Adaptive Capacity for Eutrophication Governance of the Laurentian Great Lakes

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Abstract

The Great Lakes are the largest freshwater system in the world, holding 20% of the world's fresh water. Together, the watersheds of Lakes Superior, Michigan, Huron, Erie and Ontario are home to over 35million Americans and Canadians, a factor that leads to severe human related stress to the lakes' ecosystems. The eutrophication of Lake Erie is one manifestation of this anthropogenic stress. Nutrient enrichment in that lake arises from farming, sewage treatment plant discharges, airborne emissions and nutrient flows from paved surfaces. This paper examines the eutrophication of Lake Erie and shows that it is a "wicked problem" that can benefit from an adaptive governance approach. More specifically, it proposes a framework for assessing adaptive capacity and tests this framework through key informant interviews in a specific case study where adaptive capacity was displayed. The case study was eutrophication in Lake Erie, a system that went from severe eutrophication the 1960s to significant nutrient reduction and ecosystem restoration in the 1990s. Results of this analysis are used to identify gaps in adaptive capacity for current eutrophication governance of Lake Erie.

Introduction

Eutrophication refers to the nutrient over-enrichment of water bodies and is one manifestation of anthropogenic adverse impact on the environment worldwide (Smith, 2003). The interactive world map on the World Resources Institute Website (World Resources Institute, 2015) vividly showcases examples of eutrophic water bodies worldwide, including Lake Erie in Canada and the United States, the Susquehanna River in the United States, Lake Winnipeg in Canada and the Bohai Sea in China. Lake Erie has been subject to severe eutrophication in the 20th century, with excessive nutrient loading in the 1960s and 1970s. Indeed, it was primarily eutrophication that prompted the US and Canada to sign the Great Lakes Water Quality Agreement (GLWQA) in 1972, with stipulated nutrient loading reduction targets for the lake. These phosphorus (P) loadings were from both point (sewage treatment plants, industrial discharges) and non-point sources (agriculture, urban runoff), but measures in the GLWQA focused on point source reduction through phosphorus control technologies and regulations for phosphorus in detergents and sewage treatment effluents (DePinto et al., 1986). Whilst these measures were successful and resulted in P load reductions and the concomitant return of Lake Erie's resiliency (DePinto et al., 1986; Botts and Muldoon, 2005; Scavia et al., 2014), increases in hypoxia, beach closings and algal biomass since the mid-1990s are indications that Lake Erie has become eutrophic again (Bridgeman and Penamon, 2010; Burns et al, 2005; Michalak et al., 2013; Scavia et al., 2014). The term re-eutrophication has been used to describe this phenomenon (Culver and Conroy, 2012; Scavia et al., 2014).

While the causes of eutrophication of Lake Erie in the 1960s and 1970s seemed simple and could be linearly traced to P loadings, the current eutrophication of Lake Erie is highly complex and compounded by interacting stressors such as aquatic invasive species and climate change (Pennuto et al., 2014). The eutrophication of Lake Erie now displays the symptoms of a "wicked problem", where all the information is not known and the solution is not clear cut and is highly complex (Xiang, 2013). As such, a new model of governance is needed for the restoration of Lake Erie, a governance model that moves from the old command and control paradigm that worked well in a highly certain world, to one that embraces uncertainty. One such governance model is adaptive governance, as it is the facilitator of adaptive capacity that allows better response in an uncertain environment.

This paper introduces the concept of adaptive capacity and shows its relevance to eutrophication of Lake Erie. A framework for assessing adaptive capacity is developed and conceptualized by formulating determinants of adaptive capacity from the literature. These determinants are then validated through semi-structured interviews in a baseline case of Lake Erie, which went from severe nutrient enrichment in the 1970s to significant P reductions in the early 1990s. This paper argues that an analysis of these determinants can show the gaps in building adaptive capacity and can prove valuable in the implementation of actions for nutrient management and hence in the implementation of Annex 4 (Nutrients) under the Great Lakes Water Quality Protocol 2012.

Eutrophication of Lake Erie – Baseline Case

The Laurentian Great Lakes are the largest freshwater body on earth and comprise Lake Superior, Lake Michigan, Lake Huron, Lake Ontario and Lake Erie. All the Great Lakes are subject to a host of anthropogenic stressors, as illustrated in the land use pattern shown in Figure 6.1. Lake Erie is the least forested of all the Great Lakes and has the most intensive farmlands and urban areas. According to Environment Canada and USEPA (1995), 63% of Lake Erie watershed is being farmed while 84% of its shoreline is for residential uses, 35% is used for agriculture and 22% for commercial uses.

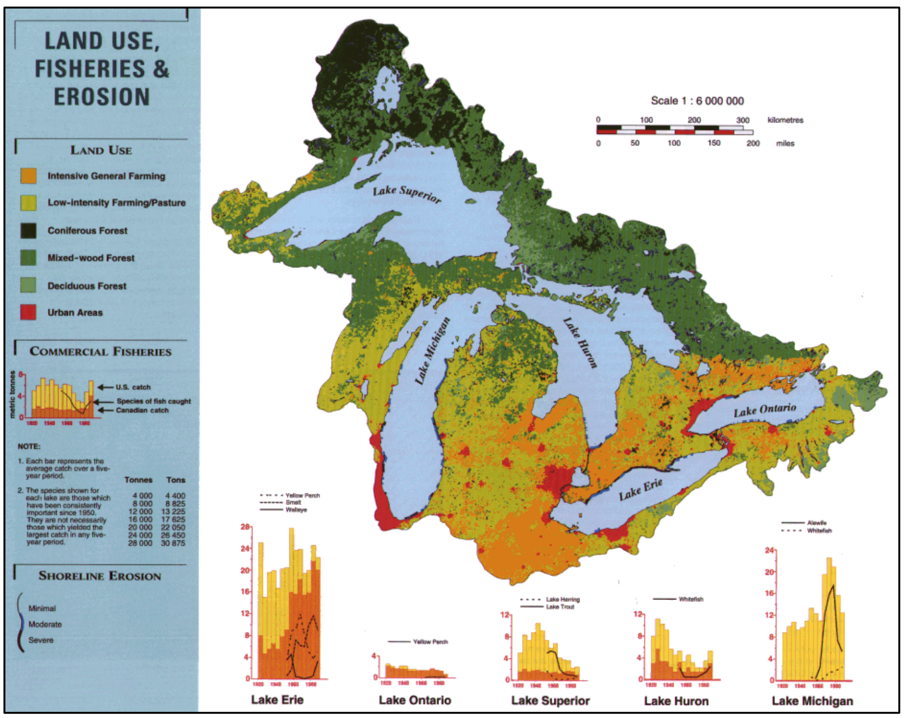


Figure 1 – Great Lakes Land Use (Botts and Krushelnicki, 1987)

This land use pattern means that, compared to the other Great Lakes, Lake Erie is subjected to the greatest assault from anthropogenic impacts such as pesticides, sediment and nutrients. The impact of excessive nutrients is particularly felt, as Lake Erie is the smallest and shallowest of the

Great Lakes. While Lake Erie has been subject to excessive nutrient loading from both nitrogen and phosphorus, scientists have found that phosphorus is the limiting nutrient in temperate lakes such as Lake Erie (Schindler, 2012; Scavia et al., 2014). During the 1960s and 1970s, phosphorus was heavily loaded into the lakes from sewage treatment plants, from detergents in washing liquids and from non-point sources, leading to the growth of algae which visibly contaminated the lakes and led to fish kills and taste and odor problems. The problem of eutrophication was one of the drivers that stimulated the governments of the United States (US) and Canada to sign an agreement to protect the quality of the waters of the Great Lakes, the Great Lakes Water Quality Agreement 1972 (Agreement), which has gone through several amendments leading up to the current 2012 protocol. The 1972 Agreement led to significant actions from the government directed at controlling point sources of pollution such as upgrading sewage treatment plants and regulating phosphorus in detergents. These actions led to the target Lake Erie phosphorus load of 11 000 metric tons per annum (MTA) being met, and resulted in eutrophication being reduced or eliminated (Michalak et al., 2013).

Notwithstanding these early improvements, it was evident by the harmful algal blooms (HAB) of 2011 that eutrophication has resurfaced since the 2000s and remains very much a current problem. Trends have shown that while point source P has decreased since the 1970s, non-point sources continue to be a problem (Figure 6.2). In the spring of 2011, heavy precipitation events, coupled with heavy loading of dissolved reactive phosphorus from agricultural runoff and warm temperatures, led to an extensive algal bloom of more than 5000km^2 (IJC, 2014). An analysis of this by a team of Great Lakes scientists found that HABs are linked to the uncertain weather pattern associated with climate change, and are caused as much by increased precipitation as by agricultural practices, weak lake circulation and dormancy of the lake (Michalak et al., 2013).

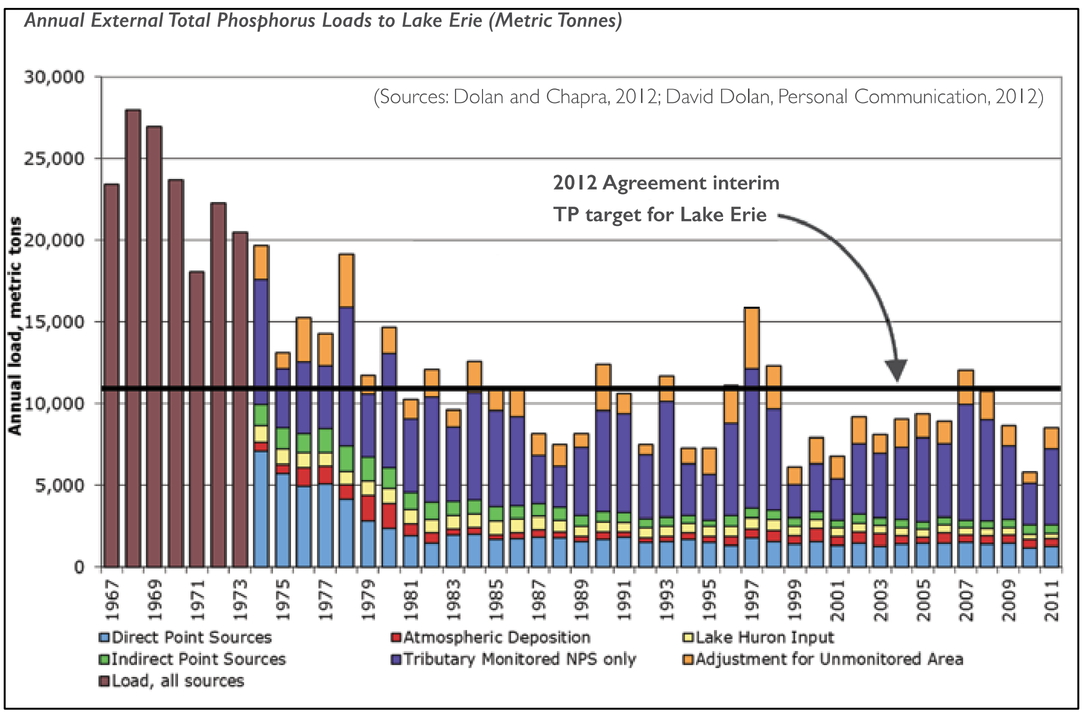
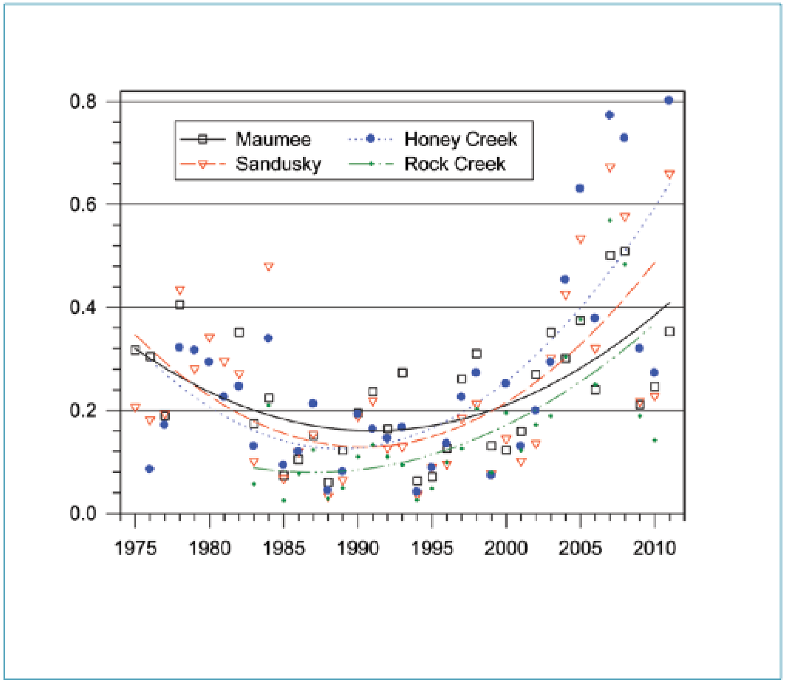


Figure 2– Total external phosphorous load in metric tons to Lake Erie (IJC, 2014)

This confluence of long term farm nutrient practices and intense and frequent precipitation are characteristic of changing climate and conditions that would become very prevalent in our changing world. This uncertainty makes building adaptive governance very important and hence the study of the determinants of adaptive capacity crucial to this dialogue of eutrophication governance. The framework of adaptive governance is needed to reduce input of nutrients under the uncertain climate conditions to prevent harmful algal blooms.

As Figure 6.2 illustrates, the total phosphorus input into Lake Erie has decreased since the 1960s, so it seems counterintuitive that algal blooms have increased. However, total phosphorus is made up of particulate and dissolved reactive phosphorus (DRP), the second of which is biologically very available and readily taken up by plants and algae, and is the most likely to support algae



blooms (Vanderploeg et al., 2009). Although total phosphorus has decreased, DRP from agricultural practices non-point sources has increased over the last 40 years (Figure 6.3), leading to increased algal bloom (Michalak et al., 2013).

Figure 3–Dissolved Reactive Phosphorous loads into Lake Erie (IJC, 2014)

It might be expected that reduction in nutrient inputs would lead to proportional decrease in eutrophication, but this is not the case: evidence that eutrophication is indeed a wicked problem. Reductions in nutrient loading alone may not decrease eutrophication proportionally, because of the significant impact of meteorological factors, which are comparable to human induced nutrient loading in accounting for harmful algal bloom extent and oxygen depletion (Michalak et al., 2013). Solutions for the eutrophication of Lake Erie are therefore not obvious or straightforward, reinforcing the need for an adaptive, responsive governance regime.

Water Governance

What are some of the guidelines for governing the nearshore areas in this increasingly uncertain environment of eutrophication? Given the complex interactions of climate change, aquatic invasive species and nutrient loading, what factors can aid stakeholders in the reversals of eutrophication of Lake Erie? These are questions of governance, more specifically water governance. Water governance can also be seen as one arm of environmental governance, which deals with natural resource governance and describes the collection of norms, rules and laws and organizations that determine the use and protection of natural resources (Lemos and Agrawal, 2006).

It is necessary to take a look at governance in general before diving into the governance of water. There are organizations such as the World Bank that still conceptualize governance in a top down command and control paradigm, The World Bank defines governance as the "process by which authority is conferred on rulers, by which they make the rules, and by which those rules are enforced and modified" (World Bank, 2014). This is in stark contrast to the more participatory approach as defined by the Institute on Governance (Institute on Governance, 2014) as follows "Governance determines who has power, who makes decisions, how other players make their voices heard and how account is rendered". The inclusion of voices in the decision making process is a more recent practice, and represents a shift to the more inclusive and participatory rather than the more traditional controlling rule of government.

All these definitions of water governance illustrate that different disciplines conceptualize water governance in different ways based on their reality of water governance systems. There is one clear consensus emerging from the literature, however: traditional governance approaches characterized by the 'command and control' model and fragmented institutions and regulations can no longer maintain the resilience of complexly linked socio-ecological systems as such approaches seek to reduce uncertainty inherent in these systems rather than embrace it (Dietz et al., 2003, Gleick, 2003, Pahl-Wostl, 2009). Traditional models of governance treat each natural resource problem discretely, oblivious to the coincident or parallel effects of complex socio-ecological systems that are plagued by wicked problems, such as climate change or eutrophication of Lake Erie, with no clear or linear solution (Folke et al.,2005). For the governance of eutrophication in the Great Lakes, there are many federal and state, provincial agencies that operate as sectorial siloes, working independently of the local municipalities and stakeholders. The command and control paradigm is evident in the operations of these Great Lakes Institutions.

Disenchantment with traditional forms of water governance has led to the emergence of new paradigms for managing uncertainty in complex socio-ecological systems; models that are more inclusive and adaptive to change. Key terms emerging from this discourse include vulnerability, resilience, adaptive capacity and adaptive governance. These discourses are more suited to a complex problem like eutrophication of Lake Erie as they hold the promise of increased collaboration among local, regional and governmental actors. The local nature of the problem of eutrophication means that communities in the nearshore areas can play a significant role in generating workable solutions. These discourses propose loose networks of actors and institutions at many levels, sharing resources and information as an alternative to the top down command and control paradigm.

Authors such as Lemos and Agrawal (2006) consider these new governance models better as they facilitate integration and transmission of local, scientific and technological knowledge expeditiously and are operationalized in a flexible and redundant manner among multiple actors who work across scales to develop cooperation and synergy to solve common problems. These models are especially relevant to the problem of eutrophication in the nearshore areas of the Great Lakes as they promote social learning and compromise seeking, which are especially relevant for the multiplicity of actors at the local, regional and federal level with a stake in nearshore governance. According to Lemos and Agrawal (2006), these new governance models also recognize that the relationship between international regimes and non-state actors is crucial for economic and legal arrangements, factors that are particularly relevant for eutrophication governance of the Great Lakes. However, one of the limitations of these new models is that they may fail to limit the negative externalities associated with implementation deficits (Lemos and Agrawal, 2006), an issue that is especially relevant to the eutrophication in the nearshore areas of the Great Lakes. While the Great Lakes Water Quality Protocol 2012 contains an entire Annex (4) devoted to nutrients, Lake Erie's ever-changing ecosystem has responded poorly to the linear implementation focus of the past Agreement, which may indeed have exacerbated the problems.

Changing Governance Lens – Social Ecological Systems

Water governance can simply be seen as the chain that links humans and water bodies. Humans make decisions to govern water bodies, decisions that impact the water body, decision makers, and other stakeholders. Berkes and Folkes (1998) have coined the term Social Ecological Systems (SES) to formally link the processes between humans and the environment and the feedback systems between them. As conceptualized by these authors, SES assumes that resource management is necessary, not just in a practical sense to target a maximum sustained yield, but also to target the social institutions that influence the resource. They argue that the management of an ecosystem requires equal emphasis on the resource and the social institutions impacting the resource. This concept of SES is a useful framing of the complex interactions between the human systems that impact the water body and the water body itself in a complete, unified whole, and is thus useful in advancing the dialogue on eutrophication governance.
The literature on SES governance homes in on the primacy of informal, self-organizing and non-institutional forms of governance that are driven by collaboration at various scales and that emerge to more closely match governance to the scale of the environmental problem at hand (Brunner et al, 2005; Scholz and Stiftel, 2005; Ostrom 2007; Ostrom 2009). One such informal collaboration in the Great Lakes was Great Lakes United, a group that emerged out of frustration with the apparent inability of governments to deal with problems of the Great Lakes. The emergence of Great Lakes United resulted in a gradual shifting of power from bureaucratic federal and state top down decision making to a sense of Great Lakes Community, where there were more locally driven networks of individuals and communities united around Great Lakes issues (Botts and Muldoon, 2005). This in a sense was the start of the transition to the more inclusive governance that is characteristic of adaptive governance.

Adaptive Governance

The term "adaptive governance" can be found in the business literature as early as 1997, in a paper on loyalty in the supply chain, looking at how buyers adaptively shift the weight from loyalty and profitability to an emphasis on loyalty in the network interacting with suppliers (Klos and Nooteboom, 1997). The term was coined in the aforementioned paper in 1997 but its use in the environmental context can be traced to a 2003 publication by Dietz, Ostrom and Stern. These authors made mention of the term once in the body of the work but went on distinguish its difference to adaptive management as adaptive governance

> "conveys the difficulty of control, the need to proceed in the face of substantial uncertainty and the importance of dealing with diversity and reconciling conflict among people and groups who differ in values, interests, perspectives, power and the kinds of information they bring to situations" (Dietz, Ostrom and Stern, 2003, p1911).

This original conceptualization of adaptive governance in the context of governing the commons (the environment) described a flexible, multi-scalar, adaptive system for governing human and natural systems (in effect SES) in a highly uncertain, changing environment where knowledge of the system can be wrong or incomplete (Dietz et al, 2003). Environmental application of the concept of adaptive governance can also be traced to two other schools of thought: literature on collaborations for environmental governance by political scientists (Brunner et al, 2005; Gunderson et al, 1995); and resiliency literature (Holling, 1973, Walker et al, 2004, Berkes et al, 2003. Folke et al, 2006). Scholars from political science have advocated for adaptive governance that integrates scientific and other types of knowledge into policies that advance open decision making structures, recognition of diverse viewpoints, the role of non traditional science, and community based efforts (Brunner et al, 2005; Gunderson et al, 1995). This local scale participation in adaptive governance was further advanced by literature on the conservation movement in the developed world, putting an emphasis on context and consensus building (Wondollect and Yaffee, 2000; Brunner et al, 2005). Similar views are expressed in the resiliency literature, in which there are many definitions of adaptive governance that address the paradigm shift from traditional government controlled static institutions with clear boundaries to the view of institutions as dynamic, flexible, pluralistic and adaptive to cope with the limits of predictability inherent in future climatic conditions (Berkes and Folke, 1998; Carpenter and Gunderson, 2001; Pahl-Wostl, 2007b).

It is clear across the literature that adaptive governance is seen as the facilitator of adaptive capacity. The corollary is that the adaptive capacity of institutions and communities can be increased through governance and policy approaches that are more flexible, participatory, experimental, and designed for learning, because these approaches contribute to building social-ecological systems resiliency under uncertainty. Adaptive governance systems facilitate these participatory approaches as under this paradigm, "systems self organize as social networks with teams and actor groups that draw on various knowledge systems and experiences for the development of a common understanding and policies" (Folke et al, 2005). Though experimental and flexible, adaptive governance systems are not ad hoc but respond to and shape ecosystem dynamics and change in an informed manner that acknowledges our dependence on the biosphere (Westley et al., 2011).

Despite the many discussions and interpretations of adaptive governance in the literature, there is little empirical evidence of successful implementation. According to the Stockholm Resiliency Centre (2014), adaptive governance is still an "***evolving*** research framework for analyzing the social, institutional, economical and ecological foundations of multilevel governance modes that are successful in building resilience for vast challenges posed by global change, and coupled complex adaptive SES" (author emphasis added). Medema et al. (2008) have noted that adaptive governance is an emerging field with teething problems in implementation, in real world applicability and political pitfalls characteristic of adaptive theories. Some of the real or perceived pitfalls of adaptive approaches include the high cost of information gathering and monitoring, resistance from key players who fear increased transparency, political risk due to uncertainty of future benefits, difficulties in acquiring stable funding for experiments and the fear of failure (Lee, 1999).

Within the adaptive theories literature, "adaptive governance" and "adaptive capacity" are often used interchangeably, with no clear distinction between the two. In fact, the two terms are very closely connected, as adaptive governance can be seen as the means of building adaptive capacity. Much of the literature has focused on governance for adaptive capacity in the context of climate change (Pahl-Wostl et al., 2007; IPCC 2007; Huitema et al., 2009). One of the central goals of the current research is to demonstrate the applicability of adaptive governance to other stressors, in this case eutrophication. Eutrophication governance fits neatly in this research theme as eutrophication in the Great Lakes is compounded by climate change and invasive species and as such, it has many parallels with models for climate governance, with similar uncertainties and complexities. This paper also aims to answer two other important knowledge gaps: the most important factors in adaptive governance that can lead to more resilient real world outcomes; and the most effective ways of governing for adaptive capacity in addressing stressors on large-scale ecosystems such as the Great Lakes.

Adaptive Capacity

Water governance is inextricably linked to adaptive capacity, a key factor in the resiliency of ecosystems. According to Kashyap (2004), water governance is the ability to develop adaptive capacity, where adaptive capacity is defined as the "the ability or potential of a system to respond successfully to climate variability and change" (IPCC, 2007). There are four general factors that build adaptive capacity in social-ecological systems (Folke et al., 2002): i. learning to live with change and uncertainty; ii. nurturing diversity for resilience; iii. combining different types of knowledge for learning; and iv. creating opportunity for self-organization toward social-ecological sustainability. According to Dietz et al. (2003), governance that facilitates these principles would involve many mechanisms for coordination and multiple decision-making centers.
In addition to governance, the IPCC (2001), as reported in Yohe and Tol (2002) has an extensive list of system-, sector and location-, and governance-specific determinants of adaptive capacity, as follows:

1. The range of available technological options for adaptation,
2. The availability of resources and their distribution across the population,
3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed,
4. The stock of human capital including education and personal security,
5. The stock of social capital including the definition of property rights,
6. The system's access to risk spreading processes,
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and
8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

Of these determinants, the third, about the structure of critical institutions and decision making authority, has received widespread attention in the literature as being crucial for adaptive capacity. Authors such as Pahl-Wostl et al. (2007a) and Olsson et al. (2004a) argue that building this kind of adaptive capacity in institutions requires flexibility and approaches that embrace experimentation and learning by doing. One such approach is the concept of adaptive governance, which has arisen from the failure among current approaches and the increased vulnerability of SES (Olsson et al, 2006).

Adaptive Capacity for Eutrophication Governance

This work is the first to advance the concept of adaptive capacity for eutrophication governance. This concept is useful for eutrophication governance as it has the potential to shift the dialogue from 'firefighting' or preventing nutrient over-enrichment to looking at the factors necessary to build adaptive capacity for eutrophication governance of Lake Erie, in which the governance system has the ability to alter processes or act proactively to restore Lake Erie's resiliency. It is hypothesized here that adaptive capacity is uniquely positioned to move the Great Lakes ecosystem under the stressor of eutrophication from a state of vulnerability to a more resilient status. Eutrophication governance that leads to adaptive capacity must contribute to SES resilience through adaptive measures at different levels and scales.

It is argued here that the concept of adaptive capacity can be transferred to eutrophication for, like climate change, eutrophication in general, and the current eutrophication event of Lake Erie, have all the characteristics of a wicked problem. According to Xiang (2013), a wicked problem is a social system problem where information is conflicting, leading to an ill formulated problem and where vested parties disagree on norms and values and goals. Some of the characteristics of wicked problems include i. the problem and solutions are not clear cut; ii. the problem can be managed but not completely solved; and iii. there are conflicting values amongst stakeholder groups, which vary with time. Due to the compounding and complex interacting impacts of aquatic invasive species, climate change, nutrient loading and multiple level interactions of fragmented institutions, the eutrophication of Lake Erie is a wicked problem that needs novel governance solutions. Given Michalak et al.'s (2013) view that the impact of climate change on eutrophication, HABs and hypoxia is comparable to that of phosphorus loading in Lake Erie, governance systems for eutrophication must address not only phosphorus loadings but also the complexity of extreme weather events and a changing climate. Such a governance system must be flexible, able to deal with complex interacting stressors, and able to adjust to uncertainties and changes. This paper argues that one such approach is the building of adaptive capacity for eutrophication governance.

Governing for adaptive capacity-enabling factors

Recognizing the difficulty of translating governance for adaptive capacity into real world applications, a number of studies have attempted to operationalize the concept through attributes, determinants, dimensions or factors for governing for adaptive capacity (Dietz et al, 2003; Huitema et al., 2009; Huntjens et al. 2011; Pahl-Wostl et al., 2012). The identification and nurturing of characteristics of SESs that will increase adaptive capacity and resilience of the system to uncertainty by transforming to a better state is of importance to decision makers (Engle and Lemos, 2010). Further, the governance determinants of adaptive capacity play an important role in defining the ability of SESs to prepare for and respond to stress (Yohe and Tol, 2002). The earliest determinants of adaptive capacity were associated with adapting to climate change. The associated literature is extensive, with many discussions on determinants for climate-induced stressors.

The broad determinants that contribute to adaptive capacity (IPCC, 2001) have paved the way for more discussion of a more detailed range of determinants in the literature (Yohe and Tol, 2002; Folke et al., 2005; Engle and Lemos, 2010; Engle et al., 2011; Pahl-Wostl et al., 2012). These determinants have varied depending on the thematic area of focus, with most being developed in the context of adaptation to climate change. There are no determinants for adaptive capacity in the literature as applied to stressors such as eutrophication. As such, much more empirical studies are needed in order to create a robust analytical framework to identify, measure and sustain the components of adaptive capacity. This will aid decision makers who are interested in identifying and nurturing system characteristics that will build resilience and adaptive capacity (Engle and Lemos, 2010).

While the past may not be a good predictor of the future in a highly uncertain environment, institutions can use experience from the past to inform responses to present and future challenges (Huntjens et al., 2011). The literature has identified such learning as being essential for coping with uncertainty and change (Folke et al., 2006; Pahl-Wostl, 2007a). This study builds on that thinking by studying the evolution of eutrophication and associated governance in Lake Erie from the 1960s to the 1990s.

Framework for Assessing Adaptive Capacity

Many determinants of adaptive governance are described in the literature. This study has grouped them according to those most relevant to the ***Great Lakes Water Quality Protocol 2012*** (the Protocol), as this can inform the implementation of actions as stipulated under the Protocol. This research proposes six categories of determinants of adaptive capacity that are based on a broad survey of the literature: **public participation, science, networks, leadership, flexibility and resources**. These determinants were carefully chosen based on relevance to the Great Lakes Water Quality Protocol 2012 and on the results of key informant interviews. Key informant interviews were useful in 'weeding out' determinants that were important in the theory but had no practical importance to eutrophication governance as identified by the experts (e.g., equity). They also revealed determinants that the researcher had eliminated as not directly applicable to the Great Lakes Water Quality Protocol 2012. The initial determinants as extracted from the literature were evaluated for their relevance to the Great Lakes Water Quality Protocol 2012 and to situate them in the context of the stressor of eutrophication. This process resulted in the elimination and merging of some determinants, and eventually led to the identification of six final categories: public participation, science, networks, leadership, flexibility and resources.

Table 1 presents the determinants of adaptive capacity and their basis in the literature. This study validated those determinants in a set of key informant interviews on a past eutrophication event in Lake Erie, where (because the system was able to deal with the stressor of eutrophication, as demonstrated by a reduction of phosphorus loading and resurgence of key ecosystems) it is assumed that adaptive capacity was realized. This validation was then complemented with data from key informant interviews conducted with experts who were active players in the Lake Erie eutrophication event from 1970s to 1990s. Conceptually, this combination of inductive (bottom-up) and deductive (top-down) approach enabled context-specific but transferable analysis, approaches that will be useful in scaling up this research.

The question of whether specific determinants such as leadership and resources are prerequisites for enabling adaptive capacity or outcomes of the presence of adaptive capacity is answered here by defining adaptive capacity such that the determinants are process indicators, rather than outcomes. As such, adaptive capacity is defined as "the ability of a resource governance process to first alter processes and if required convert structured elements as a response to experienced or expected changes in the societal or natural environment" (Pahl-Wostl, 2009) and not as "the ability of a system to adjust to climate change, to moderate potential damages to take advantage of opportunities and or cope with consequences" (Engle and Lemos, 2010). Following from the former definition, in the context of eutrophication, adaptive capacity is defined as the ability of the water body to first alter processes in response to nutrient enrichment, and if required convert structured elements as a response to experienced or expected changes in the societal or natural environment due to *eutrophication* (following from Pahl-Wostl, 2009).

The six determinants selected for this study are discussed in more detail in the next section.

Determinant	Description	Relevant Literature

Public Participation (D1)	Adaptive capacity will be built when there is participation of diverse, interested stakeholders to allow access to new modes of knowledge and stakeholder buy in to deal with the highly complex and uncertain environment of eutrophication. One challenge is determining which of the public is included and excluded for efficiency in	Berkes and Folke, 1998; Brunner et al., 2005; German et al., 2007; Hahn et al., 2006; Heathcote, 2009; Pahl-Wostl et al., 2007b; Pahl-Wostl, 2007c; Newig et al., 2005.Jolley, 2007; Day et al., 2003.
Science (D2)	Adaptive capacity will be built when sound science is used to guide decision making processes on eutrophication issues across multiple scales.	Scholz and Stiftel, 2005;Pahl-Wostl et al. 2007a;
Networks (D3)	Adaptive capacity will be built when different actors operate across multiple scales on the same issues in horizontal governance networks such as epistemic communities, transnational advocacy coalitions and global civil society.	Folke et al, 2005;O'Brien et al, 200; Smit et al, 1997; Betsill and Bulkeley, 2004; Adler and Haas, 1992; Keck and Sikkink, 1998; Smit and Wandel, 2006; Rosenau, 2000; Kofinas, 2009; O'Toole, 1997; Finger et al, 2006.
Leadership (D4) Experience Decision Making	Adaptive capacity will be built when there is a new kind of leader who can interact with stakeholders and facilitate public learning to overcome uncertainty, distrust and conflict in the highly uncertain environment of eutrophication. A leader with more experience would more ably deal with uncertain events in an effective and timely manner. Complex uncertain problems such as eutrophication require leaders to consider and balance their thinking with others and to engage in new approaches to decision making.	Bryant et al., 2008; Heathcote, 2009; Folke et al., 2005; Olsson et al., 2006. Engle and Lemos, 2010; UNECE, 2009. Musselwhite, 2009; IISD, 2006; Huntjens et al., 2011.
Flexibility (D5)	Adaptive capacity will be built when there are mechanisms for information feedback loops that are as a result of monitoring and are used to guide decisions and adjust programs. Sound science is used in this culture of learning.	Engle and Lemos, 2010; Gunderson, 1999; Tompkins and Adger, 2001; UNECE, 2009; Engle et al. 2011.
Resources (D6)	Adaptive capacity will be built when there is availability of skilled human resources for functions such as innovation and monitoring and financial resources for implementation of policy measures.	IPCC, 2001;Pelling and High, 2005; Adger, 2003;Yohe and Tol, 2002; Olsson et al, 2006; Engle and Lemos, 2010.

Table 1 – Framework for assessing adaptive capacity

Determinants of Adaptive Capacity

The following sections describe each of the final determinants of adaptive capacity in more detail.

Public Participation

Building adaptive capacity requires the participation of a group of diverse stakeholders including representatives of both governmental and non-governmental organizations and representatives of key citizen groups who are affected by eutrophication and can impact the nutrient enrichment of the lakes due to their activities. Governance approaches that involve diverse roles of non-governmental actors are a major part of natural resources management (Berkes and Folke, 1998; Brunner et al., 2005; Hahn et al., 2006; Pahl-Wostl et al., 2007b). Public participation in watershed management can take diverse forms in three key areas: participation in problem definition; participation in planning; and participation in implementation (German et al., 2007). Public participation in the development and implementation of policies is crucial in new forms of governance to embrace change in the highly complex and uncertain environment of stressors such as climate change (Pahl-Wostl, 2007c) and eutrophication. Key stakeholders can retard progress by putting up resistance during the implementation process, so inviting their participation can aid in reducing uncertainties that can be introduced by their opposition to implementation (Newig et al., 2005). Environmental focusing events such as organic contamination at Love Canal and the Cuyahoga fires were valuable lessons for governments, making them realize that time and money can be saved when the public concerns are addressed in a timely manner (Heathcote, 2009). An added advantage of having broader participation is the contribution of different kinds of knowledge that can lead to better assessment of the problem and hence more innovative solutions (Berkes and Folke, 1998).

While inclusion of the public is desirable, an additional challenge lies in determining representation. Broader representation of the public leads to buy in and mutually beneficial trade offs, but can also increase the time for deliberations and lead to an inefficient process if not managed. According to Jolley (2007), non-expert respondents may lack the proper knowledge when responding to questions of natural resource policies and problems. Science-based processes involving technical experts fail to access, recognize and integrate differing values, wisdom and perceptions of non-technical stakeholders (Day et al., 2003). There is agreement in the literature that the involvement of the public allows a wide variety of viewpoints, and the access to historical and traditional knowledge and risk perceptions that is absent from a gathering of technical experts (Day et al. 2003). Well designed representation of diverse opinion will facilitate prompt response and lead to better solutions.

Science/Knowledge

A scientific understanding of eutrophication is a fundamental requirement of adaptive governance for Lake Erie. Solutions to the problem of eutrophication will only be successful if the nature of the problem is understood. Eutrophication governance intersects with disciplines such as agriculture, hydrology, transport and heat exchange processes, geology and a range of life sciences. Policy makers and politicians expect to be given one clear answer by science but, as is evidenced by the debate genetically modified organisms (GMOs), science doesn’t always speak with a single voice. In the case of eutrophication, policymakers would prefer one single answer to causation but the scientific community knows that the phenomenon is an interaction of non-linear processes and that more time is needed to study the problem. As such, policy processes that are aligned with scientific processes and knowledge production would be more effective users of science.

According to Scholz and Stiftel (2005), there are three dimensions to the alignment of policy and science processes: i. specialists will have differing views on the human and natural systems and decision venues that clarify and contrast differences can lead to both productive synthesis and heightened conflicts; ii. Scientific knowledge can be advanced through policy processes that provide a forum for experts to review existing results and design research projects to fill gaps; iii. Policy decisions may take the form of scientific experiments where critical assumptions are tested by monitoring outcomes. All of these dimensions could add value to the adaptive governance landscape.

Networks

Adaptive capacity is built when there is evidence of institutional change through networking that embraces new paradigms and ways of thinking. There are three types of transnational networks in global environmental governance: epistemic communities, transnational advocacy coalitions and global civil society (Betsill and Bulkeley, 2004).

An epistemic community is a network of experts who share a common understanding of the scientific and political nature of the problem. It has four defining features: i. shared normative and principled beliefs, ii. shared causal beliefs, iii. shared notions of validity, and iv. common policy enterprise (Adler and Haas, 1992). The motivation for involvement in these networks is usually emotional and intellectual. Transnational advocacy networks (TANs) are more likely to emerge when channels between domestic groups and their governments do not resolve existing conflict, where activists believe that networking would further their cause and where international conferences create hubs for strengthening the networks (Keck and Sikkink, 1998). International examples include Greenpeace, Friends of the Earth and the World Wildlife Fund. The global civil society approach takes the discourse away from state-centred approaches to the multitude of actors and institutions that influence the ways in which global environmental issues are addressed across different scales, through spheres of authority (Rosenau, 2000:172). According to Rosenau (2000), governance occurs on a "global scale through both coordination of states and the activities of a vast array of rule systems that exercise authority in the pursuit of goals that function outside normal jurisdiction." Transparency International, Nature Conservancy and International Rivers are other examples of global civil society networks.

For any of these networks, the presence of a strong kinship serves to increase adaptive capacity through greater access to pooled resources, increasing human resources capacity, and buffering psychological stress (Smit and Wandel, 2006). Further, adaptive governance systems often self-organize as social networks with actor groups that draw on various knowledge systems and experiences to develop common understanding and policies (Folke et al. 2005). Adaptive co-management requires flexible social networks that trump bureaucracies in their quick response time for rapid changing and uncertain conditions (Folke et al. 2005). Engle and Lemos (2010) suggest that the greater the networking and connectivity between groups and stakeholders involved in the management process, the greater will be the adaptive capacity. Bridging organizations such as management councils, learning networks and associations are important central nodes for interactions across scales but challenges remain in fostering adaptive learning between these bridging organizations and larger society (Kofinas, 2009). According to the UNECE (2009), network connectivity does not necessarily mean that there is a willingness to cooperate, posing a challenge to the development of adaptive capacity.

Empirically, there are three areas of research on networks: i. determine what networks exist; ii. examine the historical and dynamic dimensions of network formation and development; and iii. explore the array of networks in a broadly comparative perspective (O'Toole, 1997, 48).

Leadership

The top down command and control paradigm of natural resources governance has been associated with a bureaucratic leadership model, where the leader issues centrally-directed commands with little input from others (Folke et al., 2005). In this paradigm, leadership is defined as “the process where one or more individuals succeeds in attempting to frame and define the reality of others”, and where the leader has an obligation or perceived right to shape and define the reality of others (Smircich and Morgan, 1982, p 258). This definition points to the shortcomings of this model of leadership in a highly dynamic, complex and uncertain environment; a model in which one person sets the reality of others will not be able to respond rapidly to changes in the system and will not necessarily build trust, effective networks and a common vision. There are many ways in which people exert leadership, and it equally holds that persons in power do not always employ leadership. According to Heathcote (2009, p113), three main categories of leadership include:

a. Positional Leaders – These are persons in positions of leadership by virtue of their role in an organization. This role positions them higher in a bureaucratic structure and implies power over those at lower positions in the organization structure.
b. Reputational Leaders – These persons are viewed as key decision makers by community members. They could include public officials, persons of wealth, and respected persons in public and private organizations, but also persons in non-governmental organizations who are highly knowledgeable.
c. Decisional Leaders – These are persons who were key decision makers in community meetings. The distinguishing element between reputational and decisional leaders is that while reputational leaders have the ability to influence, decisional leaders also show interest to influence decisions through active participation in meetings.

Heathcote (2009) goes on to state that all three types of leaders are beneficial in most situations. However, it is clear that in a highly dynamic and uncertain environment, such as that associated with eutrophication, a new model of leadership that is interactive and dynamic is needed to facilitate adaptive capacity and outcomes such as learning, networking and information sharing. According to Folke et al. (2005), vision, trust and innovative flexible leadership can facilitate key functions for adaptive governance, functions such as building trust, managing conflict, making sense, linking actors, initiating partnerships, compiling and generating knowledge and mobilizing broad support for change. These functions are important as they serve to bridge the interests of stakeholders leading to better collaboration, faster conflict resolution, and hence the faster decision making that is necessary in an adaptive governance environment. The criteria of vision, leadership and trust can also be used to test for accountability, as an unaccountable system will not generate trust among its citizens (Olsson et al., 2006). Leadership and vision can also be seen as requirements for political will to foster adaptive responses to stressors such as eutrophication.

The experience of a leader can also be important in fostering adaptive capacity. According to Engle and Lemos (2010), more experience would translate into greater ability to deal with both everyday and extreme events in an effective and efficient manner. Decision making is another important consideration in leadership for building adaptive capacity. Complex and uncertain problems such as eutrophication require leaders to consider and balance their thinking with others and to engage in new approaches to decision making. In a survey of 40 000 managers, Musselwhite (2009) found that the appropriate degree of inclusion of actors into the decision making process can be determined by considering five factors: i. problem clarity (consideration of the nature and scope of the problem; ii. information (facts and knowledge needed to make the best decision); iii. level of commitment (degree of buy-in and support needed to implement the decision); iv. goal agreement (degree to which stakeholders have common or competing goals among themselves and with their organization); and v. time (degree of urgency surrounding the decision and the time and effort others must make to participate in the decision making process). Devolved decision making to the lowest level means that the system would presumably be better able to recognise and respond to unforeseen circumstances (IISD, 2006). However, it can be argued that decision making can be difficult with many stakeholders who are vested in the process making the decision and thus decentralization is not a clear cut solution to water governance. A centralized governance structure is needed in a large scale complex system as it will facilitate participatory processes, set standards, build capacity, resolve conflicts and assist in building of cooperation across scales and boundaries through the provision of information to the local levels (Huntjens et al., 2011).

Flexibility

The Oxford Online Dictionary defines flexibility as "the ability to be easily modified". When applied to institutions, flexibility refers to an ability to bend without breaking and to learn iteratively by incorporating efficiently and effectively lessons learnt through experience (Engle and Lemos, 2010). This links back to the concept of learning by doing and making adjustments that are integral parts of adaptive governance. Adaptive capacity therefore requires flexible management institutions that will support the implementation of structured actions designed to promote learning.

Flexible management systems that self adjust based on new information are important for building resilience (Tompkins and Adger, 2001). Engle and Lemos (2010) propose that adaptive capacity will also be greater when the legislation and institutions are more flexible. However, when it comes to legislation, there is a tradeoff between the certainty or predictability required in law and the flexibility necessary for adaptive governance (Engle et al. 2011). On the one hand, by its very properties law requires that all rules and regulations be applied consistently and fairly, with little room for adjustments to circumstances. However, it can be assumed that consistency in the application of legislation and regulations will enhance adaptive capacity provided that the laws reflect the principles of equity and ecological integrity.

Resources

The factors listed in the literature as determinants of adaptive capacity represent some form of resources or the use of resources: economic resources, technology, information and skills, infrastructure, institutions, social capital and collective action (Pelling and High, 2005; Adger, 2003;Yohe and Tol, 2002;IPCC, 2001). Financial resources are useful for many actions aimed at bolstering adaptive capacity such as remedial action, building capacity for monitoring and environmental feedback, enforcing laws, responding to other environmental change and responding to extremes and feedback (Olsson et al, 2006). According to Engle and Lemos (2010) financial and human capital are vital for the success of a governance structure and since education and wealth varies within and between locations (they use the example of river basins), the greater the resources the greater will be the adaptive capacity of these locations/basins. However, one should recognize that even though more resources can increase adaptive capacity, thoughtful allocation and utilization of resources is important for program efficiency and effectiveness.

Methodology

Assessment of Adaptive Capacity

The measurement of adaptive capacity can be challenging as it is latent in nature, which means it can only be measured only after it has been mobilized or realized (Engle and Lemos, 2010). As discussed in Section 6.8, this study identified a number of governance determinants of adaptive capacity from a comprehensive literature review, and validated them using key informant interviews. For the case of eutrophication, system responses to past eutrophication events, specifically the eutrophication of Lake Erie in the 1970s and the lake's subsequent return to resiliency in the 1990s, can help in identifying governance determinants that aided system response. This approach has been described in the climate adaptation literature but has not been applied to eutrophication.

This research assumes that adaptive capacity is present if the eutrophication event has been governed successfully, resulting in reduction of nutrient loading to the water body, as in the case of Lake Erie in the 1970s to 1990s. The governance determinants of adaptive capacity are used to explore adaptive capacity in the selected case of Lake Erie where there was a past eutrophication event. While it is recognized that the past may not be a good indicator of the future in a highly uncertain environment, the focus on these past eutrophication events can provide useful insight for the governance of future events. Decision makers should be able to assess and develop responses to future eutrophication events through better understanding of the determinants of adaptive capacity.

Key Informant Interviews

Interviews provided access to experts' knowledge of Lake Erie eutrophication in the 70s-90s to capture their understanding of the determinants of adaptive capacity. For the purposes of this research, an expert was considered to be someone who was knowledgeable about the water body under investigation as evidenced by their involvement in prior projects (such as involvement in eutrophication issues in Lake Erie) or by their position in an institution whose mandate included some aspect of eutrophication governance of the water body under consideration. Fifteen key informant interviews were conducted with Great Lakes experts who were involved in eutrophication governance of Lake Erie during the period of 1972 to 1990. These key informants were carefully selected based on their roles in eutrophication governance of Lake Erie. Some of the key informants were involved in the Pollution from Land-Based Activities Reference Group (PLUARG) while others were past staff members of the International Joint Commission (IJC) or past members of the IJC Advisory Boards. Interviews were conducted either in person or on the phone using a standardized questionnaire, from June 2014 to December 2014. Interviews were approximately 1-2 hours in duration.

The expert interviews allowed the researcher access to the knowledge of the key stakeholders who possessed the technical knowledge and who also manage the consequences of this knowledge in practical decisions on eutrophication governance. For all the interviews, snowball sampling was employed: during an interview, an expert was asked to identify and recommend another expert who could add another dimension or additional knowledge from a different perspective on the subject under investigation.

The interview process started with a literature review, where organizations relevant to Lake Erie eutrophication were identified. The next step was to list these organizations and decide what information was needed from each. These organizations were then researched using the Internet, scholarly literature, and other reports. Relevant personnel were identified through this process and in consultation with experts. The researcher then designed the study to determine what information was needed and the preferred mode of extracting this information from the expert.

The interview was recorded using hand notes and then transcribed into Word and stored for coding. The transcribed information was then analyzed to inform this research.

Assessment of Adaptive Capacity in the Great Lakes- Validation of Determinants

The results of the key informant interviews were coded and analyzed in Nvivo 10 for Mac, a data analysis software package designed for use with qualitative research methods such as interviews. Figure 4 illustrates a word cloud of the words used most frequently by the key informants, and reveals the most common themes emerging from those interviews.

Figure 4 – Key themes from key informant interviews

The most frequently used words include IJC, the public, information, science, people, farmers, agriculture and money. In the following sections, these themes will be discussed further as part of the results from each determinant of adaptive capacity.

Results: Assessment of Determinants of Adaptive Capacity

Public Participation

As might be expected with the multi-level, cross sectoral nature of the problem of eutrophication, multiple stakeholders contribute to the problem and therefore multiple stakeholders are needed to devise effective solutions. The public was engaged in Great Lakes issues throughout the early years of the Great Lakes Water Quality Agreement 1972 (the Agreement), by taking part in meetings, by advocating for issues to be resolved and by participating in implementation of solutions. This public involvement in Great Lakes issues evolved through the years, as there was no involvement of the public in the development of the original 1972 Agreement. The public did influence the governments to create the Agreement through their growing awareness and concern for the pollution of the lakes:

The local public was telling the local government to get this under control. It is not a municipal issue. Our fishing and recreational outings could be at stake at the table. The pressure from the public reinforced the need for action. The focus on Lake Erie is not just because government is calling for it; it is a highly visible issue and people are calling for it. [GL2D1]

What happened was after World War II, there began to be more concern for water quality, as incidents occurred that were blamed on pollution in detergent. Newspaper stories on fish dying in streams and foamy water led to public outcry in the early 1960s………There was a considerable amount of concern after the Cuyahoga River caught fire and US funding seemed to go up considerably, aimed at Sewage Treatment Plant upgrades. [GL5D1]

Through the 1970s, the International Joint Commission provided (and continues to provide) information to the public through public hearings, although prior to 1972 the commission's communications were confidential and "only made available to the public by permission of the governments" (IJC, 1965). There is record of public hearings in Toronto, ON and Cleveland OH in 1969 and in Erie, PA, London ON, Rochester, NY and Brockville ON in 1970 (IJC, 1970). There is evidence that public concerns were heard by the IJC, as it is documented in the report by the IJC (1970) that there was widespread alarm and increasing awareness by the public of the impact of industrial and municipal discharges and nutrient enrichment of the lakes. Some of the testimonials of the public as recorded by the IJC are as follows:

We have become alarmed at the dramatic and shocking changes which are taking place with respect to the condition of this grand water-way. The Federal Government should increase its financial assistance to the States for waste treatment. We have heard a lot of words. When is the action going to start, because the longer we procrastinate the worse the problem become? Our community is dedicated to pollution abatement. [IJC, 1970]

Although the voice of the public was heard by the IJC, the general public had no role in decision making. According to the key informants in the current research, although the public was informed, the public was not empowered in decision making:

In those days we informed the public rather than empowered them to have a voice in the decision making process. We provided information rather than facilitating empowerment of the public. The challenge was how to get people empowered. [GL1D1]

There was a command and control environment so the general public was not involved. The key stakeholders were mostly scientists. [GL2D1]

There wasn't that much of a public movement. I worked in different agencies so was very seldom involved in giving information to the public. There weren't many major stakeholder groups. People weren't organized at that level until the late 70s early 80s. [GL1D1]

There was a major paradigm shift for each period of time. The mechanism through the 70s and middle 80s was that there was no public participation. In the early 80s we were discouraged from talking to colleagues. Later during the late 80s and the early 90s we had more experience of talking to the public. IJC biennial meetings became a forum for the public. [GL3D1]

This concern for the environment led to the formation of groups that advocated for a cleaner lake. There were non-governmental organizations that were actively involved in advocacy and in pollution prevention. These groups became more active with the push to ban phosphorus in detergents. Some of the groups that were involved included the League of Women Voters, the Clean Water Alliance, and Great Lakes United:

There were formation of groups and there was a citizen environment lab called the Clean Water Group. While it grew out of grass roots, Great Lakes United started being a more forceful organization. Everybody didn't think of environment until concerns such as the Cuyahoga catching fire. The Detroit River became known as the most polluted river in North America. [GL1D1]

The public was kept informed. The public got involved in the phosphorus free movement to ban phosphorus in detergents, in the educational campaign, and shared in the distribution of information. [GL2D1]

The League of Women Voters was a long standing advocacy organization in the US that still exists. However, as women have become more active in working life, membership has declined. I became involved. I worked with the Illinois League of Women Voters leadership; we worked together and pushed for public participation in meetings on Lake Michigan and the Calumet enforcement conference. [GL5D1]

The public at large obtained information through newspapers. Public attention in Chicago was drawn to the Chicago Tribune that carried a series of articles and was the first paper that signed a reporter as first environmental editor. In the 1960s they ran a series of articles on the pollution of Michigan, the terrible die off of alewife; that series focused on Lake Michigan but then the focus shifted to Lake Erie. Science showed the effects of pollution but the publicity generated was a large factor in informing the broader public and led to private citizen involvement which was tremendous. [GL6D1]

The participation of the public evolved with the requirement in the 1972 Great Lakes Water Quality Agreement (and in the 1978 Amendment) under Article VIII, that the IJC and the Boards provide a public information service for the programs, including providing for public hearings. The reports of the boards were made public and further communicated through workshops. The workshop organized by the Research Advisory Board (RAB) was the fertile ground that led to the establishment of 17 public advisory panels for the Pollution from Land-Based Activities Reference Group (PLUARG) watershed study (Botts and Muldoon, 2005). These reports and meetings were recognised by the key informants of this study as being instrumental in the evolution of public involvement in Great Lakes matters and helped in creating a sense of community, even though the meetings were initially adversarial in nature:

IJC biennial meetings were a way to set up communication. The Science Advisory Board set up a table at the front of the room and had a microphone for open questions and answers; people commented with a great deal of anger. The IJC would not give an answer as they are political appointees. I remember going to an IJC public meeting in 1992, but a lot of it was grandstanding, protesting, marching around with public demonstrations of concern. That's complaining and was not a good environment for fostering good understanding and communication.[GL3D1].

For the IJC work, we set up a public participation network which involved people at the local level in each geographic area. At these meetings, people would participate as they wanted. Many of the persons who came to meetings were active outside of meetings to talk with friends, to represent issues to other people, to lobby politicians at local, state and provincial levels. Under the 1972 GLWQA, the IJC was given the mandate for the Pollution from Land-based Activities Reference Group (PLUARG) which included non-point source pollution. PLUARG set up an extensive public information network to inform the public. This helped the public to become engaged on the issues. Engagement was on a couple of levels; persons presented their ideas, told others of the issue and got concerns expressed to politicians. It was a positive success; it engaged hundreds of people across the Great Lakes region…It was like a spider web, persons outside of the Great Lakes area hosted meetings.[GL7D1]

There was a fair bit of public participation. I am aware of meetings with farmer groups and groups *around problems such as erosion and sediment yield and phosphorus and around Best Management Practices (BMPs). There were many stakeholders associated with PLUARG including federal and provincial and university people. There were public meetings. One of the things that helped immensely was that there was a group of farmers called innovation farmers. These were landowners and they formed way before PLUARG. They were aware of poor land management and downstream issues. They committed to do something on land on their own. They were an increasingly important group of landowners when it came to meeting more bureaucrats and enrolling other farmers. That helped having an initial group of people. We valued them immensely as they had a lot of good ideas and good experience. That was an important point; PLUARG made use of it.* [GL11D1]

The key informants felt that the engagement of the public was one factor that positively contributed to the nutrient reduction and restoration of Lake Erie. In Canada, the process of transitioning to full engagement of the public was a slow one. According to one of the key informants, the Municipal Industrial Strategy for Abatement did not include NGOs or the public, something that was later seen as a major flaw in the process (GL7D1). However, this improved in Ontario through the 1993 Environmental Bill of Rights, which gave the public rights to environmental information, while in the United States (US) it was law that information had to be shared with the public.

The evolution of public involvement that has occurred over the last several decades can be demonstrated by the time stakeholders spent to prepare for meetings and the mode of engagement of the public. For instance, public involvement in the Grand River Strategy was invited through a limited series of advertisements in the newspapers, where the public was invited to submit their resumes to apply for positions on advisory committees. The public was very interested as was evident by the numerous applications received, but there were only six to eight spots to be filled:

The Grand River is a major river in Lake Ontario that drains to Lake Erie, with 13 different municipalities so a lower tier of government is involved. Public involvement was through open meetings but was limited in committees to a series of advertisements in newspapers asking people to submit resumes. This was one of most progressive processes in 70s and 80s to involve the public in the significant issue of eutrophication in Lake Erie. It yielded a lot of applicants, although there were not a lot of spaces to fill, only about six or eight seats on a committee. The Grand River had quite a strong influence with strong technical working groups that had about 12 members at most. What worked well, was to have these small groups working together for a long time. It helped to build a sense of team and rapport, trust, things that were lacking in places like the IJC biennial meetings. Those committees worked as a team and developed technical recommendations that eventually led to the Grand River plan. It had a lot of impact on the final decision. [GL3D1]

During the 1970s, the public spent little time to prepare for meetings as they were given limited information with which to prepare (GL3D1, personal communication). This has evolved considerably in recent years. For example, for phosphorus trading in Lake Simcoe Basin, the public interest groups spend at least 2 days to prepare for meetings because more information is made available to them, as there is the expectation that there will be more substantive input (GL3D1, personal communication). As the public were encouraged to become more involved, there was no exclusion at the IJC meetings as these were made open to the general public through provisions in the 1972 Great Lakes Water Quality Agreement. This even led to the engagement of private companies and spurred them to investigate alternatives to phosphates in detergents:

There were a series of local meetings and the information was compiled to provide a broader picture across the GL basin. There was a strong voice, no exclusion from process and there was an effort to try to engage people or organizations or companies that were responsible for the problem. For *example, Proctor and Gamble were major laundry detergent manufacturers that we tried to bring into discussion so that they could understand how the problems were, how they were contributing to the problem and how they could develop alternatives. P&G worked to develop alternatives to P in detergents. There was no level of government excluded. If a particular state or provincial government was responsible, we brought them into the discussion*. [GL7D1]

The evidence from the key informant interviews presented above shows that, from the 1970s to the 1990s, there were varying levels and diverse modes of participation of interested stakeholders in the nutrient enrichment of Lake Erie. Key informants felt that this involvement played an important role in reducing nutrient input and hence building adaptive capacity for eutrophication governance of Lake Erie. The self organization of stakeholders into advocacy groups such as the League of Women Voters and the Clean Water Group helped in the development of a common understanding of nutrient enrichment through the organization of conferences and the bringing together of diverse stakeholders to speak to the issue of eutrophication. These groups acted as bridging organizations that lowered the cost of collaboration. In some cases, enabling legislation and policy, such as the Great Lakes Water Quality Agreement, facilitated the sharing of information with the public. This helped in the provision of key information for dealing with the poorly understood problem of eutrophication. Adaptive capacity was demonstrated by social systems making use of available information to self organize and to drive policy that resulted in improvements to the Lake Erie ecosystems.

Science/Knowledge

During the eutrophication of Lake Erie in the 1970s, scientific information was used to determine the cause of the problem, including the effects of phosphorus and nitrogen on algal growth in Lakes.

In 1964 the governments of Canada and the US issued a reference to the IJC to help determine the cause. Funding to the experimental lakes area resulted in scientific breakthroughs. [GL1D2]

A series of whole lake experiments were conducted by Schindler and Lee (1974) in which lakes were fertilized with combinations of phosphate, nitrates, and/or carbon to determine the limiting factor for eutrophication. These experiments demonstrated that the control of phosphorus was important in controlling eutrophication at that time (Schindler and Lee, 1974). A key informant noted that another big influence on the science at that time was the publication 'Algal Bowl' by Jack Vallantyne (GL1D2).

This use of science in making decisions for the Great Lakes region is embedded in the Boundary Waters Treaty (1909) where Article IX states that the IJC examines each case so as to report on 'facts'. This principle was carried forward into the Great Lakes Water Quality Agreement (1978), where the terms of reference of the Science Advisory Board (SAB) stipulate that scientific information should be reviewed to determine its impact, adequacy and reliability and also to identify gaps. Scientific models were used to determine target loads. According to the key informants of this research, science was the driving force behind decisions, driving the focus on elimination of P in detergents and the regulations for sewage treatment plants:

The 1972 GLWQA set Canada and US nutrient discharge at 0.5mg/l using the Vollenweider Model… We set these target loads…..Science and engineering had the lead. Part of the reason we removed phosphorus out of sewage treatment plant effluent was that we could do it; we did what we could do; only what we can manage through the technology that we have. The notion that we can address anything with technology came out of the 60s and 70s. We no longer believe that. [GL1D2]

> *Lake Erie was hypereutrophic and nobody knew why. Stakeholders were mostly scientists. Once scientists revealed that phosphorus was the issue, the decision was made. A report was produced by the IJC with the help of good science. It was a highly visible issue with fish kills. What was NOT known was acceptable loading to Lake Erie and this was worked out through extensive modeling that was shared binationally. There was innovation in methods; the method used to determine that phosphorus was a limiting nutrient was innovative. Modeling revealed where there was a gap in information.* [GL2D2]

> *Science did drive decisions to a point. The phosphorus (P) model didn't come on until the 1970s. Changes were made in phosphorus content in detergents, but a lot of the decisions made were political…Is money better spent on upgrading sewage treatment plants or best management practices on agriculture?.. Models became important for answering questions like that.* [GL3D2]

There was little innovation in the integration of Traditional Ecological Knowledge into the decision making. As one key informant put it "scientists scoffed at the mere idea of traditional ecological knowledge" (GL3D2). However, there was innovation in analytical methods in 70s to 80s, for example in the way phosphorus was analyzed. PLUARG drove the innovation in field measurement and the innovation in the eutrophication model for specific high risk systems like the Grand River; there were species specific eutrophication models for *Cladophora*, *Myriophllyum* (Eurasian milfoil) and *Potamogeton* (pond weed). These were three species that have been problematic in that system, as they have different phosphorus uptake dynamics and therefore required a different plant growth model for each species.
According to those surveyed, the use of scientific information was essential for the reduction of nutrient enrichment in Lake Erie. The information was used to show that the actions of sewage plant upgrades and banning of phosphorus in detergents made a difference in Lake Erie:

> *Science was an important factor in driving decision-making and answered questions as to how much phosphorus is essential for plant life in water. When there is too much phosphorus it is a problem. Science tells us what reduction in phosphorus loading is necessary in order to restore Lake Erie to a desirable environmental quality. Science established the relationship in the amount of phosphorus and plant growth in lakes.*[GL7D2]

> *The phosphorus concentration was going down from the mid 70s to the mid 90s; this was the turnaround period. We used that information to show how the system was cleaning up…. There was a huge amount of support for monitoring and research. Huge amounts of money were spent on monitoring in Lake Erie and it was very coordinated. The USEPA was the primary funder for monitoring and players collaborated. Science did drive decisions and decision makers were waiting for scientists…Groups were using same sampling and analysis technique, incredibly well done. Sharing and transmitting information was well done.*[GL12D2]

There was consensus amongst the key informants that the necessary science was developed and that the use of science was integral to the reduction of nutrients in the lake. Governance during this period facilitated the scientific process that was used to identify phosphorus as the limiting nutrient for eutrophication, which in turn led to improved understanding of the system as a whole. Adaptive capacity was demonstrated here through the generation of knowledge that led to improved understanding of eutrophication, which prompted adjustments in legislation and policy that resulted in decreased nutrient loading to Lake Erie.

Networks

During the period from the 1960s leading up to the 2000s there were several factors that contributed to creating strong networks and hence a sense of community amongst Great Lakes stakeholders. Firstly, there were the newspaper stories that stimulated public interest to save a 'dying Lake Erie'. Pictures such as the Cuyahoga river catching fire united the general public to reverse the situation.

The network was strongest amongst the epistemic community and was facilitated by the Agreement and the participation of scientists in the advisory boards of the IJC. According to the key informants, it was the provision in the Agreement that the IJC conduct its work through various advisory boards such as the Science Advisory Board (SAB) (or the then Research Advisory Board) and that it shared information with the public that created that strong network and the sense of community:

> *The reference to the IJC gave the IJC the ability to assemble a task force, a reference group. This reference group was populated by province and state representatives from around Lake Erie. The strength was the epistemic community's passion and commitment that was driven by a motivation to reverse a crisis situation. This group was populated by persons with similar research interests, motivated for same reason and pushed by need for action to do better.* [GL2D3]

> *The network was facilitated through the IJC during the 70s and 80s through its boards. The WQB was mainly government people on both sides of border and both levels of government. The SAB was operating for many years with broader membership of economists, lawyers, university researchers and academics. They were leading edge scientists and they had a first class way of sharing information across the border.*[GL3D3]

> *There was a great deal of collaboration; there were two centres that were very much working together-USEPA and EC. We would literally meet in the middle of the lake in boats and exchange samples to be sure that with our different instruments we are getting the same results. We would take their samples (and vice versa) and use our instruments and measure and compare results.* [GL12D3]

> *The IJC reference group was in touch with us researchers and made it clear that we had to share information and do everything openly. We were delighted to be sharing back and forth our ideas. It was a well-managed research program. We got together and tossed ideas around and had lively discussions between researchers and provincial representatives collecting data with open sharing of data.* [GL11D3]

There was an overlap of persons participating in the SAB activities and participating in IJC organized events that helped to strengthen the networks and create that sense of community. This community existed across geographical lines, areas of professional expertise and diverse experiences. There was also the formation of the International Association of Great Lakes Research (IAGLR) about 60 years ago. IAGLR hosted annual conferences that helped fostering of stronger networks. There was a sense of community amongst government staff, researchers, scientists and environmentalists as they exchanged information both formally at meetings and informally over lunch (Botts and Muldoon, 2005). This networking was also evidenced in the political sphere, for even the heads of government who couldn't 'stand each other' worked together for the signing of the 1972 Great Lakes Water Quality Agreement:

> *The political network led to the signing of the binational agreement between two national leaders who hated each other.* [GL2D3]

> *Trudeau and Nixon signed agreement in 1972. It was the Prime Minister and the President back in the 60s that set the stage. It was above the party politics and transcended it. It didn't matter whether it was conservative or liberal. Trudeau was liberal, Nixon was republican-they had political differences on other areas but on environment they came together. The issue was so great it was outside of politics.* [GL7D3]

The citizens' advocacy group Great Lakes United, an example of a Transnational Advocacy Network (TAN), was credited with strengthening that sense of community amongst Great Lakes stakeholders. Great Lakes United was a binational coalition of environmental advocacy groups that influenced policy through exchange of information with scientists and government agency staff (Botts and Muldoon, 2005). This also helped with funding as there was also networking amongst NGOs for funding and around common issues:

> *There was some collaboration amongst non governmental groups (NGOs) on specific issues. It was a competitive system but they formed consortia of groups when funding was tight.* [GL3D3]

There was also the networking that was facilitated by the PLUARG process:

> *For the PLUARG process, the strength of committees was terrific.* [GL3D3]
>
> *During PLUARG the networking linked researchers and government and conservation authorities. It was facilitated by the IJC mandate in how rigidly they said we had to share information. One individual who came to twice yearly meetings, while his belligerent manner annoyed people, was instrumental in making the sharing of information work.*[GL11D3]
>
> *One of the things that helped immensely was that there was a group of farmers called Innovation Farmers. These were landowners and they formed way before PLUARG. They were aware of poor land management and downstream issues. They committed to do something on land on their own. They were an increasingly important group of landowners when it came to meeting more bureaucrats and enrolling other farmers. It really helped having an initial group of people. We valued them immensely as they had a lot of good ideas good experience. That was an important point, PLUARG made use of it.* [GL11D3]

The PLUARG structure was successful in bridging various scales in the governance structure and functioned as a network that provided the resources necessary to facilitate change. These networks also facilitated communication and integration of technical and advocacy information and facilitated processes that encouraged diversity, hence harnessing adaptive capacity for learning and flexible adjustment (Folke et al., 2005). There was also a networking of the Ministry of Agriculture with the farmers through the agricultural extension services that PLUARG made use of:

> *There were Ministry of Agriculture and Food officers in each county; these worked closely with farmers. They had training in water resources and were closely in touch with farmers. There was a phenomenal network with farmers, the agricultural extension services.* [GL11D3]

Some authors believe that the sense of community that was created by the Agreement processes was what drove the political will of the government to meet the obligations of the 1972 Agreement (see for example Botts and Muldoon, 2005). The key informants agreed that networking drove the sense of community that was instrumental in leading to nutrient reduction in Lake Erie. Adaptive capacity was displayed during this time through strengthened capacity of the networked actors, resulting in collective learning and mobilization of resources to jointly drive nutrient reduction programs. This collective experience provided the context for the modification and acceptance of policies for reduction of nutrient loads to Lake Erie. As the key informants indicated, this collective experience was driven through different networking groups including the epistemic networks of the scientists, transnational advocacy networks and non-governmental networks.

Leadership

There were many examples of leadership displayed during the 1960s through to the nutrient reduction of Lake Erie in the 1990s. Positional leadership was displayed at the highest level through political commitment, which was especially visible when Trudeau and Nixon signed the Great Lakes Water Quality Agreement 1972:

> *There was leadership by Trudeau and Nixon but no camaraderie. This existed more at lower than at high management level agreement. EPA and Environmental Canada drove and pushed it up to the leadership. Trudeau's quote at that time was that Lake Erie was "pathetic and disgusting"……There was federal leadership as the ban on phosphates in detergents was from coast to coast*. [GL2D4]
>
> *Trudeau and Nixon signed the Agreement in 1972. It was PM and President back in 60s that set the stage. It was above the party politics, it transcended it. It didn't matter whether it was conservative or liberal.* [GL7D4]
>
> *Leadership was there in that government signed the GLWQA; the fact that government signed the agreement showed that it had their backing to move forward.* [GL9D4]
>
> *The governments of both the US and Canada were active. There was significant leadership by the USEPA and Environment Canada and a great deal of collaboration between the two. The Clean Water Act had just passed and the GLWQA was just passed and NOAA was just formed. Both USEPA and EC were formed in 1970 and so they had brand new organizational strategies to try to create a presence.* [GL12D4]

This leadership by the governments was crucial in creating the fertile ground for stakeholders to act, and is in keeping with Miller's (2003) view that the extent to which organizations and individuals take on leadership roles is a benchmark of adaptive governance. There was widespread consensus by all the key informants that the IJC played a crucial leadership role in facilitating all the processes that led to the nutrient reduction in Lake Erie:

> *In those days the IJC had a lot of clout. They moved to policy development rather than information development. Knowledge is power; at one point the IJC was a great source of public information. In the 70s, the IJC was the watchdog, it had teeth. The IJC produced reports and made recommendations to governments at a high level and listed priority things that needed to be done.* [GL1D4]
>
> *IJC did not have experience with eutrophication but had experience with bringing stakeholders together in an impartial way to resolve disputes.* [GL2D4]
>
> *IJC showed clear leadership.* [GL5D4]
>
> *IJC facilitated communication between the US Environmental Protection Agency (USEPA) and Environment Canada. The role that was given to the IJC showed that both governments were supportive of role of the IJC, it was built into the IJC.* [GL6D4]

There was also the recognition of bottom up leadership by the greater public and groups such as Great Lakes United (GLU):

> *GLU provided a network amongst local and regional environmental organizations… they provided the connection so different organizations and groups know what is going on.* [GL7D4]
>
> *There was bottom up leadership and the citizenry got engaged. There were conversations with politicians and representation of the public*. [GL8D4]
>
> *There was leadership by the private foundations which provided funding for advocacy work and initially funded the work of GLU.* [GL5D4]

This recognition of the leadership of the private foundations is important, as it points to non governmental players who were key to successful management of the issue. There was also clear emergence of reputational and decisional leaders. There were particular names and environmental organizations that were seen as key informants as pivotal to the nutrient reduction in Lake Erie:

> *GLU started being a more forceful organization.* [GL1D4]
>
> *There was leadership by the Lake Michigan Federation, the Sierra Club and the League of Women Voters. They were stimulated by the newspaper stories showing stories of fish dying in streams and foamy water. In the early 1960s the league of Women Voters was an advocacy organization in US that still exists.* [GL5D4]
>
> *The Sierra Club was an established leader in organizing an early meeting in Washington DC during Great Lakes week. Citizens went to Great Lakes week and were informed through workshops on current issues and recommendations would be discussed.* [GL5D4}

There was also recognition of leadership by industry in trying to find alternatives to phosphorus in detergents:

> *Proctor and Gamble were laundry detergent manufacturers that we tried to bring into discussion so that they could understand the problems and how they were contributing to the problem and how they could develop alternatives. P&G worked to develop alternatives to P in detergents.* [GL7D4]

While there was strong leadership, there were also conflicts: conflict in political ideology between Canada and the US and also scientific conflict as to whether P or N was the limiting nutrient. These conflicts were resolved through dialogue and the use of science in decision making:

> *There was scientific conflict but it was not a difficult conflict; workshops, think tank and experimentation were means of resolving this conflict. New information was used in the decision making process that that P was the nutrient that 'caused the death of Lake Erie'. Also it was a highly controversial move to ban P in detergents as opposed to controlled upgrading of sewage treatment plants. This move reduced loading to plants from a dominant source.* [GL2D4]
>
> *There was apparent conflict on sharing data. Threat of cutting money helped with that, during PLUARG. There was conflict amongst researchers about science; there must have been but we seemed to resolve them. People involved got on with it. The overall commitment was great; government came up with answers. What really was happening was started at the organization group level and led to consensus.*[GL11D4]
>
> *Banning of phosphorus in detergents was a conflict. Was it really important to the US to sign the GLWQA, if so they would agree on phosphorus? Why would the US want agreement with Canada, as it was of more benefit to Canada, and there was more expenditure for the US – 50/50 representation on table – when it comes to clean up Canada was an order of magnitude less contaminated? The US was 2 orders of magnitude higher.* [GL2D4]

On the characteristic of good leadership, one key informant indicated that the IJC started to investigate why some Remedial Action Plans (RAPs) made good progress while others did not. They found that number of factors including i. the right investment in the right technology was helpful ii. teams and relationship and iii. the personality of the leader fostered the previous two points (GL3D4).

Another informant indicated that commitment was a hallmark of good leadership and reiterated that the ability to bring the right persons to the table was crucial:

> *Good leadership was displayed by persons who were involved in the reference group of the IJC. They were incredibly committed to geting answers. There was a person at that time on the reference group who pulled together people with similar backgrounds to work on erosion; work on soil erosion in agriculture fields; work on hydraulic modeling. They put a team together and worked*

25 years together. There were a few people in the reference group that provided important leadership. As it evolved, people with the organization there became leaders. [GL11D4]

On the issue of experience of leaders, it was recognized that no one had experience on eutrophication but that the IJC had experience with bringing stakeholders together and that was vital to the nutrient reduction in Lake Erie. Leadership by the IJC was essential in building adaptive capacity as it brought actors together in networks and created opportunities for learning, for new interactions and for sharing of knowledge. These are factors that are essential for dealing with uncertainty and change, for nurturing adaptive responses to change, and thus for building adaptive capacity. As noted by the key informants, the IJC leadership was instrumental in driving change by setting the agendas, communicating the issues at stake, facilitating dialogue to resolve conflicts, building trust, initiating partnership amongst stakeholder groups, compiling and generating knowledge and mobilizing actors to support programs for the changes necessary to achieve nutrient reduction goals.

Flexibility

In the early days of implementation of the 1972 Agreement, flexibility was evident as experiments were done to determine the cause of nutrient pollution, steps were taken to test the hypothesis, management actions were adjusted, and monitoring tracked the recovery of the lake. The Agreement itself had built in flexibility under the review clause as it equipped the governments of the US and Canada to adapt to a changing environment. This flexibility inherent in the Agreement was pointed out during interviews:

How vital was the Great Lakes Water Quality Agreement? It provided the governance framework for bi-national cooperation in this shared water body. While it did not have treaty status in US, it formalized the cooperation between US and Canada. The term 'Up for review' was included in the Great Lakes Water Quality Agreement, so at any point of time if the loading limit is too high, governments can call for review.[GL2D5]

Article IX committed the governments to a review of the Agreement after five years. This review resulted in a revised Agreement in 1978 in which Article XIII contains amendments agreed to by the Parties. The monitoring and research that informed science facilitated this review process, including the whole-lake experiments on the limiting nutrient was for algae growth, and the PLUARG watershed scale experiments. The flexibility of targets was one area to negotiate in the Agreement:

The process of negotiating between Canada and US for the Agreement was a series of negotiations through IJC boards. The negotiators were never certain of the moves, there was no certainty that the loading number will have what they want.[GL3D5]

Science wasn't so sure about agriculture back then. PLUARG was more about soil loss. We did not consider non-point sources. We did not know how to measure the phosphorus loads. [GL1D5]

What was NOT known was the acceptable loading to Lake Erie and this was worked out through extensive modeling that was shared bi-nationally. [GL2D5]

Initially, there was also flexibility in how to achieve the targets, whether one wanted to focus on removal in sewage treatment plants or on combined sewer overflows:

With respect to targets, there was flexibility in how to achieve the targets. If the target is to have a maximum load of phosphorus in the lake, we set out to determine how to achieve it. There was flexibility in how to do it, whether it was removal of phosphorus at wastewater treatment plants, from runoff or from combined sewer overflows.[GL12D5]

There was flexibility in working with the unknown load from agriculture. Since the science and joint fact-finding were still in their infancy, and there was much uncertainty about the contribution from individual sources, there was great flexibility in setting target loads.

> *There was learning on what farmers work with and trying on the land. There was learning done at that time, learning as regards to managing technology. We tried finding ways of encouraging people to find ways to reduce the loading. Researchers talked about targets.*[GL11D5]

While there was an adaptive element in how targets were being set and a systematic process of hypothesis setting, experimental work and testing of hypothesis, this was not recognised as adaptive management:

> *In those days we were not doing adaptive management as it was not a term or technique used in the Great Lakes region in 1978. The goal in those days was a single target – 11 000 metric tonnes per year – it wasn't modified. We set the target, but after lot of discussion; modeling helped us to come up with targets. We had confidence in the model. We set a target of 11 000 metric tonnes and the lake responded. We might have had adaptive management sooner if the effort had not worked, but because it worked we thought the problem was solved and the federal government stopped its investment in monitoring and research.*[GL12D5]

What is evident here is that while there was an element of flexibility in target setting and in working with the various scenarios in the model to set the target for phosphorus loading to the lake, once the target was set the governments were reluctant to modify it (GL12D5). This was especially true as improvement was seen in the lake's trophic status. The IJC (1978) Sixth Biennial report noted that Canada had met the loading target for phosphorus and that eutrophication was slowing down. Flexibility was also apparent in a mixtures of legal versus voluntary measures. For farming, which was unregulated, there was the recognition that voluntary measures were needed to work with farmers to reduce phosphorus loading:

> *Unless and until there is an economic cost associated with environmental damage, persons would not willingly implement measures. People come up with environmental models. A farmer working on his land, there is a huge advantage for him if he loses less due to runoff; a big runoff can be an economic driver to keep phosphorus (P) on land. There is no penalty for what goes downstream. Those in agriculture said measures had to be voluntary.* [GL12D5]

> *Best management practices (BMPs) were encouraged but not legislated. This is an important point for there were all kinds of things you want to do but can't do because they were voluntary.*[GL3D5]

However, there was widespread agreement that legal measures were vital to the reduction of point source loads. The banning of phosphorus in detergents and regulations for phosphorus in sewage treatment plant effluent were seen as key moves in the reduction of point source loading and success in restoring Lake Erie:

> *We were focused on point sources, we invested money in improving sewage treatment – we set allowable limits on concentration of phosphorus coming out of sewage treatment plants. It was very effective. Legal measures were most important. This would not have happened with voluntary measures.* [GL3D5]

> *Lots of enforcement was done by the states. Voluntary measures and education go a long way, but are not working. We need to add to them. The US Clean Water Act-law cracked down on pollution sources. Billions of dollars were spent to upgrade sewage treatment using tools available under the Clean Water Act. Canada used a mix of legal and voluntary measures. It took both voluntary and legal measures. Without the Clean Water Act, much wouldn't have been done.* [GL10D5]

This approach led to the building of adaptive capacity as regulations were implemented systematically binationally and in the interest of ecological stability:

> *Regulations were put down on both sides of border. The USEPA did a lot to tighten up sewage treatment plants and also province of Ontario. Federal leadership for the ban on P in detergents was from coast to coast.* [GL2D5]

Even though there was lobbying from industry to try and prevent banning of P in detergents, this regulation was consistently applied:

> It was a *highly controversial move to ban P in detergents as opposed to controlling the upgrading of sewage treatment plants. This move reduced loading to plants from a dominant source.* [GL2D5]

There was also flexibility for the states and province of Ontario to tighten the limits to suit their own needs.

> *The legal instrument was regulatory in nature. There was a new regulation on P discharges for maximum P concentration that can come from a sewage treatment plant but the province and state can tighten the limits.* [GL2D5]

One key informant noted that Ontario's Environmental Protection Act provided a mechanism to prevent the discharge of a contaminant into the natural environment but this requirement proved difficult to enforce. Lawyers argued that phosphorus is not a contaminant and that a pipe (such as a sewer outfall) that discharged phosphorus into the water should not considered a part of the natural environment. In their words:

> *The lawyers argued that phosphorus is not a contaminant and that a pipe that discharges sewage is not a part of the natural environment. The Ontario Water Resources Act was not helpful for detergents or farmers.* [GL3D5]

There was a consensus from those interviewed that the combination of voluntary and legal measures worked best but that legal measures were vital to the success of the programs. These key informant interviews revealed that adaptive capacity was demonstrated through continuous updating of understanding of all aspects of the nutrient enrichment challenge through allowance for flexibility in the 1972 Great Lakes Water Quality Agreement, through flexibility in adoption of nutrient reduction measures and through flexibility in the mix of legal and voluntary approaches that were used to achieve the nutrient loading target to Lake Erie. Adaptive capacity was demonstrated by the learning that was incorporated into the system to meet the goal of nutrient reduction. In this adaptive system, scientists were among the actors in learning and knowledge generation, a move away from the role of the detached specialist delivering information to management.

Resources

The climate change literature indicates that the availability of resources and its distribution across the population is one determinant of adaptive capacity (IPCC, 2001). In the current study, key informants reported that resource availability was crucial to the successful nutrient reduction of Lake Erie that occurred from the 1960s to the 1990s:

> *The Federal government was the source of the strongest finances. They funded the Canada Centre for Inland Waters (CCIW). It was a real achievement of being able to take on an issue. In 1982 we did it. Five billion dollars ($5B) was spent very quickly to control nutrients by the federal governments. [GL1D6]*
>
> *Resource availability was made through references. States and provinces shared resources for monitoring. Adequate resources at that time allowed for innovation in methods*. *In the 1960s, we did not have Ministry of Environment to put forward these information collection systems and so it was created. A lot of this went on without the ministry being in Ontario. There was shared funding between the federal government and Ontario. Government provided funding to do research. Both sides did research. Without it, there would have been significant information gaps.* [GL2D6]
>
> *There was a lot more money for monitoring in 1970 and 80s than in the 2000s. Government funded PLUARG with significant money in the 70s and 80s. Funding was vital to the success of the*

programs and it was readily available in those days. [GL3D6]

Resources were essential to a successful outcome. [GL5D6]

Back in the 1970s, government seemed to have a fair amount of financial resources to put to solving problems and it was easy to justify spending money by saying we can remove this much P if we build a wastewater treatment plant (WWTP). It was easy to justify money once you know you would achieve the removal of P. Technical resources were available; people knew how to build WWTPs. Government provided funds for scientists to conduct research and surveillance and monitoring. Resource allocation was extremely critical. Government committed money and this money was spent and treatment plants built. Resources were critical to the successful outcome. [GL7D6]

We had an active group of modellers collaborating on developing solutiosn. There was a huge amount of money for monitoring in Lake Erie that was very coordinated. The USEPA was the primary funder for monitoring. Players collaborated. Monitoring and research were funded by USEPA. [GL12D6]

For those on the Canadian side, it was recognized that funding for the Canada-Ontario Agreement on Great Lakes Water Quality (COA) was essential to the execution of programs for nutrient reduction during this period:

In 1971 there was the COA. Canada had to have agreement with Ontario for the protection of the Great Lakes. The COA had provisions for monitoring, surveillance etc. Ontario had to agree to fund part of it and in the mid 80s to late 80s there was a cost sharing agreement between Canada and Ontario for funding of measures in the COA. [GL2D6]

*Scientists were central to what was going on. The first COA in 1971 has dollar amounts on it that the federal government committed to give to Ontario to help municipalities to upgrade STPs. Today's COA will do certain things but there is no dollar transfer. This was critically important for Canada. [*GL4D6]

There was also recognition of the value of foundation support to creating an active advocacy community and helping to foster a sense of community amongst Great Lakes environmental groups:

Foundation support was crucial; The Joyce foundation had been created in mid 1975 and was based in Chicago. The Joyce foundation for years (15 years) was a major supporter of activity of organizations like Lake Michigan Federation – they provided funding that made it possible for citizens to go to Washington DC for annual Great Lakes meetings. [GL6D6]

There was also recognition that human skills, research, advocacy and science were critical to the process and that having adequate financial resources was essential to having those other resources. In addition to having the resources available, the allocation of the resources was 'specific and surgical,' targeted to the programs that would result in the most nutrient reduction (GL8D6), and thus contributed to the successful outcome.

It was also felt that the problem had to be recognized as real for resources to be allocated to the issue:

If you acknowledge a problem, government may direct money there. If you say there is no problem, government shuts down. In the 1970s flood at the Grand River, we said there is a problem and there was a ton of money allocated to the Grand River. It completely built up the system to do a better job. During PLUARG, agriculture took a different position. Farmers understood the issue. There was a lot of that information being talked about. A lot of things were done pre-PLUARG. A lot of landscape change. New information was fed to PLUARG. Not as in touch with the public at large. How do you present information is crucial. [GL11D6]

It is clear from the informant interviews that having adequate resources, strategically allocated, was critical to the successful nutrient reduction of Lake Erie. The availability of resources led to enhanced adaptive capacity by facilitating networking and implementation actions such as monitoring. Funding was essential for the implementation of policy measures such as upgrade of sewage treatment plants, and to support research activities and associated experimentation. Adaptive capacity was facilitated through the distribution of resources to key areas such as networking, scientific research, public meetings and general policy implementation. Adaptive capacity was built through availability of funding for nutrient reduction measures and the willingness of the governments to allocate funding to these measures.

Discussion

This paper sets out to show that the issue of eutrophication is so complex that it can be considered a wicked problem and as such, needs an adaptive governance approach. The underlying theme is that adaptive capacity improves the ability of governance systems to influence positive responses in institutional components for building resiliency to stressors such as nutrient enrichment. The climate change literature has proposed a number of characteristics and determinants of adaptive capacity (Folke et al., 2005; IPCC, 2001; Engle 2010), including resources, knowledge, equity, leadership, and cooperation. However, this concept has not been extended to the field of eutrophication; this is where this paper makes its contribution. Further, this paper introduces a framework to characterize and foster determinants of adaptive capacity, in order to help decision makers in a meaningful set of choices to aid with the implementation of the Great Lakes Water Quality Protocol 2012 (the Protocol).

One of the questions this study asks is ‘what are the determinants of adaptive capacity for eutrophication governance?’ This question was answered first by seeking the determinants of adaptive capacity in the literature that were relevant to the Protocol in order to develop a framework for assessing the presence of adaptive capacity. Since adaptive capacity is latent in nature and thus is more readily measured once realized, this study sought to assess the presence of these determinants in a case where adaptive capacity in eutrophication was displayed: the case of Lake Erie, which went from severe eutrophication in the 1960s to a significant nutrient reduction in 1990s. A series of key informant interviews served to provide key data to validate these determinants. This study, far from providing all the answers to eutrophication governance, does however clearly point to a number of key findings.

The determinants of adaptive capacity as elucidated from the literature are crucial for fostering adaptive capacity and were present during the period of significant change for Lake Erie. There was significant public participation through IJC meetings, through demonstrations, and in other forums. Science was central to demonstrating that phosphorus was the limiting nutrient for eutrophication in Lake Erie. There were strong networks amongst the epistemic community, especially amongst the NGOs who created a sense of community that was critical to successful nutrient reduction. Learning was incorporated into the system as new information was produced and there was extensive monitoring and system feedback. There was clear leadership by the IJC, government organizations and key individuals and there were adequate resources that were vital to the success of all programs for effective nutrient reduction.

Having identified that these determinants are crucial to build adaptive capacity for eutrophication governance, a logical question is how present these determinants are now in the Lake Erie context, and what gaps can decision makers address. One key informant believes that the complexity of the situation today needs to be understood by the decision makers, that they need to understand the complexities of this wicked problem:

> *We are starting to understand the concept of multiple stressors. It used to be that if we control P we control eutrophication. It now has to do with invasive species, climate change and nutrients; now we have to transition away from the simple solution of the 1970s. We have to take a new approach. We know the approach of dealing with each issue separately; we need to get into multiple stressors, which is more complicated than we thought.* [GL1D7]

There is a definite gap in the resources available for the current eutrophication governance of Lake Erie. This was clearly expressed by several of the key informants:

> *We have a huge resource gap, we don't have the people and money to do this. When the economy tanks, environment spending crashes.* [GL2D8]
>
> *We had a lot more money for monitoring in the 1970 and 80s than in the 2000s.* [GL3D8]
>
> *Funding has been drastically cut. We used to get $1M per year in the 1970s but now less than $100 000 per year in 2014. Resources were incredibly important – I would also say they were better coordinated in those days than today.* [GL12D8]
>
> *There has been a cutback in the amount of funding government provides to support scientists, research and routine monitoring. Government has to scramble to start over again to return people to develop scientific capability.[*GL7D8]

This cutback in funding and lack of resources has important implications for eutrophication governance. The ability to do vital monitoring of ecosystem responses presents feedback loops that are essential for learning and building of adaptive capacity. Informants note that resources are simply not as available as they were during the 80s and 90s.
The interviews revealed that political leadership was paramount to the achievement of the objectives for building adaptive capacity for eutrophication governance. With strong political leadership there is more allocation of funding for environmental programs. It therefore becomes clear that the political framework within which eutrophication governance takes place needs to be adaptive to embrace large-scale and long-term changes and the increasing uncertainty of an issue like eutrophication. In the current context, key gaps that were identified for building adaptive capacity therefore included leadership, resources and flexibility.

This research does not intend to suggest that there exists a magic formula to ensure that key stakeholders govern to combat eutrophication. Simply put, what is required is the fostering of conditions that allow the determinants of adaptive capacity for eutrophication governance to be present. This means that the public should actively be allowed to participate through having a voice in decision making processes; that science and monitoring should be continued so that informed decisions are made and that feedback loops can be operationalized and adjusted to achieve sustainable nutrient reductions; and that there needs to be clear political and other leadership. In addition, it may be appropriate to empower the IJC to carry out is third party observer function, a role that was crucial to the successful nutrient reduction that occurred in Lake Erie in the 1990s. What is required is a different understanding of governance, one that emphasizes adaptability rather than command and control as this would not work in the highly complex, uncertain environment of eutrophication today.

Conclusion

This paper proposed and validated a number of determinants for adaptive capacity for eutrophication governance for the Great Lakes. The eutrophication of Lake Erie has all the markings of a wicked problem and as such, an adaptive governance approach is recommended. The framework was validated by application to the case of a severely eutrophic Great Lake that went from severe nutrient enrichment in the 1960s to significant nutrient reduction in the 1990s. The results demonstrate that all of the determinants of adaptive capacity – public participation, science, networks, leadership, flexibility and resources – were essential to the successful nutrient reduction of Lake Erie that occurred from the 1960s to the 1990s. This research informs the current eutrophication governance of Lake Erie by showing that there are significant gaps in funding, monitoring and leadership and that successful nutrient management as stipulated in Annex 4 of the Great Lakes Water Quality Agreement is more likely if these gaps are bridged.

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Electronic Green Journal, Issue 39, Fall 2015, ISSN: 1076-7975