Formal Integration of Science and Management Systems Needed to Achieve Thriving and Prosperous Great Lakes

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For over a century, governments on both sides of the Canada–US border have employed diverse policy instruments and management tools to protect the Great Lakes. This crucial freshwater resource continues to show signs of degradation. We explore how the International Organization for Standardization Risk Management Standard (ISO 31000) can be used by governments to reduce the risk of failing to achieve the policy objectives of the Great Lakes. ISO 31000 facilitates the analysis of human activities that drive the causal pathways of ecosystem pressures–effects–impacts and analyzes the links between these causal pathways and the performance of management measures operating within the Great Lakes. ISO 31000 allows governments to shed light on why, despite best intentions, management measures are not working and enables governments to continually improve the management system until the risks of policy failures are reduced to acceptable levels, bringing new hope to the future of the Great Lakes.

Keywords: freshwater, sustainability, risk management, ISO 31000, ISO 31010, Great Lakes

The Great Lakes are part of a complex, decentralized socioeconomic transboundary system (Friedman and Creed 2015). Over the past several decades, extensive efforts have been undertaken to move the needle toward a sustainable basin. Governments on both sides of the Canada–US border (local, state, provincial, and national) have employed various policy and management tools collectively and individually to protect the crucial resource (figure 1), with the recognition that the sustainability—indeed, the thrivability—of this transboundary region is directly dependent on its water resources.

Despite a century of treaties, agreements, legislation, regulation, protocols, and management measures, the Great Lakes continue to show signs of deterioration (Allan et al. 2013). Old challenges are re-emerging, and new challenges are on the horizon; there is wide concern that the Great Lakes might be close to a tipping point (Bails et al. 2005). The Great Lakes basin continues to be affected by large-scale environmental changes, such as demographic and land-use changes, biological and chemical contaminants, invasive species, the elimination of native species, food-web collapse, and climate-change impacts, all factors with multiple and interacting effects that threaten the resilience of the basin and the transboundary region (Creed and Laurent 2015). The mounting challenges lead one to question whether current policies are capable of producing sustainable water resources (Bails et al. 2005). Despite best intentions, the problem lies in our inability to connect the science and management pieces of the puzzle to the policy objectives in the face of declining social, economic, and ecological conditions (Friedman et al. 2015).

The Great Lakes Futures Project was a grassroots project that engaged over 100 stakeholders from Canadian and US governments, nongovernment organizations, and academia to suggest areas of governance reform to achieve a sustainable basin using scenario analysis in a transboundary context (Creed and Laurent 2015). The scenario analysis explored different assumptions about how causal relationships work and result in different outcomes (i.e., scenario logic, characteristics, and storylines; see e.g., Laurent et al. 2015). Participants created stories of alternative futures considering the following questions: What forces are driving changes? What are the key uncertainties associated with these drivers? How could these forces change the future from...
And if the future unfolds as was described in the scenarios, then what would we do about it? A consensus emerged that the Great Lakes basin is heading toward an “out-of-control” future earmarked by the failure of humans to enact change, with a striking imbalance between the environment and the economy (Kalafatis et al. 2015). There are fractures in the policy regime governing the Great Lakes basin—including reactive government policies with inadequate resources to implement policies and to conduct the supporting science and management; numerous and nonaligning mandates for Great Lakes basin policy at the federal, state, provincial, and municipal government levels; and a lack of policy “space” to accommodate both top-down and bottom-up perspectives—which is leading us toward an “undesirable” future (Friedman et al. 2015).

While Great Lakes basin governments mobilize, the existing governance structures are likely to be ineffectual in implementing the required large-scale transboundary actions. Policies are fragmented vertically and horizontally, and their implementation is hindered by inadequate capacity, accountability, and enforcement (Friedman et al. 2015). Dogma suggests that if policies are in place, the problem will be rectified; however, if management measures do not adequately address the challenges, then ecosystem problems persist. We suggest that to achieve policy objectives, we need a systems approach to assess the performance of existing management measures in light of ecosystem risks.

The integration of science and management systems

The ecosystem approach to resource management—which recognizes that all components of an ecosystem are interrelated and must therefore be considered when protecting or restoring ecosystems (Christensen et al. 1996)—has been the cornerstone of ecosystem-policy development for a generation. This ecosystem approach must consider the entire system of management measures (table 1), which incorporates input controls (amount of human activity that is permitted by governments), the spatial and temporal distribution of checks (where and when management measures should occur), and output controls (the amount of perturbation that is permitted by governments), as well as how these are integrated into the causal pathways influencing ecosystem pressures, effects, and impacts to prevent or mitigate risks associated with human activities (ICES 2015). To be effective, the science and management aspects of the ecosystem approach need to be explicitly linked.

We recognize the need for scientists and managers to work within existing governance structures to improve the
performance of management measures. Too often, there is a gap between science and management (Friedman et al. 2015). Science may not be asking questions relevant to policymakers. Managers may not be advising what their management needs are. Both need to fill knowledge gaps and mobilize knowledge for effective policies and management strategies that will lead to the sustainability of the Great Lakes basin.

The International Organization for Standardization (ISO) Risk Management Standard (ISO 31000; ISO 2009a) can be applied to adaptively formulate, implement, and evaluate a system of management measures within an ecosystem context (figure 2; Cormier et al. 2013). ISO 31000 is a suite of documents that includes principles and guidelines (ISO 2009a), vocabulary and definitions (ISO 2009b), as well as risk-assessment techniques (IEC and ISO 2009). ISO 31000 provides a framework and processes for the management of any form of risk in a transparent manner and within the scope of a policy objective. The standard provides managers with the assurance that risks are managed effectively, efficiently, and coherently across a given organization and policy context. The policy and stakeholder context are set prior to starting the assessment. In ISO 31000, risks are identified within the scope of the policy, considering the risk perception of the stakeholders. The subsequent analysis of the risks is to determine the nature and level of risks as is typically done in ecosystem assessments. The difference, however, is that the risks are also analyzed in relation to the effectiveness of the existing management measures. This sets the stage for a risk evaluation that considers these against risk criteria derived from policy to inform decisions as to the course of action to take. Policy context and objectives as well as stakeholder consultation drive the process in ISO 31000 and not the assessment (or the science).

Risk management starts with selecting the policy objective for which failure to achieve will create an undesired “risk event” and then, through a structured series of steps, identifies, analyzes, evaluates, and treats the risk (figure 2) within the established policy context. Remarkably, our evaluation of Great Lakes basin literature revealed a strong bias in risk-management outputs on identifying risks rather than reducing risks, with the following allocation of outputs: establishing the ecosystem management context (15%), risk identification (92%), risk analysis (11%), risk evaluation (3%), and risk treatment (13%). These activities were supported by communication and consultation with stakeholders (15%) and review and monitoring of management-plan implementation and effects (9%). In summary, 92% of the outputs focused on ecosystem management context or risk identification; only 19% on risk analysis, evaluation, or treatment; and 18% on communication/consultation or review/monitoring (figure 3, supplemental material S1).

We propose the adoption of ISO 31000 by all governance structures in the Great Lakes basin to guide a “course correction” toward a thriving Great Lakes basin to support the development of effective policies and management strategies. Science-based risk assessment is about identifying risks and analyzing the nature and level of the risks. An integrated science and management–based risk assessment is about evaluating the severity of the assessed risks in light of policy objectives to inform management that seeks to improve the performance of the management system. Management-based risk assessment still requires scientific knowledge; it makes full use of science by linking relevant elements of scientific knowledge to the advice being sought by management to improve the performance of the management system. ISO 31000 offers a structured systems approach to the analysis of management measures to reduce risk to the Great Lakes basin (IEC and ISO 2009). To our knowledge, ISO 31000 has never been applied to freshwater ecosystem management; however, it is currently being developed to achieve policy objectives in the coastal marine waters of North America (DFO 2013, DFO 2014, DFO 2015) and Europe (Cormier et al. 2013, ICES 2015). With the application of ISO 31000 and its analysis tools, the ability of current governance structures operating within the Great Lakes basin.
basin to meet their policy targets can be evaluated and necessary strategies suggested to manage cumulative impacts.

ISO 31000 adapted for ecosystem management

Step 1: Management context. The first step of ISO 31000 seeks to answer, “What are the risks, who is responsible for managing them, and what are we trying to achieve?” One of the most important and novel aspects of ISO 31000 is that the management context is set before starting the risk assessment. This ensures that it is the policy and consultation with the stakeholders that guide the management process, not the science. This is an important distinction point between management and assessment, with the latter guided by the science. Establishing the management context requires selecting the policy objective, identifying the jurisdictions responsible for setting the policy objective, implementing management measures to prevent its failure and mitigate resulting impacts, and identifying the relevant stakeholder constituency within the ecosystem. Based on the ISO 31000, risk management has to be done with the participation of all relevant authorities with the power to enact change if needed. This aligns the ISO 31000 approach directly with the processes of public-policy development, in which it is the political process informed by stakeholders that sets the public-policy objectives and establishes programs operating within the governance structure or government departments to develop management strategies to achieve policy objectives.

Step 2: Risk identification. The second step is identifying the risk: “Where do the vulnerabilities lay that may result in failure to meet the policy objective?” A system is only as strong as its weakest link. To identify the risk (the potential for a worsening effect), we need to have a predictive understanding of the causal links among pressures, effects, and impacts to identify where the weak link within the management system (i.e., the Achilles heel) may exist, which, if not managed correctly, may produce an undesired risk event.

In order to identify risk, symptoms of risk potential need to be identified and monitored as a system. In medicine, there are structures (e.g., cardiovascular systems) and functions (e.g., blood pressure) within the human body that, if under stress (i.e., disease), can result in failure of the system as a whole, meaning death. In medical terms, human health is detected not by a description of individual structures and functions but rather by the detection of pathologies (the presence or absence of symptoms of a disease) that have measurable indicators (e.g., blood pressure) and well-defined thresholds (e.g., normal pressure is 120/80). Focusing on the pathologies allows us to identify appropriate treatment priorities for the protection and preservation of human health. Following the human-health analogy, ecosystem science is devoted to the study of ecosystem structure and function as a means to embrace the understanding of ecosystem health—a socioecological concept that considers the desired “endpoint of ecosystem management” based on ecological services important for human health and well-being (Rapport et al. 1998). Rather than focusing on describing the ecosystem structure and function, one should focus on the symptoms that can be linked to the underlying mechanisms driving the changes in the state of the ecosystem. Such pathological observations would focus on an ecosystem’s structures and functions that are most susceptible to the pressures resulting from human activities that lead to undesired effects (or simply the Achilles heel of the ecosystem).

Risk identification may need a shift in “science” thinking, from focusing on cumulative impacts to focusing on cumulative pressures and their effects that result in changes in the state of the ecosystem, despite protective or restorative measures.
A suite of ecosystem “performance” indicators is required to diagnose the pressures that lead to undesired changes in the measured effects and undesired impacts. This suite of indicators requires an understanding of the prevention and mitigation measures that are being implemented to reduce the pressures and thus reduce the likelihood of the risk event. Advances in ecosystem models that incorporate additive, synergistic, or antagonistic interactions among indicators, natural and anthropogenic drivers of change, internally and externally driven feedback, deterministic and stochastic properties, linear and nonlinear behavior, and uncertainty are needed to simulate the potential trajectories of the indicators. Such models should reveal the pathways among pressures, effects, and impacts (e.g., Cormier et al. 2013, Kelble et al. 2013, Cook et al. 2014). They should capture the spatial heterogeneity and temporal variability of the ecosystem, as well as the diversity of the agents acting in it (Schlüter et al. 2012). Such ecosystem models are crucial to achieving a better understanding of the ecosystem and assist in illuminating the consequences of management decisions.

Step 3: Risk analysis. The third step is analyzing the risk: “What is the effectiveness and compliance of management measures that act as barriers to a risk event, and what is the probability the objective will not be met?” Models can be used to select the management strategies that minimize risk to the ecosystem. With the causal pathways among pressures–effects–impacts revealed, we can now use the models to analyze the performance of the system of management measures. Risk analysis is based on the following logic: If cumulative effects are the result of the residual pressures after implementing existing management measures, then we need to enhance the system of management measures to reduce pressures below detectable effects (prevention) or reduce the effects to minimize impacts (mitigation). We believe that governments would benefit by a process that sheds light on those specific management measures that are relevant and useful in addressing policy objectives.

Risk analysis requires two considerations: First, we need to discriminate between natural versus anthropogenic contributions, thereby estimating the total pressure on the ecosystem (with the models and indicators from Step 2). Second, we need to analyze the system of management measures that collectively act to reduce the pressure below an acceptable level, which may be a baseline of natural contributions or some other level that acknowledges competing priorities and accepts that the level may have to allow for some degree of human activity to persist in order to maintain economic progress while minimizing ecosystem impacts. This analysis must consider both hard controls (strategies based on actions or structures that prevent or reduce the pressure based on design criteria set by science and engineering) that contribute to the effectiveness of the management measure, as well as soft controls (strategies based on enabling, facilitating, and tracking activities) that contribute to the compliance of the management measure (table 1). This analysis must also consider measures designed to prevent (pressures-to-effects) or mitigate (effects-to-impacts) the risk event.

Risk analysis reveals the probability of failing to meet the policy objective by considering both the likelihood and magnitude of the risk event. The likelihood of a risk event (e.g., ranging from almost never observed and occurring only in exceptional circumstances to occurring regularly) and the magnitude of the impacts of this risk event (e.g., pristine, nominal response, and catastrophic response) will inform the management outcome. The models enable us to answer what-if questions using different scenarios and give an estimation of the risk based on adoption of different management measures.

The formal integration of science and management in this manner will allow ecosystem managers to identify potential weaknesses in the performance of the management system regarding gaps in scientific knowledge, lack of resources to monitor effectiveness or compliance of specific management measures, and opportunities for innovation to enhance the performance of the management system.
Ecosystems are complex systems of interactions that are entrenched with uncertainty, constraining predictability (McLaughlin and Krantzberg 2011). There is uncertainty in the science measurements needed to establish the constantly changing baseline and to estimate the cumulative pressures, as well as the management measurements needed to estimate the performance of the management measures used to reduce the cumulative pressures. By embracing these uncertainties (rather than assuming they do not exist), we can incorporate the precautionary principle (UN 1992) in risk management by setting low thresholds of risk tolerance levels (figure 4) approved by the authorities and stakeholders involved in a given governance process. Based on the placement of the effect within the risk-tolerance matrix, necessary management decisions around managing the risk become apparent and include the following: no management measures are required; existing management measures are adequate; existing management measures need enhancement; or additional management measures are needed (figure 4).

Risk criteria are used to reach a common understanding of the severity of the risks to inform a decision and, in doing so, consider not only ecological consequences but also the social and economic implications. Risk severity considers society’s “tolerance” of the risk. This is where the focus switches from ecosystem vulnerabilities to ecosystem-services vulnerabilities that are valued by society. The question then becomes “so what?” concerning the ecosystem services that may be reduced or lost if the significant ecosystem functions are not safeguarded. Stakeholders need to consider the risk in terms of ecological outcomes (e.g., frequency and magnitude of algal blooms) and the social and economic consequences of preventing/mitigating this damage (e.g., costs versus benefits and time required for the management measure to become “effective”). A stakeholder-informed understanding of the ecological, social, and economic values provides the necessary insight for scientists and managers to design optimal risk-treatment options.

Step 5: Risk treatment. The final step is treating the risk: “How do we change the management system to reduce the risk event to a level consistent with societal values?” Risk treatment implements changes to the system of management measures in order to make further progress toward preventing a risk event or mitigating its impacts. Regulators or those that have regulatory and evaluation functions in those departments implement risk treatment. These subject-matter experts are not the people who are tasked with policy development or science support. In the decision to use

Figure 4. Risk-tolerance matrices depicting the likelihood and magnitude of the effects of a risk event. Coloration within the matrices indicates the level of change required of existing management measures, from red (not tolerable, management measure needs to be changed) and orange (new management measure needed) to yellow (existing management measure adequate) and green (no management measure needed). An example showing an effect (E) that is located within the risk matrix in which new prevention measures (P) are needed to reduce the likelihood of the effect or new mitigation measures (M) are needed to reduce the magnitude of the impact (modified after ICES 2014).
ISO 31000 requires monitoring and review, as well as adaptive management accountability for implementation and monitoring. Implemented within a governance structure that includes relevant policy and management professionals.

Adaptive management
ISO 31000 requires monitoring and review, as well as communication and consultation activities, at each step, which determines whether the overall application of the standard (after risk treatment) is achieving the overall policy objectives. Based on a continuous improvement approach, such an iterative review of the performance of the management system is undertaken, and, if necessary, steps are taken to improve the performance of the management measures to reach the management target (and achieve the policy objectives), thus following adaptive management principles (Holling 1978). This iterative process requires frequent communication within the team as well as consultation with relevant policy and management professionals.

Figure 5. The ISO 31010 Bowtie Analysis for evaluating the performance of the management system (IEC and ISO 2009). Drivers are social, cultural, economic, and political influences that drive human activities. Pressures are physical, chemical, or biological agents that are introduced into the ecosystem as the result of human activities that trigger an undesirable effect. The effect is the risk event that results because of the residual pressures after implementing existing management measures. Impacts are potential harmful impacts that occur as a result of the undesirable effect. Prevention controls act to reduce the effect. Mitigation controls act to decrease the severity of the impacts as a result of the effect. Escalation factors are outside influences that undermine the performance of prevention or mitigation controls.

Figure 5

Existing management measures or to develop enhanced or new ones, risk treatment considers both the likelihood and magnitude of the impacts identified in the risk-analysis step and the severity of the risks identified in the risk-evaluation step (figure 4). Management measures are developed and implemented within a governance structure that includes accountability for implementation and monitoring.

ISO 31000 could guide risk management in the 2012 Great Lakes Water Quality Agreement
We encourage the Canadian and US governments to use the ISO 31000 Risk Management Standard combined with the ISO 31010 Bowtie Analysis (figure 5) to conduct a comprehensive risk-management analysis of the Great Lakes basin. These tools will enable a coordinated process for both the Canadian and US governments at multiple jurisdictional scales to combine science and management efforts to understand and reduce the cumulative pressures associated with increased pressures in the Great Lakes basin.

We showcase the importance of considering the entire system of management measures when adopting ISO 31000 by mapping the articles and annexes of the 2012 Great Lakes Water Quality Agreement (GLWQA) into each of the steps of the standard. This analysis showed that the 2012 GLWQA does an excellent job of covering some but not all steps of risk management. For instance, the GLWQA has extensive coverage of setting the context and the risk-identification steps, but risk analysis is absent and risk evaluation covered minimally (box 1). This analysis showcases the importance of considering the entire system of management measures when applying ISO 31000, because although the GLWQA does not cover all steps of the standard, management measures operating at different jurisdictional levels do. It can then be surmised that mapping federal, provincial, state, conservation-authority, and municipal laws and regulations will round out the analysis for a complete risk-management assessment.

By focusing on one of the Annexes of the 2012 GLWQA, Annex 4 Nutrients, we showcase how the ISO 31010 Bowtie Analysis Tool can potentially be used to complete the risk-analysis step in which the system of management measures at different jurisdiction scales is mapped over the pressures–effects–impacts of phosphorus loading in the Great Lakes basin (box 2). Bowtie Analysis is one of the 30 techniques listed in the ISO 31000 Risk Management Standard that considers the system of management measures in relation to multiple pressures and impacts as a result of a given effect (risk event; figure 5). The Bowtie Analysis is particularly well suited for an ecosystem approach because it can integrate multiple pressures and effects and their impacts in one diagrammatic representation. We conducted a preliminary ISO 31010 Bowtie Analysis on 137 federal, provincial, and state management measures related to point source and nonpoint source phosphorus loading to the Great Lakes basin (box 2). Mapping the...
Box 1. Why it is important to analyze the entire system of management measures in the Great Lakes: Insight from ISO 31000.

We showcase the importance of considering the entire system of management measures when adopting the ISO 31000 Risk Management Standard by mapping the Articles and Annexes of the 2012 Great Lakes Water Quality Agreement (GLWQA) into each of the steps of the standard. This analysis showed that the 2012 GLWQA does an excellent job of covering some but not all steps of risk management. For example, many of the Articles and Annexes of the GLWQA support setting the context and the risk-identification steps, but risk analysis is absent and risk evaluation covered minimally (figure 6).

Figure 6. The Articles and Annexes of the 2012 Great Lakes Water Quality Agreement mapped onto the ISO 31000 Risk Management Standard.

On first analysis, it may appear that the 2012 GLWQA does not sufficiently cover the necessary steps of the ISO 31000 to meet its policy objective. However, because the 2012 GLWQA is a "commitment" by Canada and the US to restore and protect the Great Lakes, it could be argued that it does an excellent job of doing what it is supposed to do: setting the context and identifying the risks that the Canadian and US governments could manage for the protection of the waters of the Great Lakes. In order to understand fully whether the Great Lakes are at risk and whether the overall purpose of the 2012 GLWQA is met, the entire suite of management measures operating within the basin at the federal, provincial, state, conservation-authority, and municipal levels of government must be considered. To analyze the effectiveness and compliance of management measures that act as barriers to a risk event that results in the failure to meet policy objectives, we suggest the adoption of the ISO 31010 Bowtie Analysis tool. This tool supports risk analysis by mapping the entire system of management measures with relation to the pressures–effects–impacts of a risk event. This is important because as we illustrated above, numerous management strategies operate at different jurisdictional scales to manage risk pressures or mitigate risk impacts, and all need to be considered to identify gaps in risk management.
A prototype ISO 31010 Bowtie Analysis was developed to showcase how the approach can be used to complete the risk-analysis step of the standard, with a specific focus on Annex 4 of the GLWQA: Nutrients. This proof of concept explores the system of management measures within the Lake Ontario and Lake Erie basins to see if they have the potential to manage eutrophication risk, a risk that fits within the general objective of the GLWQA: “To be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem” (Article 3.1.a; Governments of Canada and the United States 2012).

Pressures were nonpoint source and point source phosphorus. The effect (risk event) was adapted from Article 3 of the 2012 GLWQA (see above). The impacts were obtained from (1) Annex 4, B.1–4 and Article 3.1.a–iii of the GLWQA (Governments of Canada and the United States 2012). Preliminary analysis focused on the left side of the Bowtie, and 137 federal, provincial, and state preventative management strategies were inventoried; categorized as Avoid, Prevent, Enable, Facilitate, or Track controls (see table 1 for definitions); and mapped against the pressures and risk effect onto the Bowtie.

The Bowtie Analysis revealed potential strengths and weaknesses in the system of management measures that manage eutrophication risk in Lakes Erie and Ontario (figure 7).

Figure 7. The pressures, effects, and impacts of phosphorus-loading risk within the Lake Erie and Lake Ontario basins mapped onto a Bowtie Analysis framework (IEC and ISO 2009) along with management measures intended to prevent the pressures from causing the risk event. We analyzed and categorized 137 management strategies at the federal, provincial, and state level according to control “type,” and the number below each category indicates the number of measure that met the respective control criteria (table 1; EU 2008).

Interesting differences in the hard- and soft-control types related to point source and nonpoint source phosphorus controls included the following:

- There is a greater number of soft controls relative to hard controls for both nonpoint and point source phosphorus loading in lakes Erie and Ontario.
- Prevent hard controls outnumber avoid hard controls for nonpoint source and point source phosphorus loading in lakes Erie and Ontario.
- The US has a greater number of avoid and prevent controls (6, 21) when compared with Canada (4, 8) for nonpoint source phosphorus loading in Lake Erie; however, for Lake Ontario, the US has a greater number of prevent but fewer avoid controls (10, 2) relative to Canada (8, 8).
- Canada has a greater number of enable, facilitate, and track controls (13, 8, 14, respectively) when compared with the US (10, 2, 11, respectively) for nonpoint source phosphorus loading in Lake Erie.
- The US has a greater number of prevent controls (10) when compared with Canada (8) for nonpoint source phosphorus loading in Lake Ontario.
- Canada has a greater number of enable, facilitate, and track controls (17, 9, 22, respectively) when compared with the US (16, 8, 14, respectively) for nonpoint source phosphorus loading in Lake Ontario.

This analysis is merely a proof of concept on the applicability of the Bowtie Analysis for conducting an analysis of the entire system of management measures within the Great Lakes basin with relation to the pressures–effects–impacts of eutrophication. Although the numbers are interesting, we recognize that further analysis is required to draw conclusions on the management gaps. Therefore, we encourage governments to uptake this approach within their divisions to analyze fully the system of management measures to understand whether their own policy objectives are being met.
management measures onto the Bowtie’s pressures–effects–impacts architecture revealed potential strengths and weaknesses in prevention management measures, based on the number of management strategy “types” (i.e., hard and soft controls; table 1, box 2) for point source and nonpoint source phosphorus loading. However, although this inventory of management measures is interesting and informative, it is incomplete because an analysis of the effectiveness and compliance of these management measures is needed.

These risk-management exercises are “proofs of concepts” that could pave the way for a better structured and informed governance processes in support of the competent authorities that are mandated with the implementation of the system of management measures for the Great Lakes basin.

Conclusions
We conclude that a risk-management standard such as ISO 31000 addresses the long-awaited need to integrate formally science- and management-based assessments to sustainably manage freshwater resources such as the Great Lakes. ISO 31000 provides a standardized process and set of definitions that can streamline and integrate the plethora of high-quality science and management strategies to bridge our present disparate approaches for managing and reducing risk. Moreover, it provides a needed structure to ensure that managers and stakeholders have identified the risks and considered the possible courses of action to achieve their policy objectives. In the least, ISO 31000 provides assurance that policy-relevant scientific knowledge is fully used and integrated in decisionmaking and management. As part of ISO 31000, the ISO 31010 Bowtie Analysis introduces the needed tool to analyze gaps in management measures and evaluate the overall performance of the system of management measures in relation to the policy objectives. However, we believe it provides much more. The application of ISO 31000 and its Bowtie Analysis tool has the potential to guide us toward a policy and management system that protects and maintains the most valuable and vulnerable ecosystem functions of the Great Lakes basin.

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Supplemental material

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