Drivers and Implications for Water Governance: A case study of the western Lake Erie basin

by

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EXAMINING COMMITTEE MEMBERSHIP

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AUTHOR'S DECLARATION

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

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STATEMENT OF CONTRIBUTIONS

In the School of Environment, Resources and Sustainability, two forms of presentation of the doctoral dissertation are permitted: (1) a standard dissertation monograph, and (2) a manuscript option centred 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 used 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 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 they are in agreement 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 are reported in three co-authored manuscripts (Chapters Two, Three, and Four). These chapters have been prepared for submission to refereed journals.

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

Co-authorship for R.C. de Loë (Advisor) was determined based on meeting the following criteria:

- Substantial contributions to the conception and design of the work, and to interpretation of the data;
- Contributing to editing and revising the work critically for important intellectual content;
- Final approval of the versions of the chapters that will be published as refereed journal articles;
- Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Erin Mills 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.

Rob de Loë (Advisor)

ABSTRACT

The purpose of this study was to better understand drivers of water problems and their implications for water governance scholarship and practice. Drivers here are identified as social and environmental forces affecting a system, such as a Great Lakes basin. Eutrophication in the western Lake Erie basin provides the empirical setting to achieve the study purpose, using the following objectives: (i) identify drivers of eutrophication in the western Lake Erie basin, (ii) determine whether these drivers are taken into account in nutrient management efforts, and (iii) assess the relationships among drivers and water governance. Two parallel cases of nutrient management, in the Canadian and United States' (US) portions of the western basin, are explored using policy Delphi surveys with practitioners and researchers, and content analysis of formal nutrient management documents such as strategies and agreements.

Findings from the research revealed that nutrient management efforts are identifying many of the same drivers (e.g., agricultural operations) that emerged from the data. Overlaps between the US and Canadian case studies indicate a shared understanding of the causes of eutrophication in the western Lake Erie basin. Areas of overlap between the policy Delphi surveys and document analyses within each of the case studies indicate shared perspectives from experts and formal nutrient management documents. These overlaps were expected, since Lake Erie is a transboundary body of water shared between Canada and the US, and the two countries have worked together for over a century to address water quality and quantity concerns through binational agreements and agencies. However, there were also differences in the sets of identified drivers of eutrophication that raised questions about the strength of shared understandings both within and between the US and Canadian case studies. For example, some drivers identified in the Canadian policy Delphi were not identified in the Canadian document analysis or in the US case study. These gaps indicate areas where nutrient management in the western Lake Erie basin could be improved through coordinated efforts to develop shared problem framings of eutrophication. The study findings empirically demonstrate the importance of identifying drivers when addressing water problems as well as the challenges that can occur when problem framings are mismatched within and across jurisdictions.

When determining whether these drivers of eutrophication are taken into account by nutrient management efforts in the western Lake Erie basin, a similar pattern emerged. There was agreement among both the US and Canadian policy Delphi surveys and document analyses that several major drivers of eutrophication are taken into account in nutrient management efforts by multiple mechanisms ranging from research to regulation, including efforts involving agricultural operations. However, gaps were identified both within and between the US and Canadian case studies on whether some drivers of eutrophication are taken into account by nutrient management efforts. The concept of sufficiency emerged from Canadian and US policy Delphi participants. In this way, a driver may be taken into account to some extent, but these efforts were identified as insufficient to mitigate the driver as a cause of eutrophication. Together, these findings raise questions about the effectiveness of nutrient management efforts in the western Lake Erie basin. Specifically, the results suggest that the persistence of eutrophication may be due at least in part to a failure to take drivers into account.

From the policy Delphi survey and document analysis data, evidence also emerged regarding the relationships between drivers and water governance. Existing framings of eutrophication do not explicitly identify water governance as a driver of eutrophication. The results demonstrated that water governance could be a driver of eutrophication, for example by shaping nutrient management actions. The results also showed that there are dynamic relationships among drivers of eutrophication and the water governance system, with influences moving bidirectionally across levels and scales. This empirical demonstration

contributes to the currently understudied subject of driver directionality in the social-ecological systems and water governance literatures.

This research makes several contributions to the water governance and SES literatures. The dissertation contributes to emerging discussions in the water governance literature on the importance of identifying and accounting for drivers, including their relationships with water governance, when addressing water problems. There are currently knowledge gaps on characterizing drivers within specific contexts and understanding the relationships between driver perception and management. I address these gaps by identifying the drivers of eutrophication in the western Lake Erie basin and determining whether those drivers are taken into account by nutrient management efforts. The use of the document analyses in combination with the policy Delphi surveys was a methodological approach that has not been widely used. In this research, the two methods provided nuanced and novel perspectives on drivers of eutrophication. In the eutrophication literature broadly, and in discussions of Lake Erie specifically, drivers of eutrophication are often framed as biophysical or socioeconomic factors. The identification of the water governance system and nutrient management efforts, including actors, policies, and program effectiveness, as drivers of eutrophication in the western Lake Erie basin is a contribution to the eutrophication literature that is unique to this research. This identification and characterization of water governance systems as a driver also adds value to other explorations of water problems and their associated water governance systems. Overall, the research contributes to understandings in the water governance literature on the relationships that exist between water governance and drivers by demonstrating that these relationships are bidirectional and exist across scales. The empirical findings of the research demonstrate the utility of regional case studies for filling identified knowledge gaps in the SES literature on understanding how drivers interact, how governance affects solutions to water problems, and how these relationships have influence across scales, as well as demonstrating the need for additional research.

The findings of this research also have implications for the empirical practice of water governance in the western Lake Erie basin. By identifying gaps in identifying drivers and accounting for drivers through nutrient management efforts, the research identifies opportunities to improve nutrient management efforts and water quality outcomes in the western Lake Erie basin. Specifically, there are differences in how drivers of eutrophication are understood and taken into account by nutrient management efforts. These differences indicate that work is necessary both within the Canadian and US jurisdictions as well as binationally to deepen the shared understanding of eutrophication and how its causes are perceived. To improve water quality in the western Lake Erie basin, it is necessary to critically examine nutrient management effectiveness and incorporate the novel drivers of eutrophication identified by the research into framings of eutrophication as well as nutrient management solutions.

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Chapter 1

Introduction

1.1 Research Context and Problem Rationale

In countries around the world, water resources, and the social-ecological systems (SES) that depend on them, are at risk from pollution and overuse (UN World Water Assessment Programme 2003, Palaniappan 2012). Stressed water resources lead to negative impacts, including biodiversity loss and reduced ecosystem services provision. The persistence of water quality and quantity problems around the world, despite years of attention at the regional, national, and international levels (Gleick et al. 2011), has been attributed to many factors. Water governance failures are a prominent factor in these discussions (UN World Water Assessment Programme 2003, Castro 2007). A common example is failing to recognize that water problems are dynamic, multi-level, and multi-scale (Armitage, de Loë, and Plummer 2012, Lemos and Agrawal 2006). These challenges figure in emerging critiques in the water governance literature that argue we ignore drivers of water problems to our detriment (de Loë and Patterson 2017a, b). For example, in their assessment of water governance in the Yahara River Watershed in Wisconsin (US), Gillon, Booth, and Rissman (2016) concluded that poor water quality outcomes were a result of governance failures to identify and account for all factors causing changes in the water system.

Water systems are often affected by multiple social and environmental drivers (Fallon, Lankford, and Weston 2021). For example, Blomquist and Schlager (2005) demonstrated that ignoring the role of politics in influencing decisions undermined efforts to achieve integrated watershed management in California. Broadly, the water governance literature demonstrates that approaches that link water governance with the key drivers of a water problem are necessary (e.g., Galaz 2007, Ingram 2008, Wheater and Gober 2015, de Loë and Patterson 2017b). Water problems with multiple drivers across multiple scales would benefit from water governance approaches that recognize and account for these drivers (Fish, Ioris, and Watson 2010, Räsänen et al. 2017). Water governance actors should recognize that water problems are complex and exist within a broader social-ecological context, and should more explicitly identify and account for factors contributing to water problems (Biswas 2004, de Loë and Patterson 2017b, Wiek and Larson 2012). A crucial component of understanding a water problem is identifying the drivers affecting the SES (Kittinger et al. 2013, Holling 2001, Nyam et al. 2020).

Water quality is a globally-relevant concern that provides context for discussions of new water governance approaches. Many decisions affecting water quality are made by actors outside the water sector (UNWWAP 2012b). For example, decisions made in sectors such as agriculture and mining have implications for water quality (UNWWAP 2012b). Eutrophication due to excessive nutrient loading to water bodies is a water problem experienced globally (Khan and Mohammad 2014). Lake Erie is an example of a freshwater body experiencing eutrophication. Water quality in Lake Erie has been, and continues to be, a priority for both Canada and the United States (US). The Lake Erie basin is a significant population, agricultural, and economic hub (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). Algal blooms in Lake Erie during the 1960s and 1970s, a result of both urban and agricultural land uses and practices, drew widespread attention and resulted in cooperative binational efforts, including the development and signing of the Great Lakes Water Quality Agreement in 1972 (Baker et al. 2014, Bertani et al. 2016, International Joint

Commission 2014). Since the 2000s, algal blooms have returned, producing renewed nutrient management efforts (International Joint Commission 2014).

1.2 Purpose and Objectives

The purpose of this research was to better understand drivers of water problems and their implications for both water governance theory and practice, using the empirical setting of water quality issues in Lake Erie. Specifically, I examined nutrient management efforts in the western Lake Erie basin through two separate but parallel case studies in the Canadian and US portions of the basin. To fulfill the research purpose, I established three objectives:

1. Identify drivers of eutrophication in the western Lake Erie basin;

2. Determine whether nutrient management efforts take these drivers into account; and

3. Assess the relationships among drivers and water governance.

1.3 Literature Review: Drivers and Water Governance in an SES Context

The research is grounded in, and builds on, literature related to water governance and social-ecological systems. The water governance literature provides context to past and current trends in water governance research and practice and identifies knowledge gaps on drivers that this research could address. The SES literature and associated frameworks, and their contributions to understanding drivers, are also explored in this section. Scholarly literature that assesses the causes of eutrophication and nutrient management efforts is also considered here. Within these sections, how drivers are understood, as well as the implications for water governance research and practice, are considered.

1.3.1 Water Governance and Drivers

Although there is no universally accepted definition of water governance, there are common themes that indicate shared concerns in the literature (see Box 1). Water governance is a process of decision-making that includes state and non-state actors, and builds on existing government rules, for the purpose of addressing water problems (Lautze et al. 2011, Schulz et al. 2017, Tortajada 2010). Water governance and water management are connected in both theory and practice. Water governance refers to how decisions are made about water (Grigg 2011, Lautze et al. 2011, Rogers and Hall 2003), while water management reflects the operations necessary to meet governance objectives (Lautze et al. 2011). Any consideration of water policy is a discussion of both water governance and water management. In this research, water governance is defined as the "ways in which societies organize themselves to make decisions and take action regarding water" through a variety of mechanisms with the participation of both state and non-state actors (de Loë and Patterson 2017b, 76). There is growing recognition that the complexity of environmental problems, including water problems, can hinder the achievement of governance objectives (e.g., Cox 2011). Dynamic interactions within and between linked social and ecological systems across multiple levels and scales contribute to complex problems (Duit et al. 2010). Scales represent the multiple dimensions that comprise a system, such as space, time, and jurisdictions, and levels are the subunits within a scale, such as a watershed within the spatial scale (Cash et al. 2006, Gibson, Ostrom, and Ahn 2000).

Box 1. Water governance definition examples

- Global Water Partnership: "water governance refers to the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" (Rogers and Hall 2003, 18).
- Water governance is "a complex process that considers multi-level participation beyond the state, where decision making includes not only public institutions, but also the private sector, civil society and society in general" (Tortajada 2010, 298).
- "Water governance consists of the processes and institutions by which decisions that affect water are made" (Lautze et al. 2011).

According to Jiménez et al. (2020), water governance determines whether positive water outcomes are achieved. At the same time, addressing complex, dynamic SESs and uncertainty in decision-making can be necessary for water governance (Rockström et al. 2014). Developing appropriate solutions to complex environmental problems is a challenge for governance systems (Ostrom 2009, 2007). As far back as the 2000 World Water Form, the Global Water Partnership "stated that *water crisis is often a crisis of governance*, and identified making water governance effective as one of the highest priorities for action" (Rogers and Hall 2003, 17). The challenge of ineffective governance for persistent water problems has also been identified elsewhere with most water problems being due to governance failures, instead of solely being attributed to technical challenges (e.g., UN World Water Assessment Programme 2003, Castro 2007, Acheson 2006). According to Pahl-Wostl et al. (2012, 24), "the most persistent obstacles for the sustainable management of water resources lies in the realm of water governance". Tortajada (2010) and Wiek and Larson (2012) both argue that modifications to water governance are necessary to consider factors outside the water sector which affect water governance, and that failing to understand water problems and water governance in their broader context will lead to ineffective water governance.

Gupta and Pahl-Wostl (2013) pointed out the tension that can exist between the often-global nature of water problems and the subsidiarity principle of managing water at the most locally appropriate governance level. For example, Räsänen et al. (2017) observed that local actors are not able to account for all drivers affecting water quality, such as foreign investment in mining and agriculture, even though they can be impacted by these drivers; therefore, they recommend that the scale of water governance should match the drivers being managed. Water governance systems that recognize and account for the multiple scales at which drivers can act on a system and are flexible in the face of uncertainty and complexity are beneficial for addressing water problems (Fish, Ioris, and Watson 2010, Räsänen et al. 2017). Assessing how drivers are identified and taken into account by water governance systems in real-world situations would provide valuable insight that could extend discussions in the water governance literature.

In this context, there are arguments that ignoring the drivers of a water problem can lead to undesirable outcomes and governance failures (e.g., de Loë and Patterson 2017b). Historically, the focus of environmental policy has been mitigating the impacts of drivers, rather than the drivers themselves (Van Loon et al. 2016, Vörösmarty et al. 2010, Levy and Morel 2012). For example, investments in water infrastructure reduce vulnerability to water security threats such as water pollution but do not address the sources of pollution (Vörösmarty et al. 2010). Characterizing a water problem, including identifying drivers, is a necessary element of water governance (Nyam et al. 2020) and represents an opportunity for research to contribute to existing conceptualizations. Decision-makers should direct actions to solve environmental problems at drivers (Levy and Morel 2012, Meadows 1999). Drawing on practitioner experience can inform efforts to assess and improve water governance (e.g., Jiménez et al. 2020). Therefore, identifying and accounting for drivers is critical when proposing solutions to environmental problems, such as poor water quality. Understanding how these efforts work in practice is especially valuable.

Multiple definitions of drivers exist in multiple bodies of literature, including water governance and SESs. In the water governance literature, drivers have been broadly characterized as social, economic or environmental factors that influence a system (e.g., Gupta and Pahl-Wostl 2013, Räsänen et al. 2018, de Loë and Patterson 2017b). Comparable definitions exist in the SES literature (e.g., Nayak and Berkes 2014, McGinnis and Ostrom 2014). Other researchers acknowledge the importance of drivers for governance outcomes without defining the term (e.g., Gillon, Booth, and Rissman 2016). Levy and Morel (2012, 5) define drivers as "the overarching socioeconomic forces that exert pressures on the state of the environment", with two major drivers being economic development and population growth. However, this definition does not consider what happens once the state of the environment has changed (for example, are there feedback loops of influence between the state of the environment and drivers?) and it excludes ecological factors entirely from consideration. In this thesis, drivers are defined as dynamic social and ecological factors affecting a system (de Loë and Patterson 2017b, Millennium Ecosystem Assessment 2003, Nayak and Berkes 2014).

Drivers affect how water is both used and managed (Fallon, Lankford, and Weston 2021). Examples of drivers affecting water resources include food and energy production, land uses, global-level organizations and policies (Gupta, Pahl-Wostl, and Zondervan 2013), as well as politics (Rogers and Hall 2003). Knowledge gaps exist when it comes to understanding the most important drivers within specific contexts, as well as how perceptions of drivers affect efforts to address them (e.g., Gillon, Booth, and Rissman 2016, Räsänen et al. 2018, Räsänen et al. 2017). These knowledge gaps emphasize the value of research on water problems in specific contexts, as well the importance of incorporating practitioner perceptions into that research.

Water governance approaches that set narrow conceptual boundaries can lead to decision-making that ignores the fundamental causes of a water problem (de Loë and Patterson 2017b, Vörösmarty et al. 2010, Tortajada 2010). Work is necessary to explore how governance influences efforts to manage complex, dynamic water problems (Kirschke et al. 2017). Water governance approaches should: (i) recognize the complexity of water problems and their place within larger social and environmental contexts; (ii) determine what is relevant to consider in governance processes; and (iii) reflect on existing governance processes to determine if modifications are necessary to account for the identified drivers (Biswas 2004, Wiek and Larson 2012, de Loë and Patterson 2017a, b). Governance processes that account for interacting levels at multiple scales are associated with positive social and ecological outcomes (Cash et al. 2006). Since this modified approach requires recognizing and accounting for the embeddedness of water problems in SESs (Allan 2005, Pahl-Wostl et al. 2012), an understanding of the SES literature, including conceptualizations of drivers, is necessary.

1.3.2 Social-Ecological Systems and Drivers

Berkes, Colding, and Folke (2003) introduced the concept of linked social and ecological systems, referred to in this thesis as SES, as part of their argument that it is artificial to treat social and ecological systems as separate. These linked systems must be considered together (Folke et al. 2002, Holling 2001, Liu et al. 2007). Integrated consideration of social and ecological components within a system is necessary because there are no purely ecological or purely social systems, although the boundaries of consideration and governance that are set around a system may make it appear that way. Governance of natural systems has been limited by the assumptions that ecosystems could be predicted and controlled, and that social and ecological systems could be managed independently (Folke et al. 2002). Discussions in the SES literature represent a shift away from this conceptual and empirical separation toward an integrated understanding of the social and ecological components of a system contributing to an environmental problem (e.g., poor water quality). Therefore, an SES perspective can inform a more complete understanding of the interactions within and among systems, and lead to more effective governance processes that acknowledge the social and ecological components within a system.

Although SES are highly variable at multiple spatial and temporal scales, they can share the same basic characteristics. SES are complex, interconnected, multi-scalar, and can behave non-linearly (Folke et al. 2002, Liu et al. 2007, Sternlieb et al. 2013). These characteristics present challenges for governance, as the complexities of SES require recognizing the scales and boundaries of a system, as well as the influence of the broader social and ecological context, all of which can vary over time (Anderies and Janssen 2013, Holling 2001, Cox 2011). A water problem can be complex if there is uncertainty about the causes of a problem or if there are connections with issues beyond water (Moore 2013). Given the critical roles that water plays in economic, social, and natural systems, water governance must better account for interconnections among these systems (Pahl-Wostl et al. 2012). According to Pahl-Wostl (2015, 99), "governing water implies governance of a complex social-ecological system at and across different scales in space and time". Chaffin, Gosnell, and Cosens (2014, 56) recommend that governance must be "both flexible enough to address highly contextualized SESs and dynamic and responsive enough to adjust to complex, unpredictable feedbacks between social and ecological system components".

Understanding a problem within a SES requires identifying and understanding the drivers affecting the system (Holling 2001, Kittinger et al. 2013). Typologies of drivers have been developed to inform discussions of drivers. For example, UNWWAP (2009) distinguish between indirect and direct drivers, as well as defining drivers as processes external to the water sector that affected water. Holling (2001) also argued that the sustainability of a system is influenced by both internal and external factors; however, their descriptions of internal and external drivers overlapped and were subjective, and therefore would be difficult to apply consistently. Proximate and distal drivers, based on their scale of influence on an SES, are another conceptualization of drivers that has been applied when studying the drivers of phenomena such as tropical deforestation (e.g., Geist and Lambin 2002). This approach has recently been critiqued for ignoring the psychological drivers affecting the SES (Rueda et al. 2019). Broad categories of drivers have been applied to organize discussions of drivers, such as the economy and societal values (e.g., Jetoo et al. 2015, UNWWAP 2012a). Janssen, Anderies, and Ostrom (2007) used broad categories of drivers (socioeconomic conditions, technology, institutional arrangements) in their assessment of SES. These typologies and categories have contributed to shared framings of drivers in the water governance and SES literatures and advanced how drivers of water problems are assessed (Nayak and Berkes 2014). However, these higher-level discussions of drivers may not provide nuanced understandings of the drivers contributing to a specific water problem (e.g., water quality in the western Lake Erie basin). Therefore, case-specific empirical studies of water problems could provide novel insights to deepen assessments and conceptualizations of drivers.

Multiple frameworks have been developed with the objective of conceptualizing system components, including drivers. Frameworks are useful because they determine what is internal or external to a system, and therefore what is considered and addressed in governance processes (e.g., McGinnis 2011). The SES framework developed by Ostrom (2007, 2009) is one example, as are the related

Institutional Analysis and Development (IAD) (McGinnis and Ostrom 2014) and robustness frameworks (Anderies, Janssen, and Ostrom 2004, Anderies and Janssen 2013). The SES framework was developed to address the deficiencies of simplistic assessments of SES and to guide the analysis of complex systems so that governance solutions can be developed that match the needs of the particular problem under discussion (Ostrom 2007). The SES framework was developed specifically to assess and understand common property resources, which are common in the context of water resources. The framework takes the foundation established by the IAD framework and expands it by accounting equally for the influence of ecological and social settings on a system (Anderies and Janssen 2013, McGinnis and Ostrom 2014, Ostrom 2007, 2009). The SES framework is useful when assessing water problems for three reasons: (i) the framework can treat social and ecological factors equally; (ii) it acknowledges the broader SES context, as well as the interactions between the SES context and interactions/outcomes within the system; and (iii) the design and flexibility of the framework means that it can be applied to multiple SES (McGinnis and Ostrom 2014, Ostrom 2009). The SES framework would be appropriate when assessing water governance processes because water problems are affected by both social and environmental factors (e.g., Vörösmarty et al. 2010, Wheater and Gober 2015).

The SES framework acknowledges the relationships and multiple tiers of factors within systems. It identifies the four main interacting components of a SES (known as the first tier) as resource units, resource systems, actors, and governance systems. Each first-tier component is then disaggregated into second tier variables, with further specification to a third tier possible. At the center of the SES is the action situation, where the interactions and inputs of the system components create outcomes. The SES framework recognizes and accounts for the broader social, political, economic, and ecological context within which a system exists that can influence the system (McGinnis and Ostrom 2014, Ostrom 2009, 2007). These broader contexts have remained essentially the same through different iterations of the framework (McGinnis and Ostrom 2014). Depending on the scope of the research question, Ostrom (2007, 15186) acknowledged that "for some questions, the appropriate focal system is the broader social, economic and political settings (S) in which one compares these broader settings over time and across space". Similarly, Janssen, Anderies, and Ostrom (2007, 312) noted that "an increasing connection of SESs with higher level phenomena such as national government policies, technological change, or international economic developments" has impacted the stability of some SESs in the face of "changes in the [broader] ecological, economic, and political" settings. There are clear acknowledgements here that the social and ecological contexts impact the interactions and outcomes within a system. However, empirical assessment of these "external" settings has been limited to date, and therefore represents a gap in the SES framework literature and practice.

The SES framework provides a common language to understand SES and allows for the standardized analysis and comparison of systems (Ostrom 2007). The framework's multiple tiers of system components and variables are intended to guide researchers in their assessment of complex systems to allow for the identification of key variables to inform governance processes as well as the accumulation of knowledge from a range of SES (Cox 2011, Hinkel et al. 2015, Ostrom 2007, 2009). However, the tiered system components and predefined variables in the SES framework have also been criticized by Clement (2012) and Thiel, Adamseged, and Baake (2015) because they can inherently limit SES analysis to what is recognized by the framework. Instead of being open to emerging system components and variables to inform governance, the SES framework could limit system analysis and therefore lead to less effective governance processes (Clement 2012). Therefore, an analysis that is informed by the SES literature, but which recognizes and addresses the limitations of the framework, may be more valuable to identify and characterize drivers that may not currently be known, understood, or managed.

The SES framework recognizes and accounts for the broader social, political, economic, and ecological contexts within which a system exists (Ostrom 2007, 2009, McGinnis and Ostrom 2014). In their most recent assessment of the SES framework, Cole, Epstein, and McGinnis (2019) exclude biophysical/environmental factors that are outside the scope of management actions from the framework entirely. This exclusion appears to be an oversimplification of the relevant systems and may prevent consideration of potentially significant factors. Because important influencing factors may be outside the current scope of management actions, it is arguably both necessary and beneficial to identify and understand these factors to inform current and/or future management decisions. Therefore, current discussions in the SES literature would benefit from an improved understanding of all drivers affecting a system. de Loë and Patterson (2017a, 566) developed a "systemic but diagnostic approach" intended for use by both researchers and practitioners, that builds on the SES framework and is informed by institutional analysis (McGinnis and Ostrom 2014, Ostrom 2009, 2007) and other diagnostic approaches (e.g., Garrick et al. 2013). This framework goes beyond the structure of the SES framework to challenge its consideration of "broader political, economic and other external factors" (de Loë and Patterson 2017a, 569). I argue that an empirical assessment of drivers drawing on practitioner expertise may provide novel insights that could extend existing framings of drivers in the SES and water governance literatures explored above. Such an assessment could also inform advancements in the application of the SES framework, as well as other frameworks developed to understand drivers affecting SES and inform solutions, e.g., the Driver-Pressure-State-Impact-Response (DPSIR) framework.

The DPSIR framework was developed to guide the assessment of environmental problems and to inform management solutions (Kristensen 2004, Gari, Newton, and Icely 2015). The DPSIR framework was originally developed by Statistics Canada in 1979 as a Stress-Response Framework. The Organization for Economic Development (OECD) modified it into the Pressure-State-Response framework, and the European Environmental Agency (EEA) expanded it further into the DPSIR framework (Gari, Newton, and Icely 2015). Given the importance of identifying what is affecting a system and determining how to respond to it (Levy and Morel 2012), the DPSIR framework identifies interactions and outcomes within and among systems, scaling down from drivers (D) to pressures (P), to the state of the environment (S) and associated impacts (I), and finally the responses (R) that are implemented to address drivers, pressures, and/or the state of the environment to manage the impact (Kristensen 2004, Lewison et al. 2016). The DPSIR framework characterizes human activities as the ultimate drivers within a system (Gari, Newton, and Icely 2015). In contrast, drivers are more broadly characterized by SES authors as social, economic, and/or environmental forces (Kittinger et al. 2013). The DPSIR framework appeals to policy actors because it focuses on cause-effect relationships and it links environmental problems with policy, although it has been criticized for oversimplifying complex systems and the dynamics within them (e.g., the framework characterizes relationships, drivers, pressures, and environmental state as unidirectional) and for treating systems as static (Gari, Newton, and Icely 2015). For example, the framework characterizes the relationships between drivers, pressures, and environmental state as having unidirectional influence. Both Kristensen (2004) and Gari, Newton, and Icely (2015) argue that considering how framework elements interact with each other is important.

In practice, the DPSIR framework has taken a limited account of perspectives from multiple actors in the system and it does not bridge the gap between researchers and decision-makers (Gari, Newton, and Icely 2015). The framework has also been criticized for failing to conceptualize integrated social and ecological factors in a system, although it can conceptualize these factors individually (Lewison et al.

2016). To address these limitations, the DPSIR framework would need to broaden its understanding of the interactions between framework components to include feedback loops and multi-directional influence, which are currently not present, as well as incorporating decision-makers directly in the assessment of systems using the framework. While these modifications would make the DPSIR framework better suited to assess SES and inform governance processes, there is no standardized understanding of the framework structure and how to apply it to SES, which presents a challenge to the implementation of the framework (Lewison et al. 2016). The lack of standard characterizations of system components limits the applicability of the framework to accumulate knowledge (Ostrom 2009), as well as emphasizing the value of the SES framework with its common system components, and standard definitions and criteria.

The frameworks explored above demonstrate the long-standing attention to drivers, as well as the relevance of drivers to discussions beyond water governance, including social-ecological systems broadly. In their assessment of the Chilika lagoon SES in India, studying shrimp farming, Nayak and Berkes (2014) observed a bidirectional flow of influence between drivers at multiple levels within the spatial scale. These findings challenge framings of drivers in the environmental literature as acting directionally downward (e.g., Nelson et al. 2006, Gupta and Pahl-Wostl 2013), although there have been previous acknowledgements that there is a relationship between drivers and governance. For example, the Millennium Ecosystem Assessment (2003, 92) identifies "signals that motivate the decision-making process", while Nelson et al. (2006) discuss the feedback loops between drivers and ecosystem services, which can ultimately lead to changes in policy. Research in the water governance literature has also observed the relationships that can exist between drivers and governance (e.g., Daniell and Barreteau 2014, Biswas and Tortajada 2010). However, there are few studies examining the bidirectional relationships between drivers and the SES they are affecting, especially driver influence moving from smaller to larger scales (e.g., Nayak and Berkes 2014, Nayak and Armitage 2018). For example, Cole, Epstein, and McGinnis (2019) criticized the SES literature for oversimplifying interactions between environmental policies and environmental problems, and concluded that additional research is necessary to understand these relationships. Kirschke et al. (2017) observed that work is needed to understand driver interactions and how water governance influences efforts to address water problems.

1.3.3 Drivers of Eutrophication and Nutrient Management Limitations

The eutrophication of water bodies is experienced globally (Khan and Mohammad 2014). Responding to eutrophication can be challenging because of the multiple contributing drivers and complexity of the water systems (Jetoo 2018, Gillon, Booth, and Rissman 2016). As evidence of this, most efforts to mitigate excessive nutrient loadings to water bodies have not successfully improved water quality (Jarvie et al. 2019, Reilly et al. 2021, Jarvie et al. 2013). This pattern is also evident for water quality in Lake Erie (Sekaluvu, Zhang, and Gitau 2018). Jetoo (2018) argues that the persistence of eutrophication, including in Lake Erie, is evidence that current water governance efforts are insufficient. In a similar vein, Bieroza et al. (2019) identified a knowledge gap on the effectiveness of best management practices as part of nutrient management efforts. Building on Reilly et al. (2021), who emphasized the importance of understanding whether the multi-scale, multi-level, and dynamic drivers contributing to nutrient loadings are incorporated into nutrient management efforts, I argue that failing to identify and account for those drivers in nutrient management may be contributing to continued water quality impairment resulting from eutrophication. Therefore, work to identify drivers of eutrophication and assess whether they are taken into account by nutrient management efforts would represent a beneficial contribution to the academic literature on nutrients and eutrophication.

There are many drivers contributing to the eutrophication of water bodies. For example, in their assessment of Great Lakes water governance to manage nutrients, Jetoo (2018) identify a lack of regulation and a lack of resources as hindering governance informing nutrient management efforts. As part of the Great Lakes Futures Project, Jetoo et al. (2015), Laurent et al. (2015), and Friedman et al. (2015) found that governance is a key driver affecting the Great Lakes, including the influence of geopolitics outside the hydrological boundary of the Great Lakes Basin. More broadly, Kirschke et al. (2017) reviewed 37 water problems in Germany and found that water policy can harm water quality if policies are insufficient. While these are two examples where the influence of governance on water quality is identified, discussions of eutrophication often focus on biophysical and socioeconomic drivers while not addressing the role of governance explicitly. For example, Foulon et al. (2019) assessed eutrophication management efforts around the world, and identified human activities such as wastewater, urban runoff, and atmospheric deposition as drivers of eutrophication, while the role of governance was implied through shaping nutrient management efforts to mitigate drivers. Exploring the role of water governance in contributing to eutrophication within an empirical setting could provide the evidence necessary to expand discussions of drivers of eutrophication within the academic literature, by clearly establishing water governance as a driver.

In their discussion of the global challenge of eutrophication, Khan and Mohammad (2014) identify wastewater, atmospheric deposition, land use transformation, as well as population and economic growth, as drivers interacting and contributing to excessive nutrient loading. Discussions of Lake Erie specifically include the same drivers, as well as invasive species (e.g., Michalak et al. 2013), climate change (Smith, King, and Williams 2015), agricultural practices (Baker et al. 2014), legacy sources of phosphorous (Sharpley et al. 2013) and precipitation patterns (Daloglu, Cho, and Scavia 2012). These examples demonstrate that empirically identifying drivers of eutrophication could potentially broaden how drivers are defined in the eutrophication literature, while also informing nutrient management efforts in practice.

In the eutrophication literature, methods for identifying drivers are often not discussed. Instead, researchers often rely on other academic papers (e.g., Smith, King, and Williams 2015, Han, Allan, and Bosch 2012) and models (Scavia et al. 2017, Bertani et al. 2016, Bosch et al. 2013) when identifying sources of nutrients. Outside of water governance, policy Delphi analyses have been used to identify the drivers affecting sustainable purchasing/supply management efforts (Giunipero, Hooker, and Denslow 2012). Research on drivers has used a variety of methods, including case studies (Millennium Ecosystem Assessment 2003), participant workshops (Räsänen et al. 2017), surveys (e.g., Nayak and Berkes 2014, Nayak and Armitage 2018), and policy document analysis (Nayak and Berkes 2014, Gillon, Booth, and Rissman 2016). Scholarly literature on nutrient management in the Lake Erie basin does not appear to have used the policy Delphi as a tool to identify drivers of eutrophication, although Lee (2019) used a policy Delphi survey to evaluate agricultural nutrient management mechanisms in Lake Erie. Applying clear language to the term driver addresses the limitations of previous works that explored examples of drivers without defining the term (e.g., Gillon, Booth, and Rissman 2016) and provides a shared language for future work (as the SES framework provides a shared language for characterizing the components of social-ecological systems). How drivers of eutrophication are addressed has also generally focused on control measures such as improving agricultural practices, technical solutions, as well as engagement and outreach efforts (e.g., Khan and Mohammad 2014, Foulon et al. 2019), while greater attention to the broader social and environmental context surrounding the water system would contribute to achieving water quality objectives (Reilly et al. 2021). Empirical evidence exploring tools for nutrient management efforts would therefore be beneficial for informing both research and practice.

Lake Erie is an example of a water body with a long history of eutrophication as well as nutrient management efforts. Research in the Lake Erie basin can use water governance as the conceptual framework because it is through national and binational water legislation and agreements that nutrient management efforts have, and continue, to take place. For example, the International Joint Commission (IJC), established in 1909 to facilitate binational efforts to manage transboundary waters between Canada and the United States (US), supports binational coordination for nutrient management. The Great Lakes Water Quality Agreement (GLWQA), first signed in 1972 and renewed most recently in 2012, contains commitments from both the Canadian and US federal governments to address water quality issues in the Great Lakes, including eutrophication in Lake Erie. Therefore, any discussion of addressing eutrophication in Lake Erie must take place within the context of water governance.

The current commitments from the federal Canadian and US governments to mitigate eutrophication in Lake Erie are formalized in Annex 4 of the GLWQA, most recently renewed in 2012, although nutrient management in Lake Erie has been an area of international concern and effort since the 1960s/1970s (International Joint Commission 2014). Current efforts to address nutrient inputs to Lake Erie have not resolved the issue of eutrophication, and therefore they may not be sufficient. Similar observations have been made by researchers. For example, Baker et al. (2014, 503) found that the total phosphorous (TP) load of 11,000 metric tons per year proposed by the IJC and formalized in the GLWQA (Government of Canada and Government of the United States of America 2012) "has not prevented the re-eutrophication of Lake Erie". In fact, Bertani et al. (2016, 1190) concluded that legacy phosphorous in Lake Erie's sediment will mean eutrophication, including algal blooms, persists and the lake's visible response to nutrient management efforts will be delayed. Similarly, Scavia et al. (2017, 130) argue that "developing market-shaping policies related to modifying human dietary choices and altering energy production to reduce the demand for crops responsible for high P loss" may play an essential role in addressing nutrient issues in Lake Erie, but those actions are not currently considered in existing nutrient management efforts. Therefore, the persistence of eutrophication in Lake Erie may be a result of gaps in nutrient management efforts to identify and account for drivers and their influence on water quality.

Lake Erie is stressed as a result of phosphorous loadings from both rural and urban sources, as well as other factors such as climate change and invasive species (International Joint Commission 2014). This is supported by more recent works identifying climate change, land use changes, internal phosphorous loadings from historical land uses, invasive species, and trends in agriculture (crops and practices) and population growth as contributing factors to address (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, Jetoo 2018). Water policies and the associated strategies and documents to improve water quality in Lake Erie represent an opportunity to provide an original contribution to the water governance and eutrophication literature on drivers, while also contributing to improved nutrient management efforts in the Lake Erie Basin. Eutrophication in Lake Erie is an example of a water problem with multiple drivers affecting the system across levels and scales. This type of problem benefits from water governance that can recognize and adapt to these characteristics. Therefore, Lake Erie is used as the empirical setting to conduct this research through a case study approach. More details are provided in section 1.4 on the historical and current drivers contributing to eutrophication in Lake Erie, as well as exploring nutrient management efforts to-date.

1.3.4 Bringing the Water, SES, and Eutrophication Literatures Together

There are important benefits to identifying and understanding the drivers affecting systems, and to expanding existing conceptualizations of drivers in the water governance, SES, and eutrophication literatures to address knowledge gaps. Water governance approaches that identify and take into account drivers of a water problem are both necessary and challenging (e.g., de Loë and Patterson 2017b, Räsänen et al. 2017, Nyam et al. 2020). For example, knowledge gaps exist regarding understanding driver significance within specific contexts, as well as how framings of drivers shape efforts to manage them (e.g., Räsänen et al. 2018, Räsänen et al. 2017, Gillon, Booth, and Rissman 2016). In the SES literature, there have been long-standing efforts to characterize system components, including the development of frameworks to guide the assessment of SES. Categorizing drivers as internal or external (e.g., Kittinger et al. 2013) and direct or indirect (e.g., Gupta and Pahl-Wostl 2013) has been challenging to apply consistently. Both the SES and the DPSIR frameworks, established by researchers and practitioners, respectively, could benefit from further identification and analysis of drivers. Specifically, an empirical assessment drawing on practitioner expertise could inform expanded framings of drivers and address some of the identified limitations of the SES and DPSIR frameworks for characterizing drivers (e.g., Cole, Epstein, and McGinnis 2019, Gari, Newton, and Icely 2015). This is especially relevant in the context of the argument that predetermined driver categories, such as those in the SES framework, may ignore drivers that are currently unknown (e.g., Clement 2012, Thiel, Adamseged, and Baake 2015). Eutrophication represents a real-world water quality problem that exists globally (Khan and Mohammad 2014). The persistence of eutrophication, including in Lake Erie, is an indicator of ineffective water governance (Jetoo 2018). Reilly et al. (2021) emphasized that it is important to determine whether drivers are incorporated into nutrient management; I build on this research by arguing that failing to identify these drivers and take them into account through nutrient management can contribute to persistent water quality problems.

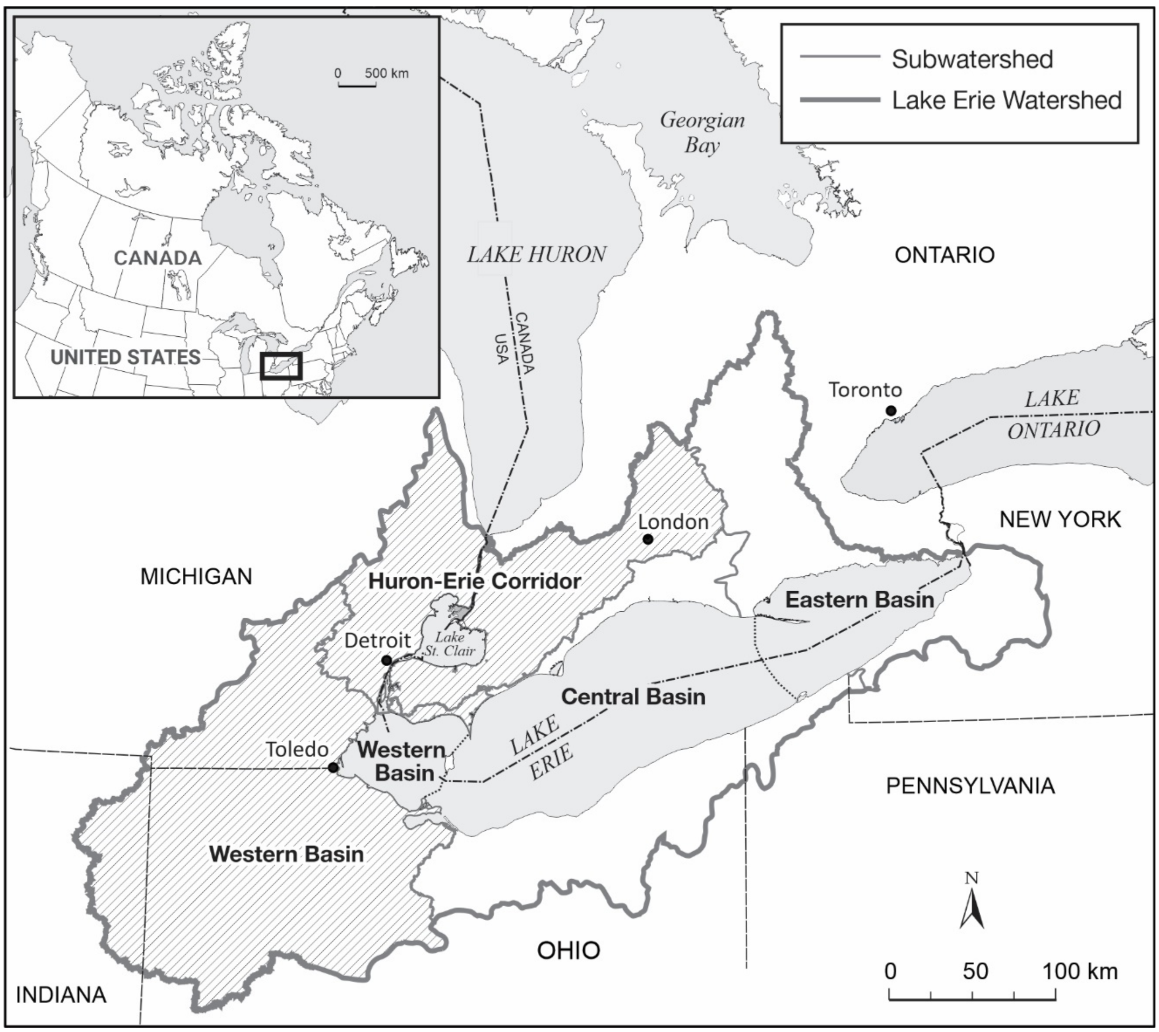
Bringing together these conceptualizations of drivers in the academic literature reveals shared challenges and opportunities for innovation. I argue that an empirical assessment could provide the evidence to advance discussions of drivers in the water governance, SES, and eutrophication literatures. Therefore, I designed the research to use practitioner knowledge and policy documents as the basis of the methods, as there is arguably value in grounding the research in the perspectives of those participating in and knowledgeable of the real-world SES, in this case the western Lake Erie basin. How these perspectives are leveraged are described in section 1.5, as well as each of the results chapters and the conclusion chapter. Individual case study applications will provide valuable insights for practitioners in the western Lake Erie basin, as well as informing broader discussions of drivers in the water governance, SES thinking, and eutrophication literatures through empirical evidence that can inform theoretical advancement.

1.4 Eutrophication in Lake Erie: A case study of the western basin

The Lake Erie basin in North America (Figure 1) is a significant economic, social, and ecological hub for its approximately 12 million inhabitants, serving as a source of drinking water as well as supporting valuable industries ranging from agriculture to fisheries to tourism (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, Londo et al. 2015). Lake Erie is a transboundary body of water that exists within the jurisdictions of both the federal US and Canadian governments, as well as the Province of Ontario and the state governments of Ohio, Michigan, Indiana, Pennsylvania, and New York (International Joint Commission 2014, Great Lakes Water Quality Board 2017). Other actors include industry, non-government organizations (NGOs), agriculture, academia, and Indigenous peoples (de Loë and Patterson 2017a, Johns 2017). The framework for transboundary water governance comes from the Boundary Waters Treaty of 1909, which establishes the International Joint Commission (IJC) as a binational institution to facilitate cooperative efforts and resolve disputes between Canada and the US, and the Great Lakes Water Quality Agreement (GLWQA)

(International Joint Commission 2014, Johns 2017). Through the GLWQA, the IJC conducts research to inform decision-making and determine the progress of Canada and the US in meeting their commitments to protect and restore the Great Lakes (International Joint Commission 2014). In this context of shared waters, Canada and the United States have worked together over the last century to establish and implement water policies aimed at addressing water quality and quantity issues in the Great Lakes Basin (Johns 2017). Despite these collective efforts, water quality in Lake Erie has been impaired for decades in part as a result of high nutrient loads causing eutrophication, and therefore represents a significant challenge for water governance (Jetoo 2018).

Figure 1. A map of the Lake Erie basin, with subwatersheds delineated. Subwatersheds draining to the western basin of Lake Erie (both the Huron-Erie Corridor and the Western Basin Subwatersheds) are highlighted.



1.4.1 Water Governance in the Great Lakes Basin

In Canada, water governance roles and responsibilities are distributed across multiple levels and types of actors and have evolved over time. Water governance by Indigenous peoples existed for thousands of years prior to Confederation in Canada (Johns 2017). In the Canadian Constitution Act (1867), water management is not explicitly discussed although much of the responsibility has been allocated to lower government levels (Brandes et al. 2005, Adeel 2017). In practice, the federal government is responsible for international relations (including transboundary waters and oceans), federal lands, navigation, and fisheries management, while provincial and territorial governments are responsible for water resources and supply, and municipal governments are responsible for drinking water provision and wastewater treatment (Bakker and Cook 2011, Adeel 2017). The federal and provincial governments share responsibilities for agriculture, health, and water issues with national significance. Within each of these levels, responsibilities are further distributed across multiple agencies. For example, at the federal level, Environment and Climate Change Canada, Natural Resources Canada, Fisheries and Oceans Canada, Global Affairs Canada, and Indigenous and Northern Affairs Canada are agencies that all have responsibilities affecting water governance (Adeel 2017). Bakker and Cook (2011) argue that the allocation of responsibilities across multiple government actors creates fragmentation that can hinder policy development in Canada, although they acknowledge that the dynamic nature of water resources means that some level of fragmentation and a lack of coordination are common to many water governance arrangements. In 1971, the federal government of Canada and the Government of Ontario signed the first Canada-Ontario Agreement (COA) to coordinate water policy in the Great Lakes which remains an essential intergovernmental effort (Johns 2017), with the most recent agreement signed in 2020 to continue addressing the overlapping authorities.

Johns (2017) points out that the Great Lakes basin is a venue of water governance in Canada where there is coordination and collaboration across multiple government levels, although there are remaining challenges to incorporate non-state actors, including civil society, into decision-making. For example, increasing the engagement of Indigenous peoples in water policy is a water governance challenge that remains (Johns 2017, Bakker and Cook 2011). The growing participation in and influence on environmental management by non-government organizations and civil society is acknowledged, but this participation does not necessarily translate to greater authority (Norman and Bakker 2013). In the Canadian portion of the Great Lakes, non-governmental organizations such as Lake Ontario Waterkeepers advocate for and participate in water governance, although they may struggle with challenges such as diverse mandates and citizen engagement (Johns 2017). Universities and Conservation Authorities in Ontario have contributed to building the capacity to understand water resources (Johns 2017). For example, the Great Lakes Futures Project represents a collaborative binational and multi-university effort to understand stressors in the Great Lakes Basin and the alternative futures that could emerge from variable policy responses (Friedman et al. 2015, Creed and Laurent 2015).

In the United States, as in Canada, responsibilities for water are distributed across multiple government levels. Distinctive federal and state authorities for water are not built into the Constitution (Huffman 2008, Hoornbeek 2007). Instead, clauses in the Constitution relating to commerce, property, and tax/general welfare/national defense created the foundation for federal opportunities for water governance (Huffman 2008, Chaloux and Paquin 2013). In practice, the federal government has often deferred to the states while state governments have delegated authorities to local governments, although the federal government has the authority to shape water policy and water management (Huffman 2008). Federal regulatory authority was expanded from interstate commerce to include environmental policy (including water) in the 1970s due to statutory enactments advocated for by environmental groups (Hoornbeek 2007). State and local governments develop and implement water policies (Hoornbeek 2007). For example, states are permitted to establish water quality programs under the federal Clean Water Act (MacDonald 2017). According to Tsatsaros et al. (2018, 1641), the US differs from Canada because there is in theory a "government-to-government relationship whereby the tribes join a process that includes consultation on matters regarding natural resources" since water rights are acknowledged by the federal government, although in practice the state and federal governments often retain these authorities.

Water governance in the US is fragmented both within and between the federal and state government levels, with multiple agencies, policies, and programs (Gerlak 2006). There are multiple federal agencies in the US with roles affecting the Great Lakes, including the US EPA. The decentralized authority over the environment, including water, means that state governments play a key role in addressing environmental issues (Chaloux and Paquin 2013). All eight states bordering the Great Lakes have authority to govern water through the Great Lakes Basin Compact, first established in 1968 (MacDonald 2017). Since 2008, the Great Lakes states, including Indiana, Michigan, and Ohio, have coordinated efforts to implement water policies through the Great Lakes-St. Lawrence River Basin Water Resources Council and the newly approved Great Lakes Compact (MacDonald 2017). Coordinating across the multiple government levels is achieved "through the US Policy Committee, with representatives of federal, state and tribal agencies" (Valiante 2008, 247).

Water governance in the Lake Erie basin is complex, with multiple categories and levels of actors across two countries. That said, the Great Lakes overall are often highlighted as an example of effective, cooperative transboundary water management for the past century (Adeel 2017, Creed and Laurent 2015, Norman and Bakker 2015). At the interface of collaborative water governance for the Great Lakes, including Lake Erie, are federally-appointed commissioners and staff for the International Joint Commission (Adeel 2017). As noted earlier, Canada and the United States are a unique case of transboundary water management because of the history of collaboration as well as the legally binding 1909 Boundary Waters Treaty that still exists (Adeel 2017, Johns 2017). The Boundary Waters Treaty created the IJC which is led by six commissioners, three each from Canada and the United States. The inherent and negotiated rights of First Nations in Canada and Native American tribes in the US "were not included in the original transboundary water treaties", including the 1909 Boundary Waters Treatment, "which were conceived as binational, rather than multi-national" (Norman and Bakker 2015, 200). The Great Lakes Water Quality Agreement in its multiple iterations has supported greater citizen involvement in water policy in the Great Lakes Basin through public hearings as well as the Science Advisory Board, which is composed of non-state representatives (Linton and Hall 2013). The binational Great Lakes-St. Lawrence Cities Initiative (Cities Initiative), launched in 2003, involves US and Canadian municipal governments in Great Lakes water policy (Johns 2017). The involvement of local governments in water governance in the Great Lakes was historically inconsistent and informal, although their role "has changed with the institutionalization of local government participation" in the Cities Initiative (Jetoo 2017, 7).

Water governance in both Canada and the US is highly fragmented (Chaloux and Paquin 2013). That said, there are also distinctions between water governance in Canada and the United States. The United States implements Great Lakes-specific legislation and "a range of detailed federal statutes with legislated appropriations to Great Lakes programs and initiatives" (Johns 2017, 170). In contrast, "the Canadian federal government, while officially adopting similar goals for the Great Lakes, does not have any 'hard law' devoted to articulating goals and dedicating resources related to transboundary or domestic efforts and the GLWQA" (Johns 2017, 170). Pentland (2013) argues that these distributions of authority have implications for water management in practice, where a weak federal approach leads to poor water outcomes compared to the US, where the federal government sets standards that states frequently surpass. The US has a stronger federal role in water governance than Canada, while Canada has a strong provincial government and the US has a relatively weak state government, creating asymmetrical roles and responsibilities in transboundary waters; the IJC compensates for this mismatch to some extent (Norman and Bakker 2009). Since the 1980s, there has been an increase in the number of transboundary water governance mechanisms beyond the federal level, including non-binding provincial-state agreements, although most transboundary mechanisms are still at the federal level (Norman and Bakker 2015). For example, the Great Lakes Charter and the Council of Great Lakes Governors, which also include the premiers of Ontario and Quebec, are both commitments to cooperate on water issues between governments (Chaloux and Paquin 2013).

The above paragraphs demonstrate the complex and dynamic nature of water governance in the Great Lakes Basin overall, which can be applied to the Lake Erie Basin specifically. Multiple state and non-state actors influence water governance, which has implications both for water management and the associated outcomes. As Valiante (2008, 265) summarizes, significant challenges exist for water governance in the Great Lakes, including "coordination of effort, ongoing commitment of resources, updating the goals, and adapting to new problems". Eutrophication in Lake Erie is an example of a persistent water problem that requires assessing both the drivers contributing to poor water quality and the existing nutrient management efforts to understand how desirable water quality outcomes can be achieved through water governance.

1.4.2 Eutrophication in Lake Erie

Lake Erie is vulnerable to excessive nutrient loading in part due to its physical characteristics: it is the shallowest, smallest by volume, warmest, and the most biologically productive of the Great Lakes (United States Environmental Protection Agency [USEPA] 2018, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, Ohio Lake Erie Commission 2016). However, Lake Erie is also stressed by human activities within the basin, including urbanization and agriculture (United States Environmental Protection Agency [USEPA] 2018, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). Additional factors affecting Lake Erie's water quality, such as climate change and invasive species, create challenges for water management efforts in the Lake Erie basin.

In the 1960s and 1970s, Lake Erie drew widespread attention because of algal blooms caused by high nutrient loads from agricultural and urban land uses (International Joint Commission 2014). In response, the federal governments of Canada and the United States developed and signed the GLWQA of 1972 to coordinate water management efforts, including phosphorous loading reduction targets for Lake Erie (GLWQA Nutrients Annex Subcommittee 2019). Through agricultural best management practices, regulatory limits on phosphorous concentrations in detergents and wastewater treatment plant updates, phosphorous loading targets were achieved (GLWQA Nutrients Annex Subcommittee 2019). These nutrient management efforts and the associated water quality improvements suggested that the eutrophication of Lake Erie was resolved (International Joint Commission 2014, Baker et al. 2014, Bertani et al. 2016).

Since the late 1990s/early 2000s, the issue of eutrophication has returned, resulting in renewed public concern and joint government action from the United States and Canada (International Joint Commission 2014, United States Environmental Protection Agency [USEPA] 2018). Eutrophication, and the associated algal blooms, presents differently in Lake Erie's eastern, central, and western basins. In the eastern basin, eutrophication has resulted in nuisance blooms of *Cladophera* which can affect fish habitat, foul beaches, clog intake pipes, and support the occurrence of botulism in birds and fish (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, United

States Environmental Protection Agency [USEPA] 2018, GLWQA Nutrients Annex Subcommittee 2019). In the central basin, eutrophication supports algal growth that leads to hypoxia (low oxygen) as the algae die and decompose which can lead to fish deaths (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, United States Environmental Protection Agency [USEPA] 2018, GLWQA Nutrients Annex Subcommittee 2019). In the western Lake Erie basin, which is the empirical setting for this research, eutrophication has led to algal blooms dominated by harmful cyanobacteria (*Microcystis aeruginosa*) which can affect human and animal health (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, United States Environmental Protection Agency [USEPA] 2018, GLWQA Nutrients Annex Subcommittee 2019). There are also economic costs resulting from algal blooms that can add up to hundreds of millions of dollars, including: increased expenses for water treatment, medical treatment following exposure to harmful algal blooms, changes to ecosystem composition and function in response to degraded water quality and associated impacts on recreational/commercial fisheries, loss of ecosystem services, property value decreases, and loss of tourism (International Joint Commission 2014). Therefore, the importance of effective nutrient management efforts is clear. Nutrient management effectiveness can be inferred by water quality improvements (or lack thereof) (Londo et al. 2015).

In response to "the worst algal bloom ever experienced on the lake" in 2011, the IJC established the Lake Erie Ecosystem Priority (LEEP) and conducted an investigation into policy and management solutions to address the causes of algal blooms (International Joint Commission 2014, 2). The GLWQA has been amended and renegotiated over the years, with the most recent version agreed to by Canada and the US in 2012. The 2012 GLWQA includes an annex for nutrients, where Canada and the US agree to take joint action to reduce nutrient loadings to the Great Lakes (Jetoo 2018, Government of Canada and Government of the United States of America 2012). The renewed 2012 GLWQA established Lake Ecosystem Objectives for Lake Erie related to nutrients, including goals to maintain cyanobacterial levels below human and ecosystem threat levels (Government of Canada and Government of the United States of America 2012, GLWQA Nutrients Annex Subcommittee 2019). The IJC's LEEP investigation resulted in several recommendations, including setting targets for phosphorous loading, encouraging the adoption of agricultural best management practices and investing in regulatory tools and incentives to reduce nutrient loading, as well as developing domestic action plans (International Joint Commission 2014). In 2018, the governments of Canada and the United States released their action plans to help meet their obligations under the 2012 GLWQA. Both domestic action plans identify the actions to be taken by the federal and provincial or state governments in the Lake Erie basin to reduce phosphorous loadings, including research/monitoring efforts, investments, partnerships, and policies/strategies (e.g., Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, United States Environmental Protection Agency [USEPA] 2018, Ohio Lake Erie Commission 2018). In the US, there are individual action plans for each state and a federal action plan, while Canada and Ontario jointly developed an action plan.

The re-eutrophication of Lake Erie and the associated algal blooms led to focused efforts to assess the causes of, and propose solutions to, Lake Erie's nutrient problem at the local, national, and international levels (e.g., International Joint Commission 2014). Between the 1970s and today's eutrophication of Lake Erie, the sources of phosphorous have shifted from mainly point sources (e.g., wastewater treatment plants) to rural and urban non-point sources (International Joint Commission 2014). Drivers contributing to the eutrophication of Lake Erie include urban stormwater, climate change, invasive species, legacy sources of phosphorous, and atmospheric deposition, among others, with agriculture often characterized as the dominant source of phosphorous (e.g., Michalak et al. 2013, Smith, King, and Williams 2015, Sharpley et al. 2013, Canadian Water Network 2017). While progress is being made to reduce phosphorous loadings, poor water quality in the western Lake Erie basin persists (International Joint Commission 2017a). In their 2017 assessment of whether Canada and the United States (the Parties) met their commitments under the 2012 GWLQA, the IJC acknowledged the efforts the Parties have made but it concluded that additional efforts are necessary to improve water quality in Lake Erie broadly, and in the western basin specifically (International Joint Commission 2017a). This research takes place in the context of that conclusion, with the intent of proposing improvements to nutrient management efforts to achieve the objectives and commitments established binationally by the Canadian and US governments.

1.5 Methods

The research uses a qualitative methodology and interrelated qualitative methods: (i) literature review, (ii) document analysis, and (iii) policy Delphi surveys. Establishing validity for the research results and associated conclusions is achieved through triangulation, where multiple methods are used to answer the same research question (Berg and Lune 2012, Bryman and Bell 2016). Triangulation in this research is achieved because each research objective is explored using all three methods. For example, in identifying drivers of eutrophication in the western Lake Erie basin, I draw from the academic literature as well as both the US and Canadian policy Delphi surveys and document analyses.

Qualitative research generally relies on multiple sources of data to inductively identify common themes, meaning to identify "patterns, categories, and themes from the bottom up, by organizing the data" (Creswell 2009). However, any research project has elements of both induction (theories emerge from the data) and deduction (theories are tested using data) (Bryman, Teevan, and Bell 2009). According to Berg and Lune (2012, 8), qualitative research is "most interested in how humans arrange themselves and their settings, and how inhabitants of these settings make sense of their surroundings through symbols, rituals, social structures, social roles, and so forth"; this perspective makes qualitative research well-suited to studying governance. This exploration of the western Lake Erie basin is a case study that provides an in-depth understanding of the region (and associated water governance system) under consideration, but it is also an instance of water governance to implement nutrient management efforts that can be applied more broadly. The Great Lakes is one example of a watershed that is at risk from eutrophication that has persisted despite years of collaborative, transboundary efforts (Jetoo 2018). However, eutrophication is one of the biggest water quality issues globally (Khan and Mohammad 2014, Foulon et al. 2019). Therefore, the findings from this research have immediate relevance beyond the case study.

The methodology presented here is used to achieve the research objectives to identify drivers of eutrophication in the western Lake Erie basin, to assess whether those drivers are taken into account by nutrient management efforts, and to examine the bidirectional relationships among drivers and water governance. Since the research objectives include identifying drivers that may not currently be included in nutrient management efforts, qualitative methods are especially suitable because "qualitative research is exploratory and is useful when the researcher does not know the important variables to examine" (Creswell 2009, 18). The research methodology was implemented as an emergent and iterative process, meaning that all phases of the research were flexible to potential changes during data collection (Creswell 2009) as information became available (Berg and Lune 2012). The methods are discussed in more detail in the following paragraphs.

1.5.1 Case Study Approach

A case study approach for the research was used because it supports an in-depth exploration of a phenomenon that can be applied to a wider range of cases (Mabry 2008, Gerring and Cojocaru 2016). The research explores eutrophication in the western Lake Erie basin as a case study of the global water quality challenge of eutrophication (Khan and Mohammad 2014). The western Lake Erie basin (and Lake Erie as a whole) is a transboundary body of water that falls within the jurisdictions of the Canadian and US federal governments, and the associated provincial and state governments. Keeping in mind this transboundary context, and the binational agencies and agreements shaping water governance in the basin, the US and Canadian portions of the basin are two embedded case studies used to examine drivers of eutrophication in the western Lake Erie basin (e.g., Berg and Lune 2012). The Canadian and US perspectives are explored separately to identify unique and shared perspectives and to compare nutrient management efforts. In each case study, a document analysis and a policy Delphi survey are used to identify drivers of eutrophication, determine whether those drivers are taken into account by nutrient management efforts and consider the relationships among drivers and water governance. The details of the document analysis and policy Delphi surveys are provided in the following sections.

1.5.2 Document Analysis

The purposes of the document analysis were to identify drivers of eutrophication, to assess whether those drivers are taken into account by nutrient management efforts, and to assess the relationships among drivers and water governance. The document analysis also provided context for the policy Delphi surveys. Potential documents were identified through an internet search using combinations of keywords, provided in Table 1, as well as references in nutrient management documents.

Table 1. Keyword searches used to identify potential nutrient management documents for analysis.

Search Term 1	Search Term 2	Search Term 3
Great Lakes Water Quality Agreement	Lake Erie	
Nutrient management	Lake Erie	
Nutrient management efforts	Lake Erie	
International Joint Commission	Lake Erie	
Water quality	Lake Erie	
Ohio	Lake Erie	Nutrient management
Michigan	Lake Erie	Nutrient management
Indiana	Lake Erie	Nutrient management
Ontario	Lake Erie	Nutrient management
Governance	Nutrient management	Lake Erie
Eutrophication	Lake Erie	
Governance	Lake Erie	
Thames River Watershed	Nutrient management	
Thames River Watershed	Water quality	

Lake St. Clair Watershed	Nutrient management	
Lake St. Clair Watershed	Water management	
Subwatersheds	Western Lake Erie Basin	
Soil Water Conservation Districts	Lake Erie	
Soil Water Conservation Districts	Michigan	
Soil Water Conservation Districts	Ohio	
Soil Water Conservation Districts	Indiana	

Once potential documents were collected (n=119), the following criteria were applied to determine whether a document would be included in the analysis:

1. The document identified drivers of eutrophication;
2. The document discussed how drivers are being addressed; and
3. The document was published in or after 2012 (so that it is informed by the problem definitions and objectives established by the 2012 Great Lakes Water Quality Agreement), unless the most recent version of the document was published before 2012, such as the St. Clair River and Lake St. Clair Comprehensive Management Plan, which was published in 2004.

After these criteria were applied, the final number of documents included in the analysis was 60 (23 US documents, 14 Canadian documents, and 23 binational documents). Selected documents included reports from US and Canadian government agencies, including the US Environmental Protection Agency (EPA), state governments in the basin, Environment and Climate Change Canada, and the Ontario Ministry of the Environment, Conservation and Parks, as well as other governance agencies such as the International Joint Commission. Other types of documents included agreements (e.g., the Great Lakes Water Quality Agreement), progress reports (e.g., Triennial Assessments of Progress under the GLWQA), and programs, strategies, and plans (e.g., domestic action plans). A complete list of documents is provided in Table 2.

Table 2. Documents included in the document analysis, organized by publication year.

Binational Documents	Canadian Documents	US Documents
Lake Erie Binational Nutrient Management Strategy (2011)	The Lake St. Clair Canadian Watershed Technical Report: An Examination of Current Conditions (2008)	St. Clair River and Lake St. Clair Comprehensive Management Plan (2004)
Great Lakes Water Quality Agreement (2012)	The Lake St. Clair Canadian Watershed Management Plan (2009)	Directors' Agricultural Nutrients and Water Quality Working Group: Final Report and Recommendations (2012)
Taking Action on Lake Erie: IJC Science Advisory Board TAcLE Work Group Science Summary Report (2013)	Lake St. Clair Canadian Work Plan (2011)	Strategic Implementation Plan for St. Clair River and Lake St. Clair (2012)
A Balanced Diet for Lake Erie: Reducing Phosphorous Loadings and Harmful Algal Blooms (2014)	Ontario's Draft Great Lakes Strategy (2012)	Lake Erie Protection and Restoration Plan (2013)
Lake Erie Lakewide Action and Management Plan: Annual Report (2014)	Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (2014)	Ohio Lake Erie Phosphorous Task Force II Final Report (2013)
Recommended Phosphorous Loading Targets for Lake Erie: Annex 4 Objectives and Targets Task Team Final Report to the Nutrients Annex Subcommittee (2015)	Clean, Not Green: Tackling Algal Blooms in the Great Lakes (2014)	Draft Strategic Implementation Plan for St. Clair River and Lake St. Clair (2015)
A Joint Action Plan for Lake Erie: A Report of the Great Lakes Commission Lake Erie Nutrient Targets Working Group (2015)	Water Quality Assessment in the Thames River Watershed: Nutrient and Sediment Sources (2015)	Informing Lake Erie Agriculture Nutrient Management via Scenario Evaluation (2016)
Recommended Binational Phosphorous Targets to Combat Lake Erie Algal Blooms: Great Lakes Water Quality Agreement Nutrients Annex Subcommittee (2015)	Expectations for Domestic Action Plans Under the Great Lakes Water Quality Agreement (2016)	Lake Erie Protection and Restoration Plan (2016)
Evaluating Watershed Management Plans: Nutrient Management Approaches in the Lake Erie Basin and Key Locations Outside of the Lake Erie Basin (2016)	Ontario's Great Lakes Strategy 2016 Progress Report (2016)	Michigan's Implementation Plan: Western Lake Erie Basin Collaborative (2016)

Lake Erie Lakewide Action and Management Plan: Annual Report (2016)	Ontario's Great Lakes Strategy (2016)	Sustaining Michigan's Water Heritage: A Strategy for the Next Generation (2016)
2016 Progress Report of the Parties: Pursuant to the Canada-United States Great Lakes Water Quality Agreement (2016)	Nutrient Management: Research Insights for Decision Makers (2017)	Ohio Integrated Water Quality Monitoring and Assessment Report (2016)
A Framework for Water Quality Trading in the Western Lake Erie Basin (2016)	Canada-Ontario Lake Erie Action Plan: Partnering on Achieving Phosphorous Loading Reductions to Lake Erie from Canadian Sources (2018)	Upper Maumee River Watershed Management Plan (2016)
Assessment of Fertilizer and Manure Application in the Western Lake Erie Basin (2017)	Nutrient Reduction Project Catalogue (2018)	Effects of Conservation Practice Adoption on Cultivated Cropland Acres in Western Lake Erie Basin, 2003-06 and 2012 (2016)
Summary of Findings and Strategies to Move Toward a 40% Phosphorous Reduction (2017)	The Thames River (Deshkan Ziibi) Shared Waters Approach to Water Quality and Quantity (2019)	Western Lake Erie Basin Initiative Fiscal Years 2016-2018 (2016)
First Triennial Assessment of Progress on Great Lakes Water Quality: Technical Appendix (2017)	Draft Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (2020)	Michigan Water Strategy: Annual Report (2017)
First Triennial Assessment of Progress on Great Lakes Water Quality (2017)		State of Ohio's Western Lake Erie Basin Collaborative Implementation Framework: A Pathway for Transitioning Ohio to a Great Lakes Water Quality Agreement Domestic Action Plan (2017)
State of the Great Lakes 2017 Technical Report: Indicators to Assess the Status and Trends of the Great Lakes Ecosystem (2017)		US Action Plan for Lake Erie: 2018-2023 Commitments and Strategy for Phosphorous Reduction (2018)
Watershed Management of Nutrients in Lake Erie (2017)		Indiana's Great Lakes Water Quality Agreement: Domestic Action Plan for the Western Lake Erie Basin (2018)
Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin (2018)		State of Michigan Domestic Action Plan for Lake Erie (2018)

Lake Erie Lakewide Action and Management Plan: Annual Report (2018)		Ohio 2018 Integrated Water Quality Monitoring and Assessment Report (2018)
Oversight of Animal Feeding Operations for Manure Management in the Great Lakes Basin: A Report Submitted to the International Joint Commission by the Great Lakes Water Quality Board (2019)		State of Ohio’s Domestic Action Plan 1.0 (2018)
Assessment of Fertilizer and Manure Application in the Western Lake Erie Basin – Supplement (2019)		Lake Erie Protection and Restoration Plan (2020)
Lake Erie Binational Phosphorous Reduction Strategy (2019)		Promoting Clean and Safe Water in Lake Erie: Ohio’s Domestic Action Plan 2020 to Address Nutrients (2020)
Progress Report of the Parties Pursuant to the 2012 Canada-United States Great Lakes Water Quality Agreement (2019)		Ohio 2020 Integrated Water Quality Monitoring and Assessment Report (2020)
Lake Erie 2019-2023 Lakewide Action and Management Plan (2019)		Lake St. Clair Watershed Implementation Priorities Plan (2020)

Documents were analyzed through content analysis and associated coding (Berg and Lune 2012, Bryman and Bell 2016). Content analysis is "the subjective interpretation of the content of text data through the systemic classification process of coding and identifying themes or patterns" (Hsieh and Shannon 2005, 1278). Content analysis was both inductive (themes emerged from the documents) and deductive (themes emerged from the academic literature before being identified in the documents) (Berg and Lune 2012). Codes are "the topics, activities, events, and people that come up in your transcripts" (Van den Hoonaard 2012). Data collection and analysis moved through multiple, iterative phases: (i) data collection, (ii) identification of codes from the data/literature, and (iii) grouping of codes into categories (Berg and Lune 2012). Open coding occurred first, where the analysis was broadly receptive to the data until a point had been reached where the same codes were being identified, after which systematic coding began, where the data was sorted into categories (Van den Hoonaard 2012, Berg and Lune 2012). Categories were used to identify themes from the data, which were then considered in the context of the literature to derive conclusions related to the research purpose and objectives (Berg and Lune 2012, Saldaña 2009). A theme is "an outcome of coding, categorization, and analytic reflection, not something that is, in itself, coded" (Saldaña 2009, 13). The same phases of content analysis were applied to the first round of policy Delphi survey responses, as will be described in the next subsection.

1.5.3 Policy Delphi Surveys

The policy Delphi method was selected for the research because it has been demonstrated to be suitable for assessing policy issues, identifying potential options for solutions and their potential consequences, and determining the acceptability and feasibility of those potential solutions (McGeoch, Brunetto, and Brown 2014, Meskell et al. 2014, Turoff 1970, 2002). Developed by Turoff in 1970 (Turoff 1970), the policy Delphi is "a method that uses iterative stages of data collection to reveal positions on an issue within a panel of people with relevant knowledge" (de Loë et al. 2016, 78). Policy Delphi surveys differ from traditional consensus-seeking Delphi surveys because "in a policy Delphi survey, consensus is an interesting outcome rather than a goal" (de Loë, Murray, and Simpson 2015, 195). The policy Delphi is suited for exploring problems with multiple perspectives where insight from experts would be beneficial to understand the problem (de Loë et al. 2016, Franklin and Hart 2007). However, it is not a decision-making tool; it is about facilitating the exploration of various perspectives that exist on a policy issue and their critical assessment by subject matter experts (Franklin and Hart 2007, O'Loughlin and Kelly 2004, Turoff 2002). Policy Delphi surveys are better at exploring a breadth of issues, which is why it is paired with the document analysis and academic literature review which can achieve a more in-depth analysis (de Loë et al. 2016, de Loë 1995).

Policy Delphi surveys as a methodological tool have strengths and weaknesses. Strengths of the method include: (i) it provides a mechanism to consult a wide range of experts across large spatial distances in a cost-effective manner than alternative methods such as workshops, (ii) it allows the researcher to understand how the academic literature translate into real-world and real-time experiences, and (iii) it can maintain participant anonymity, therefore allowing for a more frank sharing of opinions and ideas than other methods (Franklin and Hart 2007, McGeoch, Brunetto, and Brown 2014, Meskell et al. 2014). Some of the weaknesses of a policy Delphi include the large time commitments required from survey participants, as well as the time and effort required from the researcher to analyze the large amount of data generated from each round of surveys and return them to participants in a timely manner (McGeoch, Brunetto, and Brown 2014, Turoff 1970).

Participants were selected based on their ability to contribute to the research objectives (Manley 2013, Turoff 1970) and were recruited using purposive sampling (Berg and Lune 2012). Purposive sampling is commonly used in other policy Delphi surveys to recruit potential participants (e.g., Meskell et al. 2014, de Loë et al. 2016). Participants were identified during the document analysis by reviewing author lists and by looking at membership lists for working groups (e.g., the Great Lakes Water Quality Board). Academic participants were identified during the literature review, based on relevant publications discussing nutrient management efforts and/or drivers of eutrophication in the western Lake Erie basin. Participants were selected based on their demonstrated knowledge of and/or participation in water governance and nutrient management efforts in the western Lake Erie basin. I did not intend to have a representative sample of participants, given the large number and diversity of potential groups in the western Lake Erie basin. Although responses to the policy Delphi survey are anonymous so that participants could respond to survey questions without "interpersonal considerations" (de Loë, Murray, and Simpson 2015), participants were told the general composition of their fellow survey participants (Manley 2013, Turoff 2002). In the Canadian policy Delphi survey, participants included the following examples: government agencies including Environment and Climate Change Canada, Agriculture and Agri-Food Canada, and the Ontario Ministry of Agriculture, Food and Rural Affairs; environmental non-governmental organizations; university researchers; agricultural organizations such as the Ontario Federation of Agriculture; and conservation authorities. In the US policy Delphi survey, participants included the following examples: government agencies including the Michigan Department of Agriculture and Rural Development, the US Department of Agriculture, the Ohio Department of Natural Resources, Soil and Water; environmental non-governmental organizations such as The Nature Conservancy; and university researchers. In the Canadian case study, 53 individuals were approached to participate in the policy Delphi survey and 28 individuals agreed to participate. Overall, 25 Canadian participants completed both the first and second round of the survey. In the US survey, 52 individuals were approached to participate in the policy Delphi survey and 24 individuals agreed to participate. Overall, 21 US participants completed both the first and second round of the survey.

Qualtrics was used to design and deliver the surveys, and to collect survey responses. The policy Delphi surveys were delivered through two rounds of questionnaires, with the second round building on the results of the first round; participants were expected to participate in both rounds of the surveys (de Loë, Murray, and Simpson 2015, de Loë et al. 2016). The purpose of the policy Delphi surveys was to identify drivers of eutrophication in the western Lake Erie basin and to determine whether these drivers of eutrophication are taken into account by nutrient management efforts. The US and Canadian policy Delphi surveys were carried out between February and August 2019. Survey questions in the first survey round were informed by the academic literature as well as the document analysis (de Loë et al. 2016) and the research objectives to identify drivers and determine whether they are taken into account by nutrient management efforts. In the introductory text of the first survey round, participants were provided with background information on eutrophication, the purpose of the research, and important definitions. For example, we defined drivers as any factor that affects a system (Nayak and Berkes 2014). The survey questions are listed here:

1. What drivers are currently influencing eutrophication in the western Lake Erie basin?
2. What drivers of eutrophication are likely to be most important in the future?
3. Do you think all the relevant drivers that affect eutrophication in the western Lake Erie basin are accounted for in existing nutrient management efforts by Canada and the United States? Why or why not?
4. What drivers are accounted for? How are they accounted for in nutrient management efforts? Please provide examples.

5. What drivers are not accounted for in nutrient management efforts, but you think should be? Please provide examples.

Content analysis, as described in the previous section, was used to analyze the first survey round responses. Responses from participants were grouped into representative statements for the second round of the survey (Manley 2013, O'Loughlin and Kelly 2004). In the Canadian policy Delphi survey, content analysis of the first survey round responses led to 101 statements for participants to consider in the second survey round. In the US policy Delphi survey, the first survey round responses led to 103 unique statements for participants to consider in the second survey round. In the second round of the survey, participants were asked to indicate their level of agreement with the representative statements reflecting the coded results from the first survey round. A four-point scale (strongly agree to strongly disagree) was used to require participants to "take a clear position (or to clearly take no position)" because the scale does not include a neutral position, although participants were allowed to abstain from making a judgement (i.e., by selecting "I don't know" as a response) (de Loë, Murray, and Simpson 2015, 195, Turoff 1970, 2002). Participants were also asked to provide a rationale to provide context for their rating and assist the researcher in understanding the survey response (de Loë 1995). The algorithm to measure consensus and support among expert ratings on the Likert scale, developed by de Loë (1995) and improved by de Loë and Wojtanowski (2001), was used to analyze results from the second survey round. This analysis determined "whether the group supported, opposed, or was ambivalent towards an option; whether the group was split, for example, half supporting and half opposing an option, or whether no clear picture of support emerged" (de Loë 1995, 61). Therefore, the algorithm determines both whether and how strongly participants agree on a statement (the degree of consensus), as well as where they agree on the four-point rating scale (e.g., participants strongly agree with a statement) (de Loë, Murray, and Simpson 2015). Figure 2 provides the details on how consensus and agreement are measured.

Figure 2. Measuring consensus and agreement among policy Delphi participants, adapted from de Loë and Wojtanowski (2001, 8).

Case Study	**Example Statement**	**Consensus**	**Agreement**	**Rating Distribution**				
				SA	**A**	**D**	**SD**	**-**
Canadian	Agricultural practices, including nutrient management, drainage practices, and associated runoff, are a driver of eutrophication	High	SA	18	6	0	0	0
US[1]	Invasive species, such as dreissenid mussels, are a driver of eutrophication	None	None	0	6	5	1	9

Agreement measured where participants had consensus (if there was consensus):

- SA = Strong Agreement
- A = Agreement
- D = Disagreement
- SD = Strong Disagreement
- None = No agreement or disagreement

Consensus measured whether and/or how strongly participants agreed or disagreed on a statement in the survey, using the following criteria:

- High consensus: 70% of ratings occurred in one category (e.g., SA) or 80% of ratings occurred in two related categories[2] (e.g., SA-A).
- Medium consensus: 60% of ratings occurred in one category (e.g., D) or 70% of ratings occurred in two related categories (e.g., D-SD).
- Low consensus: 50% of ratings occurred in one category (e.g., A) or 60% of ratings occurred in two related categories (e.g., SA-A).
- None: Less than 60% of ratings occurred in two related categories.

Level of participation was also considered during the analysis of the second survey round responses. If more than 30% of survey respondents selected "I don't know" or left a rating blank, then the statement was considered to have insufficient participation.

[1] This is an example of a statement that had insufficient participation from survey respondents.

[2] Related categories are SA-A or D-SD.

1.5.4 Bringing the Data Together

Together, the document analyses, policy Delphi surveys, and literature review were used to achieve the research objectives and fulfil the overall research purpose. To make the evaluative conclusions that I provide in Chapters 2, 3, 4 (the three manuscripts), and Chapter 5 (the conclusion), I considered each of the three data sources first individually and then together. I first looked at the data generated by the US policy Delphi surveys on a driver to understand expert perspectives. Secondly, I examined the results from the US document analysis to see if there was agreement between the data sources within the US case study. The results from the Canadian policy Delphi survey and document analysis were then considered to identify differences and areas of overlap between the case studies. Finally, the academic literature was then reviewed to determine whether the driver has been explored by researchers. Although I conducted each method separately within the US and Canadian case studies (e.g., the Canadian policy Delphi was carried out independently of the Canadian document analysis), there was some overlap (e.g., between report authors and policy Delphi participants) and the data from each source was considered concurrently when drawing conclusions from the data.

For example, invasive species are a driver of eutrophication in the western Lake Erie basin that was identified independently in the first round of both the Canadian and US policy Delphi surveys. In the second survey rounds, there was high consensus among Canadian participants that invasive species are a driver of eutrophication; in the US survey, there was insufficient participation from respondents on whether invasive species are a driver. Invasive species were also identified in the Canadian and US document analyses as a driver of eutrophication in the western Lake Erie basin (e.g., in the 2018 Canada-Ontario Action Plan and the IJC First TAP). Similarly, invasive species are an established driver of eutrophication in the scholarly literature examining Lake Erie (e.g., Michalak et al. 2013). Therefore, I concluded that invasive species are a driver of eutrophication in the western Lake Erie basin, based on the analysis of multiple data sources across two case studies.

1.6 Organization of Thesis

This thesis is organized using a manuscript-style format with an introductory chapter, three results chapters, and a concluding chapter. In Chapter 1, I provide the research context, purpose and objectives, and a literature review that explores current arguments and gaps in water governance and SES scholarship surrounding drivers. This chapter provides details on the case study of the western Lake Erie basin as well as the research methodology. The research results are presented in the three manuscript chapters (Chapters 2, 3, and 4). In Chapter 2, I identify drivers of eutrophication in the western Lake Erie basin (research objective 1) and demonstrate the importance of identifying drivers when developing solutions to water problems. In Chapter 3, I assess whether the drivers identified in Chapter 2 are taken into account by nutrient management efforts within the western Lake Erie basin and consider the implications for water quality outcomes (research objective 2). In both Chapters 2 and 3, I compare data from the Canadian and US case studies to identify similarities and differences. In Chapter 4, I draw on the research results to characterize how drivers and water governance interact in the western Lake Erie basin and to place these findings in the context of the water governance literature (research objective 3). Finally, in Chapter 5, I bring the results together to address the overall purpose of the research to identify the implications of the results for the theory and practice of water governance, especially for addressing the eutrophication of Lake Erie specifically, and water bodies broadly. In Chapter 5, I also present the significant, original contributions of this research to the academic literature and practitioners, as well as opportunities for future research.

There were practical and conceptual benefits to organizing the thesis as described above. There were other options for how the thesis could be organized, including by exploring the Canadian and US case studies in two separate chapters. A large volume of data was generated on drivers of eutrophication and whether they are taken into account by nutrient management efforts. Analysis of the first round responses for the Canadian policy Delphi revealed more than 100 different ideas to explore in the second round of the survey, with 27 drivers identified. Each of these responses then had multiple ratings to consider, levels of consensus to assess, and rationales to analyze. A similar volume of data was generated by the US policy Delphi survey responses. From the Canadian and US document analyses, there were 1200 and 1300 references respectively in NVivo on drivers of eutrophication, and 3300 and 4171 references on drivers that are taken into account. I explored the identification of drivers and whether they are taken into account separately in Chapters 2 and 3 to allow for a more in-depth discussion and comparison of the data than could be achieved by organizing the results by case study (and therefore combining the data on drivers and whether they are taken into account by nutrient management efforts). Table 3 links each results chapter with the research objectives and data source to emphasize their unique contributions.

Table 3. Linking thesis chapters to research objectives.

Chapter	Research Objective	Chapter Contribution
Chapter 2	(1) Identify drivers of eutrophication in the western Lake Erie Basin	Discusses the drivers of eutrophication identified in the US and Canadian case studies using data from both the US and Canadian policy Delphi surveys and document analyses

Chapter 3	(2) Determine whether these drivers are taken into account by nutrient management efforts	Considers the perceived major drivers of eutrophication that were identified in Chapter 2. Uses the data from the Canadian and US case studies to determine whether these drivers are taken into account by nutrient management efforts
Chapter 4	(3) Assess the relationships among drivers and water governance	Uses the data from both case studies to examine the connections among drivers of eutrophication and water governance in the western Lake Erie basin

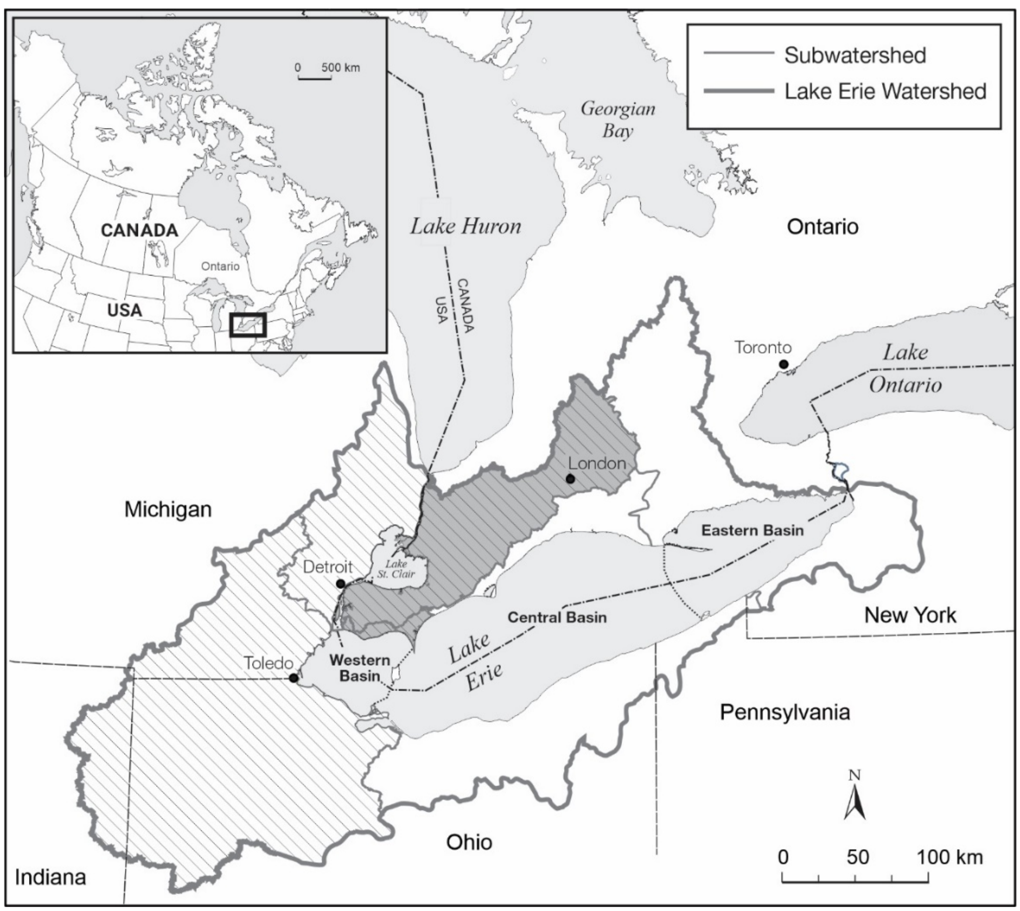
Chapter 2

Drivers of Eutrophication in the Western Lake Erie Basin

2.1 Introduction

In North America, Lake Erie (see Figure 3) has been a long-standing area of concern for water quality. The shallowest of the Great Lakes, the Lake Erie Basin is home to approximately 12 million people and falls within the jurisdictions of both the federal US and Canadian governments, as well as the Province of Ontario and the state governments of Ohio, Michigan, Indiana, Pennsylvania, and New York (International Joint Commission 2014, Great Lakes Water Quality Board 2017). The Lake Erie basin is significant both as a population hub and as a productive region for agricultural operations and recreational/commercial fisheries (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018).

Figure 3. A map of the Lake Erie basin. Subwatersheds draining to the western Lake Erie basin are highlighted with diagonal lines. The Canadian portion of the Subwatersheds draining to the western basin are marked in dark grey and the US portions are marked with diagonal lines.



The problem of eutrophication and the associated algal blooms has re-emerged since the 2000s as an issue of public concern and joint government action from the United States and Canada (International Joint Commission 2014). The sources of phosphorous have shifted since the original eutrophication problem of the 1970s from mainly point sources (such as sewage treatment plants) to rural and urban non-point sources, including runoff from agricultural areas (International Joint Commission 2014). Increasingly severe algal blooms have led to focused efforts to assess the causes of, and solutions to, Lake Erie’s eutrophication problem at local, national, and international levels (International Joint Commission 2014). Despite these efforts, the International Joint Commission continues to classify the water quality of Lake Erie’s western basin as poor (International Joint Commission 2017a, 20). The importance of effective water governance to reduce nutrient loading and associated eutrophication is emphasized by the public health risks of cyanobacterial blooms (e.g., in the City of Toledo, 2014) (Great Lakes Water Quality Board 2016) and the steep economic costs of responding to algal blooms due to changes in water treatment, ecosystem services, and loss of water-related incomes (International Joint Commission 2014). Water governance is the process by which multiple state and non-state actors make decisions and act to affect water (de Loë and Patterson 2017b). Characterizing water problems and their drivers is a crucial component of water governance that this research considers.

Drivers are where decision-makers should intervene to address environmental problems (Levy and Morel 2012, 771, Meadows 1999). Definitions of drivers are variable, but generally refer to factors that influence social-ecological systems (SES) (e.g., Levy and Morel 2012, Millennium Ecosystem Assessment 2005). Bridging the gap between environmental problems and their solutions requires combining knowledge on the integrated nature of social and ecological systems (i.e., SES thinking) (Berkes, Colding, and Folke 2003). Understanding the characteristics and impacts of drivers at local and regional spatial levels can be challenging when assessing ecosystem change (Millennium Ecosystem Assessment 2003). There is a need to identify and understand the most important drivers within specific contexts (Räsänen et al. 2017). Water governance processes for nutrient management in Lake Erie are an example of a water problem where decision-making responsibilities are shared across multiple levels of government and geography. Addressing nutrient loading to water is a priority shared globally, but successful reductions in nutrient levels have not often been achieved (Reilly et al. 2021, Jarvie et al. 2019). Research by Scavia et al. (2017) suggests current nutrient management efforts may need to look beyond the current focus on agriculture to consider social and economic factors influencing nutrient loading to Lake Erie.

The purpose of this research is to identify and explore drivers of eutrophication in the western Lake Erie basin, a case study that has implications for addressing eutrophication and other water problems more broadly. Surveys of Canadian and US nutrient management experts and practitioners are partnered with an analysis of policy documents to identify drivers of eutrophication and reflect on implications for water governance and nutrient management.

2.2 Challenges and Opportunities in the Context of Drivers

There is growing recognition that environmental problems can be complex, which can make it difficult to achieve governance objectives (Cox 2011). It can be a challenge for governance actors to avoid overly simplistic solutions to complex environmental problems (Ostrom 2007, 2009). These complex problems include dynamic relationships across scales and levels both within and among SES (Duit et al. 2010). Examples of scales and levels relevant to water governance include the spatial scale defined by hydrological boundaries, and corresponding levels from river basins to subwatersheds (Cash et al. 2006).

Water governance approaches have long been criticized for failing to resolve water problems (Castro 2007, UN World Water Assessment Programme 2003). For example, the eutrophication of water bodies is a long-standing global challenge requiring attention and action (Foulon et al. 2019, Jarvie et al. 2019, Reilly et al. 2021). Specifically, Jarvie et al. (2019) observed that although the critical role of phosphorous in freshwater eutrophication was established in the 1970s and there have been decades of research and management efforts aimed at eutrophication, water quality improvements have not broadly been achieved. In the context of agriculture as a source of nutrients, Reilly et al. (2021) link the persistence of phosphorous loading to the design and implementation of nutrient management policies.

We argue that the persistence of problems such as eutrophication may be linked to a failure to properly identify and address relevant drivers. As a result, water governance approaches can apply narrow problem definitions and scopes of action that exclude potentially relevant drivers (de Loë and Patterson 2017b, Galaz 2007, Ingram 2008). de Loë and Patterson (2017b, 82) characterize drivers as "socioeconomic or environmental forces that influence or exert pressure on a system". For example, the Great Lakes Futures Project explored eight key drivers affecting the SES of the Great Lakes Basin, including "energy, economics, demographics and societal values, geopolitics and governance, aquatic invasive species, biological and chemical contaminants, and water quantity" (Bartolai et al. 2015, 45). Building on the argument that water governance approaches that identify and address drivers of water problems are beneficial (e.g., Fish, Ioris, and Watson 2010, Räsänen et al. 2017), we suggest that assessing drivers and efforts to manage them in an empirical setting could provide novel insights that could benefit the water governance literature.

Categories of drivers have also been developed by others, including Ostrom (2007) and Lewison et al. (2016), who identified social, economic, and political settings as affecting SES. In the SES framework, these categories include economic development, demographic trends, political stability, pollution patterns, and climate patterns as socioeconomic and ecosystem factors (Ostrom 2007). Efforts have also been made to categorize drivers as internal or external (e.g., Kittinger et al. 2013) and direct or indirect (e.g., Gupta and Pahl-Wostl 2013). However, these definitions and categorizations are varied and can be challenging to apply consistently (e.g., Gari, Newton, and Icely 2015). Rueda et al. (2019) demonstrated that a focus on proximate and distal drivers of tropical deforestation (e.g., Geist and Lambin 2002) has excluded the influence of psychological drivers on decision-making within SESs. Therefore, relying on predetermined characterizations of drivers, such as those in the SES framework may ignore emerging or currently unknown drivers (e.g., Clement 2012, Thiel, Adamseged, and Baake 2015).

Excluding important drivers can lead to water governance approaches that are not well equipped to identify and implement solutions to water problems. In their assessment of the Yahara River watershed in Wisconsin, USA, Gillon, Booth, and Rissman (2016) observed that the water governance system does not account for the dynamic nature of drivers and their interactions with each other. This lack of acknowledgement has led to ineffective nutrient management efforts and a continuation of impaired water quality. Gillon, Booth, and Rissman (2016) conclude that the governance system does not take these drivers of phosphorous loading to the river into account. Similarly, Reilly et al. (2021) identified the importance of understanding the complex, multi-scale interactions and mismatches between drivers of nutrient loading and nutrient management efforts. Nutrient management in the western Lake Erie basin represents an opportunity to identify the drivers of a water problem (eutrophication) and inform nutrient management efforts.

Conceptual frameworks have been developed to characterize SES and inform context-sensitive solutions to environmental problems (Garrick et al. 2013). The SES framework is a well-established conceptual framework that applies a systemic perspective and provides widely accepted language for analyzing SES (McGinnis and Ostrom 2014, Ostrom 2007, 2009). Building on SES thinking, de Loë and Patterson (2017a) developed a diagnostic framework for researchers and practitioners to critically assess water governance and to identify drivers affecting an action situation. From a completely different starting point, the Driver-Pressure-State-Impact-Response (DPSIR) framework is another tool for conceptualizing drivers, establishing cause-effect relationships in ecosystems, and informing decision-making (Gari, Newton, and Icely 2015, Lewison et al. 2016). In this paper, we draw primarily on approaches to understanding drivers and their implications for governance that are rooted in SES thinking. The SES and DPSIR frameworks, intended to guide the analysis of SES to understand the variables contributing to environmental problems, have weak and conflicting characterizations of drivers. The DPSIR framework struggles to distinguish between driving forces and pressures, and furthermore does not explain how to identify drivers or how to assess them (Borja et al. 2006, Kristensen 2004). A more recent review of the DPSIR framework confirms the inconsistencies and contradictions in DPSIR terminology and application of the framework (Gari, Newton, and Icely 2015). In a similar vein, the SES framework, without using the term driver itself, identifies ecosystem or socioeconomic/political settings as well as multiple variables (e.g., actors, governance system features) that affect SES at multiple spatial levels (McGinnis and Ostrom 2014), but even SES scholars have argued that the framework does not provide adequate tools to understand or address them. For example, Nayak and Berkes (2014) critique the SES and environmental governance literatures for their one-directional characterization of drivers and their interactions between nested SES. We argue that identifying and characterizing drivers using the knowledge of subject matter experts and practitioners provides unique contributions to understanding drivers of eutrophication and nutrient management efforts in this research's case study of the western Lake Erie basin. These empirical findings could be used to extend current framings of drivers in the SES and DPSIR frameworks.

Understanding a problem (e.g., eutrophication in the western Lake Erie basin) from an SES perspective requires understanding the drivers influencing the system (Holling 2001, Kittinger et al. 2013). Although the conceptual frameworks described above acknowledge the importance of identifying, characterizing, and accounting for drivers, definitions of drivers and how to identify them are inconsistent. For example, some water and environmental governance reports identify specific drivers such as population growth (UNWWAP 2009), while others use scales of influence to frame drivers (e.g., ultimate drivers impacting water through proximate drivers (Millennium Ecosystem Assessment 2003, UNWWAP 2012a). Discussions of drivers in the water governance literature can use broad definitions that characterize drivers as dynamic social, economic, or environmental factors that affect a SES (de Loë and Patterson 2017a, Gupta and Pahl-Wostl 2013, Räsänen et al. 2018), while some research provides no definition at all. For example, Gillon, Booth, and Rissman (2016) discuss the impact of drivers and the importance of accounting for their dynamic nature in governance, but do not actually define what they mean by "driver". Therefore, there are research gaps on characterizing drivers in specific contexts, and the relationships between how drivers are perceived and efforts to manage them (e.g., Gillon, Booth, and Rissman 2016, Räsänen et al. 2018). As Räsänen et al. (2017, 705) noted, "few have analyzed what are considered to be the most important stressors or drivers in different contexts". Our research aims to address this gap through an empirical assessment of drivers in the western Lake Erie basin. Based on a review of drivers in the SES and water governance literatures, we characterize drivers as the social and ecological factors that affect an action situation (e.g., eutrophication in the western Lake Erie basin) (Millennium Ecosystem Assessment 2003, de Loë and Patterson 2017b, McGinnis and Ostrom 2014, Nayak and Berkes 2014). This definition moves away from human-centric definitions, where drivers are characterized as solely anthropogenic or socioeconomic factors (Gari, Newton, and Icely 2015, Levy and Morel 2012, UNWWAP 2009).

Other limitations of the SES and water governance literatures include a lack of cohesive discussions on identifying drivers and how to explore a driver's influence on a system. As noted earlier, the DPSIR framework is a tool for practitioners explicitly focused on drivers of environmental problems and proposing management solutions, and yet it provides no shared method for identifying and assessing drivers (Borja et al. 2006, Kristensen 2004). Discussions in environmental governance (e.g., Gillon, Booth, and Rissman 2016), water governance (e.g., Räsänen et al. 2017), and Great Lakes research (e.g., Bartolai et al. 2015) literatures apply a range of methods when identifying drivers, including both qualitative tools such as participatory workshops, interviews, and surveys, and quantitative tools such as GIS data and models. We refine these explorations of drivers by making an argument for the value of qualitatively identifying and characterizing drivers in the western Lake Erie basin using the two independent, but complementary, methods discussed in section 2.3.

2.3 Methods

This research examines the Canadian portion of the western Lake Erie basin and the US portion of the western Lake Erie separately as well as together. Structuring the data collection and the analysis into two case studies meant that similarities and differences in Canadian and American perspectives on drivers could be identified. This approach is useful because although there are binational efforts in place to protect Lake Erie water quality (e.g., the Great Lakes Water Quality Agreement), the lake is a transboundary body of water with two separate countries managing water quality. The fundamental methods for each case study are the same, so they are explored concurrently. Analysis of the case studies was carried out separately and the results were compared.

According to the Millennium Ecosystem Assessment (2003), research on drivers has used a variety of methods, including case studies. Nayak and Berkes (2014) demonstrate the value of using qualitative methods, including surveys and the analysis of secondary data sources such as policy documents, in their exploration of global drivers of local and regional change in the Chilika Lagoon in India. Similarly, Räsänen et al. (2017) explored how drivers are perceived and addressed through water management strategies using participatory workshops for their case studies in Finland, Mexico, and Laos. Policy analysis methods were used by Gillon, Booth, and Rissman (2016), along with GIS data, to examine the influence of drivers on water quality in the Yahara River watershed in Wisconsin, USA. These examples demonstrate that document analyses and surveys have been successfully used before to identify drivers and are therefore an appropriate choice to examine drivers of eutrophication in the western Lake Erie basin. In this research, we used document analysis of nutrient and water quality action plans, guidance documents, and agreements and policy Delphi surveys to identify and explore drivers of eutrophication in the western Lake Erie basin.

2.3.1 Policy Delphi Surveys

The policy Delphi method was used because it is suitable for assessing policy issues and identifying options for solutions (McGeoch, Brunetto, and Brown 2014, Meskell et al. 2014, Turoff 2002). Policy Delphi surveys are well-suited to exploring a breadth of issues and can be especially useful when paired with a method that allows for in-depth analysis (de Loë et al. 2016, de Loë 1995); in this case, we paired a policy Delphi survey with the document analysis. The policy Delphi allows for more cost-effective consultation with a wide range of geographically dispersed experts than alternative methods such as workshops while also allowing for a more frank sharing of ideas because of participant anonymity (Franklin and Hart 2007, McGeoch, Brunetto, and Brown 2014, Turoff 1970). Given the large spatial area of the case studies and the distribution of potential participants, as well as the research objective to identify drivers of eutrophication that may not be included in current nutrient management efforts, the policy Delphi's ability to bring together a large group of experts to discuss potentially contentious ideas anonymously is crucial to the research findings.

Policy Delphi participants were selected using purposive sampling based on their ability to provide perspectives on the problem context and policy area (Manley 2013, Turoff 1970); participants were selected for their knowledge and expertise on the research topic (Berg and Lune 2012, de Loë et al. 2016, Meskell et al. 2014). Potential participants were identified using membership of working group, agencies, and organizations, as well as author lists for nutrient management documents. Survey participants were recruited to represent decision-makers in the Lake Erie basin, as well as academic researchers familiar with governance arrangements and nutrient management efforts in the Lake Erie basin. Examples of the wide range of governance actors that participated in the research include: the Michigan Department of Natural Resources, the Ohio Lake Erie Commission, the United States Environmental Protection Agency, Agriculture and Agri-Food Canada, the Ontario Ministry of Natural Resources and Forestry, Fertilizer Canada, and Ontario conservation authorities. As seen in Table 4, not all potential perspectives were represented in the final survey participant composition, including First Nations and tribal governments in Canada and the US, respectively, as well as private sector actors in the Canadian case study and agriculture sector actors in the US case study. Given the number of potential interests in the basin, we did not expect to achieve a completely representative sample. However, other organizations such as the Great Lakes Water Quality Board have completed work understanding the diversity of perspectives, including publications (e.g., 2017 IJC First TAP). Therefore, a wide range of perspectives are also represented in the document analyses. In the Canadian case study, 53 potential participants were approached and 28 of them agreed to participate in the survey; in the US survey, 52 individuals were approached and 24 of them agreed to participate. In total, 25 participants in the Canadian policy Delphi survey and 21 participants in the US survey completed both survey rounds; in both case studies, three participants did not complete the second survey round (Table 4). **Table 4. Policy Delphi survey participants in the Canadian and US case studies.**

Category of Participant	**Number of Participants**	
	Canadian case study (n=25)	**US case study (n=21)**
Conservation Authority staff	5	0
Government staff	11	11
Agriculture sector	4	0
Non-governmental organization staff	4	5
University researchers	3	4
Private sector	0	2

Separate Canadian and US policy Delphi surveys were carried out between February and August 2019. Following a successful design in previous studies that used the policy Delphi, each survey consisted of two rounds, with the second survey round building on the results of the first round (de Loë, Murray, and Simpson 2015, de Loë et al. 2016). Background information on the policy issue (eutrophication in the western Lake Erie basin) was provided to survey participants. Survey questions in the first round were an open-ended exploration of drivers and nutrient management so as not to bias participants in their responses. For example, one of the questions was “What are the drivers currently influencing eutrophication in the Lake Erie basin?” Redundant responses were grouped to develop representative statements on drivers for the second round of the survey (Manley 2013, O'Loughlin and Kelly 2004). The second round asked participants to indicate their level of agreement with the statements on drivers using a four-point scale (strongly agree to strongly disagree) that requires participants to “take a clear position (or to clearly take no position)” (de Loë, Murray, and Simpson 2015, 195); this is an approach used with good success in our research group in other studies (e.g., de Loë, Murray, and Simpson 2015, de Loë et al. 2016). A statement was only considered to have sufficient participation for further analysis if two-thirds of respondents or more took a position using the rating scale (de Loë and Wojtanowski 2001). Consensus provides a peer-review process for assessing the validity of Round 1 responses. The “algorithmic system” for analyzing these ratings to measure consensus among experts, developed by de Loë (1995) and de Loë and Wojtanowski (2001), was used to analyze results from the second survey round. Consensus indicates where participants agree on a statement, as well as how strongly they agree. For example, low consensus occurred when 50% of participant ratings occurred in a single category (e.g., “significantly disagree) or when 60% of participant ratings occurred with two related categories (e.g., “significantly disagree” and “disagree”) (de Loë and Wojtanowski 2001). Content analysis in QSR NVivo was used to analyze the text of the first survey round results and the rationales for ratings provided in the second survey round.

2.3.2 Document Analyses

Using water and nutrient management documents directly means that the formal language used by actors to define the problem of eutrophication and identify drivers can be analyzed. Given the scope of the analyses, the types of documents included in the research ranged from regional watershed management plans to binational agreements. Documents to include in the analyses were identified using strategic keyword combinations during internet searches, such as “nutrient management” and “Lake Erie”. Given the transboundary nature of the western Lake Erie basin, several nutrient management documents are shared across the cases, such as the International Joint Commission’s *A Balanced Diet for Lake Erie: Reducing Phosphorous Loadings and Harmful Algal Blooms*. These documents were included in both document analysis datasets, since the identification and characterization of drivers was a joint process by Canadian and US representatives. Criteria for including a document in the analysis were that it be published after 2012 to reflect the commitments made under the newest version of the Great Lakes Water Quality Agreement (unless only an earlier version of a document was accessible), that it discuss drivers of Lake Erie eutrophication, and that its purpose be to contribute to Lake Erie water quality management. A total of 60 documents were analyzed (23 US documents, 14 Canadian documents, and 23 binational documents). Examples of the documents analyzed are provided in Box 2.

Box 2. Examples of nutrient management documents included in the document analyses.

Canadian Documents	Binational Documents	US Documents
• Lake St. Clair Canadian Work Plan (2011) • Ontario’s Great Lakes Strategy (2016)	• Great Lakes Water Quality Agreement (2012) • Recommended Phosphorous Loading Targets for Lake Erie (2015)	• St. Clair River and Lake St. Clair Comprehensive Management Plan (2004) • Effects of Conservation Practice Adoption on

• Canada-Ontario Lake Erie Action Plan (2018) • Thames River *(Deshkan Ziibi)* Shared Waters Approach to Water Quality and Quantity (2019) • Draft Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (2020)	• First Triennial Assessment of Progress on Great Lakes Water Quality (2017) • Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin (2018) • Lake Erie Binational Phosphorous Reduction Strategy (2019)	Cultivated Cropland Acres in Western Lake Erie Basin, 2003-06 and 2012 (2016) • State of Ohio's Western Lake Erie Basin Collaborative Implementation Framework (2017) • US Action Plan for Lake Erie 2018-2023 • Lake Erie Protection and Restoration Plan Draft (2020)

Content analysis (Berg and Lune 2012, Bowen 2009) was used to analyze nutrient management documents. Coding was an iterative process that occurred over three rounds, with each round becoming more analytical as themes emerged (Bowen 2009, Saldaña 2009). Coding for the Canadian and US datasets was carried out separately using QSR NVivo software. During the first round of coding, both in vivo and structural coding were used to allow for the identification of ideas unique to the documents while also linking the data to the question being explored (Saldaña 2009), which was to identify drivers of eutrophication. Text was coded in the first round if it met one or more of the following criteria: (i) it stated that something is a source of nutrients; (ii) it stated that something contributes to eutrophication and/or algal blooms; (iii) it stated that something is or should be addressed in nutrient management efforts; (iv) it stated that something is or should be identified as a priority in an official policy/nutrient management document. Two subsequent rounds of coding aggregated codes into similar themes (e.g., drainage management and nutrient management were both aggregated into the larger theme of agricultural practices).

2.4 Results

The purpose of this study is to identify drivers of eutrophication. Identifying drivers is a key step in efforts to ensure that the water governance system can address water problems such as eutrophication. Failing to identify drivers can contribute to the persistence of water problems (e.g., Gillon, Booth, and Rissman 2016).

Building on the findings of both case studies, we explore driver categories that were identified and described in the policy Delphi surveys and the document analyses. Driver categories are used because multiple subthemes could exist for a single driver. For example, "agricultural operations" is a driver category because agriculture is a source of nutrients to the western Lake Erie basin, while multiple subthemes provide greater detail on the specific aspects of agriculture that are a driver of eutrophication, such as nutrient management practices, drainage management practices, and crop management practices. These subthemes fall into the broader theme of agricultural operations but also have unique contributions to discussions of agriculture as a driver.

A total of 46 unique driver categories were identified between the two case studies, with 43 drivers identified in the Canadian case study, and 32 drivers identified in the US case study when both the policy Delphi survey and document analysis results were combined. From the policy Delphi surveys, 37 total drivers were identified (30 in the Canadian case study, 18 in the US case study). From the document analyses, 27 total drivers were identified with complete overlap between case studies and some overlap with the policy Delphi surveys. In the US document analysis, there were 1300 references (organized through coding into 27 nodes and 53 subnodes). In the Canadian document analysis, there were 1200 references (organized into 27 nodes and 61 subnodes). Overlap between case studies and data sources explains why the total number of drivers is smaller than the number of drivers identified in each individual case study or data source. Potential reasons for the differences between the Canadian and US policy Delphi surveys include variation in participants (e.g., the Canadian case study had five more participants than the US survey, as well as the additional perspectives of Conservation Authority staff). Some overlap between data sources and case studies was expected given the transboundary nature of the western Lake Erie basin and the partial overlap between survey participants and nutrient management document author lists, and it strengthens the findings from each source and case study. All drivers that emerged from the case studies are presented in Table 5, distinguished by the data source(s) that identified and described the driver.

Table 5. Drivers of eutrophication organized by overlap between data sources.

Driver Categories	Canadian Policy Delphi	Canadian Document Analysis	US Policy Delphi	US Document Analysis
Agricultural operations	✓	✓	✓	✓
Atmospheric deposition	✓	✓	✓*	✓
Climate change	✓	✓	✓	✓
Development pressures	✓	✓	✓	✓
Funding availability	✓	✓	✓	✓
Invasive species	✓	✓	✓*	✓
Land use change	✓	✓	✓	✓
Nitrogen	✓	✓	✓	✓
Phosphorous	✓	✓	✓	✓
Watershed characteristics	✓	✓	✓	✓
Wastewater	✓	✓	✓	✓
External policies, such as trade and fuel policies	✓	✓		✓
Food web changes	✓*	✓		✓
Politics (e.g., political will)	✓	✓		✓
Urban sources of nutrients, including stormwater	✓	✓		✓
Dredging		✓	✓	✓
Industrial sources		✓	✓	✓
Sediment loading		✓	✓	✓
Animals		✓		✓
Carbon		✓		✓

Groundwater		✓		✓
Hydrodynamics		✓		✓
Light		✓		✓
Nutrients		✓		✓
Rural sources of nutrients		✓		✓
Substrate availability		✓		✓
Synergy between drivers		✓		✓
Agricultural organizations	✓			
Availability of human resources	✓*			
Conservation Authorities	✓			
Communication and coordination among multiple agencies	✓			
Fish exploitation	✓*			
Governments	✓			
Individual accountability for actors	✓*			
Individuals	✓			
Monitoring and modeling of nutrient inputs and nutrient management efforts	✓			
Monitoring is too expensive to implement targeted nutrient management	✓			
Proportional reductions in nutrient loadings	✓*			
Reconciliation opportunities	✓			
Reliance on voluntary actions over regulation	✓			
Restoration programs	✓			
Socioeconomic drivers	✓			
Illegal dumping			✓*	
Non-point sources			✓	
Point sources			✓	
The inability of decision-makers to store water and reduce nutrient runoff			✓*	

Note: Drivers marked with an asterisk (*) had insufficient participation in the second round of the policy Delphi survey.

Eleven drivers of eutrophication were identified in both the Canadian and US case studies, in both policy Delphi surveys and both document analyses. These related to nutrients (phosphorous, nitrogen), biophysical factors (watershed characteristics, atmospheric deposition), human activities (wastewater, land use change), and social factors (funding availability, development pressures). Four drivers of eutrophication were identified in both document analyses and the Canadian survey results but were not identified in the US policy Delphi. These included the influence of external policies, politics, and urban nutrient sources such as stormwater. Similarly, dredging, industrial sources, and sediment loading were identified as drivers by all the data sources except the Canadian survey participants. More than half (n=28) of the total drivers identified (n=46) were identified solely in the Canadian and US document analyses, the Canadian policy Delphi, or the US policy Delphi. Both the US and Canadian document analyses uniquely identified several biophysical drivers of eutrophication, including animals, groundwater, the availability of light, substrate, and other nutrients such as carbon, and synergies between drivers. The Canadian survey participants, in addition to the drivers already discussed, also identified several unique drivers of eutrophication that framed nutrient management efforts and governance actors as contributing to the eutrophication of the western basin of Lake Erie. Agricultural organizations, Conservation Authorities, governments, and communication and coordination among multiple agencies are a few of the drivers identified solely by Canadian survey participants. These actors/agencies and nutrient management mechanisms are drivers because they can positively or negatively affect water quality in the western basin. For example, through their implementation of stewardship programs, Conservation Authorities can affect nutrient loading to Lake Erie. These drivers were not explicitly identified in either document analysis.

Table 5 demonstrates the wide range of drivers identified in the Canadian and US case studies, as well as the overlap between data sources. In addition to the large volume of data generated (46 unique drivers), detailed data exists for each individual driver theme. For example, atmospheric deposition was identified as a driver of eutrophication in both the US and Canadian case studies. Based on ratings alone, there is no consensus in either the Canadian or US policy Delphi that atmospheric deposition is a driver. However, the rationales provided by the participants indicate that among Canadian participants, there was a shared opinion that atmospheric deposition is a source of nutrients to the western Lake Erie basin, but it was seen as a smaller source than other drivers. Among US participants, there was insufficient participation on the question of whether atmospheric deposition was a driver of eutrophication. In contrast, atmospheric deposition was clearly identified as a driver in both the US and Canadian document analyses, where it was described as contributing approximately 6% of the external phosphorous loads to Lake Erie, which may be an underestimate given increases in urban and agricultural land uses within the airshed (IJC Science Advisory Board TAcLE Work Group 2013).

Agricultural practices are a broad theme that emerged during coding in both the Canadian and US document analyses, as well as both the Canadian and US policy Delphi surveys. Subsequent rounds of coding identified several sub-themes contributing to the overall discussion of agriculture as a driver of eutrophication. Sub-themes covered a range of agricultural practices. In the Canadian survey, example subthemes include greenhouse agriculture and the associated effluent, farmer behaviour as a driver, and the time and monetary costs of farming affecting agricultural practices (both positively and negatively). US survey participants also identified multiple subthemes relating to agriculture, including that previous nutrient management efforts to control particulate phosphorous increased dissolved reactive phosphorous loadings and contributed to the current challenges of eutrophication in Lake Erie, and the separation of land ownership from land management via renters affects how agricultural land is cared for. Both the US and Canadian policy Delphi surveys identify the reliance on voluntary actions over regulation in nutrient management, especially for agriculture, as a driver of eutrophication. Other subthemes relating to agriculture covered the following aspects of agriculture:

- Nutrient management practices, crop management practices, and drainage management practices can increase or decrease nutrient and sediment loss to water bodies in the basin (Canadian Water Network 2017, International Joint Commission 2018, Ohio Lake Erie Commission 2020). Agricultural practices and the associated runoff were also identified as a driver by Canadian participants and US participants.

- Trends toward denser livestock operations and the associated concentration of manure generation/application can increase phosphorous loading and create legacy phosphorous in soils (IJC Science Advisory Board TAcLE Work Group 2013, Great Lakes Water Quality Board 2019, International Joint Commission 2017a, U.S. Army Corps of Engineers 2004). Livestock were not identified explicitly as a driver of eutrophication in either the US or Canadian survey, although there were debates in both policy Delphi surveys whether livestock operations were taken into account by nutrient management efforts.
- Financial mechanisms and economics such as commodity prices/changing ethanol markets can change agricultural practices (LimnoTech 2017, 2019). Both the US and Canadian policy Delphi participants agree that crop/drainage/nutrient management practices are drivers of eutrophication. However, there were also differences between the case studies, for example with Canadian participants agreeing that economic factors such as commodity prices can be drivers of eutrophication, while US participants did not agree that economic incentives for high yields affect farm practices. The rationales provided by participants focused more on fertilizers as an essential component of agriculture, where the use of nutrients is necessary to reduce risk and to make a profit but excessive nutrient use cost farmers money.

Exploring each of the drivers in Table 5 in depth is not feasible in this article. We therefore used expert knowledge to indicate driver importance (Räsänen et al. 2016, Räsänen et al. 2017) via survey participant engagement and the number of documents that identified a driver. Survey participant engagement was measured by the number of participants that identified a driver in Round 1 of the policy Delphi. For example, 22 participants identified climate change as a driver of eutrophication in Round 1 of the Canadian policy Delphi survey. Round 2 participation was not a useful indicator of driver engagement, since participants were asked to provide a rating for every potential driver suggested in Round 1 and almost all did so. Round 2 rankings and rationales, as well as the evaluation of consensus among participants, were used to develop the descriptions of drivers provided below, along with data from the document analyses.

The purpose of this paper is to identify drivers of eutrophication in the western Lake Erie basin, using both Canadian and US nutrient management experts and policy documents. Therefore, based on expert engagement and agreement among nutrient management documents, we identified the most common shared perspectives on drivers from the data in Table 6. We used the top 10 drivers from each data source, acknowledging that there was not complete overlap among the data sources. These data provide insights into the problem framing and priorities for action. The level of consensus among policy Delphi participants is provided in the table. For example, in the US policy Delphi survey there are two subthemes under the driver category “Development pressures”: population growth and consumer demand. There is high consensus among participants that population growth increases demand on systems that are nutrient sources (e.g., wastewater treatment, agriculture), while there is no consensus on whether consumer demand for non-food uses of agricultural products (specifically corn and soybeans) can drive eutrophication. Two drivers identified in the US policy Delphi surveys, non-point sources (unspecified) and point sources (unspecified), are excluded from Table 6 because the Round 2 (R2) rationales link these drivers explicitly to other drivers already explored in the table, including agriculture, industrial facilities, and wastewater.

Table 6. The most important drivers of eutrophication from the Canadian and US case studies and a summary statement informed by the policy Delphi surveys and document analyses.

Major Driver of Eutrophication	Description of Driver	Level of R2 Consensus	
		Canada Case Study	US Case Study
Climate change	Climate change, and its impacts on weather patterns, runoff, and ecological conditions, affects nutrient loading to Lake Erie and can create conditions that support algal growth. Climate change also interacts with other drivers affecting nutrient loading and algal growth.	High	High
Agricultural operations	Agricultural practices, including nutrient management, drainage management, crop management, manure and wastewater from livestock operations, and effluent from greenhouse operations, can increase nutrient loading to the western basin of Lake Erie. Other aspects of agricultural operations, including factors that influence farmer behaviour, can shape agricultural practices.	Variable within subthemes	Variable within subthemes
Phosphorous and its availability	Phosphorous is the key driver of eutrophication in the western basin because it is the limiting nutrient for algal growth. Legacy phosphorous in sediments and soils are an emerging driver that increase loading to and internal phosphorous cycling within Lake Erie.	High	High
Wastewater	Wastewater infrastructure (e.g., treatment plants, lack of sanitary sewers, and aging/failing septic systems) and the associated effluent are a source of phosphorous.	High	High
Land use changes	Historical and current land use changes, especially urbanization and agricultural land management, as well as the loss of natural landscapes such as wetlands, change runoff patterns and can increase nutrient loading.	High	High
Invasive species	*Dreissenid* mussels support algal growth, especially in the nearshore area.	High	Insufficient participation
Synergy between drivers	Multiple drivers interact synergistically to affect nutrient loading and algal growth, including human activity, invasive species, and climate change. These interactions and their causal relationships create complexity and are not fully understood.	Not identified as a driver in the policy Delphi survey	Not identified as a driver in the policy Delphi survey

Nitrogen	There is growing evidence that nitrogen (including its relative amounts to phosphorous) affects the development and composition of algal blooms.	Low	High
Urban areas, including stormwater runoff	Urban areas, including fertilizer use on lawns/gardens, pet waste, and construction activities, and the associated stormwater runoff, are sources of nutrients to Lake Erie.	High	N/A
Industrial sources	Industrial discharges (e.g., outfalls and wastewater) are a point source of phosphorous to Lake Erie that is less significant than agricultural non-point sources of phosphorous.	N/A	High
Characteristics of the Lake Erie basin	The Lake Erie basin's physical characteristics (i.e., shallow, warm) and human characteristics (i.e., agricultural and urban land uses), support algal growth and make it prone to eutrophication.	High	High
Funding availability	The availability of funding affects nutrient management efforts (e.g., wastewater treatment infrastructure updates or financial support for agricultural operators), and there is insufficient funding for nutrient management efforts in the western Lake Erie basin.	High	Medium
Development pressures (e.g., population growth)	Growing and changing demand for crops and population growth affect land use and land management practices, leading to the expansion of urban areas and changing agricultural practices which can affect nutrient loading.	High	Variable within subthemes
Communication and coordination between agencies	The level of communication and coordination between nutrient management actors affects the collection and sharing of information to support decision-making and the implementation of nutrient management efforts.	Low	N/A

Climate change is a driver of eutrophication identified by survey participants and nutrient management documents. There was high consensus among both the Canadian and US survey participants that climate change affects eutrophication in the western Lake Erie basin. Subthemes from both the Canadian and US surveys identified the impact of climate change on nutrient loading due to precipitation patterns and climate change creating conditions that support algal growth (e.g., warmer temperatures). In the document analyses, there was an additional theme of climate change as a confounding factor that affects other drivers of eutrophication such as invasive species (International Joint Commission 2014, ECCC and US EPA 2017). Invasive species, specifically *Dreissenid* mussels, are identified as a driver of eutrophication in both the Canadian and US case studies, with overlap between the data sources. Invasive species change nutrient cycling within Lake Erie as well as the inshore/offshore phosphorous exchange (The Annex 4 Objectives and Targets Task Team 2015, Thames River Clear Water Revival 2019, United States Environmental Protection Agency [USEPA] 2018), create conditions that support algal growth (IJC Science Advisory Board TAcLE Work Group 2013, Michigan Office of the Great Lakes et al. 2016, ECCC and USEPA 2019), and facilitate harmful algal blooms containing cyanobacteria through selective filtration and digestion (International Joint Commission 2017a, ECCC and US EPA 2017, ECCC and USEPA 2019), with more information necessary to understand how invasive mussels affect algal bloom occurrences (Great Lakes Commission Lake Erie Nutrient Targets Working Group 2015, State of Michigan 2018). In the Canadian survey, participants had high consensus that invasive species (specifically *Dreissenid* mussels) are a driver of eutrophication, including through disruptions to the food web and internal and nearshore nutrient cycling. In the US survey, there was no consensus among participants whether invasive species are a driver of eutrophication, and there was insufficient participation in the second round of the policy Delphi survey.

Another repeatedly identified driver is land use changes. Land-based activities contributing to nutrient loading include agriculture and urban areas (U.S. Army Corps of Engineers 2004, Zehringer, Nally, and Daniels 2012, International Joint Commission 2014), both of which interact with other factors to cause eutrophication, including population growth and climate change (Canadian Water Network 2017, International Joint Commission 2017a). The loss and deterioration of coastal wetlands, specifically in the western basin, has increased nutrient and sediment loading to Lake Erie (International Joint Commission 2017a, ECCC and US EPA 2017, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, Government of the United States of America and Government of Canada 2016). Similarly, there was high consensus in the Canadian survey that land use change is a driver of eutrophication, specifically urban sprawl, agricultural intensification, and the loss of natural landscapes). Canadian participants also had high consensus that weak land use planning policies are a driver of eutrophication because they can either provide tools to protect natural areas (e.g., the Ontario Provincial Policy Statement is such a tool) that would mitigate nutrient loading, or they can fail to protect natural areas, thereby contributing to eutrophication. In the US survey, participants identified the impact of modified hydrology (e.g., in urban and agricultural landscapes) on nutrient loading to the western Lake Erie basin, which can be positive (reduced loading) or negative (increased loading).

As demonstrated above, there was not complete overlap either between the US and Canadian case studies, or between the policy Delphi surveys and document analyses within each case study. The details of these overlaps (or lack thereof) are explored below:

- In the Canadian case study, 43 driver categories were identified when the policy Delphi survey and document analysis results were combined. Of these 43 drivers, 59% of the drivers identified in the nutrient management documents were also identified in the policy Delphi survey. On the other side of that comparison, 53% of the drivers identified by Canadian survey participants were also identified in the document analysis. Overall, 39% of the total drivers identified were identified in both the policy Delphi survey and the document analysis.
- In the US case study, 31 driver categories were identified when the policy Delphi survey and document analysis results were combined. Of those 31 drivers, 52% of the drivers identified in the nutrient management documents were also identified in the policy Delphi survey. On the other side of that comparison, 80% of the drivers identified by US survey participants were also identified in the document analysis. Overall, 45% of the total drivers identified were identified in both the policy Delphi survey and the document analysis.

- When considering the Canadian and US case studies together, 46 driver categories were identified. Within the policy Delphi survey results, 37% of the drivers identified in the Canadian case study were also identified in the US case study and 61% of the drivers identified in the US survey were also identified in the Canadian survey. Overall, 24% of the total drivers were identified in both the Canadian and US policy Delphi surveys. These findings indicate differences between expert perspectives when comparing the Canadian and US case studies. There was complete overlap between the Canadian and US document analysis results, with 27 total drivers being identified.

Overall, the results presented in this section indicate that similarities and differences exist among Canadian and US subject matter experts and practitioners, as well as between expert opinion and existing nutrient management implementation efforts. These results have implications for nutrient management and water governance which will be discussed in the next section.

2.5 Discussion

This section examines the drivers that emerged from the case studies and considers them in the context of the Great Lakes literature, as well as more broadly linking the results to water governance theory.

2.5.1 Similarities and differences when identifying and describing drivers

As demonstrated in section 2.4, there were both similarities and differences in the drivers of eutrophication that were identified and described both within and between case studies. The overlap between the US and Canadian case studies, as well as between the data sources within each case study, indicate a shared understanding of drivers of eutrophication. Overall, 24% of the 46 drivers were identified in both the Canadian and US policy Delphi surveys. Within each case study, 39% of the total drivers from the Canadian data and 45% of the total drivers from the US data were identified in both their respective policy Delphi surveys and document analyses. The complete overlap between the separate Canadian and US document analyses confirms that the formal framing of nutrient management efforts includes the same drivers of eutrophication. This finding is not surprising, given the decades of coordinated water quality management efforts and binational agreements and commitments that inform national and regional strategies. For example, both the Canada-Ontario Lake Erie Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018) and the US Action Plan for Lake Erie (United States Environmental Protection Agency [USEPA] 2018), key documents guiding nutrient management efforts, are informed by the two countries' commitments under the 2012 Great Lakes Water Quality Agreement. These findings provide some reassurance that current efforts to mitigate eutrophication and the associated algal blooms are identifying appropriate drivers.

Several of the most significant drivers of eutrophication, identified in Table 5 using survey participation and number of documents as an indication of importance, are also reflected in research literature on the Great Lakes. Precipitation patterns, fertilizer application practices, and crop management practices (e.g., conservation tillage) have led to the stratification of soil phosphorous at the surface level and are therefore a cause of the re-eutrophication of Lake Erie (Daloglu, Cho, and Scavia 2012), along with increased tile drainage installation (Baker et al. 2014). Similarly, Smith, King, and Williams (2015) identify commodity prices, crop selection and management, nutrient application practices, and increasing farm size as causing harmful algal blooms in Lake Erie, with complex interactions between these drivers. Climate change is also a recognized driver of eutrophication in the Great Lakes literature (Smith, King, and Williams 2015, Bartolai et al. 2015). More broadly, eutrophication research identifies wastewater, increases in livestock operations, atmospheric deposition of nutrients, and land use transformation from natural to urban areas, along with population growth and economic growth, as drivers that interact synergistically to cause eutrophication (Khan and Mohammad 2014). Therefore, many of the key drivers from the research are supported in the literature, further confirming the validity of the methods. The unique value of this research lies in comparing the identification of drivers between the US and Canadian case studies and in comparing perspectives on drivers between policy documents and experts.

While there is some overlap within and between case studies and with the eutrophication and Great Lakes literatures, there is more nuance to the results than the summaries and themes can provide. For the policy Delphi results, consensus alone does not provide a complete picture of participant perspectives on a driver; the rationales provide context for ratings. For example, although atmospheric deposition is clearly quantified as a source of nutrients in the document analyses, perspectives from the US and Canadian participants were more nuanced. Rationales from Canadian participants suggested that atmospheric deposition is an insignificant source of nutrients compared to other drivers of eutrophication, while US participants did not sufficiently participate in the second round of the survey to draw a conclusion. Given the established role of atmospheric deposition in contributing phosphorous to Lake Erie (IJC Science Advisory Board TAcLE Work Group 2013, International Joint Commission 2014, Canadian Water Network 2017), the contradictory perspectives of the Canadian and US participants raise questions about the strength of shared understandings of the drivers of eutrophication in the western Lake Erie basin. Similarly, invasive species is another driver of eutrophication where differences exist between data sources and case studies. Although invasive species are discussed in Canadian, binational, and US nutrient management documents as a driver affecting eutrophication and algal blooms, the survey results challenge the existence of a shared problem definition. Specifically, although Canadian participants have high consensus that *Dreissenid* mussels are a driver, there was insufficient participation from US participants in the second survey round. The lack of agreement between the US policy Delphi results and the other data sources (including the US document analysis) suggest that there are potentially significant differences in how the issue of eutrophication is understood between formal policy documents and the experts responsible for researching and implementing nutrient management efforts. The results demonstrate overlaps in problem framing but also present unique perspectives, emphasizing the value of both the individual data sources as well as the separate case studies and raising the question of whether understandings of eutrophication are shared both within the US and Canada, as well as between the two countries.

2.5.2 Implications for nutrient management and water governance

Overall, the range of drivers identified in the results indicates variability in how drivers of eutrophication are understood by nutrient management researchers and practitioners as well as in nutrient management programs and strategies, with additional variability between the US and Canadian case studies. Differences between the data sources and the case studies were expected because the policy Delphi surveys are based on the informed perspectives of individual practitioners and researchers, while the plans, strategies, and reports included in the document analysis reflect formal outcomes of collaborative efforts among multiple actors and agencies.

Many of the drivers identified in the results were also generally expected, based on how the problem of eutrophication is characterized in the academic literature and nutrient management documents. For example, the Great Lakes Futures Project identified eight key drivers affecting the Great Lakes basin, which included climate change, demographics and invasive species (Creed and Laurent 2015). Similarly, the Report of the Lake Erie Ecosystem Priority, which was included in both document analyses, identifies runoff from urban and rural land uses, the increasing proportion of bioavailable phosphorous entering the lake, and the compounding influence of climate change as some of the key factors influencing the re-eutrophication of Lake Erie (International Joint Commission 2014).

What the research contributes to previous discussions of eutrophication in the western Lake Erie basin is nuance and depth through practitioner and expert knowledge. Quantifying the overlap between case studies reveals potentially significant different perceptions of eutrophication and its causes, which raises questions about the effectiveness of nutrient management efforts specifically and binational cooperation overall. Drivers where Canadian and US survey participants did not overlap reveal a potentially significant gap in nutrient management efforts. Examples revealed in this study included the role of actors and agencies and the influence of development pressures on nutrient loading. Although water governance authors have acknowledged that policies can affect water resources (e.g., Ghafoori-Kharanagh et al. 2021, Gillon, Booth, and Rissman 2016), in this paper we have clearly identified the role of water governance actors and governance system characteristics on nutrient loading and nutrient management efforts, using expert knowledge. Despite the history of binational cooperation, differing perspectives from Canadian and US practitioners and researchers indicate mismatched understandings of eutrophication.

Another important outcome of the research is the large number of drivers identified. Forty-six drivers of eutrophication were identified, including biophysical factors (e.g., watershed characteristics) and socioeconomic factors (e.g., funding availability) that acted at multiple spatial scales ranging from inside the western Lake Erie basin itself (e.g., hydrodynamics) to global-level influences (e.g., climate change), as well as temporal scales that included present-day nutrient loadings to legacy phosphorous in lake sediments and watershed soils from historical land use practices. The multiple subthemes that comprised each driver category (e.g., the multiple contributing agricultural practices and influencing factors that make agriculture a source of nutrients to Lake Erie), as well as the large number of driver categories, reveal the scope of the challenges for nutrient management in addressing multiple, interacting drivers, some of which appear to be contested or uncertain (e.g., the role of invasive species). Importantly, the relative significance of drivers appeared to vary across the study area. For example, different jurisdictions (in the form of the US and Canadian case studies) revealed variable perspectives on eutrophication. This has implications for the ability of the governance system to address these drivers. This concern was not explored in this paper but is the subject of another component of the larger study of which this paper is one part. Together, the large number of drivers identified, as well as the detailed data generated on each driver (e.g., whether there was agreement between data sources), demonstrates the unique value a regionally-focused case study approach can bring to discussions of drivers in the academic literature. Both the SES and DPSIR frameworks could derive benefits from these findings, by incorporating previously unrecognized drivers as well as practitioner knowledge into the frameworks.

The results also identified previously unexplored drivers of eutrophication through a broader framing of drivers. For example, both document analyses and policy Delphi surveys agree that land use change (e.g., wetland loss, increases in impervious surfaces) is a driver of eutrophication. The Canadian policy Delphi participants introduced a new perspective to the issue that was absent in the other data sources. The concept of land use policy as a driver of eutrophication broadens the spatial scale of drivers beyond the watershed boundaries applied in Lake Erie's nutrient management documents and introduces the role of governance in affecting water quality and the effectiveness of nutrient management efforts. The role of nutrient management actors and policies/programs as drivers of eutrophication was also a unique contribution of the research that broadens existing framings of drivers of eutrophication in the literature.

Previous discussions of drivers in the Lake Erie and eutrophication literature often do not explain their methods for identifying drivers, relying instead on academic citations (e.g., Smith, King, and Williams 2015, Han, Allan, and Bosch 2012) and models (e.g., Bertani et al. 2016, Scavia et al. 2017, Bosch et al. 2013) to discuss nutrient sources. While models and previous research are useful for quantifying and predicting the impacts of drivers both now and in the future, such an approach is ultimately limiting because it generally focuses on drivers that can be measured (e.g., biophysical drivers) and it relies on existing knowledge, without allowing for the introduction of previously unknown or emerging drivers. Therefore, the use of policy Delphi surveys and the document analysis in this research, especially when combined with the academic literature, provides a comprehensive and nuanced understanding of drivers of eutrophication, including relative importance. Specifically, we are contributing to knowledge on the perceived most important drivers based on engagement by data sources within the context of the western Lake Erie basin; this type of context-specific analysis was identified as lacking by Räsänen et al. (2017). Context is important for drivers: although a driver may be present in multiple SES (e.g., climate change is a global-level driver), the details of how a driver affects ecosystem change will be unique to the specific SES under investigation (e.g., climate change impacts at the regional scale) (Nelson et al. 2006). For example, crop prices are identified as a driver of eutrophication in the western Lake Erie basin by the data from this study, as well as by Nelson et al. (2006) as a driver of crop production in multiple places around the world. However, the details of how crop prices affect agricultural practices in the western Lake Erie basin are context-specific. Therefore, a benefit of the case studies was the characterization of driver influence within the western Lake Erie basin.

The results introduce the need to revisit how drivers of eutrophication are identified, understood, and addressed in nutrient management efforts. For example, in their work on eutrophication, Khan and Mohammad (2014) suggest very local control measures to address eutrophication, including enforcing wastewater treatment standards and establishing fertilizer requirements, despite identifying a wide range of social and drivers of eutrophication that can act at local and national/international scales. This limited perspective on addressing drivers is also observed by Räsänen et al. (2017), who identified a scalar mismatch between the drivers identified by research participants and strategies for water risk management that were being implemented. Addressing these mismatches requires identifying the drivers of the water problem before management strategies can be integrated with the broader social-ecological context. Water management efforts are informed by perceptions of drivers (Räsänen et al. 2017, Suckall, Tompkins, and Stringer 2014, Nyantakyi-Frimpong and Bezner-Kerr 2015). Therefore, the clear areas of mismatch between formal nutrient management documents and the policy Delphi results both within and between the US and Canadian case studies have implications for nutrient management efforts in the western Lake Erie basin. These mismatches reveal potential limitations within the current water governance system. The influences of drivers ranging from animal waste, hydrodynamics within the lake, and synergy between drivers are not identified by survey participants, while the document analysis ignores the role of actors (e.g., conservation authorities) as drivers that affect nutrient management outcomes and barely touches on the role of politics and political will in informing nutrient management objectives. This variation suggests that there are potentially significant gaps in current nutrient management efforts. Gaps provide insight into where and how nutrient management in the western Lake Erie basin can be improved. The findings also question the effectiveness of water governance for nutrient management in the western Lake Erie basin, given the lack of consensus that was evident among participants (e.g., invasive species in the US policy Delphi survey), as well as the role of governance system actors as drivers of eutrophication. The importance of linking water governance with the drivers of a water problem have been established in the literature (e.g., Ingram 2008, de Loë and Patterson 2017b, Nyam et al. 2020). Therefore, our work uses both practitioner knowledge and academic research to expose potentially significant mismatches in how eutrophication in the western Lake Erie basin is perceived. These findings clearly establish the importance of developing shared framings of a water problem, especially in identifying drivers, for achieving desirable water quality outcomes.

2.6 Conclusion

In addressing water problems, a key aspect of water governance is determining what are the relevant drivers (Biswas 2004, de Loë and Patterson 2017a, b, Wiek and Larson 2012), especially within specific contexts (Räsänen et al. 2017). This research combines expert opinion, nutrient management strategies and action plans, as well as insights from the academic literature, to identify the drivers that are perceived to be most important in the western Lake Erie basin based on engagement in the data. The policy Delphi surveys and document analyses within both the US and Canadian case studies provided additional nuance and depth to existing discussions of drivers in eutrophication research.

Water problems with multiple drivers and multiple scales, such as eutrophication in the western Lake Erie basin, benefit from an approach to governance that recognizes the multiple scales at which drivers can exist and act on a system, while also being flexible and adaptable to address the uncertainty and complexity that occurs when adopting a more comprehensive perspective on water problems (Fish, Ioris, and Watson 2010, Räsänen et al. 2017). This work applied qualitative methods to identify drivers of eutrophication in the western Lake Erie basin and the findings indicate that nutrient management documents, practitioners, and researchers generally agree on the most important drivers of eutrophication. However, the results also reveal drivers of eutrophication that are not included in formal nutrient management efforts, as well as potentially significant gaps between US and Canadian experts and between formal nutrient management strategies and subject matter experts. These findings have implications for the western basin specifically and for drivers of water problems more broadly, as well as water governance approaches aiming to identify and address drivers. The results contribute to discussions in the Great Lakes and eutrophication literatures on drivers both by affirming existing problem framings and introducing challenges and opportunities around identifying drivers which should be explored in other case studies. The research confirms that efforts to identify drivers and recognize the complexity of some water problems and their existence within broader social and environmental contexts are important and necessary for water governance. The research also demonstrates the importance of understanding how to prioritize among multiple drivers of a water problem from a governance perspective, and supports the recommendation that new approaches to water governance may be necessary (de Loë and Patterson 2017a). Regionally-focused research in other contexts would provide additional insight to extend discussions of drivers in the water governance literature.

Chapter 3

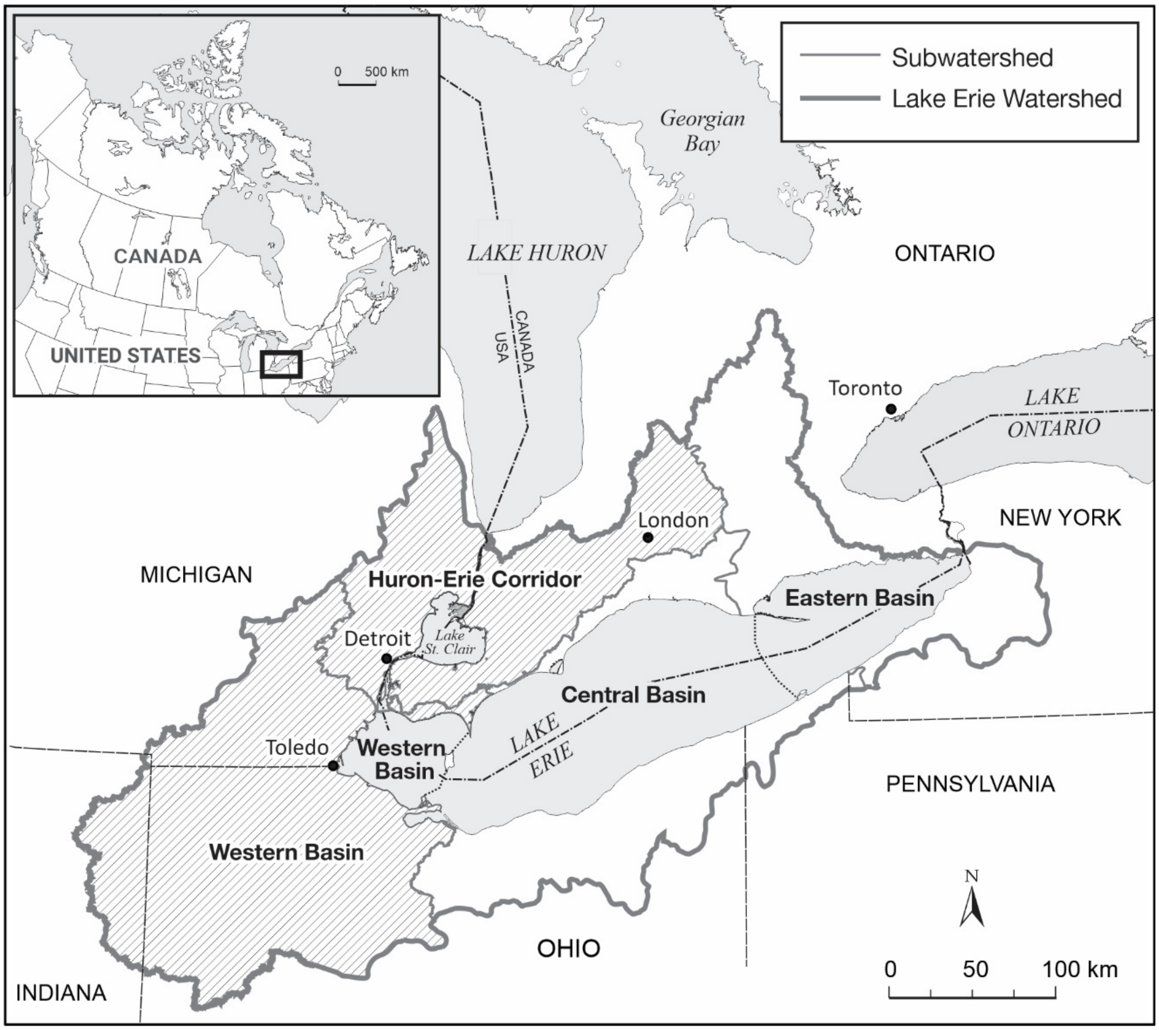
Nutrient Management in the Western Lake Erie Basin: Accounting for Drivers

3.1 Introduction

The Lake Erie basin in North America (see Figure 4) is a transboundary body of water that falls within the jurisdictions of both Canada and the United States. In Canada, formal authority for water is distributed between the federal, provincial, and municipal governments. For example, the federal government's responsibilities include international relations, navigation, federal lands, and fisheries, while provincial and territorial governments have authority for water management and protection; responsibilities for drinking water and wastewater treatment are often delegated to municipal governments (Bakker and Cook 2011, Adeel 2017). Within each of these government levels, there are multiple agencies with responsibilities that affect water (Adeel 2017). The US has a similar distribution of water responsibilities across federal, state, and municipal government levels (Huffman 2008) and fragmentation both within and between these levels (Gerlak 2006, Chaloux and Paquin 2013). There is a longstanding history of cooperation in the Great Lakes basin, including at the federal level through the 1909 Boundary Waters Treatment and the Great Lakes Water Quality Agreement, as well as the state and provincial levels through subnational agreements (MacDonald 2017, Norman and Bakker 2015).

Both countries have important responsibilities relating to nutrient management under domestic laws and an international treaty. Multiple regional actors also are involved in the development and implementation of nutrient management efforts, including the Province of Ontario and the state governments of Ohio, Michigan, and Indiana. The Lake Erie basin represents an important area of population and economic activity in both Canada and the US. For example, recreational fishing alone contributes to nearly $10 million in revenue for the charter boat industry in Ohio (International Joint Commission 2014). Therefore, improving water quality by addressing nutrient pollution has implications for both ecosystem and economic health.

Figure 4. A map of the Lake Erie basin, with watershed and subwatershed boundaries delineated. The Huron-Erie Corridor and the Western Basin subwatersheds, which both drain to the western basin of Lake Erie, are highlighted using diagonal lines.



Lake Erie is the shallowest and warmest of the Great Lakes; these physical characteristics, in combination with human activities in the watershed (e.g., agriculture, urban areas), make it prone to eutrophication and the resulting algal blooms in the western and eastern basins and hypoxia in the central basin (International Joint Commission 2014, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). The western basin of Lake Erie experiences higher phosphorous loadings than the central and eastern basins and has experienced particularly severe harmful algal blooms (International Joint Commission 2017a). These harmful algal blooms are a result of cyanobacteria such as *Microcystin* producing toxins that can harm human and animal health (International Joint Commission 2014).

Human-caused eutrophication in Lake Erie has persisted despite decades of binational cooperation between Canada and the US, along with the many strategies, agreements, and legislation developed to address nutrient pollution (International Joint Commission 2014). Algal blooms in the 1960s and 1970s because of excessive nutrient loadings from human activities, especially wastewater treatment plants, led to the signing of the binational Great Lakes Water Quality Agreement (GLWQA) in 1972 (International Joint Commission 2014). This binational agreement included commitments from both countries to reduce phosphorous loading to Lake Erie through both regulatory and voluntary efforts (GLWQA Nutrients Annex Subcommittee 2019). Although these efforts were initially successful, algal blooms recurred in the late 1990s and persist to this day (GLWQA Nutrients Annex Subcommittee 2019, Canadian Water Network 2017).

Drivers of eutrophication in Lake Erie identified since the 1990s are numerous and include urban runoff sources such as stormwater, agricultural runoff, climate change, invasive species, atmospheric deposition, and legacy phosphorous (e.g., Michalak et al. 2013, Sharpley et al. 2013, International Joint Commission 2014). Additional drivers were revealed in our other study (see Chapter 2), including governance actors, synergies between drivers, and politics. Khan and Mohammad (2014) identified human activities as the key reason for eutrophication, specifically wastewater, agricultural and urban areas, and land use change. In response to continued eutrophication, the renewed 2012 GLWQA established Lake Ecosystem Objectives related to nutrients, including goals to maintain algal and cyanobacterial levels below nuisance and human/ecosystem threat levels, respectively (GLWQA Nutrients Annex Subcommittee 2019).

While progress is being made, there are signs that these efforts will not be enough. For example, the International Joint Commission's (IJC) First Triennial Assessment of Progress (International Joint Commission 2017a) concluded that although Canada and the US had made progress in addressing eutrophication in Lake Erie, additional action was necessary to meet binational commitments made in the 2012 GLWQA and to improve water quality in Lake Erie in general, and the western basin, in particular. The purpose of this research is to assess whether drivers of eutrophication in the western Lake Erie basin are taken into account by nutrient management efforts, and to discuss the implications of these findings for achieving desirable outcomes (e.g., mitigation of eutrophication) based on the objectives established binationally and nationally through agreements and water policies (e.g., the 2012 GLWQA).

3.2 Governance Challenges Relating to Nutrient Management

There is growing recognition that environmental problems (including water problems such as nutrient pollution) occur in complex systems, meaning they are composed of multiple interacting components that can make it difficult to understand environmental problems and achieve governance objectives (Cox 2011). These problems are characterized by dynamic interactions within and among social-ecological systems (SES) at multiple scales and levels (Duit et al. 2010). Examples of scales and levels relevant to water governance include the temporal scale, with levels ranging from past to present to future (Cash et al. 2006). In this paper, we define water governance (and the associated water governance system) as: "the ways in which societies organize themselves to make decisions and take action regarding water. Water governance involves numerous public and private actors, occurs at multiple scales and levels, and takes place through diverse mechanisms that include regulations, market tools, incentives and networks" (de Loë and Patterson 2017b, 76-77).

Failures to resolve water problems frequently are attributed to water governance as well as technical issues (Castro 2007, UN World Water Assessment Programme 2003). Identifying and addressing water governance challenges is therefore a crucial component of resolving water problems. Governance actors often struggle to avoid overly simplistic solutions to complex environmental problems (Ostrom 2007, 2009). According to Mollinga, Meinzen-Dick, and Merrey (2007), both the analysis of a water problem and the action to address it need to consider the influential forces (what we call drivers in this paper) beyond the limited spatial and temporal context of the resource to avoid harmfully narrow framings of water problems and solutions. For example, in their assessment of the Yahara River watershed in Wisconsin, USA, Gillon, Booth, and Rissman (2016, 759) attribute governance failures to improve water quality to “changes in conditions that drive outcomes but lie outside the scope of intervention and monitoring”. Similarly, in their assessment of water-related risks in Finland, Mexico, and Laos, Räsänen et al. (2017) observed a mismatch between the scale of drivers identified by water managers and the implemented water strategies, and therefore concluded that water governance needs to match strategies with the drivers they are trying to address. These examples support the observation that water governance can exclude drivers from consideration and action, leading to ineffective water management efforts (de Loë and Patterson 2017b).

In their research exploring the overlap between they call the “agricultural water-management domain”, Mollinga, Meinzen-Dick, and Merrey (2007, 700) observed that addressing water problems requires considering the broader social-ecological context and ignoring this would fail to resolve water problems. From this perspective, environmental governance (and thus water governance) should involve flexible, context-specific approaches that can respond as drivers interact and build on each other to create changes in SES (Chaffin, Gosnell, and Cosens 2014, Duit and Galaz 2008, Duit et al. 2010). These examples also emphasize the importance of water governance actors in influencing the drivers that are identified and the solutions that are developed, as well as the value in understanding the perspectives of these experts and practitioners participating in water governance. We argue that achieving desirable outcomes of water governance is linked to the ability of water governance systems to identify and address drivers, which can act across multiple levels (e.g., from subwatershed to basin) (de Loë and Patterson 2017b). However, there are knowledge gaps on how water managers perceive drivers and how this perception influences efforts to address drivers (Räsänen et al. 2018). Evaluating the extent to which water governance systems account for drivers can lead to recommendations that improve water management outcomes and contributes to water governance discussions of drivers.

Many definitions of drivers are available in the environmental and water governance literatures. For example, Räsänen et al. (2017, 705) define them as “factors that influence changes”. Other definitions of drivers have limited their scope to anthropogenic factors (e.g., Levy and Morel 2012, Gari, Newton, and Icely 2015). Using the SES and water governance literatures, we define drivers as social and environmental factors that influence a system (de Loë and Patterson 2017b, Nayak and Berkes 2014). Drivers are often characterized as being multi-dimensional and context-specific factors that interact with other drivers across multiple scales and levels (e.g., Levy and Morel 2012, Nayak and Berkes 2014, Räsänen et al. 2017). Analyzing water governance to determine how it addresses complex water problems requires characterizing the drivers that affect water (e.g., how water is used and its status) (Wiek and Larson 2012). This analysis includes determining where a driver exists relative to water governance (Rogers and Hall 2003) and how a driver is addressed. The Driver-Pressure-State-Impact-Response (DPSIR) framework is an example of an approach characterizing the multiple drivers that influence a system, with the aim of informing management actions to address those drivers (Kristensen 2004).

This attention to drivers, as well as arguments in the water governance literature attributing the persistence of water problems to governance failures (Vörösmarty et al. 2010, de Loë and Patterson 2017b), support the recommendation that modified approaches to water governance may be necessary (de Loë and Patterson 2017a). Specifically, water governance should: (i) recognize the complexity of water problems and their place within larger social and environmental contexts; (ii) determine what drivers are relevant to consider in governance processes; and (iii) reflect on existing governance processes to assess whether the identified drivers are taken into account (Biswas 2004, de Loë and Patterson 2017a, b, Wiek and Larson 2012). Nutrient management in the western Lake Erie basin represents an opportunity to examine a water governance system and the associated drivers of a water problem (eutrophication), therefore addressing an identified knowledge gap on exploring the most important drivers within specific contexts (Räsänen et al. 2018).

Eutrophication is a major water quality problem globally, with impacts including ecosystem degradation and human health impacts (Khan and Mohammad 2014), and challenges including its complexity and multiple stressors (Jetoo 2018). For example, nutrient management in Wisconsin, USA that ignored the dynamic nature of drivers such as soil phosphorous variability failed to improve water quality in the context of eutrophication (Gillon, Booth, and Rissman 2016). In their assessment of drainage management in agricultural catchments to address eutrophication, Bieroza et al. (2019) identified a lack of knowledge on the effectiveness of nutrient management efforts. We extend this knowledge gap and argue that there is also a lack of knowledge on the effectiveness of nutrient management efforts more broadly, such as policy tools. In most cases of eutrophication, water management efforts to mitigate phosphorous loading to freshwater basins have not led to water quality improvements (Jarvie et al. 2019, Reilly et al. 2021). This pattern is also evident in the western Lake Erie basin (Sekaluvu, Zhang, and Gitau 2018). Reasons for this lack of progress include dynamic interactions between phosphorous sources, legacies from past decisions, and non-linear pathways of ecosystem recovery (Jarvie et al. 2013), as well as the confounding influence of drivers such as climate change (Reilly et al. 2021). According to analysts such as Jetoo (2018), the persistence of eutrophication and associated algal blooms in the Great Lakes is an example of a governance failure. Therefore, in the context of the governance challenges discussed above, we argue that efforts to improve eutrophication management are necessary and will require examining whether drivers are taken into account. A policy Delphi survey does not appear to have been used before to assess drivers of eutrophication in the western Lake Erie basin, although the method is known for providing cutting edge knowledge that may take more time to emerge from the academic literature, as well as generating more frank discussions on an issue (e.g., Franklin and Hart 2007).

3.3 Methods

Nutrient management in the western Lake Erie basin is an important opportunity to explore drivers of eutrophication and to determine whether they are taken into account by nutrient management efforts. Nutrient management in the Lake Erie basin take place primarily at the subnational and national levels, but the 2012 GLWQA is a key source of shared targets and objectives. The International Joint Commission has important responsibilities under the GLWQA, including supporting and advising Canada and the United States on their nutrient management efforts. In practice, the US and Canada have structured their approaches to nutrient management in the western Lake Erie basin separately, as evidenced by the Canada-Ontario Lake Erie Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018) and the US Action Plan for Lake Erie (United States Environmental Protection Agency [USEPA] 2018). Therefore, dividing the research into two separate case studies means that distinctive Canadian and US perspectives on eutrophication can emerge from the data. This approach allows for a more nuanced perspective on drivers and how they are taken into account through nutrient management efforts and allows for differences in problem framings and eutrophication solutions to be identified and explored.

3.3.1 Accounting for Drivers

The terms "taken into account" or "not taken into account" are used in this evaluation. Two conditions need to be met before a driver can be classified as taken into account: the driver is both identified as a driver and actions are being taken to manage it through nutrient management efforts (e.g., there are policies/programs in place that describe how the driver is being or will be addressed). A driver is not taken into account when there is no agreement that it is a driver (e.g., expert knowledge and implementation efforts do not match) or when it is identified as a driver, but actions are not being taken to manage it through nutrient management efforts (e.g., there are no policies/programs in place that describe how the driver is being or will be addressed). Policy Delphi surveys and analyses of nutrient management documents were used to identify drivers and to assess whether they are taken into account by the water governance system through nutrient management efforts.

3.3.2 Policy Delphi Surveys

Policy Delphi surveys are a qualitative method suited to exploring complex policy issues and providing opportunities for conversations among researchers and decision-makers (de Loë et al. 2016). Separate policy Delphi surveys using the same design were conducted for each of the Canadian and US cases. The aims of the two surveys in this research were to explore the understanding of US and Canadian water researchers and practitioners regarding eutrophication and nutrient management in the western Lake Erie basin (Meskell et al. 2014); to identify drivers of eutrophication; and to explore whether they are taken into account by nutrient management efforts from the perspective of knowledgeable participants.

The focus of this paper is on assessing whether drivers of eutrophication are taken into account by nutrient management efforts. Participants were selected because of their knowledge of the issues. Knowledge, in this context, was indicated by the publication of academic journal articles on the subject matter (for water researchers), participation in working groups or implementing agencies (for water researchers and practitioners), and through authorship of nutrient management reports, strategies, and plans (for water researchers and practitioners). Potential participants in each country were contacted by phone or email with the aim of representing government, academic, agricultural, private sector, and non-governmental organization (NGO) perspectives through purposive sampling (Berg and Lune 2012). Examples of the agencies represented in the policy Delphi surveys include: Environment and Climate Change Canada, the Ontario Ministry of Agriculture, Food and Rural Affairs, the United States Environmental Protection Agency, the Indiana Department of Environmental Management, the Great Lakes Commission, and Environmental Defence. In the Canadian case study, 53 experts were contacted with a final number of 28 participants; 25 of those participants completed both survey rounds. In the US case study, of the 52 potential participants contacted, 24 agreed to participate in the study; 21 of those participants completed both survey rounds. Categories of policy Delphi survey participants are provided in Table 7. The large number of potential interests in the western Lake Erie basin means that we did not set out to establish a representative sample of all possible perspectives. For example, as evident in Table 7, First Nations and tribal governments were not represented in the Canadian and US case studies, respectively. However, given the organizations that were represented in the document analysis through reports, such as the IJC and the Great Lakes Water Quality Board, and their work to understand the diversity of perspectives in the Great Lakes Basin (e.g., International Joint Commission 2017a), we believe that some of the participant gaps for both policy Delphi surveys are filled through the combination of the two methodologies. Given the large spatial area of the case studies and the diversity of participant locations, as well as the research objective to identify whether drivers are taken into account by the water governance system for nutrient management, the ability of the policy Delphi to bring together participants to anonymously discuss their ideas is an important aspect of the research design.

Table 7. Policy Delphi survey participants for the Canadian and US case studies.

Participant Type	Number of Participants	
	Canadian Case Study (n=25)	US Case Study (n=21)
Government staff (federal, provincial, or state agencies)	11	11
NGO staff	4	5
Agricultural sector	4	0
University researchers	3	4
Conservation Authority staff	5	N/A
Private sector	0	2

The Canadian and US surveys were conducted between February and August 2019. Following established practice, each survey had two rounds of questions (de Loë et al. 2016): the first round asked open-ended questions about drivers of eutrophication (e.g., what drivers are taken into account by nutrient management?), while the second round asked participants to reflect on, and assess, the results of the first survey round. To provide a common baseline for responses (Turoff 2002), background information on the purpose of the research and key terms used in the survey (e.g., “driver of eutrophication”) were provided in the preamble of the first survey round. First round responses were analyzed using QSR NVivo 10 to identify similarities and differences among responses, with similar responses grouped together into representative statements (Manley 2013, O'Loughlin and Kelly 2004). The second survey round then asked the same participants to rate their level of agreement with the representative statements from the first round, and to provide a rationale for their rating. A four-point Likert scale ranging from significantly agree to significantly disagree, with no neutral option, was provided to participants. This design requires participants to clearly take a position or to indicate that they did not have an answer (Turoff 2002). If one-third of participants did not provide a rating at all or provided a non-response (i.e., selecting “I don’t know” in response to a statement), the statement was classified as having insufficient participation and was not analyzed further (de Loë and Wojtanowski 2001).

The second survey round is a peer-review process that assesses the validity of Round 1 responses. Round 2 ratings were analyzed using the algorithm developed by de Loë (1995) to determine consensus among participants, along with content analysis in QSR NVivo 10 to analyze rationales where provided. The purpose of calculating consensus was to identify both when and how strongly participants agreed on drivers of eutrophication and whether they are taken into account by nutrient management efforts. For example, high consensus occurred when more than 70% of participant ratings occurred in a single agreement category (e.g., “significantly agree”) or when 80% of participant ratings occurred in two related agreement categories (e.g., “significantly agree” and “agree”). Consensus level and rationales together provided important nuance to participant responses in the second survey round.

3.3.3 Document Analyses

For each case, a document analysis was conducted to identify drivers and to determine whether they are included in nutrient management efforts. Documents were found through internet searches using strategic keywords, such as “nutrient management” and “western Lake Erie basin”. Documents selected for the research included state and provincial strategies, domestic action plans, regional watershed management plans, and binational agreements, reports, and recommendations. Only documents published after 2012 were included in the analysis, to reflect commitments and problem framings established binationally in the most recent version of the Great Lakes Water Quality Agreement. An exception was made in cases where a post-2012 document could not be found; in such cases, the most recent document was used, e.g., the Lake St. Clair Canadian Work Plan published in 2011. Only documents that discussed drivers of eutrophication in Lake Erie and that were intended to inform/guide water quality management in the Lake Erie basin were included in the analyses, keeping in mind the research focus on the western basin. Separate document analyses were carried out for the US and Canadian case studies. However, given the level of binational cooperation in the Lake Erie basin, and the role of the IJC, relevant binational documents were included in the Canadian or US cases, as appropriate. Following screening, a total of 60 documents were identified and analyzed (23 binational documents, 14 Canadian documents, and 23 US documents). Examples of documents are provided in Box 3.

Box 3. Examples of nutrient management documents included in the document analyses.

Binational Documents	**Canadian Documents**	**US Documents**
• Great Lakes Water Quality Agreement (2012) • Recommended Phosphorous Loading Targets for Lake Erie: Annex 4 Objectives and Targets Task Team Final Report to the Nutrients Annex Subcommittee • Evaluating Watershed Management Plans: Nutrient Management Approaches in the Lake Erie Basin and Key Locations Outside of the Lake Erie Basin	• Ontario's Great Lakes Strategy • Nutrient Management: Research Insights for Decision Makers • Canada-Ontario Lake Erie Action Plan: Partnering on Achieving Phosphorous Loading Reductions to Lake Erie from Canadian Sources	• Lake Erie Protection and Restoration Plan • Upper Maumee River Watershed Management Plan • State of Michigan Domestic Action Plan for Lake Erie

Content analysis (Berg and Lune 2012, Bowen 2009) was used to examine nutrient management efforts for how or whether they take into account the drivers that were identified in the policy Delphi surveys and the document analyses. Content analysis was carried out separately using QSR NVivo for the US and Canadian case studies. Coding occurred iteratively over three separate rounds for each case study, using both in vivo and structural coding to allow ideas to emerge from the data sources while also linking the analysis to the research questions (Saldaña 2009), which was to assess whether drivers of eutrophication are taken into account by in nutrient management efforts. Text was coded in the first round of analysis if it met one or more of the following criteria: (i) mechanisms to understand and/or manage a driver were discussed; (ii) an information and/or implementation gap relating to a driver was identified. The second and third rounds of analysis grouped codes into similar themes (e.g., codes on agricultural best management practices and the regulation of nutrient management practices, such as the *Nutrient Management Act, 2002*, were both grouped into the larger theme of "accounting for agricultural practices").

3.4 Results

Using data from both case studies, this section presents the research findings on whether drivers of eutrophication are taken into account by nutrient management efforts. Drivers of eutrophication were identified and explored in detail in Chapter 2. In total, 43 drivers were identified in the Canadian case study; 32 drivers were identified in the US case study. Drawing on that analysis, Table 8 presents the most significant drivers of eutrophication in the western Lake Erie basin according to the data sources used in this research. Participant engagement (number of participants that identified a driver in the first round of the policy Delphi survey) and number of documents that identified a driver were used as indicators of driver significance (Räsänen et al. 2017, Räsänen et al. 2016).

Table 8. The perceived most significant drivers of eutrophication in the western Lake Erie basin (adopted from Table 6 in Chapter 2).

Driver of Eutrophication	Description of Driver
Climate change	Climate change, and its impacts on weather patterns, runoff, and ecological conditions, affects nutrient loading to Lake Erie and can create conditions that support algal growth. Climate change also interacts with other drivers affecting nutrient loading and algal growth.
Agricultural operations	Agricultural practices, including nutrient management, drainage management, crop management, manure and wastewater from livestock operations, and effluent from greenhouse operations, can increase nutrient loading to the western basin of Lake Erie. Other aspects of agricultural operations, including factors that influence farmer behaviour, can shape agricultural practices.
Phosphorous and its availability	Phosphorous is the key driver of eutrophication in the western basin because it is the limiting nutrient for algal growth. Legacy phosphorous in sediments and soils are an emerging driver that increase loading to and internal phosphorous cycling within Lake Erie.
Wastewater	Wastewater infrastructure (e.g., treatment plants, lack of sanitary sewers, and aging/failing septic systems) and the associated effluent are a source of phosphorous.
Land use changes	Historical and current land use changes, especially urbanization and agricultural land management, as well as the loss of natural landscapes such as wetlands, change runoff patterns and can increase nutrient loading.
Invasive species	*Dreissenid* mussels support algal growth, especially in the nearshore area.
Synergy between drivers	Multiple drivers interact synergistically to affect nutrient loading and algal growth, including human activity, invasive species, and climate change. These interactions and their causal relationships create complexity and are not fully understood.
Nitrogen	There is growing evidence that nitrogen (including its relative amounts to phosphorous) affects the development and composition of algal blooms.
Urban areas, including stormwater runoff	Urban areas, including fertilizer use on lawns/gardens, pet waste, and construction activities, and the associated stormwater runoff, are sources of nutrients to Lake Erie.

Industrial sources	Industrial discharges (e.g., outfalls and wastewater) are a point source of phosphorous to Lake Erie that is less significant than agricultural non-point sources of phosphorous.
Characteristics of the Lake Erie basin	The Lake Erie basin's physical characteristics (i.e., shallow, warm) and human characteristics (i.e., agricultural and urban land uses) support algal growth and make it prone to eutrophication.
Funding availability	The availability of funding affects nutrient management efforts (e.g., wastewater treatment infrastructure updates or financial support for agricultural operators), and there is insufficient funding for nutrient management efforts in the western Lake Erie basin.
Development pressures (e.g., population growth)	Growing and changing demand for crops and population growth affect land use and land management practices, leading to the expansion of urban areas and changing agricultural practices which can affect nutrient loading.

The drivers identified in Table 8 are relevant for both the US and Canadian case studies. Within each case study, most drivers are identified by both data sources, although some drivers are only identified by one data source. In the Canadian case study, there were 43 unique themes in the survey results on whether drivers are taken into account (5 of those statements did not have sufficient participation to be included in the analysis), paired with 3300 references coded in the document analysis which were split into 30 nodes on drivers that are taken into account by nutrient management. In the US case study, there were 54 unique statements in the survey results on whether drivers are taken into account (20 of those statements did not have sufficient participation to be included in the analysis), paired with 4171 references coded in the document analysis which were split into 28 nodes on drivers that are taken into account by nutrient management. Using the perceived most significant drivers of eutrophication identified in Table 8, Table 9 summarizes the results from both case studies on whether these drivers are taken into account by nutrient management efforts.

Table 9. Results from the Canadian and US case studies on whether drivers are taken into account by nutrient management efforts, distinguished by the data source.

Driver Categories	Is the Driver Taken Into Account?				Example Mechanisms
	Canadian Policy Delphi Survey	Canadian Document Analysis	US Policy Delphi Survey	US Document Analysis	
Climate change	No	Yes	No	Yes	• Commitments and/or recommendations to undertake research, monitoring, and/or modeling to understand climate change impacts on nutrient loading and algal growth. • Under Annex 4 of the GLWQA, the US and Canadian governments commit to collaborating with others to research the impact of climate change on nutrient loading to the Great Lakes and algal growth (Government of Canada and Government of the United States of America 2012).
Agricultural operations	Yes	Yes	Yes	Yes	• Nutrient application practices are taken into account through commitments and recommendations to improve nutrient practices through voluntary Right Time, Right Place, Right Source, Right Rate (4R) practices and other BMPs. • The 4R nutrient stewardship principles promote the "right fertilizer source" to match with soil and crop needs, the "right rate" of nutrient application to meet crop requirements, the "right time" for nutrient application, and the "right place" for applying nutrients to match the cropping system and soil properties (IJC Science Advisory Board TAcLE Work Group 2013, International Joint Commission 2014).
Phosphorous and its availability	Yes	Yes	Yes	Yes	• Phosphorous loading targets have been established for Lake Erie's basins through binational agreements and domestic action plans. • In 2015 the governors of Ohio and Michigan and the premier of Ontario signed a Collaborative Agreement to reduce dissolved phosphorous loadings to Lake Erie's western basin by 40% in 2025, with an interim goal of a 20% reduction by 2020 (United States Environmental Protection Agency [USEPA] 2018).

Wastewater	Yes	Yes	Yes	Yes	• Regulating or recommending phosphorous concentrations for wastewater treatment plant effluent. • Ohio Senate Bill 1 requires any wastewater treatment over 1MGD with a phosphorous discharge limit over 1mg/L complete a feasibility study to determine the capability and costs of reducing phosphorous discharges to below 1mg/L (State of Ohio 2017).
Land use changes	Yes	Yes	N/A	Yes	• The protection and restoration of land (including coastal wetlands) to reduce nutrient loading and mitigate algal blooms. • The Ontario Ministry of Natural Resources and Forestry and Ducks Unlimited Canada are developing wetland restoration projects in the Lake Erie basin, focusing on priority areas identified by the Canada-Ontario Lake Erie Action Plan (Government of Canada and Government of the United States of America 2019).
Invasive species	Unclear	Yes	Yes	Yes	• Commitments and/or recommendations to undertake research to understand the influence of invasive species on nutrient cycling and algal growth. • The Canada-Ontario Lake Erie Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018) says that additional research is necessary to understand the influence of invasive species on nutrient cycling and algal growth.
Synergy between drivers	N/A	Yes	N/A	No	• Commitments to improve understanding of the relationships between drivers and algal blooms. • Canada and Ontario commit to improving the understanding of the relationship between factors such as precipitation patterns, invasive species, land use, hydrological processes, internal nutrient cycling, and algal blooms (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, Environment Canada and Climate Change and Ontario Ministry of Environment 2019).
Nitrogen	Unclear	Yes	Yes	Yes	• Commitments and/or recommendations to undertake research to understand the influence of nitrogen on algal growth and toxicity. • Canada is researching the role of nitrogen in controlling algal growth and toxicity in the western basin and nearshore area (Government of Canada and Government of the United States of America 2019).

Urban areas, including stormwater runoff	Yes	Yes	Yes	Yes	• Commitments and/or development of policies that provide guidance and support for stormwater management tools/technologies/practices (e.g., green infrastructure) to reduce nutrient loading. • In the Canada-Ontario Agreement, Canada and Ontario commit to providing support for green infrastructure, low impact development systems, and supporting research on the relationship between phosphorous reduction and stormwater management technologies (Environment Canada and Climate Change and Ontario Ministry of Environment 2019).
Industrial sources	N/A	Yes	Yes	Yes	• Industrial sources of nutrients have been addressed through regulatory approaches such as environmental compliance approvals. • Industrial sources of phosphorous are managed in Ohio through the National Pollutant Discharge Elimination System permitting program administered by the Ohio Environmental Protection Agency (Ohio Lake Erie Commission 2020).
Characteristics of the Lake Erie basin	N/A	N/A	N/A	N/A	• No explicit actions to address the influence of watershed characteristics on eutrophication.
Funding availability	No	Yes	Unclear	Yes	• Funding to support nutrient management efforts exists, such as the Great Lakes Restoration Initiative in the US. • The Great Lakes Restoration Initiative in the US and the Great Lakes Nutrient Initiative in Canada have supported monitoring efforts to measure nutrient loads and their sources and timing (Environment and Climate Change Canada and US EPA 2016).
Development pressures (e.g., population growth)	No	No	IP	No	• No explicit actions to address the influence of development pressures on eutrophication.

Yes The driver is taken into account.
No The driver is not taken into account.
IP There was insufficient participation among policy Delphi survey respondents to include in the analysis.
Unclear There was no consensus among participants.
N/A Not discussed.

In Table 9, the results from the US and Canadian case studies are summarized to indicate whether drivers are taken into account nutrient management efforts in the western Lake Erie basin. Example mechanisms for how drivers are taken into account are also provided. It is important to note that using a single word to represent whether a driver is “taken into account” is an oversimplification of the level of detail that emerged from the data. The coded references from the document analyses and the rationales within the surveys revealed more details. For example, the data generated on addressing phosphorous as a source of nutrients to the western Lake Erie basin revealed gaps in nutrient management efforts related to the legacy phosphorous sub-theme. Among Canadian participants there was high consensus that legacy phosphorous in soils and lake sediment is not well understood or actively managed, while there was no consensus among US participants regarding whether internal loadings and legacy phosphorous are understood well enough or taken into account properly (although they did agree that legacy phosphorous is being researched to understand its impact on eutrophication). In the document analyses, discussions of legacy phosphorous generally centered around the importance of research to quantify legacy phosphorous in sediment and soils and understand their influence on eutrophication (ECCC and USEPA 2019, Canadian Water Network 2017, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018), especially since the amount and bioavailability of legacy phosphorous entering Lake Erie is unknown (United States Environmental Protection Agency [USEPA] 2018, International Joint Commission 2018). The IJC has observed that loadings of legacy phosphorous in non-agricultural soils such as wetlands or riparian areas are “largely outside of current management and policy consideration” (LimnoTech 2017, 74, International Joint Commission 2018, 5). There are some existing and future efforts committed to characterizing legacy phosphorous loading and understanding its role in eutrophication in both Canada and the US (including binationally), but the results indicate a lack of understanding and attention to sources of legacy phosphorous. Overall, there was agreement between case studies and within data sources in the Canadian case study; agreement within the US case study was less clear since survey participants were polarized on the question of whether legacy phosphorous is understood or taken into account by nutrient management efforts.

There were several drivers where all or most of the data sources agreed. Agricultural operations, phosphorous and its availability, wastewater infrastructure and associated effluent, and urban areas (including stormwater runoff) were identified as drivers that are taken into account by nutrient management, with complete agreement between the survey results and the document analyses within the Canadian case study. These same drivers were also identified as taken into account in the US case study by subject matter experts and nutrient management documents. Example mechanisms accounting for these drivers ranged from funding and technical support (e.g., to reduce stormwater runoff through green infrastructure such as low impact development) to regulation (e.g., Ontario’s Nutrient Management Act, 2002 and Ohio’s Senate Bill 1, both of which restrict fertilizer/manure application on frozen/snow-covered/saturated ground).

There was agreement among most data sources that land use changes, invasive species, nitrogen, and industrial sources are taken into account by nutrient management efforts. In the Canadian case study, there was agreement between the survey and document analysis results that land use changes are taken into account, although participants had high consensus that current nutrient management efforts accounting for land use changes are not effective and could be improved. In contrast, land uses were not discussed by US participants even though mechanisms were coded in the US document analysis. Based on our definition of the term “taken into account” and the evidence from the survey and document analysis, land use does not appear to be taken into account as a driver of eutrophication in the US case study. Both the US survey and document analysis indicated that nitrogen and industrial sources are taken into account by nutrient management efforts. Industrial sources are not discussed by Canadian participants, although the document analysis discusses regulatory mechanisms to reduce industrial nutrient discharges, and therefore we conclude that industrial sources may not be taken into account. There was no consensus among Canadian participants that nitrogen or invasive species are taken into account by nutrient management efforts, although nutrient management mechanisms applying to invasive species are discussed in the document analysis. In contrast, US participants agreed that the role of invasive species in eutrophication is understood and is taken into account through research, with binational and US documents also discussing research to improve understandings of invasive species.

Most data sources also agreed that development pressures are not taken into account by nutrient management. Among Canadian participants, there is consensus that the influence of growing and/or changing demands for agricultural production are not addressed in nutrient management efforts. There are no explicit actions being taken in the document analyses to address the influence of development pressures on eutrophication in the western Lake Erie basin, although the importance of changing demographics and future trends in agricultural and urban areas are acknowledged (Government of the United States of America and Government of Canada 2016). In the US document analysis, Zehringer, Nally, and Daniels (2012) cautioned that agriculture needs to be able to meet the demands of a growing global population without being hindered.

There were other areas of agreement between the case studies on nutrient management efforts. For example, there was consensus among Canadian participants that nutrient management efforts are focused on phosphorous, although it was unclear whether this focus was beneficial for water quality outcomes. The US policy Delphi survey and both the Canadian and US document analyses indicated that phosphorous is taken into account through a variety of mechanisms, including commitments under the 2012 GLWQA to meet substance objectives for phosphorous and through phosphorous loading targets (e.g., in the Lake Erie Lakewide Action and Management Plan and the 2015 Western Basin of Lake Erie Collaborative Agreement) (Government of the United States of America and Government of Canada 2016, International Joint Commission 2017a, ECCC and USEPA 2019). However, the IJC identified limitations to Canadian and US nutrient management efforts, including missing details on the programs and efforts to reduce nutrient loadings in domestic action plans and a lack of binational long-term monitoring efforts tracking phosphorous loadings to Lake Erie (International Joint Commission 2017a, b). Therefore, although phosphorous is clearly included in nutrient management according to both the case studies and the individual data sources, there are some uncertainties and limitations to existing efforts.

There were also areas of disagreement in the results. In both cases, there is disagreement between the document analysis and survey regarding whether climate change is taken into account by nutrient management efforts. In the document analyses, taking into account climate change impacts on eutrophication happens through multiple mechanisms, including research, monitoring, and modeling efforts (International Joint Commission 2014, 2018, State of Indiana 2018); considering climate change when establishing phosphorous concentrations and loading targets for Lake Erie (Government of Canada and Government of the United States of America 2012); and reducing nutrient loading through enhancements to municipal wastewater and stormwater infrastructure (Environment Canada and Ontario Ministry of Environment and Climate Change 2014). Among US participants, there was medium consensus that the role of climate change in eutrophication is uncertain and not addressed, although it is within the scope of nutrient management efforts (e.g., efforts to change agricultural practices in response to climate change impacts). There was no consensus among Canadian participants that climate change is taken into account and only a medium consensus that it is not taken into account due to uncertainty. Canadian participants discussed challenges such as climate change being acknowledged as a driver but not taken into account, underestimating climate change impacts in domestic action plans, and the insufficient/incomplete accounting of climate change as a driver that affects eutrophication and nutrient management objectives.

As another example, although both the US and Canadian document analyses identified synergy between drivers as contributing to eutrophication, the Canadian document analysis indicated that synergies are taken into account while the US document analysis suggested that synergies are not taken into account by nutrient management efforts. Synergies between drivers were not discussed by either Canadian or US survey participants. In the Canadian document analysis, synergies are taken into account through federal and provincial commitments in the Canada-Ontario Agreement (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, 16, Environment Canada and Climate Change and Ontario Ministry of Environment 2019, 19) to improve the "understanding of the causal relationships between factors such as "duration, intensity, frequency and timing of storms, aquatic invasive species, land use and management, hydrological processes, internal nutrient cycling, hypoxia and harmful and nuisance algal blooms". There is also an acknowledgement in the Canada-Ontario Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018) of existing research and monitoring efforts to understand the multiple processes affecting phosphorous in the nearshore waters of Lake Erie. US documents do not discuss accounting for synergies between drivers. Binational documents include recommendations from the IJC to research synergies between agricultural practices that affect phosphorous runoff, as well as the connections between drivers such as invasive species, climate change, runoff from agricultural and urban areas, and algal blooms (IJC Science Advisory Board TAcLE Work Group 2013, International Joint Commission 2017a). Accounting for synergistic interactions between drivers of eutrophication occurs through research, with no other actions evident in the data to manage those synergies.

Discussions of other drivers also revealed potential limitations in nutrient management efforts. For example, there was no consensus among Canadian participants that nutrient application practices are taken into account, but the rationales shared common themes: nutrient application is not adequately taken into account, it is partially taken into account, it is taken into account but not enforced, or it is taken into account but could be improved. There was also high consensus among Canadian participants that existing agricultural policies for nutrient management are insufficient mostly due to inadequate enforcement. Comparable discussions were observed in the US policy Delphi survey: although best management practices are being implemented, it was unclear whether they will be enough to achieve nutrient reduction targets, with high consensus that voluntary programs and efforts to manage small animal feeding operations are insufficient to reduce nutrient loading from agricultural operations. Likewise, the IJC has concluded that continued eutrophication and algal blooms in Lake Erie are proof that "voluntary programs alone are not sufficient to achieve target loadings set by the Parties" (International Joint Commission 2017a, 102). Generally, US, Canadian, and binational documents discussed multiple mechanisms for reducing nutrient loading to the western Lake Erie basin from agriculture, including best management practices, legislation and regulation, voluntary and incentive programs, and financial support from the government (Zehringer, Nally, and Daniels 2012, Government of the United States of America and Government of Canada 2016, Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, Upper Thames River Conservation Authority 2018).

These types of discussions were also observed regarding accounting for invasive species as a driver of eutrophication. There was no consensus among Canadian survey participants regarding whether invasive species are taken into account by nutrient management efforts such as domestic action plans, with rationales indicating that the role of invasive species is not fully understood, and that invasive species are acknowledged but not taken into account in any meaningful way. In the Canadian and US document analyses, codes identified multiple programs, strategies, and mechanisms aimed at managing invasive species introductions and existing populations broadly in the context of water management. Examples include: invasive species annexes under the 2012 Great Lakes Water Quality Agreement (Government of Canada and Government of the United States of America 2012) and the 2014 and 2020 Canada-Ontario Agreements (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, Environment Canada and Climate Change and Ontario Ministry of Environment 2019), Ontario's Invasive Species Strategic Plan (Ontario Ministry of Environment and Climate Change 2016), as well as the Great Lakes Panel on Aquatic Nuisance Species (International Joint Commission 2017a, ECCC and USEPA 2019) and Invasive Mussel Collaborative (Michigan Office of the Great Lakes et al. 2016).

Specific to nutrient management efforts, there are also commitments from the US and Canada to consider invasive species when establishing substance objectives for phosphorous concentrations and phosphorous loading targets under Annex 4 of the Great Lakes Water Quality Agreement (Government of Canada and Government of the United States of America 2012). However, in the Canada-Ontario Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018), which represents the federal and provincial effort to meet nutrient management objectives, the only mention of invasive species is an acknowledgement that more research is needed to understand the relationship between invasive species, nutrient cycling, and algal growth. Both the US Action Plan (United States Environmental Protection Agency [USEPA] 2018) and Michigan Action Plan (State of Michigan 2018) include a commitment from Michigan to support research that explores the role of invasive species in causing harmful algal blooms in Lake Erie, while the Ohio Action Plan (Ohio Lake Erie Commission 2018) and Indiana Action Plan (State of Indiana 2018) do not discuss invasive species at all. In contrast, there is medium consensus among US policy Delphi participants that the role of invasive species in eutrophication is understood and is taken into account, with rationales describing research efforts.

Overall, the results from the Canadian and US case studies indicate that 8 of the 13 perceived most important drivers of eutrophication in Table 8 are taken into account in some way through nutrient management efforts. There was agreement between data sources and between case studies that development pressures such as population growth are not taken into account by nutrient management efforts, while results for 4 of the 13 drivers of eutrophication are less clear. The results demonstrate areas of agreement and disagreement within and between case studies and reveal potential gaps in nutrient management efforts. The results also introduced the idea that nutrient management efforts are insufficiently addressing multiple interacting drivers of eutrophication, exposing crucial limitations that could mean provincial, state, national, and binational failures to achieve nutrient management targets and objectives. The implications of these findings will be discussed in the next section.

3.5 Discussion

Two main findings emerge from this analysis. First, areas of disagreement within and between case studies reveal potential gaps in nutrient management efforts, and therefore the importance of understanding water managers' perspectives when exploring drivers. Second, existing nutrient management efforts may be insufficient to remediate eutrophication in the western Lake Erie basin specifically, and in Lake Erie overall, which requires additional research to explore nutrient management effectiveness. This section explores the implications of the findings for informing nutrient management efforts in the western Lake Erie basin as well as discussions of drivers in the literature.

Areas of overlap within and between the US and Canadian case studies indicate shared understandings of drivers and shared priorities for nutrient management efforts. As demonstrated in Tables 8 and 9, there is overlap both in perceptions of the most important drivers of eutrophication and in determining whether they are taken into account by nutrient management. Per Table 8, 69% of the drivers were identified in both case studies, as well as the policy Delphi surveys and document analyses within each case. This is not surprising, given the decades of binational cooperation in the Lake Erie basin to improve water quality (e.g., the 2012 GLWQA) and the work of the IJC to share knowledge on water quality threats with both the US and Canadian federal governments. These drivers of eutrophication are also identified in the academic literature, including land uses (e.g., agriculture, urban runoff), resource consumption (e.g., energy), and socioeconomic factors (e.g., population growth, globalization) (e.g., Khan and Mohammad 2014). Table 9 reveals potentially significant areas of disagreement in the data, since only 30% of the drivers are identified as taken into account with complete agreement between the case studies, including the data sources. This means that 70% of the drivers in Table 9 have some level of disagreement between the Canadian and US case studies and/or between formal nutrient management documents and subject matter experts.

We applied a broad understanding of “taken into account” in the data analysis, defining a driver as taken into account if survey participants said that it was and if there was independent evidence of clear action or commitment towards managing a driver of eutrophication in the document analyses. This open-ended exploration meant that we avoided limiting participant responses with a narrow definition and we were able to get a more complete picture of what taking a driver into account could mean. Drivers identified as generally taken into account with complete agreement (e.g., agricultural operations, phosphorous and its availability, wastewater) or majority agreement (e.g., land use changes, invasive species) within and between case studies align with the eutrophication literature. This literature often focuses on phosphorous as the limiting nutrient for algal blooms and land use change, specifically agriculture, as the current dominant source of phosphorous, with wastewater effluent a major historical source (e.g., Han, Allan, and Bosch 2012, Vollmer-Sanders et al. 2016, Khan and Mohammad 2014, Watson et al. 2016). However, where there was not agreement between the policy Delphi survey and document analysis, results reveal potential gaps in nutrient management efforts that should be explored further in future research (e.g., land use change was not identified as being taken into account in the policy Delphi for the US case study and industrial sources were not identified as being taken into account by policy Delphi participants in the Canadian case study). The novel insights provided by practitioners through the policy Delphi surveys compared to the academic literature or nutrient management documents emphasizes the importance of understanding how and/or whether drivers are perceived by managers, as well as the value of the policy Delphi survey method.

Other important gaps are revealed in the data analysis that contribute to the first main finding explored in this paper. Disagreements within and between case studies for multiple drivers of eutrophication, including climate change, synergies between drivers and invasive species, reveal conflicting perspectives on nutrient management efforts. These disagreements may have implications for water quality outcomes in the western Lake Erie basin. Taking into account invasive species as a driver of eutrophication is an example where both the case studies and the data sources are contradicting each other: Canadian survey participants do not think that invasive species are being taken into account sufficiently, while US participants think they are taken into account through research. Both the Canadian and US document analyses discuss efforts to manage invasive species outside of nutrient management (e.g., the Canada-Ontario Invasive Species Centre), identify research priorities in nutrient management documents (e.g., in Ontario's Great Lakes Strategy and the Canada-Ontario Agreement), and expose the limited (or missing) attention to invasive species in domestic action plans. Therefore, the case studies demonstrated that a driver can appear to be taken into account while there are gaps in nutrient management efforts. Managing phosphorus is another example of an implementation gap, including understanding nutrient management effectiveness. Binational phosphorous loading targets have been in place for several years (Government of Canada and Government of the United States of America 2012, Great Lakes Water Quality Board 2016, International Joint Commission 2017a). For example, Annex 4 of the 2012 GLWQA includes commitments from Canada and the US to achieve 0.5 mg/L phosphorous concentration for discharges into Lake Erie and to consider more stringent restrictions. However, results from the Canadian and US surveys reveal gaps in nutrient management efforts to address legacy sources of phosphorous, which have implications for water quality outcomes. In their assessment of algal blooms in Lake Erie, Ho and Michalak (2017) established a causal relationship between internal phosphorous loading and remediation outcome delays, which will require additional reductions in phosphorous loading to decrease algal bloom severity. Liu et al. (2007) and Sharpley et al. (2013) also discussed the legacy effects of past decisions and actions and the time lags that delay visible outcomes. When those conclusions are considered in the context of our results, the implications for nutrient management are clear: failures to understand and quantify legacy phosphorous sources, in combination with a lack of effort to mitigate legacy phosphorous loading, may mean that nutrient management objectives in the western Lake Erie basin will not be met, especially within the target timelines.

Walker and Salt (2012, 11) noted that a common challenge for resource management is failing to recognize that natural resources are influenced by linked social, economic, and biophysical components, where "you can't understand one domain without understanding the connections with others and their feedback effects". Similarly, Räsänen et al. (2016) observed that interactions between drivers can make it difficult to distinguish between social and biophysical stressors and between spatial scales, so they recommend taking driver interactions into account instead of trying to categorize drivers individually, as well as acknowledging that drivers are dynamic across spatial and temporal scales. For nutrient management in the western Lake Erie basin, these challenges and their implications are clear: although nutrient management documents acknowledge and agree (for the most part) that there are multiple drivers causing eutrophication and that these drivers can interact with each other, nutrient management in practice generally fails to establish any explicit action to manage these interactions between drivers, with the exception of Canada and Ontario's commitments to research synergies between drivers (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). This means that nutrient management efforts may ultimately fail to remediate eutrophication and the associated algal blooms, because interactions between drivers are not fully understood or managed. Therefore, nutrient management efforts may need to be modified to address synergies between drivers, rather than considering each driver individually.

In Table 9, example mechanisms for how drivers are taken into account were provided. In the academic literature, eutrophication is addressed through various mechanisms, including modelling nutrient loading (e.g., Han, Allan, and Bosch 2012, Bosch et al. 2013) and phosphorous control measures. For example, Khan and Mohammad (2014) identified eutrophication control measures including improving fertilizer application practices and wastewater treatment infrastructure, increasing awareness and support for nutrient management, and legislative tools. Foulon et al. (2019, 4) observed that the following approaches are often used in nutrient management: "regulatory approaches, incentive-based approaches; risk mitigation approaches, and outreach, engagement, and educational activities". In our examination of the western Lake Erie basin, we observed that similar mechanisms are used to account for drivers of eutrophication. We also found additional mechanisms to account for drivers in nutrient management: (i) research/monitoring/modeling to improve understanding of a driver and collect data to inform nutrient management efforts, such as nitrogen and its role in algal toxicity (e.g., State of Michigan 2018) and (ii) government support, which could include commitments to promote certain investments and programs such as municipal wastewater infrastructure updates (e.g., Ohio Lake Erie Commission et al. 2013) or the provision of financial or capacity-building support, such as funding for projects assessing best management practice effectiveness or developing initiatives that would support local phosphorous reduction efforts (e.g., Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). For example, under Annex 1 of the Canada-Ontario Agreement, Canada and Ontario commit to contributing funding to projects that can "demonstrate effectiveness of beneficial management practices and innovative approaches to reducing phosphorous loads" (Environment Canada and Climate Change and Ontario Ministry of Environment 2019, 17). Similarly, applications of the DPSIR framework focus on "changes in policy; legislation and enforcement; behavioural change; institutional strengthening; investment (both for coastal infrastructure and institutional capacity); new pricing strategies; and conducting further research" to address ecosystem state changes (Lewison et al. 2016, 115). Our findings therefore contribute to the nutrient management literature, as well as discussions in the SES literature, on how to account for drivers.

The second theme that emerged from the results was the issue of *sufficiency* in nutrient management efforts. For multiple drivers, policy Delphi participants introduced caveats to discussions of whether drivers are taken into account, including climate change, funding availability, agricultural operations, and invasive species. Although both the US and Canadian document analyses indicated that climate change, funding availability, agricultural operations, and invasive species are taken into account through multiple mechanisms, survey responses indicated otherwise by exposing gaps and/or limitations within nutrient management efforts. Even nutrient management efforts for agriculture, which is arguably an established driver of eutrophication in both nutrient management documents and the academic literature (e.g., Reilly et al. 2021, Smith et al. 2019, International Joint Commission 2014), are characterized by both Canadian and US as potentially insufficient to achieve nutrient reduction targets.

Accounting for climate change exemplifies this concept of sufficiency. In their examination of nutrient management measures in six global case studies, including Lake Erie, Foulon et al. (2019) concluded that climate change, a key driver of future HAB frequency, is being managed in all case studies. In contrast, our data indicate that climate change is not sufficiently taken into account in nutrient management efforts. Both US and Canadian survey participants agreed that climate change is not addressed in nutrient management efforts, citing uncertainties about impacts. This marks a diversion from discussions in the document analyses about taking into account climate change impacts on eutrophication, including research, modeling, and taking climate change into account when establishing phosphorous loading targets. This contradiction emphasizes the value of bringing together the document analyses and policy Delphi surveys; on their own, the document analyses suggest that climate change is taken into account by nutrient management efforts, while results from both the Canadian and US policy Delphi surveys suggest that these mechanisms are not enough. The conclusions from Canadian and US nutrient management and water governance experts that some drivers of eutrophication are not sufficiently taken into account have significant implications for nutrient management efforts and emphasizes the value of exploring nutrient management efforts through the perspectives of subject matter experts and practitioners.

Although the crucial role of phosphorous in eutrophication was established in the 1970s, the subsequent decades of research and nutrient management efforts have not translated into water quality improvements (Jarvie et al. 2019, Jarvie et al. 2013, Reilly et al. 2021). Specifically, nutrient management efforts in North America, including the Great Lakes, have had limited success, with eutrophication persisting (Jarvie et al. 2013, International Joint Commission 2017b). Bieroza et al. (2019) identify a gap in the nutrient management literature on the evaluation of nutrient mitigation measure (i.e., best management practices) effectiveness. The effectiveness of nutrient management efforts are evident in the water quality of Lake Erie and its tributaries (Londo et al. 2015).We extend that knowledge gap to a broader issue in nutrient management: considering the effectiveness (i.e., the sufficiency) of nutrient management efforts in their entirety. Applying this idea specifically, the persistence of eutrophication and the associated harmful algal blooms in the western Lake Erie basin could be because some drivers of eutrophication are not currently taken into account, or not sufficiently taken into account, in nutrient management efforts and therefore sources of nutrients are not being mitigated. For example, by not taking into account the role of development pressures, funding availability, synergies between drivers, or the role of invasive species, the effectiveness of nutrient management efforts are limited, since governance should intervene at the driver level to address environmental problems (Levy and Morel 2012). Therefore, although some drivers are being managed by nutrient management efforts through mechanisms ranging from regulatory to voluntary to knowledge-gathering, eutrophication remediation objectives may not be achieved, and algal blooms may persist in the Lake Erie SES. Further exploring and quantifying nutrient management effectiveness, although not within the scope of this research, represents an important contribution for future research.

3.6 Conclusion

Overall, the research indicates that the perceived most significant drivers of eutrophication in the western Lake Erie basin are taken into account in nutrient management efforts. Areas of agreement within and between the US and Canadian case studies confirm that binational and national nutrient management efforts are generally identifying and managing the same major drivers of eutrophication. These overlaps are expected given the long-standing history of binational cooperation on water governance in the Great Lakes, and Lake Erie specifically. However, the research also revealed differences between the case studies as well as between the surveys and document analyses within the US and Canadian case studies. These differences may mean that nutrient management efforts between the two countries are diverging in their understanding of eutrophication or in their priorities. For example, synergies between drivers have elicited research commitments from Canada and Ontario, but similar commitments were not observed in the US case study. The research also introduced the question of whether nutrient management efforts are sufficient. Specifically, responses from both the US and Canadian surveys question the effectiveness of current nutrient management efforts to address multiple drivers of eutrophication in the western Lake Erie basin, including climate change and invasive species.

Drivers of eutrophication that are not taken into account or that are not addressed effectively have potentially significant implications for nutrient management in the western Lake Erie basin. Specifically, our research suggests that nutrient loading targets and ecosystem objectives established binationally under the Great Lakes Water Quality Agreement and committed to nationally by Canada and the United States may not be achieved. Further research exploring nutrient management effectiveness and comparing efforts between Canada and the US is therefore necessary to improve water quality in the western Lake Erie basin, as well as the entire Lake Erie basin.

Chapter 4

Understanding the relationship between water governance and drivers: A case study of the western Lake Erie basin

4.1 Introduction

The persistence of water problems despite years of attention (Gleick et al. 2011) has been attributed to many factors, including failures of water governance (UN World Water Assessment Programme 2003). We define water governance as "the ways in which societies organize themselves to make decisions and take action regarding water" (de Loë and Patterson 2017b, 76). From this perspective, water governance includes both state and non-state actors, and takes place through a variety of formal and informal institutional arrangements (de Loë and Patterson 2017b). A common challenge for water governance is responding to the dynamic, multi-level, and multi-scale nature of some water problems (Armitage, de Loë, and Plummer 2012, Lemos and Agrawal 2006). These types of challenges support an emerging critique in the water governance literature that water governance systems ignore the characteristics of water problems and their drivers to their detriment (de Loë and Patterson 2017a, b). For example, in their assessment of nutrient reduction strategies in the Maumee River watershed, within the Lake Erie basin, Scavia et al. (2017) suggest in their concluding remarks that dietary trends may need to be addressed to reduce phosphorous loading and improve water quality. Failing to implement tools to address these drivers affecting phosphorous loading may mean that water quality objectives are not achieved (Scavia et al. 2017).

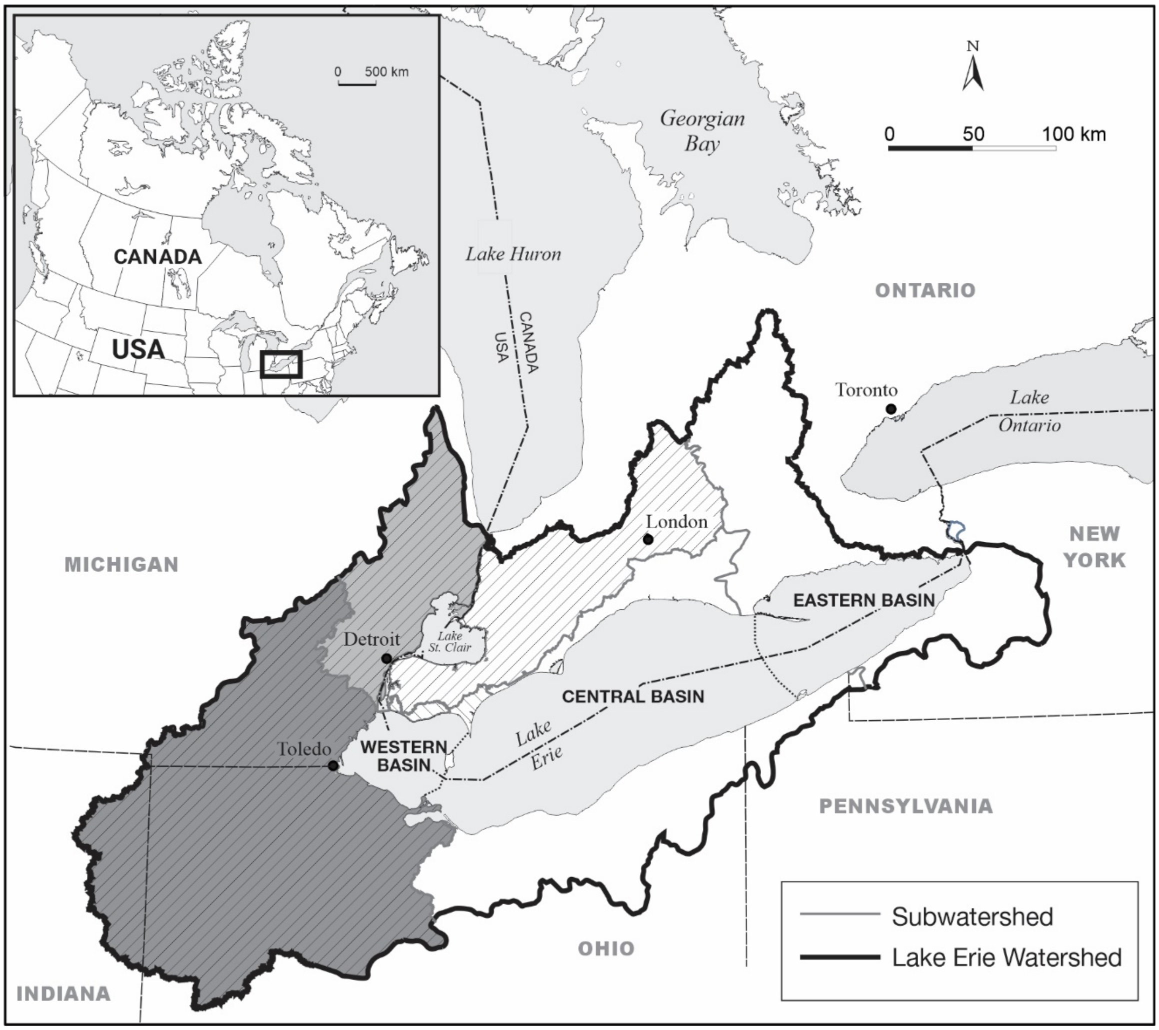
Both the analysis of a water problem and the action to address it needs to consider the broader contexts within which water problems exist (Mollinga, Meinzen-Dick, and Merrey 2007). For instance, some argue that water governance approaches should recognize that water problems exist within broader social and ecological contexts (UNWWAP 2012b, Tortajada 2010). Using the example of increasing foreign investment in mining/forestry/agriculture, Räsänen et al. (2017) observed that local actors are not able to address all drivers through their strategies, even if they are impacted by the driver. They conclude that water governance needs to match the scale of its strategies with the drivers they are trying to address (Räsänen et al. 2017). Mollinga, Meinzen-Dick, and Merrey (2007) proposed the problemshed concept because they acknowledged that water problems are contributed to and/or caused by factors such as institutional arrangements and policies beyond both the spatial and temporal context of the resource being managed. In this way, policies can be both a cause of and solution to water problems. Because water governance exists within these broader contexts, governance changes are necessary to account for the challenges both within and around the water sector (Biswas and Tortajada 2010). In parallel, Nayak and Berkes (2014) argue that social-ecological systems governance needs to incorporate knowledge and action at multiple scales and levels. Levels are "units of analysis" within a scale, while scales are the dimensions of a system (e.g., spatial, temporal, jurisdictional) (Cash et al. 2006, 9, Gibson, Ostrom, and Ahn 2000). The broader social context within which water governance functions includes drivers such as economic policies and politics (Rogers and Hall 2003). Gupta, Pahl-Wostl, and Zondervan (2013) identify agricultural practices, energy production, land use, global environmental change, international law, and multinational corporations as examples of factors influencing water systems. Räsänen et al. (2017, 705) define drivers as dynamic, multi-scale, and context-specific "factors that influence changes". Similarly, we define drivers as the dynamic social and ecological factors that affect a social-ecological system

(Millennium Ecosystem Assessment 2003, Nayak and Berkes 2014, de Loë and Patterson 2017a). Understanding the interactions between drivers and their influence on social-ecological systems (SES) is a prerequisite for achieving a sustainable SES (Tenza et al. 2019). According to Nayak and Armitage (2018), additional research is necessary to understand the bidirectional relationships between governance and other drivers, especially to understand driver influence acting directionally upward.

In the water governance literature, Mollinga, Meinzen-Dick, and Merrey (2007, 701) observed that institutional reforms in the irrigation sector have been informed by both internal and external pressures, such as environmental and political factors, "international macroeconomic trends", and economic pressures; this indicates that drivers have the potential to influence water governance. Other work has also demonstrated that water governance affects and is affected by other decision-making processes (e.g., Daniell and Barreteau 2014). Biswas and Tortajada (2010) attributed changing trends in governance to more collaborative, multi-actor approaches to social and economic factors such as economics and demographic changes. In this work, we are demonstrating the bidirectional relationships between drivers and governance empirically as well as discussing the implications of acknowledging and accounting for this relationship.

The purpose of this research is therefore to use nutrient management efforts in the western Lake Erie basin as a case study to empirically explore the relationships among drivers and governance. Freshwater systems are often influenced by dynamic socioeconomic and environmental drivers that affect how water is used and how it is managed (Fallon, Lankford, and Weston 2021). The Lake Erie Basin in North America (Figure 5) is a transboundary body of water that has been an area of focused coordination between the federal governments of Canada and the United States (US) to address persistent water quality issues, especially excessive nutrients and the associated algal blooms (International Joint Commission 2014). The Great Lakes Water Quality Agreement (GLWQA), first negotiated in 1972 and most recently renewed in 2012 (Government of Canada and Government of the United States of America 2012), is one example of binational cooperation between Canada and the US. Despite these efforts, eutrophication and the associated negative ecosystem impacts have persisted, especially in the western Lake Erie basin in the form of harmful algal blooms (Sekaluvu, Zhang, and Gitau 2018). Lake Erie is a significant economic and agricultural hub, and addressing algal blooms could save hundreds of millions of dollar currently lost to water treatment and other economic costs resulting from algal blooms (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, International Joint Commission 2014). Addressing eutrophication and improving water quality in the western Lake Erie basin is one example whose exploration contributes to a global discussion of water quality challenges (UN World Water Assessment Programme 2003).

Figure 5. A map of the Lake Erie basin, with the US and Canadian subwatersheds draining to the western Lake Erie basin marked with diagonal lines. The US portions of the subwatersheds are shaded in grey.



4.2 Drivers and Governance

Multiple frameworks have been developed to inform the assessment and management of social-ecological systems, including the SES framework and frameworks derived from it (e.g., Ostrom 2007, Anderies, Janssen, and Ostrom 2004), and the Driver-Pressure-State-Impact-Response (DPSIR) framework (Gari, Newton, and Icely 2015). The SES framework was developed by Ostrom and colleagues to support research exploring and characterizing SES (Ostrom 2007, Cole, Epstein, and McGinnis 2019, McGinnis and Ostrom 2014). The DPSIR framework was developed by practitioners for practitioners, including the European Environment Agency and the Organization for Economic Cooperation and Development, to assess environmental problems and inform management decisions (Lewison et al. 2016, Gari, Newton, and Icely 2015).

In Ostrom's SES framework, drivers are exogenous ecosystem or socioeconomic/political settings that can act on any part of a SES (such as water governance for nutrient management in Lake Erie) (McGinnis and Ostrom 2014). In the DPSIR framework, drivers are often framed as human-related factors such as demographic and development trends (Lewison et al. 2016). In the SES framework, influence between these exogenous influences and a SES are bidirectional, meaning they affect each other. In their recent reflection on the SES framework, Cole, Epstein, and McGinnis (2019) conclude that there are still dynamic biophysical/ecological factors, which they do not specify, that are not within the scope of management and therefore exclude them from the framework, which seems like an oversimplification of the importance of these factors. Although they may not be within the immediate scope of management, it is arguably still necessary to identify these factors which may be affecting the social-ecological system under consideration, may be contributing to cumulative effects, and may merit response from authorities outside the immediate management regime.

In their related modified robustness framework, Anderies and Janssen (2013) include exogenous drivers from other ecosystems and/or other social/economic/political structures as affecting the policy context. In the robustness framework, exogenous socioeconomic and ecological drivers act directionally downward on the policy context (Anderies and Janssen 2013). Hinkel et al. (2015) argue that the SES framework struggles to account for the relationships that can exist between multiple system components as well as the dynamic characteristics of those system components. In the parallel DPSIR framework, there is a unidirectional, linear-causality perspective to the relationships between drivers, pressures, states, and impacts, with only the relationship between impact and response characterized as bidirectional (Kristensen 2004). Both Kristensen (2004) and Gari, Newton, and Icely (2015) note that it is important to consider the dynamics between elements (e.g., between drivers and pressures). These frameworks demonstrate the attention in the SES literature and practice on understanding social-ecological systems, as well as the importance of understanding the relationships between an SES and the influencing drivers. We argue that both the SES and DPSIR frameworks could benefit from an analysis of drivers within a specific empirical context, given the acknowledged limitations of having predefined drivers and other SES variables (e.g., Thiel, Adamseged, and Baake 2015, Clement 2012). We therefore chose to apply an approach that uses practitioner knowledge and subject matter expertise to explore drivers and their relationship to water governance, as practitioners have demonstrably contributed to water governance discussions (e.g., Jiménez et al. 2020), while being informed by the SES literature.

The feedback loops between SES and the drivers that influence them have not been a focus of research; instead, research has tended to focus on the one-directional influence of drivers on an ecosystem (Levy and Morel 2012, Ghafoori-Kharanagh et al. 2021). For example, there have been limited efforts to empirically understand the relationship that exists between drivers and water management strategies (Räsänen et al. 2017). In the literature, Gillon, Booth, and Rissman (2016, 760) identify a gap when it comes to assessing and identifying “the long-term effects of shifting drivers on environmental outcomes and associated governance implications”. Specifically, Gillon, Booth, and Rissman (2016) draw attention to the challenges for environmental governance to establish objectives and measure success in the face of dynamic drivers (e.g., climate and social-ecological changes); they use the Yahara River watershed as an example, since phosphorous loading in this region has not changed significantly despite years of nutrient management efforts. Cole, Epstein, and McGinnis (2019, 25) find that discussions in the SES literature on dynamic relationships between environmental challenges and policies have been oversimplified and that work exploring the “explicit sequence of challenge and response” would be valuable. In sum, interactions between drivers as well as between drivers and policy responses are understudied.

Work is necessary to understand how governance influences actions to address complex water problems, especially since dynamic contributing factors, interactions between factors, and knowledge gaps can affect whether water quality is improved if measures to address them are not appropriate (Kirschke et al. 2017). Water governance refers to how decisions are made about water (Grigg 2011, Lautze et al. 2011, Rogers and Hall 2003), while water management reflects the operations necessary to meet governance objectives (Lautze et al. 2011). The ability of water management to achieve positive outcomes in the context of dynamic systems is informed by water governance (Jiménez et al. 2020). Specifically, achieving desirable outcomes is linked to the ability of water governance to identify and address drivers that exist horizontally within levels and vertically across multiple levels (de Loë and Patterson 2017b). An example in practice is provided by Räsänen et al. (2018) in their assessment of how drivers are identified and addressed through water management strategies. Räsänen et al. (2018) found a mismatch between the scales of drivers identified by water managers and the risk/water management strategies being implemented, including a lack of integrated policies to address the connections between drivers.

The role of the governance system as a category of drivers affecting water problems has been discussed in the literature. For example, Gillon, Booth, and Rissman (2016) observed that agricultural practices are affected by agricultural policies at the state and federal levels, with more intense production encouraged and practices to reduce nutrient loading discouraged. Similarly, Jetoo (2018, 418) identified the perceived absence of regulatory measures for nutrient management efforts in the Great Lakes as a "key barrier to eutrophication governance", along with inadequate resources and the eroding leadership and accountability of the IJC. More broadly, in the Great Lakes Futures Project, governance and geopolitics were identified as one of the key drivers affecting the sustainability of water resources in the Great Lakes Basin (Jetoo et al. 2015, Laurent et al. 2015). Specifically, institutional fragmentation within and between Canada and the US, the decentralization of water governance responsibility from higher to lower levels of government without a transfer of capacity, limited capacity to implement policies, and geopolitics both within and outside the Great Lakes Basin are water governance challenges that hinder the ability of the governance systems to respond to other drivers affecting the ecosystem, such as climate change (Jetoo et al. 2015, Friedman et al. 2015). A review of 37 water problems in Germany revealed that the formulation and delivery of water policy, which is hindered by problem complexity (e.g., dynamic drivers and high uncertainty for policy effectiveness), are inferred to have negative impacts on water quality if policy measures are ineffective and/or inappropriate (Kirschke et al. 2017). Jetoo et al. (2015) recommended steps to address governance as a driver: support coordination and build stronger relationships between government levels, increase funding for Great Lakes protection, increase government capacity, formalize engagement in decision-making, and a recommitment from the US and Canadian federal governments to binational cooperation. In these discussions, the roles of the governance system in affecting SES are generally implied. More explicitly, Ghafoori-Kharanagh et al. (2021) approached their assessment of groundwater overexploitation with groundwater governance challenges, including regulations and policies, identified as driving forces that negatively impact groundwater resources and therefore they recommended modified approaches to groundwater governance.

Environmental policy, including for water, has generally focused on reducing the adverse effects of drivers, rather than on addressing drivers directly (Levy and Morel 2012, Vörösmarty et al. 2010, Van Loon et al. 2016). The importance of taking drivers into account, by which we mean the driver is identified and there are explicit actions to address it, extends beyond water and environmental governance and is linked to broader discussions of social-ecological systems. For example, in their case study of shrimp-farming in Chilika lagoon in the Bay of Bengal, Nayak and Berkes (2014) observed a bidirectional influence between drivers at nested spatial scales. This bidirectional relationship between drivers is a significant finding that challenges the implicit assumption in the environmental literature of driver directionality, where higher level drivers affect lower level drivers (e.g., Nelson et al. 2006, Gupta and Pahl-Wostl 2013), as well as extending the literature on drivers through the argument that drivers and their impacts on social-ecological systems are a two-way process (Nayak and Berkes 2014, Nayak and Armitage 2018).

In this paper, we extend that concept of a bidirectional relationship between drivers at multiple spatial scales to a bidirectional relationship between drivers and governance, as well as providing nuance to how drivers and governance have been previously distinguished. Drivers are often discussed as something for governance to address. For example, Gupta and Pahl-Wostl (2013) identify multiple scales of influence on water moving from policies to drivers to ecosystem services, which implies that influence moves from larger (policies) to smaller (drivers) scales. This framing exists elsewhere in the academic literature; for example, a unidirectional flow of driver influence is built into the DPSIR framework (e.g., Kristensen 2004). We argue that drivers shape governance, in addition to interacting with each other and causing changes in a SES. Previous discussions of this relationship have been broad. The Millennium Ecosystem Assessment (2003, 92) distinguishes between "physical drivers of ecosystem change" and "signals that motivate the decision-making process", which suggests that drivers and governance can influence each other. In their summary of the Millennium Ecosystem Assessment's discussion of drivers, Nelson et al. (2006) note the feedback loop that can exist between ecosystem services and drivers, where ecosystem changes can lead to policy changes. Similarly, Nayak and Armitage (2018) observe that humans both create and respond to social-ecological change, and that understanding the drivers that influence social-ecological systems can inform governance.

4.3 Methodology

The western Lake Erie basin was used as a case study for the research. Lake Erie is a transboundary body of water that is shared by Canada and the United States. Although there are longstanding and successful efforts to coordinate efforts binationally, as evidenced by the existence of the binational International Joint Commission (IJC) and the 2012 Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States, water management ultimately occurs nationally. For example, despite binational commitments to achieve phosphorous loading reduction targets to address eutrophication in Lake Erie, the US and Canada undertook separate efforts to develop domestic action plans for nutrient management. Therefore, the US and Canadian portions of the western Lake Erie basin were explored separately to allow for unique perspectives from each country to emerge from the data. The research used both policy Delphi surveys and document analyses to explore the bidirectional relationship between drivers and water governance, in this case nutrient management efforts in the western Lake Erie basin, and establish validity for the results (Berg and Lune 2012, Bowen 2009). Expert judgement from the policy Delphi and level of engagement in the document analysis were used to determine a driver's importance (Räsänen et al. 2016, Räsänen et al. 2017).

4.3.1 Policy Delphi Surveys

The policy Delphi method was chosen for the research because of the number (n=25 in Canadian case study, n=21 in US case study) and spatial distribution of survey participants across the western Lake Erie basin. The western Lake Erie basin case study is a large geographic area that falls under the jurisdiction of two federal governments, three US state governments, and one provincial government, along with multiple non-state subject matter experts and practitioners in two countries. An in-person workshop would have placed additional demands on research participants for travel, in addition to the time commitment, while a policy Delphi survey meant that a dispersed set of participants could develop and review ideas on drivers and nutrient management ideas remotely. Other benefits of the method include the ability to receive more up-to-date information on an issue, especially expert opinion, than from the literature, as well as stimulating frank discussions because of participant anonymity (Franklin and Hart 2007). Policy Delphi surveys are used to explore areas of agreement and disagreement between experts and generate information that can inform decision-making (de Loë 1995). Participants were selected for their expertise in nutrient and water management, based on authorship of reports, strategies or academic papers, or participation in relevant working groups. Participants included academic researchers, staff from government and non-government agencies, and agriculture actors, although not all possible perspectives are represented in the policy Delphi surveys (see Table 10). Examples of agencies include: the Michigan Department of Agriculture and Rural Development, the Ohio Department of Natural Resources, Soil and Water, the International Joint Commission, Environment and Climate Change Canada, and Environmental Defence. Participants were recruited by phone and/or email; policy Delphi surveys were carried out using Qualtrics.

Table 10. Participants from the Canadian and US policy Delphi surveys.

Type of Participants	**Case Study**	
	Canadian Policy Delphi (n=25)	**US Policy Delphi (n=21)**
Government staff (federal, state, provincial)	11	11
Non-government organization staff	4	5
Agricultural sector	4	0
Academia	3	4
Conservation Authority staff	5	N/A
Private sector	0	2

The policy Delphi consisted of two rounds to explore drivers of eutrophication and nutrient management efforts in the western Lake Erie basin. In the first round, participants were asked to identify drivers of eutrophication and to identify the drivers that are or are not taken into account by nutrient management efforts. Responses were analyzed using QSR NVivo 10 and grouped into representative statements. These representative statements were shared with participants in the second round, where they were asked to indicate their level of agreement with statements using a four-point Likert scale, as well as provide a rationale for their rating. No neutral options were provided, although participants were able to select an “I don’t know” rating if they did not feel they could provide an answer (Turoff 2002). Participant ratings were then analyzed to measure areas of consensus among experts; the purpose of this analysis was to identify whether participants agreed, disagreed, or were ambivalent towards the results from the first survey round (de Loë 1995, de Loë and Wojtanowski 2001). There could be high, medium, or low consensus among participants. If fewer than one-third of participants provided a rating for a statement, then the statement was determined to have insufficient participation and was not included in the analysis (de Loë and Wojtanowski 2001). Rationales were examined to provide context for participant’s ratings; for example, two participants can give the same rating but have different reasons; without allowing the space for a rationale, these reasons would be unknown (de Loë 1995). To confirm the results, participants were provided with the survey results from round one and two for verification (de Loë et al. 2016).

4.3.2 Document Analyses

The policy Delphi surveys were paired with a document analysis of water and nutrient management documents in the Lake Erie basin from Canada, the US, as well as binational documents (e.g., co-authored or written by a binational agency such as the IJC). Documents were found through an internet search using keywords, such as "Lake Erie basin" and "nutrient management", as well as searching document reference lists. Documents were included in the analysis if they were intended to improve water quality in the Lake Erie basin and/or if they were specific to addressing eutrophication in the Lake Erie basin. Example documents are provided in Box 4.

Box 4. Example documents included in the document analyses.

Canadian Documents	US Documents	Binational Documents
• The Lake St. Clair Canadian Watershed Management Plan • Clean, Not Green: Tackling Algal Blooms in the Great Lakes • Nutrient Management: Research Insights for Decision Makers • Canada-Ontario Lake Erie Action Plan: Partnering on Achieving Phosphorous Loading Reductions to Lake Erie from Canadian Sources • Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2020 (Draft)	• Directors' Agricultural Nutrients and Water Quality Working Group: Final Report and Recommendations • Western Lake Erie Basin Initiative: Fiscal Years 2016-2018 • State of Ohio's Western Lake Erie Basin Collaborative Implementation Framework: A Pathway for Transitioning Ohio to a Great Lakes Water Quality Agreement Domestic Action Plan • US Action Plan for Lake Erie: Commitments and Strategy for Phosphorous Reduction • State of Michigan Domestic Action Plan for Lake Erie	• Taking Action on Lake Erie: IJC Science Advisory Board TAcLE Work Group Science Summary Report • Recommended Phosphorous Loading Targets for Lake Erie: Annex 4 Objectives and Targets Task Team Final Report to the Nutrients Annex Subcommittee • Evaluating Watershed Management Plans: Nutrient Management Approaches in the Lake Erie Basin and Key Locations Outside of the Lake Erie Basin • Assessment of Fertilizer and Manure Application in the Western Lake Erie Basin • 2016 Progress Report of the Parties: Pursuant to the Canada-United States Great Lakes Water Quality Agreement

Documents were only included if they were published in 2012 or later, to reflect the commitments and understandings of water quality challenges established by the 2012 GLWQA, unless a document published before 2012 was the most recent version of a document that could be found (e.g., the Lake St. Clair Canadian Watershed Management Plan was published in 2009). A total of 60 documents were included in the document analysis (14 Canadian documents, 23 US documents, and 23 binational documents). Document analyses were coded both inductively and deductively through an iterative process (Berg and Lune 2012, Bowen 2009) moving from open coding to focused coding to identify themes (Van den Hoonaard 2012) relating to drivers of eutrophication and nutrient management efforts in the western Lake Erie basin.

4.4 Results

This section presents results from both the Canadian and US case studies on the relationship that exists between drivers and water governance in the western Lake Erie basin, in the context of identifying drivers of eutrophication and whether these drivers are taken into account by nutrient management efforts. The results for both case studies are presented together in this section. Results that are pertinent to individual case studies are emphasized where appropriate. Some overlap in the perspectives represented by the data sources was expected, since potential policy Delphi participants were identified using author lists from nutrient management documents, along with participation in contributing working groups.

As explored in detail in Chapter 2, 46 drivers of eutrophication were identified by the Canadian and US case studies. Canadian policy Delphi participants identified 30 drivers of eutrophication. US policy Delphi participants identified 18 drivers of eutrophication. There was partial overlap between policy Delphi survey data. In the document analyses, 27 drivers of eutrophication were identified (1207 coded references in the Canadian case study, and 1315 coded references in the US case study), with complete overlap between the case studies. Examples of drivers identified include: agricultural operations, climate change, development pressures (such as population growth), funding availability, nitrogen, phosphorous, and wastewater treatment infrastructure.

In both case studies, policy Delphi participants identified the water governance system and nutrient management efforts themselves as drivers of eutrophication in the western Lake Erie basin. In the Canadian policy Delphi, participants identified governance actors such as government agencies and conservation authorities, the relationships and coordination within the governance system, and the structure of nutrient management efforts such as regulatory/voluntary mechanisms and funding availability as drivers of eutrophication. For example, there was high consensus among Canadian participants that governments are a driver of eutrophication, either as a cause of eutrophication or as a solution to eutrophication because governments affect eutrophication through inaction and/or action. There was also high consensus among Canadian participants that lack of political will to address eutrophication, weak land use planning policies (that fail to protect and/or restore natural features) and the limited availability of funding for nutrient management efforts are all drivers of eutrophication. In the US policy Delphi, participants identified insufficient nutrient management efforts as drivers of eutrophication. US participants also identified the tension between regulatory and voluntary mechanisms, funding availability, as well as the potential unintended consequences that can occur due to nutrient management (such as the role of erosion-control efforts in increasing dissolved reactive phosphorous loading to Lake Erie) as drivers of eutrophication. For example, there was high consensus among US participants that a lack of regulation and reliance on voluntary programs for agricultural nutrient management is a driver of eutrophication. US policy Delphi participants did not identify governance actors, coordination within the governance system, or politics as drivers of eutrophication in the western Lake Erie basin. In summary, both Canadian and US policy Delphi participants agreed that governance actors and nutrient management efforts affect eutrophication and whether water governance objectives are achieved, although Canadian and US participants did not have complete overlap in the details of how this influence is exerted (e.g., whether politics shapes nutrient management efforts).

These governance system- and nutrient management effort-related drivers of eutrophication were not engaged with in the same way through either the US or Canadian document analyses. As in both policy Delphi surveys, types of drivers identified in both the Canadian and US case studies included biophysical (e.g., atmospheric deposition) and socioeconomic drivers (e.g., human activities such as land use change). The role of the governance system and the associated nutrient management efforts in explicitly causing eutrophication were not discussed, except for an observation by the IJC that "geopolitical economic factors", such as Chinese tariffs on US soybean imports and ethanol markets, can affect phosphorous loading to Lake Erie (LimnoTech 2019). Instead, codes in the document analyses revealed discussions of the roles and obligations of the governance system to respond to and manage other drivers of eutrophication. These discussions imply that the water governance system plays a role in shaping water quality outcomes and is therefore a driver of eutrophication.

There were 43 statements on taking drivers into account in the Canadian policy Delphi and 54 in the US policy Delphi. From the document analyses, there were 3300 coded references in the Canadian case study (with 30 distinct themes) and 4171 coded references in the US case study (with 28 distinct themes) on drivers that are addressed in nutrient management efforts in the western Lake Erie basin. These data were explored in more detail in Chapter 3. In the Canadian case study, there was agreement between the policy Delphi and document analysis that the identified major drivers of eutrophication, including agricultural operations, phosphorous and its availability, wastewater, urban areas (including stormwater runoff), and land use changes are taken into account by nutrient management efforts. Similarly, in the US case study, there was agreement that most of the perceived significant drivers of eutrophication are taken into account, including agricultural operations, wastewater, invasive species, and nitrogen. Canadian data sources agreed that development pressures such as population growth are not taken into account in nutrient management efforts. Although population growth was identified in the first US Delphi round as a driver of eutrophication that is not taken into account, there was insufficient participation in the second survey round.

Due to differences between the policy Delphi and document analysis results, it was unclear in the Canadian case study whether drivers such as climate change, invasive species, or nitrogen were taken into account by nutrient management efforts. Differences were also present in the US case study, so it was unclear whether climate change, land use changes, or funding availability were taken into account by nutrient management efforts. For example, in both the US and Canadian documents analysed, there were discussions of including climate change in nutrient management through multiple mechanisms, including the establishment of phosphorous loading targets that consider climate change (Government of Canada and Government of the United States of America 2012). However, both policy Delphi surveys revealed a more nuanced discussion of accounting for climate change. Canadian participants had medium consensus that climate change is not taken into account, while US participants had medium consensus that taking climate change's role in eutrophication into account is uncertain and not addressed in nutrient management efforts.

Many of the governance-related drivers identified in the Canadian policy Delphi (e.g., governance actors such as governments and conservation authorities) were not discussed as drivers that are taken into account by nutrient management efforts. Canadian participants did have high consensus that although the provision and availability of funding is a driver of eutrophication, it is not resolved through nutrient management efforts. There was also medium consensus among Canadian participants that the role of agribusinesses in nutrient management is acknowledged but not taken into account, and therefore changes to how agribusinesses participate in nutrient management may be necessary (although no specific examples for how to do this are provided). Among US policy Delphi participants, there was not much engagement with accounting for the governance system as a driver of eutrophication. Exceptions included high consensus among US participants that agriculture needs to be regulated in nutrient management efforts, but this is opposed, with rationales identifying resistance to regulation including from stakeholders and politicians. Although US participants identified insufficient effort and funding for nutrient management, and the impacts of politics on nutrient management efforts as not taken into account by nutrient management in the first survey round, there was insufficient participation in the second survey round to determine consensus among participants. There is a disconnect between the identified roles of governance actors and the influence of nutrient management efforts on eutrophication emerging from the policy Delphi surveys and the lack of discussion on whether these influences are taken into account.

Although not directly identified as a driver of eutrophication, the document analysis data in both case studies revealed attention to the role of the governance system in affecting nutrient management efforts. For example, the Canada-Ontario Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018, 6) framed strong governance as a crucial prerequisite of achieving nutrient management objectives: "managing phosphorous loads and delivering on an action plan will be a complex and challenging task that will require strong governance and co-operation among all involved, including several levels of government, Indigenous communities, key sectors, and a broad network of partners". The role of the governance system in shaping nutrient management, as well as the associated mechanisms of action, and affecting eutrophication was a theme that emerged from the analysis. Monitoring, research, modeling, legislation, financial and/or technical government support, education and outreach, and the establishment of programs are some of the mechanisms being used to take drivers of eutrophication into account. These mechanisms have been developed and implemented by government agencies and the IJC, sometimes in partnership with other governance actors such as agricultural and academic agencies, for multiple drivers ranging from agricultural practices to land use change to wastewater infrastructure. For example, under Annex 4 of the Great Lakes Water Quality Act (Government of Canada and Government of the United States of America 2012), both Canada and the US federal governments commit to undertaking the monitoring and modeling necessary to understand climate change impacts on nutrient loading, and to assess both current phosphorous concentrations and identify phosphorous loading targets.

When analyzing the Canadian and binational documents to determine whether agricultural practices are taken into account by nutrient management efforts, the influence of the governance system in shaping nutrient management efforts and water governance outcomes became evident. For example, recommendations and guidance for implementing the right time, right place, right type, right amount (4R) nutrient stewardship practices, where the 4R program is "promoted by the Fertilizer Institute (TFI), International Plant Nutrition Institute (IPNI), the International Fertilizer Industry Association, and the Canadian Fertilizer Institute (CFI)" (IJC Science Advisory Board TAcLE Work Group 2013, 33-34), included commitments and support from government agencies at the binational, federal, and provincial levels and agricultural actors such as the Ontario Agribusiness Association (International Joint Commission 2014, Environmental Defence and Freshwater Future Canada 2014, Government of the United States of America and Government of Canada 2016). Other mechanisms accounting for agricultural practices as a driver of eutrophication in the Canadian document analysis identified the role that the governance system plays in shaping nutrient management efforts, such as establishing and implementing legislation (Ontario's Nutrient Management Act, 2002) (e.g., Lake St. Clair Canadian

Watershed Coordination Council 2008, International Joint Commission 2017a, Upper Thames River Conservation Authority 2018), efforts to implement or encourage best management practices to reduce phosphorous loading (e.g., IJC Science Advisory Board TAcLE Work Group 2013), research/monitoring/modeling activities to understand or improve nutrient use and nutrient application practices/outcomes (Environment Canada and USEPA 2014), voluntary stewardship and nutrient reduction programs (International Joint Commission 2017a), and government funding to support nutrient management efforts such as the Great Lakes Protection Initiative (Government of Canada and Government of the United States of America 2019). Similarly, in the US document analysis, mechanisms accounting for agricultural practices as a driver of eutrophication demonstrated the crucial role of the governance system in establishing and implementing best management practices (e.g., revisions to the USDA-NRCS's Nutrient Management Standard to promote nutrient management practices) (Zehringer, Nally, and Daniels 2012), legislation such as Ohio's Senate Bill 1 which restricts the application of fertilizer and manure on frozen, saturated, or snow-covered ground in the western Lake Erie basin (Government of the United States of America and Government of Canada 2016), and governmental support for nutrient management efforts including the Great Lakes Restoration Initiative, which supports the Conservation Action Project to include fertilizer dealers' clients in a nutrient management program (Ohio Lake Erie Commission et al. 2013). These are just a few examples relating to nutrient management practices in agricultural operations that are indicative of similar roles for the governance system in accounting for other drivers of eutrophication. These examples demonstrate the key role that the water governance system plays in nutrient management.

The role of the governance system in shaping and implementing nutrient management efforts in the western Lake Erie basin was also evident for drivers that the data indicated may not be taken into account, such as invasive species. In the 2012 GLWQA's Annex 4 (Government of Canada and Government of the United States of America 2012), both Canada and the US commit to taking invasive species into account when establishing phosphorous concentration and loading objectives. Similarly, the Canada-Ontario Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018) says that additional research is necessary to understand the relationship between invasive species and algal growth. The Michigan Action Plan (State of Michigan 2018) also commits to supporting research to understand invasive species as a driver of harmful algal blooms (United States Environmental Protection Agency [USEPA] 2018). Although there are both binational, federal, provincial and state recognition and commitments to understand invasive species as a driver of eutrophication, Canadian policy Delphi participants have no consensus that invasive species are taken into account, for example in domestic action plans. In contrast, US participants have medium consensus that the role of invasive species is understood and is taken into account through research and adaptive management.

Another driver that appears to be minimally present in nutrient management efforts is the synergy that exists between drivers. Synergy between drivers contributes to and exacerbates algal blooms, and these synergies were identified in both the Canadian and US document analyses but not the Canadian or US policy Delphi surveys. In binational documents, it was acknowledged that climate change, hydrological characteristics, invasive species, land use and population patterns, agricultural activities, and nutrient management planning itself all interact to make understanding algal blooms in Lake Erie more challenging (International Joint Commission 2014, The Annex 4 Objectives and Targets Task Team 2015). Similarly, Canadian documents identified interactions and synergies between drivers such as climate change, human activities such as land use change, and invasive species (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, Environment Canada and Climate Change and Ontario Ministry of Environment 2019). US documents also discussed the multiple interacting factors contributing to eutrophication, including climate change and invasive species (Michigan Office of the Great Lakes et al. 2016) and changes in agricultural practices (State of Michigan 2018). These synergies exist across multiple levels in multiple directions, including spatial and jurisdictional scales. Synergies between drivers of eutrophication have implications for nutrient management efforts. Whether synergies between drivers are taken into account were not discussed in either the Canadian or US policy Delphi surveys. Taking synergies into account was not explicitly discussed in US documents, while binational documents acknowledged that the lack of knowledge on synergies between drivers creates challenges for nutrient management efforts (IJC Science Advisory Board TAcLE Work Group 2013, International Joint Commission 2014, 2017a). In the Canadian document analysis, there were mostly recommendations and acknowledgements that research is necessary to understand potential interactions between factors, except for the 2014 and 2020 Canada-Ontario Agreements (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, Environment Canada and Climate Change and Ontario Ministry of Environment 2019), which included commitments from Canada and Ontario to develop an understanding of the relationships between drivers of eutrophication.

4.5 Discussion

Overall, the results demonstrated the connections that exist between drivers of eutrophication and the governance system. Two main themes emerged from the data relating to the relationship between drivers and water governance: (i) the governance system itself is a driver of eutrophication challenges, rather than solely a system for managing drivers, and (ii) drivers of eutrophication and water governance have a bidirectional relationship that is evident at multiple scales and levels. These themes will be explored in the following paragraphs.

4.5.1 Governance as a Driver

The policy Delphi surveys demonstrated that water governance can be a driver affecting eutrophication by shaping nutrient management efforts through a variety of mechanisms, including cooperation across jurisdictions, and the influence of political landscapes in shaping the priorities around environmental issues. According to survey participants, water governance actors and nutrient management efforts are drivers because they can contribute to eutrophication (e.g., weak land use planning policies that lead to the degradation/loss of natural features and therefore increase nutrient loading) or a solution to eutrophication (e.g., funding from government agencies to support nutrient management efforts).

The role of the governance system was engaged with differently in the document analyses for both case studies. Nutrient management documents discussed the roles and responsibilities of governance system actors and the mechanisms of action, such as legislation and the development of strategies/plans/programs, to respond to and/or manage drivers of eutrophication. The governance system was not identified as a driver directly; it was implied through the role of actors and institutions in shaping nutrient management efforts and therefore determining whether and/or how other drivers of eutrophication would be taken into account by nutrient management efforts. For example, although invasive species were identified as a driver of eutrophication in the western Lake Erie basin in both case studies (and both the policy Delphi surveys and document analyses within each case study), Canadian policy Delphi participants did not agree whether invasive species were taken into account by nutrient management efforts. In this perceived failure to address a driver, the governance system becomes a driver of eutrophication through ineffective or missing efforts: if nutrient management efforts do not address the influence of invasive species of eutrophication, then eutrophication will persist because of this inaction. The governance system can also affect eutrophication positively through nutrient management efforts. For example, agricultural organizations, government agencies, and conservation authorities are governance actors in Canada and the US that have developed and/or implemented and/or enforced nutrient management legislation and nutrient reduction programs (e.g., IJC Science Advisory Board TAcLE Work Group 2013, Government of the United States of America and Government of Canada 2016). These efforts are intended to address agriculture as a driver of eutrophication and reduce nutrient loading from these operations. The governance system affects drivers of eutrophication through their inclusion or exclusion from nutrient management efforts and is therefore a driver of eutrophication itself.

The water governance literature has acknowledged the influence of water governance on water problems (e.g., Jetoo et al. 2015, Laurent et al. 2015, Kirschke et al. 2017). For example, in their assessment of 37 water policy issues in Germany, Kirschke et al. (2017) concluded that further research was necessary to assess how water governance affects policy approaches to complex problems. Discussions of eutrophication in general, and in Lake Erie specifically, often frame drivers of eutrophication as biophysical and socioeconomic factors and do not explicitly discuss the role of the governance system as a driver. In their global scan of eutrophication management, Foulon et al. (2019, 1) identify the human causes of eutrophication as agriculture, "industrial and municipal wastewater treatment plants, leaky home septic systems, runoff from lawns, and even atmospheric deposition", with governance actors shaping nutrient management through regulatory, incentive, risk mitigation, and outreach/educational approaches to address drivers of eutrophication. Other discussions of phosphorous loadings to Lake Erie focus on these drivers as well (e.g., Daloglu, Cho, and Scavia 2012, Michalak et al. 2013). Climate change (Smith, King, and Williams 2015), agricultural practices such as tile drain installation (Baker et al. 2014) and the interactions between multiple drivers including land use change and population growth (Khan and Mohammad 2014) are some of the other drivers contributing to eutrophication in Lake Erie. The role of the governance system is often implicitly linked to determining nutrient management efforts. This is supported by the data from both case study document analyses, where codes relating to the governance system recognized the roles and responsibilities of governance actors, and the mechanisms by which other drivers of eutrophication were addressed to reduce nutrient loading. Our results challenge these conceptualizations of drivers in the water governance for eutrophication literature and supports framings of water problems that acknowledge the role of the governance system in contributing to as well as addressing problems. Specifically, our data make explicit the influence of the water governance system on nutrient loading and water quality outcomes.

4.5.2 Bidirectional Relationship Between Drivers and Governance

The results also confirm the dynamic, multi-scale relationships that exist between multiple drivers and create stress on a social-ecological system (Cumming et al. 2015, Räsänen et al. 2017). According to the overview of drivers of ecosystem change from Nelson et al. (2006), drivers have influence across multiple levels at spatial, jurisdictional, and temporal scales, where drivers can impact SES over short- and long-term time scales as well as across different levels of governance (ranging from local land use planning to international agreements) and space (climate change is a global phenomenon that has local impacts). In the results, these interactions could be observed between drivers, including the governance system. Specifically, bidirectional influences between drivers and water governance could be observed in both the US and Canadian case studies.

Drivers shape water governance because water governance needs to adapt to SES as information becomes available (as drivers are identified) and/or the system changes. For example, although synergies between drivers are acknowledged to affect nutrient loading to the Lake Erie basin (Michigan Office of the Great Lakes et al. 2016, IJC Science Advisory Board TAcLE Work Group 2013), there was also an acknowledged lack of information on synergies and how they contributed to eutrophication (e.g., International Joint Commission 2017a), as well as minor Canadian commitments to research the relationships between drivers (e.g., Environment Canada and Climate Change and Ontario Ministry of Environment 2019). Unstated is the implication that the outcomes of this research will provide information on driver synergies which will likely require/lead to modifications to nutrient management efforts.

Bidirectional influence was observed at multiple scales, including the spatial, temporal and jurisdictional scales. The data from the case studies on climate change is an example where the governance system interacts with other drivers at eutrophication at multiple levels. Climate change is a global phenomenon with regional impacts on the Great Lakes Basin; these impacts cause and exacerbate eutrophication and algal blooms in the western Lake Erie basin. Responding to climate change includes binational/federal/provincial/state commitments to consider and respond to climate change impacts in nutrient management efforts. While the scale of influence might appear to be unidirectional, the use of monitoring/modeling/research to assess climate change impacts and inform nutrient management efforts means that the governance system at multiple levels are informed by new information and/or SES changes. An example of the temporal scale from the data is that nutrient management decisions in the past have an effect on eutrophication now and in the future, such as decisions to recommend/implement conservation tillage to reduce erosion and particulate phosphorous loading, which then led to increases in soil phosphorous at the surface level via soil stratification, and increases in dissolved reactive phosphorous loading which is bioavailable and therefore difficult for nutrient management; this has also been discussed in the eutrophication literature (e.g., Foulon et al. 2019). These results challenge traditional framings of drivers, where drivers act directionally downward from larger to smaller scales (e.g., Gupta and Pahl-Wostl 2013). They also contribute empirical evidence to emerging discussions on the bidirectional relationships between drivers at the spatial and jurisdictional scales (e.g., Nayak and Berkes 2014). The research also makes explicit the bidirectional influences that exist between governance and other drivers that has previously been implied in the literature, especially for water governance (e.g., Mollinga, Meinzen-Dick, and Merrey 2007, Biswas and Tortajada 2010).

The challenge arising from these results is that recognizing the governance system as a driver does not appear to happen in formal nutrient management efforts in the western Lake Erie basin. Failing to acknowledge the role of the governance system in eutrophication, for example through ineffective/absent efforts to manage other drivers of eutrophication, has implications for achieving nutrient management objectives such as the phosphorous loading targets agreed to by Canada and the US (Government of Canada and Government of the United States of America 2012). This conclusion is based on results from both the Canadian and US document analyses; although both Canadian and US policy Delphi participants identify aspects of the governance system as drivers of eutrophication, those discussions are only implied in nutrient management programs and strategies.

The bidirectional relationships among drivers (including the governance system) at multiple scales and levels also has implications for water governance and nutrient management outcomes in the western Lake Erie basin. An indication of how challenging it is to understand and take these relationships into account comes from the document analyses for both the US and Canadian case studies. Although the results identified dynamic interactions between drivers such as invasive species, climate change, land use change (Environment Canada and Ontario Ministry of Environment and Climate Change 2014, Michigan Office of the Great Lakes et al. 2016, International Joint Commission 2014), and agricultural practices (State of Michigan 2018), there was little visible evidence in nutrient management documents that there are efforts to improve understandings of how these interactions affect eutrophication and algal bloom formation. The results found that the Canada-Ontario Agreements from 2014 and the draft 2020 version established commitments to understand driver synergies. However, in the remainder of documents analyzed, relationships between drivers are minimally acknowledged as a challenge (e.g., International Joint Commission 2017a) or not addressed at all.

There are two issues exposed by the results: (i) the governance system isn't explicitly mentioned as a driver that dynamically interacts with other drivers, and (ii) the implications of these synergies for nutrient management efforts are unclear. These findings have implications for both the empirical case study of the western Lake Erie basin, as well as the literature, including SES frameworks and water governance. In practice, these results indicate that the role of the governance system in shaping eutrophication and nutrient management efforts may be underestimated in current framings of nutrient management. This underestimation, as well as the dynamic nature of the western basin SES, affects both nutrient management outcomes and the governance system itself, which will likely need to undergo changes in the future as nutrient management outcomes are not achieved or as new information becomes available about drivers of eutrophication (including the dynamic relationship between governance and other drivers). In theory, the research results challenge the relationships between drivers and governance that are formalized in SES frameworks. In these frameworks, drivers and governance are generally treated as separate and/or having influence move one-way between management responses and drivers, as in the DPSIR framework. The research also extends the literature on the bidirectional relationships between drivers (e.g., Nayak and Berkes 2014, Nayak and Armitage 2018) by demonstrating that these bidirectional influences exist at multiple scales beyond spatial, including jurisdictional and temporal. We also provide empirical evidence of water governance as a driver itself, as well as being influenced by other drivers through dynamic interactions.

Our results demonstrate that knowledge gaps (many of which are actively being addressed through research/monitoring/modeling), the dynamic nature of the Lake Erie SES, and potentially ineffective nutrient management efforts have implications for water governance to address eutrophication. To address the factors inhibiting Great Lakes management, Friedman et al. (2015) recommended recognizing that Great Lakes policies are affected by and should consider other policies, strengthen collaboration and cooperation among Great Lakes actors, establish shared objectives for Great Lakes policies, and build capacity and accountability for policies, including tracking policy effectiveness. Coordination between governance actors and across scales is important to account for drivers that have previously been ignored, such as population growth and climate change, and that contribute to complexity in water management (UNWWAP 2012c). This is especially relevant when you consider that drivers are interacting with each other in addition to influencing water systems directly (UNWWAP 2012c). Gillon, Booth, and Rissman (2016) argued that social and environmental change (i.e., drivers) need to be incorporated into the establishment of baseline conditions and management goals used to measure environmental management successes, and therefore recommended establishing management objectives that include drivers where possible. One of the challenges for environmental governance is to be able to address "landscape-scale problems in a manner both flexible enough to address highly contextualized SESs and dynamic and responsive enough to adjust to complex unpredictable feedbacks between social and ecological system components" (Chaffin, Gosnell, and Cosens 2014, 56).

4.6 Conclusion

In the global context of persistent water problems, dynamic drivers, and the associated challenges for water governance, we have previously used the western Lake Erie basin in North America as a case study to identify drivers of eutrophication and assess whether they are taken into account in nutrient management efforts, as seen in Chapters 2 and 3, respectively. In this paper, we build on those chapters to assess the relationships between drivers and the water governance system. Document analyses and policy Delphi surveys were carried out through separate US and Canadian case studies. Our research has two major findings: (i) although drivers are often framed as something for governance to address and the role of governance as an influencing factor can be implicit, our results provide empirical evidence that the water governance system can be a driver of eutrophication, and (ii) the bidirectional relationships between drivers and governance are evident across multiple scales and levels. These findings have implications for achieving governance objectives in the western Lake Erie basin specifically, and for water governance theory more broadly. First, the water governance system can be a driver of eutrophication because it shapes nutrient management both positively and negatively and therefore affects whether and how other drivers of eutrophication are addressed. This influence is not explicitly acknowledged or addressed in either nutrient management efforts or the water governance literature. Second, the results provided empirical evidence of the bidirectional relationship between other drivers of eutrophication and water governance, meaning that water governance affects drivers and that drivers affect water governance. These findings provide additional depth and nuance to discussions in the SES literature on driver directionality as well as extending the literature on bidirectional relationships between drivers to include the temporal scale and governance in understanding where and how drivers have influence.

Two recommendations emerge from the research. First, in the empirical example of the western Lake Erie basin, the role of the governance system as a driver of eutrophication should be formally acknowledged and taken into account in nutrient management efforts, for example through measures of policy effectiveness such as evaluating whether nutrient management objectives and targets are met. Second, in the literature on water governance, eutrophication governance, and frameworks to assess and manage SESs, the bidirectional relationship between other drivers and the governance system should be incorporated more explicitly into problem framings and driver definitions, especially regarding the synergies that can exist between drivers. Together, these recommendations will lead to improved empirical and conceptual understandings of water governance and drivers of water problems.

Chapter 5

Conclusion

This chapter reviews and synthesizes the main findings of the research and places these results within the context of the academic literature. The purpose and objectives are reviewed in section 5.1 and the major findings of the research are summarized in Section 5.2. The significant, original contributions to knowledge that this research makes to the academic literature are discussed in Section 5.3, as are implications for water management practitioners, especially in the case of the western Lake Erie basin. Limitations of the current work and ideas for future research are also discussed in Section 5.3.

5.1 Purpose and Objectives

The purpose of this study was to better understand drivers of water problems and their implications for water governance research and practice, using the empirical setting of eutrophication in the western Lake Erie basin. Lake Erie is a transboundary body of water that exists within the jurisdictional boundaries of both Canada and the United States. The water basin includes the jurisdictions of both the federal Canadian and US governments, as well as the Province of Ontario and the state governments of Indiana, Michigan, New York, Ohio, and Pennsylvania (International Joint Commission 2014, Great Lakes Water Quality Board 2017). Other actors in the basin include industry, non-government organizations, agricultural organizations, academia, and Indigenous peoples (Johns 2017, de Loë and Patterson 2017a). As an economic, ecological, and social hub in North America, the Lake Erie basin supports a population of approximately 12 million people (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018). To achieve the study purpose, the following three objectives informed the research:

1. Identify drivers of eutrophication in the western Lake Erie basin;

2. Determine whether these drivers are taken into account in nutrient management efforts; and

3. Assess the relationships among drivers and water governance.

I carried out two embedded case studies of nutrient management in the US and Canadian portions of the basin using policy Delphi surveys and analyses of formal nutrient management documents. The policy Delphi survey responses and document analyses results were used to identify drivers of eutrophication and to determine whether they are taken into account in nutrient management efforts. These results were then compared both within case studies and between the US and Canadian case studies to identify shared or diverging perspectives between countries. Finally, I examined the relationships among water governance and other drivers of eutrophication.

5.2 Major Findings

The research findings were organized into three manuscript chapters. Individual chapters were informed by the research purpose and objectives. As demonstrated in Table 11, Chapter Two contributed to Objective One, Chapter Three contributed to Objective Two, and Chapter Four contributed to Objective Three. Each of the results chapters were written to be standalone journal articles grounded in the same theoretical and empirical contexts. In this section I summarize the major research findings.

Table 11. Linking the manuscript chapter contributions to the research objectives

Chapter	Research Objective	Chapter Contribution
2	(1) Identify drivers of eutrophication in the western Lake Erie basin	Identifies drivers of eutrophication in the western Lake Erie basin based on the results of the Canadian and US policy Delphi surveys and document analyses
3	(2) Determine whether these drivers are taken into account in nutrient management efforts	Determines whether the drivers identified in the Canadian and US policy Delphi surveys and document analyses are taken into account in nutrient management efforts in the western Lake Erie basin
4	(3) Assess the relationship between drivers and water governance	Uses the data from both the US and Canadian case studies to assess the relationship between drivers of eutrophication and water governance in the western Lake Erie basin

Chapter Two identified drivers of eutrophication in the western Lake Erie basin (research objective 1); through this process, I explored similarities and differences within and between the two embedded case studies and their implications for nutrient management efforts. Many drivers (n=46) were identified when the two case studies were combined, demonstrating the complexity of eutrophication in the western Lake Erie basin and the challenges of accounting for these drivers in nutrient management efforts. The identified drivers included nutrients themselves, biophysical factors such as watershed characteristics, and socioeconomic factors such as development pressures. Some overlap within and between case studies was observed, especially for the most significant drivers of eutrophication; these overlaps indicate shared understandings of eutrophication. A complete overlap in driver identification was found for the Canadian and US document analysis results. Areas of agreement were expected, given the history of collaboration and shared problem framings and objectives such as commitments made by the Canadian and US federal governments under the 2012 GLWQA and its predecessors.

Despite the transboundary water governance setting, and the associated years of collaborative water management efforts, differences in the drivers of eutrophication and how they are perceived were also observed. These differences were observed between case studies, as well as within the US and Canadian case studies. For example, governance actors and nutrient management efforts were uniquely identified as drivers of eutrophication by Canadian policy Delphi participants because they have an impact on water quality in the western basin that can be positive or negative. Areas of disagreement between the policy Delphi survey and the document analysis (i.e., where a driver is identified by one data source and not the other) within a case study reveal that subject matter experts may have different understandings of the causes of eutrophication and use different formal language to characterize the causes of eutrophication in nutrient management documents. Differences between the Canadian and US surveys also reveal diverging perspectives on drivers between the two countries that share jurisdiction over the basin. Drivers of eutrophication where there was not a shared understanding either within or between the US and Canadian case studies indicate potentially significant constraints on the effectiveness of nutrient management efforts. These different understandings indicate areas where nutrient management in the western Lake Erie basin could be improved. The importance of identifying drivers, especially for informing water governance to address drivers of water problems, was demonstrated empirically by the research. The findings also contribute to discussions in the water governance and nutrient management literatures on how to identify drivers as well as the challenges that can occur when there are mismatched understandings of water problems.

Chapter 3 determined whether the major drivers of eutrophication identified in Chapter 2 are taken into account in nutrient management efforts (research objective 2), comparing data from policy Delphi surveys and document analyses both within and between the US and Canadian case studies. A driver was classified as being taken into account if policy Delphi participants classified it as such and if there were explicit nutrient management actions applying to the driver identified within the document analyses. This analysis revealed two main themes: first, gaps between the data sources and two case studies reveal potentially significant gaps in nutrient management efforts in the western Lake Erie basin, and second, these nutrient management efforts may be insufficient to meet water policy objectives. Agreement within and between case studies was observed for several perceived major drivers of eutrophication, including agriculture, phosphorous, and land use changes; accounting for these drivers is also a common theme in the nutrient management literature. Some overlap within and between the US and Canadian case studies was expected, given the transboundary and collaborative nature of water governance and the associated nutrient management efforts in the western Lake Erie basin.

Multiple areas of disagreement about whether drivers are taken into account in nutrient management existed within and between case studies. Whether drivers such as climate change and invasive species are taken into account was unclear, based on the results. For example, while Canadian survey participants agreed that invasive species are not taken into account sufficiently, US participants indicated that invasive species are taken into account through research efforts; both the US and Canadian data analyses included research commitments to understand the relationship between invasive species and algal blooms, but domestic action plans demonstrated a noticeable lack of action to address invasive species as a driver of eutrophication. The data suggests that although a driver may appear to be taken into account in nutrient management, there can be gaps in implementation efforts. Contradictions between data sources and case studies raise questions about the strength of shared understandings of drivers and priorities for nutrient management efforts in the western Lake Erie basin. Uncertainty about whether nutrient management efforts sufficiently address drivers of eutrophication, including climate change and agriculture, reveals broader concerns about whether nutrient management efforts are effective enough to resolve eutrophication and achieve water quality objectives. This finding suggests that the persistence of eutrophication in the western Lake Erie basin, in the face of decades of nutrient management efforts, may be due to ineffective nutrient management efforts, specifically when it comes to taking drivers of eutrophication into account. Not taking drivers of eutrophication into account, in combination with some drivers of eutrophication being taken into account insufficiently, may explain why water policy objectives in the western Lake Erie basin, such as phosphorous loading targets, are not achieved. Additional research is needed to assess nutrient management effectiveness and explore the causes of diverging understandings and priorities for nutrient management both within and between Canada and the US.

In Chapter 4, I used the results on drivers and nutrient management efforts to assess the relationships between drivers and water governance (research objective 3). I also used the data to contribute to framings of drivers in the SES and water governance literatures and discuss the implications of the research for water governance theory and practice. Two major insights emerged from the results in Chapter 4. First, I observed that the water governance system can be a driver of eutrophication in the western Lake Erie basin, for example by shaping nutrient management efforts. Second, the data indicates that there are dynamic, bidirectional relationships between drivers of eutrophication and water governance across levels and scales. The water governance system and nutrient management efforts were explicitly identified as drivers of eutrophication by Canadian and US policy Delphi participants. Weak land use planning policies that fail to protect natural areas, the availability of funding for nutrient management efforts, and the reliance on voluntary mechanisms over regulatory tools are a few examples of influential governance action and inaction that emerged from the data. However, these drivers were not discussed by Canadian or US survey participants as drivers that are taken into account in nutrient management. In the Canadian and US document analyses, the governance system was discussed in the context of managing drivers of eutrophication, rather than as a driver itself. In this way, the influence of the governance system in affecting water quality through nutrient management efforts (or inaction) is evident but not critically examined.

These findings challenge existing framings of eutrophication, where governance is not explicitly identified as a causal factor (e.g., Khan and Mohammad 2014, Michalak et al. 2013). The results also empirically demonstrate the bidirectional relationships that exist between drivers, including the water governance system. Water governance affects drivers by shaping nutrient management efforts. Drivers affect water governance because governance needs to respond to emerging drivers and/or changing SES. For example, changes to nutrient management efforts may be necessary as research on synergies between drivers reveals new information. These bidirectional influences could be observed at multiple scales and levels, including temporal, jurisdictional, and spatial. Legacy phosphorous and the unexpected consequences of past nutrient management decisions such as no-till practices are two examples of drivers acting across the temporal scale to influence present-day water quality in the western Lake Erie basin with implications for the water governance system. Chapter 4 concludes with both empirical and theoretical recommendations. The water governance system is not currently recognized as a driver of eutrophication, meaning that its influence may be underestimated in nutrient management efforts in the western Lake Erie basin. The relationships between drivers and water governance are currently understudied in the SES and water governance literatures. This research has provided empirical evidence of the bidirectional relationships and their importance for understanding the dynamic drivers shaping water problems and creating challenges for water governance research and practice.

Collectively, the results demonstrate the importance of identifying drivers to inform water governance. The research confirms that ignoring the influence of drivers is detrimental to water governance, by exploring nutrient management efforts in the western Lake Erie basin and revealing that multiple drivers of eutrophication are either not taken into account at all, or not sufficiently to achieve nutrient management objectives. The research also contributes to ongoing debates in the water governance literature on the persistence of water problems and the attributed failures of governance in accounting for drivers. The significant and original contributions of this research to both theory and practice are discussed below.

5.3 Contributions

5.3.1 Academic Contributions

The aim of this research was to improve understandings of drivers in the water governance literature and their implications for water governance research and practice. To that end, the research built on frameworks and discussions in the SES and the water governance literatures related to identifying drivers and to characterizing the relationships between water governance and drivers. The research makes four significant and original contributions to the academic literature (Table 12).

Table 12. Linking academic contributions to the manuscript chapters

Chapter	Academic Contributions
2	• Provides empirical evidence demonstrating that identifying and characterizing the drivers of a water problem (e.g., eutrophication), as well as acknowledging the broader social and ecological context, are necessary to achieve desirable water governance outcomes (e.g., improved water quality in the western Lake Erie basin), in support of de Loë and Patterson (2017b, 2017a) • Demonstrates the value of empirical, nuanced case studies for advancing discussions of drivers in the SES literature • Addresses an identified gap in the academic literature on characterizing drivers in specific contexts (e.g., the western Lake Erie basin) to determine their importance (e.g., identifying the perceived most important drivers using the level of engagement by the data sources) (Räsänen et al. 2018) • Expands framings of drivers in the eutrophication literature by identifying the influence of water governance actors and nutrient management efforts (e.g., policies) as drivers of eutrophication in the western Lake Erie basin • Demonstrates the value of the policy Delphi surveys and document analyses in identifying drivers of eutrophication
3	• Addresses an identified gap in the academic literature on understanding the relationship between water managers' perceptions of drivers and how drivers are addressed (e.g., some of the drivers identified by the Canadian and US policy Delphi participants are not clearly taken into account or taken into account sufficiently by nutrient management efforts) (Räsänen et al. 2018) • Demonstrates that the academic literature would benefit from incorporating the unique contributions of regional, empirical research • Addresses, as well as extends, an identified gap on evaluating the effectiveness of nutrient management efforts (Bieroza et al. 2019) • Demonstrates the value of the policy Delphi surveys and document analyses for assessing whether nutrient management efforts take drivers into account
4	• Improves knowledge on the relationships between water governance and other drivers of eutrophication, including the bidirectional nature of the relationships, using empirical evidence

The first contribution relates to demonstrating the importance of identifying drivers of water problems. Supporting Vörösmarty et al. (2010), I argue that making problem definitions that recognize the dynamic and multi-level nature of water problems is a governance challenge. Attention to drivers is necessary because water problems are heterogenous, dynamic, and context-specific; therefore, identifying drivers and characterizing their influence on water resources and decision-making is essential (Nyam et al. 2020). Identifying the drivers contributing to a water problem is a crucial component of water governance that can contribute to the persistence of water problems (e.g., de Loë and Patterson 2017b). Nonetheless, environmental policies often address the effects of drivers, rather than the drivers themselves (Van Loon et al. 2016, Vörösmarty et al. 2010). Instead, water governance should recognize that water problems exist within broader social and environmental contexts, determine the drivers that are necessary to consider, and assess whether existing water governance approaches account for those relevant drivers (Biswas 2004, de Loë and Patterson 2017a, Wiek and Larson 2012). Currently, there are knowledge gaps on characterizing drivers in specific contexts to determine their importance, and on understanding the relationships between how water managers perceive drivers and how they address drivers (Räsänen et al. 2018). Characterizing the drivers of eutrophication in the western Lake Erie basin provides a nuanced perspective on drivers, and their implications for water governance, that emphasizes the value of regionally-focused, empirical research. In my case study of the western Lake Erie basin, I identify and characterize the perceived most important drivers of eutrophication based on nutrient management documents and subject matter expert survey responses. Climate change, invasive species, land use changes, and synergies between drivers are just a few of the drivers of eutrophication in the western Lake Erie basin identified in the case studies that emerged most frequently from the data. Whether these drivers are taken into account by nutrient management efforts is variable and provides opportunities for empirical contributions that are discussed in the next section. The research findings demonstrate the importance of incorporating practitioner perspectives as well as the value of research within specific contexts.

Research to understand the relationships between drivers of nutrient loading and nutrient management efforts is necessary (Reilly et al. 2021). Based on the findings of the research, and in support of de Loë and Patterson (2017a, 2017b), I argue that achieving desirable outcomes of water governance requires more attention to the identification and management of drivers, as well as their interactions. Areas of disagreement both within and between the US and Canadian case studies reveal potentially significant differences in how the causes of eutrophication are perceived, which raises questions about the depth of binational cooperation in the western Lake Erie basin as well as the effectiveness of nutrient management efforts. Since driver perceptions inform water management efforts (e.g., Suckall, Tompkins, and Stringer 2014, Räsänen et al. 2017), failure to identify drivers of eutrophication in either the US or Canadian portions of the region may negatively affect water governance outcomes. The continued eutrophication of freshwater bodies has been attributed to governance efforts that fail to address the drivers affecting phosphorous loading (e.g., Gillon, Booth, and Rissman 2016). The research findings support and provide depth to those discussions by demonstrating that several drivers of eutrophication are not identified or taken into account sufficiently in nutrient management efforts, including synergies between drivers, climate change, and invasive species. This research also contributes to filling a gap on evaluating the effectiveness of nutrient management measures identified by Bieroza et al. (2019) in their Swedish case study. That gap was identified specifically for agricultural best management practices, but I extend that finding to nutrient management as a whole by demonstrating the importance of assessing the effectiveness of nutrient management efforts. The US and Canadian policy Delphi survey results introduced the concept of sufficiency in nutrient management, where a driver could be classified as taken into account, but not sufficiently. This concept of taking a driver into account sufficiently is an important finding of the research and reveals potentially significant gaps between water problem definitions and water problem solutions designed and implemented via a water governance system. Both case studies also revealed multiple drivers that are not classified as taken into account, based on either one or more of the data sources.

The second contribution relates to expanding framings of drivers in the eutrophication literature. Specifically, recognition of the role of water governance actors and nutrient management efforts such as policies and programs as drivers of eutrophication is a contribution from this research to the eutrophication literature. Discussions of eutrophication in general, and in Lake Erie specifically, typically frame drivers of eutrophication to include biophysical or socioeconomic factors only (Foulon et al. 2019, Khan and Mohammad 2014, Michalak et al. 2013), without explicitly recognizing water governance as a category of drivers. Although other water governance authors have acknowledged that policies and characteristics of the governance system (e.g., inadequate resources) have an effect on water resources (e.g., Gillon, Booth, and Rissman 2016, Jetoo et al. 2015, Ghafoori-Kharanagh et al. 2021), I explicitly identify and characterize the role of water governance actors and characteristics of the governance system (including funding and politics) as directly affecting nutrient loading or nutrient management efforts in practitioners' perspectives. By empirically demonstrating that water governance affects eutrophication, I have provided evidence that can be used to expand discussions of drivers within the academic literature on eutrophication. The focus of this work was on assessing the outcomes of various governance scenarios, and therefore my work makes two related contributions: through my empirical demonstration that water governance can be a driver of eutrophication, I extend this understanding of governance as a driving force to other water problems and water governance systems as well as arguing for the importance of additional work to understand the implications of these findings for improving water governance in the context of persistent water problems.

For the third contribution, the research also demonstrated the value of the methods for identifying drivers and assessing nutrient management efforts for their inclusion of drivers. Developing a clear characterization of drivers and their implications for water governance is a prerequisite for addressing drivers. The policy Delphi surveys provided more up-to-date information on this aspect of water governance than the literature as well as a less filtered discussion among experts (Franklin and Hart 2007), while the document analyses provided an opportunity to compare these ideas with the formal strategies and actions being implemented in nutrient management efforts. Drawing on practitioner knowledge and subject matter expertise introduced novel and nuanced discussions of drivers of eutrophication and nutrient management efforts. These contributions demonstrated the value of approaching this research from the empirical setting rather than relying on academic frameworks alone, such as the SES or DPSIR frameworks. The combination of the policy Delphi and the document analysis methods ultimately provided a more complete view of drivers than each data source individually. The policy Delphi surveys and the document analyses confirmed some drivers and introduced others, while providing new insights on drivers that are not currently present in nutrient management efforts. The use of a policy Delphi survey to identify drivers of eutrophication in the western Lake Erie basin appears to be unique to this research, and therefore represents a contribution to the SES and water governance literature on the use of the method for identifying drivers of environmental problems, including water.

For both my second and third contributions to theory, my research demonstrates the unique value of a nuanced case study not only for empirical applications (as demonstrated in section 5.3.2) but also for advancing discussions in the academic literature on identifying drivers and taking them into account. In the SES literature, frameworks and typologies have been developed to inform shared framings of drivers and advance how environmental problems have been understood (e.g., Nayak and Berkes 2014). Building on the critique that pre-defined system components can limit the analysis of an SES (e.g., Thiel, Adamseged, and Baake 2015), I argue that empirical assessments of an environmental problem can provide novel insights into the drivers affecting a system. The most recent iteration of the SES framework excludes drivers from consideration that are outside the scope of management (Cole, Epstein, and McGinnis 2019). The DPSIR framework has been critiqued for failing to connect researchers and decision-makers within a system (Gari, Newton, and Icely 2015). Although both frameworks are paying attention to the empirical implications, challenges have been identified in the literature. By identifying what practitioners and subject matter experts prioritize in the two embedded case studies, these results give insight into what the literature could also benefit from. The identification and management of drivers at the regional scale, assessed in this research using the western Lake Erie basin, is informed by driving concerns in that context. Therefore, I recommend that literature should respect the specificity and nuance of empirical concepts, and that this respect should be built into the conceptual frameworks that inform academic assessments of SES and drivers, including the SES and DPSIR frameworks. In this way, conceptual frameworks that shape framings of drivers and how they are addressed can draw from practitioner perspectives to develop more nuanced understandings of water problems. For example, such an approach could explore previously unknown drivers still benefiting from the shared language and frame of reference to accumulate knowledge that Ostrom (2007) identified as a strength of the SES framework.

The fourth contribution of the research is in improving knowledge on the relationships between water governance and other drivers, specifically in challenging previous framings of unidirectional relationships and emphasizing the dynamic nature of these interactions. Understanding how drivers interact and how they influence SES is important (Tenza et al. 2019). Work is necessary to understand the ecological/physical processes affecting SES that are outside the current scope of management efforts (and excluded from the new combined SES-IAD framework) as well as the tools that can be used to address those external processes (Cole, Epstein, and McGinnis 2019). Specifically, the SES literature can oversimplify the relationships between environmental challenges and policy responses and therefore work exploring these relationships is valuable (Cole, Epstein, and McGinnis 2019). Kirschke et al. (2017) observed that work is necessary to understand how drivers interact and how governance affects efforts to address water problems. Identifying feedback effects between policy interventions and water risks is context-specific and challenging because decision-makers “may not have the requisite scientific knowledge of system components or awareness of outcomes from similar actions in different locations” (Wyroll et al. 2018, 559). In their research on inland fisheries, Song et al. (2018) note that lower spatial scale events/situations can affect higher level processes, although they do not explore this direction of influence in detail and instead focus on the vertical influence of drivers such as climate change and globalization acting downward to affect resource sustainability. Similarly, SES research has identified bidirectional relationships between governance and other drivers across spatial scales (Nayak and Berkes 2014, Nayak and Armitage 2018). However, additional work is necessary to understand these relationships, especially driver influence that moves from smaller to larger scales (Nayak and Armitage 2018).

In the western Lake Erie basin, water governance clearly affects drivers of eutrophication by shaping nutrient management efforts (positively or negatively). For example, inappropriate land use policy was identified by Canadian policy Delphi participants as a driver of eutrophication itself and lack of funding was identified as a challenge affecting nutrient management efforts. The influence also moves in the other direction. My results demonstrated that drivers affect water governance because water governance will need to adapt as an SES changes or as knowledge of a SES improves (in terms of identifying drivers). For example, failures to understand, quantify, and/or manage legacy phosphorous as a driver of eutrophication will mean less effective nutrient management efforts. In addition, ongoing efforts to understand legacy phosphorous will require changes to water governance in the western Lake Erie basin as information becomes available about sources and potential mechanisms to account for it. The data also provided evidence that these interactions between drivers and water governance extend across spatial scales (e.g., climate change is a global level issue with impacts felt at the local level), jurisdictional scales (e.g., multiple government agencies coordinating nutrient management efforts), and temporal scales (e.g., past impacts from nutrient management efforts and uncertainties about climate change impacts in the future). Together, the research demonstrated that there are bidirectional relationships between drivers and water governance and that this influence exists across multiple scales and levels. Therefore, the research provides evidence on driver interactions that contribute to the SES and water governance literatures. For example, by providing evidence that water governance and drivers of eutrophication in the western Lake Erie basin are affecting each other, the results support the argument made by Cole, Epstein, and McGinnis (2019) that work exploring the relationships between policy responses and environmental problems is valuable.

5.3.2 Recommendations for Practice

In addition to this research's contribution to academic scholarship, there were also contributions to the practice of water governance. By identifying drivers and assessing whether nutrient management efforts in the western Lake Erie basin take those drivers into account, the research identified opportunities to improve nutrient management efforts and water quality outcomes. The findings provide some reassurance that current efforts to reduce nutrient loading and mitigate eutrophication in the western Lake Erie basin are identifying and taking into account many drivers of eutrophication. However, the limitations of nutrient management efforts were also exposed in the nuance and depth provided by the research results. Quantifying the overlap between the US and Canadian case studies, as well as between data sources within each case study, revealed differences in how eutrophication and its causes are perceived. These differences question the depth of binational cooperation in developing shared problem framings as well as the effectiveness of nutrient management efforts. For example, neither US nor Canadian survey participants identified drivers ranging from animal waste to synergies between drivers, while both the US and Canadian document analyses did not identify water governance as a driver of eutrophication. Options to address these differences and improve nutrient management efforts include strengthening shared framings of eutrophication, such as the identification of drivers. Existing governance actors such as the International Joint Commission and binational agreements such as the 2015 Western Basin of Lake Erie Collaborative Agreement between the Governors of Ohio and Michigan and the Premier of Ontario are two examples of how the existing water governance system could be leveraged to reduce differences in the drivers of eutrophication that are identified in nutrient management efforts.

When assessing nutrient management efforts, similarities and differences were also observed within and between the US and Canadian case studies. These have implications for practitioners. Research (e.g., Sekaluvu, Zhang, and Gitau 2018) and progress reports (International Joint Commission 2017a) have both observed that water management efforts to manage nutrient loading to the western Lake Erie basin require improvements to achieve water quality objectives. My research contributes to these discussions and provides a possible explanation for the persistence of eutrophication in the face of decades of cooperative nutrient management efforts. I argue that observable differences between the US and Canadian case studies reveal gaps in nutrient management efforts that may be contributing to persistent eutrophication in the western Lake Erie basin. For example, although nutrient management documents acknowledged that drivers of eutrophication can interact with each other to affect nutrient loading and algal growth, beyond commitments to undertake research on driver synergies in the Canada-Ontario Action Plan (Environment and Climate Change Canada and Ontario Ministry of the Environment and Climate Change 2018), I did not observe any explicit actions to manage these synergies in nutrient management efforts. Further, results from the Canadian and US policy Delphi surveys provided evidence that existing nutrient management efforts for drivers of eutrophication, including climate change, may be insufficient to achieve the nutrient loading targets established binationally by Canada and the US. Developing and applying criteria to measure nutrient management effectiveness, potentially in the US and Canadian domestic action plans, are one example of how to identify areas of weakness as well as opportunities for improvement in nutrient management efforts. Another example would be for water governance actors to use domestic action plans to establish priorities and guidance for how to address synergies between drivers.

Overall, these results have implications for nutrient management efforts in the western Lake Erie basin specifically, and the Lake Erie basin more broadly. Differences in the drivers of eutrophication that were identified by different documents and policy Delphi participants suggest diverging perspectives on the causes of eutrophication that are likely to affect the scope of nutrient management efforts. Drivers that are not taken into account or not taken into account sufficiently also reveal potentially significant differences between the US and Canadian governance regimes and contexts. Insufficient nutrient management efforts indicate that nutrient management efforts may be ineffective at resolving eutrophication and achieving water quality objectives. Therefore, my research identifies areas where water governance actors and nutrient management practitioners should assess existing problem definitions of eutrophication and the associated effectiveness of water policies for nutrient management to improve water quality outcomes in Lake Erie and achieve the binationally established nutrient loading targets. Specifically, I recommend that decision-makers and experts participating in nutrient management in the western Lake Erie basin examine existing problem definitions in the context of this research to determine whether and to what extent additional drivers should be incorporated into nutrient management efforts. Existing transboundary agreements such as the 2012 Great Lakes Water Quality Agreement, as well as the 2018 Canada-Ontario Agreement within Canada, provide the foundation that these recommendations build upon. Since these relationships already exist, identifying and characterizing drivers of eutrophication, as well as developing strategies to account for these drivers, that are shared between the two countries is more straightforward than other contexts where this level of cooperation and collaboration may not exist.

5.3.3 Limitations and Ideas for Future Research

5.3.3.1 Limitations of the Research

One of the limitations of this research relates to research design constraints. During the recruitment of policy Delphi participants, one of the main limitations was that I did not have a more diverse group of participants. Specifically, almost half of the Canadian and US policy Delphi participants were from the federal, state, and/or provincial government agencies. Within the Canadian case study, perspectives that were represented included government agencies, university researchers, non-governmental organizations, conservation authorities, and members of the agricultural sector. Perspectives from the private sector and First Nations governments are absent from the research. Within the US case study, participants included government agencies, non-governmental organization staff, private sector actors, and university researchers. Agricultural actors and tribal governments are missing from the research. For the non-government agency agricultural actors (e.g., The Andersons Inc.), these perspectives are absent from the data because I did not receive responses from those actors during participant recruitment. For First Nations governments in Canada and tribal governments in the US, these perspectives are not represented because of the lens that I applied to my research, and the subsequent methods I used to identify potential policy Delphi participants.

I approached the research with the purpose of identifying drivers of eutrophication and assessing nutrient management efforts in the western Lake Erie basin using a water governance lens. In designing the US and Canadian policy Delphi surveys, I applied the lens of water governance shaping nutrient management efforts, which informed how I identified participants. Potential participants were identified during the completion of the document analysis. Given the scope of my research and the water governance lens I applied, the document analyses examined nutrient management documents such as action plans and assessments of progress. The authors of these reports were noted as potential participants given their evident expertise and participation in nutrient management efforts in the western Lake Erie basin. Similarly, academic researchers were identified by noting authors of journal articles on eutrophication and water governance in Lake Erie.

In reflecting the existing composition of nutrient management researchers and practitioners and the water governance actors participating in nutrient management, I did not identify or recruit all potential participants. The purpose of this research was not to have a complete representation of all possible perspectives on eutrophication in the western basin. Instead, the purpose was to draw on the knowledge of experts to identify drivers and assess nutrient management efforts. Other lenses have been applied to conduct research in the basin, such as discourse analysis which used media documents as a data source (e.g., Isaac and de Loë 2020). Other lenses or disciplinary perspectives exist and could be applied to the western Lake Erie basin, which would identify and include other actors and perspectives than those represented in my research.

Another limitation of this research relates to data analysis. In analyzing the Canadian and US policy Delphi survey and document analyses, I did not distinguish between the multiple, potentially diverging, perspectives that likely exist within each case study given the range of policy Delphi participants and types of documents included in the data analyses. Data was grouped and presented by their case study of origin. For example, within the Canadian case study I did not analyze whether perspectives on drivers of eutrophication differed between Conservation Authority staff and federal government staff, although it is likely that there are some differences. Instead, the focus of the analysis was to compare the Canadian and US case studies and to compare expert opinion with formal nutrient management documents.

5.3.3.2 Opportunities for Future Research

Considering the research limitations discussed above, I see five areas where future research on eutrophication in Lake Erie could be beneficial. First, I believe there is an opportunity to explore whether the actors absent from this case study bring new insights to the question of identifying drivers of eutrophication and assessing nutrient management efforts. For example, it is likely that actors from the private sector have unique perspectives on the causes of and solutions to eutrophication in the western Lake Erie basin that would add value to both the scholarship and practice of nutrient management. Actors in the western Lake Erie basin that are affected by eutrophication, including recreational and commercial fishers, local communities, cottagers’ associations, and municipal governments, would also provide valuable and unique perspectives on drivers that did not emerge from this research. Additionally, distinguishing between participant types (e.g., private sector, state government) in the policy Delphi survey analysis and sources of nutrient management documents in the document analyses would likely provide a more comprehensive perspective on drivers and nutrient management efforts.

Second, this research was a case study of the western Lake Erie basin. Lake Erie has three distinct basins: western, central, and eastern. Harmful algal blooms in the western basin, hypoxia in the central basin, and large shoreline blooms of nuisance algae in the eastern basin resulting from the eutrophication of Lake Erie (International Joint Commission 2014) present unique challenges for improving water quality through nutrient management. Identifying drivers of eutrophication within all three of these basins, as well as assessing whether and to what extent (and with what adequacy) those drivers of eutrophication are taken into account by nutrient management efforts, would be a useful exercise to understand differences and areas of overlap both within the individual basins, and across the whole of Lake Erie. Assessing drivers of eutrophication and nutrient management to compare the US and Canadian portions of each basin as well as the entire Lake Erie basin could be a useful area of future work to determine the strength of existing binational water governance in the Great Lakes.

Third, additional efforts to identify and characterize drivers would contribute to ongoing discussions on drivers in the water governance and SES literatures, including identifying the most important drivers in specific contexts (Räsänen et al. 2017). The document analyses and policy Delphi surveys in both the US and Canadian case studies generated a wealth of data that could not be discussed in this thesis given the space constraints of the manuscripts. Therefore, future research that would explore these drivers of eutrophication in greater detail would be beneficial to both the practice and the theory of water governance broadly, and nutrient management in the Lake Erie basin specifically. For example, the role of biofuels and renewable energy policies in driving the use of phosphorous has been identified in the academic literature (e.g., Jarvie et al. 2015). Although the impact of trade and fuel policies on agricultural practices did emerge from the data, they were not a key driver of eutrophication using participant engagement as an indicator of perceived importance and were therefore not discussed in this research. Exploring the drivers of eutrophication that could not be discussed in this research due to time and resource constraints represents a valuable topic for future work. A more in-depth exploration of drivers of eutrophication at a regional scale, such as the other Lake Erie basins, could identify and map out the multiple ways in which each individual driver affects nutrient loading and/or algal growth, as well as assessing how drivers interact with each other to create synergies. Identifying these mechanisms of action and the interactions between drivers could improve understandings of what causes eutrophication and how nutrient management efforts can be structured to reduce nutrient loading and improve water quality in Lake Erie. More detailed characterizations of drivers would also create a more nuanced treatment of drivers, potentially allowing for the development of a driver typology, or a critical examination of existing ones, that could also map out the synergies that exist between drivers. These findings could also be used to inform research on eutrophication in other freshwater bodies globally. Further, detailed explorations of drivers and their influence could also extend discussions in the SES literature on frameworks to identify the factors affecting action situations and propose natural resource management solutions, through in-depth empirical assessments that would provide greater nuance and context-specific understandings of SESs.

Fourth, the issue of sufficiency in nutrient management efforts represents an area where future work could provide valuable insight for practitioners. There were several drivers (e.g., climate change) where nutrient management efforts are identified as ineffective, meaning that water quality objectives may not be achieved. Therefore, research to understand how to increase the effectiveness of nutrient management efforts would be beneficial for addressing eutrophication in the western Lake Erie basin specifically, the Lake Erie basin more broadly, and could also be applied to other nutrient management contexts. Additionally, future work could develop criteria to measure the effectiveness of nutrient management efforts.

A fifth opportunity for future research is to explore why these areas of disagreement exist between Canadian and US expert views on nutrient management efforts. My research identified areas of overlap and disagreement between the Canadian and US case studies, but I did not explore why they exist. Future work could use interviews to assess these differences in depth. There are also opportunities to take the results of the individual US and Canadian policy Delphi surveys and conduct a policy Delphi survey with a mix of Canadian and US participants to explore why perspectives on drivers and nutrient management efforts can diverge between the two case studies. Developing an understanding of why these differences exist could improve efforts to address these differences and inform nutrient management efforts.

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Appendix: Research Instruments

A. Policy Delphi Survey Information Letter

This letter provides background information about a study I am conducting as part of my PhD in the School of Environment, Resources & Sustainability at the University of Waterloo, Ontario, Canada under the supervision of Professor Rob de Loë. I would like to provide you with more information about this project and what your involvement would entail if you decide to take part.

Around the world, solutions to water problems remain elusive despite decades of effort and attention. This may be because decision-makers are not aware of key drivers that affect their decisions. At the same time, there is little guidance about how to identify and account for such key drivers in water governance. Although the range of drivers is vast, understanding the drivers that affect water governance can lead to new insights and ideas for tackling water governance problems.

The purpose of this study is to identify drivers affecting nutrient management in the western Lake Erie basin, and then to recommend how those drivers can be handled in our decision making. The study will identify and evaluate the importance of key drivers in water governance in the western Lake Erie basin. As a person involved in, or knowledgeable about, the decisions made in the western Lake Erie basin regarding nutrient management, I would like to get your perspective on water governance in the area.

Participation in this study is voluntary. It will involve two rounds of surveys through an online survey platform regarding your knowledge of decision-making in the western Lake Erie basin for nutrient management. You may decline to answer any of the survey questions if you wish. Furthermore, you may withdraw from this study at any time prior to publication without any negative consequences simply by letting me know. From beginning to end, the two rounds of the survey will take approximately two months. This time frame includes survey completion, analysis, and distribution. The first round of the survey will take no more than 30 minutes to complete. The second round of the survey will be longer and could take an hour or more to complete. You will have ten days to complete the first round of the survey, and two to three weeks to complete the second round of the survey. Approximately two weeks after you submit the first round of the survey, I will send you a second survey, including copies of the answers from the first survey as an appendix to give you an opportunity to confirm the accuracy of my interpretation of the answers and to add or clarify any points that you wish. The second survey will be based on anonymized responses from the first round. If you participate in the study, I will ask you to indicate whether or not I can use quotations from the survey (with or without attribution as you prefer). If you give me permission to use quotations, I will include any I would like to use in publications in the survey summary for you to review. When the research is complete, I would be pleased to send you a summary of the findings.

You will be completing the study by an online survey operated by Qualtrics. When information is transmitted or stored on the internet privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). Qualtrics will be collecting your name and email address in order to send you a unique link inviting you to complete the survey.

I will be publishing my findings in a thesis, in journal articles, and in conference presentations. Your employment sector and state or province in which you work will not appear in any thesis or report resulting from this study without your permission. However, because the case study under investigation is relatively small, it may be possible for someone familiar with the case study to identify you without identifying information. Data collected during this study will be retained for at least seven years on secured computers at the University of Waterloo. Only researchers directly associated with this project will have access to the data. There are no known or anticipated risks to you as a participant in this study.

If you have any questions regarding this study or would like additional information to assist you in reaching a decision about participation, please contact me. You can also contact my supervisor, Professor Rob de Loë.

I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE #40462). If you have questions for the Committee contact the Office of Research Ethics.

I hope that the results of my study will be of benefit to those organizations directly involved in the study, other organizations not directly involved in the study, the broader Great Lakes public and policy community, as well as to the broader research community.

I very much look forward to speaking with you and thank you in advance for your assistance in this project.

B. Policy Delphi Survey Questions Round 1

In North America, Lake Erie has been a long-standing focus of concern for water quality. Through coordinated nutrient management efforts, the United States and Canada successfully addressed algal blooms in the 1960s and 1970s. Unfortunately, the problem of algae blooms (including harmful algal blooms and their associated potential to negatively impact human health) has returned since the 2000s.

I am conducting a two-round survey of nutrient management practitioners, researchers and other people with expertise in nutrients and water management. The purpose of this first-round survey is to identify key drivers affecting eutrophication in the western Lake Erie Basin. Suggestions from the first round are then synthesized and returned to the survey participants in the second round for evaluation. Through this process, we will identify internal and external drivers affecting nutrient management efforts in the western basin of Lake Erie.

Important definitions:

Water governance: Water governance is a process of decision-making that includes the interactions of state and non-state actors, and builds on government rules, to address water problems (Lautze, de Silva, Giordano, & Sanford, 2011; Schulz, Martin-Ortega, Glenk, & Ioris, 2017; Tortajada, 2010).

Drivers: A driver is defined as any factor that affects a system directly or indirectly (Nayak & Berkes, 2014). This can include environmental factors, actors, and institutions. Actors can be individuals or organizations whose actions affect the system de Loë and Patterson (2017, p. 84). Institutions include legislation, social norms, and other rules that guide human decisions (Young, 2008, p. 115). Some drivers are internal to the system in question, while others may be thought of as external because they are not normally considered by the people involved.

Governance system: A governance system is defined as a combination of the institutions and actors that inform how governance is structured and the processes through which governance occurs (Pahl-Wostl, Lebel, Knieper, & Nikitina, 2012).

Survey Questions

1. What drivers are currently influencing eutrophication in the western Lake Erie basin?
2. What drivers of eutrophication are likely to be most important in the future?
3. Do you think all the relevant drivers that affect eutrophication in the western Lake Erie basin are accounted for in existing nutrient management efforts by Canada and the United States? Why or why not?
4. What drivers are accounted for? How are they accounted for in nutrient management efforts? Please provide examples.
5. What drivers are not accounted for in nutrient management efforts, but you think should be? Please provide examples.

Sources for Definitions:

de Loë, R. C., & Patterson, J. J. (2017). Rethinking water governance: moving beyond water-centric perspectives in a connected and changing world. Natural Resources Journal, 57(1), 75-99.

Lautze, J., de Silva, S., Giordano, M., & Sanford, L. (2011). Putting the cart before the horse: water governance and IWRM. Natural Resources Forum, 35, 1-8.

Nayak, P. K., & Berkes, F. (2014). Linking global drivers with local and regional change: a social-ecological system approach in Chilika Lagoon, Bay of Bengal. Regional Environmental Change, 14(6), 2067-2078.

Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: toward adaptive water governance in river basins. Environmental Science and Policy, 23, 24-34.

Schulz, C., Martin-Ortega, J., Glenk, K., & Ioris, A. A. R. (2017). The value base of water governance: A multi-disciplinary perspective. Ecological Economics, 131(2017), 241-249. doi:http://dx.doi.org/10.1016/j.ecolecon.2016.09.009

Tortajada, C. (2010). Water governance: some critical issues. International Journal of Water Resources Development, 26(2), 297-307.

Young, O. R. (2008). Building regimes for socioecological systems: institutional diagnostics. In O. R. Young, L. A. King, & H. Schroeder (Eds.), Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers (pp. 115-144). Cambridge, Massachusetts: MIT Press.

C. Policy Delphi Survey Questions Round 2 (Introductory Text)

I analyzed all of the ideas from the first survey, searching for similarities and differences. I combined the ones that were basically the same and preserved all the unique ones. This means that every idea from the first survey round is captured here.

In this round, I would like you to rate your level of agreement with the drivers suggested in the first survey round. You'll use a four-point scale to rate your agreement with the suggested external drivers in terms of affecting nutrient management efforts. I also need you to provide a brief rationale for your rating. For example, if you "Strongly disagree" with an identified driver, I am asking you to briefly explain why. The anonymous "raw" responses from Round 1 are contained in the supplied Appendix. This survey page provides summarized and synthesized versions of the suggestions.

Important definitions:

Water governance: Water governance is a process of decision-making that includes the interactions of state and non-state actors, and builds on government rules, to address water problems (Lautze, de Silva, Giordano, & Sanford, 2011; Schulz, Martin-Ortega, Glenk, & Ioris, 2017; Tortajada, 2010).

Drivers: A driver is defined as any factor that affects a system directly or indirectly (Nayak & Berkes, 2014). This can include environmental factors, actors, and institutions. Actors can be individuals or organizations whose actions affect the system de Loë and Patterson (2017, p. 84). Institutions include legislation, social norms, and other rules that guide human decisions (Young, 2008, p. 115).

Governance system: A governance system is defined as a combination of the institutions and actors that inform how governance is structured and the processes through which governance occurs (Pahl-Wostl, Lebel, Knieper, & Nikitina, 2012).

Instructions:

For each of the following statements, indicate your level of agreement using the following four-point scale, and provide a brief rationale in the space provided that explains your rating. There is no "neutral" option; if you can't decide on a rating, or don't know, leave the response blank.

Rating Scale for Evaluation:

1. Strongly agree
2. Agree
3. Disagree
4. Strongly disagree

If you can't decide or don't know, leave the rating blank.

Thank you for completing the survey. Once all responses have been collected, I will prepare a summary report for participants that pulls together the findings and offers implications and recommendations.

Sources for Definitions:

de Loë, R. C., & Patterson, J. J. (2017). Rethinking water governance: moving beyond water-centric perspectives in a connected and changing world. Natural Resources Journal, 57(1), 75-99.

Lautze, J., de Silva, S., Giordano, M., & Sanford, L. (2011). Putting the cart before the horse: water governance and IWRM. Natural Resources Forum, 35, 1-8.

Nayak, P. K., & Berkes, F. (2014). Linking global drivers with local and regional change: a social-ecological system approach in Chilika Lagoon, Bay of Bengal. Regional Environmental Change, 14(6), 2067-2078.

Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: toward adaptive water governance in river basins. Environmental Science and Policy, 23, 24-34.

Schulz, C., Martin-Ortega, J., Glenk, K., & Ioris, A. A. R. (2017). The value base of water governance: A multi-disciplinary perspective. Ecological Economics, 131(2017), 241-249. doi:http://dx.doi.org/10.1016/j.ecolecon.2016.09.009

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