Water Innovation Centre

iisd International Institute for Sustainable Development
Institut international du développement durable

Peak Phosphorus: Opportunity in the Making

Why the Phosphorus Challenge Presents a New Paradigm for Food Security and Water Quality in the Lake Winnipeg Basin

Andrea Ulrich
Diane Malley
Vivek Voora

December 2009

Peak Phosphorus: Opportunity in the Making

Why the phosphorus challenge presents a new paradigm for food security and water quality in the Lake Winnipeg Basin

Andrea Ulrich
Diane Malley
Vivek Voora

December 2009

Published by the International Institute for Sustainable Development

The International Institute for Sustainable Development contributes to sustainable development by advancing policy recommendations on international trade and investment, economic policy, climate change, measurement and assessment, and natural resources management. Through the Internet, we report on international negotiations and share knowledge gained through collaborative projects with global partners, resulting in more rigorous research, capacity building in developing countries and better dialogue between North and South.

IISD's vision is better living for all—sustainably; its mission is to champion innovation, enabling societies to live sustainably. IISD is registered as a charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Government of Canada, provided through the Canadian International Development Agency (CIDA), the International Development Research Centre (IDRC) and Environment Canada, and from the Province of Manitoba. The institute receives project funding from numerous governments inside and outside Canada, United Nations agencies, foundations and the private sector.

International Institute for Sustainable Development
161 Portage Avenue East, 6th Floor
Winnipeg, Manitoba
Canada R3B 0Y4
Tel: +1 (204) 958–7700
Fax: +1 (204) 958–7710
Email: info@iisd.ca
Website: www.iisd.org

Executive summary

The long-term security of our global food and water supplies may be impacted by the mismanagement of our phosphorus nutrient resources. Essential to plant growth and all life, phosphorus is mined from rock phosphate deposits and synthesized into mineral fertilizers destined for agricultural fields. Easily mined rock phosphate reserves are dwindling and the constraints this could place on fertilizer production pose risks to our long-term ability to feed the planet. Excess phosphorus from agricultural fields runs off the landscape and eventually gets flushed into the ocean, where it takes millions of years to mineralize. Under the right conditions, phosphorus loads can choke water bodies as algae rapidly grow, die and decompose, depriving lakes, rivers, streams and coastal waters of oxygen. This process, referred to as eutrophication, threatens the security of our freshwater supplies and aquatic ecosystems. Phosphorus is fundamental to long-term food security, yet we mismanage it, allowing excess phosphorus to imperil our water resources.

Within the Canadian Prairies, "peak phosphorus" could have serious economic consequences. Rising fertilizer costs will hit the bottom lines of agricultural producers, which may result in higher food costs. Phosphorus mismanagement is also being exhibited within the water bodies of the region. Lake Winnipeg, which drains the Canadian Prairies, is the most eutrophic large lake in the world. This situation clearly points to a need to better manage phosphorus resources by finding more effective ways to use, recover and recycle this precious nutrient.

Fortunately, opportunities to accomplish this are abundant. Adopting agricultural practices that improve plant nutrient uptake and limit phosphorus runoff can lower application requirements. Phosphorus recovery from manure and human and food waste can also lower our dependence on mineral fertilizers. For instance, phosphorus recovery systems could become standardized within wastewater treatment plants. Composting manure as well as human and food waste also represents an important source of phosphorus. Closing the loop on our food systems and moving toward phosphorus independence are crucial to ensuring the long-term security of our food and water supplies. Treating phosphorus as a finite resource shifts our management paradigm from mitigating a noxious substance to recovering and recycling a precious element.

Introduction

Phosphorus has been termed "life's bottleneck," as it is an essential building block for all living organisms for which there is no substitute. It is a basic component of our DNA, plays a fundamental role in cellular energy production, and is integral to cell membrane and bone structure.

Highly reactive, phosphorus is never found as a free element on Earth. Phosphorus composes about 0.7% of a typical crop but only 0.12% of soil, which gives its concentration a plant-to-soil ratio of 5.8. This ratio is far greater than for any other mineral element (Conrad, n.d.). Consequently, phosphorus is frequently the first nutrient in which agricultural soils become deficient. Moreover, unlike carbon and nitrogen, which can be fixed from the atmosphere, phosphorus has no gaseous form.

The most important commercial use of phosphorus is the production of fertilizers for food production (Figure 1). In common fertilizer formulations, designated as N-P-K, phosphorus (P) and potassium (K) usually contribute similar proportions, which are each less than half that of nitrogen (N).

The prospect of depleting the world's mineral rock phosphate reserves is of great concern and is increasingly being compared to peak oil. Nevertheless, there is hope. Unlike irreversible impacts such as the consumption of fossil fuels and species extinction, phosphorus as an element can be neither created nor destroyed, but is endlessly recycled through the living and non-living phases (organic and inorganic elements) of the Earth. While we can never run out of phosphorus, when washed from the land to the oceans it is not returned for tens of millions of years to mineral forms that can be mined.[1] Yet much of the phosphorus stores within agricultural soils, crops, food, composts, biomasses and waste water can be controlled, managed and recycled rather than being lost to the oceans.

The word *phosphorus* means "light bearer" in Greek mythology. Thus, the global management of phosphorus can be a remarkable opportunity to "light the way" toward global cooperation, policies and practices in general. We can choose to turn the "peak phosphorus" prospect from threat to opportunity.

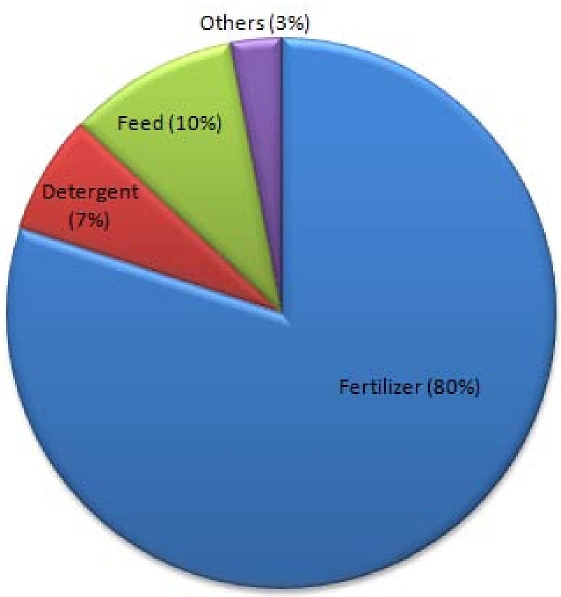


Figure 1: World use of rock phosphate. (Data source: International Fertilizer Industry Association, 2008.)

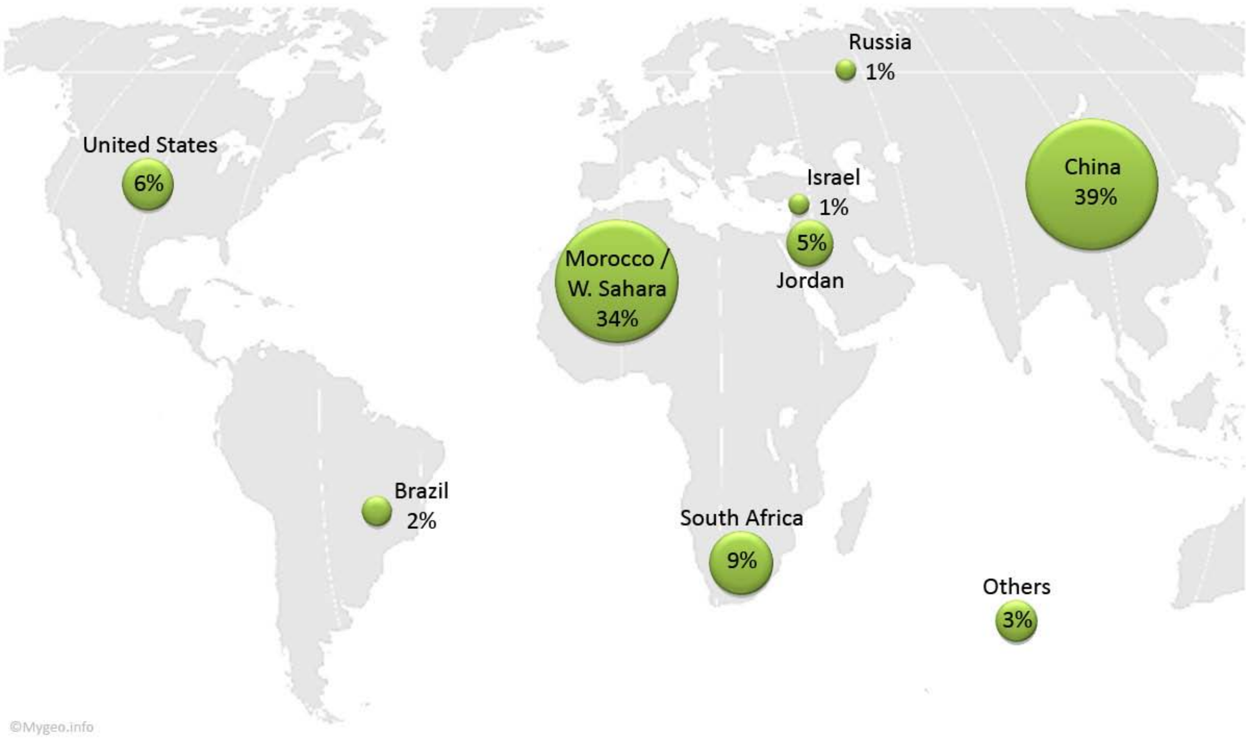
[1] Rockstrom et al. (2009) estimate that the world currently releases 8.5 million to 9.5 million tonnes of phosphorus into the ocean annually. This is substantially greater than humanity's pre-industrial emissions of approximately 1 million tonnes per year. The authors suggest that for humanity to remain within a "safe operating space," phosphorus emissions flowing into the ocean cannot exceed 11 million tonnes per year.

The peak phosphorus challenge

Peak phosphorus describes a moment in time when demand for rock phosphate will exceed supply. While our total global phosphorus reserves remain unknown, statistics on deposits found in recent decades indicate that more phosphate is being extracted than discovered. Despite technological and methodological advances, new deposits are fewer and of lower quality than previously. Statistical efforts to predict phosphorus demand and supply in a highly complex, dynamic system can only provide general estimates. Depending on the calculation, researchers predict that phosphorus production will peak in twenty to several hundred years. Australian scholars predict that since rock phosphate is being consumed at a pace greater than its discovery rate, it is conceivable that peak world extraction could be reached as early as 2030 (Global Phosphorus Research Initiative, 2008). Peak production was reached in the United States in the late 1980s (Déry & Anderson, 2007).

Known phosphate reserves are unevenly distributed around the world and highly concentrated. Most deposits are found between the 40th parallels north and south (Harben & Kuzvart, 1996). Worldwide reserves in 2007 amounted to 18 billion tonnes, with almost 90% located in four countries: China, Morocco/Western Sahara, South Africa and the United States (Figure 2). The world's known resource base, nevertheless, is substantially higher, but its exploitation remains uneconomical. Even if market prices turn unattractive resources into economical ones, a number of limitations prevail, such as environmental protection, energy constraints and geopolitical risks (Box 1).

Figure 2: World rock phosphate mine reserves 2005. (Data source: Röhling, 2007.)



Box 1: Five reasons for slowing the rock phosphate flow: A comprehensive perspective

The exact number of global phosphorus reserves is unknown, but statistics on deposits found in recent decades suggest an alarming conclusion. More phosphate is being mined than is being discovered. At present, there are 1,600 mines, deposits and occurrences worldwide (U.S. Geological Survey [USGS], 2008). Despite new technology and methods, fewer deposits are being detected, and these generally have lower quality grades than previously. Even with technological advances and favourable market prices, a number of constraints prevail:

Economics: Extracting, processing, marketing and shipping phosphorus from mine to farm is energy intensive. Phosphorus prices will increase with rising fossil fuel prices and lowered access to inexpensive energy. Ever-increasing global demand will accelerate this process. Newly found phosphate deposits are generally harder to mine and demand additional energy inputs. Deep-sea sediment harvesting, for example, is an expensive option, as technological advances have yet to evolve.

Environment: The human-influenced phosphorus life cycle imposes certain pressures on the environment. Phosphate rock mining, which is mostly conducted through strip mining, results in landscapes exposed to increased physical and biochemical erosion. In aquatic ecosystems, excess phosphorus loads can lead to eutrophication that can impact biodiversity and ecosystem services.

Geopolitical risks: While major quantities of phosphorus fertilizer are used in industrialized countries where sufficiency and efficiency prevail, developing and emerging countries face shortages, often due to pricing. This uneven distribution in supply and availability could lead to social and political unrest. Failure to respond to North–South distribution inequalities and an oligopolistic market structure could result in conflict. An international organization may be needed to regulate export rates.

Logistics: Global phosphate reserves are unevenly distributed and concentrated on Earth. Since transportation, storage, production capacity and reliability of delivery are important aspects of the supply chain, long-haul transportation poses a considerable challenge, particularly with regard to rising energy costs.

Quality: The overall quality of raw phosphate is declining, and more hazardous waste is produced during processing. An increasing number of heavy metals and other materials posing potential risks to human health and the environment, such as gypsum and cadmium, are found in mined phosphorus compounds. This drives up extraction costs to ensure safe conditions for fertilizer production.

The phosphorus market is controlled by China, the United States and Morocco, as they account for two-thirds of the world's production (USGS, 2009). In 2005, the world produced 146.8 million tonnes of rock phosphate. China surpassed the United States, historically the world's largest producer, in 2007 (Figure 3). Mean annual production of rock phosphate in the United States amounts to 30 million tonnes, which primarily originates from Florida and North Carolina (85%), complemented by Utah and Idaho (USGS, 1999).

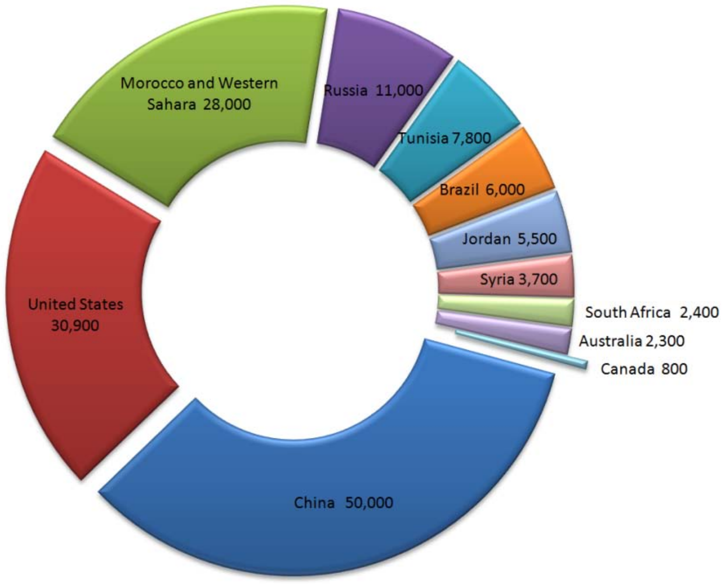


Figure 3: World rock phosphate production 2008: 148.4 million tonnes. (Data source: USGS, 2009.)

According to the International Fertilizer Industry Association (2007), over two-thirds of mined rock phosphate is destined for domestic consumption, and only one-third is traded internationally. North American companies such as Agrium and Mosaic produce large quantities for their domestic market, while the Moroccan Office des Chérifien des Phosphates markets their product almost exclusively internationally.

Canada, which is the largest global potassium supplier, remains largely inactive in phosphorus production. In 2003, Agrium started operating Canada's first and so far only mine, located in Ontario, producing 1.1 million tonnes of rock phosphate in 2007. Along with many other countries, Canada depends heavily on phosphate imports to meet its demands and is thus vulnerable to shifting world supplies.

As a response to rising demands and tight supply conditions, current production will be expanded in Africa, China and Jordan. New mining operations are also being projected for Australia, Brazil, Peru and Saudi Arabia.

Since the 1960s, phosphorus fertilizer consumption has risen continually, from an annual average during that decade of 28 million tonnes to roughly 160 million tonnes in 2008 (International Fertilizer Industry Association, 2008). This trend was only interrupted by the oil crisis of the 1970s and the collapse of the Soviet Union in the early 1990s. The consumption of phosphate fertilizers in emerging and industrialized countries increased until the late 1980s. Industrial countries have since reduced their consumption rates substantially. The market is currently driven by demand in Asia/Oceania, North America and Africa/West Asia—a trend that is likely to continue in the future (Figure 4).

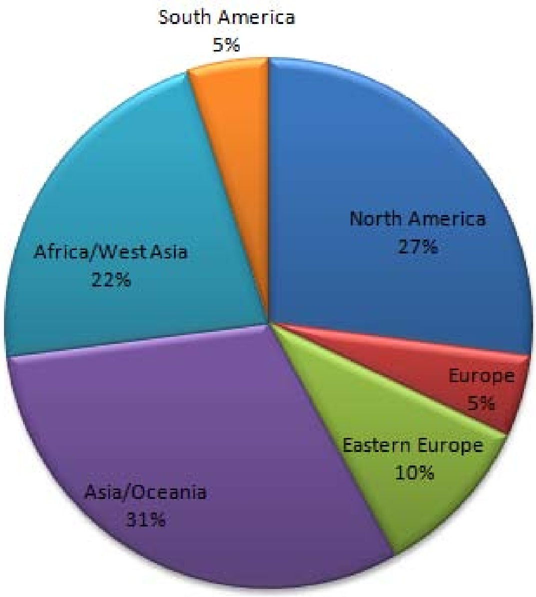
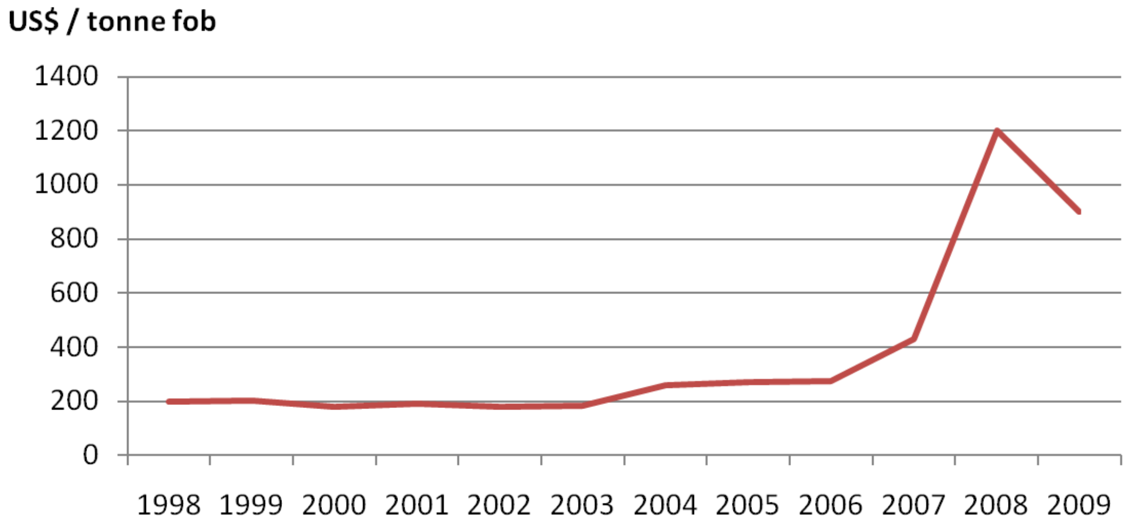


Figure 4: World rock phosphate consumption 2005: 146.8 million tonnes. (Data source: International Fertilizer Association, 2007.)

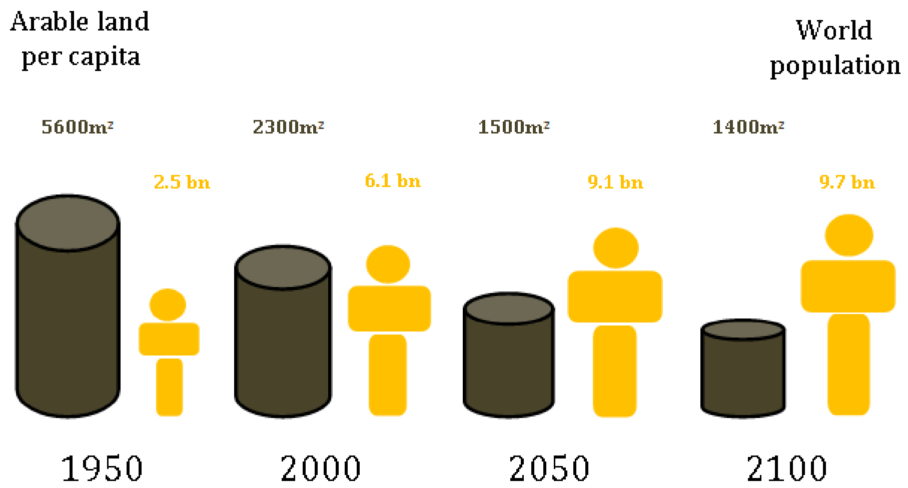
Prices for raw phosphate and phosphate derivates differ depending on their regional markets. No uniform prices exist on a global scale. Since 2002, prices of monoammonium phosphate, diammonium phosphate and raw phosphate have risen dramatically (Figure 5). In 2007, market expectations and demand for natural resources soared. The continued dramatic rise in market prices in early 2008 was attributed to China's decision to impose a 135% export tax on its phosphate. The anticipation of reduced supplies, increasing demands and reduced Moroccan production accelerated this development. The global economic recession and China's removal of its export tax has recently deflated rock phosphate prices. They will likely rise again as availability is reduced and global demand continues to increase.

Figure 5: Diammonium phosphate fertilizer prices for northern Africa. fob = free on board. (Data source: Fertecon, 2008.)



The invention of industrial fertilizers in 1840 and their application to the land have altered the natural dynamics of the phosphorus cycle and supported unabated population growth by increasing food production. Phosphorus scarcity is a likely scenario, since its consumption is interlinked with soil losses, soil nutrient depletion and population growth as well as food, biofuel and energy production. To feed the additional two billion people projected to populate the Earth by 2050, food production must increase, and fertilizer use will be essential in this endeavour (Figure 6). Our current reserves provide us with a window of opportunity to make a planned transition toward less dependency on mineral fertilizers by adopting responsible phosphorus management practices, including nutrient recycling and efficient application methods.

Figure 6: Arable land and world population, 1950 to 2100. (Data source: UN Food and Agriculture Organization, 2009.)



Lake Winnipeg: A barometer of phosphorus management

Lake Winnipeg, the tenth-largest freshwater lake in the world, provides one of the most visual and striking global images of extreme eutrophication. The lake now experiences massive blue-green algae blooms that are visible from space (Figures 7 and 8).

Figure 7: Satellite view of Lake Winnipeg in August 1999, showing the large expanse of blue-green algae (green area) in the North Basin of Lake Winnipeg. (Photo by Greg McCullough.)

Figure 8: Accumulation of mats of blue-green algae on a recreational beach on Lake Winnipeg. (Supplied by Karen Scott.)

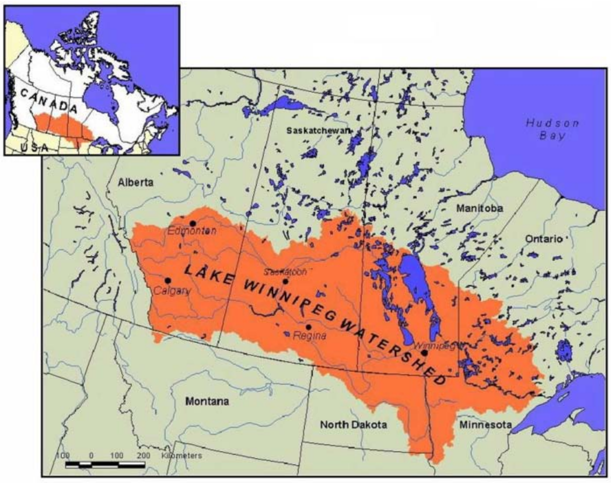


Figure 9: Waters from the Lake Winnipeg Basin (in red) flow into Lake Winnipeg and drain into the Nelson River at the north end of the lake and finally into Hudson Bay. (Source: Manitoba Water Stewardship, n.d.[2])

The Lake Winnipeg Basin (Figure 9) is the second-largest drainage basin in North America, covering nearly 1 million square kilometres and draining parts of four U.S. states and four Canadian provinces. It is home to 6 million people and 17 million livestock, and includes 55 million hectares of agricultural land. Approximately half of its area is agricultural land, including major livestock production areas that receive the largest inputs of commercial phosphate in the form of fertilizers. Waters passing through Lake Winnipeg flow into the Nelson River drainage system, which empties into the Hudson Bay.

---

[2] Permission to reproduce this image is provided by the Queen's Printer for Manitoba. The Queen's Printer does not warrant the accuracy or currency of the reproduction of this information.

The sources of extreme eutrophication of Lake Winnipeg are less obvious than they were in the case of Lake Erie in the 1960s (U.S. Environmental Protection Agency, 2000). Lake Erie lies in an area of high population pressure from both sides of the Canada-U.S. border. Reflecting an era when phosphates were used prominently in detergents and tertiary treatment of domestic waste water was little practiced, Lake Erie responded well when these phosphorus flows to the lake were dramatically reduced (Box 2).

The situation in Lake Erie also initiated important research into the nutrient causes of eutrophication. The federal government's 1970 Experimental Lakes project in northwestern Ontario examined, in a whole-lake experiment, the drivers of eutrophication.

Box 2: Lake Winnipeg and Lake Erie

Two major differences distinguish lakes Winnipeg and Erie—their geology and the sizes of their watersheds. Lake Erie is situated on the Precambrian Shield. Lakes in this geological setting tend to have naturally low phosphorus concentrations because the dominant granitic rocks erode and release nutrients slowly. Lake Erie has a watershed that covers only three times the lake's surface area. In contrast, Lake Winnipeg lies along a fault between the Precambrian Shield to the east and north and low-relief Interior Plains to the west and south. The Plains are dominated by sedimentary soils and water bodies with naturally higher levels of phosphorus. The Lake Winnipeg Basin is nearly 40 times greater in area than Lake Winnipeg, the highest ratio for any large lake in the world. Furthermore, even though Lake Erie is a shallow lake with a mean depth of 19 metres, Lake Winnipeg is even shallower, with a mean depth of 12 metres. Compared with Lake Erie, the state of Lake Winnipeg is dominated by natural inputs of phosphorus and non-point rather than point sources of anthropogenic nutrient additions. Once the major point sources of phosphorus to Lake Erie were controlled, lake quality improved reasonably quickly, aided by the relatively low content of naturally occurring phosphorus in the water entering from the watershed.

Monitoring of the phosphorus flows into Lake Winnipeg reveals that the Red River has historically been the largest contributor, with annual loads increasing from the 1970s to 2000 (Figure 10). Recent findings indicate that there have been sudden increases in loadings associated with more frequent flooding incidences. Evidence suggests that parts of the Lake Winnipeg Basin are experiencing a wetter climatic period than usual. Since flood waters interact with more land area than is normal for rivers and streams, they accumulate considerably more phosphorus than rivers and streams under normal weather conditions. Climate change adds complexity to understanding and managing the phosphorus that makes its way into Lake Winnipeg. Overall, Lake Winnipeg is more influenced by its watershed processes and by the volume and composition of its water sources than are most other great lakes.

Agriculture, an important part of the economy, is also important for its non-point phosphorus emission sources within the Lake Winnipeg Basin. A total of 100,816 farms across the basin, covering approximately 47.16 million hectares of land and equipped with farm capital valued at Cdn$112 billion, participated in Statistics Canada's 2006 agricultural census (Agriculture and Agri-Food Canada, 2006). Gross farm annual revenues within the basin amounted to approximately Cdn$18.51 billion, and net annual revenues were estimated at Cdn$2.24 billion in 2006 (Agriculture and Agri-Food Canada, 2006). Phosphorus emissions flowing off agricultural lands and originating from intensive livestock or dairy operations contribute a fair share of the phosphorus load that ends up in Lake Winnipeg. Agriculture has been an important source of employment and has greatly influenced the landscape. Enabling farming operations to thrive alongside healthy natural environments and water bodies is imperative for the long-term sustainability of the basin.

Lake Winnipeg serves multiple purposes for people, including recreation and commercial fisheries, and it is the world's third-largest hydroelectric power–generation reservoir. These functions affect or are affected by high phosphorus levels. Additional algal biomass can impact hydroelectric power–generation capacity by fouling equipment, causing surface drag and slowing water flow velocities.[3] Recreation is adversely affected by the accumulation of blue-green algae on beaches and the risk of contacting toxic chemicals released by some of the algal species. Reduced dissolved oxygen concentrations resulting from algal decomposition following blooms can lead to the formation of anoxic zones that can threaten aquatic species. At the same time, the additional algal biomass has increased lake productivity, benefiting commercial and subsistence fishermen as harvests surpass maximum yields experienced in previous decades. Nevertheless, increasing anoxia in the lake presents a poorly understood risk to the continuing success of the fishery.

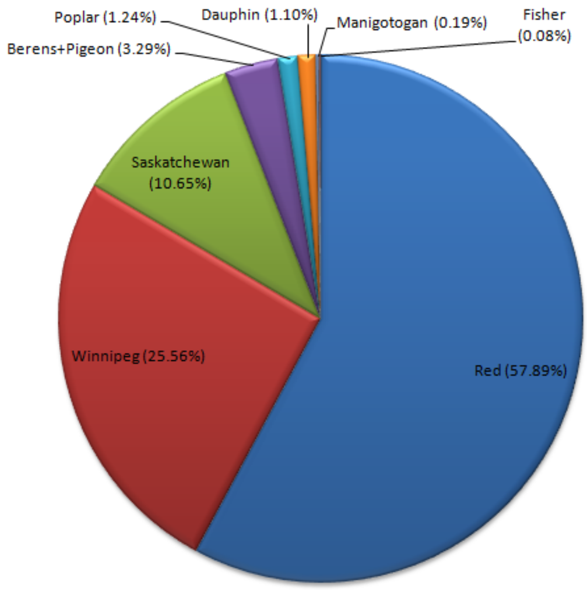


Figure 10: Contributions to the phosphorus loads flowing into Lake Winnipeg from its main river systems. (Source: Adapted from Lake Winnipeg Implementation Committee, 2005.)

The Lake Winnipeg Basin is highly complex, and its phosphorus monitoring, management and conservation strategies could provide models for peak phosphorus responses in other parts of the world. Engaging urban and rural communities; national, state and provincial jurisdictions; and First Nations communities to endorse research, technological development and social change is a worthy endeavour for improving the health of Lake Winnipeg and maintaining the phosphorus supply to agricultural lands in the breadbasket of Canada.

Exploring paths for a phosphorus-safe future

Fortunately, phosphorus can be used more effectively, as well as recovered and recycled. Numerous efforts are underway in many parts of the world to keep nutrients within the farming system. Cycling phosphorus exported in food products back to the land requires effort. This can be challenging due to the distances between food production and consumption. In North America, for example, a meal generally travels 1,500 kilometres from origin to plate (Smith & Mackinnon, 2007). Facilitating the recovery and recycling of phosphorus sources is therefore imperative.

[3] Laboratory-scale experiments carried out by a research team in Australia found that biofilms (diatoms and long filamentous algae streamers), which foul power scheme canals and turbulent wall structures, can increase surface drag, thus slowing flow velocity (Andrewartha, Sargison & Perkins, 2008).

One of the most promising opportunities for phosphorus recovery is in the wastewater treatment sector. Research on recovering phosphorus from waste water is being conducted worldwide, and large-scale complexes are undertaking promising pilot programs. Phosphorus is being recovered from a municipal wastewater treatment plant in the Netherlands, and Edmonton's Gold Bar wastewater treatment plant has been deemed suitable for the implementation of a commercial-scale nutrient-recovery system.

Phosphorus and ammonium can be recovered from waste water in the form of struvite, a magnesium-ammonium-phosphorus precipitate. Ostara, a Vancouver-based corporation, invented a technology used to recover phosphorus from waste water using struvite so that it can be converted into a slow-release fertilizer, magnesium ammonium phosphate or MAP, sold as Crystal Green. The process is a polishing step that precipitates phosphorus out of the waste water that is returned to the plant. Gilbert (2009) estimates that roughly 30% of Canada's fertilizer consumption could be met by converting all of its wastewater treatment plants to biological treatment systems with struvite recovery technology. The company has three pilot plants in operation and opened its first commercial phosphorus-recovery facility in Portland, Oregon, in May 2009.[4]

Phosphorus recovery needs to become a standard design consideration when developing or upgrading wastewater treatment plants. The City of Winnipeg, faced with over a billion dollars in expenditures to upgrade its wastewater treatment plants, could benefit in a number of ways from implementing a struvite recovery system. The system will prevent wastewater return pipes from clogging and will produce a substantial amount of fertilizer (potentially more than 500 tonnes per year), which can be sold to the agricultural sector.

Moving upstream from the wastewater treatment plant, another effective phosphorus-recovery strategy would be the use of composting toilets and the separation and collection of urine by using equipment such as waterless urinals in households, large apartments and office buildings. Urine makes an excellent fertilizer, as it has the correct ratio of nitrogen, phosphorus and potassium. Replacing flush toilets with human waste recovery systems would also reduce domestic water consumption and municipal wastewater treatment requirements.

Food waste must be reduced and disposed of in a manner that recycles phosphorus back to the land to support further plant growth. This includes finding alternatives to landfills for disposal of organic substances. A recent study on global food waste indicates that approximately 40% of all food is wasted worldwide (Stuart, 2009). According to the study, the world's hungry could be fed more than seven times over with food waste originating from Europe and the United States alone. Other studies point out that large amounts of all fruits and vegetables produced never see the inside of a supermarket, since they don't meet size and structure regulations (Friends of the Earth, 2005). In the case of vegetables and salad this can amount to 40% to 50% of produce (Henningsson et al., 2004). The underlying problem leading to food waste stems in part from consumer behaviors supported by an economic system built to produce more than we need.[5]

In addition to waste water and food waste, other opportunities exist to recover phosphorus. Sewage sludge that contains more than 300 organic pollutants and pathogens, including hormones, antibiotics, and heavy metals such as cadmium and zinc, can be treated using monocombustion that concentrates phosphorus and heavy metals through mass loss (Adam et al., 2008). The ashes offer less favourable phosphorus availability than biosolids; nevertheless, the

---

[4] The plant is located at the Durham Advanced Wastewater Treatment Facility in Tigard, Oregon (suburban Portland), and is operated by Clean Water Service. The plant serves more than 500,000 people in Portland and surrounding counties. The US$2.5 million struvite recovery system is expected to produce 450 tonnes of fertilizer per year (Clean Water Services, 2009).

[5] Water and energy used in producing, transporting and distributing food, along with emissions released during these processes, render the ecological footprint of many agricultural products consumed and wasted in industrialized countries unsustainable.

final product surpasses most European environmental standards for fertilizers in terms of permissible heavy-metal content. Other research initiatives, such as the European Union–funded SUSAN project, are investigating thermochemical treatment of biosolid ashes, which could provide a sustainable and safe strategy for phosphorus recovery in the future.

Bone and meat meal are also being examined as potential phosphorus sources, due to their high phosphorus content. Nevertheless, regulatory and legislative barriers prevail. In 2001, Germany banned bone meal as a phosphorus source in animal feed over fears of bovine spongiform encephalopathy infection (U.S. Department of Agriculture, 2009). New research projects are underway combining bone meal with microorganisms. The first positive experiments have been obtained from growing tomatoes in Israel.

The predicted long-term increases in fertilizer prices must lead to expanded efforts to recover phosphorus from secondary sources and improve fertilizer-application efficiencies. Most applied fertilizers are not taken up immediately by plants, but remain in soils, where they accumulate over time or wash off into waterways. Improvements to plant uptake of phosphorus can be achieved through site-specific nutrient management, soil-phosphorus content assessments and matching nutrient delivery to crop requirements. In addition, agricultural practices, such as no-till, that have less impact on mycorrhizal fungal growth can increase plants' phosphorus uptake.

Within the Lake Winnipeg Basin opportunities abound to better use, recover and recycle phosphorus. Livestock in the basin emit approximately 166,283 tonnes of phosphorus per year,[6] potential non-point emissions originating from croplands range from 1,851 to 33,191 tonnes of phosphorus per year,[7] and point sources (from industrial and municipal wastewater) emit approximately 1635 tonnes of phosphorus per year.[8] Recovering and recycling this phosphorus could potentially displace costly mineral fertilizers. Approximately 55,000 farms applied fertilizer to 19.44 million hectares of land, and 60,000 farms paid Cdn$1.51 billion to purchase fertilizer and lime across the Lake Winnipeg Basin in 2006 (Agriculture and Agri-Food Canada, 2006). In addition to recovering phosphorus, opportunities exist to use it more effectively by adopting agricultural practices that match fertilizer and plant requirements and facilitate plant uptake of fertilizer. Practices such as conservation tillage and no-till promote the growth of mycorrhizal fungi, which are central to phosphorus absorption by many crops. In 2006, approximately 33,000 farms reported using conventional tillage on 5.33 million hectares of land (Agriculture and Agri-Food Canada, 2006). There are clearly many opportunities in the Lake Winnipeg Basin to lessen our dependence on rock phosphate–derived mineral fertilizers.

Peak phosphorus has the power to bring people together to transform our global food production systems. Fundamental changes in agriculture may be needed for it to adapt to a world without inexpensive fertilizers. In such a scenario, rethinking the way we consume, recover and recycle phosphorus will be crucial. Although this is no easy task in times of economic turmoil, failure to act will burden future generations with a food- and water-security crisis. Furthermore, being proactive will help the economy, as supporting new technologies and innovative processes could bolster green markets in order to secure a sustainable future.

---

[6] Livestock phosphorus emissions were compiled from Statistics Canada (2006), estimated by multiplying the total number and type of livestock with a livestock phosphorus coefficient (Hofmann, 2008; Hofmann & Beaulieu, 2001).

[7] Cropland phosphorus emissions were estimated by multiplying emission coefficients (0.07 to 1.27 kilograms of phosphorus per year per hectare [Belcher, Edwards & Gray, 2001]) with total cropland area (26.14 million hectares).

[8] Point-source phosphorus loads were estimated based on National Pollutant Release Inventory (Environment Canada, 2007) and Municipal Water and Wastewater Survey data (Environment Canada, 2006). Smaller point-source phosphorus loads were estimated based on a methodology developed by Chambers et al. (2001).

Action instead of reaction

Peak phosphorus equals the end of inexpensive fertilizer. Exploiting lower grades of phosphate rock will likely be insufficient to replace dwindling financially viable reserves quickly enough to meet increasing demands. More effective application methods and best management practices have to be explored, innovative technology development supported, and social dialogue and decision-making facilitated. The ultimate goal: a green New Deal focusing on the sustainable evolution of agriculture, the energy sector and our daily lives. The following are potential steps toward making the transition to mineral-fertilizer independence.

Increasing our scientific understanding

- The phosphate issue is part of a much greater problem, which is human-induced stress on our natural and life-supporting systems. A systems approach is therefore necessary, linking climate change, peak oil and peak phosphorus to develop sound strategies.
- Our scientific understanding of global and regional phosphorus flows has to improve. We need to examine source and sink dynamics and develop models to explore peak phosphorus scenarios and their implications.
- We require integrated watershed management that considers ethnoecology,[9] nutrient flows, meteorology, land use, soil, population, household consumption, catchment hydrology and aquatic phosphorus-sink dynamics. This approach would lead to improved water management focused on recovering phosphorus from wastewater streams.
- Scientists need to provide the required information to enable effective phosphorus and water resource management. They also need to empower communities with community-based abilities to assess and monitor phosphorus and water. Knowledge transfer and cooperation are therefore central components in managing phosphorus flows effectively.

Box 3: Promoting closed P-cycle management

Phosphorus flow management is a systems approach that allows analysis and monitoring of the entire nutrient cycle—from source to tap to disposal to storage. It includes everything from the extraction of phosphorus rock from the environment to phosphorus production, use and consumption, collection, reuse and release back into the environment. Flow charts on a regional and global level present a helpful tool to assess sufficiency and efficiency of use of the resource. Flow structure and volumes allow conclusions to be drawn concerning the system's long-term sustainability. Managing phosphorus sustainably, therefore, means influencing these flow characteristics in such a way as to increase resource-use efficiency and keep phosphorus in the system to secure food production in the long term. In such a sustainable system, avoidance needs to take precedence over recovery, followed only by minimal disposal.

[9] Ethnoecology is the study of human-environment interactions. It analyzes how different environments are perceived and used by different people. As a result, the method aims to understand the relationship between people and the environment that surrounds them. One goal of including ethnoecological perspectives is the development of relationships based upon a cross-cultural and holistic approach to bring about positive change and environmental stewardship for future generations. An ethnoecology project is currently underway in the Lake Winnipeg Basin (see Moar & Watts, 2009, for more information).

Enhancing social processes

- The cost of environmental pollution and depleting phosphorus reserves renders many policies and economic models obsolete. We need to reassess current policies and management strategies so that we can implement improved approaches to deal with phosphorus deficiencies. An economic evaluation of the vulnerability of agriculture confronted with declining phosphorus availability could accelerate this process.
- We must discuss a new paradigm in phosphorus management (Box 3). Current practice in many industrialized countries is unsustainable in peak phosphorus scenarios. Changes must include substantial shifts in production and consumption patterns.
- Increasing globalization and demographic changes such as population growth and urbanization present challenges in sustainable phosphorus management. We need to take these key aspects into account to build and maintain sustainable communities.
- Knowledge brokers need to translate and disseminate scientific information to decision-makers and society in order to raise awareness and facilitate understanding. This despite the fact that advocating solutions to the phosphorus issue, such as soil and manure management, food-waste reduction, composting, sewage treatment and reduced landfilling, may seem less than glamorous.
- Transitioning toward sustainable phosphorus management requires the harmonization of various resource-utilization patterns and goals. Measures to recycle or conserve phosphorus are more likely to succeed if local communities are engaged in decision-making, benefit-sharing and shouldering responsibilities.

Engaging in the flow of life

Every crisis has a deeper meaning. The world is presently facing an unprecedented limits-to-growth problem that is well-represented by the phosphorus challenge and offers ecological, social and economic opportunities. Sound phosphorus management responses have to be formulated that include strategic long-term visions and goals as well as determined action to better use, recover and recycle phosphorus.

The responsibility for developing a phosphorus-secure future cannot be solely imposed on agriculture. Efforts in agriculture are limited, and regulatory approaches such as proposed application thresholds can only do so much to optimize phosphorus management. Modern agricultural methods and production practices are answers to demand patterns that have been established over time by industry, policy and society. They frame the system within which agriculture operates. Inevitably, only collaboration with and support by other interest groups such as distributors, consumers, disposal and recycling companies, and regulators will enable an effective response in order to maintain phosphorus supplies. Responsibility must be shared by all stakeholders. This amounts to adopting a life-cycle, cradle-to-grave approach to phosphorus-based products, which include fertilizers, food and fibre.

Long-term phosphorus availability at local, regional and global scales depends on cross-sectoral and cross-social investments and integrated dialogues between individuals, communities and governments. This process will promote coordinated exchanges between stakeholders of information on goals and needs as well as technical knowledge, to maximize participative efforts for phosphorus stewardship (Box 4).

Box 4: The grounds for phosphorus stewardship

Phosphorus is one of the most important life-supporting elements on Earth. It represents one of the three crucial nutrients for plant growth (nitrogen, phosphorus and potassium), which are fundamental for modern farming and critical for global food security. But phosphorus is also a pollutant for aquatic ecosystems, resulting in eutrophication of surface waters and loss of biodiversity. As a finite, non-renewable, non-substitutable resource with high pollution potential, it must be managed carefully. These characteristics, consequently, form the basis of and need for action—in the form of phosphorus stewardship. The call for phosphorus stewardship draws its legitimization from these nine key drivers:

1. Pursuit of independence from rock phosphate or fertilizer imports
2. Environmental and human health protection
3. Waste avoidance and preservation of a limited, potentially scarce resource
4. Safeguarding economic profitability and competitiveness
5. Food security
6. Groundwater and drinking-water quality
7. Sustainable development
8. Intergenerational justice and fairness
9. Distributive justice between the northern and southern hemisphere

In the Lake Winnipeg Basin, a collaborative process is already underway. It will be crucial to establish a clear vision and common goals for food and water security as well as the protection of natural ecosystems within the basin. Action cannot be postponed at the expense of intra- and intergenerational disparities in adequate nutrition and water supply. Efforts to overcome phosphorus deficits have to be based on closing the nutrient cycle. This cannot be accomplished simply through policy choices on investments, trade or subsidies, or regulations such as recovery quotas. We require a much broader approach, including public participation and social collaboration beyond borders.

As the world moves toward less phosphorus availability, the Lake Winnipeg Basin is facing an unprecedented opportunity to be at the forefront of sustainable phosphorus research and action, green job creation and sustainable, integrated watershed management. The choices made today will provide the basis for an evolutionary transition to the future, a future in which Lake Winnipeg can be a global symbol of responsible phosphorus management.

Suggested reading

- Centre Européen d'Etudes sur les Polyphosphates (CEEP) (www.ceep-phosphates.org).
- Cummins, D. (2009, June). Peak phosphorus. A more important "peak" than oil? *Landmark Magazine*.
- Food and Water Security in the Lake Winnipeg Basin (www.foodandwatersecurity.net).
- Gilbert, N. (2009). The disappearing nutrient. *Nature, 461*(8), 716–718.
- Global Phosphorus Research Initiative (GPRI) (www.phosphorusfutures.net).
- Institut WAR, Technische Universität Darmstadt: Introduction to phosphate recycling (www.phosphorus-recovery.tu-darmstadt.de).
- Phosphate Recovery (www.nhm.ac.uk/research-curation/research/projects/phosphate-recovery/intro.html).
- Tweed, K. (2009, November). Sewage's cash crop. *Scientific American*, 28.
- Vaccari, D. A. (2009, June). Phosphorus: A looming crisis. *Scientific American*, 54–59.

References

Adam, C., Peplinski, B., Kley, G., Kratz, S., Schick, J., & Schnug, E. (2008). Phosphorus recovery from sewage sludge ash—Results from the EU Project SUSAN. *Österreichische Wasser-und Abfallwirtschaft, 60*(April), 55–64.

Agriculture and Agri-Food Canada. (2006). *Census of agriculture data*. Retrieved September 3, 2009, from ftp://ftp.agr.gc.ca/pub/outgoing/nlwis-lc/CEN_CA_AG_INTRP/DataTables

Agrium. (2009). *Monoammonium phosphate (MAP)*. Retrieved August 6, 2009, from http://www.agrium.com/products_services/ingredients_for_growth/phosphate/monoammonium_phosphate.jsp

Andrewartha, J. M., Sargison, J. E., & Perkins, K. J. (2008). The influence of freshwater biofilms on drag in hydroelectric power schemes. *WSEAS Transactions on Fluid Mechanics, 3*(3), 201–206.

Belcher, K., Edwards, C. K., & Gray, B. (2001). *Ecological fiscal reform and agricultural landscapes—Annex 2c*. Ottawa: National Round Table on the Economy and the Environment.

Chambers, P. A., Guy, M., Roberts, E. S., Charlton, M. N., Gagnon, C., Grove, G., et al. (2001). *Nutrients and their impact on the Canadian environment*. Hull, Quebec: Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada.

Chernoff, C. B., & Orris, G. J. (2002). *Data set of world phosphate mines, deposits, and occurrences*. U.S. Geological Survey. Retrieved June 14, 2008, from http://geopubs.wr.usgs.gov/open-file/of02-156

Clean Water Services. (2009). *Durham houses first full-scale commercial nutrient recovery facility in the nation*. Retrieved from http://www.cleanwaterservices.org/AboutUs/WastewaterAndStormwater/Ostara.aspx

Conrad, J. (n.d.). *A bottleneck in nature*. Backyard Nature, http://www.backyardnature.net/phosphor.htm. Based Asimov, I. (1982). Isaac Asimov looks at "life on Earth." *Mobil Viewer's Guide*. http://www.asimovonline.com/oldsite/Essays/biology.html

Déry, P. & Anderson, B. (2007, August 13). Peak phosphorus. *Energy Bulletin*. Retrieved from http://www.energybulletin.net/node/33164

Environment Canada. (2006). *Municipal wastewater survey—Export data 2006*. Retrieved September 3, 2009, from http://www.ec.gc.ca/water/mwws/en/export_tables.cfm

Environment Canada. (2007). *2007 National Pollutant Release Inventory (NPRI). Reviewed facility data release*. Retrieved from http://www.ec.gc.ca/inrp-pri/default.asp?lang=en&n=00C79591-1

Fertecon. (2008). *Databank*. http://www.fertecon.com

UN Food and Agriculture Organization. (2009). *Land use database*. Retrieved August 3, 2009, from http://faostat.fao.org

Friends of the Earth. (2005). *Checking out the environment? Environmental impacts of supermarkets*. Retrieved from http://foe.org.uk/resource/briefings/checking_out_the_environme.pdf

Gilbert, N. (2009). The Disappearing Nutrient. *Nature, 461*(8), 716–718.

Global Phosphorus Research Initiative (GPRI). (2008). *Phosphorus (P)*. Retrieved August 14, 2009, from http://phosphorusfutures.net

Harben, P. W. & Kuzvart, M. (1996). *Industrial minerals: A global geology*. Surrey: Metal Bulletin Books Ltd.

Henningsson, S., Hyde, K., Smith, A., & Campbell, M. (2004). The value of resource efficiency in the food industry: A waste minimisation project in East Anglia. *UK Journal of Cleaner Production, 12*(5), 505–512.

Hofmann, N. (2008). A geographical profile of livestock manure production in Canada 2006. *EnviroStats, 2*(4), 12–16.

Hofmann, N., & Beaulieu, M. S. (2001). *A geographical profile of manure production in Canada 2001*. Ottawa: Statistics Canada, Agricultural Division.

International Fertilizer Industry Association (IFA). *Databank*. (2008). http://www.fertilizer.org

Jasinski, S. M. (2008). *Phosphate rock*. United States Geological Survey. Retrieved from http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/myb1-2007-phosp.pdf

Lake Winnipeg Implementation Committee. (2005). *Restoring the health of Lake Winnipeg*. Retrieved from http://www.redriverbasincommission.org/lake_wpg_final.pdf

Lake Winnipeg Stewardship Board. (2006). *Reducing nutrient loading to Lake Winnipeg and its watershed: Our collective responsibility and commitment to action*. Winnipeg: Province of Manitoba, Minister of Water Stewardship.

Manitoba Water Stewardship. (n.d.). *Quick Facts*. Retrieved October 15, 2009, from http://www.gov.mb.ca/waterstewardship/water_quality/lake_winnipeg/facts

Moar, L., & Watts, P. (2009). Building capacity and vision for action and stewardship on food and water security—People of the Lake Winnipeg watersheds. Retrieved from http://foodandwatersecurity.net/doc/Gathering2010_u.pdf

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, S., Lambin, E. F.,… Foley, J.A. (2009). A safe operating space for humanity. *Nature, 461*(24), 472–475.

Röhling, S. (2007, April). W*ie lange reichen die Rohstoffe für die Mineraldüngerproduktion noch aus?* Bundesarbeitskreis Düngung (BAD). *Rohstoffverfügbarkeit für Mineraldünger—Perspektiven unter hohen Energiekosten und begrenzten Ressourcen*. Retrieved August 7, 2009, from http://www.duengung.net

Smith, A., & Mackinnon, J. B. (2007). *The 100-mile diet: A year of local eating*. Toronto: Random House.

Statistics Canada. (2006). *National accounts—Manure production, Canada, major drainage areas and sub-drainage areas, every 5 years (tonnes)*. Retrieved September 3, 2009, from http://cansim2.statcan.gc.ca/cgi

-win/cnsmcgi.pgm?Lang=E&RootDir=CII/&ARRAY_VREL =1530040&PortalID=3764&ResultTemplate=V3764

Stuart, T. (2009). *Waste: Uncovering the global food scandal*. London: Penguin Books.

United Nations. (2003, December 9). Department of Economic and Social Affairs. *World Population in 2300. Highlights*. Draft. Retrieved from http://www.un.org/esa/population/publications/.../WorldPop2300final.pdf

U.S. Department of Agriculture. (2009). *Pathogens and contaminants. BSE*. Retrieved August 9, 2009, from http://fsrio.nal.usda.gov/document_fsheet.php?product_id=169

U.S. Environmental Protection Agency. (2000). *Lake Erie lakewide management plan*. Retrieved August 15, 2009, from http://www.epa.gov/lakeerie

U.S. Geological Survey (USGS). (1999, September). *Fertilizers—Sustaining global food supplies*.

USGS Fact Sheet, FS-155-99. Retrieved from http://pubs.usgs.gov/fs/fs155-99/fs155-99.html

U.S. Geological Survey (USGS). (2009). *Phosphate rock. Statistics and information*. Retrieved August 6, 2009, from http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock