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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