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Lake Winnipeg Basin: Advocacy, challenges and progress for sustainable phosphorus and eutrophication control

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HIGHLIGHTS

- Action research examining eutrophication in the context of P supply security concerns
- Demonstrated synergies between reversing eutrophication and promoting food security
- Shift of phosphorus problem perception from noxious to precious
- Need for continued and broadened multi-stakeholder engagement

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ABSTRACT

Intensification of agricultural production worldwide has altered cycles of phosphorus (P) and water. In particular, loading of P on land in fertilizer applications is a global water quality concern. The Lake Winnipeg Basin (LWB) is a major agricultural area displaying extreme eutrophication. We examined the eutrophication problem in the context of the reemerging global concern about future accessibility of phosphate rock for fertilizer production and sustainable phosphorus management. An exploratory action research participatory design was applied to study options for proactivity within the LWB. The multiple methods, including stakeholder interviews and surveys, demonstrate emerging synergies between the goals of reversing eutrophication and promoting food security. Furthermore, shifting the prevalent pollutant-driven eutrophication management paradigm in the basin toward a systemic, holistic and ecocentric approach, integrating global resource challenges, requires a mutual learning process among stakeholders in the basin to act on and adapt to ecosystem vulnerabilities. It is suggested to continue aspects of this research in a transdisciplinary format, i.e., science with society, in response to globally-expanding needs and concerns, with a possible focus on enhanced engagement of indigenous peoples and elders.

1. Introduction

Since the 1950s, human activities have been impacting biogeochemical cycles at an unprecedented rate, including the essential water and phosphorus cycles (Smil, 2000). These activities have intensified agricultural production in many world regions while increasing stress on ecosystem integrity (Hibbard et al., 2007; Sharpley and Tunney, 2000). A dynamic new research field has emerged that is concerned with questions on how to best meet food production demands while at the same time ensuring ecological integrity (Foley et al., 2011). Phosphorus (P) is a growing interface between sustainable resource management and environmental quality. Phosphorus is often present in soils at concentrations too low for optimal agricultural production and in waters at concentrations exceeding natural levels, resulting in a common imperative of keeping P on the land. While the evolving focus on these global challenges has been greatly expanded in the past decade, relatively little emphasis has been given to specific geographic areas of challenge and change. The Lake Winnipeg Basin (LWB) in many ways epitomizes these challenges at a scale that will influence the future well-being of two of the most economically dominant countries, the U.S. and Canada. Although the basin extends over significant urban and intensive agricultural settings, the shoreline is generally populated by aboriginal communities dependent upon the health of the

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lake. Canadian aboriginal cultures represent an inherent potential to embrace and realize a more sustainable ecocentric approach (Mosquin, 2002). The primary goal of the current research was to characterize the current social, political and organizational platform for action on the challenges associated with stewardship of this key aquatic resource and the movement toward P sustainability.

Recognizing that much has been written about the P challenge both in this special issue and elsewhere, it is useful to outline a perspective on the linkage with eutrophication. High levels of P in inland waters, estuaries, and coastal waters cause eutrophication and dead zones (Rabalais et al., 2010; Schindler and Vallentyne, 2008). These high-nutrient zones in water bodies and sediments represent an important temporary sink in the global biogeochemical P cycle, as well as in the global budget of the element. Diaz and Rosenberg (2008) note that the number of dead zones, i.e., areas of nutrient enrichment and associated oxygen depletion, has increased by a factor of 32 since the 1960s, rising to more than 400 worldwide. Globally, cultural over-enrichment of nitrogen (N) and P is a pervasive water quality concern (Selman et al., 2008; Sharpley et al., 2015; World Resources Institute, 2012). Despite decades of research-based progress, Smith and Schindler (2009) conclude that the situation remains problematic. Additional critical factors are deficiencies in suitable governance approaches such as long-term monitoring and proactivity, public participation of a wider group of stakeholders, and societal learning via problem reframing and adaptation (Asthana, 2010; Bleser and Nelson, 2011; Pahl-Wostl et al., 2011; Smit et al., 2009).

By linking the *too much* challenge to the limited, nonrenewable, nature of global phosphate rock reserves, and to the *too little*, sustainable P management strategies, this case study provides an example of multi-sector progress on P management and eutrophication reversal. As much as P is considered a key driver for aquatic ecosystem pollution, it is also a key limiting nutrient for plant growth and essential for agricultural production. Phosphorus naturally moves into the biosphere through biogeochemical weathering of rocks. Presently, due to P's natural low availability in the environment, new supplies are delivered to the modern agricultural system principally by industrial mineral fertilizer made from non-renewable phosphate rock. Cropping continuously removes this keystone resource from the soil. Since the 1850s, the world's food production system has become increasingly dependent upon artificial phosphorus fertilizer and has largely contributed to a tripling of the P cycle rate (Smil, 2000). Renewed interest in the question of how long the world's phosphate rock reserves will last emerged in 2007 (Déry and Anderson, 2007; Ulrich and Frossard, 2014). By applying the Hubbert peak logistic model, Cordell et al. (2009) postulated a peak in global phosphate rock production around 2030, with severe implications for food security. These scarcity concerns have led to a growing debate on P security and, more comprehensively, sustainable P use and management (GPRI, 2010; Schröder et al., 2010). Although imminent depletion has since become a less serious concern for many as better data became available (Van Kauwenbergh, 2010; Van Kauwenbergh et al., 2013), the stewardship of phosphate resources and the sustainable management of phosphorus remains topical because of related global justice, economic access, and environmental pollution concerns. This *resources perspective* has also gained recognition in the field of sanitation because of the inherent nutrient recycling potential (Britton et al., 2005; Dagerskog and Bonzi, 2010; Udert and Wächter, 2012). Nevertheless, few studies have successfully coupled long-term sustainability of phosphate resources in eutrophication management with broader societal P considerations. Although research has been mostly focused on specific biogeochemical features of P land and water dynamics and their management (Vaccari, 2011), there have been increasing calls to include legal, market and social considerations (Bleser and Nelson, 2011; Pahl-Wostl et al., 2007). In the current work, we provide insights from the LWB on integrated approaches as they contribute to large-scale solutions.

The current work aims to identify and evaluate trade-offs and synergies that result from aligning food security and water quality considerations as well as to investigate the contributions of this approach to eutrophication mitigation. The following questions form the framework for this discourse. First, can the desire for a secure P supply resolve conflict between agricultural intensification and improving water quality? Second, can action research contribute to this discourse and help generate an effective knowledge management framework that addresses both increasing eutrophication and phosphate rock accessibility concerns? Last, what are the potential roles of science, society, and science-practice interactions in meeting the complex challenges related to sustainable nutrient in the LWB?

1.1. Study area and problem background

Lake Winnipeg in Manitoba, Canada, is the world's tenth largest freshwater lake (North America: 7th, Canada: 3rd; Herdendorf, 1990), covering an area of 23,750 km^2, its basin (LWB), which ultimately drains into Hudson Bay, ranks second in watershed size in Canada (Fig. 1.2). In its declining health, it potentially defines the future of the country.

Lake Winnipeg provides one of the most visual and striking global examples of the complex problems arising from human-induced watershed changes and large P loadings resulting in extreme eutrophication (Brunskill et al., 1980; Salki et al., 2007). Nevertheless, despite its large size, severe eutrophication and cultural significance, it has been little studied (Wassenaar and Rao, 2012).

Numerous regulatory authorities, including international transboundary, federal and inter-provincial/inter-state entities govern more than 6.5 million people in the LWB, including a significant Aboriginal population (Statistics Canada, 2006a). Of the sixty-three First Nations in Manitoba, many reside along the shores of Lake Winnipeg. Eutrophication impairs vital ecosystem functions upon which the First Nations depend for economic, cultural, and spiritual activities. Further, low income and food security are major concerns for Aboriginal people in the province (Hallett et al., 2006). The ecosystem services of the lake are multiple and significant, including recreation and commercial fisheries, as well as the world's third largest hydroelectric power-generation reservoir with a capacity of 5480 MW (Manitoba Hydro, 2010). Total services produce an estimated $720 million/year in revenues (Lake Winnipeg Implementation Committee, 2005). More than 70% of the LWB is agricultural land, including a 17 million head livestock industry (Lake Winnipeg Implementation Committee, 2005) and 29 million hectares of crop land in the three Prairie provinces alone (Statistics Canada, 2006b). Despite relatively P-rich soils in parts of the LWB, agriculture-based economy is reliant on supplies of mineral fertilizers. For Manitoba, Schindler et al. (2012) report an increase in P fertilizer application from approximately 70,000 tons in 1970 to more than 300,000 tons in 2009. Small and intermittent phosphate mining in Canada, large mineral P fertilizer price elasticities and generally uncertain long-term, secure economic access to phosphate rock may render the LWB vulnerable to shifts in phosphate rock supply and its fertilizer derivates (Grimm, 1997, 1998).

Since the 1990s there has been continual expansion of blue-green algae in Lake Winnipeg (Kling et al., 2011) reaching over 10,000 km^2 in 2009 (Fig. 1.1). It has been suggested that these blooms result from increased P loadings triggered by rapidly growing agricultural activity, i.e. concentrated animal husbandry and fertilization, particularly in the Red River Basin, and more frequent and intense spring floods (Bunting et al., 2011; Schindler et al., 2012). The average annual total phosphorus (TP) loading from anthropogenic (e.g. wastewater) and natural sources is estimated at around 8000 tons per year (Lake Winnipeg Stewardship Board, 2006). The Red River is historically the largest phosphorus contributor (Bourne et al., 2002; Environment Canada and Manitoba Water Stewardship, 2011; McCullough et al., 2012; Stainton et al., 2003). In addition to these two main drivers, cultural land use changes such as reducing wetlands by 70% (Ducks Unlimited Canada), regulating

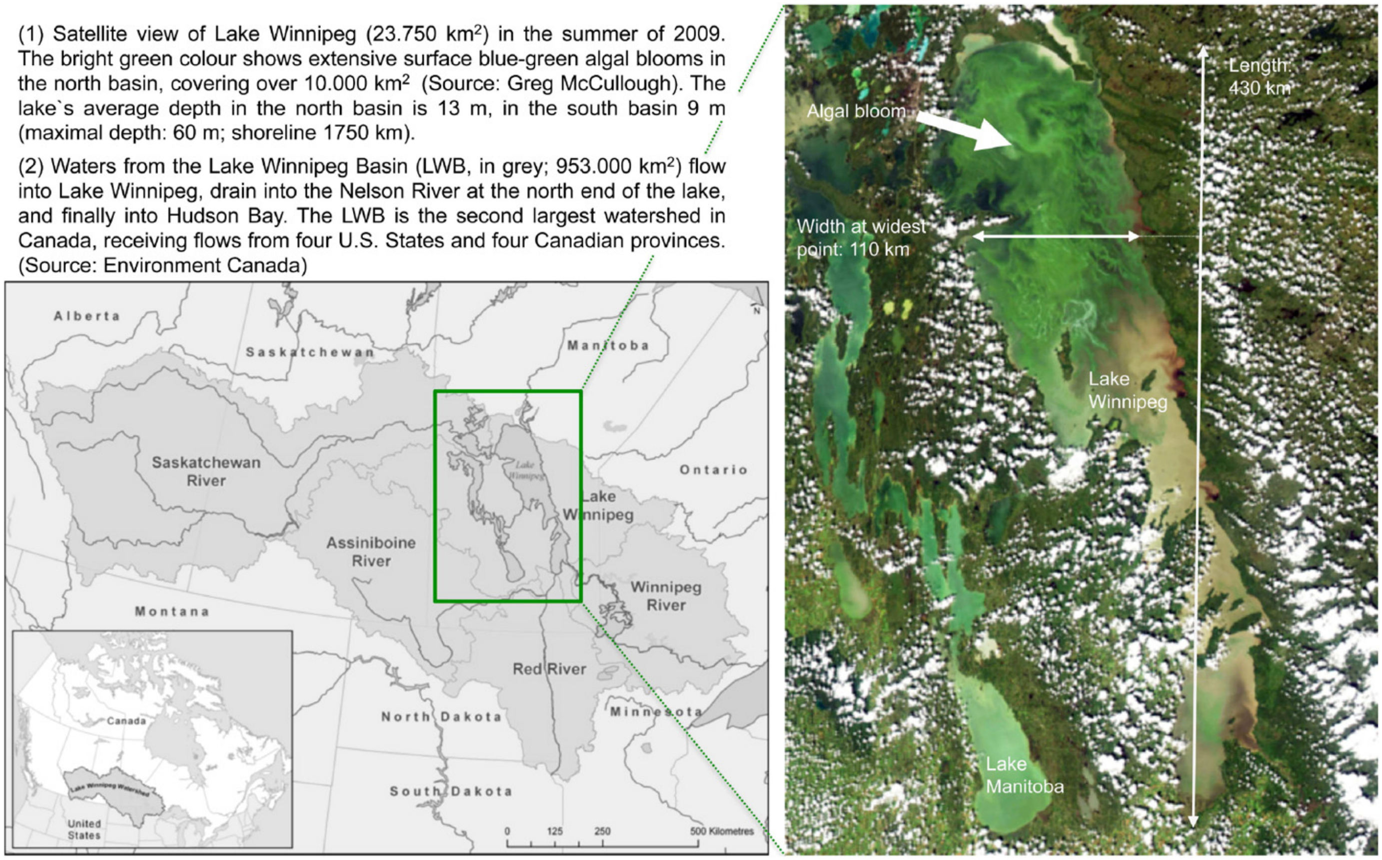

Fig. 1. Shaded map of the study area and satellite image of Lake Winnipeg illustrating the high eutrophic level in the north basin.

water levels, and changing socio-economics have further led to an increase in P loads.

In the LWB, most nutrient transport processes are driven by runoff from rainfall and snowmelt (Salvano et al., 2009; Shrestha et al., 2010), and frequent flooding. Evidence suggests that some parts of the LWB are experiencing a wetter climatic period than usual while others are drier than previously (Schindler and Smol, 2006). How climate change affects the hydrology of the basin undoubtedly adds complexity to understanding and managing P flows to Lake Winnipeg (Akinremi et al., 1999; Ehsanzadeh et al., 2011). Regardless, there is a critical need to be cognizant about the management of change. This is further influenced by the vast land drainage to lake surface area ratio of 42:1 (Schindler et al., 2012). Moreover, the lake's relative shallowness renders it sensitive to excess P loadings. Best soil management practices such as conservation tillage appear to not apply well to the cold, dry and flat regions where nutrient dynamics occur mainly during snowmelt (Tiessen et al., 2010). Compared to most other great lakes, Lake Winnipeg appears to be influenced more by its watershed processes, volume, and composition of its water and P sources when compared to most other eutrophication-troubled areas.

The overall potential for P reduction in LWB is affected by complex environmental, technological, and social-cultural variables (Lake Winnipeg Implementation Committee, 2005). There is no single solution to the problem, and any recovery from eutrophication is likely to take substantial time. To achieve the target of a 50% phosphate reduction to pre-1990 levels (Target 3.7 of the Federal Sustainable Development Strategy, Environment Canada, 2013) it will be necessary to slow the flow of P off the land and reduce flooding. In addition to these external nutrient loadings, internal loads from lake sediment to water need also to be considered as they affect the eutrophication process in the lake. Several multi-level joint initiatives aimed at finding orientations to recovery from eutrophication are examining the pollution problem (Wassenaar and Rao, 2012), mainly from an ecology and hydrology perspective (www.lakewinnipeg.org). Nevertheless, a resources perspective, which includes the basin's vulnerability to dependence on imported mineral phosphate fertilizer, has yet to be thoroughly described.

2. Methods

Investigating complex issues, such as improved P use efficiency, pollution mitigation, and sustainable phosphorus management in the LWB, requires distinctive methods that can build a bridge between scientists and stakeholders from practice, i.e. government, industry, non-governmental organizations, by accommodating and synthesizing different ways of understanding. The current work borrows from the participatory paradigm of Action Research, originally developed by Kurt Lewin (1946), with the aim of advocating understanding of this real-world problem and empower stakeholders. Action research differs from conventional social science methods, as it moves toward democratizing the research process (Bradbury Huang et al., 2011) via repeated cycles of a multi-step process conducted closely with a wide range of stakeholders (Lewin, 1946). According to Quigley and Kuhne (1997), such a process includes stages of planning, acting, observing, and reflecting. The participatory framing in the present work borrowed from action research was exploratory, not focused on measuring specific positive change, yet validated by the broad concern over the *health* of Lake Winnipeg and global phosphate rock accessibility.

2.1. Study design, data acquisition, and selection of participants

Three multiple-step research cycles were conducted, one in 2008, a second in 2009 and the third with ongoing assessment and participation in positive change. The two dialog and data-gathering cycles employed methods aimed at gaining a broad perspective on the matrix of the challenges. Methods and research cycles are summarized in Table 1. Details are provided to help in the design of both follow-up initiatives and parallel advocacies in other settings.

In 2008, the websites of fifty-three key agencies and organizations were analyzed, focusing on agricultural and/or aquatic ecosystems. Twenty-nine stakeholders from key organizations were selected for qualitative, semi-structured, and open-ended interviews (27 face-to-face; 2 via telephone). The interviews were conducted in Manitoba, each lasting one to two hours. Thirty participants were asked to complete a brief questionnaire on agricultural and water planning in the LWB (return rate 73%). Further, six First Nations representatives, one Métis representative, and four professionals working in the First Nations health sector were interviewed to learn about their water quality issues and priorities ($N = 11$).

Table 2 describes the stakeholder groups of both advocacy research cycles. In 2008, stakeholders were identified as follows: i) agencies located in the region, identified through a website search, that demonstrated a clear link to agricultural and aquatic ecosystems, ii) those who are or will be affected directly or indirectly by the problems addressed, and iii) those who, according to Geels and Kemp (2007), should participate due to their capacity to take part in the process, contribute to an understanding of the issue, or to influence the process.

Participants were further selected through personal contacts and snowball sampling, a technique used to obtain additional key agents by referral from previously identified stakeholders (Vogt and Johnson, 2011). Participants were grouped as academic, government, and non-governmental organizations (NGOs)/non-profit organizations (NPOs) (see Table 2).

Based on the 2008 findings reported in Malley et al., a second multi-step process was conducted in 2009. The action included open-ended qualitative telephone interviews ($N = 16$) with selected participants from the 2008 study, lasting one hour. The follow-up emailed questionnaire survey (return rate 81%) was designed to assess i) the prospects of how to act on the earlier findings, ii) the level of interest in cross-cultural consensus-building as a next-step approach, iii) perceptions of institutional arrangements for managing P, and iv) the value of the inquiry. Questions were framed to elicit information that verified and supplemented the interviews.

In the first analytic step, open coding (Berg, 2009; Corbin and Strauss, 2008) was applied to the qualitative interview data. Central ideas and concepts to conceptualize the challenges in the LWB and how they are being approached were identified and evaluated. Questionnaire data was analyzed with PASW Statistics 18.0.

3. Results

3.1. Interviews

Across and within the stakeholder groups, considerable variety was found in the adaptations, practices, and technologies suggested by organizations in response to P pollution. In agriculture, often quoted suggestions were implementing best management practices, reduced fertilizer application, increasing mineral fertilizer use efficiency, manure composting, and organic farming. For protecting or restoring ecosystem integrity, suggested activities included: wetland conservation, nutrient monitoring, flood damage reduction, and enhanced public involvement. Several participants emphasized that a key challenge remained in understanding P dynamics in soil and water related to the naturally relatively high levels of P concentrations in soil and vegetation and the geography.

Expected or desirable changes in practices and policies focused on P discharge decrease, pollution prevention regulation, flood protection, and stronger inter-provincial and international cooperation, especially considering that the U.S. Red River Basin is one of the main contributors of P loading. Participants pointed out the need to form a permanent coalition that links many interest groups regarding phosphate-related challenges. Although considerable effort has been undertaken to respond to the recommendations of various reports, important implementation steps remain to be completed. Participants repeatedly attributed this lack of action to resource constraints. Table 3 summarizes a set of meaningful enhancement areas synthesized by the 2008 interviews. The enhancement areas were widely confirmed in the 2009 action research cycle.

In the First Nations/Métis survey, participants showed a general reluctance to rank priorities in water security issues. Rather, participants focused on selected priority issues, notably, providing safe and sufficient freshwater and adequate treatment of wastewater. Engaging First Nations and/or Métis cultures and representatives appears to be complicated by two hierarchal regimens with many of these cultures, i.e. advocacy associations fulfilling a political function by representing First Nation chiefs and councils, and traditional elders who best represent the relationship heritage between the land and waters of North America and its people. While the surveys were being conducted, it

Table 1
Data collection method and purpose of inquiry according to research and advocacy in 2008 and 2009*.

Time period		*N*	Type of method	Purpose	*Action research cycles
2008	May - August September - October October September - November	53 29 11 20	Literature review, website analysis Case agent interviews First Nations/Métis interviews Questionnaire survey	To identify: . Positions, policies, perspectives, advice, actions on P regarding food security and/or water quality . The role of P in the basin . The link between agriculture and aquatic ecosystem integrity . Any acknowledgement of concern over declining phosphate rock reserves . To specify water security issues and priorities . To assess the level of resource planning and awareness	**Planning** **(phase I)** 1. Problem definition (reviews, implementation) 2. Conceptualization of the project design (e.g., resources) 3. Intervention measures (e.g., timeline, method) **Acting/Observing** **(phase II)** 4. Implementation: acting and observing (data collection, dialog over data and events)
2009	January/April May May/June December	 16 13	Report (Malley et al., 2009) Case agent interviews Questionnaire survey Primer (Ulrich et al., 2009)	. To summarize findings and share conclusions with participants . To elicit the value of the 2008 inquiry, evaluate the research, and discuss cross-cultural consensus building . To elicit impacts of the 2008 inquiry and evaluate options for future discourse space . To summarize findings and share conclusions with the wider public	**Reflecting** **(phase III)** 5. Process evaluation 6. Decision on new direction, future action research cycles) Repetition of Step I. 1-3 Step II. 4 Step III. 5–6

* Phases and steps of action research according to Quigley and Kuhne (1997).

Table 2
Detailed description of stakeholder groups participating in the questionnaire surveys.

Stakeholder group	*N* questionnaires (frequency)		Participating organizations/institutions
	2008	2009	
Academic	7 (35%)	3 (23.1%)	Brandon University; *University of Manitoba; *University of Winnipeg (Biology, Biosystems Engineering, Soil Science)
Government	4 (20%)	4 (30.8%)	Agriculture and Agri-Food Canada; *Agri-Environment Services Branch; *City of Winnipeg - Water and Waste Department; Environment Canada; *Manitoba Conservation; *Manitoba Agriculture, Food and Rural Initiatives
** NGO/NPO	9 (45%)	6 (46.2%)	*Beyond Factory Farming; Friends of the Earth Canada; *International Institute for Sustainable Development; *International Water Institute; Keystone Agricultural Producers; Lake of the Woods Water Sustainability Foundation; Lake Winnipeg Research Consortium; *Manitoba Eco-Network; *Manitoba Water Caucus; National Farmers Union; Organic Food Council/Canadian Organic Growers; *Red River Basin Commission
Total	20 (100%)	13 (100%)	

* Representatives of these organizations/institutions also participated in the 2009 action research cycle.
** NGO = Non-governmental organization; NPO = Non-profit organization.

became increasingly clear that a significant opportunity exists to engage the traditional leaders of the First Nations in the LWB to help better define the challenges and opportunities associated with food and water security.

3.2. Questionnaire survey

Participants were asked to judge the focus of activities in the LWB related to water conservation, P conservation, and best use of nutrients to maximize crops. Fig. 2.1 illustrates that respondents rated neither water conservation practices nor P conservation practices as adequate. In contrast, respondents were more satisfied with activities for the best use of nutrients for crop yield. Nevertheless, government representatives repeatedly rated the adequacy of the focus on all three activities higher than did academics and NGO/NPO representatives. These findings validated that there is a focus on P and water conservation as more important than only the best use of nutrients.

Subsequently, participants were asked to judge the awareness level of issues associated with water and agriculture from five different perception levels: at home, in their organization, within their community, in the Lake Winnipeg Basin, and within Manitoba (illustrated in Fig. 2.2). Across all perception levels, considerable diversity was found. Notably, government representatives judged the awareness level quite differently from the others. These differences were especially evident at home, within the representative's own organization, and at the provincial level.

To identify the level of agricultural and water planning in the LWB, participants were asked to rate the need to link associated agriculture and freshwater ecosystem matters to ascertain whether advocacy campaigns between or within different groups in the basin were needed to address this issue (Fig. 2.3). The most substantial need was observed between First Nations and other stakeholders in the basin. Further, participants agreed that advocacy development was needed among First Nations, between the private and public sectors, within the mandates of NGOs, as well as in university extension programs. Interestingly, within the respondents' own organizations, only a modest need for such campaigns was acknowledged.

3.3. Advocacy and Research 2009

Stakeholder interviews and the questionnaire survey focused on four topic areas: i) the relevance of the first inquiry and output, ii) interest in cross-cultural consensus building to manage resources sustainably, iii) views on establishing an organization concerned with P stewardship, and iv) participants' evaluation of the overall inquiry process. In addition, we assessed the constraints and need to move forward with questions about potential P strategies, the creation of a sustainable P and water management vision for the basin, and cooperation with other stakeholders. Highlights of the interview and questionnaire results are jointly presented in Table 4 as they support and supplement each other.

Table 3
Interview-derived set of enhancement areas for developing phosphorus sustainability in the Lake Winnipeg Basin.

Action level*	Areas of enhancement
MB, LWB	1. *Stakeholder cooperation*: by (a) ensuring a suitable level of various group representations in relevant forums and meetings (b) establishing a regional round table in cooperation with existing networks and agencies
LWB, N, G	2. *Phosphorus accounting*: reservoir/flow data collection and monitoring (volume and rate)
MB, LWB	3. *Comprehensive watershed communication plan*: to establish regular communication between all stakeholders and representative commissions, boards and agencies
LWB, N	4. *Policy review of phosphorus*: with the goal of identifying regulatory approaches for sustainable use and reuse of P in agriculture and beyond
MB, LWB	5. *Integrated watershed management process*: to include aspects of water, carbon, land, and related resources for optimizing social and environmental welfare without compromising ecosystem functions
MB, LWB	6. *Promotion of stewardship and recycling of phosphorus in municipalities, households, and the agricultural sector led by the Province of Manitoba*: by reducing food waste, composting, avoiding food and organic waste in the landfill, tertiary treatment of municipal wastewater, recycling of manure in an agronomical sound manner, and continuing to improve understanding of P dynamics in soil and the landscape

*MB = Manitoba, LWB = Lake Winnipeg Basin, N = national, G = global.

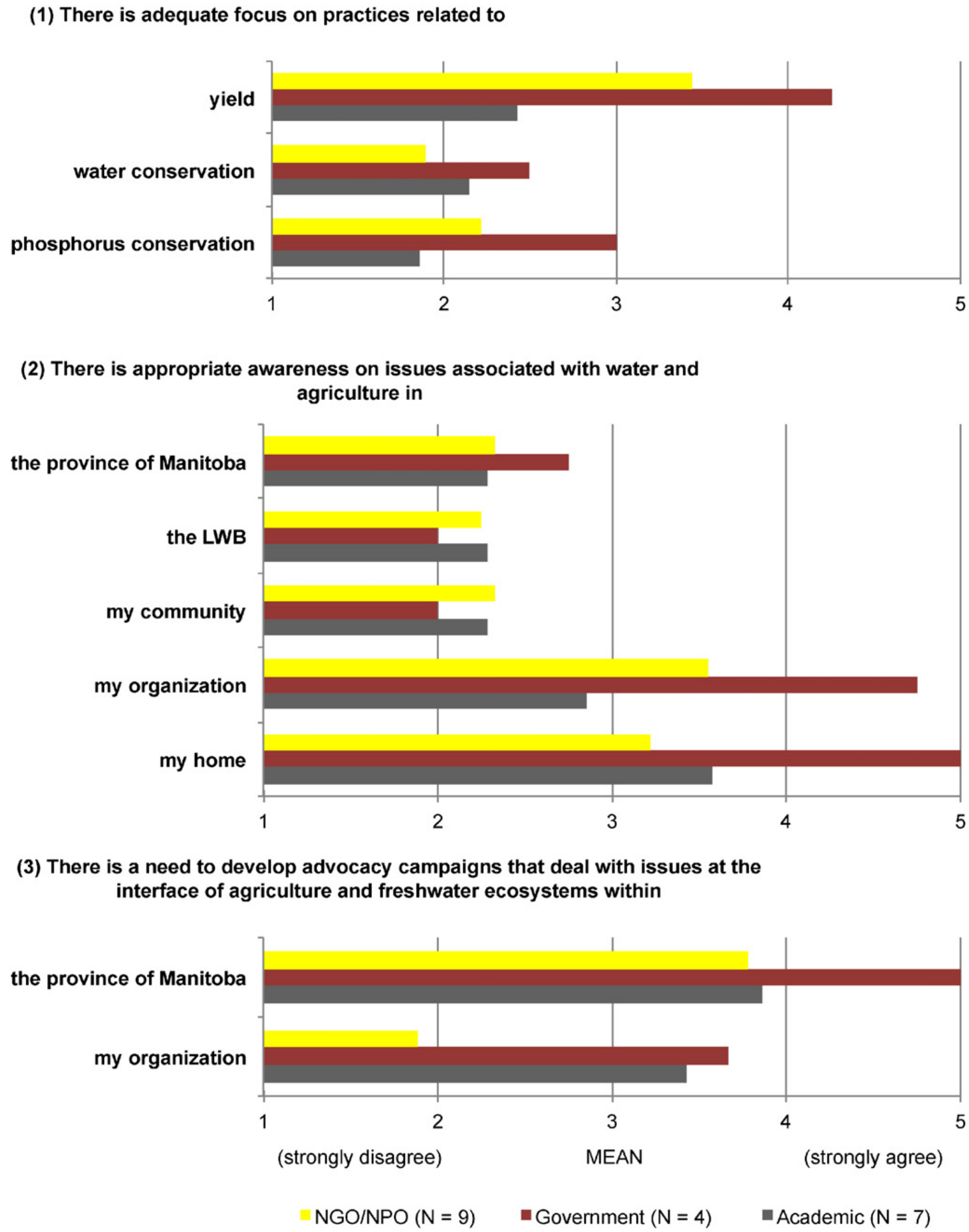

Fig 2. Three examples of in-group comparisons highlighting how the three groups diverge in their judgment.

4. Discussion

The main focus of the current analysis is concerned with i) the level of awareness of the short- to medium-term accessibility of phosphate rock reserves, ii) the need for advocacy campaigns, cross-cultural consensus building, as well as possibilities for phosphate governance, and iii) the value of the chosen approach, including constraints on how to move forward. Results confirm that eutrophication and phosphate rock accessibility concerns link well to the ongoing work in the basin for improved P management. Although the current research was not in itself a complete Action Research approach, the participatory benchmark herein combined with the analysis of actions in the following years, can provide the basis for a targeted Action Research design. In 2011, the Manitoba Government moved to reduce the flow of P and nitrogen into Lake Winnipeg and improve water quality. In 2014, a pilot project was initiated in Portage la Prairie, Manitoba, to recover P through the use of struvite. While global efforts in the area of sustainable P management have developed significantly, there has been little progress on engagement in terms of social process. The focus on water quality and eutrophication control may in part be the mantra to meet that goal. The LWB is well positioned as a rallying point for citizen engagement on water quality.

4.1. P availability concerns: from symptomatic challenge to systems thinking

The results reveal three contributions of the resource lens for sustainable P management in the LWB. First, concerns about future global phosphate rock supply allow for a new perspective on sustainable transition. This is due to the widening of the problem field for analysis across the entire P supply and demand chain, which may promote improved understanding of structural causes when the economic (input) limit, non-renewable (throughput) limit, and ecological (output) limit are considered jointly. The identified and confirmed enhancement areas, for example, P accounting (Table 3), provide promising entry points for assessing the LWB's overall vulnerability to phosphate fertilizer

Table 4
Four examples of the content and diversity of answers from the 2009 interviews (I) and questionnaire (Q) according to topic area.

Topic area	Major findings	I	Q
Relevance of the first inquiry and output	• Participants differed in their vision of how to use the information in the summary report of the first study cycle for development in their organization. A majority found that the generic set of enhancement areas (Table 3) was directly important to their mandate. The remainder, most of whom were academics, drew a less direct link.	★	
	• A majority stated that they would use the summary report as a reference and would raise the issue within their area of influence.	★	
	• Most participants agreed the summary report was valuable as learning tool. This was followed by the report's value for building contacts with other stakeholders and experts, promoting motivation for sustainable action, and further developing methods of incorporating P and water.		★
	• 77% of the participants (N = 11) acknowledged that their level of awareness about P adequacy concerns and resources had changed or increased during the process. Academics, nevertheless, reported that their level was largely unaltered.	★	
	→ These results suggest a need to develop science-practice engagement strategies that aid in discussing types of different knowledge and understanding in a democratic process.	★	
Cross-cultural consensus building	• There was unambiguous agreement that all stakeholders need to be approached and engaged in the process, including First Nations and Métis. The latter groups should be engaged from the outset, as the challenge requires the holistic traditional perspective held by indigenous peoples for millennia.	★	
	• All agreed they were generally interested in participating in a cross-cultural process. Nevertheless, one third limited their level of potential involvement in any process due to time, workload, or resources constraints.	★	
	• Participants stressed that problem resolution efforts had to involve everyone's capacity to change or interact.	★	
	• The traditional knowledge of First Nations seems effectively, although unintentionally, sequestered outside related decision-making processes. Moreover, integrating cultural and economic drivers such as aboriginal/non-aboriginal or urban/rural is a challenge in itself.	★	
	• The spatial separation of stakeholders was stressed as a major geographical challenge.	★	
	• It was strongly agreed across all groups on the need to develop a comprehensive watershed communication plan to establish regular contact.		★
	→ These findings support an increase in efforts for capacity building across different stakeholder groups to engage in and to facilitate joint problem framing and to build resolution efforts.		
Establishing an organization concerned with P stewardship	• Positions on the question of establishing an organization with a P stewardship mandate, e.g., fostering collaboration for responsible resource planning, ranged widely. Although all participants acknowledged that such an institution could provide a helpful frame for managing the issue, the level of support for establishing such an institution was disputed.	★	
	• A majority (69%; N = 9) deemed the international perspective as highly appropriate, yet pointed toward the weak points of such an approach. The main concern raised was the overwhelming complexity with which many international bodies such as the United Nations have to deal.	★	
	• Respondents judged the international level for establishing such an organization as the most appropriate, followed by the national, basin-wide, and provincial levels.		★
	• Tow mandates for such an institution were mainly considered: 1) increasing scientific and technical awareness and knowledge of the challenge and 2) extension/outreach, including communication, linking government, industry, public, and science.	★	
Constraints and need to move forward	• A need was expressed by all stakeholder groups to create synergies between technology innovations and behavioral change to attain food and water security.		★
	• All respondents agreed that policy support, more research and information on P, water, and their interface, and allocation of new resources and stronger cooperation were required to engage in P sustainability issues. This response integrates with and strengthens the work of the multi-stakeholder organizations such as SERA-17, concerned with minimizing agricultural P loss; the Red River Basin Commission, engaged in integrating natural resources management, and the Manitoba Livestock Manure Management Initiative.	★	
	• It was suggested that a political framework supporting P recycling, increased efficiency in use, integrated nutrient management, and water conservation should be established.	★	
	• For a successful approach to integrated watershed management, it was stressed that P use policies should be reviewed and holistic analysis of LWB characteristics and impacts of human activity be performed.	★	
	• A block of six questions directly addressed whether activities in the water and P domain deserved improved regulation, leadership, integration, role allocation, coordination and connectedness. Averaged over the six items, academics and representatives of NGO/NPOs generally tended to judge the need for such improvements as greater than did the government representatives.		★
	• Academics and NGO/NPOs judged the need for increased government regulation and involvement for improving sustainability in the food and water sector higher than did the government representatives.		★

availability and accessibility. Related research methods such as agent-oriented P flow analysis (Brunner, 2010; Ott and Rechberger, 2012), P life-cycle analysis (Suh and Yee, 2011), and scenario analysis (van Vuuren et al., 2010) could provide promising data for a scientifically-based management of the lake, a need postulated by Kling et al. (2011). Second, accessibility concerns may be viewed as a wake-up call to develop alternatives to current agricultural practices and handling of other anthropogenic point and non-point sources in the basin, if aquatic ecosystems are to recover and vulnerabilities to phosphate fertilizer price fluctuations are to be kept at an acceptable level or reduced. Third, phosphorus sustainability considerations may act as a catalyst for genuine science-practice cooperation to assess the realities of the problems for different stakeholder groups. Potentially, this is a key area for the application of Action Research responding to the critical need to engage society and measure change in that engagement in response to directional facilitation. Critically, project design must include appropriate time-frames and resources to measure change.

4.2. Action research: a new direction for actionable research-oriented studies and cooperation

The observed increased level of awareness and constraints outlined suggest openness and the need for future co-learning. Given the acknowledged complexity, dispersion of knowledge across a broad stakeholder group, and the lack of capacity to act, broader societal engagement is necessary to develop sustainable P management orientations. Hence, the hypothesis is put forward that improved awareness based on shared reliable information from different stakeholders could be an important factor determining the quality of future management. We suggest action research has great potential as a reformative process with a social change agenda, but it is not revolutionary. Although the current work only applied a participatory format for action research, our follow-up indicates that systems thinking was widely improved as a result. The project fulfilled the goal of uncovering and transferring information and knowledge useful for a specific group, and facilitating the motivation of those agents involved to use the information elicited in the process (Almekinders, 2009; Berg, 2009) for further research or action. The relatively small number of participants and the limitations of representative sampling due to the explorative nature of the study are acknowledged. Future research should include agricultural producers, for example. Nevertheless, the main conclusion is that there needs to be an approach that includes a measurement of change as part of research structure and funding. In that sense, there is a further need to balance the focus on human needs as well as ecosystem capacity, an approach that has been outlined elsewhere in the field of Ecohealth (Anabieza et al., 2010; Custer et al., 2014). Engagement of the aboriginal communities in this form of Ecohealth Action Research may be an optimal development point, in the problematic nature of existing cross-cultural and community-based politics. The inherent focus of indigenous people on the ecocentric approach is an untapped resource. The results also indicate that further research must be, ideally, transdisciplinary, i.e. integrating knowledge from science and practice, as well as action-oriented, and relevant to policy, and it must incorporate multi-level innovation. The IISD Bioeconomy Project, to which the study results were fundamental, is an example of co-shaping and continuing the discourse (personal communication, IISD, 2010, 2012).

4.3. New roles for science and society

Only stakeholders from academia acknowledged awareness of phosphate rock depletion concerns. This finding may indicate the need to reshape the responsibility of this stakeholder group. An increasing number of voices, such as Kassen (2011), stress the role of scientists in more effectively sharing knowledge with the wider public and decision-makers on global environmental change issues in order to manage our natural resources more sustainably (Pahl-Wostl et al., 2009). Such efforts may parallel and supplement existing efforts as a single top-down, bottom-up, or sectorial approach is unlikely to support transitions in a meaningful way.

The fair degree of stability observed in the government representatives' ratings of the need for certain actions inherent in or close to their mandate, e.g., increased regulation, leadership, which was consistently lower than the other stakeholder groups (Fig. 2), was unexpected. This effect might imply that participants assume that more awareness exists at home and within their organization than actually does. Further, the results might be evidence of reluctance by the government to engage in costly and long-term obligations, such as complete Action Research designs or resource conservation. These observations suggest that any general knowledge-generating or awareness-raising process may be hindered by the initial large effort needed to get the attention of these groups, as they all perceive themselves and their own organizations as aware or knowledgeable. The importance of this is clear. The observed manifestation of the *illusion of control effect* (Langer, 1975) and *overconfidence effect* (Svenson, 1981) are cognitive biases that may have implications for managing P and water more sustainably. Both effects have been reported to hinder learning or to increase risk-taking (Fenton-O'Creevy et al., 2003; Gollwitzer and Kinney, 1989).

Interestingly, agencies other than the government were found to believe that increased governance is the answer, while jurisdictional representatives tended to disagree. In addition, the impetus for change appears to be much stronger in the non-government sectors than within the jurisdictional representation, as reflected by the government representatives' tendency to neither agree nor disagree. This finding could be interpreted as an indication that leadership needs to be maximized outside the government to redefine jurisdictional actions through democratic processes. The challenge may well be to convince governments to fund this type of participatory Action Research design.

Examining the efficiency of sustainable resources management of the International Joint Commission (IJC), the managing body for transboundary water issues between the U.S. and Canada, Bleser and Nelson (2011) stressed the need for more pro-active governance practices, long-term monitoring, and funding. As is evident from the interviews conducted in 2009, there is some restricted support across all stakeholder groups for advancing the institutional setting for P stewardship and recycling. The apprehension about effectiveness and implementation concerns, and the need to approach improved cooperation and exchange mechanisms, points toward the preferred option of using the opportunities inherent in existing institutions. There appears to be a need for a process that weighs the involved interests, costs, and benefits, as well as responsibilities to best arrange for a workable organizational approach concerned with knowledge production and outreach. Important factors in this equation are the interdependencies present among stakeholders at different levels, as well as the degree of willingness to act and the scope of action which actually exists so that effective measures can be implemented. These factors should be investigated in greater detail in the future.

4.4. Regional Profile of Change 2010-2014

It is now well recognized that phosphorus plays a key role in the LWB as a pollutant, and is treated on and across many levels in agricultural and water planning. It was found that conserving water and P is considered more important than improving nutrient use. This may be due to considerable efforts over the past years that have been put into stipulating and implementing improved agricultural P management practices in the basin (Environment Canada, 2010; Stuart et al., 2010), including the management of the land application of livestock manures. Additional research on conserving resources may well link to ongoing scientific efforts. An example is the Lake Winnipeg Basin Initiative, a project of the Government of Canada's Action Plan for Clean Water and the Province of Manitoba (Government of Canada, 2010), which aims to improve understanding of geography-specific nutrient dynamics.

Our findings further suggest a strong need for advocacy campaigns regarding issues at the agriculture-water interface. A major challenge in this effort, though a relevant opportunity, is the inclusion of groups within societies who otherwise are poorly engaged, such as First Nations. Support for such an approach was found in the expressed need for linking First Nations and other stakeholders more strongly. The traditional elder approach is often of interest in various settings. Nevertheless, currently, no programs capture knowledge that would apply to the LWB. International agencies such as the Ecosystem Services and Poverty Alleviation Group, although global, will not focus on any projects within Canada, due to the relative wealth of the country, regardless of the status of First Nation peoples. A national approach to knowledge management that includes indigenous peoples is one way to engage First Nations beyond the political framework of chief and council. A second possibility is to work through the highly developed tertiary education system in Manitoba to establish a transdisciplinary extension program on this issue. This might best be initiated by Manitoba's University College of the North. Action could build upon the institution's aboriginal focus and mandate for leadership on the much needed socio-economic development of Northern Manitoba. Nevertheless, there would need to be a significant focus on partnership development to expand the existing expertise within that regional institution.

5. Conclusions

The interface of the P cycle and the hydrological cycle is a unity that may stimulate societal commitment to address the growing number and severity of issues undermining resource availability and environmental quality as an integrated whole. A focus on the field of Participatory Action Research regarding the future of LWB emerges as a priority locally, and an indication of how change might best be addressed elsewhere. There is a benefit of pollution–resource systems thinking for further consideration in the LWB and beyond through action research–enabled awareness and learning increments within all participant groups. Particularly of interest for future studies is the engagement of the ecocentric vision of aboriginal people and a focus on how well the issue is understood in the specific sub-basin and province/state contexts. An extended participatory approach, in the form of a transdisciplinary process of resolve, could open new territory for tangible scientific and socially relevant outcomes. The critical scientific and societal challenge, then, is to develop and implement an open, constructive discourse space to not only mutually improve understanding of problems and challenges but also to generate, in cooperation, viable orientations on how to sustainably manage P resources for securing food production and water quality.

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