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A Lake of Opportunity: Rethinking Phosphorus Pollution and Resource Availability

Andrea E. Ulrich

Since the Second World War, inorganic phosphorus fertilizers have become an increasingly crucial building block in our modern agricultural systems, which have both achieved vital growth rates in global food production and spurred population growth. Since 2007, however, discussions surrounding the potential decline of the global supply of easily accessible, high-quality phosphate rock for fertilizer production continue to emerge. The term "peak phosphorus" has been applied to the potential scarcity of rock phosphate in the twenty-first century. The use of this term aims to encourage a new perspective on regional and global food security and water quality: in other words, the relationship between the modern agricultural production system and the prevention of eutrophication, or the excessive plant growth resulting from antrophogenic nutrient loadings. This contribution outlines the "global P problem sphere" before moving to insights obtained from a Canadian case study that examines the opportunities of applying a paradigmatic focal shift to phosphorus understanding—"from noxious to precious"[1] — as assessed and evaluated through the direct participation of local stakeholders. The conclusion of this study was that a broadened science-practice mutual learning process can enhance our ability to sustain phosphorus supplies for soils and crops.

A short story about (peak) phosphorus

In 1669, Henning Brand discovered the chemical element phosphorus (P) in Hamburg, Germany while trying to uncover the secret principle of the philosopher's stone,

The author wishes to express her thanks to Diane Malley and Paul Watts for contributions and comments on this work as well as to Fridolin Brand and Bao Quand Le for critically reading and providing valuable suggestions for its improvement. She also thanks Claudia Whiteus for polishing up the language of this piece.
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1 International Institute for Sustainable Development, "Moving Phosphorus from Noxious to Precious: IISD report sets out the challenges for Lake Winnipeg," press release, March 4, 2010, http://www.iisd.org/media/press.aspx?id=164.

which at the time was believed to be able to transform base metals into gold. Because the material resulting from a synthesis using urine glowed in the dark and ignited when it was exposed to air, it was given the name "phosphorus," which is the latin word for light-bearer. Instead of calling it life-bearer—which would have stressed the element's fundamental role in life's metabolism—Isaac Asimov called phosphorus the "bottleneck of life" because the nutrient, for which there is no substitute, plays an essential role in all fundamental biochemical processes including photosynthesis, respiration, cell division (ATP/ADP), and heredity (DNA). In 1842, Justus von Liebig declared phosphorus one of the six elements indispensable to life on earth (together with carbon, hydrogen, nitrogen, oxygen and sulfur). Since phosphorus is highly reactive and is never found as a free element, it is frequently the first nutrient in which agricultural soil becomes deficient. Therefore, phosphorus plays an essential role in soil fertility, food production, and fertilization. In fact, its most important commercial use is in fertilizer production. Today, only one-fifth of all phosphorus produced is used in feed, detergents, and other non-fertilizer products.

The phosphate industry was founded in 1846 by John Lawes, who mechanized the labor-intensive activity of releasing phosphorus from bones, apatite, phosphorite, and other substances containing phosphoric acid. By 1853, there were fourteen superphosphate manufacturers in England. In 1867, South Carolina began mining mineral phosphates, and in 1887, Florida followed suit, establishing the United States as the world leader in phosphate rock mining until well into the twentieth century. In 1847, five hundred tons were mined, and world production rose to five thousand tons in 1850 and 148 million tons in 2008.

Today, the phosphorus market is dominated by China, Morocco, and the United States, together accounting for two-thirds of world production. Overall, the world's consumption of phosphorus is expected to continue to rise, especially in emerging countries and developing regions such as East Asia. With the economy recovering, the demand for P fertilizer experienced an 8.8 percent increase in 2009/2010, and is expected to increase by 4.5 percent in 2010/2011. *The Fertilizer Outlook 2010-2014* predicts that the world's demand for P fertilizer will rise in the medium term by 3.1 percent. Nevertheless, as environmental scientist Vaclav Smil pointed out in 1999, "it would be a sign of naiveté and intellectual irresponsibility to suggest that with no serious resource obstacles ahead of us the future of global fertilizer use will be a case of unimpeded growth."[2] This comment essentially refers to the fact that P, like any other element, cannot be viewed in isolation from other resources such as land, water, soil, and energy, or seen in a compartmentalized view. Instead, the study of P requires a whole life-cycle demand-supply chain view embedded in a coupled human-environment system perspective for assessing related challenges and opportunities of its sustainable use.

The staggering increase in the use of inorganic phosphorus during the second half of the last century has altered the natural dynamics of the phosphorus cycle. The volume of anthropogenic P flows compared to the natural flows has doubled, if not tripled. The natural global phosphorus cycle extends from the earth's crust, where weathering and other geological processes convert phosphate rock to soil. Erosion, leaching, and rainwater run-off transport P to rivers, lakes, and eventually to the ocean floor, where through geological processes that take up to ten to fifteen million years, P again becomes part of the lithosphere in the form of a calcium phosphate known as phosphorite. Outside the influence of humans, terrestrial ecosystems cycle P tightly through the phytomass, back to the soil, and through the phytomass again. On average, this process occurs several hundred times before P finally joins the mineral cycle, mainly through erosion. Nevertheless, as outlined above, industrial fertilizers have become the main source of nutrient addition, and humans have sped up the terrestrial cycling of P to an extent that not only questions its overall long-term availability, but also puts severe stress on our fresh water and marine ecosystems through an excess of this element and an imbalance in related cycles.

Insights into the emerging matrix of phosphorus criticality

Since 2007, there has been an almost contagious increase in attention to phosphorus. There are several reasons why phosphorus has recently been subjected to debate. For one, the question of how long P reserves will last has emerged several times in the last century on both national and international research agendas and in literature (Box 1).

2 Vaclav Smil, "Long-Range Perspectives on Inorganic Fertilizers in Global Agriculture" (International Fertilizer Development Center, Travis P. Hignett Memorial Lecture Florence, Alabama, November 1999), 19.

Aldous Huxley's Literary Perspective

Excerpt from *Point Counter Point* * on progress, wasteful resource use, and endless growth:

'With your intensive agriculture,' he went on, 'you're simply draining the soil of phosphorus. More than half of one per cent a year. Going clean out of circulation. And then the way you throw away hundreds of thousands of tons of phosphorus pentoxide in your sewage! Pouring it into the sea. And you call that progress. Your modern sewage systems!' His tone was witheringly scornful. 'You ought to be putting it back where it came from. On the land.' Lord Edward shook an admonitory finger and frowned. 'On the land, I tell you.'

'But all this has nothing to do with me,' protested Webley.

'Then it ought to,' Lord Edward answered sternly. 'That's the trouble with you politicians. You don't even think of the important things. Talking about progress and votes and Bolshevism and every year allowing a million tons of phosphorus pentoxide to run away into the sea. It's idiotic, it's criminal. it's ... it's…it's fiddling while Rome is burning.' He saw Webley opening his mouth to speak and made haste to anticipate what he imagined was going to be his objection. 'No doubt,' he said, 'you think you can make good the loss with phosphate rocks. But what'll you do when the deposits are exhausted?' He poked Everard in the shirt front. 'What then? Only two hundred years and they'll be finished. You think we're being progressive because we're living on our capital. Phosphates, coal, petroleum, nitre—squander them all. That's your policy. And meanwhile you go round trying to make our flesh creep with talk about revolutions.'

*Aldous Huxley, *Point Counter Point* (Leipzig: The Albatross, 1937), 77-8.

In 1938, for example, President Roosevelt stressed that "the disposition of our phosphate deposits should be regarded as a national concern. The situation appears to offer an opportunity for this Nation to exercise foresight in the use of a great national resource heretofore almost unknown in our plans for the development of the Nation."[3]

3 Franklin D. Roosevelt, "Message to Congress on Phosphates for Soil Fertility, May 20, 1938," *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/index.php?pid=15643.

In 1975, a case study in mineral resource analysis revealed that given recycling and a certain cost threshold of phosphate rock, the concept of phosphorus "exhaustion" was incorrect.[4] The appropriate way of thinking about the issue, the study's author F. J. Wells argued, was not that we will run out of phosphate rock, but that its cost will increase. The main uncertainty, he continued, relates to whether this cost will ever be prohibitive. Today, five years after the emergence of the new wave` peak P discussion, the underlying assumptions and time prognosis are once more being challenged.[5]

It is both interesting and important to note the remarkable similarities between questions and concerns that have arisen in the past and in today's discussion on future phosphorus resource availability. Hence, taking a rear-view mirror perspective opens helpful new horizons for learning about the current situation, especially given the void in research on rock phosphate reserves over the last two decades, and the complete lack of a concerted effort to formulate a remedial social process to support adaptive capacity building in coping with current and future challenges. Nevertheless, there are two new aspects that differ from past research; firstly, the worldwide reflection on phosphorus (both as a commodity in the form of phosphate rock and as an element) and its role in global food security as well as water quality and, secondly, the broad spectrum of connections to other knowledge sets, information opportunities, and social, economic, and environmental strategies. We should not, however, treat the new challenge presented by potential P reserve depletion as just another case of "the boy who cried wolf." The challenge is not only economic.

The nine points below summarize priority issues in P management and stewardship:

- Regional and global food security
- Securing drinking, ground surface and marine water quality
- Environmental and human health protection
- Global geopolitical stability and security
- Independence from phosphate rock or phosphate fertilizer imports
- Safeguarding ecological diversity and ecosystem integrity

4 Frederick John Wells, "The Long-Run Availability of Phosphorus: A Case Study in Mineral Resource Analysis," *Resources for the Future* (Baltimore: Johns Hopkins University Press, 1975), 69.

5 For more details see Allenby et al. *Global TraPs Workshop Propositions* (5 February 2011): http://www.uns.ethz.ch/gt/news/GT_Newsletter_2.pdf, and Mew, Michael, "Future Phosphate Rock Production - Peak or Plateau?" *Fertecon Research Center Limited* (3 March 2011): http://www.fertecon-frc.info/page15.htm.

- Safeguarding economic profitability and competitiveness (green innovation)
- Sustainable development (especially intergenerational justice and fairness, as well as distributive justice between the northern and southern hemispheres)
- Waste avoidance and conservation of an essential (eventually limited, in human terms non-renewable) resource using the precautionary principle

A connection frequently made in the current discussion is that “peak P” is the successor of peak oil. However, unlike with oil, there is no substitute for phosphorus. The element is an absolute requirement for life and the production of food. Also unlike oil, phosphorus is not destroyed when it is used, but is endlessly recycled by the earth’s natural processes. While we can never “run out” of phosphorus, when it is washed from the land to the oceans, it is returned to mineral forms that cannot be mined for tens of millions of years. Yet phosphorus stores within agricultural soils, crops, foods, composts, biomasses, and wastewater can be controlled, managed, and recycled rather than being lost to the oceans.

Intitial research results suggest a paradigmatic shift in resource understanding: that is, to consider phosphorus both as an essential, ultimately finite commodity in the form of phosphate rock and as a critical nutrient along the global phosphorus supply chain—from “cradle to cradle.” This could alter the focus from managing phosphorus as a pollutant to protect the environment, or as a cheap, readily available commodity used to increase soil fertility and crop yield towards managing it in an integrative manner as a life-supporting resource that secures global food production to support a growing world population. This attitude, that is the understanding of phosphorus both as a strategic resource and as a vital element should be synergistic with other issues, such as productivity of land and water, waste management, energy production, and the efficiency of water and energy use. Such a shift in focus has the potential to significantly transform the management of fertilizers on land and land management, by reducing loss of nutrients and encouraging the precise recycling of nutrients in composts, manures, and bio-solids or their derivatives. These strategies need to be clearly linked to social processes at the local level. Below is an example of a strategic intervention in one significant North American ecological system.

Eutrophic Lake Winnipeg: The need to slow the phosphorus flow

Figure 1: Accumulated blue-green algae at Connaught Beach, Lake Winnipeg in 2008. **Source:** Greg McCullough.

Historically, activities surrounding food production and the protection of water quality have often been at cross-purposes to one another, since one of the sources of P in water bodies is the agricultural use of fertilizers. Focusing on food security, these two activities are synergistically moving in the same direction, with a common interest in keeping phosphorus on the land for crops. Therefore, the present loss of P in Lake Winnipeg and the Hudson Bay represents an unacceptable waste of an essential resource that, particularly given Canada's heavy dependence on imported phosphate rock, puts soil fertility and agricultural production in one of the world's strategic agricultural areas at risk. The image of Lake Winnipeg beaches covered by a thick layer of floating algae provides a striking example of the adverse impact of elevated phosphorus levels in one of the world's largest lakes (see Figure 1). Improving the lake's health will require a decrease in the flow of phosphorus throughout the Lake Winnipeg basin, which includes portions of the United States (see Figure 2).

The case study region: The Lake Winnipeg basin

Lake Winnipeg, the world's tenth largest freshwater lake, is the most eutrophic large lake on Earth. Striking images of this extreme eutrophication have been captured from space (Figure 2). Its basin is the second largest in North America, draining portions of water from four Canadian provinces and four American states (see Figure 3).

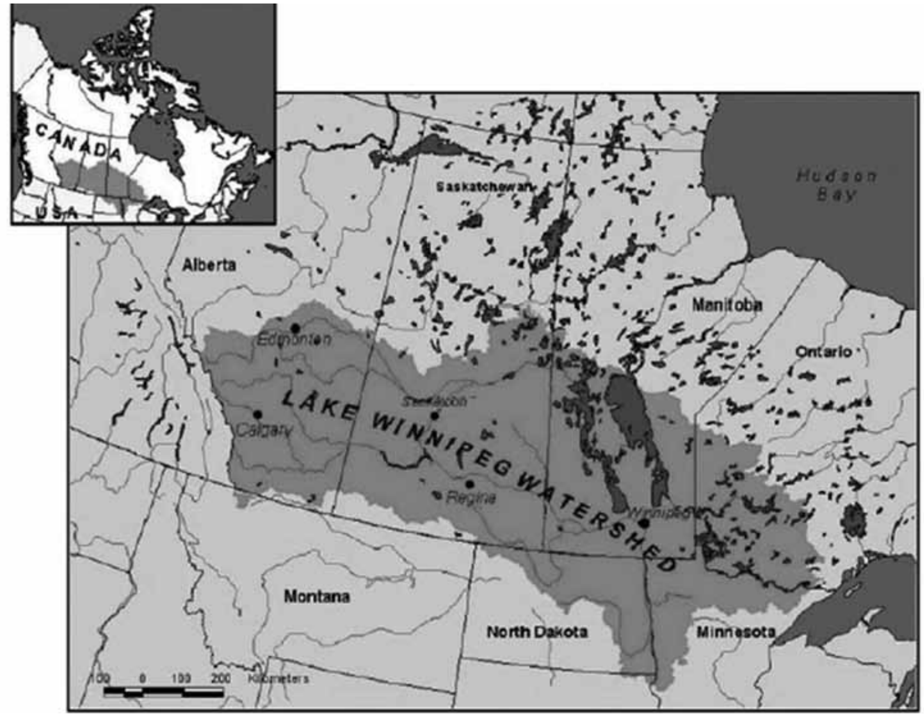

Figure 2: Waters from the Lake Winnipeg Basin flow into Lake Winnipeg drain into the Nelson River at the north end of the lake, and finally into Hudson Bay. **Source:** Manitoba Water Stewardship.

Home to six million people and seventeen million farm animals, the watershed covers nearly one million square kilometers, including fifty-five million hectares of agricultural land. Major livestock operations receive the largest input of commercial phosphate in the form of fertilizers. Waters that pass through Lake Winnipeg flow into the Nelson River and finally into Hudson Bay. Lake Winnipeg serves multiple purposes, including recreation and commercial fishing. Moreover, the lake is arguably the world's larg-est reservoir for hydro-electric power generation. These functions affect—or are being affected—by high phosphorus levels. For instance, Manitoba Hydro's dams control the water flows and levels in the lake, affecting nutrient flow. As members of the Lake Winnipeg Research Consortium state, this adds to the difficulties the lake is facing.

Figure 3: Satellite image of Lake Winnipeg in 2009 showing the large expanse of surface blooms in the North Basin. In 2005, 13,000 square kilometers were covered by surface blooms. Source: Greg McCullough.

Lake Winnipeg's phosphorus sources are less obvious than they are in some other eutrophic lakes. In the case of Lake Erie, for example, a reduction of phosphate content in detergents and tertiary wastewater treatment in the 1960s resulted in a dramatic amelioration of the lake's poor water quality. For Lake Winnipeg, on the other hand, the majority of phosphorus flows are from non-point sources. Agriculture, which plays a key role in the basin's economy, is important for non-point phosphorus emissions. Prior to the arrival of Europeans, the ecosystem was dominated by grasslands that held phosphorus except for the cyclic background flows to streams, rivers, and lakes that had evolved over time. Cultivation and land use changes introduced vast areas to wind and water erosion as well as run-off. This resulted in a significant increase in the flow of phosphorus to water bodies. Furthermore, new data suggests that frequent floods and climatic conditions that predominantly come from the Red River Basin that is shared with the United States are causing increased phosphorus loading.

Linking agricultural P nutrient management to water pollution

As a result of water quality issues and the uncertainty of global rock phosphate supplies, phosphorus management on land and the prevention of excessive nutrient pollution run-off into aquatic ecosystems are connected. The key objective of this ongoing work is to study the confluence of these two intertwined areas of global importance within the Lake Winnipeg Basin. From the initial efforts of the conducted studies (Box 2), synergies from aligning both perspectives have been identified.

How We Conducted the Lake Winnipeg Study

The circular participatory action research concept structured and guided the Lake Winnipeg Basin-study methodologically. This concept dates back to social psychologist Kurt Lewin, who defined this method as a “spiral of steps” composed of a circle of planning, action, and fact-finding. In its practical and explorative research format, this study strove for a better understanding of the pollution-resource nexus in the basin, and aimed at co-generating knowledge through mutual learning of the researcher and participants alike.

The empirical study was conducted in 2008, and a follow-up study was conducted in 2009. Together with Diane Malley and Paul Watts, I surveyed representative agencies and organizations (government, private, non-profit, and academic) in the Lake Winnipeg watershed that focus on agricultural systems, aquatic ecosystems, or both for their positions, policies, perspectives, advice, and actions regarding sustainable phosphorus use and the protection of water bodies. Data was assembled via website research, individual interviews, and questionnaires. This information was finally compiled in a report that was subject to evaluation by participants, and followed-up on in 2009 to assess a basis for future pathways to jointly move forward in developing abilities to improve and sustain both food security and water quality in the basin.

These efforts can be used as the basis for a next phase of the project. Further efforts should focus on the assessment of phosphorus flows in the basin, obtaining a better understanding of system vulnerabilities, avoiding unwanted rebound effects, and increasingly looking for opportunities to create supportive and remedial social process activities.

There are many good reasons to engage in interdisciplinary approaches and perspectives on sustainable resource management challenges. Each discipline has aspects that are being addressed in a more progressive fashion than others, yet as a whole, these different disciplinary constraints can be overcome. Engaging various disciplines can promote innovative exchange on both challenges and potential strategies for enhanced phosphorus security. Therefore, this research project combines methods, tools, and perspectives from different disciplines, including resource management, agronomy, political science, social and natural sciences (e.g. geochemical cyles, limnology), and industrial ecology, and integrates them under the common normative framework of sustainable development and global change.

Nevertheless, it is not sufficient to think about complex problems horizontally. It is similarly important to view the issues vertically by integrating science and practice cooperation. The resulting exchange between researchers, practitioners, and other societal groups working in different disciplines on various scales is likely to result in a better understanding of inherent complexities, and will allow the formulation of entry points for improving current practices. The development of linkages for these strategic inputs is intended to serve as a foundation for social process, thus supporting desired changes in values and practices through a transdisciplinary approach.

Outlook: Making space for discourse

Given that the problem sphere surrounding phosphorus is not only a pressing and contested environmental and societal challenge, but at the same time is an issue in which scientific knowledge is scattered across different disciplines or stakeholders and sometimes simply not readily available, an expansion of the initial action-research approach should make broader use of transdisciplinary perspectives, which means switching from the concept of "science for society" to "science with society." In this situation of uncertainty and major societal risks concerning the P challenge, novel and synthetic approaches are necessary. We must bridge knowledge dimensions from different scientific disciplines and link science with wider societal actors in order to enhance sustainability learning and encourage socially conscious behavior, such as recycling and reusing P. The definition, representation, and transformation of these challenges demand the interaction of theory and practice.

The Lake Winnipeg case study is embedded within this effort as part of a broader global initiative called *Global TraPs*, a project led by NSSI, ETH Zurich, and IFDC (International Fertilizer Development Center, USA) in cooperation with a wide pool of international cooperation partners from science and practice backgrounds. The current phase of this project aims to address the need for global cooperation in order to improve our collective understanding of the issue by facilitating a global transdisciplinary learning process along the phosphorus supply chain and addressing three issues central to sustainable resource management: the long-term management of biogeochemical cycles, closing fertilizer loops and related food security issues, and sustainability learning on a global level. The project will organize transdisciplinary learning processes (case studies) that strive to build regional and global capacity to use phosphorus sustainably.

Opportunity in the making

The Lake Winnipeg Basin, arguably the most organized watershed in North America, faces unprecedented challenges in terms of resource use. Above, I presented a possible way of approaching these challenges. The idea reflects what Rachel Carson proposed in 1953:

> The real wealth of a Nation lies in the resources of the earth—soil, water, forests, minerals and wildlife. To this, the previous and current work emphasizes the additional wealth represented by the people themselves, their values and principles. To utilize all of these sources of wealth means not only a consideration of present needs but also ensuring their preservation for future generations. These goals require a delicate balance of science within society and a continued program, based on extensive research and action. The research administration is not properly, and cannot be, a matter of politics.[6]

The phosphorus challenge represents a vast and complex task that cannot be dealt with as a question of science alone. In an economically, environmentally, and socially interdependent world and focusing on an issue so inherently global, going beyond the nation-state is essential in developing abilities to sustain agricultural production and improve water quality. These goals far exceed the capabilities of governments and institutions, and so the questions of scale and genuine cooperation are essential. Furthermore, we need to emphasize the importance of bridging the existing information gap in existing coping strategies within a society, anticipating and preparing a society for adaptation, and mitigating the different needs and rationales of a diverse stakeholder group.

6 Rachel Carson in Linda Lear, *Lost Woods: The Discovered Writing of Rachel Carson*, edited by Linda Lear (Boston; Beacon Press, 1998), 99.

The pace of change necessary to keep up with increasing national and international efforts on the issue requires significant coordination. In this respect, it seems essential to create coherence so that efforts towards sustainable P use do not contradict or duplicate one another, but instead go beyond fragmented and partial answers by creating a synergy. It appears critical to create a multi-stakeholder forum that includes groups who have traditionally been excluded, for example First Nations and their traditional knowledge. This is also a basic finding of our previous study suggesting that everyone—and not just policy makers, agronomists, and experts—can contribute to the sustainable use of phosphorus and, by extension, towards increased food security and water quality. Perhaps the key message of "peak phosphorus" emerged from the earlier phase of the current study, which was, according to the president of DALUHAY, Paul Watts, "a potentially critical tipping point in the global approach to public participation and social process."[7]

In such a scenario, the Lake Winnipeg Basin is uniquely positioned at the forefront of sustainable phosphorus management, stewardship, and governance. Given Canada's economic, environmental, social, and scientific richness, the Lake Winnipeg Basin features a supportive foundation from which to act as a pioneering agent. As an indicative case study region, the strategic actors of the basin can enhance the well-being of the people and gain competitive economic advantages by managing essential resources according to the sustainability principle, demonstrating responsibility at a critical stage of evolution. This, however, requires overcoming what has been termed the "mikado and silo mentality." The former relates to the concept that characterized the Copenhagen Climate Summit. It is the unwillingness to move forward and show commitment to necessary action. The second relates to disciplinary boundaries that need to be opened and linked for an integrated system-wide approach. The "window of opportunity" presented at this time should therefore be used to take action toward the stability and security of the future wealth of the basin in societal, environmental, and economic terms. Thus, in this respect, Lake Winnipeg can indeed become a lake of opportunity.

7 For more information on DALUHAY, see http://ecosystemics.info.

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