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Thriving and prosperous: How we rallied to confront collective challenges

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ABSTRACT

Scenario analysis can be a useful tool to explore paths to a desirable future. This paper is a 'future history' describing the how stakeholders in the Great Lakes–St. Lawrence River basin of North America rallied to confront regional challenges 50 years into the future (2013–2063). This future scenario was developed by considering how nine drivers of change (aquatic invasive species; biological and chemical contaminants; climate change; demographics and societal values; economy; energy; governance and geopolitics; water quantity; and technology) might impact the region. This “thriving and prosperous” scenario envisions that in the beginning, Great Lakes residents, scientists, and policymakers saw “the writing on the wall,” recognizing that past approaches to environmental policy failed to provide long-term environmental, social, and economic prosperity. In response, policymakers in the Great Lakes region began formulating and implementing new policies, but actions were scattered across the region and uncoordinated across geopolitical boundaries. Recognizing the need to coordinate their efforts, Great Lakes stakeholders began “marching in step” by agreeing on a common set of guiding principles for future policy actions. Building on this momentum, Great Lakes policymakers implemented a suite of regulations and initiatives that recognized the Great Lakes region as a complex social–ecological system. Between 2053 and 2063, the region began to reap the benefits of coordinated policy action. By 2063, the Great Lakes region showed how a long-term commitment to improving the environment can sustain a thriving and prosperous ecosystem and economy.

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Introduction

By the year 2063 the Great Lakes–St. Lawrence River basin of North America is “thriving and prosperous,” delivering economic benefits while maintaining social and ecological integrity. Prosperity in the region has been fostered by cooperation between Great Lakes region residents, non-government organizations, academic institutions, government, and industry. Residents of the Great Lakes region have been an integral part of the policy making process over the past

50 years thanks in part to new technologies, including social media, that lower the barriers to participation in policy discussions. Non-government organizations continue to play an important advocacy role in promoting initiatives that improve quality-of-life in the region while protecting the environment. Academic institutions in the Great Lakes region support researchers who craft innovative solutions to complex social–ecological problems. Government provides incentives for social–ecological research and green technology development. Industry responds to public demand for ecologically responsible goods and services by implementing solutions proposed by researchers and experts (including local residents who may or may not have formal scientific training) and by taking advantage of government incentives.

The “thriving and prosperous” scenario described in this paper occupies the upper-right quadrant of a two-dimensional coordinate plane. The horizontal axis represents the human capacity to affect change, and the vertical axis represents environment and economic balance (as described in Laurent et al., *this issue*). We envision moving toward this upper-right quadrant through an amalgamation of newly applied policies spanning an intricate framework of institutions: from

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¹ The Great Lakes Futures Project brought together graduate students and expert mentors from universities and institutions in Canada and the United States. Each paper required collaboration between a number of authors with many of them sharing co-leadership that we denote using a ¹.

the average Great Lakes resident to researchers, policymakers, natural resource managers, and industry.

This paper covers a broad spectrum of topics with the goal of providing future researchers, policymakers, and advocates a foundation from which they can consider possible avenues to a desirable future for the Great Lakes region, not only within specific sectors (e.g. water quality, air quality, soil quality, and economic health), but as a whole (i.e. improving quality-of-life while sustaining environmental and economic health). This is crucial, as the Great Lakes region is known to be an interactive and dynamic system influenced by complex, non-linear interactions and relationships. While it is impossible to predict the future with absolute certainty, the development of plausible scenarios as a means of forward-thinking, as we have done in this special issue, provides a proactive approach to decision-making. The “thriving and prosperous” scenario presented here is characterized by a potent human capacity to affect change and an environment–economy balance that fosters prosperity.

A strong human capacity to affect change in the Great Lakes region was reflected in a set of guiding principles for policymaking established in the 2040 Great Lakes Region Sustainable Resources Agreement (GLRSRA). The GLRSRA was signed by the US and Canadian governments (federal and sub-national), Tribal Nations, and First Nations. The GLRSRA detailed principles for decision-making in the Great Lakes region, with a focus on promoting and enhancing human well-being and environmental health. In this “thriving and prosperous” scenario, scientists, industry, the public, and decision-makers are assumed to be capable of working together to understand, respond to, and prepare for future environmental, social, and economic challenges.

A desirable environment–economy balance was hard earned. Globally, natural resource scarcity led to (sometimes violent) conflict. This spurred mass migrations to regions with abundant natural resources, like the Great Lakes region. Despite growing human populations over the past 50 years, the Great Lakes region successfully eluded violent conflict over natural resources by avoiding three types of resource scarcity: supply induced scarcity, demand induced scarcity, and structural scarcity (Bernauer et al., 2012; Homer-Dixon, 1991, 1994). Policymakers and natural resource managers in the Great Lakes region successfully (a) maintained healthy stocks of water, timber, and wetlands (avoiding supply induced scarcity); (b) reduced per-capita consumption of natural resources (avoiding demand induced scarcity); and (c) ensured equitable distribution of natural resources throughout society (avoiding structural scarcity). The region's economy, once driven by fossil fuels, the automotive industry, and the shipping industry, is now driven by green energy, social–ecological research, green technology development, and clean transportation systems. A thriving economy balanced with a healthy ecosystem was crucial in providing resiliency to withstand unpredictable future events.

With a focus on precaution and adaptability, Great Lakes region stakeholders controlled and prevented invasive species introductions, reduced biological and chemical contamination, developed clean energy sources, modified agricultural practices, improved data-sharing and communication, upgraded transportation systems, and revitalized the economy. A thriving and prosperous Great Lakes region exists in 2063 because stakeholders (including residents, academics, business leaders, community leaders, non-government organizations, policymakers, and decision-makers) prioritized long-term ecosystem and human well-being. Through effective government and industry action, supported by research and strong public participation in decision-making, a balance between economic prosperity and environmental protection persists.

Scenario narrative

This section describes a future history of the Great Lakes region decade-by-decade from 2013 to 2063. Fig. 1 summarizes the major events described in this section. These events were conceived by

considering nine drivers of change in the Great Lakes region: aquatic invasive species (AIS); biological and chemical contaminants; climate change; demographics and societal values; economy; energy; governance and geopolitics; water quantity; and technology. Other articles in this special issue (Bartolai et al., in this issue; Campbell et al., in this issue; Cornwell et al., in this issue; Jetoo et al., in this issue; Kelly et al., in this issue; Maghrebi et al., in this issue; Méthot et al., in this issue; Pagnucco et al., in this issue) describe how these drivers impacted the Great Lakes region over the past 50 years (1960–2010) and project their impacts 50 years into the future. Although “technology” was not originally identified as a driver of change, it was added to the future histories found in this special issue after conferring with Great Lakes region stakeholders. The future states of some of these drivers of change were not fully described in the main text of this article due to length considerations. Thus, Appendix A describes in detail the state of each driver in 2063 (see Table A1 for a summary).

The writing on the wall (leading up to 2023)

“Most of us can read the writing on the wall; we just assume it's addressed to someone else” – Ivern Ball (Benson, 2010, p. 51)

By 2013, the Great Lakes region had faced serious environmental, social, and economic challenges. Environmental challenges included threats from AIS (e.g., quagga mussels and Asian carp) as noted in Mills et al. (1993), Pagnucco et al. (this issue), and Rixon et al. (2005); biological contamination (e.g., excess phosphorus and *Escherichia coli*) as noted in Cornwell et al. (this issue) and Whitman et al. (2003); chemical contamination (e.g., mercury and brominated flame retardants) as noted in Cornwell et al. (this issue); Stewart et al. (1999), and Zhu and Hites (2004); and climate change (e.g., uncertain impacts on the hydrologic cycle and habitat suitability for native species) as noted in Bartolai et al. (this issue); Hayhoe et al. (2010), and Mortsch and Quinn (1996). Social challenges included health risks from exposure to contaminated water, soil, and air (Dorevitch et al., 2012; Kelly et al., this issue; Martinez et al., 2012; Venier and Hites, 2010) and urban sprawl (Méthot et al., this issue). Economic challenges included municipal budget crises, like the City of Detroit declaring bankruptcy in 2013 (Patton, 2013), declining jobs in the manufacturing sector (Campbell et al., this issue), and substantial spending on invasive species control (Pimentel et al., 2005).

These problems were not new for the Great Lakes region; the US and Canadian governments had been trying to overcome these persistent environmental, social, and economic problems for some time. For example, the 1972 and 1978 Great Lakes Water Quality Agreement (GLWQA) and its implementation protocols (e.g. 1987 and 2012) aimed to improve Great Lakes water quality, in part, by cleaning up contaminated “areas of concern” in the US and Canada (Jetoo et al., in this issue). Despite numerous attempts to work across geopolitical boundaries and protect natural resources in the Great Lakes region (e.g. the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem, the Great Lakes–St. Lawrence River Basin Water Resources Compact, the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, the GLWQA and its Protocols, and the Great Lakes Restoration Initiative), overconsumption of natural resources continued, excluding and ignoring the needs of future generations.

By 2023, a number of particularly troubling events underlined the link between the environment and the economy and opened peoples' eyes to the sensitivity and vulnerability of the Great Lakes basin. First, in 2013, reports confirmed that Asian carp were reproducing in the Lake Erie basin (Fig. 1). These fish threatened to wreak havoc on the Great Lakes basin ecosystem and, by extension, the economy and society. Second, large toxic algal blooms became commonplace in locations such as Lake Erie, Saginaw Bay, the southern shore of Lake Ontario, and Lake Michigan near Chicago. A massive toxic algal bloom spread across most of Lake Erie in 2015, reminiscent of earlier large

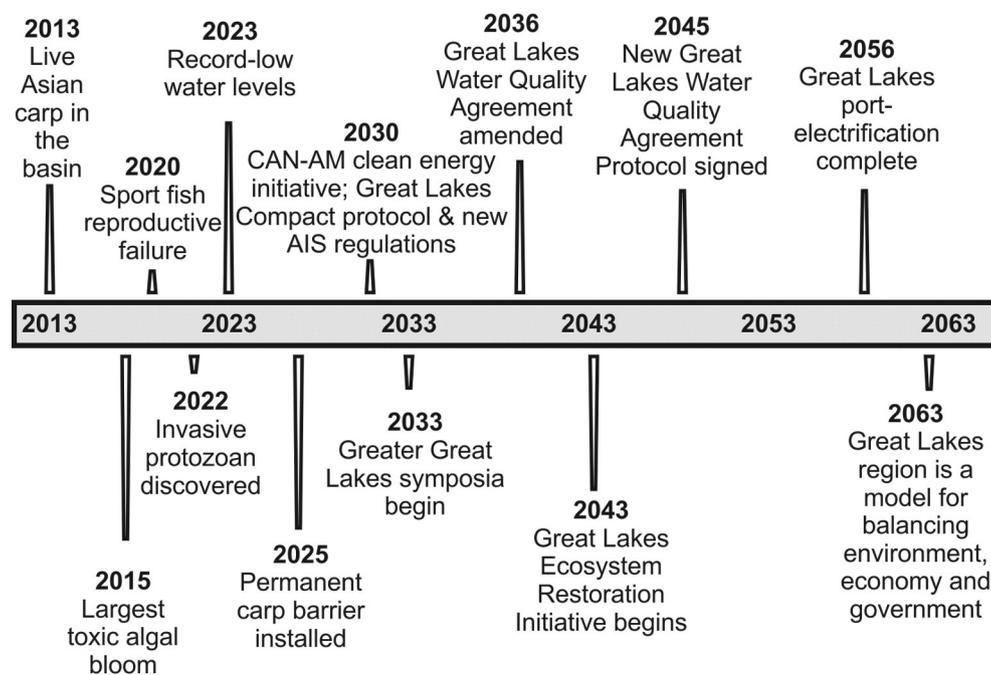


Fig. 1. Timeline of the events occurring from 2013 until 2063 within the Great Lakes–St. Lawrence region under the “thriving and prosperous” scenario.

blooms in 2011 and 2013 (IJC, 2014; Michalak et al., 2013; Steffen et al., 2014), causing drinking water plants to temporarily shut down. Further, the toxic algae reportedly led to the death of a number of pets who drank lake water and it resulted in lost tourism revenue. Third, there were widespread sport fish reproductive failures in 2020 (Fig. 1), which were believed to have been caused by toxic levels of anthropogenic chemical contaminants; the resulting population crash crippled sport and commercial fisheries. Fourth, a new microscopic biological invader was discovered in the Great Lakes basin in 2022 (Fig. 1). It was an invasive protozoan that affected low-trophic-level species in the basin and threatened to undermine the food web. The protozoan was likely introduced via ballast water from ocean-going vessels transiting the lower Great Lakes and the St. Lawrence River. It thrived in warm Great Lakes waters: average Great Lakes water temperatures were 2.5 °C warmer than in the previous decade, an alarming increase. Lastly, 2023 saw the lowest water levels in history in the Great Lakes basin (Fig. 1). Ships could not keep up with demand for bulk goods due to light-loading; many homeowners' docks no longer reached the water; some marinas where commercial fishers stored their boats were virtually dry; and the Fermi II nuclear reactor, located between Toledo and Detroit, suffered a near meltdown when record low water levels, coupled with a sudden oscillation of water caused by extreme winds, temporarily prevented the cooling intake pipes from getting enough water. These events sparked petitions from basin residents who demanded government action to protect public health, the Great Lakes regional economy, and their way of life.

Taking the first steps (2023–2033)

“The journey of a thousand miles begins with a single step” — Lao Tzu (Ni, 1979, ch.64)

The Great Lakes region is geographically large and populous, and it spans numerous geopolitical boundaries at multiple scales (e.g. municipal, state, provincial, tribal, national, and supranational). These factors made it difficult to formulate, implement and evaluate

environmental and economic policies at a regional scale, resulting in highly fragmented ecosystem and economic restoration initiatives in the region. A number of policies aimed at protecting the environment and promoting the economy had been attempted prior to 2023, but with limited success. These policies were criticized for treating the symptoms rather than the causes of environmental degradation and economic troubles. For example, projects to “restore” water quality often focused on temporary clean-up in specific areas of concern but did not address the sources of the increasing number of pharmaceutical and agricultural contaminants inundating the Great Lakes basin's waters.

While Great Lakes region stakeholders had seen the writing on the wall by 2023, decision-makers tried to tackle complex social–ecological challenges under existing governance frameworks. To restore the Great Lakes region sport fishery, lake trout continued to be stocked in large quantities each year. However, at this point, the effects of AIS and chemical contamination were affecting so many native organisms that stocking individual species was no longer effective. It was clear that a healthy commercial and sport fishery would require controlling AIS introductions and chemical contamination at their sources.

To prevent the inflow of Asian carp into Lake Michigan, the US Army Corps of Engineers and the Illinois Department of the Natural Resources finished the installation of a permanent hydrologic barrier in the Chicago Sanitary and Ship Canal in 2025. The barrier stemmed the flow of AIS through the canal but at the expense of short-term economic costs associated with disrupting shipping between the Illinois River and the Great Lakes and upgrading Chicago's sewage and storm water treatment and management facilities. However, the long-term benefit of protecting the Great Lakes ecosystem from Asian carp seemed to justify the costs of constructing new goods-transfer infrastructure and upgrading wastewater treatment facilities in Chicago. Ongoing Asian carp management was in effect in Lake Erie following years of research on effective control, and to curb future AIS introductions, new ballast water regulations were introduced in 2026 that required on-board ballast water treatment for ocean-going vessels or the use of variable buoyancy technologies, which eliminate the need for ballast (Parsons, 2010). While this requirement increased the cost to ship goods via

ocean-going vessels, shipping remained the least costly alternative for transporting bulk goods into the region. However, intra-basin travel was exempt from ballast water treatment policies and therefore ballast water discharges (and the biofouling of vessel hulls) continued to facilitate the transport of invasive species throughout the basin. This concern was confirmed following the discovery of another new invasive protozoan in Lake Ontario in 2027, which spread to Lake Huron in 2028 and Lake Michigan in 2029. Thus, beginning in 2030, the International Joint Commission recommended, and federal governments implemented, a suite of policies to minimize new AIS introductions and mitigate the impacts of already established invaders (Fig. 1). First, on-board ballast-water treatment policies were extended to include intra-basin movements: this affected the domestic Great Lakes basin shipping fleet, but again, shipping remained the preferred option for transporting bulk goods (iron ore, grain, aggregate, etc.) in the region. Next, a comprehensive list of threatening species was created. Listed species were immediately banned from all forms of live trade and movement, with strict penalties for violating these rules, including sizeable fines. Rapid-response protocols were created to enable quick response to new invasions, though managers across the basin emphasized prevention over control, as it is more expensive to control invasions than prevent them.

To meet the goals of the 2012 GLWQA Protocol, binational standards were established in 2031 to virtually eliminate harmful chemicals in the Great Lakes region. Legacy contaminants of concern were closely monitored using newly developed detection methods. Many novel chemicals of concern, including pesticides, personal care products, and pharmaceuticals, were listed based on the precautionary principle and slated for virtual elimination. Agencies created comprehensive regulations reducing or preventing the use of these chemicals of concern. Additionally, specific, attainable goals for reducing current contaminants were created, and they were informed by scientific research. During this time, innovative government and industry-based research programs produced viable alternatives to these chemicals.

To curb phosphorus and nitrogen loading to the lakes, non-point source agricultural runoff was reduced through the expanded use of nutrient management plans. Agricultural operations were required to calculate overall nutrient inputs and outputs and create individualized plans to reduce and manage excess nutrients. The 2012 GLWQA sparked state and provincial jurisdictions to require that all agricultural operations complete these nutrient management plans by 2024 and renew the plans every three years. Furthermore, nitrogen was added to the list of contaminants of concern under the GLWQA (in addition to phosphorus, which was already included). Government incentives and financial support to create these plans were put in place to minimize the cost to farmers. The initial costs of the transition program were justified by the reduction in fertilizer costs, the ecological resiliency gained by the new farm management practices, and safer drinking water. During this decade, expansions and upgrades to wastewater treatment facilities were completed on a case-by-case basis to further curb sewage effluents and reduce nutrient loading. However, without US and Canadian federal agricultural policy reform to lower the thresholds for nutrient surpluses, the problems of toxic algal blooms persisted in many areas.

To combat low lake levels, in 2026 the US Army Corps of Engineers, with the approval of the International Joint Commission, began diverting more water into Lake Superior from the Long Lac and Ogoki diversions and out through the St. Mary's River. While water levels were reduced in Long Lac and the Ogoki Reservoir, water levels throughout the entire Great Lakes basin were raised, helping maintain the ecological integrity of wetlands and bolstering the Great Lakes basin shipping industry. Additionally, Great Lakes region Governors and Premiers reaffirmed their commitment to preventing out-of-basin diversions by signing the Great Lakes Compact Protocol in 2030 (Fig. 1).

To begin tackling climate change and its associated regional effects, new policies incentivizing clean energy technology development and

implementation were established in 2023. These policies, chosen for their positive results over short time periods (see Changnon, 1995) had been implemented in some US states successfully. In 2023, rules were established creating an energy-efficiency rating system for residential, commercial, industrial, and public buildings (following Iowa's policy). This was funded by taxes on gas and electric utilities (Changnon, 1995). In 2025, once again following in Iowa's footsteps, all new construction of buildings, or renovations, required the submission of at least three proposals, one of which was required to reflect "the lowest life cycle cost possible using commercially available technology" (Changnon, 1995). Within this policy, taking after Connecticut, electrical energy efficient standards for substantially renovated buildings were determined for each class of electric customers. These standards were based on cost-effectiveness, building design, insulation, efficiency of lighting, heating, and the usage of electrical appliances (Changnon, 1995). Green tax credits and energy incentives (as proposed by the American Recovery and Reinvestment Act of 2009) were once again provided; penalties were applied to those not meeting basic standards. In 2030, these policies, among others, were incorporated in the CAN-AM Clean Energy Initiative, a binational agreement to support clean energy development and air pollution reduction in the Great Lakes region.

To respond to biological and chemical contamination, this decade saw increasing, yet scattered, local initiatives to clean up their communities. Small-scale plans were developed that improved short-term environmental quality while planning for long-term monitoring and adaptation. However, these plans were uncoordinated across governments. Eventually, local government officials began to understand that improving the environmental quality of their communities would require working with other municipalities, reaching across political borders, unifying intentions, and incorporating the viewpoints of multiple stakeholders.

Marching in step (2033–2043)

"We all do better when we work together. Our differences do matter, but our common humanity matters more." –President Bill Clinton (Benedetto, 2004, para. 20)

Until 2033, policies aimed at improving the environment and the economy of the Great Lakes region had seen varying success. While environmental quality (e.g. water quality, air quality, and soil quality) began to improve, the Great Lakes region needed innovative and creative pathways toward a desirable future. Between 2033 and 2035, the Transborder Research University Network (TRUN) for Water Stewardship Consortium facilitated a series of symposia called Greater Great Lakes (Fig. 1) that brought together Great Lakes basin stakeholders including business leaders, politicians, regulators, academics, community leaders, aboriginal peoples, and interest groups. Additionally, the general public was invited to participate in person or through social media. (The social media boom of the early 21st Century provided an excellent platform through which information could be disseminated and debated.) The symposia were incorporated into the meetings and conferences held at the annual Great Lakes Week. Because Great Lakes Week brings Great Lakes organizations and other stakeholders together from across the basin, the symposia were well attended.

The Greater Great Lakes symposia highlighted the importance of cooperation between stakeholders. The symposia were slated to end in 2035, but given their success, they were extended through an amendment to the 2012 GLWQA, which occurred in 2036. Since 2036, the biannual Greater Great Lakes symposia have been moderated by the binational Great Lakes Executive Committee (established by the 2012 GLWQA Protocol) and alternate between the US and Canada. Surveys of Great Lakes regional regulators and natural resource managers suggested that they appreciated the input of business leaders, academics, community leaders, interest groups, and the public. The

feeling seems to be mutual: 90% of stakeholders surveyed felt that their concerns were listened to by decision-makers and 80% felt that their ideas were incorporated into Great Lakes regional policies.

At these Greater Great Lakes symposia, a set of guiding principles for future policies was created. In 2040, these guiding principles were incorporated into the Great Lakes Region Sustainable Resources Agreement (GLRSRA, Fig. 1), which was signed by local, state/provincial, federal, tribal, and aboriginal governments in the US and Canada. Some of the guiding principles in the 2040 GLRSRA are complementary to the “principles and approaches” found in Article 2 of the 2012 GLWQA Protocol (e.g., participation, cooperation, and precaution), but they are farther reaching. For example, the guiding principles established in the GLRSRA advocate the following: enhancing well-being as the chief goal of public policy; applying a social–ecological systems approach to problem solving; expecting uncertainty and surprise in complex social–ecological systems; recognizing natural limits to growth; and acknowledging tradeoffs in policy decisions. The 2040 GLRSRA espoused the following eight guiding principles for future policy development:

1. *Well-being.* Improving well-being should be the chief goal of public policy and economy (Daniels, 2010a,b; DeCanio, 2009; Parrish, 2007). The well-being and quality-of-life of Great Lakes basin residents are of paramount importance, and well-being should not be traded off in the name of increasing gross regional product. In fact, Costanza (2008) argues that excess consumption can reduce well-being. Instead of using GDP, which can increase even when well-being decreases (think of expenditures for cleanups after natural disasters), other measures of well-being could be adopted. There are many proposed measures of well-being, including the Genuine Progress Indicator which separates market activity that reduces or improves well-being and estimates the value of non-market environmental and social goods and “bads” (Costanza, 2008). A similar Genuine Progress Indicator could be developed for the Great Lakes region, as Maryland has done (Maryland DNR, 2011).
2. *Participation.* To promote environmental justice, those who are impacted by policy decisions must be able to participate meaningfully in the decision-making process (Cutter, 1995). As Funtowicz and Ravetz (2003) note, in an age of post-normal science where “facts are uncertain, values in dispute, stakes high, and decisions urgent”, we must acknowledge, accept, and integrate the various ethical questions, ways of knowing, uncertainties, and legitimate differing viewpoints of stakeholders in environmental policy problem-solving. Further, the burdens of outreach and communication are to be placed on governments to ensure that those who will be affected by policies are well-informed and have the opportunity to voice their opinions.
3. *Social–ecological systems approach.* The environment is part of a complex social–ecological system (Collins et al., 2010). Policy decisions must move beyond an “ecosystems approach” and recognize that the Great Lakes region is part of a complex system that is sensitive to both ecological and social changes. While the ecosystems approach certainly considers human impacts on natural systems and uses scientific knowledge to inform policy, a social–ecological systems approach would go one step further and incorporate natural scientists, social scientists, policymakers, and non-expert stakeholders into policy decision-making in the Great Lakes region (Lash-Marshall et al., In prep.).
4. *Expect the unexpected.* Uncertainty and surprise are inherent in complex social–ecological systems (Swart et al., 2004). Acknowledging the role of uncertainty and surprise should be encouraged by adaptive management approaches in the Great Lakes region, promoting healthy ecological, social, and economic systems.
5. *Limits to growth.* Technology, labor, and capital cannot be substituted for natural resources indefinitely (Costanza et al., 1997; Dietz and Neumayer, 2007). The Great Lakes region has vast natural resources,

but there are natural limits that must be respected. These natural resources should be used in a sustainable manner, as overuse may trigger a tipping point from which Great Lakes basin ecosystems cannot recover (Bails et al., 2005; Krantzberg, 2012). Authors have noted that reduced economic growth or even degrowth does not necessarily mean reduced well-being, provided basic needs are met (as summarized by Schneider et al., 2010).

6. *Cooperation.* Transparency and sharing scientific knowledge facilitate proactive, instead of reactive, management of natural resources, especially when knowledge is co-produced by scientists and laypeople (Roux et al., 2006). Thus, we support initiatives that facilitate collaboration and learning between laypersons, researchers, policymakers, and resource managers rather than “knowledge transfer” from one group to another.
7. *Precaution.* Protecting the earth's life support systems is crucial to long-term sustainability (Dietz and Neumayer, 2007). Specifically, we want to continue protecting and improving air, water, and soil quality in the region. To do this, we agree that the precautionary principle should be the default position when considering new policies.
8. *Trade-offs, not win–win.* Policies rarely, if ever, produce truly “win–win” outcomes (McShane et al., 2011). Thus, policy alternatives should be evaluated in terms of social, environmental, and economic trade-offs. These trade-offs are already being made. Whether or not a policy is ethical may depend on the answer to the following question: who bears the brunt of the economic, environmental, and social costs?

The 2040 GLRSRA was used to evaluate the desirability of management decisions and policy proposals in the Great Lakes region. Since its adoption, significant progress has been made toward meeting the goals of policies related to ecological, social, and economic restoration. The act of bringing stakeholders together reshaped how policymakers and decision-makers in the Great Lakes region thought about good governance. New policy proposals were vetted against criteria found in the 2040 GLRSRA, and policies were monitored and adapted after implementation to ensure they achieved desirable environmental and economic results while minimizing environmental, social, and economic costs.

Setting ourselves up for success (2043–2053)

“Coming together is a beginning; keeping together is progress; working together is success.” – Henry Ford (Andersen, 2013, para. 5)

With the 2040 GLRSRA and the Greater Great Lakes symposia serving as a foundation, the Great Lakes region was poised to make big strides toward improving environmental, social, and economic quality. The Greater Great Lakes symposia sparked interest from the public, industry, and government to contribute to, and participate in, pollution and invasive species prevention research. There were also calls for research and development to create innovative green technologies. Thus, governments and industries invested in the academic future of the Great Lakes region by passing the Great Lakes Ecosystem Research Initiative (GLERI) in 2043, which unlike the US-only Great Lakes Restoration Initiative, was a binational venture (Fig. 1). The GLERI provided funding for research, ecosystem monitoring, and green-technology development. It also supported research activities aimed at preventing and reducing AIS introductions as well as biological and chemical contamination. Governments and industries recognized that the recurring costs of remediation and invasive species control could be better spent in research and program development. Supporting science-based and prevention-focused research and development fit nicely within the newly adopted GLRSRA framework.

To help specify a path forward, a revised GLWQA Protocol was signed by the US and Canada in 2045 with a particular focus on

agricultural runoff; greenhouse gases and air pollution; transportation; renewable energy; and data and information sharing (Fig. 1). Agricultural runoff was more effectively dealt with binationally by establishing nutrient thresholds similar to European standards, which greatly reduced the allowable levels of nutrient excess and runoff. Fines were assessed to agricultural operations that exceeded allowable nitrogen–phosphorus–potassium (N–P–K) levels, and nutrient management plans were more strictly monitored for compliance. New technologies made waste control more efficient, in many cases turning waste into biofuels or ensuring their re-use as compost. Farmers frequently incorporated ecologically-based management practices using buffer zones, catch crops, and crop rotations as nutrient management practices.

While the GLWQA historically dealt with water quality as its main concern, the 2045 GLWQA Protocol also tackled greenhouse gas emissions and other air pollutants: utilities and transportation were two major sources (Bartolai et al., in this issue). For utilities, building on the US Energy Policy Act of 2005 (as amended in 2025) and the CAN-AM Clean Energy Initiative of 2030, policies were implemented

to sustain the transition toward low-carbon energy sources, and utilities were also required to use a portion of their operating revenues to support the development of residential, commercial, and industrial energy-efficiency programs. The CAN-AM Clean Energy Initiative also limited emissions from passenger and freight transportation. By 2050, many passenger vehicles were powered, at least in part, by electricity. However, this was not the case for the freight transportation sector. Through the GLERI, port electrification projects were funded for major Great Lakes basin ports including Montreal, Hamilton, Cleveland, Toledo, Detroit, and Duluth in 2053, and completed by 2056 (Fig. 1). This allowed Great Lakes basin commercial marine vessels to plug in to shore-power delivered by the (now cleaner) electric grid. This greatly reduced air pollution in near-port communities, leading to health benefits. In 2053, electric rail projects were in the works for major freight corridors and the first long-haul electric freight rail in the region made its inaugural run between Toledo and Buffalo in 2058. Finally, heavy-duty trucks were finding novel ways to reduce their fuel consumption and emissions through new technologies, including all-



Fig. 2. Original artwork illustrating the outcomes of a “thriving and prosperous” scenario for the Great Lakes–St. Lawrence River region in the year 2063.

electric freight trucks.

The 2045 GLWQA Protocol also called for improved data sharing and communication among Great Lakes basin researchers, policy-makers, and natural resource managers. Great Lakes basin stakeholders (especially academics and natural resource managers) touted the importance of collecting and sharing data and information across the basin. Building off of existing data-sharing projects like the Great Lakes Observing System, a Great Lakes region-wide online database containing physical, biological, and social data (e.g. demographics) was launched in 2050. Data were made freely available to everyone (Fig. 1). Having a clearinghouse for Great Lakes regional data that was well organized and consistently updated served as a launch pad for multidisciplinary collaboration, helping solve socio-ecological problems in the region.

Lighting the way (2053–2063)

“Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed it’s the only thing that ever has.” – Margaret Mead (Sommers and Dineen, 1984, p. 158)

The Great Lakes region went from the “Rust Belt” to the “Green Belt” and became a model for integrating environmental, social, and economic values into long-term decision-making. As this decade passed, the Great Lakes region found itself reaping the rewards of its dedication and hard work. The ecosystem showed definitive signs of rehabilitation; academics flocked to the region with the promise of cutting-edge research opportunities; companies invested in green energy and green technology; and government implemented policies that reflected the collective values of Great Lakes basin stakeholders (Fig. 1).

By 2063, there were decades of collaboration among government, business, industry, interest groups, academia, and the public. Mostly, policies were chosen based on their potential to improve the long-term well-being of humans and ecosystems. Those living in the Great Lakes region invested in protecting vital, life-sustaining natural resources. The imperatives of environmental protection also facilitated the creation of a green economy where recreation and service industries were booming, green energy became a large source of revenue, and the Great Lakes region became a leader in innovative research and technology. Further, all levels of government recognized the importance of adaptive management practices to quickly respond to changes in complex social-ecological systems like the Great Lakes basin. Community partnerships, binational agreements, and strong public support allowed emerging problems to be solved collectively and were critical to developing a thriving and prosperous Great Lakes region (Fig. 2).

Conclusion

Over the past 50 years, decision-makers in the Great Lakes region have responded to environmental, social, and economic challenges, including invasive species, toxic algae, biological contaminants, chemical contaminants, fluctuating water levels, and climate change. At first, Great Lakes basin governments reacted defensively by implementing policies that were limited in scope, both geographically and temporally. Realizing that the *status quo* was failing, decision-makers, business leaders, community representatives, politicians, natural resource managers, academics, and the public got together and developed a set of guiding principles that would be used to judge the desirability of new policies. Two important principles were (1) any policy must improve the long-term well-being of Great Lakes basin residents and; (2) decision-makers must be upfront about the trade-offs of policy alternatives (i.e., who wins and who loses). Once this framework for policy formulation, implementation, and evaluation was established, a suite of policies that recognized the Great Lakes region as a complex social-ecological system were implemented. These policies adhered to

the precautionary principle, recognized that there are natural limits to growth, and focused on cooperative adaptive management. Great Lakes regional leaders leveraged public participation, fostered strong support for academic research, collaborated with business and industry, and promoted value-driven policy analysis to create a thriving and prosperous environment, economy, and society (Fig. 2).

This future-visioning scenario is intended to spark debate among Great Lakes basin stakeholders and present some pathways toward a desirable future for the basin. While some of the events and solutions mentioned here might seem unlikely or unattainable under present geopolitical circumstances, we felt it was important to put forth a few bold ideas nonetheless. In future work, some of the solutions presented in this paper will need to be compared to alternative policies and their trade-offs will need to be made explicit. Identifying the reasons why some of our ideas might, or might not, work in practice will be helpful as Great Lakes basin stakeholders search for ways to work together to protect and promote human, ecosystem, and economic well-being. Our hope is that future researchers, policymakers, natural resource managers, and non-expert stakeholders can use this paper as a reference to draw ideas and inspiration about ways to achieve a more thriving and prosperous Great Lakes region.

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Appendix A. Drivers of change

Table A1

The state of nine drivers of change in the Great Lakes region in 2063.

Driver	Description
Aquatic invasive species	Negative consequences of invasive species have been minimized <i>via</i> specialized management committees aimed at identifying threats and initiating rapid response programs. US and Canadian regulations on shipping and live trade, coupled with public awareness programs, have minimized new introductions.
Biological and chemical contaminants	Biological contaminants such as phosphorus and nitrogen have been reduced through agricultural policy. Legacy contaminants and contaminants of emerging concern have been eliminated, reduced, or prevented from being introduced throughout the Great Lakes region, resulting in delisting some of areas of concern, regulating chemicals produced by industries, and using less harmful personal care products and pharmaceuticals. Wastewater treatment and cleanup programs have improved water quality.

(continued on next page)

Table A1 (continued)

Driver	Description
Climate change	The Great Lakes region has adapted well to climate change, owing to adaptive and preventative measures taken at the national, regional, and especially local levels. Measures to mitigate climate change include implementation of policies aimed at reducing anthropogenic emissions as well as investment in green energy sources.
Demographics and societal values	While there are over 60 million people living in the Great Lakes region in 2063, with many so-called “climate refugees,” a shift toward a more communitarian and egalitarian worldview for most Great Lakes region residents, coupled with a focus on ethical decision-making, has enabled population growth without environmental catastrophe.
Economy	A focus on reducing greenhouse gases has led to a thriving economy centered on green energy sources rather than fossil fuels. Further, improved air, water, and soil quality has helped the economy by reducing the negative impacts of environmental degradation and promoting responsible business development, tourism, and recreation.
Energy	National and regional energy policies have paved the way toward investment in green energy and energy efficiency in electricity generation, transportation, industrial, commercial, and residential sectors.
Governance and geopolitics	A strong, peaceful relationship persists among and between all levels of government in the Great Lakes region. Governance focuses on improving well-being, enhancing participation in decision-making, applying a social–ecological systems-thinking approach to policy analysis, recognizing natural limits to growth, and considering the trade-offs of policy decisions rather than claiming “win–win” solutions.
Water quantity	Great Lakes basin surface water has remained within the basin and has not been diverted to other regions. Additionally, scientists continue to accurately predict water level fluctuations, leading to effective planning and management of activities that rely on water quantity (shipping, fishing, recreation, etc.). Groundwater protection has been strengthened with policies limiting aquifer withdrawals by private companies.
Technology	A number of new technologies have emerged that have helped improve environmental and economic prosperity. In particular, social media platforms have facilitated the sharing of data, analyses, and recommendations among and between scientists and policymakers. Technologies developed over the subsequent decades at universities in the region have helped propel the Great Lakes region to the forefront of developing green energy solutions.

A2. Drivers of change in the year 2063

Aquatic invasive species

In the past, invasive species were a powerful driver of change in the Great Lakes–St. Lawrence River basin. Aquatic invasive species caused ecosystem disruptions, food web imbalances, and economic losses in the Great Lakes states estimated at \$100 million dollars per year in 2012 (Rosaen et al., 2012). Ballast water exchange regulations of 2006 and 2008 were effective at reducing the influence of this vector, and the addition of these regulations to include all ships traveling within the Great Lakes basin curbed new species introductions. The threat of further invasions caused governments to respond by closing the Chicago Sanitary and Ship Canal to prevent new species entering the basin. Waters are closely monitored so that rapid response programs can be initiated if new species are introduced. Public education and outreach programs help to mitigate further spread.

Biological and chemical contaminants

The reduction of contaminants in the Great Lakes basin can be attributed to effective, collaborative regulation across the basin. By

strengthening cooperation among all levels of government, chemical and nutrient loading into the Great Lakes basin has been reduced. Specific, attainable goals for reducing current contaminant levels were established and were effective. Additionally, new potentially harmful chemicals were banned by applying the precautionary principle, and agricultural operations are monitored and regulated to prevent nutrient runoff. Biological contaminants have been reduced by on-board ballast water treatment technologies including UV filtration, ozonation, and biocides (Gonçalves and Gagnon, 2012). Lastly, new technologies have replaced chemicals, including pharmaceuticals, flame retardants, personal care products and plastics with safer alternatives.

Climate change

Climate change in the Great Lakes region has already impacted the system and its effects continued (e.g. see Angel and Kunkel, 2010; Bartolai et al., this issue; Brown et al., 2010; Changnon, 2004; Hay et al., 2001; MacCracken et al., 2003; Maghrebi et al., this issue; Smith, 1991). Lake levels decreased, affecting drinking water, recreation, and shipping (Campbell et al., this issue; Smith, 1991; Upper Great Lakes Study Board, 2012). Changes in precipitation and temperature impacted the agriculture and tourism industries, particularly growing seasons and winter recreation. These changes led local governments to implement adaptation strategies. Policies to reduce anthropogenic greenhouse emissions, first implemented in various regions of the US (see Changnon, 1995), were put in place after the aforementioned adaptation, and have been successful.

Demographics and societal values

Over the past 50 years, the population of the Great Lakes region has grown, particularly on the Canadian side of the border. The population of the region has grown from approximately 48.5 million in 2010 (30.8 million in the US and 17.7 million in Canada) to about 62 million people by 2060 (35 million in the US and 27 million in Canada) as predicted by Méthot et al. (this issue). Relatively higher immigration to Canada has led to a smaller population gap between the US and Canadian portions of the region. Additionally, immigration has led to greater diversity on both sides of the border, particularly on the Canadian side. Méthot et al. (this issue) put forth a “Friendly Folks” scenario where people in the Great Lakes region work cooperatively, are non-materialistic, and care about the environment. Greater population growth on the Canadian side of the border helped drive a shift toward a more egalitarian and communitarian world view for the basin. Canadians as a whole are considered more egalitarian and communitarian than Americans (Lipset, 1990), and Canada sought immigrants who are more likely to assimilate to the existing culture (MacDonald, 2013). Because many of those who immigrated to Canada had or developed communitarian worldviews, cooperation in the region improved.

Economy

The economy is thriving and prosperous as a result of effective environmental policies and initiatives that have made the Great Lakes region a desirable place to live. In addition, there are a number of excellent research universities and high-tech industries in the Great Lakes region in 2063 that are focused on developing green technology. While it took a few decades to see strong economic growth, the Great Lakes region now benefits from the hard work of preventing environmental catastrophes before they happen.

Energy

Energy was a major factor driving a thriving and prosperous Great Lakes Region. Energy sources in the Great Lakes region in 2013 revolved around fossil fuels, and cities within the region had previously been the

central hubs of the automotive industry. Over time, policies incentivized renewable energy and energy efficiency. New practices by the energy, transportation, and construction industries enabled green technologies to slowly meld into the economy, providing a transition that was economically feasible and regionally sustainable. This transition allowed the Great Lakes region to evolve into a world leader in green energy.

Governance and geopolitics

The Great Lakes region has benefited from a relatively peaceful world and an emerging culture of cooperation in the region itself. Over the past 50 years, the various governments of the region (national, provincial, state, tribal) have maintained peace within and across their borders. Improving the quality and efficiency of governance in the Great Lakes region has been a major focus over the last 50 years. Policymakers and regulators recognized that institutional fragmentation and overlapping jurisdictions complicated governance in the region. Thus, through an amendment to the 2012 GLWQA, an annual forum was created where Canadian, US, and tribal governments at all scales, as well as academics, business leaders, community leaders, and the public, came together to discuss common problems. Further, to help meet the objectives established in earlier agreements and initiatives, the 2040 GLRSRA was established. The GLRSRA incorporated principles into Great Lakes basin decision-making that have been recognized as crucial to developing and maintaining the quality of social–ecological systems. Great Lakes regional governance focuses on improving well-being, enhancing participation in decision-making, applying a systems-thinking approach to policy analysis and management, recognizing natural limits to growth, enhancing intergovernmental cooperation, applying the precautionary principle, and encouraging the consideration of policy trade-offs rather than claiming “win–win” solutions.

Water quantity

Water quantity affects industry, recreation, tourism, and drinking water supplies. Given water's importance, steps were taken to maintain water quantity in the face of climate change. For example, the Governors and Premiers of the Great Lakes states and provinces reaffirmed their commitment to prevent out-of-basin water diversions from the Great Lakes basin. Within the basin itself, policies revolving around the protection of groundwater were put in place. Included in these policies were limits to groundwater withdrawals from aquifers by private companies.

Technology

Social media technologies provided an efficient means of communication between Great Lakes region stakeholders and decision-makers. Additionally, by investing in research and development of new technologies, the Great Lakes region was poised to overcome the collapse of the automotive sector in the early 2000s. Supported by government incentives and industry–academy partnerships, businesses began developing green technologies. Technological developments spanned the industrial, transportation, commercial, and residential sectors, and these technological advancements helped propel the region toward a clean technology future, driving environmental, social, and economic prosperity.

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