solutions - informed by leading-edge water science and supported by innovative decision-making tools - to manage water futures in Canada and other cold regions where global warming is changing landscapes, ecosystems, and the water environment. Global Water Futures (GWF) aims to position Canada as a global leader in water science for cold regions and will address the strategic needs of the Canadian economy in adapting to change and managing risks of uncertain water futures and extreme events. End-user needs will be our beacon and will drive strategy and shape our science (GWF, 2020b).

Lake Futures was a six-year research collaboration between Co-Investigators at four universities, in addition to other collaborators at more than 20 other organizations and institutions. The main goal of Lake Futures is "to deliver risk management solutions that will enhance the resilience and adaptive capacity of Canada's large lake basins under changing climate and land use, with a specific focus on water quality and associated ecosystem impacts (Basu, 2017, 3)." The first phase was three years long (May 2017-August 2020) and addressed re-eutrophication of the lower Great Lakes; this was the context for this dissertation. The second phase (September 2020-August 2023) focuses on decision-making strategies, processes, and tools for water security in the Great Lakes Basin, in Canada, and in cold regions across the globe. Deliverables outlined in the proposal include integrated carbon modeling, risk mapping, an algal bloom early detection framework, and tools to help authorities address eutrophication (e.g., a decision-support system and roadmap to strategies).

Lake Futures is divided into work packages that are comprised of individual research subprojects. This research falls under Work Package 3, which has three subprojects. The first subproject within this Work Package uses fuzzy cognitive modeling to build an understanding of human activities that contribute to *Cladophora* (benthic algae) growth in Lake Erie's eastern basin. The second project tested for changes in the trophic ecology of young-of-the-year walleye between different habitat zones in the southern Grand River using stable isotope analyses of nitrogen and carbon, in addition to using acoustic telemetry methods to identify the movement patterns and spawning habitat of mature spring spawning walleye. The third subproject – this research – strives to propose an organizational structure and process framework (collectively referred to as 'the collaboration framework') for water quality monitoring in the Grand River interface and the nearshore of Lake Erie's eastern basin that enables cumulative effects monitoring of nutrients/*Cladophora*. Cumulative effects are incremental and accumulating environmental changes caused by one or more natural or human activities in a region over a specified time (CWN, 2016; Grand River Conservation Authority, 2010). More specifically, these effects are defined as "changes to the biophysical, social, economic, and cultural environments caused by the combination of past, present and 'reasonably foreseeable' future actions (Northwest Territories, 2015)."

This research is based in the School of Environment, Resources, and Sustainability at University of Waterloo. Therefore, the three goals of the School provide context for this research as well: (1) assess implications of actions towards sustainability; (2) understand social-ecological interactions in complex systems, acknowledging that humans impact the environment in many ways; and (3) examine alternatives to what we do to improve social-ecological health (SERS, 2016). These goals extend beyond theoretical exploration, encouraging the implementation of sustainable actions and innovative alternatives to current practice. This research fulfills all three goals. The co-creation of the collaboration framework is an approach to aquatic monitoring that is relatively new (regarding both co-creation and cumulative effects), requiring an in-depth assessment of implications should this alternative approach be implemented (goals 1 and 3). Social-ecological interactions are theoretically considered in a transdisciplinary context (goal 2). Thus, this research follows the four guiding principles for research under the School (SERS, 2017):

1. Recognizing disciplinary knowledge, grounding research in the sciences
    a. This research does not apply conventional science (Kuhn, 1962), but applies decolonizing approaches to post-normal science methodologies (Smith, 1999).
2. Performing research that reaches beyond disciplines
    a. This research is 'issue-driven' (*Funtowicz & Ravetz, 1993).*
3. Committing to stakeholder involvement

   a. This research centers on community (e.g., stakeholder) and rightsholder involvement and collaboration.

4. Embracing systems-thinking to address complexity within sustainability challenges

   a. The quest of this research to enable cumulative effects monitoring, and its discussions around holistic thinking, support systems approaches considerate of complexity and sustainability.

In summary, Global Water Futures provides a mandate for user-driven research that connects water science and management. Within GWF, Lake Futures strives to maintain and promote the health of the Canadian Great Lakes. Lake Futures Work Package 3 emphasizes Lake Erie; both the second subproject and this research (the third subproject) focus on the (lower) Grand River and the nearshore area of Lake Erie's eastern basin. The School of Environment, Resources and Sustainability promotes pursuits to understand complex social-ecological interactions and their implications on sustainability, encouraging real-world application (and action) to improve human-nature interactions.

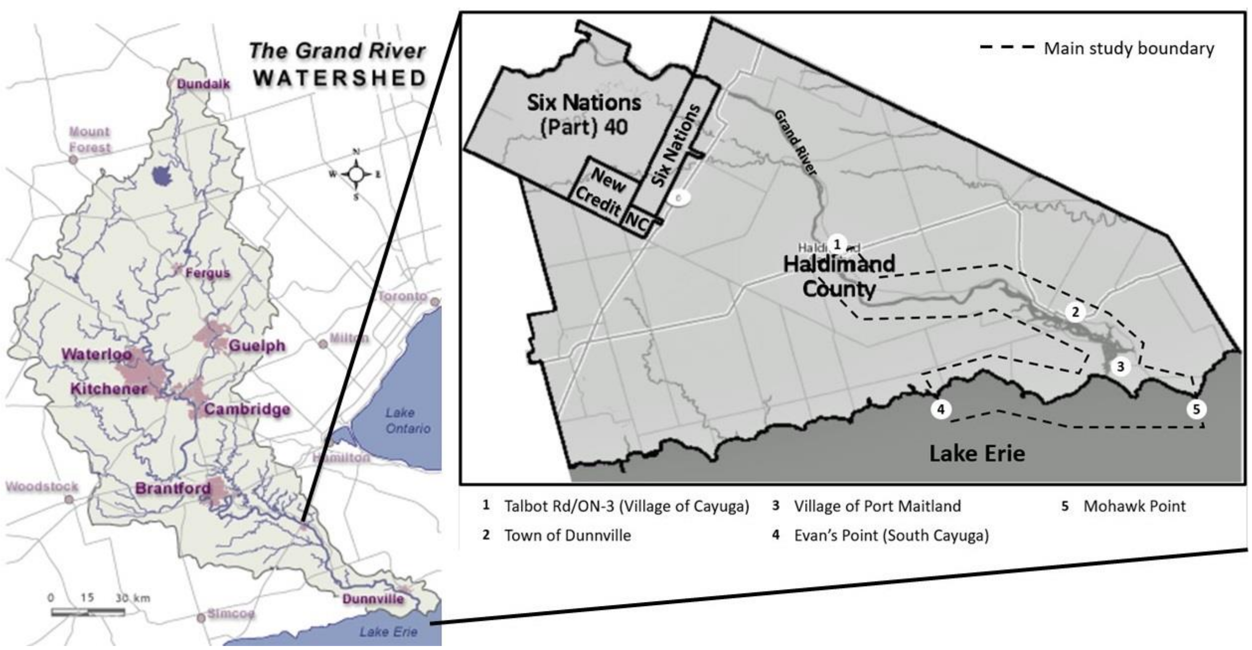
Appendix C: Interview routing questionnaire

Pre-interview questionnaire (via Survey Monkey)

This questionnaire will help the researcher select the most relevant questions for you. Questions with an asterisk (*) are required.

1. First and last name*:

2. Which of the following statements best describes you*?
   - I live in the Grand River watershed and/or nearshore Lake Erie – see Figure (below)
   - I work in the Grand River watershed and/or nearshore Lake Erie, or at least one of these areas is part of my professional portfolio – see Figure (below)
   - Both of the above
   - None of the above, but I am familiar with the Grand River watershed and/or nearshore Lake Erie– see Figure (below)
   - None of the above
   - Optional – details:



3. Please select the topics you are comfortable discussing in detail (select all that apply)*:

- Cumulative effects related to water monitoring
- Environmental and/or water monitoring
- Collaboration or coordination of multiple parties for resource monitoring or management purposes
- Surface water monitoring in the lower Grand River watershed (including strengths and weaknesses of current monitoring activities in the lower Grand River) – see Figure
- Monitoring activities at the mouth of the Grand River into the nearshore of Lake Erie (including strengths and weaknesses of current monitoring activities in this area) – see Figure
- Integrating science and decision-making in general (e.g., the role of science in decision-making, how it is used, and by whom)
- The use of information from water monitoring activities in decision-making (e.g., using trends and changes identified, and/or state of the resource, to inform decisions; how often this is done, by whom)

4. Are there any comments you would like to share with the researcher that will help with question selection, or that you feel the researcher needs to be aware of prior to the interview? This information will ensure time spent for the interview is as relevant and succinct as can be.

5. Do you require a list of question topics prior to the interview*?
    - Yes
    - No

Closing screen

Thank you for participating in the Key Informant pre-interview questionnaire! Your responses will ensure your interview questions are relevant to you and that our interview time is well-spent.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23008). If you have questions for the Committee contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

Elaine will email you to arrange a mutually-convenient place and time for your interview. If you have any general comments or questions related to this study, please contact Elaine Ho, PhD Candidate (School of Environment, Resources and Sustainability), at e23ho@uwaterloo.ca.

Appendix D: Interview question pool

PART A – Monitoring

1. Please describe your background and experience with monitoring.
2. Based on your experience, what are some strengths of monitoring activities?
    - E.g., what aspects of current monitoring are strong or successful, and what gives the current approach an advantage over other approaches?
3. Based on your experience, what are weaknesses of existing monitoring programs? What gaps exist?
    - E.g., what aspects of current monitoring are not as effective as they were expected to be, and what gives the current approach a disadvantage over other approaches?
4. If you could imagine your ideal watershed monitoring program, how would you describe it?
    - Anything different from current best practices?
    - Who should oversee this program?
    - What are the preconditions, pieces, and relationships that must be in place for this ideal monitoring program to succeed?
5. Do you know of a monitoring program that is like this? If not, in your experience, what do we need to do to bring programs you are familiar with to this point?
6. What are the things you (personally, not as an employee) value most about the Grand River and/or Lake Erie?
    - E.g., what do you think is memorable or special about it, whether water-related or not? What do you most like about living, working, and playing here? What should be a priority (either to improve or to protect)?

PART B – Cumulative effects

1. What does "cumulative effects" mean to you?
2. Do you know of any good examples in which cumulative effects are considered in monitoring programs? If so, what are these examples and how are these programs different than programs that do not consider CE?
3. If you were to adapt an existing monitoring program so that it would incorporate cumulative effects, what would you do?
    - E.g., what steps would you take to ensure CE are captured and applied to decisions? What would you need to know?

PART C – Decisions and coordination

1. Some people argue that decision-makers should make better use of scientific information to guide decisions, while others argue the information available is inadequate for use in decision-making. What are your thoughts on whether monitoring information is useful in decision making, and how to make sure monitoring information is used in future decision making?
    - *Decision-makers only*:
        1. Once you know what information you need to inform decisions, how do you go about finding it?
        2. Do you feel you have the kind of information you need to make the decisions you need to make? If not, please explain.
        3. What kind of decisions do you make or do you wish to make based on monitoring data or information?
2. What are the current water-related priorities for your organization?
3. Are Decision Support Tools used in your role or by others in your organization to guide decisions related to fresh water resources?
    - *If yes*: Is the information used in decision making? How so, or why not?
    - *If no*: Would DSS tools be considered, and would the information they provide be used in decision making? Why or why not?
4. Water monitoring is done by multiple organizations, carried out by many individuals. For example, in the Grand River watershed, the Conservation Authority, municipalities, industries (e.g., drinking water, aggregates, developers), academics, government, and some community groups all do different kinds of monitoring of the water system. Then there are also Federal authorities and groups under the Binational Agreement at the mouth of the river into Lake Erie. How effective do you think coordination among the different organizations is, and why? How can coordination be improved?

Part D – Conclusion

1. The end goal of this research is to propose a monitoring framework for the lower Grand River and nearshore Lake Erie that considers cumulative effects and aligns with or influences resource management decisions. With this in mind, is there any other information that you want to share?
2. Would you be interested in being contacted for future involvement in this research (e.g., if there are follow-up questions from this interview at a later date, or if there is another opportunity to be involved, e.g., an online survey)?
3. Do you want a copy of a report summarizing the results of this phase of the research?

Appendix E: Research participants

Interviewees

Federal level

- Mark McMaster, Research Scientist, Environment and Climate Change Canada
- Trevor Swerdfager, Senior Vice-President Operations, Parks Canada (former Assistant Deputy Minister of Science, Fisheries and Oceans Canada)
- Sandra George, Great Lakes Programs Coordinator, Environment and Climate Change Canada
- Luca Cargnelli, Great Lakes Program Officer (Lake Erie Lead), Environment and Climate Change Canada
- Todd Howell, Great Lakes Ecologist, Ministry of Environment and Climate Change

Ontario level

- Chris Jones, Benthic Monitoring Research Scientist, Ministry of the Environment, Conservation and Parks
- Tom MacDougall, Rehabilitation Ecologist, Lake Erie Management Unit, Ministry of Natural Resources and Forestry
- Georgina Kaltenecker, Provincial (Stream) Water Quality Monitoring Network, Ministry of Environment and Climate Change

Watershed/community level

- Crystal Allen, Supervisor of Natural Heritage, Grand River Conservation Authority
- Ryan Hamelin, Ecologist, Grand River Conservation Authority
- Sandra Cooke, Chief Water Quality Specialist, Grand River Conservation Authority
- Felix Barbeti, Grand River Fisheries Management Plan Implementation Committee (1st Vice Chair, Ontario Federation of Anglers and Hunters, Zone J)
- Warren Yerex, Grand River Fisheries Management Plan Implementation Committee (Trout Unlimited, Middle Grand Chapter)
- Larry Halyk, Grand River Fisheries Management Plan Implementation Committee (President of Trout Unlimited, Middle Grand Chapter)
- Joe Tetreault, Grand River Fisheries Management Plan Implementation Committee (2nd Vice Chair, Ontario Federation of Anglers and Hunters, Zone J)

- Stephanie Morningstar, Indigenous Knowledge Mobilization Specialist, Global Water Futures (McMaster University); community member from Six Nations of the Grand River

Other

- Lorne Greig, independent scientist (former Ministry of Natural Resources and Forestry); Associate, ESSA Technologies Ltd
- Elizabeth Hendriks, Vice-President, Freshwater, World Wildlife Fund Canada (former Water Policy and Governance Coordinator with POLIS Water Sustainability Project)
- Katherine Griffiths, Postdoctoral Fellow, LakePulse Network
- Kevin Reid, Assessment Manager and Biologist, Ontario Commercial Fisheries Association
- Jack Imhof, retired (formerly Ministry of Natural Resources and Forestry and National Biologist/Director of Conservation Ecology for Trout Unlimited)

Artists contributing to *Grand Expressions*

- Thomas H. Anderson
- Clinton Bomberry-Smith
- Olivia Bomberry-Smith
- Ashley Cattrysse
- Cody Doolittle
- Trinity Gordon
- Paityn Hill
- Tayler Hill
- Adriana Johnson
- Steve Johnson
- K.M.C. Miller
- Hannah Wallace-Lund

October 5, 2020 workshop

- Mark McMaster, Research Scientist, Environment and Climate Change Canada
- Gerald Tetreault, Research Scientist, Environment and Climate Change Canada
- Georgina Kaltenecker, Provincial (Stream) Water Quality Monitoring Network, Ministry of Environment and Climate Change

- Luca Cargnelli, Great Lakes Program Officer (Lake Erie Lead), Environment and Climate Change Canada
- Tom MacDougall, Rehabilitation Ecologist, Lake Erie Management Unit, Ministry of Natural Resources and Forestry
- Todd Howell, Great Lakes Ecologist, Ministry of the Environment, Conservation and Parks
- Dorienne Cushman, Program Analyst, Ministry of Agriculture, Food and Rural Affairs
- Debbie Balika, Source Water Protection Lead, Conservation Ontario
- Mark Anderson, Water Quality Engineer, Grand River Conservation Authority
- Andrea Dunn, Coordinator, Monitoring Ecology, Conservation Halton
- Trevor Swerdfager, Educational Partnerships and Government Relations, School of Environment, Resources and Sustainability, University of Waterloo (former Parks Canada and Fisheries and Oceans Canada)
- Jack Imhof, retired (formerly Ministry of Natural Resources and Forestry and National Biologist/Director of Conservation Ecology for Trout Unlimited)
- Mary-Kate Gilbertson, Biologist, Anwaatin
- Jenn Richards, Program Analyst, Environmental Management Branch, Ministry of Agriculture, Food and Rural Affairs
- Martin Keller, Source Protection Program Manager, Grand River Conservation Authority
- Kim Funk, Aquatic Monitoring Ecologist, Conservation Halton
- Lorne Greig, independent scientist (former Ministry of Natural Resources and Forestry); Associate, ESSA Technologies Ltd
- Bill Christmas, President, Ted Knott Chapter, Trout Unlimited
- Larry Mellors, Vice-President, Middle Grand Chapter, Trout Unlimited Canada

December 7, 2020 workshop

- Brad Bass, Nutrient Management Lead, Lake Erie, Environment and Climate Change Canada
- Gerald Tetreault, Research Scientist, Environment and Climate Change Canada
- Tracie Greenberg, Environmental Scientist, Environment and Climate Change Canada
- Mark McMaster, Research Scientist, Environment and Climate Change Canada
- Erin Ussery, Environment and Climate Change Canada
- Chris Jones, Benthic Monitoring Research Scientist, Ministry of the Environment, Conservation and Parks

- Ryan Sorichetti, Senior Surface Water Scientist, Ontario Ministry of the Environment, Conservation and Parks
- Rob Mackareth, Research Scientist, Ministry of Natural Resources and Forestry
- Christopher Duke, Program Analyst, Ontario Ministry of Agriculture, Food and Rural Affairs
- Anna Crolla, Engineer, Energy & Crop Systems, Ontario Ministry of Agriculture, Food and Rural Affairs
- Jo-Anne Rzadki, Business Development & Partnerships Coordinator, Conservation Ontario
- Mark Anderson, Water Quality Engineer, Grand River Conservation Authority
- Crystal Allen, Supervisor of Natural Heritage, Grand River Conservation Authority
- Stephanie Nolet, Water and Wastewater Technologist, Haldimand County
- Lorne Greig, independent scientist (former Ministry of Natural Resources and Forestry); Associate, ESSA Technologies Ltd
- Gregary Ford, Project Coordinator, Niagara, Swim Drink Fish
- Jan Cibrowski, Professor Emeritus, Biology, University of Windsor