Mapping Phosphorus Flows in the Ontario Economy

Exploring Nutrient Recovery and Reuse Opportunities in a Provincial Context

Pollution Probe

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About this Report

Phosphorus (P) is a non-renewable and non-substitutable resource with a wide range of applications. Canada relies heavily on foreign imports of P that have the potential to increase in price as supplies are depleted, pointing to a critical need to take proactive measures to ensure its sustainable use over the long-term. At the same time, excessive P in the environment contributes to dense populations or overgrowths of algae (i.e., algal blooms), which can have significant harmful effects on supporting ecosystems, including alteration of aquatic food chains, the production of toxins, an increase in infrastructure maintenance costs and eutrophication — oxygen depletion in a waterbody.

The National Nutrient Recovery and Reuse (NNRR) Forum was hosted by the International Institute for Sustainable Development (IISD) on March 8, 2018, in Toronto, to explore nutrient recovery and reuse (NRR) in a Canadian context, including as it relates to P. Over 80 attendees reviewed recovery activities in Canada to identify opportunities for new technologies and programs, to broaden the network of support for NRR and to identify ways to implement adaptive technologies to address P issues, particularly in those locations experiencing considerable challenges related to nutrient loading (e.g., Lake Erie). Key drivers for P recovery highlighted during the forum included:

- P is a scarce and strategic resource that is critical for food security and its future supply is uncertain.
- P is an environmental pollutant when present in excess. It can threaten drinking water supplies and is also the key nutrient responsible for eutrophication.
- P is physically conserved and can be recycled indefinitely.[1]

The resulting forum report, *Nutrient Recovery and Reuse in Canada: Foundations for a national framework*, laid out three key recommendations, including the need to create a Canadian NRR platform, a number of regional hubs to coordinate regional perspectives, and studies across Canada that show where P moves in and out of the economy. These P flow studies can act as the basis for identifying areas of opportunity for NRR in support of the effective deployment of associated technologies. A comprehensive analysis of P flows will contribute to informed decision-making and support for NRR technologies by quantifying areas of P use and loss and estimating the amount that could potentially be recovered and reused.

In 2021, Environment and Climate Change Canada (ECCC) provided funding so that Pollution Probe could lead the first provincial study of P flows through Ontario's economy, in collaboration with Canadian academic experts on P and NRR and their teams. The province of Ontario was chosen as an initial study area based on the complexity of its economy, the availability of data and its proximity to geographic locations facing significant challenges associated with P (e.g., Lake Erie). This initial study will serve as a template for similar studies in other regions across Canada (e.g., Atlantic Canada, the Prairies, Québec and BC).

The project team for this work was comprised of professors and students from Université Laval (Dr. Céline Vaneeckhaute and Dr. Edgar Martín Hernández), McGill University (Dr. Sidney Omelon, Samantha Gangapersad and Tian Zhao) and the University of Waterloo's Water Institute (Dr. Roy Brouwer and Jorge Andres Garcia Hernandez). The team worked collaboratively to undertake a comprehensive review of existing literature and data sources and pursued an integrated approach to determining critical P flows, and associated processes and factors for a number of relevant sectors of importance to Ontario's economy.

This work benefited from the guidance of a previously established Nutrient Recovery and Reuse Working Group (NRR Work Group) made up of a number of Canada's foremost experts on NRR, primarily representing government (e.g., ECCC, Agriculture and Agri-food Canada, Ontario Ministry of the Environment, Conservation and Parks, Ontario Ministry of Agriculture, Food and Rural Affairs, etc.). The NRR Work Group was consulted on overall strategic direction and provided subject-matter and technical expertise on the methodologies pursued and study outcomes. Input from the NRR Work Group members enhanced the value and relevance of the findings from this study.

This report's findings provide important insight into how P is used and where losses occur, a necessary first step for informing further discussions about the role for NRR technologies and solutions in reducing excess nutrients in receiving waterbodies, improving long-term food security and agricultural soil health, supporting nutrient-related economic growth and informing national and regional policy, regulation, standards development and investment in the NRR sector based on circular economy principles.

Study Overview

The main objective for this study was to estimate the flow of P through Ontario's economy and its relevant sectors, in an effort to identify where it can be recovered from waste streams. More specifically, the study sought to:

- Source and analyze relevant data for the purpose of developing a P flow map that identifies how much is estimated to move through different sectors of Ontario's economy. This information can be used to help inform future decision-making related to the recovery and reuse of P in the province.
- Produce a report to accompany the P flow map that outlines how the flows were determined. The report will also act as a template, identifying the information and expertise required to complete similar studies for other provinces.

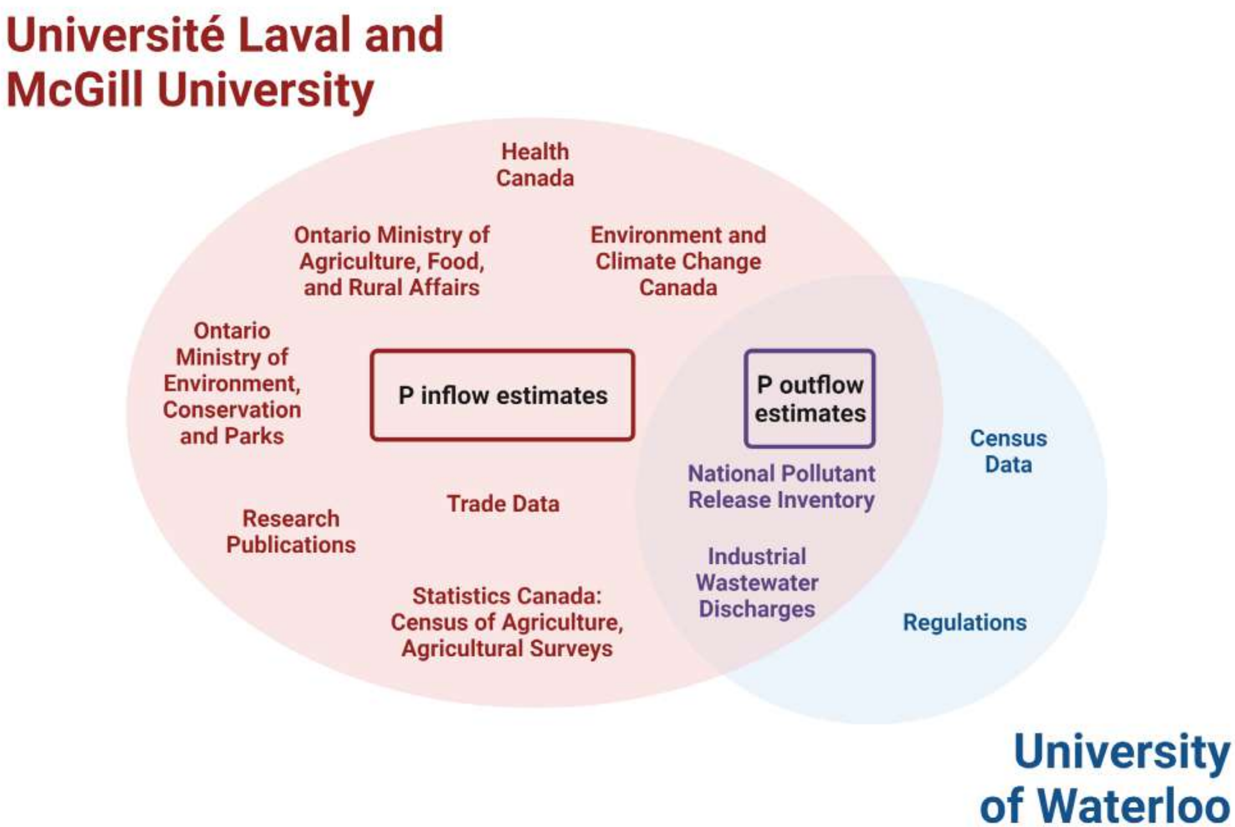
A comprehensive review of existing data and information was undertaken by the project team, complemented by input from subject-matter experts to help fill gaps. Key sectors where P is found or used were identified based on the findings from this review, the project team's collective expertise and guidance from the NRR Work Group. The findings are organized according to three main sectors of the Ontario economy based on their significant P inflows and outflows. The academic teams divided their efforts according to these sectors and as follows:

- **Agricultural Sector**: livestock and crop production, including greenhouses (Université Laval)
- **Urban Sector**: municipal wastewater treatment plants (WWTPs) (University of Waterloo's Water Institute and McGill University), food and organic waste (McGill University), septic systems and stormwater (Université Laval)
- **Industrial Sector**: steel, forestry, food & beverage, chemical and vehicle manufacturing (McGill University and University of Waterloo's Water Institute)

Key Data Sources and Considerations

A number of global, federal and provincial data sources were used by the academic teams to estimate P flows for this study. Figure 1 shows key data sources, and highlights whether they were referenced for inflows or outflows, as well as the respective teams that made use of them. A more detailed description of the strengths and challenges associated with the use of these sources and the specific data referenced for individual P flows are identified within each respective section of this report. A full list of data sources is found in Appendix A.

Figure 1. Key Data Sources for the Flow of Phosphorus through Ontario's Economy



Spatial Resolution

Where possible, the spatial resolution for P flows in this report was determined for the census division level.[2] Many data sources report at this resolution, but where this was not the case, data was often available by county or at the provincial level. Not all Ontario counties align directly with census division boundaries so data for these areas was either merged or split. Where deemed appropriate throughout this report, data reported at the provincial level were scaled down based on a related magnitude reported at the census division level. This distribution was determined proportionally and according to the related magnitude (e.g., eggs produced in the province[3] can be allocated proportional to the number of laying hens in each census division[4]). It should be noted that the P flow analysis for many of the industrial sectors did not allow for spatial resolution so overall estimations were considered in these cases.

Uncertainty

As previously noted, the objective for this report was to determine estimates for the magnitude of P flows in Ontario's economy. P flows are estimated using different approaches and factors dependent on the type of data available, such as the material flow, P concentration of different materials, production rates, and export coefficients, among others. In some cases, data sources were not available (e.g., interprovincial flows of P chemicals). Given this complexity, there are inherent errors and uncertainty expected in these values. For example, where P concentration data was reported and available, error values were not generally provided. Material flow magnitudes are also commonly reported without error values. A number of P flow estimates in this report are based on factors reported in scientific literature and governmental reports where uncertainty levels are also unknown. When factors or values with errors are then multiplied, the final estimates determined for P could look quite different.

Where appropriate, this report highlights those estimates that are considered order of magnitude based on uncertainties. It should also be noted that while many significant digits are included in this report, they are not representative of numerical precision for the reasons discussed.

Report Outline

This report is divided into six sections outlining P flows for the Ontario economy. Potential opportunities for NRR are highlighted, along with case studies that point to the potential for practical applications of NRR technology for certain waste streams.

Section One provides a general introduction to P, its impacts on the environment and NRR. The contents of this section provide important context for the remainder of the report.

Section Two outlines the movement of P throughout Ontario's economy and summarizes the data types and sources used to estimate P flows for the purposes of this report.

Section Three explores P flows through the agricultural sector, including those associated with livestock and crop production.

Section Four introduces P flows associated with urban sources, including wastewater treatment plants, septic systems, stormwater and food and organic waste.

Section Five outlines P flows from a wide range of industrial sectors where P is found or used. These include mining, forestry, food and beverage processing, chemical, transportation and aquaculture.

Section Six summarizes the findings of the report, outlines potential next steps and identifies where opportunities may exist for the implementation of NRR technologies.

Appendix A includes a detailed list of the data sources used in this study.

Appendix B provides a high-level description of P flows in the **natural environment**.

Appendix C includes further **methodologies** and **data sources** related to the **agricultural sector.**

Appendix D outlines further **methodologies** and **data sources** associated with the **industrial sector.**

Appendix E introduces select **policies and programs** related to **P and NRR**.

Appendix F highlights select **NRR technologies** of relevance in an Ontario context.

Appendix G summarizes the magnitude estimates used to produce **Figure 6 and Figure 7** of this report

Appendix H shows a **comparison of the main databases** used for estimates in the urban and industrial sectors

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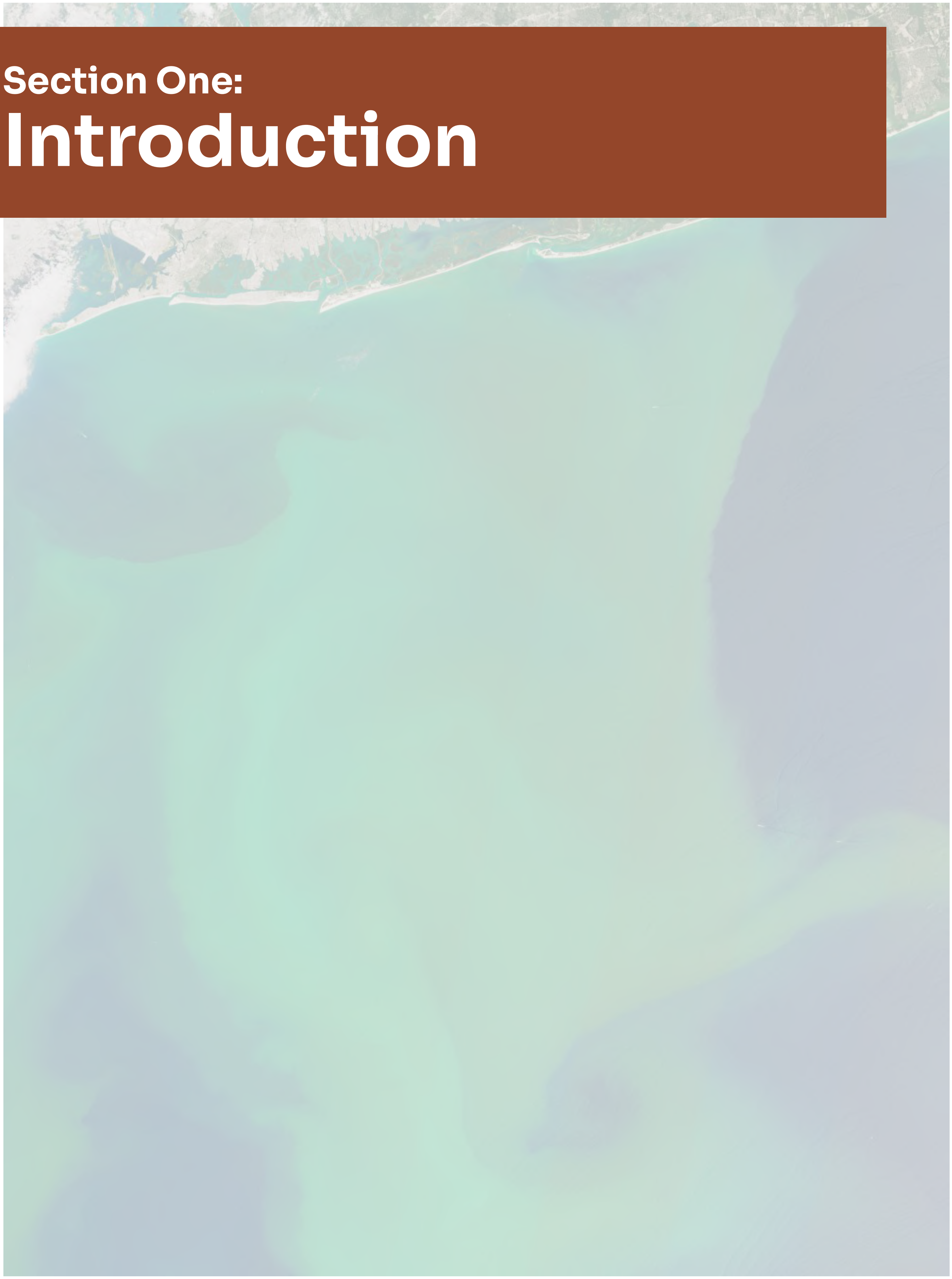
Section One:
Introduction



Introduction

Phosphorus (P) is a naturally occurring element found in the Earth's rock crust in raw form. It is a non-renewable and non-substitutable resource with a wide range of applications, including as a component of agricultural fertilizer. It is used in numerous industries, including agriculture, steel, forestry, food and beverage, chemical production, and transportation. It is also considered the limiting nutrient for crop production and is found in urban areas within wastewater effluent, stormwater, and food and organic waste.

In a natural P cycle, soluble P salts are released from rocks through weathering and are taken up by plants and animals. The P is then returned to the soil through the breakdown and decay of plant material and residues, in a form that is available for plant uptake.[5] Natural P is always a component of a phosphate ion. This natural phosphate ion is typically found in one of four forms:

1. A dissolved phosphate ion in solution, known as soluble inorganic orthophosphate (o-Pi)
2. As part of an inorganic solid, concentrated in ore and referred to as "phosphate rock" because of its unusually high P concentration
3. As organic P, ubiquitous in life forms and found in DNA, phospholipids and proteins
4. As a polymer of phosphates linked together in a chain, which are generally called condensed phosphates and are found in life forms.

The amount of P measured in a solution or liquid sample is defined by a combination of its o-Pi concentration, its inorganic condensed phosphate concentration, and all of the P that is part of another organic molecule, called organic phosphates. The sum of these concentrations is known as the total phosphorus concentration. Solid samples can also contain soluble inorganic orthophosphate, condensed phosphate, and/or organic phosphate. P concentration can be presented as "% dry mass" or "% wet mass" or for some solids, notably fertilizers, it may be reported as the equivalent P contained in P_2O_5 (phosphorus pentoxide). This unit is a consequence of x-ray fluorescence data generation, which by convention, balances the charges of elements such as P^{5+} with O^{2-}.

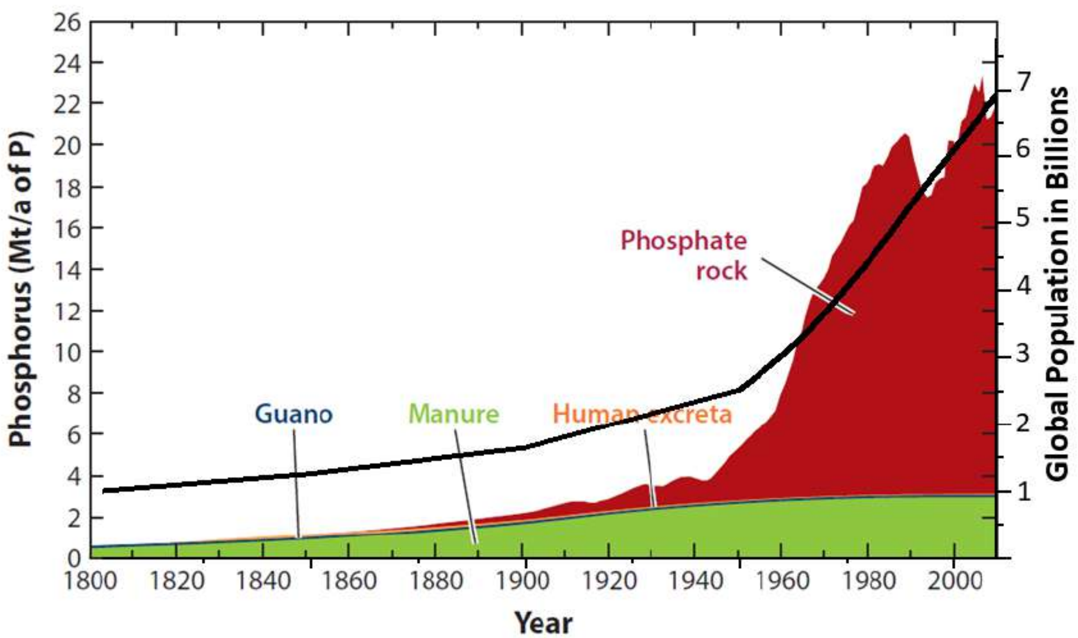
Phosphate rock is produced over geological time scales, mainly by bacteria that live in the ocean floor. It is not evenly distributed around the world, with conservative estimates pointing to Morocco and the Western Sahara holding more than 70% of the global phosphate rock reserves, followed by China, Russia, and the U.S.[6] By comparison, Canada has only 0.1% of the world's P reserves and relies heavily on imports of phosphate rock.[7,8] While an estimated 240 Mt/a of P was mined globally in 2019, its quality has continued to decline over time, making it more difficult to secure high quality commercial phosphate.[9] At the same time, current P use is considered inefficient, with only one-fifth of phosphate rock mined for fertilizer remaining in the end-product.[10] There is no consensus in the literature about when P demand will peak (predictions usually fall somewhere around 2035) or about when global P reserves will be depleted (from the next 30 to 40 years for high quality phosphate to the next 350 years).[11] Regardless of the exact year, it is evident that transitioning to the more sustainable use and management of P is urgently required to ensure the future food security of Canada and other countries as it will take time to effectively implement solutions.

Phosphate rock contains calcium phosphate minerals, heavy metals[12] and radioactive elements.[13] After mining, phosphate rock is ground into small particles to separate those that are P-rich from other minerals. To make useful products, concentrated phosphate rock is dissolved in sulphuric acid to produce phosphoric acid and solid waste called phosphogypsum.[14] All stages of phosphate rock processing release its heavy metal and radioactive elements into the environment; these contaminants are also found within phosphogypsum. Phosphoric acid is used to make fertilizer and other industrial P products.

There are no substitutes for P as a plant nutrient. Its importance for the growth of crops is well established, but without replenishment, crop production has the potential to reduce the amount of soil P reserve. To address this issue, different sources of plant-accessible P have been applied over time to supplement what is found naturally in soil. These have included guano (i.e., bird and bat droppings deposited over thousands of years), manures, crop residues, and human excreta. When large phosphate-rich rock deposits were eventually discovered that could be easily mined, human engineered mineral or synthetic fertilizers — concentrated, soluble P fertilizers from phosphate rock — and agricultural productivity increased. This enabled the growth of the human population, which in turn, increased the need for mined phosphate rock.[15]

Figure 2 shows historical sources of P for global fertilizer use and the human population over time.

Figure 2. Global Phosphorus Types Applied as Fertilizers and Population

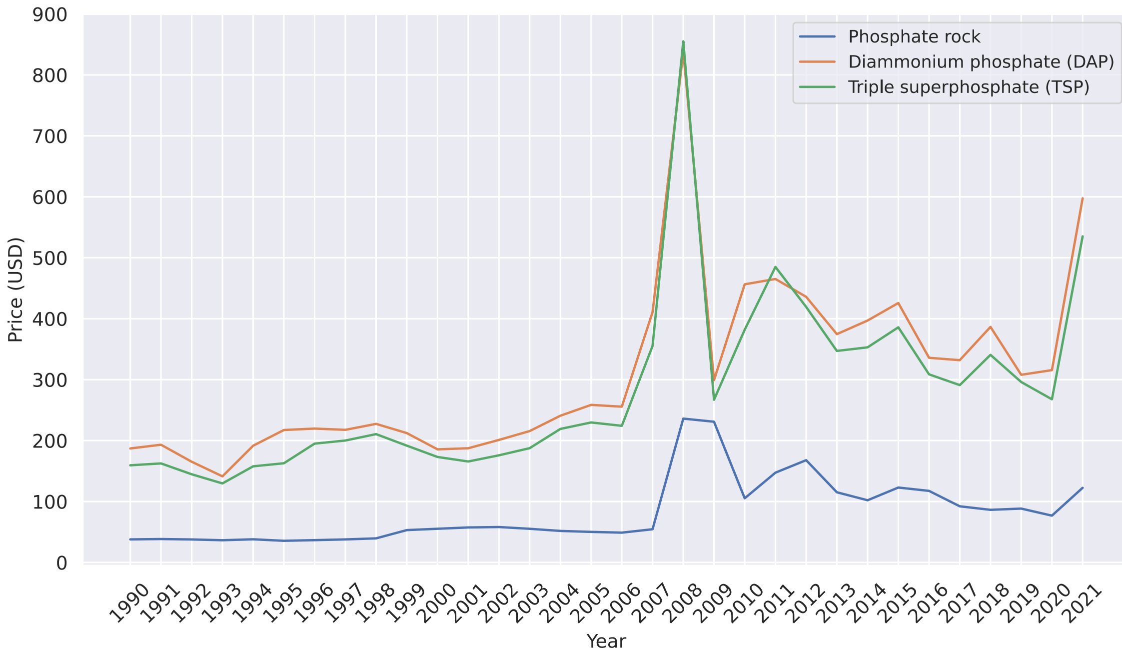


*Adapted from Cordell and White (2014)

As global phosphate rock reserves are depleted, it is anticipated that the price of P will continue to rise. Political instability in those areas with large P reserves and any associated transportation logistics also have the potential to contribute to additional costs. Fluctuations in the price of phosphate rock could be significant, as evidenced in 2008 and 2009, where there was an increase of approximately 800% globally, skyrocketing to CAD $569/metric ton in March of 2009. By comparison, the price of Moroccan phosphate rock sat at around CAD $226/metric ton in March 2022. Figure 3 shows the global price of P fertilizers in USD over time, highlighting the significant increase in 2008 and 2009, along with a smaller price increase in 2019.[16] Fertilizer prices also increased by more than $200/metric ton when war recently broke out in Ukraine. Price fluctuations will continue to have a considerable impact on farmers who are reliant on fertilizer for crop production. The current impact of price increases in urea, liquid nitrogen and anhydrous ammonia in the U.S. may offer a preview of the impact of future P shortages.

Geopolitical issues also have the potential to impact the price of phosphate. The Western Sahara has been occupied by Morocco since 1975 and as previously noted, holds more than 70% of global phosphate rock reserves.[18] By comparison, the next largest reserve in China, has just under 6%. However, Western Sahara has been experiencing a growing political and human rights conflict.[19] It is anticipated that as domestic reserves in other countries are depleted, this disputed region could have a monopoly over phosphate rock, with considerable implications for global food security.

Figure 3. Global Commodity Price Data for Phosphorus Fertilizers in USD (1990 to 2021)[17]



1.1 Phosphorus in the Environment

When found in excess in soil or water, P can contribute to negative environmental impacts. Increasing populations and intensive agricultural practices (e.g., livestock, poultry, dairy, hog operations and cash crop production, etc.) can lead to P inputs from rural and urban point and nonpoint sources entering local waterbodies, including through municipal wastewater effluent and stormwater runoff from urban areas. Due to the chemical properties of P, it does not evaporate but can travel by wind and water after binding to soil particles.

Nutrient pollution has been described as one of the most widespread, expensive and challenging environmental issues to address.[20] Too much P can produce an overgrowth of algae (often referred to as algal blooms, which can be harmful nuisance algal blooms). A prominent eutrophication study in the IISD Experimental Lakes Area showed that in the absence of artificial nitrogen inputs, P is the main contributor to algal blooms.[21] Algal blooms can adversely impact drinking water supplies and have significant harmful effects on supporting ecosystems, including eutrophication — oxygen depletion in the water body — and the alteration of aquatic food chains, the production of toxins, decreases in water transparency, declining fish populations and fisheries and reduced recreational opportunities.

Algal blooms have also been shown to produce methane emissions, a greenhouse gas (GHG) that is estimated to be at least 34 times more efficient at trapping heat in the atmosphere than carbon dioxide (some studies put this number closer to 87 times).[22] A study for the U.S. Environmental Protection Agency predicted that the growth of algal blooms in the world's lakes could increase global methane emissions by 30% to 90% over the next century.[23] In addition, the extraction and processing of commercial phosphate rock and the production of fertilizer are highly energy intensive activities and significant sources of GHG emissions. Because most phosphate is sourced at a distance, its transport also contributes to our changing climate.

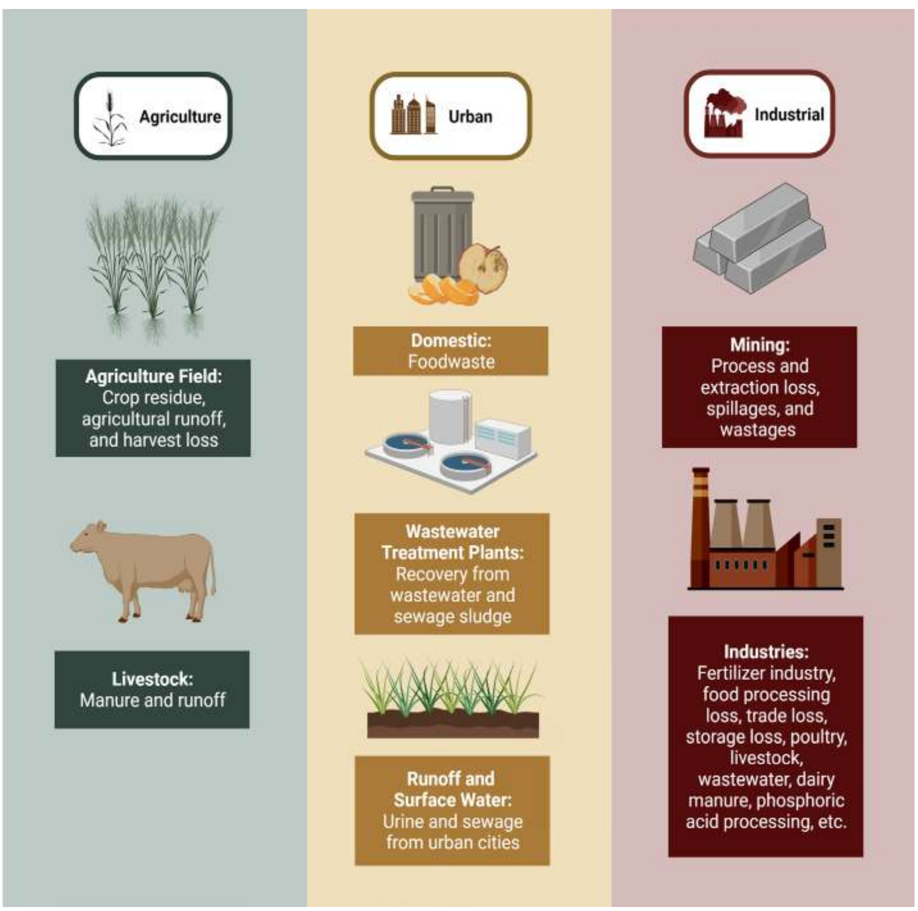
1.2 Nutrient Recovery and Reuse: A Circular Economy Approach to Addressing Phosphorus

A circular economy approach prioritizes the conservation of a material's value within the economy over a traditional linear "take-make-waste" system. Ontario's Strategy for a Waste-Free Ontario: Building the Circular Economy defines resource recovery as the "extraction of useful materials or other resources from things that might otherwise be waste, including reuse, recycling, reintegration, regeneration or other activities".[24] Applying the concept of circularity to P management has the potential to contribute to a reduction in the extraction and processing of commercial phosphate rock and the prevention of environmental impacts, including the degradation of soil health, water and air quality. It can also strengthen P security by reducing dependence on imports through an increase in domestic availability that avoids the need for long-distance transport.

The current use of P typically follows a linear model with losses at each stage from extraction through to application. While nutrient capture strategies can successfully stop P from flowing into the environment, a number of technologies are being explored with the objective of recovering P from different sources and throughout the P cycle for the purpose of reuse. For example, P extracted from sewage sludge that would typically be sent to landfill, can be reused as fertilizer for crop production, effectively closing the loop.

Figure 4 shows the points of the P cycle where there is the potential for recovery. A list of select NRR technologies currently being piloted or in the market is found in Appendix F, while case studies highlighting specific technologies and practices currently used in Ontario or Canada are explored in Section Six.

Figure 4. Recovery Options across the Phosphorus Cycle



*Adapted from Sarvajayakesavalu et al. [25]
Figure created with BioRender.com

Some P recovery and reuse (PRR) technologies also promise further environmental savings from energy capture or a reduction in energy consumption associated with wastewater treatment or large livestock operations, providing yet further emissions reductions. At the same time, P recovery can provide economic benefits in some cases. For example, P recovery via struvite precipitation has been shown to improve sludge separation operations during wastewater treatment and to extend the life of facilities by decreasing the potential for scaling in pipes and pumps.[26] Recent tests of a new on-site P recovery technology showed that P removal from dairy manure results in a liquid manure that has a nitrogen to P ratio that is aligned with crop requirements, which could lead to a reduction in nutrient applications.[27]

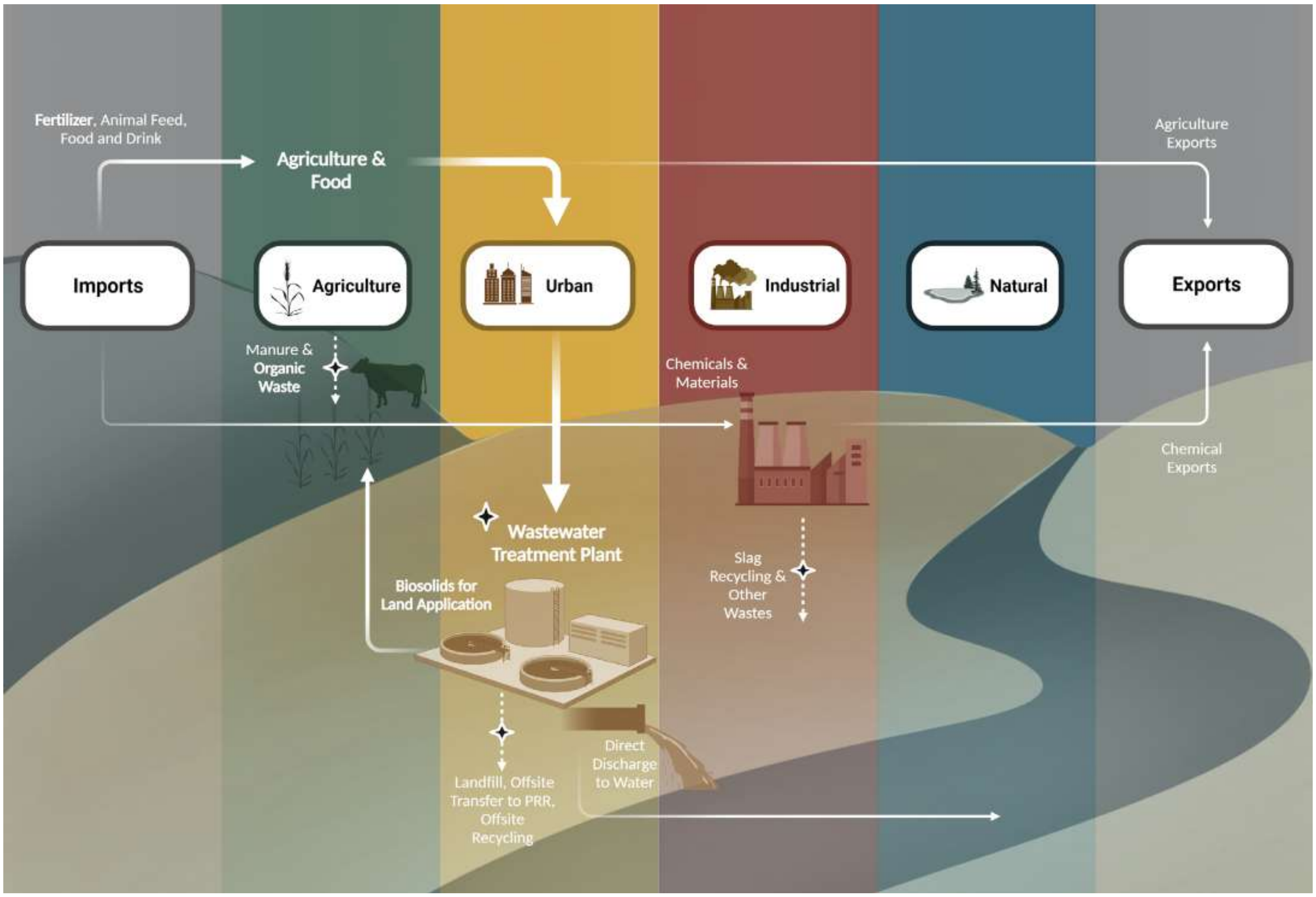
Ontario's Food and Organic Waste Framework – Policy Statement refers to existing wastewater treatment infrastructure, biosolids processing technologies, and co-management practices as streams with the capacity to support NRR and the creation of high-value end products. However, the feasibility of these technologies is dependent on a range of factors, including regulatory frameworks, accessibility of raw materials, existing infrastructure, market accessibility, public acceptance and economic drivers.[28] As previously noted, a comprehensive understanding of Ontario's P flows as outlined in this report can play a critical role in determining how to address potential barriers associated with these factors, identify sources of P in the economy and support the effective deployment of NRR technologies.

Section Two:
Phosphorus Flows in Ontario's Economy

Phosphorus Flows in Ontario's Economy

This section provides an overview of study findings to contribute to the development of an overall understanding of the most significant P flows across Ontario's economy. Many of these flows are intrinsically linked or interconnected, with an outflow from one sector acting as an inflow for another. There are many intersections between the agricultural and urban sectors, given their interdependence (e.g., food containing P is grown for human consumption, which in turn produces organic waste containing P). Flows can also move between subsectors (e.g., manure from livestock is used as fertilizer for crop production in the agricultural sector).

Figure 5. Key Phosphorus Flows in Ontario's Economy

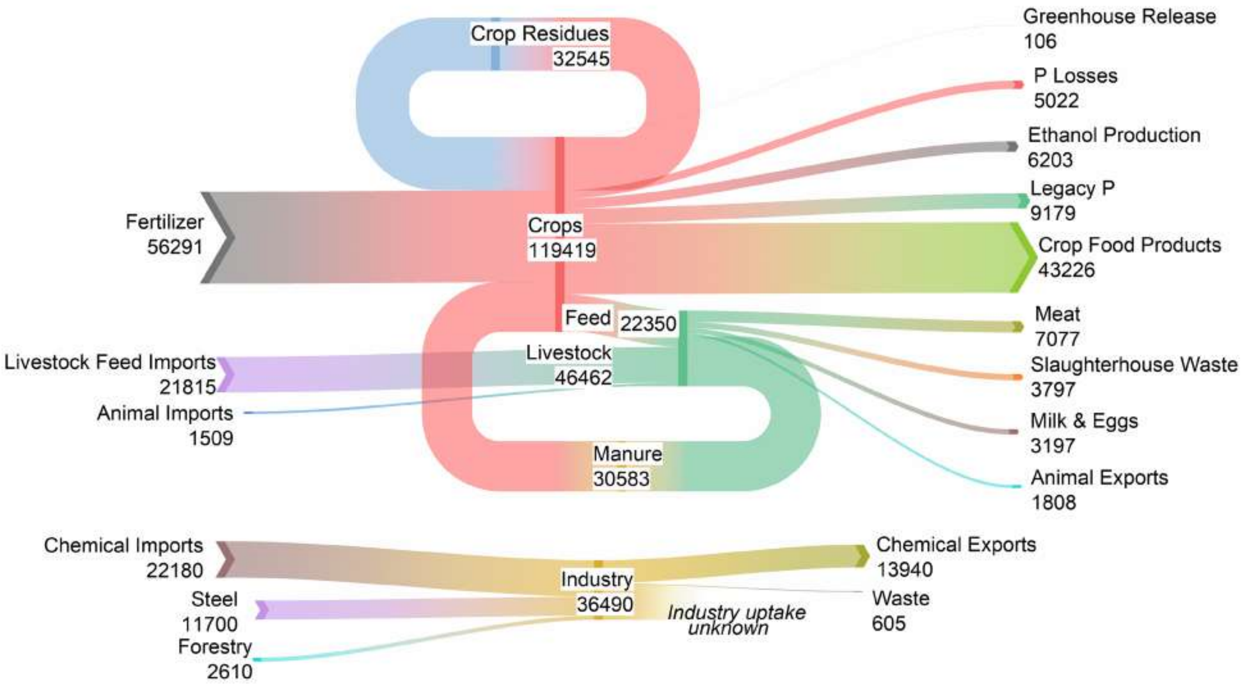


*Diamonds represent Nutrient Recovery & Reuse Opportunities.
Figure created with BioRender.com

2.1 Phosphorus in the Environment

Figure 6 shows estimates of the magnitude of P flows (t/a) through the Ontario economy from the agricultural and industry sectors as outlined in this report. It should be noted that significant numbers do not represent the precision of these estimates. Those sectors with smaller P flows have not been included in an effort to simplify and further highlight those that are most identifiable and quantifiable. A separate figure was produced for urban P flows, based on the fact that they are primarily related to food and the associated waste (see Figure 8). Imports into the province are depicted by arrow tails, while outflows, including as specific products, are shown as arrow heads. Loops depict outflows that become inflows (e.g., crop residues provide P back to the soil for future crop production).

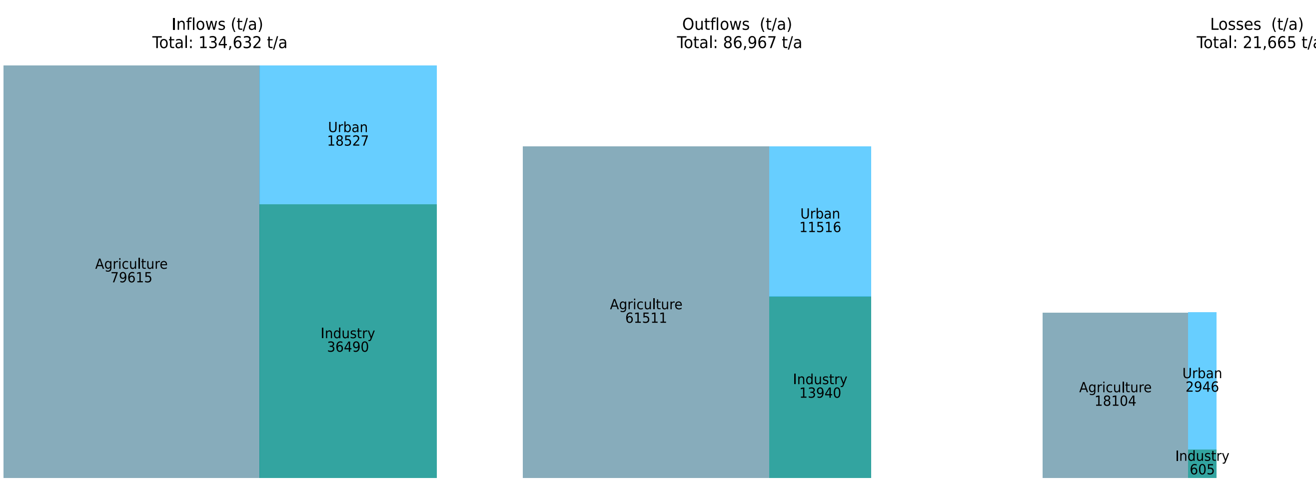
Figure 6. Phosphorus Flows (t/a) through Ontario's Agricultural and Select Industrial Sectors (2019)



*Note: The estimated magnitude of P flows shown in this figure are representative of one year. Given the periodic nature of agriculture, this diagram does not represent a steady-state snapshot of P flows in Ontario at any given time.
**Note: Food products in this figure include those grown in the field and in greenhouses.

Figure 7 shows the combined inflows, outflows and losses for Ontario's agricultural, urban and industrial sectors. It highlights the fact that the majority of P is found within the agricultural sector. It also shows that overall for each sector, there are relatively large outflows of waste that if recovered and reused, could contribute to meeting Ontario's demand for P, shown as inflows, locally within the province. It should be noted that the inflows for the urban and industry sectors do not equal the sum of their respective outflows and losses. This is due to the fact that data is insufficient for determining some of the flow of P for these sectors. For further information about the estimates used in Figure 6 and Figure 7, please see Appendix G.

Figure 7. Phosphorus Inflows, Outflows and Losses (t/a) in Ontario's Agricultural, Urban and Industrial Sectors



*Note: The magnitude of the P inflows do not equal the sum of the outflows and losses as there are many unknowns related to a lack of data, primarily in the industrial and urban sectors, including where P is released to the environment. The purpose of this figure is to provide a high-level sense of where P is found at a glance and according to the three broad sectors outlined in this report. More data and research is required for the balancing of P inflows and outflows.

2.1.1 Agriculture

Figure 6 highlights the fact that agricultural activities, including both livestock and crop production, are associated with the most significant P flows in the province, by an order of magnitude. Given that P is required for both livestock and plant growth, imports for the purpose of livestock feed (21,815 t/a) and fertilizer use for crop production (56,291 t/a for open field and greenhouse crops) are associated with the largest inflows within the agricultural sector. As previously noted, the costs associated with imported fertilizer are anticipated to increase over the coming years, pointing to a critical need to explore options for finding alternative sources of P to ensure long-term food security, including through recovery and reuse.

Much of the P that enters the crop production sector, leaves in the form of food products (43,226 t/a) for human consumption (along with additional flows associated with meat, milk and eggs from the livestock sector). Other flows from the crop production sector include those related to P released to the environment as part of runoff or through erosion (5,022 t/a) and the portion of P applied to soil in the form of synthetic fertilizer, manure, or crop residues left in the field after crop harvest that is not taken up by plants and as a result, accumulates in the soil (9,179 t/a). This can contribute to a buildup of legacy P over time, which is available for future use by crops but also has the potential to be lost to the environment and transported to local waterbodies. There is a critical need to better manage P from agriculture given its significant negative impact on the environment when found in excess.

The agricultural sector is also associated with three significant P flows that are internal, connecting livestock and crop production. The largest of these is crop residues (32,545 t/a), which includes those parts of the plant that are not considered a food product, and which are often left on the field after harvest as a means of fertilizing the soil. The second is manure (30,583 t/a), produced by livestock and applied to agricultural fields as a fertilizer. Finally, there is P in livestock feed (22,350 t/a), which is the crops grown locally for the purpose of feeding the province's livestock.

Despite the magnitude of the P flow associated with manure, its use as a fertilizer for crops is typically limited to those fields located in close proximity to the generation site as it is bulky and expensive to transport. In some regions, this may result in excess of P being applied to the field through the reuse of manure as fertilizer. The sheer magnitude of manure produced in Ontario points to an important opportunity to prioritize exploring how the P it contains can be effectively recovered and reused and transported to farms located at greater distances from the generation site. Research is also being conducted on the potential for a smaller waste flow from the livestock sector, slaughterhouse waste (3,797 t/a), for recovery and reuse.

2.1.2 Industry

The most significant inflows associated with Ontario's industrial sectors are for imports to the chemical industry (22,180 t/a), for steel production (11,700 t/a) and for the forestry sector (2,610 t/a). Exports from the chemical industry make up the majority of outflows from industry (13,940 t/a).

The use of P within industrial processes is less understood than in other sectors (e.g., agricultural), in part due to limited data. Current options and technologies associated with recovery and reuse are also fewer in number. However, technologies aimed at recovering P at breweries and wineries are already in the market, while recovery of P from slag from steel production is also being explored.

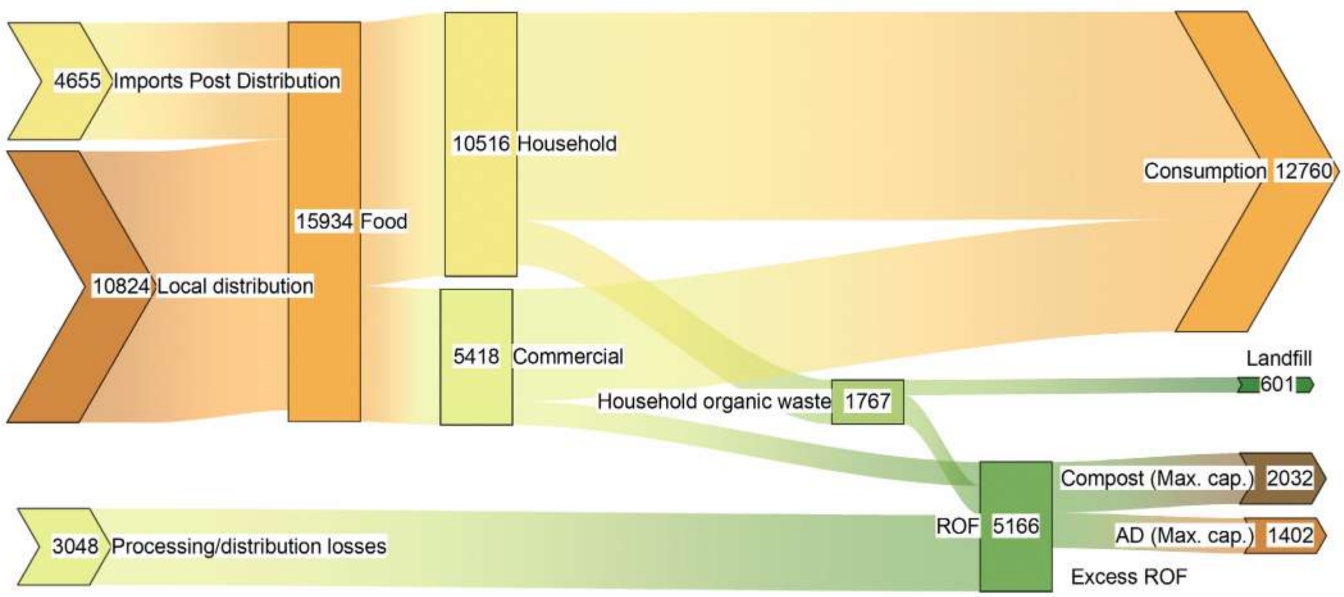
2.1.3 Urban

The urban sector includes a number of P flows with the potential for recovery and reuse. Urban areas are known to act as P "hot spots", where there is a demand for P-rich organic products and an accumulation of the associated waste. It is clear that as the population in municipalities across the province continue to grow, the P flows associated with urban sources, will also increase substantially.

While there is the potential to recover P from a number of these anthropogenic waste streams, only a fraction of available P is currently recovered and reused from urban sources.

Figure 8 shows the overall P flows for Ontario associated with food imports, consumption and associated waste streams (e.g., recycled organic feedstock (ROF), anaerobic digestion (AD), septic systems, etc.). It highlights the fact that a number of these P flows are significant, pointing to a need to further explore recovery and reuse options.

Figure 8. Phosphorus Flows (t/a) through Food Imports, Consumption, and Associated Waste Streams



2.2 Considerations for Phosphorus Recovery and Reuse

While an understanding of the magnitude of P flows is an important starting point for identifying where efforts for recovery and reuse should be prioritized by decision-makers, industry and other stakeholders, a range of other considerations factor into the suitability of various P flows. For the purposes of this report, these considerations were explored for each specific P flow, according to the following categorization and criteria:

- **Magnitude**: This category refers to the total estimated amount of P in the flow and is classified according to the following quantities:

Very low	0 - 10 t/a
Low	11-100 t/a
Medium	101-1,000 t/a
High	1,001 - 10,000 t/a
Very high	> 10,000 t/a

- **Phosphorus concentration**: This category refers to the concentration of P associated with a specific flow and is determined as follows:

Levels	**Solid (weight %)**	**Liquid (concentration, mg/L, ppm)**
Low	less than 0.01 %	<1
Medium	0.01 % - 0.5 %	1-20
High	> 0.5 %	>20

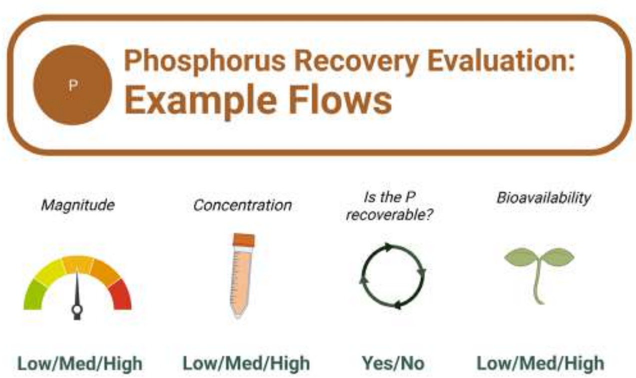
*Note: Magnitude categories are meant to highlight the different orders of magnitude of P flows. Concentration categories were selected to distinguish three rankings, bracketed by the range of reported and/or estimated values.

Different measurements are commonly used to denote P concentrations for solid or liquid flows. Solids are often reported in weight percent values (wt %). Dissolved P concentrations in solution are normally reported as a mass per unit volume (ex: milligrams per liter (mg/L)), or mass per unit mass of solution (parts per million: ppm), which are assumed to be equivalent in dilute, ambient temperature solutions.

- **Potential for Recovery**: This category identifies where there is the potential for P to be recovered and is presented as either yes or no. A number of factors can have an impact on the potential for recovery including, the stage of technology development or whether the P is dispersed (e.g., legacy P found in soil).

- **Recovery considerations**: Key risks associated with potential and/or currently available P recovery strategies for a specific P flow are detailed here.

- **Bioavailability**: This category identifies whether the form of P in a specific flow is available or can be made available for uptake or use. It is presented as low, medium or high, with low meaning no P is immediately bioavailable, high meaning all P is bioavailable, and medium reflecting those cases where there are different P fractions with some being bioavailable, while others are not.



For consistency throughout this report, a graphic representation for each P flow also appears in each respective section.

Table 1 provides an overview of the assessment of key P flows in this report against these categories and criteria, in an effort to further highlight potential challenges and opportunities for recovery and reuse. This table can serve as a tool for prioritizing future NRR efforts in Ontario.

Table 1. Potential for Phosphorus Recovery and Reuse by Flow

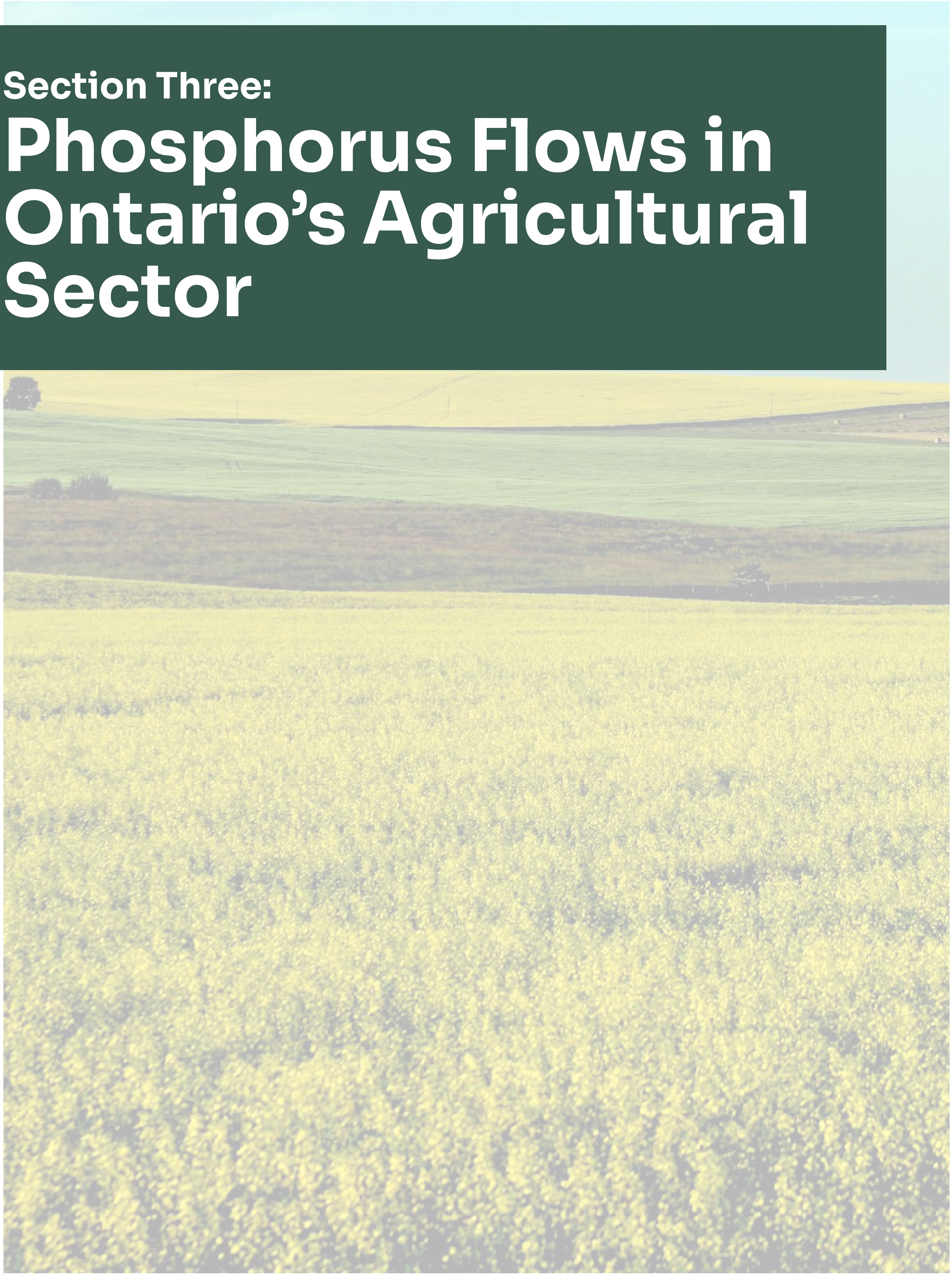
Source	Phosphorus Magnitude (t/a)	Phosphorus Concentration (%wt, solid mg/L, liquid)	Current Recovery and Reuse	Future Recovery and Reuse	Technology Required	Technology Development Stage	Bioavailability
Agricultural Sector							
Manure (Section 3.3.1)	**Very high** 30,583	**Medium to High** 0.08% - 0.58%	**Yes** ▪ Local application of manure to crop fields	**Yes** ▪ P-based materials such as struvite	▪ P precipitation, adsorption systems, physical separation processes ▪ Potential combination with anaerobic digestion	▪ Precipitation technology available, but may not yet be cost effective	**Medium** ▪ Soluble inorganic forms of P in manure are readily bioavailable. ▪ Mineral P becomes slowly bioavailable. ▪ Organic forms of P in manure are not bioavailable unless they undergo mineralization process.
Slaughterhouse waste (Section 3.3.1)	**High** 3,797	Not identified	▪ Recovered but not reused (chemical precipitation	**Yes**	▪ Struvite production	▪ Chemical precipitation: commercial ▪ Struvite: R&D	**Medium** ▪ Soluble inorganic forms of P in manure are readily bioavailable ▪ Mineral P becomes slowly bioavailable. ▪ Organic forms of P are not bioavailable unless they undergo mineralization process.
Crop residues (Section 3.3.2)	**Very high** 32,545	**Medium** 0.05% - 0.43%	**Yes** ▪ Locally (left in crop fields)	Being studied	▪ Thermal processes, chemical and supercritical extractions, use of ionic liquids	▪ R&D	**High** ▪ After decomposition of organic matter and the natural mineralization of organic P in soil.
Greenhouse nutrient feedwater (Section 3.3.2)	**Medium** 103	Not identified	**No**	**Yes**	▪ P precipitation, adsorption systems	▪ R&D	**High**
Losses from agricultural fields (Section 3.3.2)	**High** 5,022	Not identified	**No**	**No**	▪ Controlled tile drainage (regulates water table depth with structure at tile drain outlet) combined with adsorption tech	▪ Controlled tile drain structures and adsorption technology are available, but not as combined structure	**Medium** ▪ Soluble inorganic forms of P are readily bioavailable. ▪ Mineral P becomes slowly bioavailable.

Source	Phosphorus Magnitude (t/a)	Phosphorus Concentration (%wt, solid mg/L, liquid)	Current Recovery and Reuse	Future Recovery and Reuse	Technology Required	Technology Development Stage	Bioavailability
Urban Sources							
Recoverable organic feedstock (Section 4.3)	**High** 900 - 7,600	**Medium to High** 0.2% - 3.1%	**Yes**	**Yes**	▪ Composting, anaerobic digestion	▪ Commercial compost and anaerobic digestion	**High** ▪ Improved with composting or anaerobic digestion
Septic systems (Section 4.4)	**High** 1,445	not identified	**No**	**No**	▪ No, if returned to the environment ▪ Yes, if transported to a WWTP	▪ Unknown	**High**
Sewage sludge (Section 4.2)	**High** 6,500 (-1,000 to ash)	**Medium** 15±7 mg/g (primary) 16±7 mg/g (biosolids)[29]	**Yes**	**Yes**	▪ Different technologies being explored to improve the bioavailability of iron and aluminum phosphate	▪ Struvite, commercial, and others	**Low** ▪ If iron and/or aluminum used to reduce
Sewage sludge ash (Section 4.2)	**Medium** 1,000	**High** 94±3 mg/g [30]	Not for reuse as fertilizer	**Yes**	▪ Required to recover a P-fertilizer	▪ R&D	**Low** (unless treated)
Industrial Sector							
Mining tailings and waste rock (Section 5.3.2)	**Very high** 55,000	**Low to Medium** 0.03% - 0.13%	**No**	**No**	▪ Unknown	▪ Commercial	**Unknown**
Steel slag (Section 5.2.2)	**High** 6,700	**Medium** 0.4%	**No**	Used by other industries	▪ Yes	▪ R&D	**Low**
Pulp and paper (Section 5.2.3)	**High** 374	not identified	**No**	Unknown	▪ Unknown	▪ Unknown	**Unknown**
Dog and cat food production (Section 5.2.4)	**Very low** 10	not identified	**No**	Possibly	▪ Possibly compost or anaerobic digestion	▪ Possibly Commercial	**High**

Source	Phosphorus Magnitude (t/a)	Phosphorus Concentration (%wt, solid mg/L, liquid)	Current Recovery and Reuse	Future Recovery and Reuse	Technology Required	Technology Development Stage	Bioavailability
Dairy processing wastewater (Section 5.2.4)	**Low - Medium** 37-343	**Medium to High** 8-86 mg/L wastewater	Partially yes	Partially applied to land, sent to WWTP	▪ Possibly compost or anaerobic digestion	▪ Possibly commercial	**High**
Grain and oilseed milling (Section 5.2.4)	**Medium** 120	Unknown	Partially yes	Partially applied to land, sent to WWTP	▪ May not be required for land application, if sent to WWTP	▪ N/A	**High**
Brewing (Section 5.2.4)	**Medium** Wastewater: 130 **Medium** spent grain: 150 **Low** spent yeast: 30	**Medium to High** wastewater: 30-100 mg/L spent grain: 0.46% spent yeast: 1.5%	Unknown	Unknown	▪ P removal technologies (ex: Econse) may generate a waste flow with recoverable P	▪ Unknown	**High**
Juice/fruit processing (Section 5.2.4)	**Very low** 6	unknown	Unknown	Unknown	▪ Unknown	▪ Unknown	**High**
Soft drink production (Section 5.2.4)	**Low** 18 - 56	**High** 20-40 mg/L	Unknown	Unknown	▪ Unknown	▪ Unknown	**Unknown**
Rainbow trout aquaculture (Section 5.2.7)	**Low** 56	Unknown	**Yes**	**No**	▪ No	▪ If the P in the water can be collected, adsorption, precipitation, or electric current technologies are possible candidates (dependent on P concentration)	**High**
Bioethanol	**High** 6,203	Unknown	Unknown	Unknown	▪ Unknown, might be similar to ROF	▪ Unknown	**High**

Section Three:

Phosphorus Flows in Ontario's Agricultural Sector



Phosphorus Flows in Ontario's Agricultural Sector

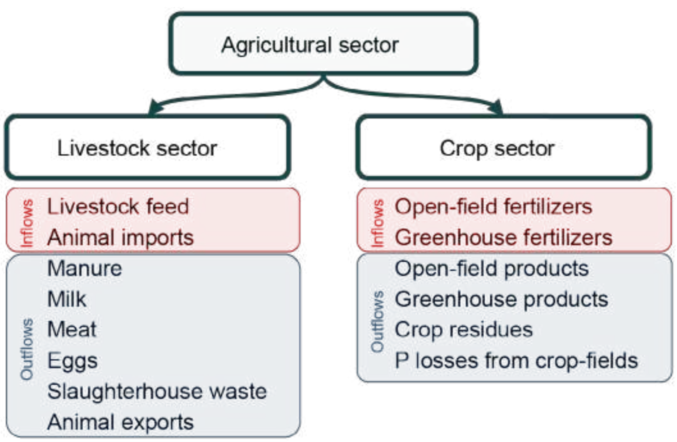
While the agricultural system relied almost exclusively on natural P inputs in the past (e.g., manure, compost), the introduction of artificial P in recent decades allowed for an intensification of agriculture. The dependency of modern agriculture on synthetic P fertilizers and the finite nature of global phosphate rock points to a critical need to better understand where there are opportunities to further NRR in this sector.

The agricultural sector in Ontario is a prominent source of nutrients and has some of the most significant P flows identified through this study. The sector drives major P inputs to the province's economy, including through the use of fertilizer and livestock feed, and is the source of large quantities of P outflows, primarily related to manure and food products. While P is applied to fields to provide crops with the nutrients necessary to grow and produce food, it may not be fully utilized by growing plants. This can result in P being lost from farmers' fields, with direct impacts to downstream water quality, and contributing to eutrophication and algal blooms. These algal blooms may also contribute to degraded air quality through the emission of methane[31] and toxins found in lake spray aerosol.[32]

3.1 Methodology

This section estimates the flows of P in Ontario's agricultural sector by focusing on two key subsectors: livestock and crop production. P is supplied to animals at livestock facilities, either in food or as a feed supplement. It is also one of three macronutrients (together with nitrogen and potassium) that are essential for crop growth. As shown in Figure 9, these subsectors are further organized in this report according to specific inflows and outflows.

Figure 9. Inflows and Outflows in Ontario's Agricultural Sector



Livestock production in this section refers to the commercial farming of animals (i.e., cattle, swine, sheep, poultry, and other livestock animals). P flows into the agricultural sector include livestock feed and animals imported into the province, while outflows are related to manure, livestock products (i.e., milk, meat, eggs, and slaughterhouse waste), and the export of animals.

This study used animal units (AU) and AU equivalents to compare different livestock. An AU is defined as 1,000 pounds (453.6 kg) of live weight — the weight of an animal while living — typically representative of one mature cow.[33] Animal unit equivalents are used to determine the number of a particular animal type equivalent to one animal unit (e.g., one animal unit is equivalent to one cow, four sows or 125 broiler chickens). Using this metric, beef and dairy cows are the most prominent livestock in Ontario, accounting for 27.7% and 31.8% of the AUs for the province, followed by swine (21.9% of AU), poultry (12.8% AU), sheep and lamb (2.24% AU), and other livestock (3.6%).

Crop production in this section refers to the commercial growth of a range of different types of crops, including field crops (e.g., grains, beets, potatoes, etc.), forage crops (e.g., alfalfa, ryegrass, timothy, etc.), field vegetables and fruit, and greenhouse crops. The main crops grown in Ontario are soybeans (27.6%), alfalfa (22.8%), corn (21.3%) and wheat (11.4%). P inflows associated with crop production are related to the application of manure or synthetic fertilizers (also referred to as mineral fertilizers) for crop growth, as P is one of the key macronutrients required for plant development. A portion of the P applied as fertilizer or in manure is taken up by crops, and in turn, it is transferred to the food system as part of agricultural products or as forage and silage — "pickled pasture," or grasses and other crops that have been fermented and compressed to feed livestock. The fraction of P that is not taken up by crops accumulates in soil or can flow to natural waters.

Straw and stover — the leaves and stalks of field crops, referred to as crop residues in this study —are typically left on the land following harvest and the P contained in them is transferred to the soil, which can be available for future crops. Similarly, the P from manure and synthetic fertilizers that is not taken up by the crops also remains in the soil.

As previously noted, the P found in soil may eventually find its way into waterbodies via runoff and erosion, contributing to eutrophication. P can also be transported when a storm event occurs following the application of manure or synthetic fertilizer and before the crops have time to take it up. However, soil also plays a role as a P reservoir, with a buffering capacity that can mitigate short-term P deficits or surpluses, supplying or accumulating P to balance changes in the its concentration.[34] Soils with a high P sorption capacity may need to have more P added to suppress the amount adsorbed by the soil and to raise the amount available for plants to an appropriate level (i.e., soils with high buffering capacity need a larger supply of fertilizer to increase their P level[35]). The continuous application of fertilizer has an impact on P inputs and outputs over the long-term, and can lead to the accumulation of P in soil.

P releases also occur from greenhouse nutrient feedwater (GNF) — the nutrient solution removed from a closed circulation system at a greenhouse operation, and from the septic tanks at dwellings in the vicinity of the greenhouses that are used by the labour force.

3.1.1 Key Data Types and Sources

Understanding the strengths and challenges associated with the data used for this study is important context as it can help with highlighting potential uncertainties that can be updated in future with new or improved data. For the purposes of this report, estimations of P flows are carried out at the census division level for the years 2006 to 2020.[36] While some data is available for 2001 to 2005 and for 2021, it is not complete. As such, these years were not included in an effort to ensure a consistent approach to the analysis.

P flow estimations for the agricultural sector were determined based on production data for specific materials where these were reported and publicly available. Where production data were not available, a number of different methods were used to estimate the P flow based on approaches established in the literature. For example, P inflows associated with synthetic fertilizers could be directly estimated based on application data reported in the Fertilizer Shipments Survey (FSS).[37] Conversely, P flows associated with manure were determined indirectly by accounting for the magnitude from which the flow of P could be derived. In this case, this estimate was based on the number and type of animals reported for Ontario in the Census of Agriculture[38], multiplied by the concentration of P in manure for each animal type.

Census of Agriculture and Agricultural Surveys: The primary data source used to calculate estimations for P flows in the agricultural sector is the Census of Agriculture, which provides a comprehensive and integrated profile of the physical, economic, social and environmental aspects of Canada's agriculture industry.[39] Reported by Statistics Canada, the Census of Agriculture is conducted every five years and includes information about a wide range of agricultural products, including poultry and livestock (e.g., cattle, sheep, swine) inventories, the area attributed to open field crops (e.g., grains, potatoes and vegetables) and for greenhouse crops (e.g., tomatoes, cucumbers and peppers), inputs to agricultural soils, and manure application areas. Additional data from a variety of national surveys reported by Statistics Canada were used to determine the number of live animals (e.g., cattle, swine and sheep) imported and exported from the province (Livestock Survey) and fertilizer shipments (Fertilizer Shipment Survey).

Production Data: Provincial production data for milk and eggs was sourced from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)[40, 41] while P flows associated with meat products and slaughterhouse waste are based on the number of animals slaughtered as reported by both federally and provincially licensed meat plants.[42,43] Data on livestock slaughter and carcass weights is reported by Agriculture and Agri-Food Canada (Red Meat and Livestock Market Information).

Other Data Sources: Data reported by OMAFRA was used to estimate water discharges from greenhouses and its average P concentration. The P content of livestock feed and for manure by animal type is reported by Statistics Netherlands.[44] These values were determined to be in agreement with data for Canada reported by Van Staden et al.[45] and OMAFRA.[46] Data on crop yields and P content for a variety of crops were sourced from reports issued by the U.S. Department of Agriculture.[47]

Demographic, Social and Economic Data: Data related to farm revenues and expenses reported under the Agriculture Taxation Data Program (ATDP), an annual census of tax filer records used to estimate financial agricultural variables, was sourced from Statistics Canada. Data reported by the Government of Canada's Job Bank was used to determine the number of workers in greenhouses in Ontario.

Scientific Literature: Data reported in the scientific literature was used to obtain the value of P loads from agricultural fields. These data are obtained from studies performed in a certain region of Ontario, however, as a consequence of the scarcity of data, these average values were extrapolated to estimate P losses from agricultural soils across the entire province of Ontario.

3.2 Phosphorus Flows in Ontario's Agricultural Sector

An overview of the main P flows in the agricultural sector in Ontario for the year 2019 is shown in Figure 10 with inflows and outflows organized as follows:

Inflows	Outflows
Livestock feed: Feed provided for cattle, swine, poultry, sheep and goats, rabbits, and other livestock (horses, mink, bison, and llamas).	**Eggs:** Eggs from layers.
Animal imports: The import of cattle, swine, sheep, and lambs.	**Milk:** Milk from dairy cows.
Open field fertilizer: Fertilizer applied to open field crops.	**Meat:** Meat production from cattle, swine, sheep and lambs, goats, chicken, turkeys, and rabbits.
Greenhouse fertilizer: Fertilizer applied to greenhouse fruit and vegetables.	**Slaughterhouse waste:** Waste from meat production from cattle, swine, sheep and lambs, goats, chicken, turkeys, and rabbits.
	Animal exports: The export of cattle, swine, sheep, and lambs.
	Open field food products: Crops grown in open fields.
	Greenhouse food products: Crops grown in greenhouses.
	Non-food products: Silage and forage.
	Crop residues: Straw and stover.

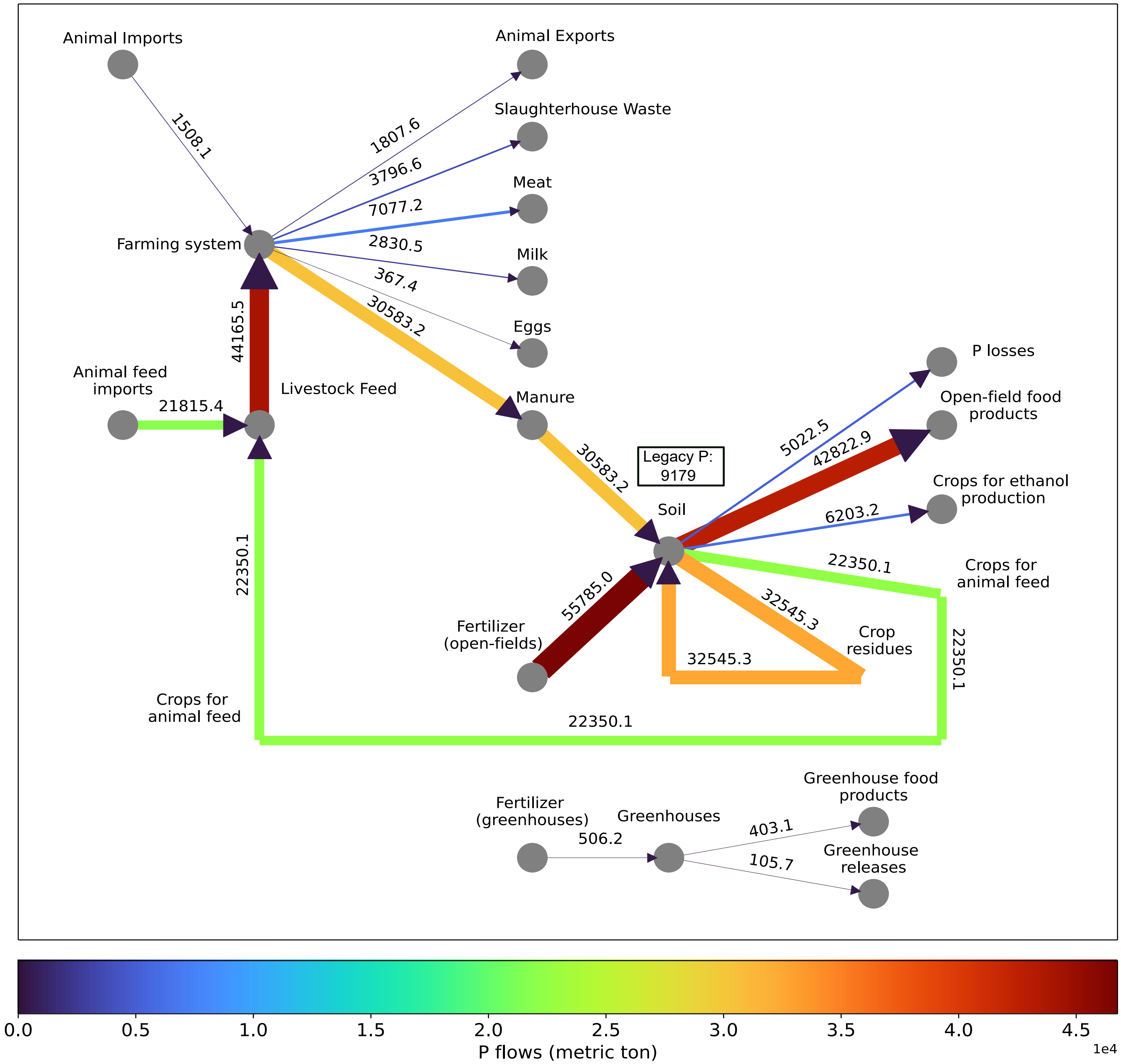
Figure 10 shows P flows associated with the agricultural sector. Total P inflows account for a total of approximately 79,615 t/a with the two main inflows attributed to phosphorus imports to cover livestock feed requirements (21,815 t/a) and the application of fertilizer (56,291 t/a combined for open field and greenhouses).

Total P outflows from the agricultural sector are approximately 70,437W t/a, with the livestock sector accounting for 15,879 t/a, and the crop production resulting in 54,556 t/a. The main P outflow for the agricultural sector is from open field crops (42,823 t/a), while the crops used to produce ethanol account for 6,203 t/a of P. Grain residues from ethanol production are commonly recycled for livestock feed as brewers grains or dried distillers grains with solubles. However, no data could be sourced to accurately estimate the fraction of this residue used for feed within the province. Outflows from greenhouses, accounting for discharges from both GNF systems and the labour force (i.e., septic systems), account for approximately 106 t/a.

Determining the amount of P lost as a result of erosion and runoff is challenging as it is dependent on a broad range of factors with large temporal and spatial variability, including the amount of rainfall, soil type, slope, and the method of manure application. A rough estimate for P losses from croplands was performed based on P load measurements of those fertilized with either synthetic fertilizer or manure, for a total of 5,022 t/a of P.

This study found a net accumulation of P in the crop production sector of 9,970 t/a. This represents the accumulation of P in agricultural soils as a result of its application in excess of crop removal. This accumulation has been discussed in previous studies.[48, 49]

Figure 10. Phosphorus Flows in Ontario's Agricultural Sector (2019)



Manure is an important internal flow (30,583 t/a) in the agricultural sector, where P is transferred from the livestock sector as an outflow to crop production as an inflow. For the purposes of this study, it was assumed that all of the manure generated in the livestock sector is applied in fields for the purpose of growing either food or non-food crops (e.g., forage and silage).[50] However, it should be noted that a portion of the P found in the manure applied to fields is not taken up by the plants. Instead, it remains in the soil where it has the potential to be transported to surface and groundwater via erosion and runoff. This fraction of P is shown as an outflow, labelled as "P losses".

The crops used for livestock feed (e.g., alfalfa, timothy, and other fodder crops) and crop residues in the form of straw and stover contribute to other important internal P flows, which are estimated at 22,350 t/a and 32,542 t/a, respectively. An additional 21,815 t/a of P is imported to meet the P requirements of livestock feed. The P flow for crops used as livestock feed is an internal flow connecting crop and livestock production, while the P in crop residues is also considered an internal flow to the soil reservoir.

It should be noted that P as a component of pesticide applied in the agricultural sector has not been included in this report due to the lack of data for the years studied. However, data for 2013/2014[51] can be used to give a general idea of P inflows related to pesticides. A total of 542 t/a of P were estimated to be applied to fields as a component of various pesticides that year, as follows:

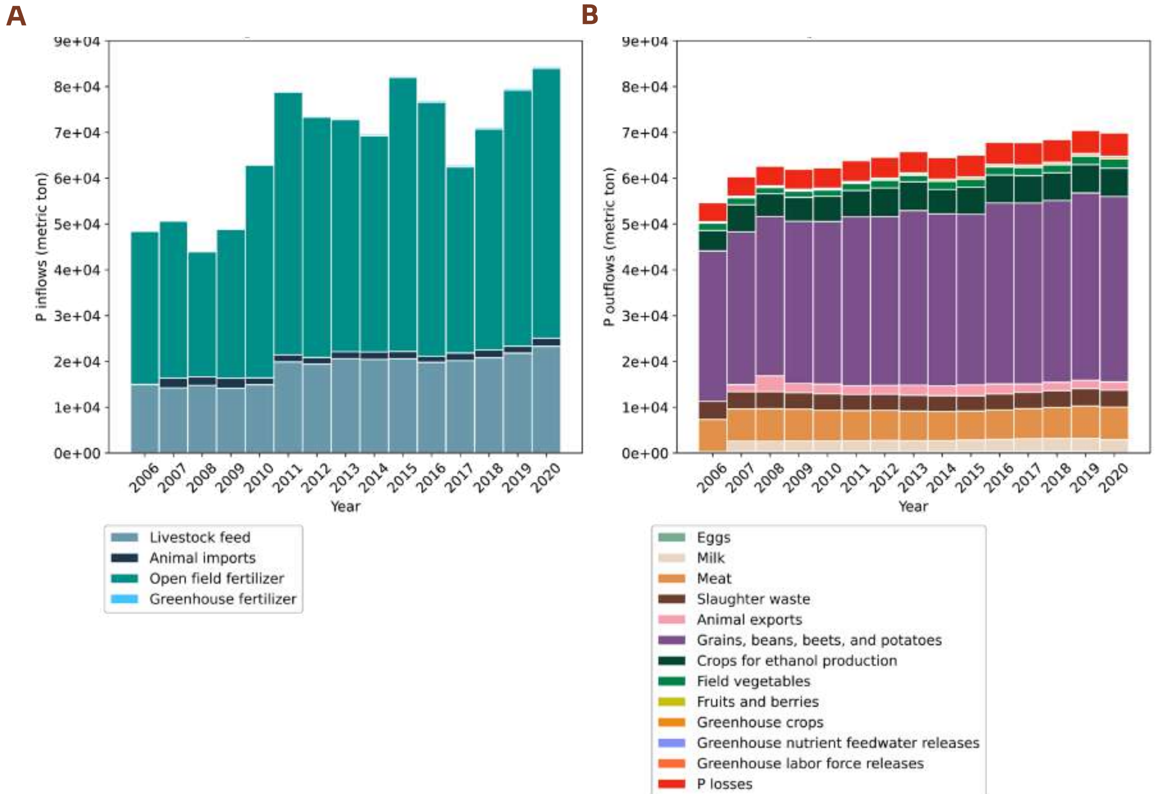
- **Herbicides (98.8%)**: More specifically, the application of 2,909 t of glyphosate, which contained 533 t of P.
- **Insecticides (0.37%)**: Mainly related to the use of phosmet, malathion, and diazinon.
- **Crop growth regulators (0.012%)**: More specifically, ethephon.
- **Fungicides (0.73%)**: Mainly through the use of fosetyl-AL and dipotassium phosphonate.

Figure 11 shows P inflows and outflows in the agricultural sector for the years 2006 to 2020. While the categorization of inflows remains the same as for Figure 10, open field and greenhouse food products are further broken down into the following categories:

- **Grains, beans, beets, and potatoes**: This category includes barley, buckwheat, corn, oats, rye, wheat, canola, soybeans, sunflower, dry beans, sugar beets, and potatoes.
- **Fruits and berries**: This category includes apples, peaches, pears, plums and prunes, sweet cherries, sour cherries, apricots, strawberries, raspberries.
- **Field vegetables**: This category includes peppers, cabbage, carrots, celery, cucumbers, onions, peas, sweet corn, sweet potatoes, pumpkin, asparagus, broccoli, cauliflower, rutabaga, radishes, and tomatoes.
- **Greenhouse crops**: This category includes greenhouse grown tomatoes, cucumbers, and peppers.

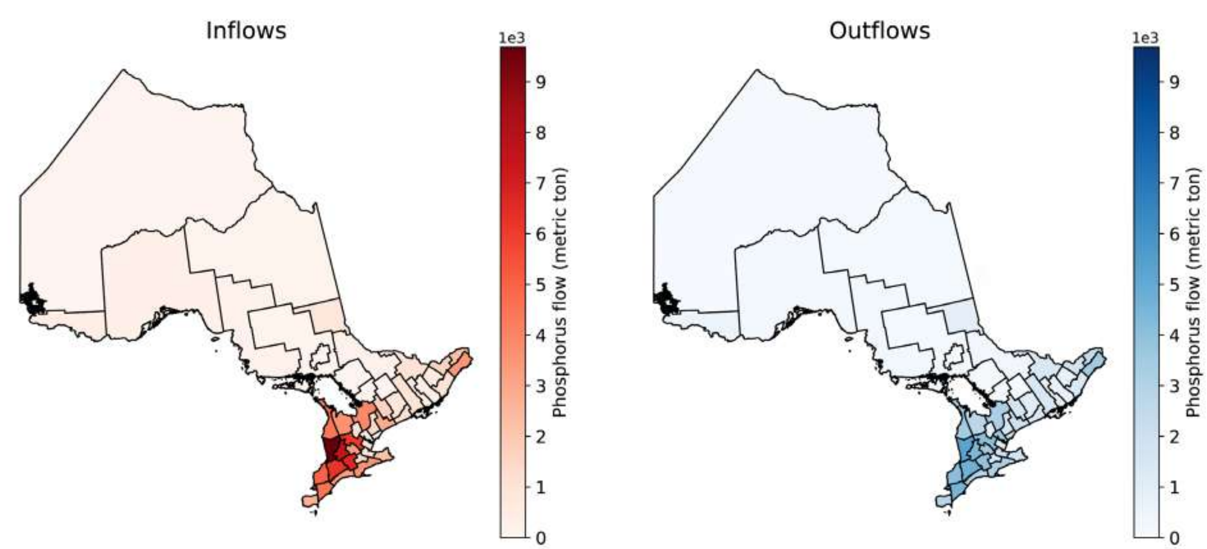
It should be noted that manure and crop residues are not shown in this figure because they are internal flows for the agricultural sector.

Figure 11. Phosphorus Inflows (A) and Outflows (B) in Ontario's Agricultural Sector (2006 to 2020)



The flow of P through Ontario's agricultural sector is not distributed evenly across the province. Figure 12 shows the geographic distribution of P inflows and outflows for 2019, with the majority concentrated in southern Ontario census divisions associated with more intensive agricultural activity. It should be noted that P flows from the import and export of animals are not included in Figure 11 because they are reported at the provincial level (i.e., not according to census division). Flows from manure, crops for livestock feed, and crop residues are also not represented because they are internal flows when looking at the overall agricultural sector (i.e., outflow from livestock and inflow for crop production).

Figure 12. Geographic Distribution of Phosphorus Flows in Ontario's Agricultural Sector (2019)

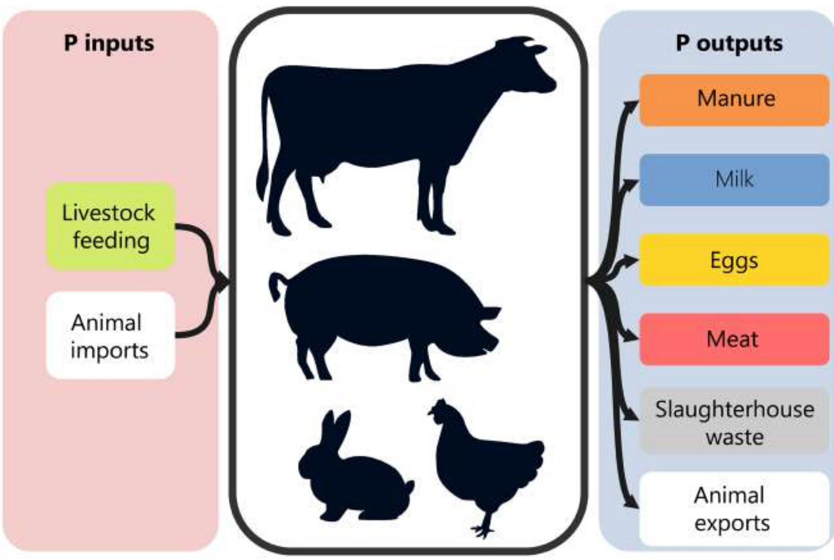


3.3 Phosphorus Flows in Specific Agricultural Sectors

3.3.1 Livestock Sector

Figure 13 shows key P flows in the livestock sector. As previously noted, P inflows include those related to livestock feed and animal imports, while outflows are associated with manure, milk, eggs, meat, slaughterhouse waste and animal exports.

Figure 13. Phosphorus Flows in the Livestock Sector



The majority of P flows for the livestock sector are based on the number and type of animals found in the province. Livestock census data was used to determine the number of each animal type by census division. The Census of Agriculture is published by Statistics Canada every five years (i.e., 2001, 2006, 2011, and 2016) for cattle[52] , sheep[53] , swine[54] , poultry[55] , and other livestock[56] , with the exception of rabbits, where data is not available prior to 2009. For the purposes of this report, the number of animals for the years in between census reporting have been estimated using a linear interpolation.

Provincial production data was used to find the amount of milk and eggs produced in Ontario and was then multiplied by the average concentration of P found in these products.[57, 58] The P content in meat and slaughterhouse waste is based on the number of animals slaughtered, as reported by both federally and provincially licensed meat plants.[59, 60] The definition of meat plants includes abattoir facilities, meat processing facilities, as well as facilities performing both activities.[61] Only facilities reporting on slaughtered animals are considered for the estimation of P flows through meat and slaughterhouse waste. P flows associated with animal imports and exports are estimated based on data reported by Statistics Canada.[62, 63, 64]

Figure 14 shows P flows by animal type for 2019, according to the following categories:

- **Dairy**: dairy cows and heifers
- **Beef:** beef cows and calves
- **Swine:** pigs and piglets
- **Poultry:** layers, broilers, pullets and turkeys
- **Sheep:** sheep and lambs
- **Other livestock:** rabbits, horses, mink, bison, and llamas

Figure 14. Phosphorus Flows in the Livestock Sector by Animal Type

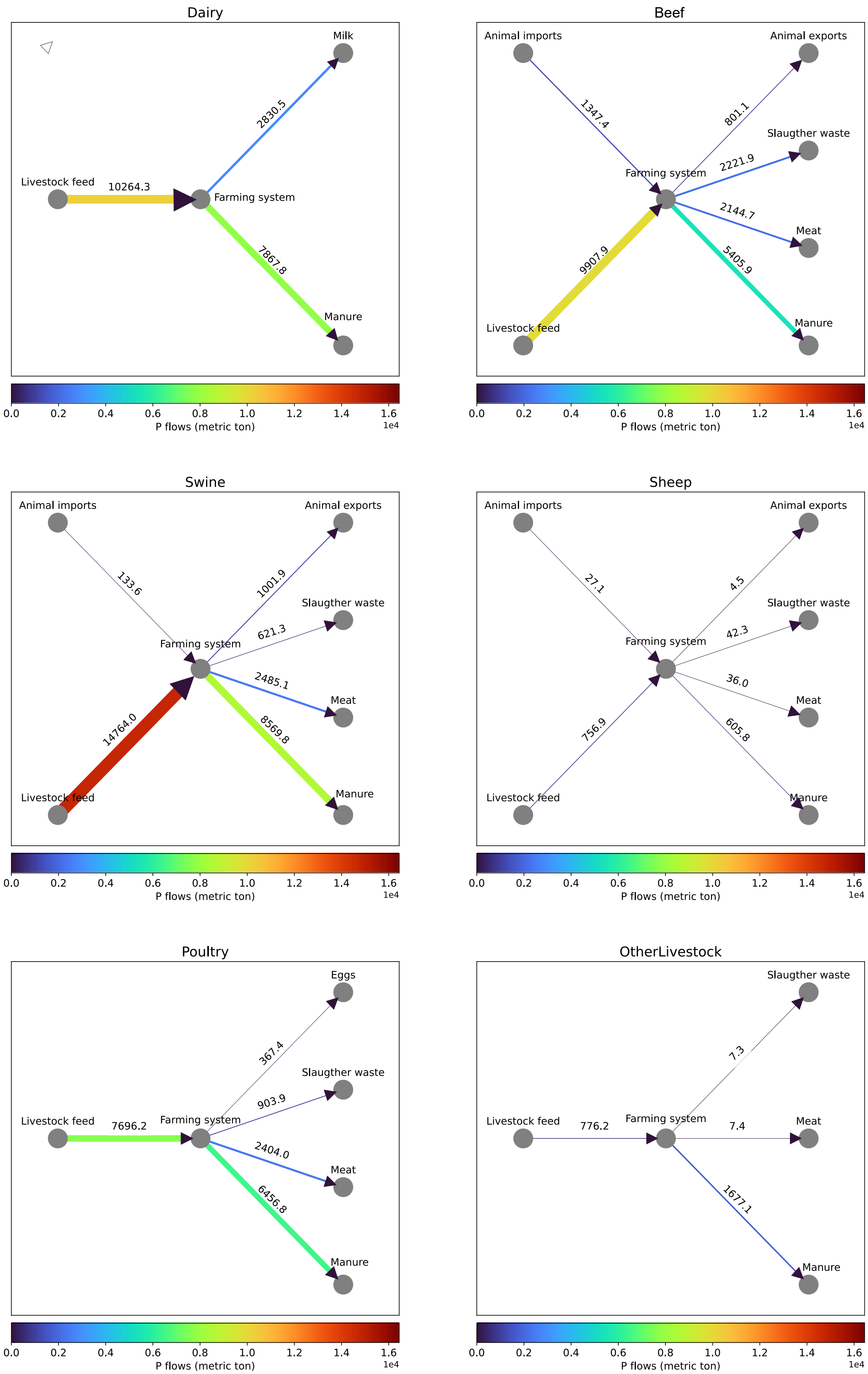


Figure 15 shows the geographic distribution of P inflows from livestock feed (denoted in red) and outflows associated with manure, eggs, milk, meat, and slaughterhouse waste (denoted in blue) in Ontario. The main P flows are found in southern Ontario census divisions where livestock operations are concentrated.

Figure 15. Phosphorus Flows in the Livestock Sector by Census Division (2019)

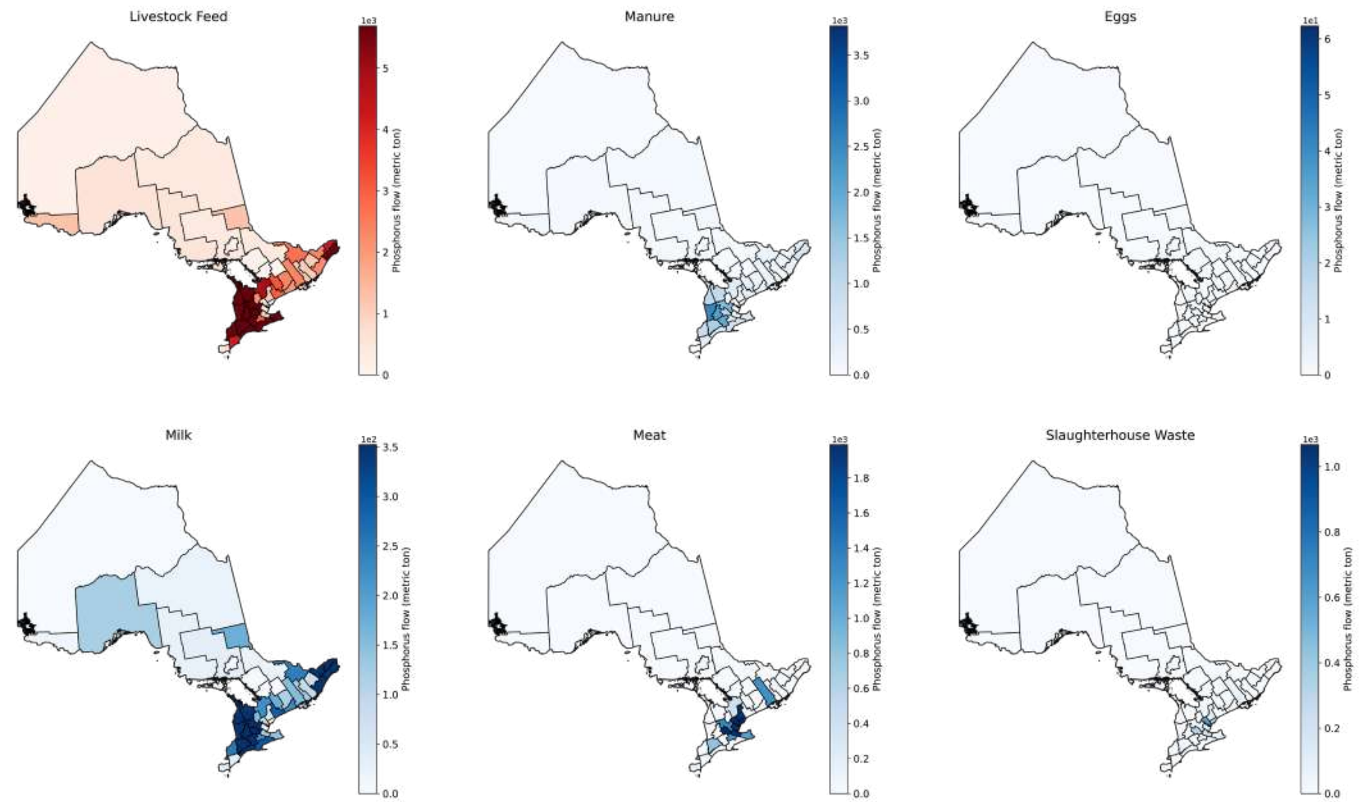
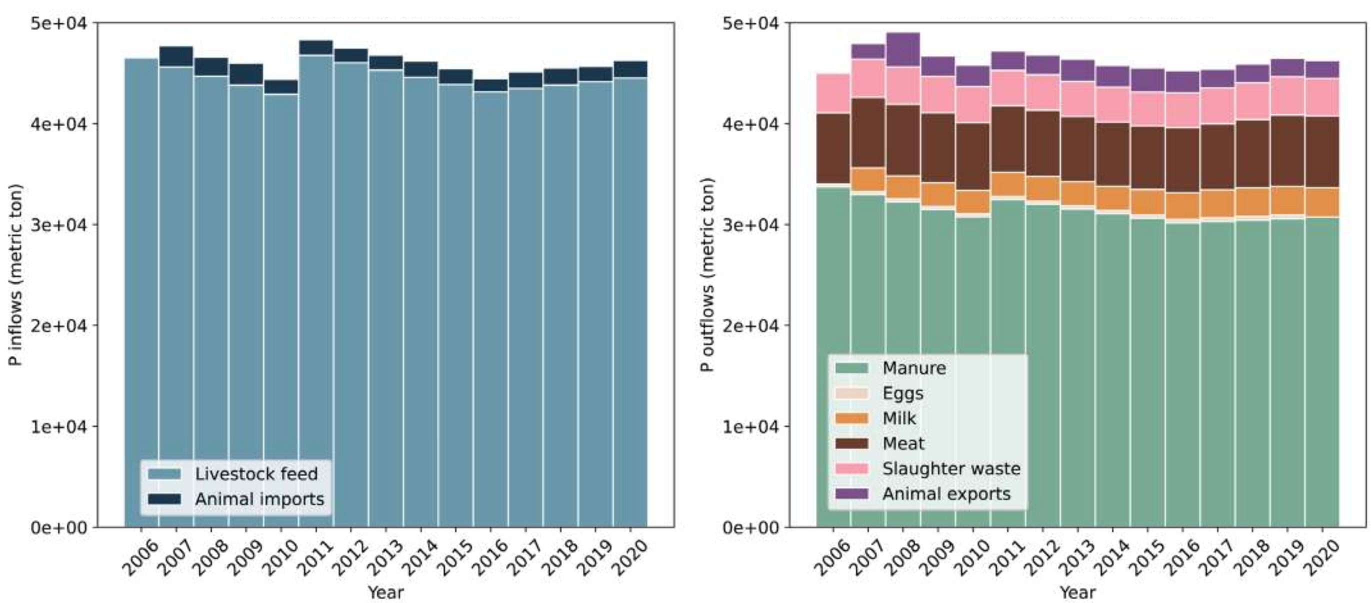
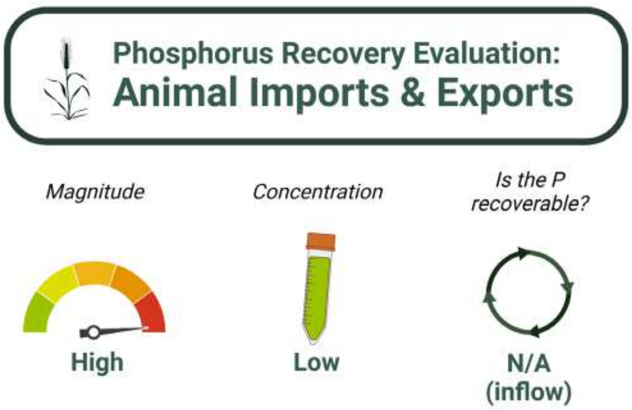


Figure 16 shows P inflows and outflows related to the livestock sector in Ontario between 2006 and 2020. The main P inflow is related to livestock feed, while the main outflow is through manure. Meat is the agricultural product that contains the greatest amount of P.

Figure 16. Phosphorus Inflows and Outflows for the Livestock Sector in Ontario (2006 to 2020)



Animal Imports & Exports



Live animals imported and exported represent a significant flow of P entering and leaving Ontario. Provincial imports and exports of cattle, swine, and sheep were retrieved from Statistics Canada.[65, 66, 67] Data was unavailable for the import and export of poultry and for the "other livestock types" category, while data for hogs was only available from 2007 onwards. It should be noted that animal imports and exports are reported at the provincial level but not by census division, resulting in a lower spatial resolution for this analysis.

Figure 16 shows animal imports accounting for inflows to the livestock sector of between 1,300 t/a and 2,200 t/a of P per year between 2006 and 2020. Similar values are observed for P outflows through animal exports. Table 2 shows the number of imports and exports of cattle, swine and sheep and the associated P flow for 2019. The percentage of the total contribution of P from imports and exports for each type of livestock was calculated using an average from the years 2006 to 2020.

In 2019, P flows through animal imports and exports were approximately 1,509 t/a and 1,808 t/a, respectively. However, the contributions of each animal type to these flows varied significantly. Cattle represented the majority of the P inflows in Ontario from animal imports, accounting for almost 95%. This is due to the more significant number of cattle being imported than other livestock types, their large size, and the more significant P to live weight ratio.

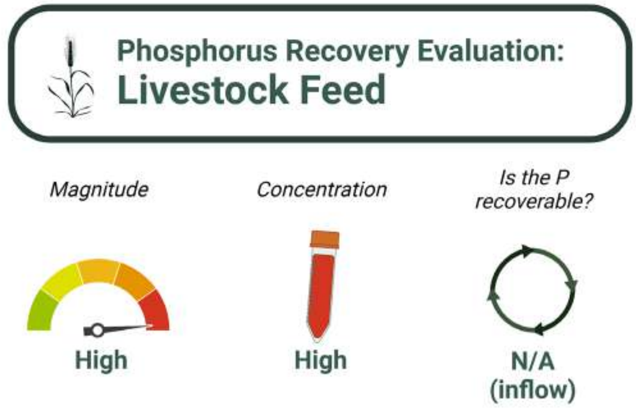
P inflows for cattle and sheep are shown to be greater than outflows, based on more of these animals being imported than exported. Conversely, P outflows for swine are significantly greater than for their import, due to the much larger number being exported.

Table 2. Phosphorus Flows from Animal Imports and Exports (2019)

		Heads	Phosphorus/Live weight (%)	P flows in t (2019)	Average % P flows (2006 – 2020)
Imports	Cattle	220,500	0.74	1,348	94.24
	Swine	189,900	0.53	134	4.14
	Sheep	121,900	0.52	27.1	1.61
	Total	**532,300**	**-**	**1509.1**	**100.00**
Exports	Cattle	131,100	0.74	801	44.03
	Swine	1,424,500	0.53	1,002	55.74
	Sheep	20,300	0.52	4.5	0.24
	Total	**1,575,900**	**-**	**1807.5**	**100.00**

*Note: detailed calculations are found in Appendix A

Livestock Feed



Livestock feed is the main P inflow associated with the livestock sector and includes forage such as alfalfa for cattle, grain supplied to swine and cattle, concentrates — feeds rich in energy or protein but low in fiber, such as corn or soybean meal — for cattle, swine, poultry, and molasses.

The amount and type of feed required varies by livestock type. As such, analyses were conducted separately for each animal type according to the following categories:

- **Cattle:** beef cows, beef calves, dairy cows and dairy heifers
- **Swine:** mature and immature pigs
- **Sheep:** sheep and lambs
- **Poultry:** broilers, pullets, laying hens and turkeys
- **Other livestock** includes horses, goats, rabbits, mink, bison, llamas and alpacas. It should be noted that llamas and alpacas are considered as a single animal type as they are presented in aggregate in livestock census data.[68]

Since the animals studied belong to different types and life stages, animal heads are normalized by means of AUs. As previously noted, an AU is a metric defined as an animal equivalent of 1,000 pounds (453.6 kg) live weight.[69] For example, 2.67 mature pigs are equal to one AU, while a beef cow is also equal to one AU. Where a census division has an inventory of 100 mature pigs and 100 beef cows, the corresponding number of AUs would be 37.5 (i.e., 100/2.67) for the pigs and 100 for the beef cows, for a total of 137.5 AUs for the census division. This normalization is important for performing estimations related to manure generation and feed requirements. The animal head to AU equivalencies used in this study are shown in Table 3.

Table 3. Animal Head to Animal Unit Equivalencies[70, 71, 72, 73, 74]

Livestock type	Animal Unit equivalent (animal head/AU)	Livestock type	Animal Unit equivalent (animal head/AU)
Dairy cow	0.74	**Turkey (mature)**	50
Dairy heifer	0.94	**Turkey (immature)**	67
Dairy calf	4	**Sheep**	5
Beef cow	1	**Lamb**	7.14
Beef calf	4	**Mink**	150
Swine (mature)	2.67	**Horses**	0.91
Swine (immature)	9.09	**Rabbits**	50
Layers	250	**Goat**	5.88
Pullets	455	**Llamas/alpacas**	3.5
Broilers	455	**Bison**	0.91

P flows through feed were estimated by multiplying the number of each type of animal by its specific P requirements from feed. P feed requirements were retrieved from an analysis undertaken by Statistics Netherlands[75] that provided detailed data on P inflows related to livestock feed. These values were then validated by data for Canada reported by Van Staden et al.[76]

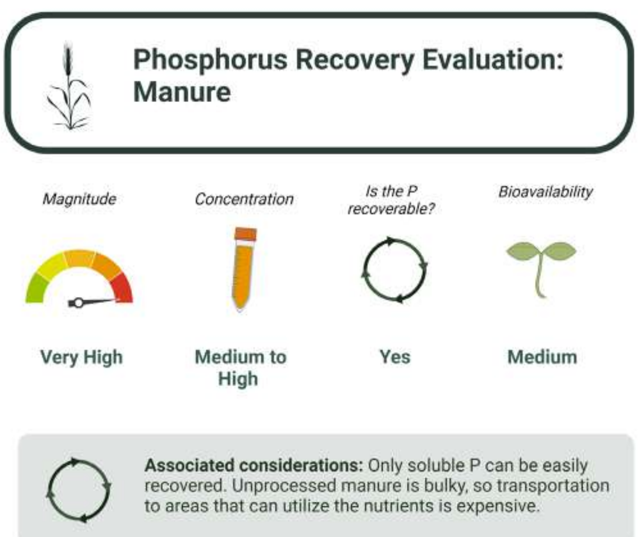
Table 4 shows the contribution of each animal type to P inflows based on the amount of feed they are provided. The number of animals and total amount of P are calculated using data from 2019. The percentage of the total contribution of P from livestock feed for each type of livestock was calculated using an average from the years 2006 to 2020.

Table 4. Phosphorus Flows from Feed by Animal Type

	Cattle	Swine	Sheep	Poultry	Other Livestock	Total
Number of animals in AU (2019)	1,376,984	506,768	52,227	148,508	83,498	2,167,985
Average % P in livestock feed (2006 – 2020)	47.20	26.33	2.03	18.05	6.39	100
P flows from livestock feed in t (2019)	**20,171**	**14,764**	**757**	**7,696**	**776**	**44,164**

Figure 16 shows P inflows from livestock feed ranging from between 43,000 t/a and 46,500 t/a for each year between 2006 and 2020. For 2019, this flow has a value of approximately 44,166 t/a (see Figure 14 for a further breakdown of contributions by animal type). Feed for cattle and swine makes up the majority of the flow of P into the agricultural sector, accounting for 47% and 26%, respectively. The input from poultry feed is 18%, while all other animal types have marginal contributions.

Manure



A large proportion of the P from livestock feed is not used by the animal and is excreted. P associated with manure is the most significant outflow from the livestock sector. Each animal type produces different amounts of manure, and a number of factors contribute to its composition, including age or life stage (e.g., actively growing animals typically utilize some nutrients more efficiently than mature animals) and type of feed (some nutrients found in feed may not be in a form that is available to the animal).

P in manure is present in both inorganic and organic forms. Organic P is chemically bound to other organic compounds and requires more time and enzymatic activity to be taken up by crops, while inorganic P is water soluble and available for uptake. Inorganic P is mainly found in the liquid portion of manure or bound to soluble minerals. The P flows through manure outlined in this section are associated with total phosphorus (TP), thus accounting for both organic and inorganic P.

For the purposes of this study, estimations for manure generated and the related P content were calculated for each livestock type based on the number and age of the animal, as reported by the Census of Agriculture. To determine the manure generation rate for each animal type based on life stage, a normalization was first required using AU. Manure production was estimated for each type of animal by multiplying the number of animals reported by the Census of Agriculture and the manure generation rate. The amount of P contained in manure is then calculated based on the composition specific to each type of livestock found in the literature.

Table 5 shows the manure generation rates and composition for each type of animal based on their life stage. The P content of poultry and rabbit manure is significantly larger than for other livestock, although their generation rate is low due to their small size. Conversely, cattle and swine generate large amounts of manure, which results in larger amounts of P, even if the associated concentrations are lower than for some other animal types.

Table 5. Manure Generation Rates and Composition for Different Types of Livestock[77, 78, 79, 80, 81, 82, 83]

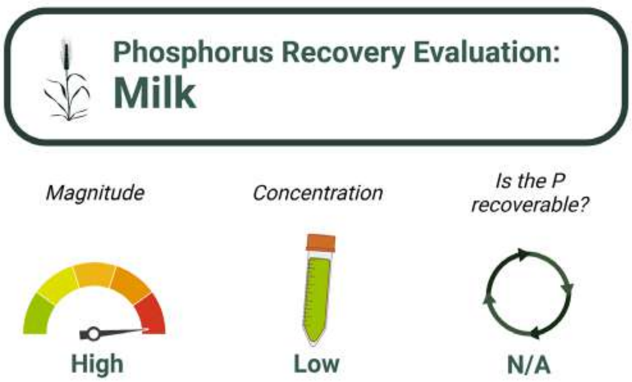
Livestock type	Water (%)	Organic Matter (%)	N_{total} (%)	P_{total} (%)	K_{total} (%)	Manure (kg/day/AU)	Animal Unit Equivalent (Animal head/AU)
Dairy cow	87	10.98	0.59	0.08	0.2	37.88	0.74
Dairy heifer	83	13.04	0.48	0.09	0.21	29.95	0.94
Dairy calf	83	9.28	0.51	0.06	0.13	29.95	4
Beef cow	88	10.58	0.34	0.08	0.24	28.58	1
Beef calf	88	10	0.58	0.1	0.38	28.14	4
Swine (mature)	90	9.15	0.76	0.22	0.47	15.19	2.67
Swine (immature)	90	8.31	0.83	0.14	0.37	36.51	9.09
Layers	75	19.3	1.93	0.58	0.68	28.46	250
Pullets	75	19.3	1.93	0.58	0.68	20.68	455
Broilers	75	19.09	1.09	0.32	0.62	37.21	455
Turkey (mature)	74	20.42	1.5	0.42	0.65	22.67	50
Turkey (immature)	74	20.42	1.5	0.42	0.65	20.33	67
Sheep	75	20.75	1.13	0.18	0.75	18.16	5
Lamb	75	20.75	1.13	0.18	0.75	18.16	7.14
Mink	54	45.8	3.28	1.82	0.79	42.74	150
Horses	85	11.92	0.6	0.13	0.37	23.38	0.91
Rabbits	54	46	1.22	0.87	0.57	51.64	50
Goat	68.8	31.2	1.06	0.37	1.03	20.94	5.88
Llamas/ alpacas	69	31	0.71	0.38	0.24	12.49	3.5
Bison	78.9	21.1	0.4	0.07	0.07	44.88	0.91

Figure 16 shows that P outflows associated with manure from livestock ranged from 30,000 t/a to 33,000 t/a for each year between 2006 and 2020. In 2019, manure accounted for a P flow of 30,583 t/a. Table 6 summarizes the contribution of P from manure for all livestock types in 2019. The percentage of the total contribution of P from manure for each type of livestock was calculated using an average percentage from the years 2006 to 2020. Cattle are the main contributor to P outflows from manure (43%), followed by swine (28%) and poultry (21%). As previously noted, this is due to the large number of these animal types, as well as the large amounts of manure generated. P flows for livestock feed and manure are directly related, and the outflows from manure for each livestock type is similar to the inflow of P from livestock feed.

Table 6. Phosphorus Flows from Manure

	Cattle	Swine	Sheep	Poultry	Other Livestock	Total
Number of animals (AU, 2019)	1,376,984	506,768	52,227	148,508	83,498	2,167,985
Average % P flows through manure (2006 - 2020)	43.40	28.02	1.98	21.11	5.48	100
P flows through manure in t (2019)	13,273	8,570	606	6,457	1,677	30,583

Milk



P from livestock feed can also be excreted in milk, contributing to an outflow from the livestock sector. The quantity of cow milk produced in Ontario by county was retrieved from available provincial data[84] for the years 2007 to 2020. While most of the counties in Ontario align directly with census divisions, there are exceptions where there may be two or three census divisions within the boundaries for one county. Milk production data for these counties were merged or broken down to align with the corresponding census divisions.

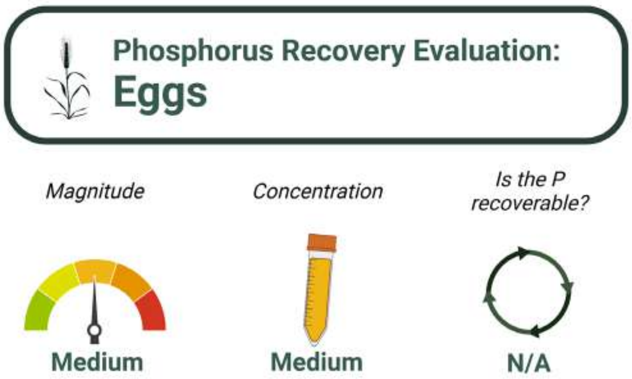
Table 7 shows those counties that were broken down or merged to align with census divisions. Where county data was broken down into several census divisions, milk production was determined by dividing the proportion of dairy cows in the targeted census divisions by the total number of dairy cows in the original county, using data from the Census of Agriculture.[85]

Table 7. Alignment of Counties to Census Divisions for Milk Production Data

County	Corresponding Census Division(s)	Action
Essex and Kent	**Essex; Chatham-Kent**	**Broken down**
Haldimand; Norfolk	**Haldimand-Norfolk**	**Merged**
Hamilton-Wentworth	**Hamilton**	**Renamed**
Dundas; Glengarry; Stormont	**Stormont, Dundas and Glengarry**	**Merged**
Grenville; Leeds	**Leeds and Grenville**	**Merged**
Ottawa-Carleton	**Ottawa**	**Renamed**
Prescott; Russell	**Prescott and Russell**	**Merged**

Figure 16 shows that P outflows from milk for the years 2007 to 2020 were between 2,300 t/a and 2,900 t/a. In 2019, 308,293 dairy cows were reported in Ontario (equivalent to 416,611 AU) and milk production was reported to be approximately 3,011 million litres. For the purposes of this study, the P content of milk is considered to be 0.94 g/L, based on data from Health Canada.[86] This means that there was a flow of 2,830 t of P from milk that year.

Eggs



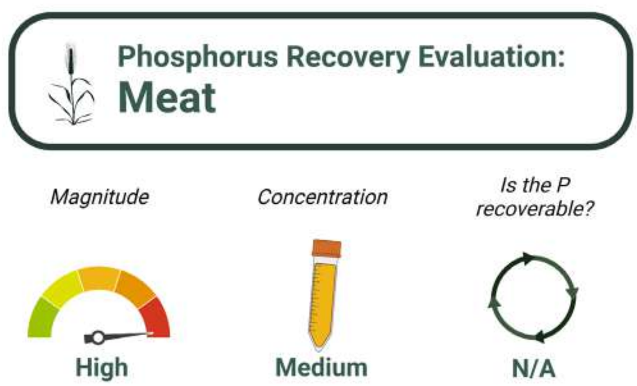
The number of eggs produced in Ontario is reported at the provincial level by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA).[87] Data is available for the years 2001 to 2019 and was scaled to census division proportionally by the number of layer chickens reported by the Census of Agriculture.[88]

The average size of a large egg in Canada is assumed to be 59.5 g/egg.[89] The elements of the egg (i.e., white, yolk, and shield) each contain different amounts of P. As a result, estimating an average value for P contained in the egg must consider these different elements. There is not a clear consensus in the literature regarding the P content of eggs so for the purposes of this report, an average value of 173 mg/100g egg was assumed based on findings from different studies showing values ranging from 158 mg/100g egg to 198 mg/100g egg.[90, 91, 92]

Figure 16 shows that P outflows associated with eggs are relatively small but there has been a steady increase in the P flow over time, ranging from 260 t/a in 2006 to 367 t/a in 2019 (based on a reported 3,632 million eggs). This is likely the result of an increase in egg production in Ontario over time.

Meat

Meat is an important agricultural product in Ontario, and it is associated with a significant flow P out of the livestock sector. Meat plants can be either federally or provincially registered.[93] As such, both types of facilities and the animals they slaughter must be accounted for when determining the associated P flow.
Data from the following sources were used to estimate P outflows associated with meat:



- **Cattle, calves, hogs, sheep and lambs:** The total number of cattle slaughtered in federal and provincial facilities in the province of Ontario was retrieved from Agriculture and Agri-Food Canada.[94] It should be noted that data for goats is only available for 2014 onwards. The number of sheep and lambs slaughtered in Ontario at federally inspected facilities was determined based on the ratio of animals culled at provincially licensed plants to those in the western provinces for each study year.
- **Chicken & turkey:** The number of chickens and turkeys slaughtered in federally and provincially licensed plants was retrieved from Agriculture and Agri-Food Canada.[95] However, the data for federally inspected facilities is reported in aggregate for Ontario and the western provinces.

Further detail about this data is found in Appendix C.

The P contained in meat for each animal type was estimated using the meat to warm carcass weight and P to warm carcass weight ratios outlined in Table 8. Warm carcass is defined as the weight of the carcass after the internal organs have been removed prior to cold storage.[96] Average warm carcass weights for Canada are reported by Agriculture and Agri-Food Canada.[97] The P content in meat products was estimated proportionally to the weight of the carcass destined for the production of meat products.

Table 8. Carcass Weight, Meat to Live Weight and Phosphorus to Live Weight Ratios

	Cattle	Hogs	Calves	Sheep	Goat	Rabbit	Chicken	Turkey
Average warm carcass weight (kg)	404.63	105.77	173.30	19.7	14.19	1.25	2.44	10.85
Meat/warm carcass weight (%)	49	80	55	46	50	53	72	77
Phosphorus/warm carcass weight (%)	0.74	0.53	0.8	0.52	0.63	0.6	0.5	0.51

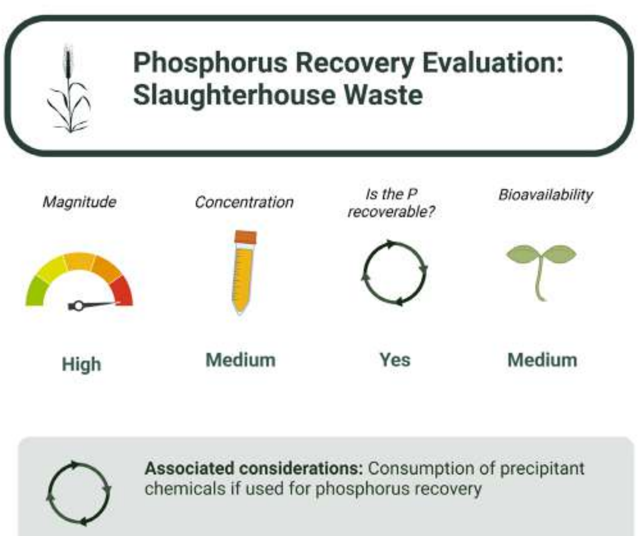
Figure 16 shows P outflows of between approximately 6,300 t/a and 7,200 t/a of P through the production of meat in Ontario for each year between 2006 and 2020. Table 9 shows that in 2019, the total outflow of P from meat was 7,077 t/a. The table also includes the number of animals (heads) slaughtered in federal and provincially licensed facilities and the total amount of P by animal type for the same year. The percentage of the total contribution of P from meat for each type of livestock was calculated using an average from the years 2006 to 2020. Although the largest number of slaughtered animals in terms of heads are poultry, the largest P contributions are from cattle and swine due to the larger size of these animals.

Table 9. Phosphorus Flows for Meat Products

	Cattle	Swine	Sheep	Rabbit	Poultry	Total
Animals slaughtered in federally licensed facilities (heads, 2019)	628,366	4,010,926	84,721	Not available	238,979,246* (total)	244,663,410
Animals slaughtered in provincially licensed facilities (heads, 2019)	99,561	368,267	266,946	225,377		
Average % P flows through meat products (2006 - 2020)	30.31	35.11	0.51	0.10	33.97	100
P flows through meat products in t (2019)	**2,145**	**2,485**	**36**	**7.4**	**2,404**	**7,077**

* Data for poultry are reported in aggregate rather than separately by provincial and federal licensed facilities

Slaughterhouse Waste



The waste from the slaughtering process is comprised of blood, internal organs, bones, and meat that is lost when processing the carcass. This slaughterhouse waste contains P and represents a significant flow from the livestock sector. Similar to the process of estimating P content for meat products, slaughterhouse waste was determined based on data reported by federally and provincially licensed slaughterhouse facilities in Ontario.

The amount of P from slaughterhouse waste is directly related to the amount of meat being produced and is determined based on the number and type of animal slaughtered. As previously noted, Table 8 shows the average weight for the live warm carcass of different animals. It is assumed that the difference between live weight and meat weight is slaughterhouse waste. The P content of slaughterhouse waste is estimated proportionally to the weight of waste over the warm carcass weight.

Figure 16 shows outflows of between approximately 3,300 t/a and 4,000 t/a of P per year for slaughterhouse waste for each year between 2006 and 2020. Table 10 shows that in 2019 there was an estimated 3,797 t/a of P from slaughterhouse waste. The table also shows the number of animals slaughtered in federally and provincially licensed facilities and the total amount of P by animal type calculated for the same year. The percentage of the total contribution of P from meat for each type of livestock was calculated using an average from the years 2006 to 2020. P flows from slaughterhouse waste and meat are proportional, since both depend on the number of animals and their weight. Cattle and swine are the main contributors to the P flow associated with slaughterhouse waste.

Table 10. Phosphorus Flows from Slaughterhouse Waste

	Cattle	Swine	Sheep	Rabbit	Poultry	Total
Animals slaughtered in federally licensed facilities (heads, 2019)	628,366	4,010,926	84,721	Not available	238,979,246 (total)	244,663,410
Animals slaughtered in provincially licensed facilities (heads, 2019)	99,561	368,267	266,946	225,377		
Average % P flows through slaughterhouse waste (2006 - 2020)	58.53	16.36	1.11	0.19	23.81	100
P flows through slaughterhouse waste in t (2019)	2,222	621	42	7.3	904	3,796.6

3.3.2 Crop Production Sector

This section outlines the P flows related to crops grown in open fields (i.e., field crops, forage crops, fruits, and vegetables) and those grown in greenhouses. P inputs associated with the growth of crops are primarily from synthetic fertilizer and manure application to croplands, while outputs are related to P uptake by crops or P loss from agricultural fields via runoff or soil erosion.

While most of the P found in grains, beans, beets, and potatoes is transferred to humans in the form of food products, a fraction of the corn produced is used for ethanol production, while silage and forage are provided to animals for consumption. As previously noted, a portion of the P applied to croplands in manure and synthetic fertilizer is not taken up by plants and remains in the soil. Crop residues (i.e., straw and stover) are commonly left in the field after harvest where the P contained in them are recycled back to the soil.

Figures 17 shows the inflows and outflows associated with open field crops for 2019. The most significant P inflows are those related to fertilizer application in open fields, while the main outflows are related to P in grains, beans, beets, and potatoes, silage and forage, and that remaining in the soil (i.e., legacy P not taken up by crops). The P losses from agricultural fields include both surface and subsurface losses, for a total of 5,022 t/a. The total P inflows were approximately 86,368 t/a, with 55,785 t/a in the form of synthetic fertilizers and 30,583 t/a through manure applied to open fields. The P associated with manure as an inflow to the crop production sector is assumed to be equivalent to the amount of the outflow identified in the livestock sector (i.e., 30,583 t/a).

Figure 17. Phosphorus Flows for the Ontario Crop Production Sector (2019)

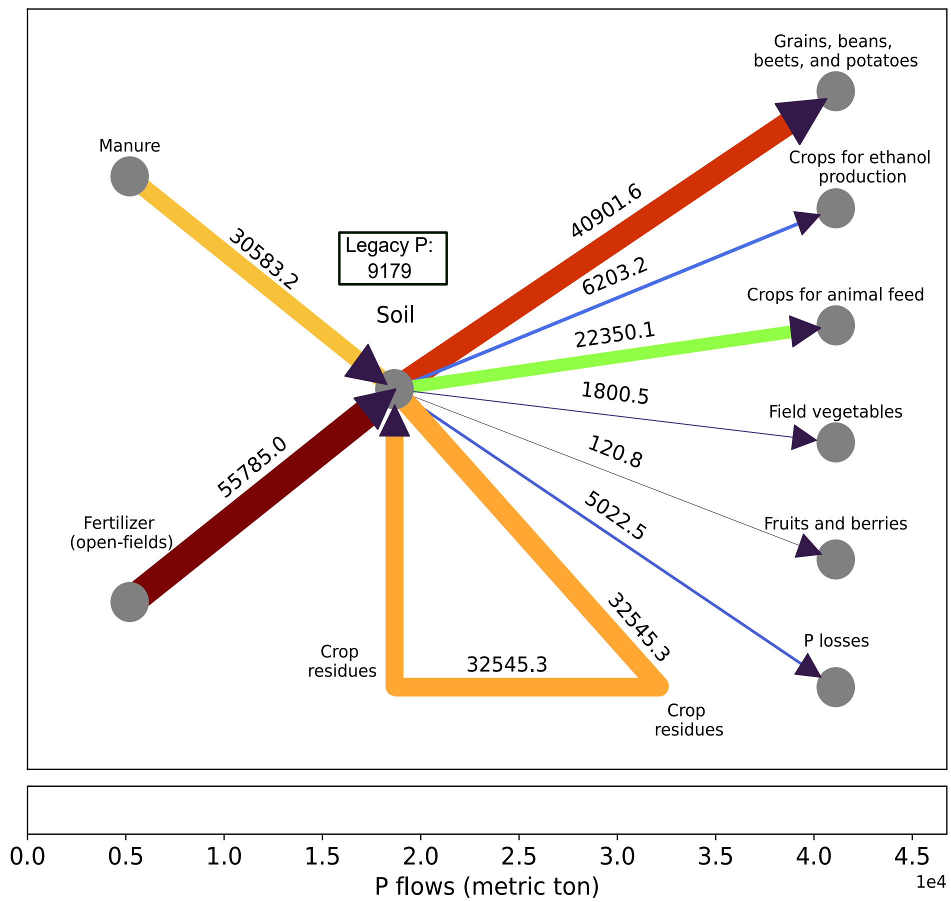
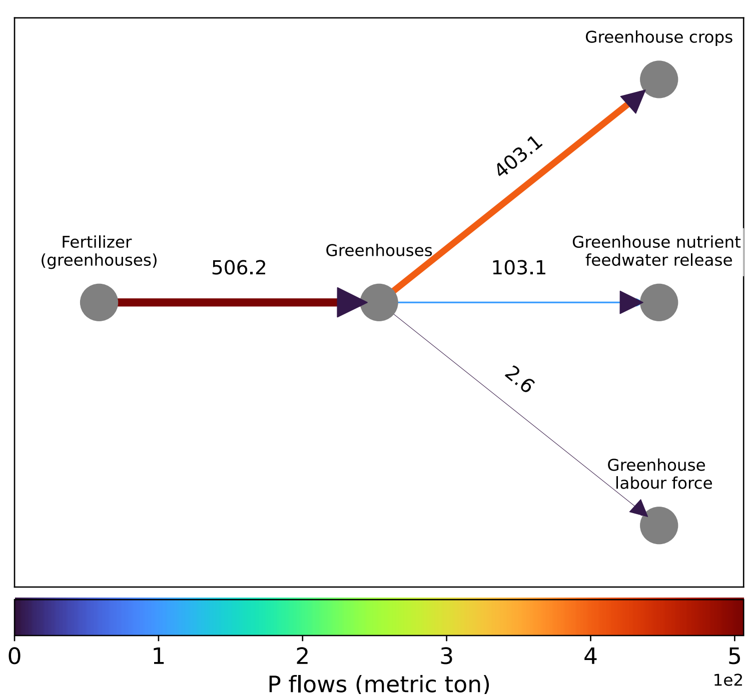


Figure 18 shows P flows related to greenhouses. P losses to water are estimated at 106 t/a and include P releases from GNF systems, and those from septic tanks in dwellings inhabited by the labour force in the vicinity of the greenhouses.

Figure 18. Phosphorus Flows for the Ontario Greenhouses Sector (2019)



Manure

As previously noted, manure is a by-product of livestock production and a key source of P for the growth of crops. The use of manure as a fertilizer for crop production is a beneficial way to reuse P and other nutrients within the agricultural sector and is a common manure management practice. Livestock operations tend to be located on or nearby large areas of productive agricultural land where manure can be applied and where it has been shown to contribute to improvements to soil tilth, aeration and water holding capacity. However, not all of the P found in manure is taken up by crops, contributing to a build-up of P in some areas and a greater potential for its release into the environment. Figure 17 shows the inflow of P in manure to the crop production sector to be approximately 30,583 t/a, which as is equivalent to the estimated outflow from the livestock sector.

Livestock manure is typically applied in solid, semi-solid, or liquid forms. While solid manure is often used for bedding, the liquid can be applied to crops. However, manure is bulky and expensive to transport, which is a key challenge for its redistribution to P-deficient areas. Manure can also be composted to reduce pathogens, bulk and odor, while making it easier to handle. Compost can be applied more evenly and with better control than manure and the availability of P (and most other nutrients) is similar to, but often less than, the availability in fresh manure. Compost is also less expensive to transport given its lower moisture content and higher market value.[98]

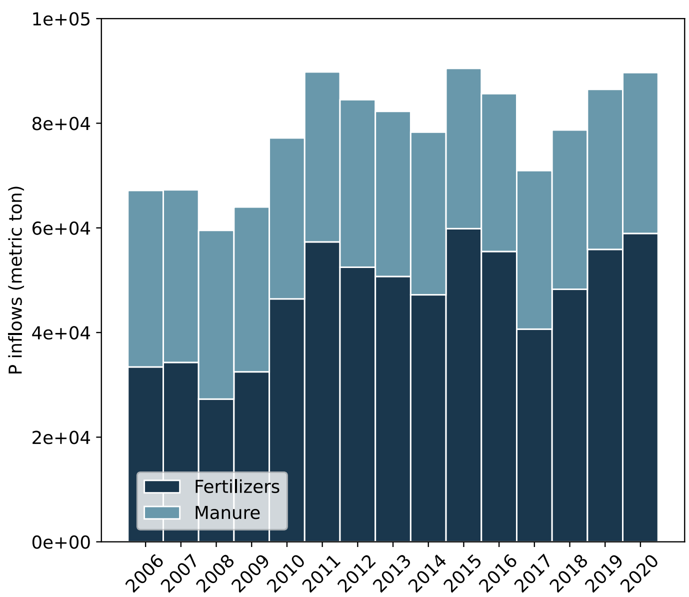
Field Crops, Forage Crops, Fruits and Vegetables

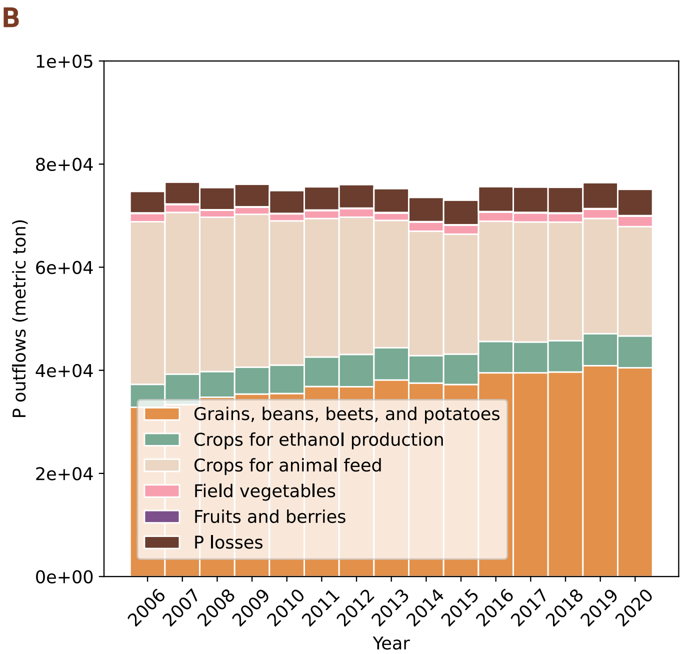
For each open field crop, the amount of P was divided according to whether it was the grain, fruit or vegetable, or straw and stover component of the plant. This was necessary to determine the amount of P for different flows since grains, fruits and vegetables become food or feed, while straw and stover remain in the field after harvesting as crop residues. Specific yield and P content values reported for open field crops are found in Appendix C. It is estimated that the 33% of Ontario's corn production is used for ethanol production.[99]

Figure 19 shows the inflows, uptake, and release of P to the soil related to open field crops from 2006 to 2020. P inputs in the form of manure and synthetic fertilizers are applied in approximately equal quantities across this timeframe.

Figure 19. Phosphorus Inflows (A), Outflows (B), and Crop Residues (C) for Open Field Crops (2006 to 2020)

A





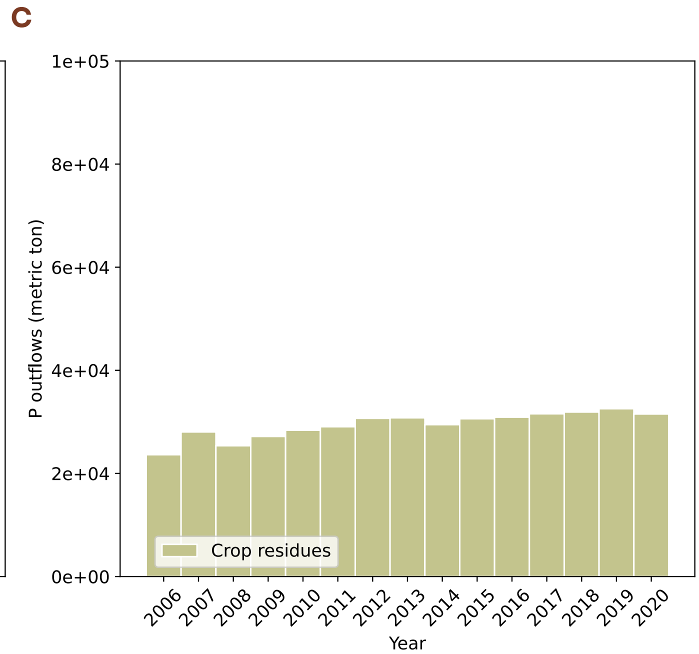
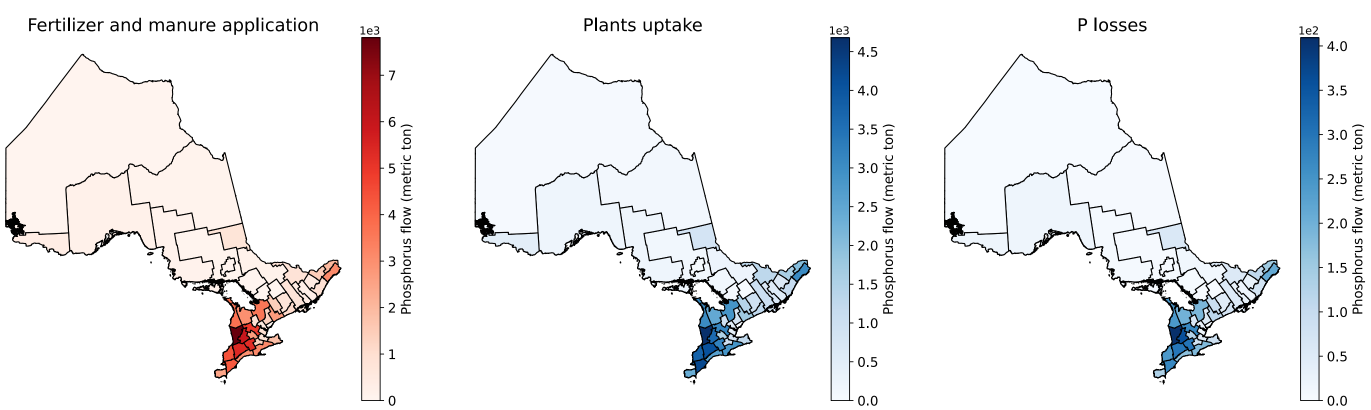
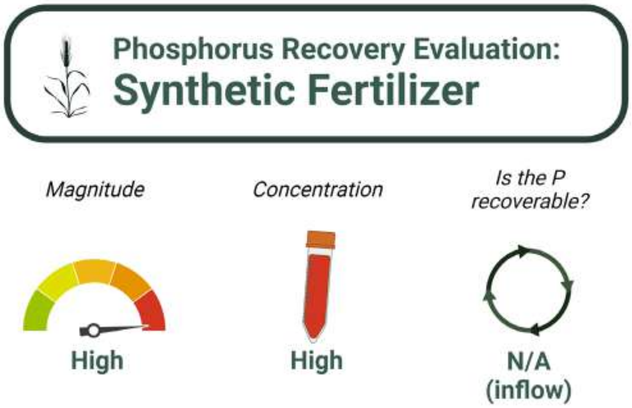


Figure 20 shows the geographic distribution of P flows for open field crops, including grains, beans, beets, and potatoes, field vegetables, fruits and berries, and silage and forage. The figure is organized according to P associated with the application of synthetic fertilizers and manure, taken up by crops, and left in the soil (i.e., P not taken up by crops and from straw and stover remaining in the field after harvest). P flows related to crops grown in open fields are concentrated in southern Ontario and more specifically, the census divisions where agricultural activities are most intensive. It should be noted that these census divisions are located in close proximity to the Great Lakes, increasing the risk of P being transported to the lakes.

Figure 20. Geographic Distribution of Phosphorus Flows for Open Field Crops by Census Division (2019)



Synthetic Fertilizer Application for Open Field Crops

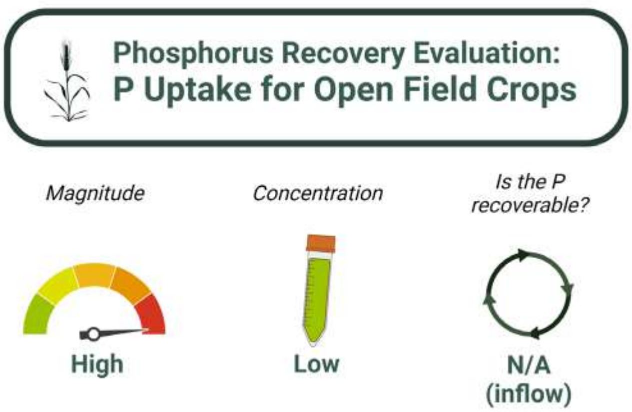


The application of synthetic fertilizers represents a major inflow of P in the agricultural sector, and more specifically the crop production sector. As shown in Figure 17, P inflows from synthetic fertilizers applied to open fields are estimated to be approximately 55,785 t/a in 2019.

For the purposes of this study, P in fertilizer applied to open fields in Ontario is estimated based on the amount of fertilizer products traded to Ontario's agricultural markets containing P, as reported by Statistics Canada.[100] A limitation of this approach is that it assumes that the P content of fertilizer is similar, regardless of the type of crop it is applied to.

The amount of P in fertilizer applied to open field crops in each census division, shown in Figure 20, was determined based on the fraction of fertilizer area in each census division (i.e., dividing the reported area of land fertilized for each census division by the total fertilized area of land in Ontario).[101, 102] Those areas that correspond with greenhouse crops for each census division were then removed.[103] These calculations were performed using data from the 2016 Census of Agriculture.

Phosphorus Uptake for Open Field Crops



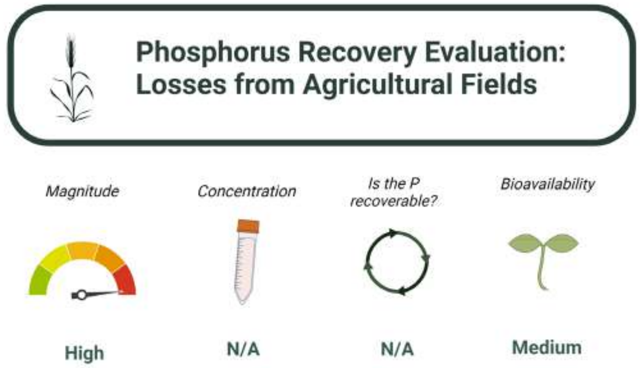
The amount of P that a plant requires differs between species and can depend on soil conditions. The uptake of P by crops in Ontario was determined based on the area used to grow each type by census division[104, 105, 106] and its yield[107, 108] multiplied by the specific P content for each crop type.[109, 110] It should be noted that for certain crop products, particularly fruits and berries, production data is directly reported[111] , simplifying the calculations required.

Figure 19 shows that the majority of P uptake is by crops categorized as grains, beans, beets, and potatoes, which increased steadily over time as a result of an expansion of the cultivation area for these crops in the province, as well as improved yields. Silage and forage crops also take up a large amount of P when compared to other open field crops, however a downward trend can be observed over time. The overall amount of P remaining in the soil (i.e., legacy P) is shown to have increased slightly over time.

For 2019, P uptake in crops included a total of 40,902 t/a attributed to grains, beans, beets, and potatoes, 6,203 t/a to crops for the production of ethanol, and 22,350 t/a attributed to crops for livestock feed. In addition, 32,545 t/a of P were taken up by the straw and stover fractions of crops and released back into the soil as crop residues. P in agricultural residues was plotted separately since it represents an internal flow of the cropping system.

Phosphorus Losses

As previously noted, P in agricultural soils can be lost through erosion, runoff or drainage, which can be affected by a range of factors, including the amount of synthetic fertilizer or manure applied, soil composition and texture, slope and precipitation, resulting in a complex and data-intensive process for estimating P losses from crop fields. For the purposes of this report, a rough estimate for P was determined based on the assumption that all agricultural fields in use have some type of fertilizer applied, either synthetic or manure. P loads of 1.115 kg/ha/year were assumed for agricultural fields fertilized using synthetic fertilizers[112], while 2.242 kg/ha/year was assumed for fields with liquid manure and 1.511 kg/ha/year for fields with solid manure.[113]

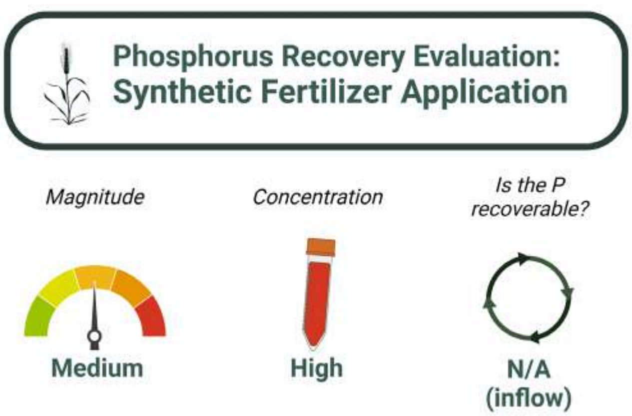


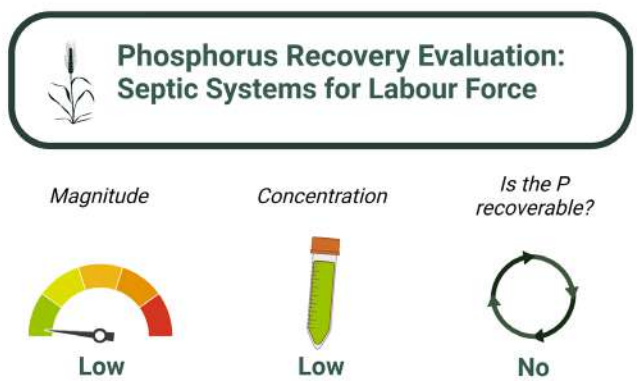
These P loads were calculated for subsurface P losses, which account for 96% of the P losses for free drainage fields, and about 68% of losses for fields with tile drainage.[114] Approximately 1,065,418 ha of the agricultural fields in Ontario are equipped with tile drainage systems[115], while 2,374,506 ha are agricultural fields with free drainage.[116]

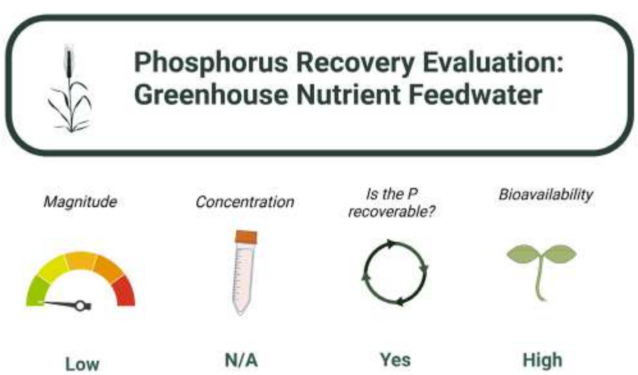
Approximately 12% of P runoff in agricultural soil in Ontario is attributed to surface runoff, while the remaining is considered subsurface runoff. However, P load coefficients are only available for subsurface runoff. For the purposes of this report, the subsurface P load coefficients were corrected by 12% to account for the surface runoff. Runoff associated with fields fertilized by synthetic fertilizers accounted for 1.267 kg/ha/year, while liquid manure was approximately 2.548 kg/ha/year, and solid manure was 1.717 kg/ha/year.

The corrected P load coefficients were then multiplied by the total area fertilized with synthetic fertilizer[117], and the total area where liquid and solid manure were applied[118] in each census division to obtain an estimation of the P lost from agricultural land. Based on this approach, P losses from croplands for 2019 are estimated to be approximately 5,022 t/a, (see Figure 17).

Greenhouse Crops







Due to the limited availability of data to estimate the amount of synthetic fertilizer used in greenhouses in Ontario, the amount of P applied in the form of synthetic fertilizers is estimated to be the sum of P uptake by greenhouse crops (i.e., tomatoes, peppers, and cucumbers)[119] and the P releases from GNF systems. As with P uptake by crops grown in open fields, uptake in greenhouses was estimated by multiplying data on the production of tomatoes, peppers, and cucumbers in Ontario[120] by the P content for each respective vegetable type.[121, 122]

The P outflow from GNF systems was calculated by multiplying the average concentration of P in GNF outlet streams (33.6 mg/L[123]), and the water discharges from GNF systems.[124] It was assumed that the water discharged from GNF systems is equivalent to 25% of the total water applied in greenhouses, corresponding with the worst-case scenario of no water recirculation in the GNF system. The average water consumption in greenhouses in Ontario was assumed to be 1,000 L/m^2/year.[125] As a consequence of the scarcity of data, this approach assumes that the average values for P concentration and water consumption found in studies conducted in greenhouses in certain regions of Ontario can be extrapolated across the province. Further studies extending the spatial scope and providing up-to-date measurements are necessary for more accurate estimations.

The labour force in Ontario greenhouses is estimated to be approximately 3,451 year-round workers and 6,699 seasonal workers.[126] For the purposes of this report, the average length of time spent by seasonal workers is assumed to be 25 weeks.[127] It is assumed that only seasonal workers live in households in the vicinity of the greenhouses that may use septic systems. An average P load rate of 0.0156 kg P/person/week for septic systems was used to estimate the P flow from these households.[128]

Figure 21 shows P used for greenhouse crops between 2006 and 2020. There has been a steady increase in P applied over time as a result of the increase in the production of vegetables grown in greenhouses in Ontario.[129] For 2019, the P applied in greenhouses in the form of synthetic fertilizers is estimated to be approximately 506 t/a. P outflows within greenhouse crops are approximately 403 t/a, while P releases from the GNF systems and septic systems are 103 t/a and 2.6 t/a, respectively.

Figure 21. Phosphorus used (t/a) for Greenhouse Crops (2006 to 2020)

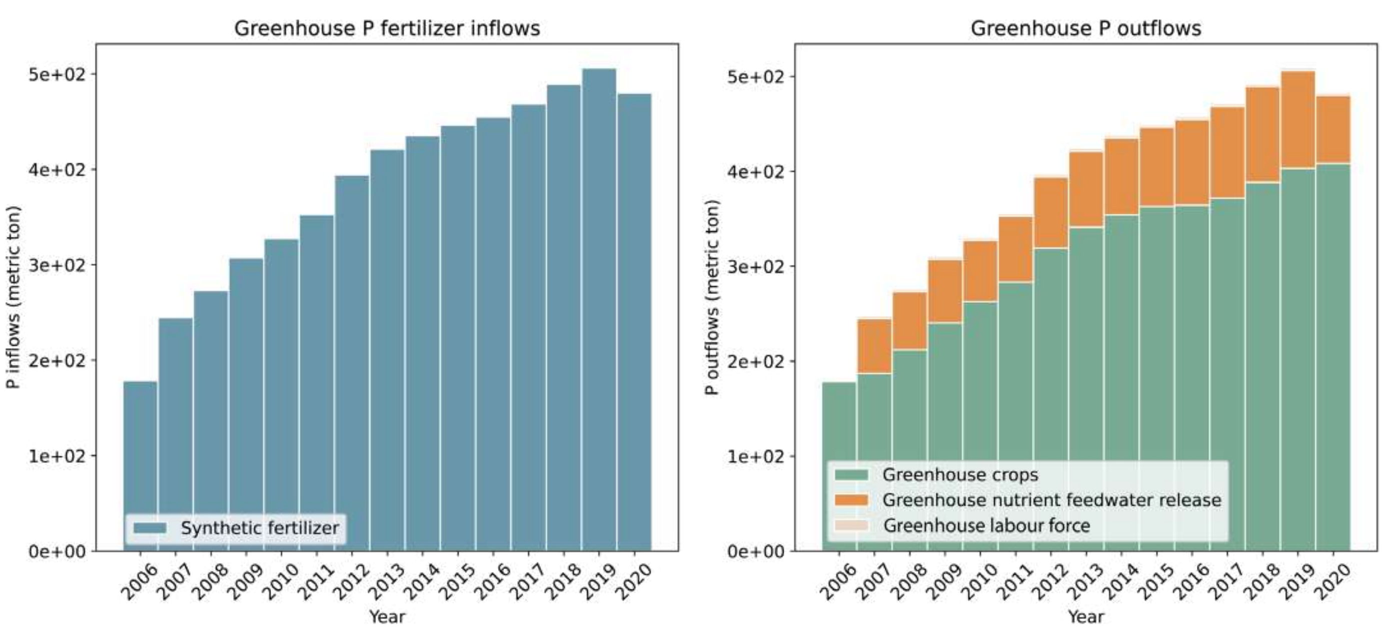
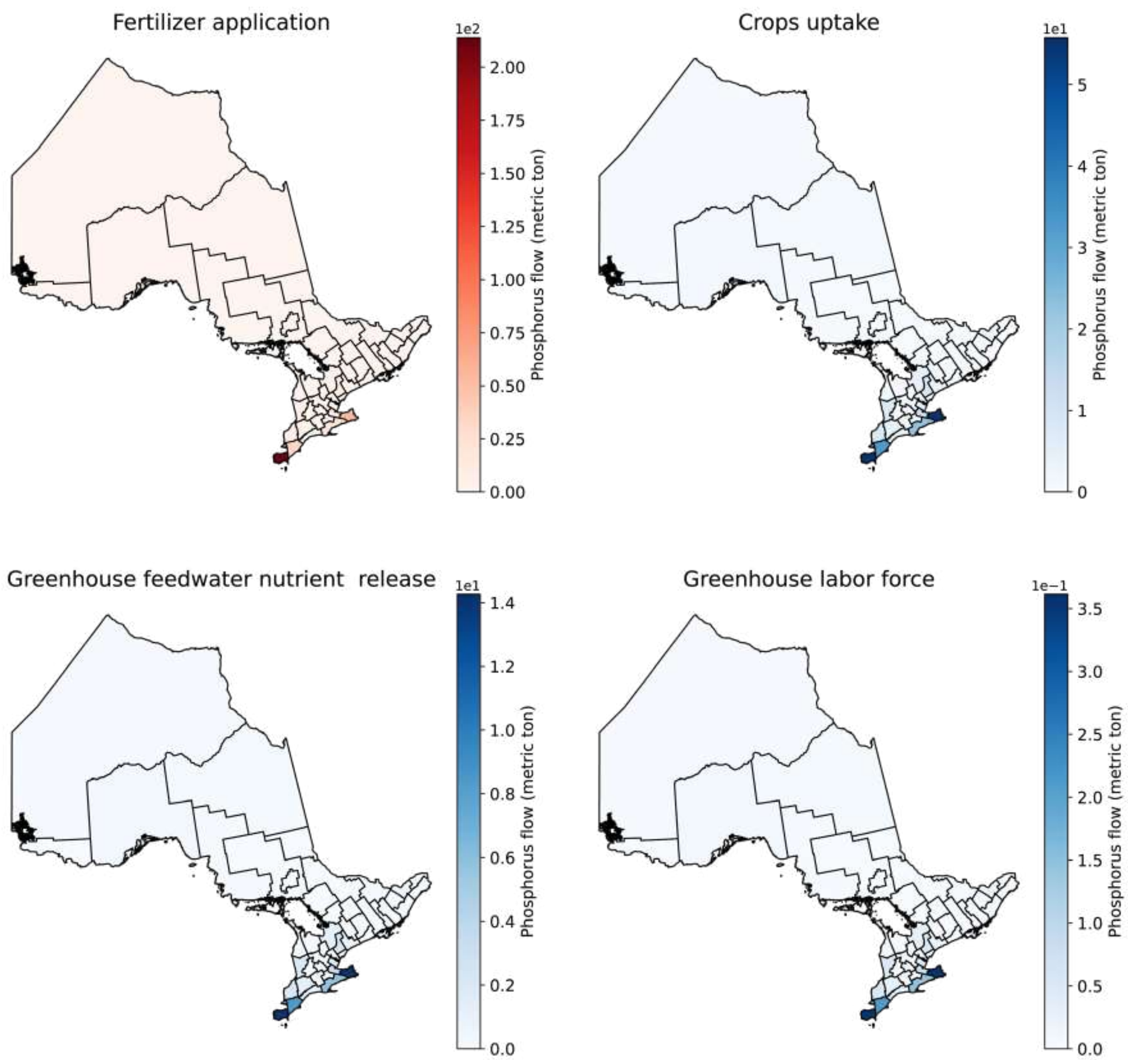


Figure 22 shows the geographic distribution of P from fertilizer application in greenhouses across the province based on the area determined to be devoted to greenhouse crops for each census division.[130] P flows related to greenhouse crops are highly concentrated in a few regions in southern Ontario where the majority of the province's greenhouses are located.[131]

Figure 22. Geographic Distribution of Fertilizer used in Greenhouses by Census Division (2019)



Legacy Phosphorus in Ontario's Agricultural Soils

Crop production over sustained periods of time requires the continuous application of P to the soil in the form of synthetic fertilizer or manure. It is typical for P to be applied in greater quantities than crops require to ensure satisfactory yields.[132] As a result, a fraction of the P supplied for crop production is not taken up by the plants and remains in soil, resulting in the accumulation of P over time. This buildup is often referred to as "legacy P".

P losses from agricultural soils have been shown to be a key source of nutrients found in local waterbodies.[133] Agriculture and Agri-food Canada's Soil Landscapes of Canada study[134] conducted for the years 1981 to 2016, measured the concentration of soluble P accumulated in the surface layers of agricultural soils. The study area did not cover all of the province but did include the province's main agricultural areas in southern Ontario.

Figure 23 shows the average concentration of soluble P for the agricultural soils studied. From 1981 to 2004, the amount of accumulated P increased steadily, before decreasing between 2004 and 2009. The average soluble P concentration remained relatively stable between 2010 and 2016. Figure 24 shows the geographic distribution of soluble P for the most recent year of the study (2016). The geographic locations with the highest concentrations of P in soil are found in the south of the province, where most of Ontario's crop production occurs, and in the Thunder Bay area.

Figure 23. Average Concentration of Soluble Phosphorus in Agricultural Soils in Ontario (1981 – 2016)

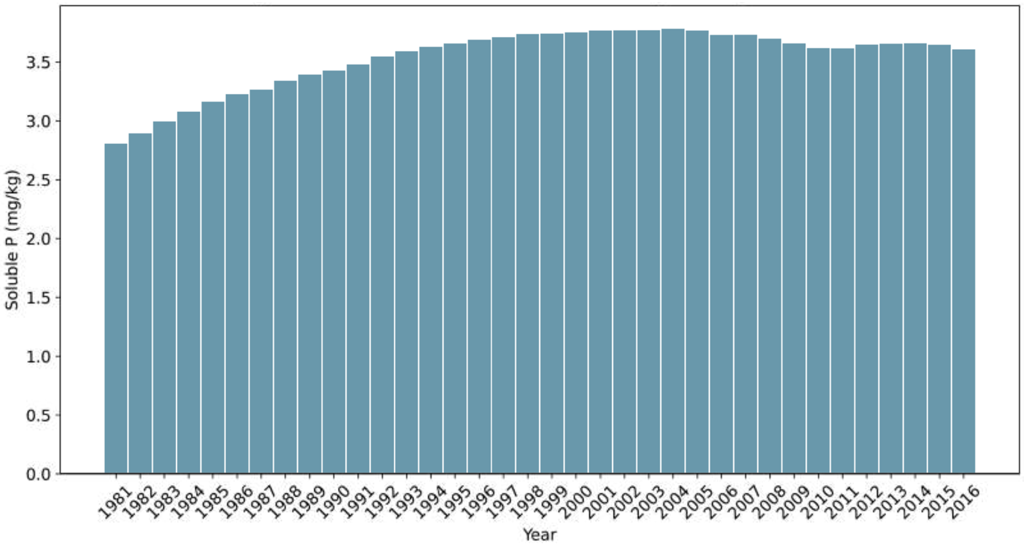
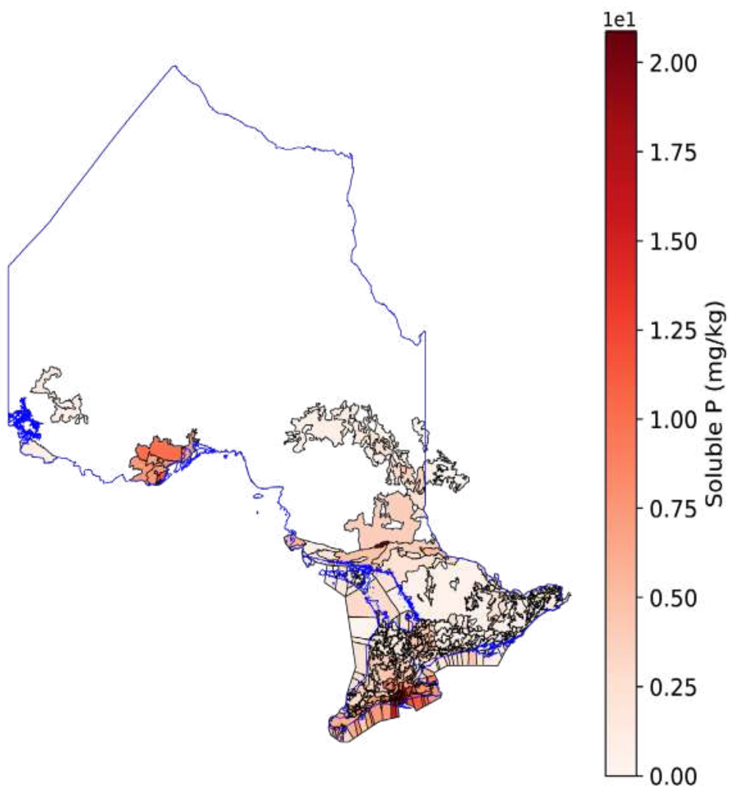
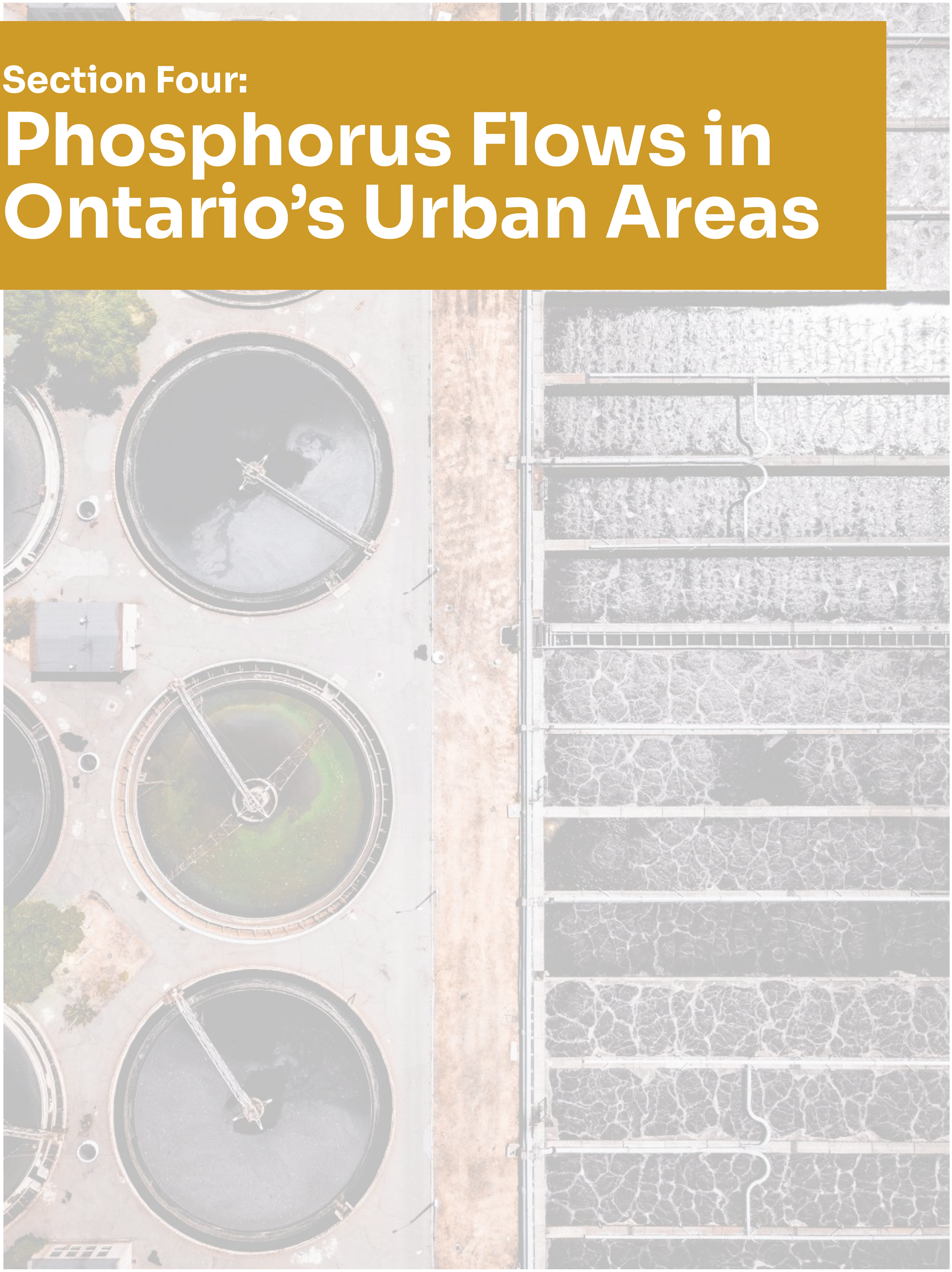


Figure 24. Geographic Distribution of Soluble Phosphorus Accumulated in Agricultural Soils in Ontario (2016)



Section Four:
Phosphorus Flows in Ontario's Urban Areas



Phosphorus Flows in Ontario's Urban Areas

Urban areas are known as P "hot spots", where there is a demand for P-rich organic products and an accumulation of the associated waste.[135] As the population continues to grow in municipalities across Ontario, cities will play an increasingly important role in provincial and regional P cycles and provide important opportunities for NRR.

P flows related to urban areas include those from municipal WWTPs, septic systems, organic food and waste, and stormwater runoff. This section focuses primarily on those flows associated with municipal WWTPs as they have been identified as being some of the most significant in Ontario. While there is substantial potential to recover P from anthropogenic waste streams, including wastewater effluent and food and organic waste, only a fraction of available P is currently recovered and reused. It should also be noted that while there are similarities across urban areas, each has its own unique set of factors influencing how P moves through the area and as a result, opportunities for NRR may vary. This section also explores where P flows from urban areas are distributed throughout the province, which can shed light on where to prioritize NRR strategies in the near-term.

4.1 Methodology

The methods used to calculate the P flows from the municipal wastewater treatment sector relied on data reported by WWTPs on their disposals, transfers and releases. In some cases, these numbers were upscaled to account for releases from facilities not required to report emissions. Wastewater effluent data was then used for the purpose of validating the P flow estimates.

4.1.1 Key Data Types and Sources

Municipal Wastewater Treatment Plants

National Pollutant Release Inventory (NPRI): The main data source used to determine P flows for WWTPs is the NPRI— a national public inventory of releases, disposals and transfers of pollutants, overseen by ECCC. The NPRI reports on over 320 pollutants, including P, from more than 7,000 facilities across the country, including manufacturing facilities, mines, oil and gas operations, power plants and WWTPs.[136] Information is collected on releases of different pollutants, including P, to air, water or land, and disposals and transfers at facilities and other locations. A key challenge with the use of this dataset is that only those facilities that meet NPRI requirements report their pollutant emissions. Therefore, it was necessary to develop a scaling process to calculate the amount of P potentially generated by non-reporting facilities.

Wastewater Systems Effluent Regulations (WSER): Developed under the Fisheries Act, these regulations came into force in 2012 to manage wastewater releases by facilities that collect an average daily influent volume of 100 cubic metres or more.[137] The WSER sets a national baseline for effluent quality standards achievable through secondary wastewater treatment and outline specific requirements for effluent monitoring and reporting. This database contains information submitted by owners and operators of Canadian wastewater plants at the federal, provincial, and municipal level, on effluent, suspended solids, and carbonaceous biochemical oxygen demand. Data is available for the year 2013 onwards for more than 430 WWTPs in Ontario, identified by name and geographic coordinates. This dataset was used to obtain effluent data from all of the WWTPs in the province to complement and scale up the data reported to the NPRI.

Municipal Treated Wastewater Effluent (MTWE)[138] **:** The MTWE is a provincial dataset that contains annual reports with water quality data and effluent levels for municipal WWTPs in Ontario. Data is available from 2008 onwards and includes the volumetric water flows and/or P released in effluent. The initial intention was to use this dataset as the main source of information to estimate P flows for this sector, however the data includes only the municipality name as an identifier and not the coordinates for each facility. This created challenges with determining facility locations around the province and where these P flows are generated. In addition, the MTWE only provides information about releases, and does not specify the amount of P disposed of, or transferred to, another facility. Instead, the MTWE was used to validate the P flows calculated using data from the NPRI.

Food and Organic Waste

OMAFRA was the main source of publicly available data for food produced in Ontario for sale. These food masses, and the food chain loss factors published by the Food and Agriculture Organization of the United Nations (FAO) for North America at each processing step (i.e., production through handling/storage, processing, distribution, and consumption) were used to estimate the agricultural masses that generated the reported food amounts. However, it should be noted that these factors may not accurately reflect the realities in Ontario food production. Food import and export masses were collected from national trade data and scaled for Ontario with population data. The Canadian Nutrient File[139] provided P concentration values for the different food types.

Septic Systems

Demographic, Social and Economic Data: Data from the Households and the Environment Survey reported by Statistics Canada was used to determine the number of households using a septic system in Ontario. However, the geographic distribution of households with a septic system is not provided through this survey.

Scientific Literature: Data reported in the scientific literature was used to obtain the average P load from septic tanks. This value is based on a specific region in Ontario however, due to the scarcity of data available, it was assumed that it is representative across the province. The use of an average P load from septic tanks reported for a certain region of the province, as well as the estimation of people living in households with septic systems based on the average population of each household in Ontario, are significant sources of uncertainty for this study, resulting in a rough estimation of P flows from septic systems.

Stormwater

Scientific Literature: There is a lack of data for the province related to both the amount of stormwater and the concentration of P associated with its contents. P flows associated with urban stormwater were estimated using a P export coefficient capable of describing the flow of P through a particular stream per unit of area. For the purposes of this study, it was assumed that the export coefficient estimated for the Bay of Quinte area of the province could be extrapolated to the entire province of Ontario. This simplified approach was necessary due to the complexity of estimating P flows associated with stormwater. The use of an average export coefficient for the entire province results in a significant level of uncertainty, since the unique geographic characteristics of different regions (e.g., land use, slope, design of drainage systems, etc.,) are not captured.

4.2 Municipal Wastewater Treatment Plants

Municipal WWTPs concentrate and treat a combination of sewage, surface runoff and other wastewater from residential, industrial, commercial, and agricultural activities. These facilities have incremental stages of treatment, known as primary (removal of suspended solids and organic matter by physical and/or chemical processes), secondary (removal of suspended solids and organic matter by biological processes), and tertiary (removal of substances of concern – solids, nutrients, and contaminants by physical, chemical, and biological processes). WWTPs can vary significantly in size, type of wastewaters and the technologies that they employ to treat them.

In 2017, 12 million people (89.1% of the population) in Ontario were reported to be serviced by municipal WWTPs. This included 0.3% of the population serviced by primary treatment systems, 50.4% serviced by secondary treatment systems, and 38.4% serviced by tertiary treatment systems. Due to variable treatment efficiencies and the large volume of influent (i.e., pre-treatment), municipal wastewater effluent (i.e., post-treatment) is a prominent point-source of P into aquatic environments.

To meet dissolved phosphate regulations, WWTPs in Ottawa, Toronto and possibly other facilities, add soluble iron chloride to their treatment process. Precipitation of insoluble iron phosphate reduces the dissolved phosphate concentration and adds phosphate to the solid waste stream. The significant P waste flows from municipal WWTPs are a potential opportunity to recover and reuse P as a more effective agricultural nutrient. However, iron phosphate is not a readily bioavailable plant nutrient.[140, 141, 142, 143]

This section outlines two approaches used to determine P flows associated with WWTPs, providing an opportunity to compare and validate findings.

4.2.1 Method One: Upscaling to Determine Phosphorus Disposals

For the purposes of determining P flows associated with WWTPs, an upscaling method was developed using data from facilities reporting to the NPRI and an estimate for facilities not reporting to the NPRI. This method and the results of the analysis are explored in further detail herein.

Methodology

The following data sources were used to determine P for WWTPs:

National Pollutant Release Inventory (NPRI)[144]: Reporting facilities are identified by a six-digit North American Industry Classification System (NAICS) — an industry classification system developed by statistical agencies in Canada, Mexico and the U.S. to provide common definitions and a framework for economic analysis — code (level 5 classification), their geographic coordinates, and number of employees.

The NPRI includes reported data on the following:

- **Releases:** refers to direct discharges of pollutants to the environment (air, water, land, other).
- **Disposals:** management of substances on-site or off-site to limit their release, including via landfill, land application and underground injection.
- **Transfers:** quantities sent elsewhere for recycling, energy recovery or treatment before final disposal.

Opportunities for recovery and reuse primarily lie in quantities that have been disposed of or released. As such, the data presented in this report focuses on disposals and releases, with the exception of where transfers are used as part of the upscaling method.

Wastewater Systems Effluent Regulations (WSER): Since this dataset contains information from all of the province's WWTPs, it was used to obtain effluent data from these facilities, and to complement and scale up the data reported to the NPRI.

Municipal Treated Wastewater Effluent (MTWE)[145]: This data was used to validate the amount of effluent and P released to waterbodies as part of the upscaling method.

The following steps were taken for the upscaling process:

Determining P quantities from facilities reporting to the NPRI:

1. The first step involved analyzing data from facilities reporting to the NPRI. Releases, disposals, and transfers from WWTPs corresponding to NAICS code 221320 (i.e., "Sewage treatment facilities") were summed and aggregated by year and according to census division.

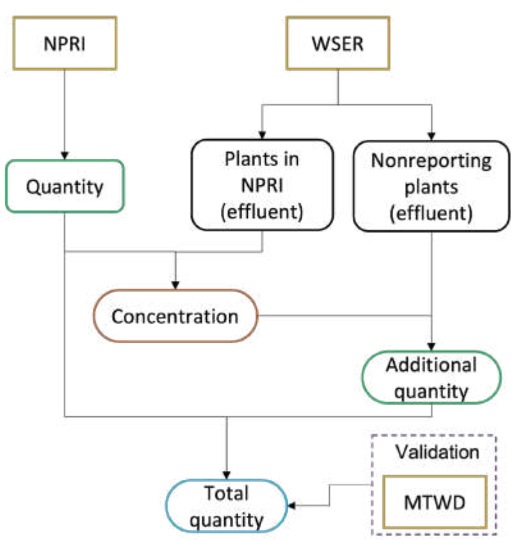
Determining P quantities for facilities not reporting to the NPRI:

2. WWTPs reporting to the NPRI were matched against those reporting to the WSER database.
3. Effluent data from the NPRI reporting facilities and the non-NPRI reporting facilities found in the WSER were summed and aggregated by year and according to census division.
4. P concentrations were calculated based on the mean of quantity for releases, disposals, or transfers from step 1, divided by the mean of effluent for those facilities in the WSER database that also report to the NPRI from step 3. This concentration was calculated for each year and by census division. Those census divisions with no facilities reporting to the NPRI were assigned the mean concentration value for the province for that year.
5. Additional P quantities released, disposed of, or transferred, were calculated by multiplying the concentrations determined in step 4 and the effluent of facilities not reporting to the NPRI identified in step 3.

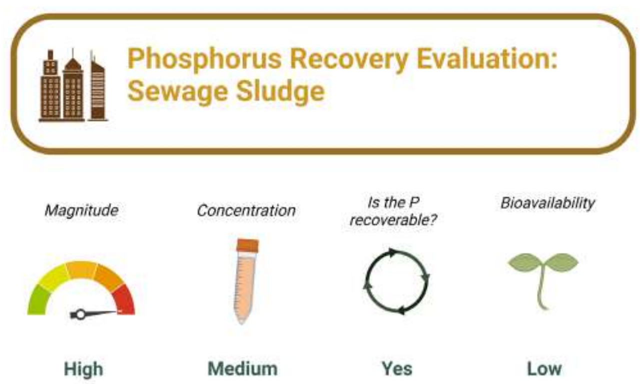
Determining and validating P quantities for all facilities:

6. The total quantity released, disposed of, or transferred was determined by adding the totals from step 1 and step 5 for each year and by census division.
7. To validate these calculations, both P releases to water and the amount of effluent reported by facilities in the MTWE were compared with the values obtained in step 6.

Figure 25. Upscaling Method for Determining Phosphorus Flows from Wastewater Treatment Plants*



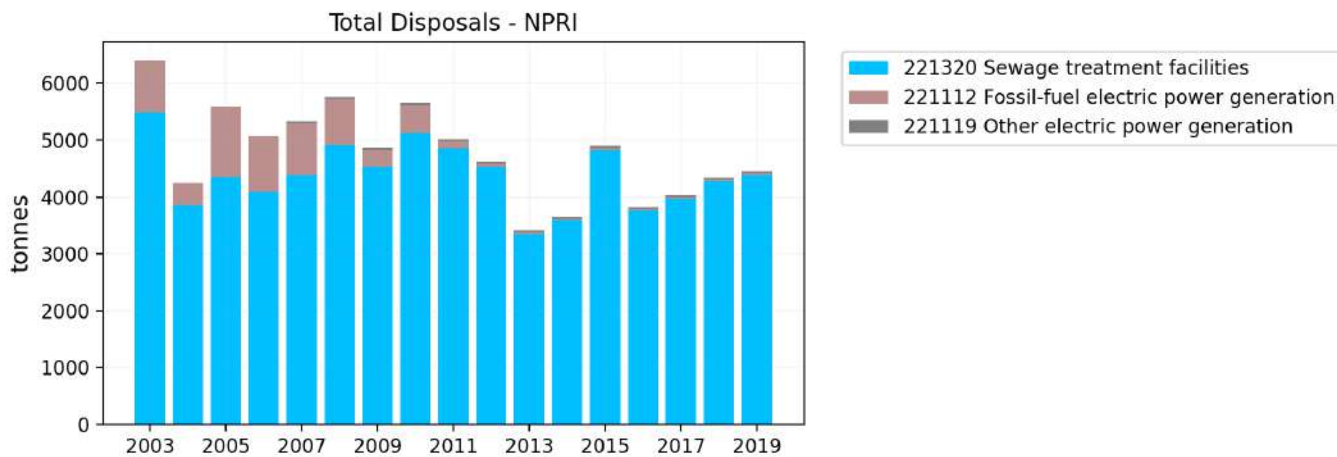
*Note: quantity refers to disposals, releases, and transfers



Phosphorus Outflows from Municipal Wastewater Treatment Plants

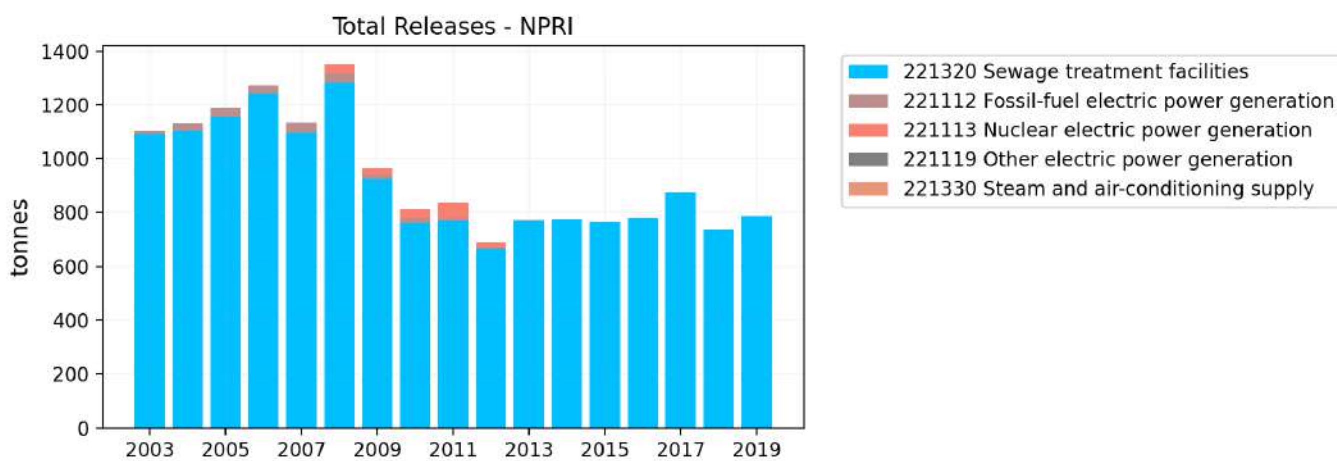
WWTPs are by far the most significant contributor to P disposals and releases in urban areas in Ontario. Figure 26 outlines P disposal quantities as reported to the NPRI, pointing to an upward trend initially, followed by a downward trend, before slowly increasing over the last seven years. Figure 27 shows that releases followed a similar trend with quantities increasing for the first five years, decreasing for the next four and leveling off in the last seven years.

Figure 26. Total Disposals from the Utilities Sector in Ontario Reported to the NPRI



*Note: "sewage treatment facilities" is the NAICs category used for municipal WWTPs

Figure 27. Total Releases from the Utilities Sector in Ontario Reported to the NPRI



*Note: "sewage treatment facilities" is the NAICs category used for municipal WWTPs

Upscaled Disposals of Phosphorus

In 2019, the upscaled total disposals of P from WWTPs were approximately 5,491 t/a, of which 99% were reported to be off-site, and the remainder were on-site. This quantity aligns with estimations of TP disposed of through incineration or to landfill (i.e., 6,000 t/a, ±1,200 t) found in previous studies.[146] However, the large proportion of off-site disposals points to the potential for double-counting the quantity of total disposals. This may occur where one WWTP sends P to another for disposal. Therefore, the upscaled total should be considered an upper bound when looking at potential opportunities for recovery and reuse measures for P disposals at WWTPs.

Table 11 shows P flows associated with disposals from WWTP according to census division. The most significant disposals occur in large, more densely populated areas, such as Toronto and Hamilton.

Table 11. Phosphorus Disposals from Wastewater Treatment Plants by Census Division (2019)

Location	Phosphorus (t/a)	Percentage (%)
3520 – Toronto	1,570	28.63
3525 – Hamilton	1,110.1	20.22
3539 – Middlesex	312.3	5.69
3506 – Ottawa	283	5.15
3524 – Halton	273.9	4.99
3526 – Niagara	211.4	3.85
3543 – Simcoe	209.4	3.81
3558 – Thunder Bay	204.4	3.72
3530 – Waterloo	111.9	2.04
3538 – Lambton	105.5	1.92
Other census divisions	1,099.1	19.97
Total	**5,491**	**100.0**

Upscaled Releases of Phosphorus

In 2019, total upscaled P releases from WWTPs were approximately 900 t/a, of which 99.5% were to waterbodies, 0.33% to air, 0.11% to other media, and 0% to land. This quantity is in alignment with estimations for the release of P to the environment (i.e., 1,000 t/a, ±400 t) from previous studies.[147]

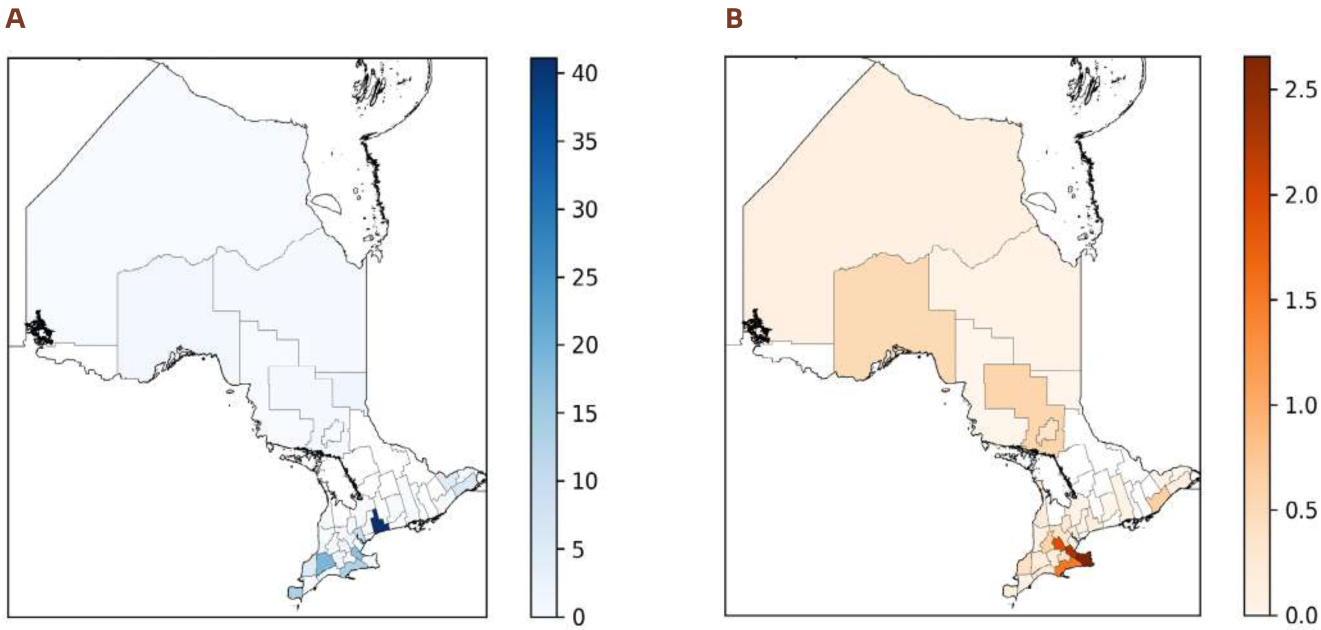
Table 12 shows P releases from WWTP according to census division. As with disposals, the most significant releases occur in locations with larger populations, including Toronto, Peel, Ottawa, and Hamilton.

Table 12. Phosphorus Releases from Wastewater Treatment Plants by Census Division (2019)

Location	Phosphorus (t)	Percentage (%)
3520 – Toronto	292.6	32.5
3521 – Peel	122.1	13.6
3506 – Ottawa	85	9.4
3525 – Hamilton	72.1	8.0
3518 – Durham	61.5	6.8
3526 – Niagara	31.4	3.5
3539 – Middlesex	30.6	3.4
3537 – Essex	25.6	2.8
3524 – Halton	20	2.2
3530 – Waterloo	11.8	1.3
Other census divisions	147.9	16.4
Total	**900.6**	**100.0**

Figure 28 shows the geographic location of upscaled disposals and releases from WWTPs by census division for 2019. The census divisions with the greatest potential for P reuse and recovery from WWTPs are located in southern Ontario and align with areas that have more significant population densities.

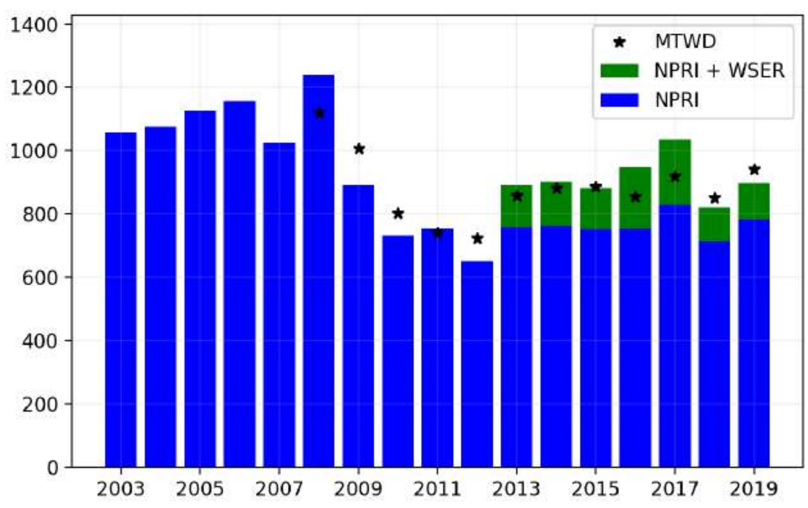
Figure 28. Total Upscaled Disposals (A) and Releases (B) of Wastewater Treatment Plants (2019)



Validation

As previously noted, data from the MTWE was used to validate the upscaled calculations for P quantities from WWTPs. Figure 29 shows P releases to water as reported to the MTWE, the NPRI, and the total from the upscaling method that includes the NPRI, and the non-NPRI reporting facilities found in the WSER (from 2013 onwards). The upscaling method provides an additional 12% to 20% of releases above those reported in the NPRI. These quantities are in agreement with those from the MTWE, indicating that the NPRI data captures the majority of the associated P flows.

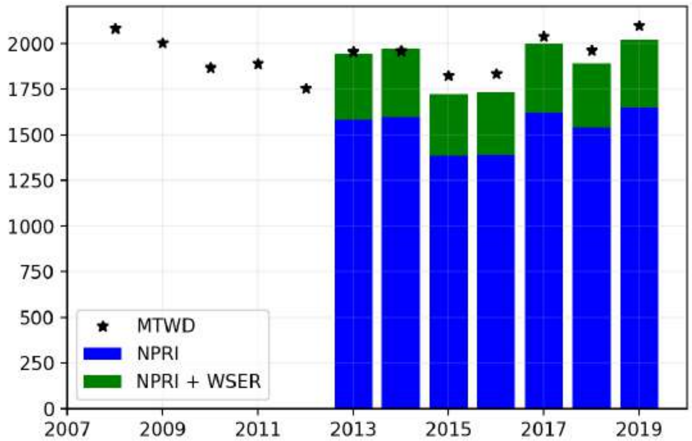
Figure 29. Phosphorus Releases to Water [tonnes]



*Data from the MTWE is available for 2008 onwards. Data from the WSER is available from 2013 onwards.

Figure 30 shows that there is also alignment between the amount of effluent reported to the MTWE and from the WWTPs reporting to the WSER (i.e., NPRI + WSER). The WTTPs that report to the NPRI account for roughly 80% of the total effluent in the province.

Figure 30. Effluent Reported by Wastewater Treatment Plants [million m³]



*Data from the MTWE is available for 2008 onwards. Data from the WSER is available from 2013 onwards.

4.2.2 Method Two: Phosphorus Waste from Municipal Water and Wastewater Treatment

A separate analysis of the data reported to the NPRI was also conducted as part of this study. As previously noted, there are a number of different ways in which to estimate P flows and highlighting where there is alignment or differences in the results is an important means of better understanding and validating the outcomes.

P emissions data from the NPRI for municipal WWTPs were sorted according to reported destination. For 2019, P emissions from all reporting Ontario industries was approximately 62,000 t/a. With just over 7,450 t/a of P emissions reported in total, municipal wastewater treatment is the second largest NPRI-reported sector after mining (52,500 t/a).

As previously noted, one challenge with interpreting P disposals and releases reported to the NPRI from municipal WWTPs is that some outputs are transported to other municipal WWTPs. Querying the NPRI database showed that approximately 670 t/a, or 9% of WWTP outputs were directed to other WWTPs. For this reason, the adjusted total P emission estimation for municipal WWTPs is approximately 6,800 t/a. Subtracting transfers between WWTPs, approximately 5,700 t/a is off-site disposal. This off-site disposal value includes ~ 1,000 t/a of P from York region's WWTP, which is reported to be transferred to cement processing.

Figure 31 shows P flows reported to the NPRI for 2019 that were transferred to land, likely as biosolids on farms, from municipal WWTPs. The Greater Toronto and Hamilton Area are shown to be where the most significant transfers occur.

Figure 31. Phosphorus Flows from Wastewater Treatment Plants to Land Treatment in t/a (2019)

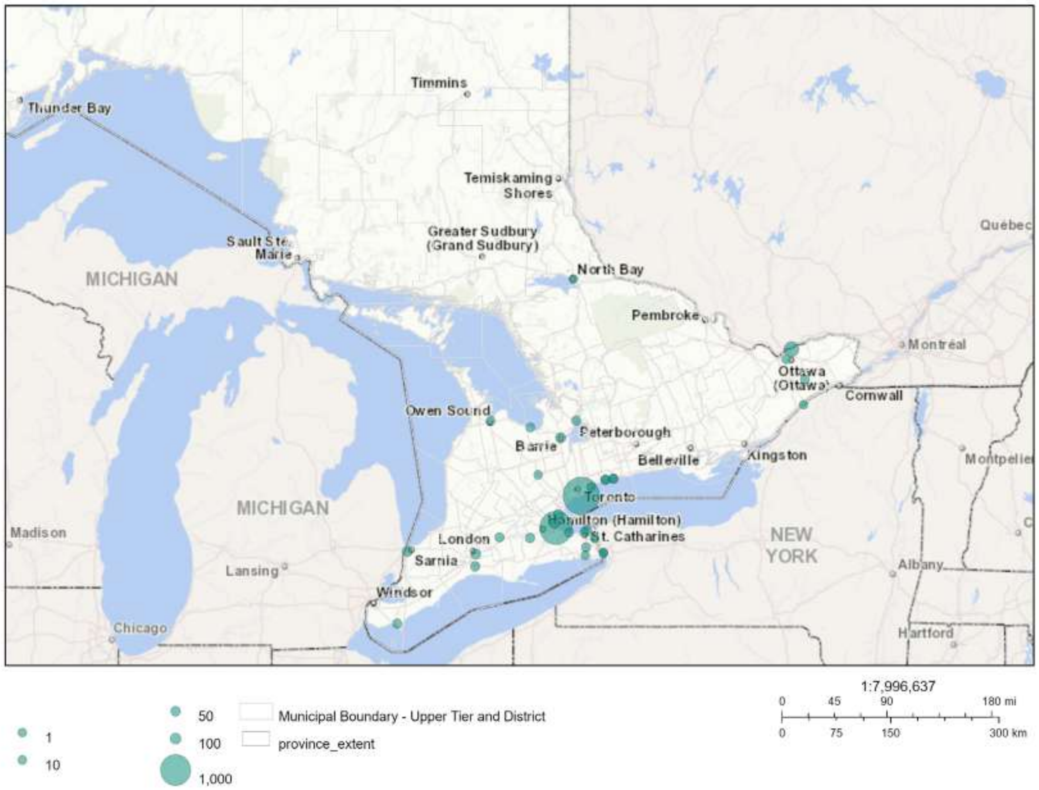


Figure 32 shows P flows from WWTPs directly to water. The location of these emissions corresponds with areas with the largest populations (e.g., the Great Toronto and Hamilton Area and Ottawa).

Figure 32. Phosphorus Emissions from Wastewater Treatment Plants to Water in t/a (2019)

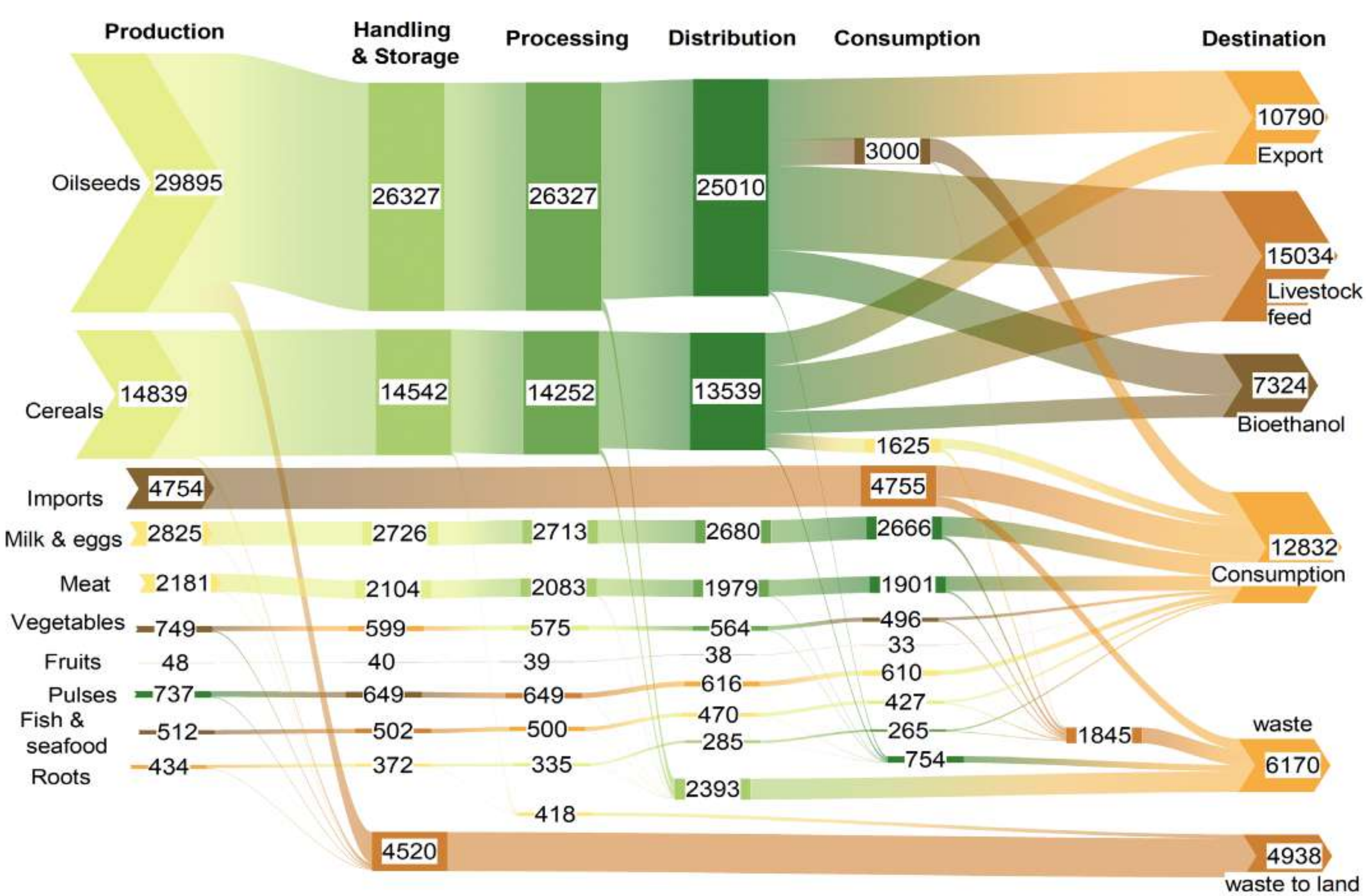
4.3 Municipal Food and Organic Waste

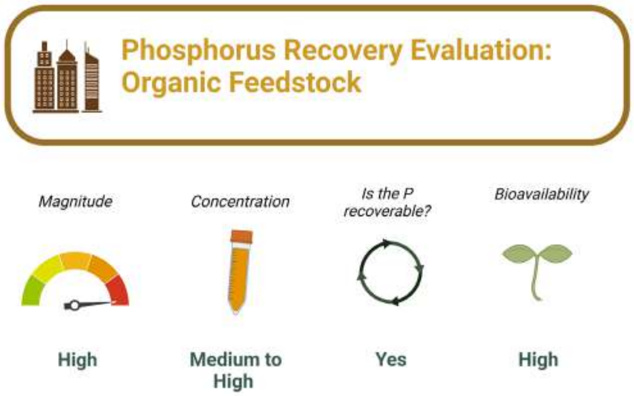
Organic waste generated, and sometimes collected, by municipalities is a key urban source of P. For this estimate, the initial organic input to domestic and commercial users was determined from the value of distributed food for 2019. The calculation involved estimating the flow remaining after food loss factors for steps associated with food production.[148] Food production values were obtained from OMAFRA.[149, 150] Specific factors and additional details about this calculation are found in Appendix D.

Different food types and their P values were summed to estimate the total flows from production through to consumption. To determine the initial agricultural P flow for production, the production data were assumed to be the remainder after the first loss from the initial agricultural production loss. A back-calculation was made with the loss fraction and production data to estimate the initial agricultural production. Beef and pork production data were calculated based on Ontario imports, exports, and total availability. Approximately 12% of grains and oilseeds production was attributed to human food, 19% to bioethanol, 28% to export, and 39% to livestock feed.[151]

Figure 33 shows the estimated P flows and wastes generated at each food processing step, where data were available. It was assumed that the P concentration was equivalent for each split. The sources for Ontario agricultural food production, P content and loss amounts used in this estimate are found in Appendix D.

Figure 33. Phosphorus Flows (t/a) along the Food Chain from Production to Consumption for Selected Foods[152, 153]





The P values from imported food were determined by scaling Canadian food imports with the population of Ontario for a total of 7,178,000 t/a for 2019. The total P content was determined by multiplying the estimated Ontario import amount of each commodity with its P concentration. The estimated total for all imported food was 5,078 t/a. It is assumed that imported food joined the food chain loss estimate at the distribution stage, and added 4,466 t/a to P consumed, with 1,024 t/a of imported food becoming food waste in Ontario.

From these results, the sum of distributed P in food was used to estimate the fate of the organic products. A 2022 Ecostrat publication prepared for the Atmospheric Fund reported that over 1,943,800 t/a of recyclable organic feedstock (ROF) was produced by industrial, commercial, institutional, and municipal sources.[154] It is assumed that this value is representative of 2021. The report suggests that approximately 34% of this ROF (662,500 total mass t/a) was commercial liquids, 37% (704,000 total mass t/a) were commercial solids, and 29% (557,350 total t/a) were "source separated organics" (SSO). SSOs were assumed to be the organic waste that is separated by consumers.

Table 13 shows the P flows from the ROF stream, determined using the low and high dry mass values and the low and high % P values from Moller (2016)[155], and the total P quantities from the Ecostrat report. It is estimated that approximately 887 t/a – 7,615 t/a of P could be the content of ROF waste streams. This aligns with the distribution and consumption factored losses of ~ 6,170 t/a P shown in Figure 33.

Table 13. Estimate of Recyclable Organic Feedstock Supply (2019)

	Total mass (t/a)	Percent total (%)	% Dry mass low	% Dry mass high	% P low	% P high	P low (t/a)	P high (t/a)
Direct source	Ecostrat	Ecostrat	Moller 2016	Moller 2016	Moller 2016	Moller 2016		
ROI type								
Liquid ICI	662,498	34	2	12	0.36	3.15	48	2,504
Solid, not dried ICI	704,012	37	20	30	0.24	1.45	338	3,062
Source separated organics (assumed to be municipal)	557,348	29	50	75	0.18	0.49	502	2,048
Total	**1,923,858**	**100**					**887**	**7,615**

Ecostrat also reported the anaerobic digester and composting capacities of Ontario. Table 14 shows P recovery capacities and the assumed P contents in their products. P processing capacities at anaerobic digesters range from 170 t/a to 1,550 t/a, while composting capacity is estimated to be between 790 t/a and 3,240 t/a. The balance, assumed to be P sent to landfill, is estimated to be between 610 t/a and 2,510 t/a.

Table 14. Phosphorus Flow Estimates for Anaerobic Digestion and Composting Capacity in Ontario

	Total mass (t/a)	% Dry mass low	% Dry mass high	% P low	% P high	P low (t/a)	P high (t/a)
Direct source	Ecostrat	Moller 2016	Moller 2016	Moller 2016	Moller 2016		
Anaerobic Digestion Capacity	359,500	20.00	30.00	0.24	1.45	173	1,564
Composting Facilities	704,012	50.00	75.00	0.18	0.49	794	3,241
Sent to Landfill	881,900	50.00	75.00	0.18	0.49	614	2,048

Another method used to estimate the ROF generated in Ontario is with publicly available factors. This calculation assumed that ~10,824 t/a of P in distributed food was produced in Ontario and 4,655 t/a was found in imported food (after initial factored distribution losses). This value included the assumption that 12% of grains and oilseeds produced was for human food. Food distribution factors of 65% to domestic, and 35% to commercial (hotels, restaurants, and institutional (HRI)) consumers were assumed.[156] FAO factors for quantifying food losses and waste at the consumption step of the food supply chain for North America range from 0.11 to 0.33, depending on food and loss type.[157] These factors were used to estimate the amount of P lost in waste organics after distribution and during consumption. The total P amount in food waste during consumption was estimated to be ~2,720 t/a.

An average of 66% of all Ontario households composted organic kitchen waste in 2019.[158] The balance of Canadian household organic waste was assumed to be sent to landfill. The P loss factors for commercial consumption were assumed to be similar to domestic, with 100% of commercial food waste assumed to be part of the ROF P flow. Table 15 shows that the ROF P flow was distributed to the assumed maximum anaerobic digestion and compost capacities.

Table 15. Estimated Maximum Phosphorus Flows from Ontario Anaerobic Digesters and Composters

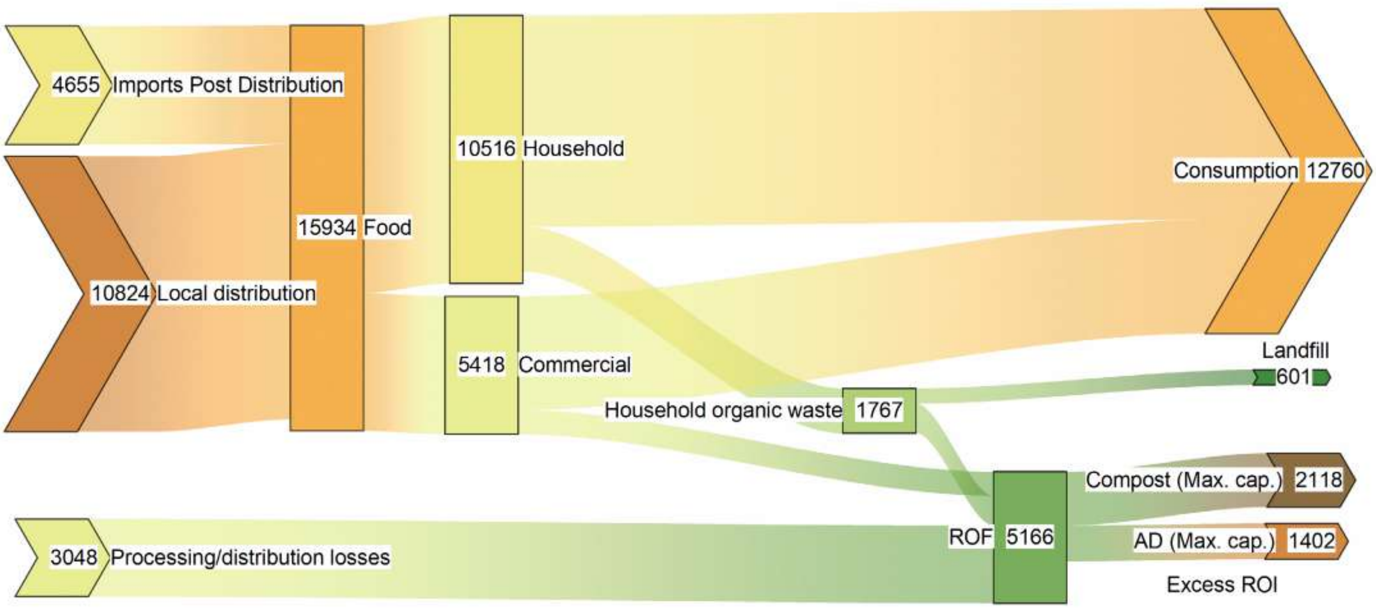
	Total mass (t/a)	% Dry mass avg	% P avg	P avg (t/a)
Direct source	Ecostrat	Moller 2016		Moller 2016
Anaerobic Digestion Capacity	359,500	42.4	0.92	1,402
Composting Facilities	881,900	64.0	0.36	2,032
Sent to Landfill	682,458	64.0	0.36	1,572

Figure 34 shows the P flows from food distribution (local and imported) to consumption and disposal in Ontario, estimated using FAO food loss factors for commodity types. Compost and anaerobic digestion facility capacities are assumed to be 100% utilized, and the balance of food waste is assumed to report to landfill. Of all estimated P loss by consumption (~2,720 t/a), it was assumed that household ROF was sent to compost (66%, ~1,170 t/a) or landfill (~600 t/a). It was assumed that all of the estimated commercial food consumption P waste (~950 t/a) was diverted to ROF. The commercial ROF split between compost, anaerobic digesters, and landfill is unknown.

The estimated P consumption from imported and locally grown food was ~12,760 t/a. Assuming the minimum human requirements of 700 mg/day[159], and ~14.5 million Ontario citizens in 2019, there would be an annual human P uptake of ~ 3,700 t/a. The control group of a clinical study reported approximately 58% P excretion from 1,144 mg/day P intake.[160] Therefore, an estimated 2,591 t/a of P is taken up by Ontario citizens. Subtracting this estimated uptake from consumption, approximately 10,169 t/a of P would be in human sewage. This value is 11% higher than the sum of the WWTP disposal and transfers (6,800 t/a), release (900 t/a), and septic (1,445 t/a) values.

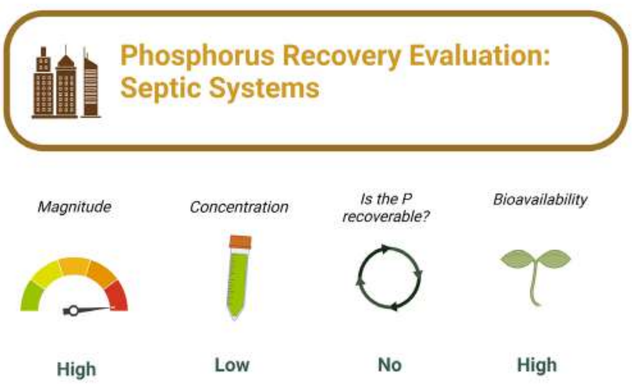
There is crop waste associated with production, storage, and distribution further up the food chain that includes grains and oilseeds that are not for human consumption. The crop waste associated with the total crop processing was estimated using FAO loss factors for production (~4,360 t/a), storage (~ 400 t/a), and processing/distribution (~5,770 t/a). Production and storage losses (~4,750 t/a) were assumed to be returned to the field. If food processing or distribution losses are combined with ROF (~2,120 t/a after subtracting unrecovered household waste) for processing by anaerobic digestion or compost, ~5,170 t/a of food chain losses could be recovered for re-use. This is close to the higher ROF estimate shown in Table 14. Grains and oilseeds used for bioethanol production (19% of Ontario's grain production[161]) could produce an estimated 7,300 t/a of P in ROF, assuming negligible P in bioethanol production.

Figure 34. Phosphorus Flows and Losses (t/a) after Distribution to Consumption and Disposal*



*HRI = hotels, restaurants & industrial, HOW = household organic waste, ROF =Recyclable organic feedstock, AD = Anaerobic digestion and Max. cap = maximum capacity

4.4 Septic Systems



Households that are not connected to a sewer system and serviced by a WWTP are often equipped with septic systems — underground wastewater treatment structures. Septic systems use a combination of technology and nature to treat wastewater from household plumbing. A typical septic system consists of a septic tank and a drainfield, or soil absorption field. The septic tank digests organic matter and separates floatable matter and solids from the wastewater. Soil-based systems discharge effluent from the tank into a series of perforated pipes buried in a leach field, chambers, or other special units designed to slowly release it into the soil.[162]

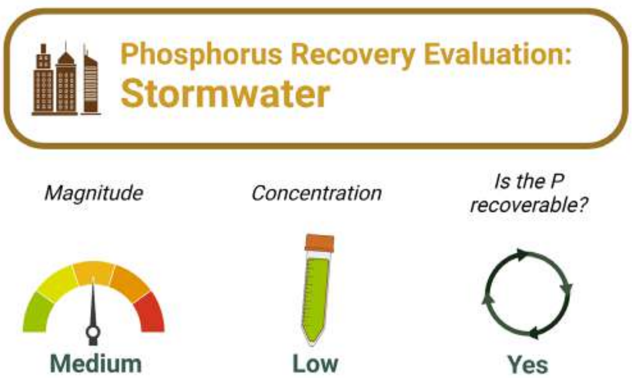
Some systems may use pumps or gravity to help move the effluent through sand, organic matter, constructed wetlands or other media in order to remove or neutralize pollutants, including pathogens and nutrients, such as P. However, a portion of the P released can still end up in the soil and eventually, local waters.

According to Statistics Canada, approximately 13% of households in Ontario use septic systems.[163] The geographic distribution of households with a septic system is difficult to determine based on a lack of data but these households tend to be located in rural areas that are not in close proximity to municipal infrastructure. For the purposes of this study, a rough order of magnitude estimation for P flows associated with septic systems was calculated based on the following assumptions:

- In 2017, there were a reported 5,321,812 households in Ontario with an average of 2.58 people per household.[164]
- If 13% of households use a septic system, this equals 1,784,936 people (5,321,812 households x 13% using a septic system x 2.58 people).
- Oldfield et al. (2020) estimate that the average annual P load rate from septic systems into the Lake Erie Basin is 0.81 kg per person, per year.[165]

Taking this into account, it is estimated that the P flow for septic systems in Ontario is approximately 1,445 t/a.

4.5 Stormwater

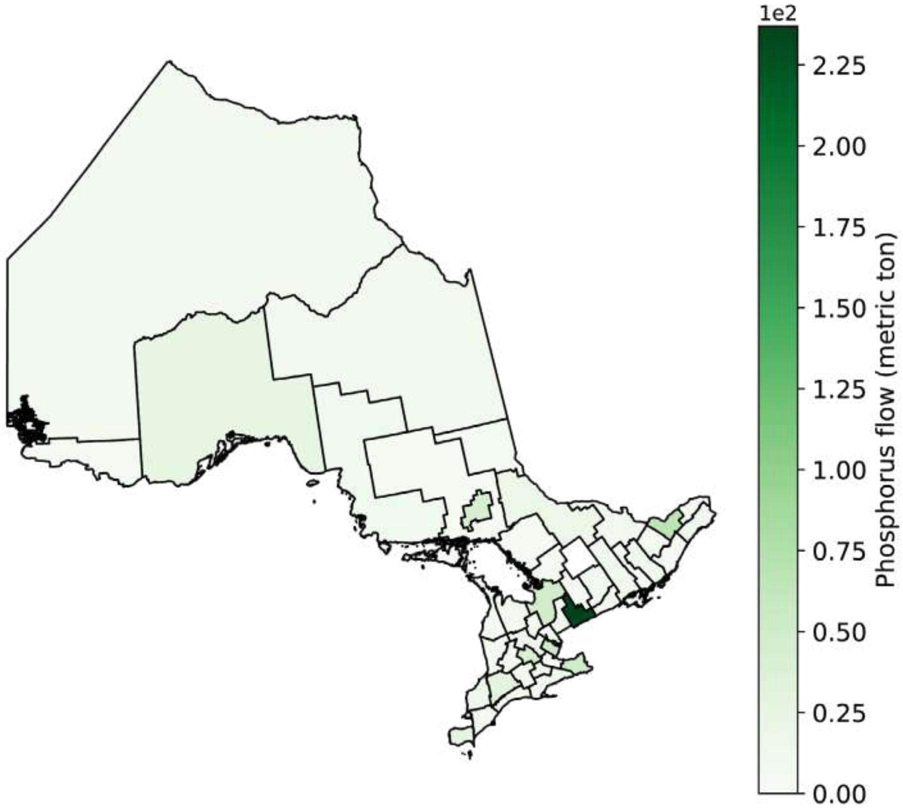


Periods of heavy rainfall or snowmelt can cause the water volume reaching sewer systems to exceed their capacity, resulting in the release of untreated wastewater directly into local waterbodies. Discharges of partially treated or untreated sewage can contain pathogens, P and harmful pollutants, with potentially devastating impacts on human health and the environment.

Impermeable surfaces such as sidewalks and streets do not allow water to be absorbed easily into the ground. During storms, water runs off surfaces, collecting oils, road salt, pesticides, and P from lawn fertilizer, sediment, leaves and landfills, as it moves across land, eventually ending up in nearby bodies of water. Combined sewer systems in some municipalities collect and transport this stormwater runoff to treatment plants in the same pipes that carry domestic sewage and industrial wastewater. During extreme weather, the volume of water accumulated commonly exceeds the capacity of the sewer system. When this happens, sewage mixed with stormwater is redirected through a bypass and released directly into the nearest body of water. This release of sewage into local waterways is known as a combined sewer overflow (CSO).

Estimating the contribution of stormwater to P flows is a challenge since the P concentration of stormwater can vary significantly.[166] In addition, there is a lack of data related to both the amount of stormwater and the concentration of P within it. However, a rough estimation of P transported by urban stormwater can be performed by using export coefficients. These coefficients describe the flow of P through a particular stream (e.g., leaves, soil particles, pet waste) per unit of area. For the purposes of this study, it was assumed that an export coefficient estimated for the Bay of Quinte (Ontario) of 119 kg/km^2/year is applicable to the entire province.[167] This coefficient was then multiplied by the urban area of census divisions in Ontario[168] and an estimate of 881 t/a of P flow was determined to be associated with urban stormwater. Figure 35 shows the geographic distribution of P flows from urban stormwater. Those areas with the most significant P flows are large urban centres, including Toronto.

Figure 35. Phosphorus Flow (t/a) from Urban Stormwater



Section Five:

Phosphorus Flows in Ontario's Industrial Sectors

Phosphorus Flows in Ontario's Industrial Sectors

This section aims to map P flows through those industries in Ontario that use raw materials containing P in their processes, as well as those with significant P in their waste streams or by-products. P-containing chemicals are used as raw materials in several manufacturing processes in the province, including those related to vehicle, chemical, and food and beverage manufacturing. P also accumulates in slag, a by-product of the steelmaking industry, and is released from wood chips during pulp and paper manufacturing.

Analysis of NPRI data shows that the mining, steelmaking, forestry, and food and beverage, chemical and vehicle manufacturing industries generate the largest amount of P in their waste streams. Mining P waste flows are large in magnitude, but due to the low P content in the waste rock and separated fine rocks, these are assumed to be unrecoverable. P flow diagrams provided for each industry illustrate how P moves and allows for comparison of inflows and outflows as products or waste. The majority of the estimates outlined herein were generated from production numbers, allowing them to be used to project how waste P flows would differ with changes in industry size.

5.1 Methodology

P flows through imports, production, exports and waste were mapped for the steel, forestry, food and beverage, chemical and vehicle manufacturing industries in Ontario. Other industries where P is found are also explored in less detail (e.g., aquaculture, cannabis). Unless otherwise stated, the analysis in this section is completed for 2019, as it is the most recent year with sufficient trade flow, production and waste data.

Industrial P flow estimates were determined using different strategies outlined in this section. National databases and provincial population values were used to scale some values, while others were estimated from waste type and magnitude databases, or from detailed process or P-content values. Some values were estimated with more than one method, which results in different estimates. We assume these results are within the error of the estimations. A number of assumptions were required to estimate magnitudes for industry, based on minimal data and a limited understanding of how P flows in this sector.

5.1.1 Key Data Types and Source

Production data were sourced from various national and company-based materials and content. Waste P flow data were obtained from the NPRI database, while P composition data were compiled from academic publications and national databases such as Health Canada's Canadian Nutrient File.[169] Component balancing — estimating the P amounts in and out of a process based on the total masses and P concentrations — was undertaken to estimate unknowns. Where applicable, detailed methods for estimating P flows for specific industries or subsectors are provided in Appendix D.

Trade Data: National import and export trade flows, including those for a number of agricultural or industrial materials and products containing P were primarily obtained from World Integrated Trade Solutions.[170] The percentage of these trade flows attributed to Ontario were estimated based on the Government of Canada's Trade Data Online.[171] Where there were information gaps, additional production data were sourced from various company websites or resources. The trade and production flows calculated from these data sources provided good estimates of the solid mass flows of the product. However, calculating the P flows from the corresponding mass flows was a challenge since many trade goods or products vary in composition. Where available, P concentrations were sourced from various websites or resources, but they were often a rough estimate.

Canadian Nutrient File: Health Canada publishes the Canadian Nutrient File, a comprehensive, computerized bilingual database that reports up to 152 nutrients, including P, in over 5,690 foods. The Canadian Nutrient File was one source of food P concentration data used to help estimate the P composition of various foods in the food and beverage sector, together with findings from academic literature.[172] The Canadian Nutrient File is a relatively accurate database for P amounts in food and beverage due to its large sample size. However, it only records the edible portion of food and therefore, it may not represent the actual P in food waste. In addition to including a wide variety of food items, the Canadian Nutrient File also includes a variety of brands for each food item. It was assumed that the selected food item from a specific brand was representative for all brands of the same food item.

Industrial Waste Streams

As with WWTPs, the main data source used to estimate P flows from disposals, transfers and releases for industrial sectors was the NPRI. The following secondary data sources was also used to upscale these values to account for the contribution of the non-reporting facilities:

Industrial Wastewater Discharges[173]: Industrial facilities located in Ontario are required to report quarterly to the Ministry of the Environment, Conservation and Parks (MECP) on wastewater discharges to waterbodies under the Effluent Monitoring and Effluent Limits (EMEL/MISA) Regulations. The Industrial Wastewater Discharges (IWD) database contains the amount of P released to water from 2004 onwards. However, only the municipality, and not the coordinates of specific facilities are provided. As such, this dataset was used to scale up the amount of P released, disposed of, and transferred by the manufacturing facilities.

Census of Population[174, 145]: Statistics Canada's 2011 and 2016 Census of Population provided data on jobs by economic sector within each census division. The most recent census (2021) could not be sourced as this data was not available at the time of the analysis, and the 2006 census does not provide the necessary disaggregation by job industry classification. These census data were used to scale up the emissions reported to the NPRI by the manufacturing sector.

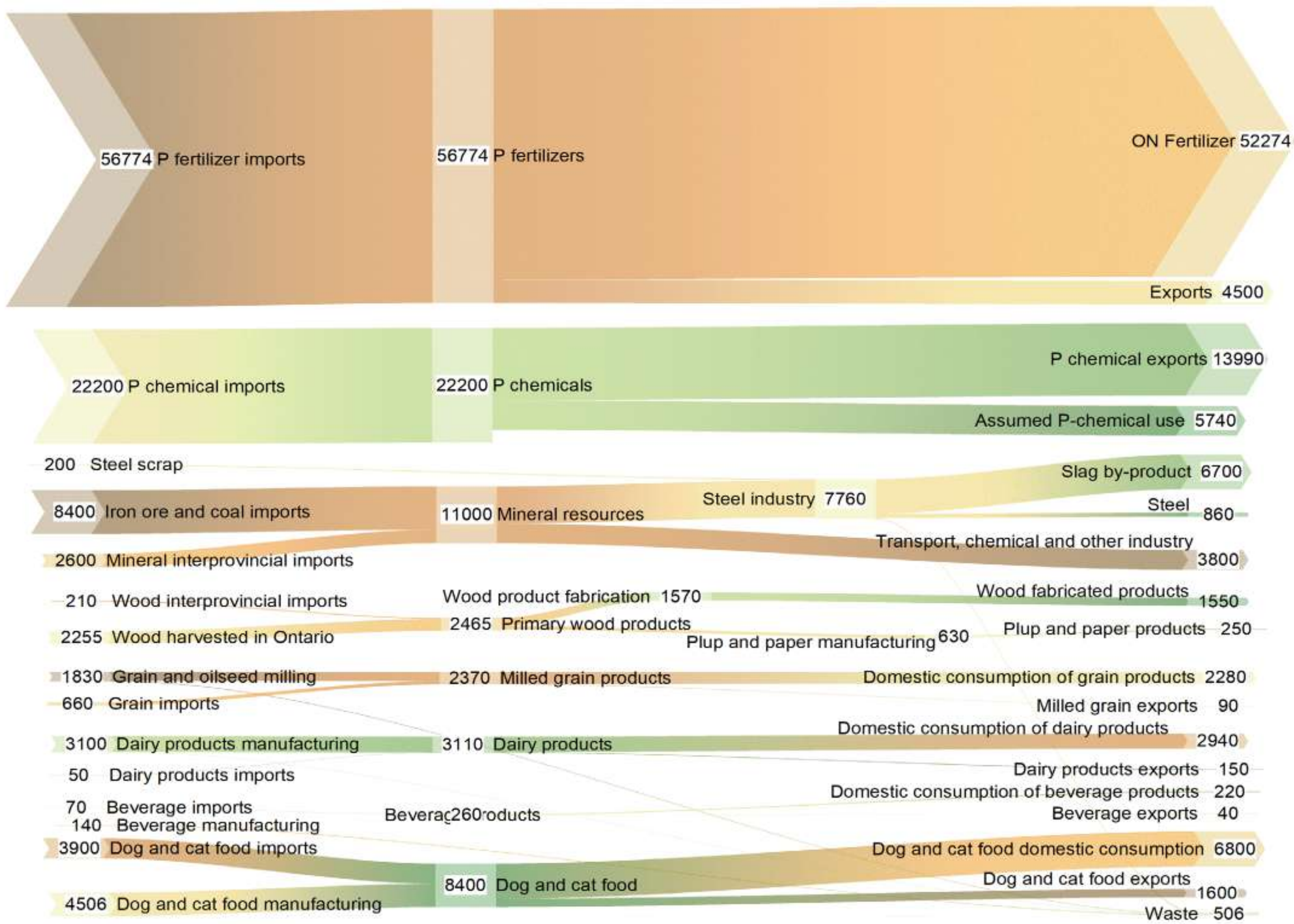
5.2 Phosphorus Flows for Specific Industrial Sectors

5.2.1 Overview of Phosphorus Flows in Ontario's Industrial Sectors

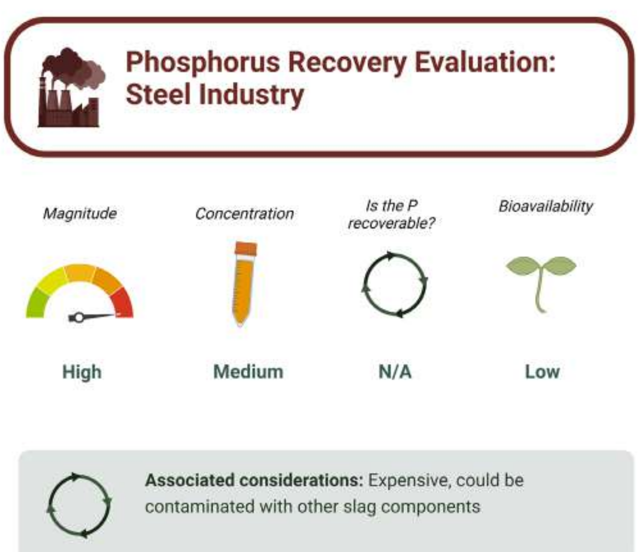
A summary of the P flows estimated in this section for Ontario's fertilizer, chemical, steel, forestry (i.e., wood and pulp and paper), grain and oilseed, dairy, beverages (not including fruit juice), and dog and cat food processing are shown as a Sankey diagram in Figure 36. Company size thresholds limit public reporting of some data such as NPRI waste P flows. Therefore, these flows may underestimate the actual values.

The Agricultural Sector denoted in the figure represents the P fertilizer sold in Ontario. A fraction of fertilizer processed in Ontario is exported, which is not included in the final Agriculture Sector value. P waste generated by fertilizer processing was also too small to include in Figure 36, along with fruit juice production P flows. However, data were available to make connections between some of these flows. For example, iron ore and coal imports were divided between the steel industry and the transport, chemical and other industry sectors, such as rubber production. The P flow splits from the chemical production industry to food and beverage manufacturing, transport, and other industries were not available.

Figure 36. Phosphorus Flows (t/a) for Some Industrial Production Sectors



5.2.2. Steel Industry



In 2020, the Canadian steel industry contributed $2.5 billion to the national GDP through the manufacturing of steel for use in buildings, automobiles, railroads, and bridges. Of the 13 plants that manufacture steel in Canada, six are located in Ontario, including large plants in Hamilton and Sault Ste. Marie.

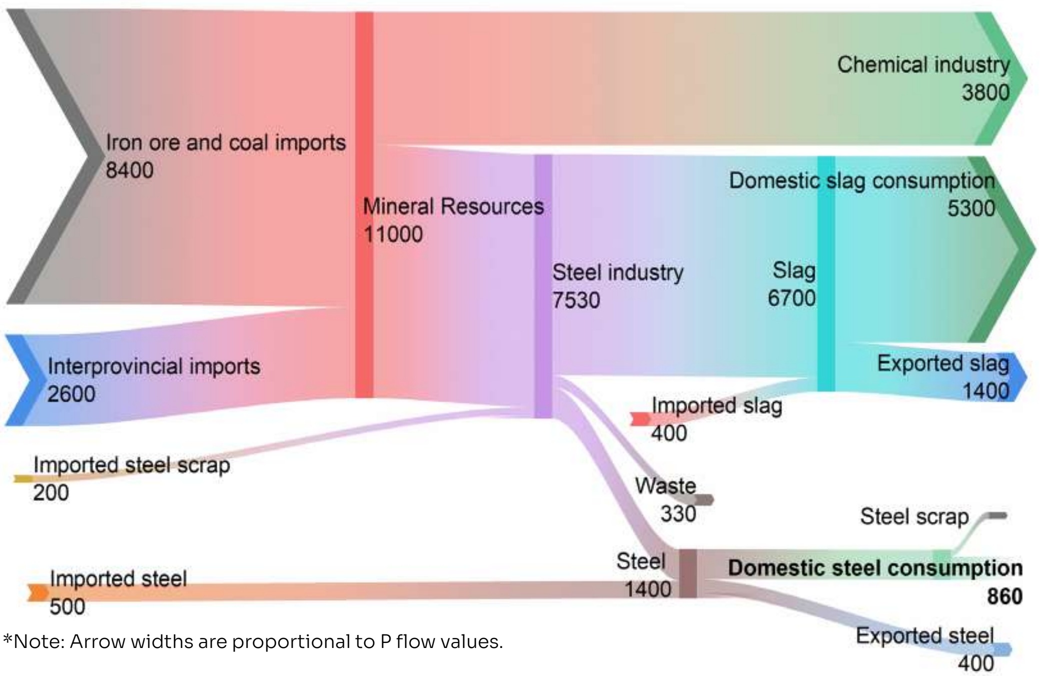
Steel is fabricated after producing iron from iron ore, coal and/or coke. The ironmaking process also removes many impurities in the form of a solid called "slag". The iron is then further refined into steel products. P is a minor component in iron ore and coal. While P is also added to steel to create desired surface coatings to reduce corrosion, it is largely considered to be an impurity that is removed during refinement.

There is an average 0.06% P in iron ore and 0.05% P for coal. Product steel is assumed to have 0.01% P.[176] As previously noted, during the steelmaking process, P accumulates with other impurities in the slag. For the purposes of this report, it is assumed that the P content in slag is equal to the difference between the P imported into the steelmaking industry, and the sum of the P in the product steel and production waste. This results in an estimated average of 0.4% P in slag.

Estimates of actual steel production in 2019 by major steel companies in Ontario were made as fractions of production capacity in some cases. Specific values are reported in Appendix D and are used to estimate the P flow in steel products. Slag imports and exports were also accounted for.

Figure 37 maps P flows through the Ontario steel industry and shows that 85% of P inputs were in the by-product slag (~6,700 t/a). while 12% were as a component of the steel product (~ 1,300 t/a) and 3% was in steel waste (~ 330 t/a). Some of the silicate and oxide components of slag are similar to those found in cement, qualifying it as a "pozzolan". This means that steel slag has cement-like properties. For this reason, slag is commonly sold as an additive for cement in concrete production. However, this use does not capitalize on the high P content in slag. Research is being conducted on recovering P from steel slag.[177, 178]

Figure 37. Estimated Phosphorus Flows (t/a) through Ontario's Iron and Steel Industry*

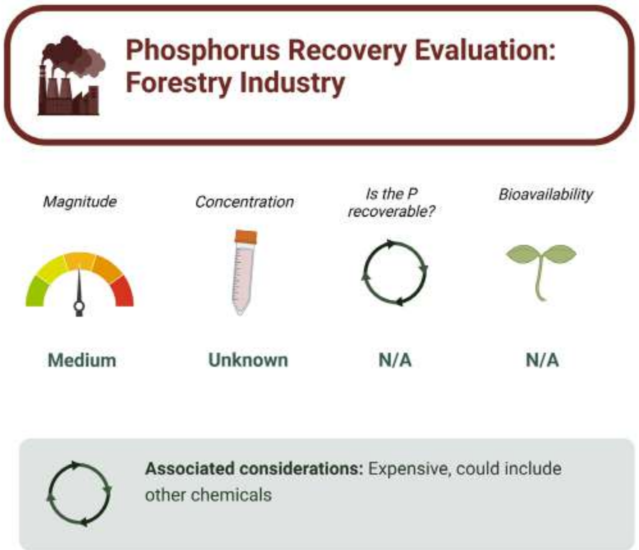


*Note: Arrow widths are proportional to P flow values.

There are several variables to consider with these estimates. For example, they are based on data for large-scale steel producers but there is also a community of smaller-scale, secondary steel facilities, referred to as mini mills, that produce steel products from recycled scrap steel. Steel production from Ontario mini mills is not included in these estimates. In addition, the P content of the raw materials can vary considerably depending on the source of iron ore, coke, and coal.

5.2.3. Forestry Industry

The forestry industry contributes wood for building homes, furniture, paper and packaging, and as an energy source."[179] Ontario harvests 30 million cubic metres annually, with the most popular species by harvest volume being Spruce, Balsam Fir and Jack Pine.[180] In 2018, Ontario exported almost $6.5 billion (96% of total exports) in forestry products to the U.S. Trees absorb P from the soil in the form of phosphate during plant growth. With Ontario representing 21% of Canada's forestry industry and $4.3 billion in provincial GDP, the sheer volume of forestry materials that run through the Ontario economy result in a large P flow, despite the 0.01% P content of wood.[181]

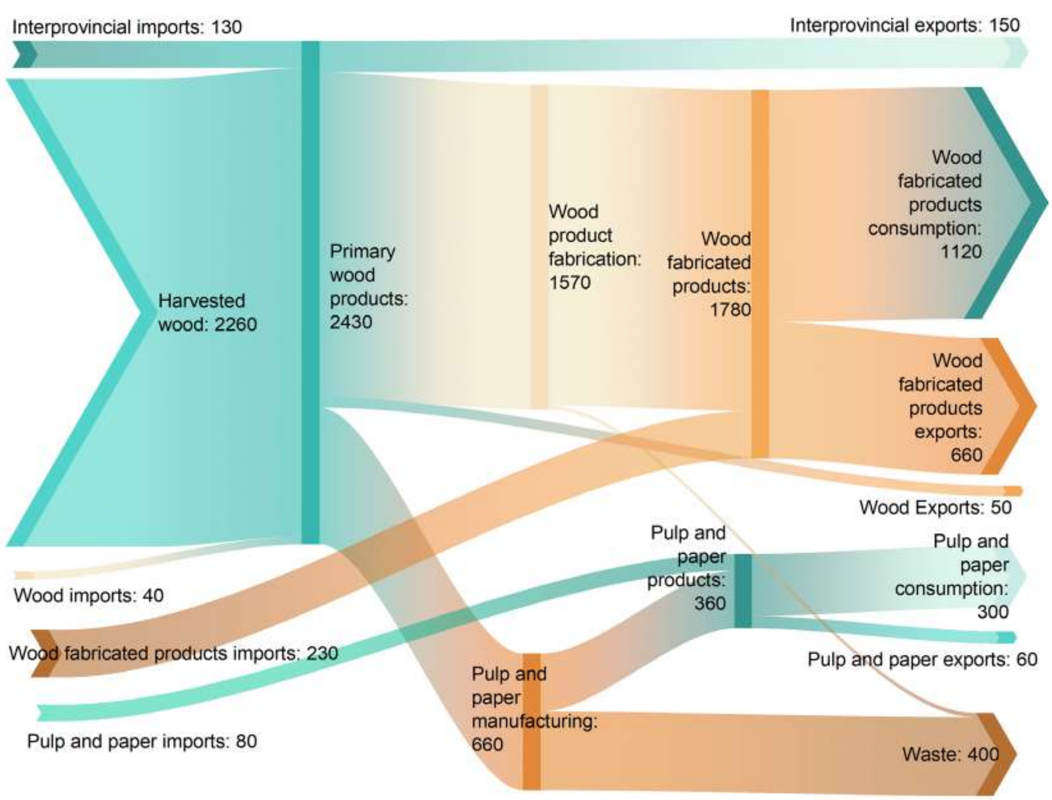


Ontario's forestry industry consists of pulp and paper production, and wood product fabrication. The P content in pulp and paper products was estimated to be 0.005%, based on the 2019 reported mass of pulp and paper products (6,062,000 t/a) and an estimate of the total P in these products that was a component of pulp and paper feedstocks (280 t/a). This is much lower than the starting material for this process (i.e., wood), and implies that pulp and paper manufacturing should demonstrate significant P waste production.

Statistics from the Canadian Forest Service[182] provided the data necessary for completing these estimations. In 2019, there was approximately 2,260 t of primary wood in Ontario. Primary wood availability is a combination of wood harvested in Ontario, as well as interprovincial and international imports. Data for wood harvested in Ontario was unavailable for 2019, so an average of annual volumes from 2010 to 2018 was calculated and used in this estimation. Interprovincial flows of wood were based on its monetary trade value in 2018. A detailed methodology of the P flows through the Ontario forestry industry and the values used for these calculations are found in Appendix D.

Figure 38 shows P flows for Ontario's forestry industry. It is estimated that approximately 70% of the P from primary wood in Ontario is used for wood product fabrication (1,780 t/a). Using the method of component balancing, it was assumed that the remaining 29% of P (660 t/a) from Ontario's wood resources flows to the pulp and paper industry. Over 60% of the P in the pulp and paper industry (approximately 400 t/a) ends up in waste streams.

Figure 38. Phosphorus Flows (t/a) through Ontario's Forestry Industry



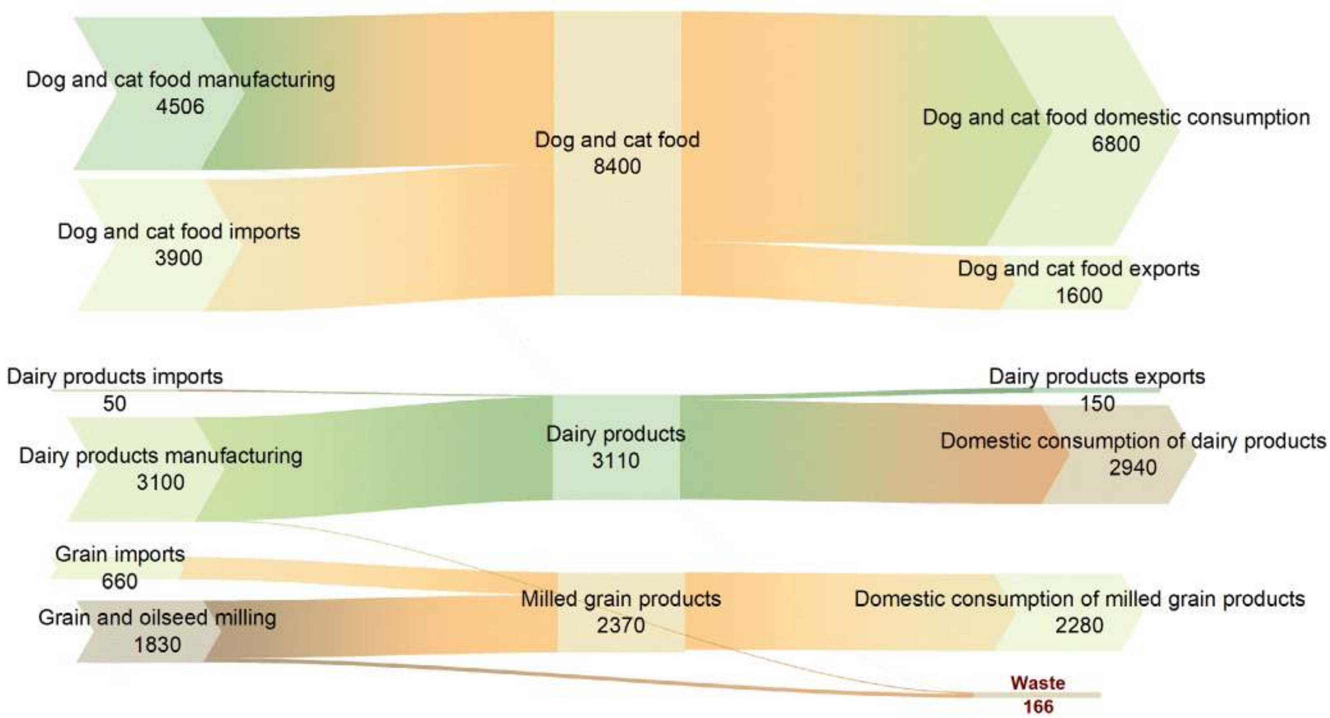
*Note: Arrow widths are proportional to P flow values.

5.2.4. Food and Beverage Industry and Industrial Production of Dog and Cat Food

The Ontario food and beverage processing sector (defined as soft drinks, beer, wine, ciders, and spirits) is the third largest in North America with manufacturing revenues of more than $48 billion.[183] The sector has more than 3,000 establishments in the province and includes global companies such as Coca-Cola, PepsiCo, Nestlé, and Mars, Incorporated, along with local companies Weston Foods Canada and Maple Leaf Foods. Large P flows through this industry suggest that there is potential for identifying P recovery opportunities in this sector.

The estimates in this section are for the largest identified P flows in food and beverage production. Note that "beverage" is defined as "water, tea, coffee, alcohol and soft drinks"[184] and does not include fruit or vegetable juices, or dairy-based drinks. Figure 39 shows that dog and cat food production represents the largest of these estimated P flows, followed by dairy production (estimated with OMAFRA data), grain and oilseed processing, and production of beverages (beer and soft drinks) and fruit juices. It should be noted that data for dairy-related P waste flows may be underestimated due to only two dairy companies reporting to the NPRI in 2019.

Figure 39. Phosphorus Flows (t/a) for Ontario's Dog and Cat Food, Dairy, and Grain Processing Industries



*Note: Arrow widths are proportional to P flow values.

Dog and Cat Food Manufacturing

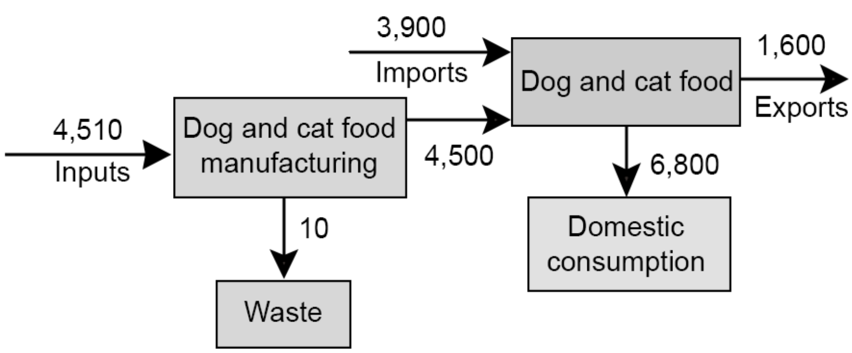
Dog and cat food producers utilize the same input streams as for human food production, including many of its by-products and co-products.[185] While it has been argued that dog and cat food is composed of by-products of human food production, recent data suggest that food that could be consumed by humans is used in dog and cat food production.[186] Dog and cat food contains P from a number of sources, including its organic ingredients and supplemented inorganic phosphate used as a preservative and to achieve the desired texture.[187] The ratio of P from organic inputs to the inorganic phosphate is not known.

An estimated 33 ± 6% of dog and cat food energy is animal-derived, while human food is approximately be 19%.[188] As animal-based foods are estimated to be 7 times more P-intensive than vegetable-based foods[189], the dog and cat food industry is associated with a fairly significant P-flow.

Dog and cat food consumption was estimated using the population of dogs and cats in Ontario and their average daily consumption. There are an estimated 2.8 million dogs and 3.2 million cats in the province. This estimate is based on data for the population of dogs and cats in Canada scaled to the provincial level, and the assumption that the average number of pets owned per person was the same for Ontario's population.[190] Food consumption per dog and cat were calculated using the recommended consumption for medium sized dogs (50 lbs) of 0.5 kg/day, and for cats (8 lbs), of 0.15 kg/day.[191]

The amount of P required to produce dog and cat food was assumed to be equal to the sum of exports and domestic consumption, while subtracting P associated with imported food. Figure 40 shows the estimated P flows through the dog and cat food sector. It highlights that this sector has a very significant P flow in Ontario, estimated to require the import of approximately 4,510 t/a of P. The annual amount of inorganic phosphate added to the dog and cat food production process is unknown. The NPRI reported P waste value (10 t/a) is only 0.2 % of P entering the process. However, this may be an underestimation given that this is a coarse estimate.

Figure 40. Ontario Phosphorus Flows (t/a) from Dog and Cat Food Production



Dairy Product Manufacturing

The P flows in the dairy industry are significant. The State of Vermont recently launched a "Pay for Phosphorus Program" to encourage their dairy and other farmers to reduce P losses to the environment.[192] As previously noted, dairy cattle largely transform feed to milk, with a high P concentration (approximately 0.93 g P/L)[193], and P-rich manure.

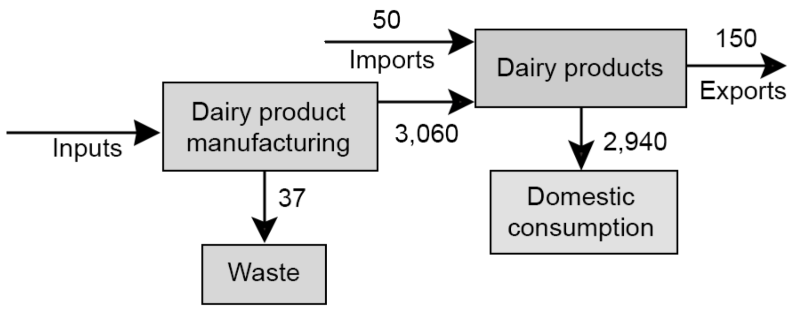
Dairy product manufacturing was estimated using national supply-disposition data, downscaled for Ontario values. Supply-disposition data from Statistics Canada and online trade and revenue data were used to estimate the 2018 annual dairy industry production values. National import and export values were scaled for Ontario using revenue ratio data[194] and the ratio of "Ontario value/ Canadian value" from trade data online.[195] Trade and revenue data showed that Ontario generated 42% of the dairy product manufacturing revenue for Canada. The P concentration in each dairy product was determined based on data sourced from Health Canada's Canada Nutrient File.[196] The detailed methodology, data sources and estimates for this analysis can be found in Appendix D.

Wastewater volumes from dairy facilities differ based on the type of production system[197] and the cleaning agent used has a large effect on milking facility effluent.[198] While one study found P concentrations in the wastewater stream ranging from 15 - 42 mg/L based on the different detergents used and the dilution[199], another reported ranges from 8 - 86 mg/L.[200] For the purposes of this report, a preliminary estimate of the annual P flow in dairy production wastewater was based on an estimate wastewater production volume of 0.8-1.3 L cleaning water/L milk. This generated an estimated wastewater P range of 5 – 115 mg TP/ L milk. This results in approximately 36 t/a - 164 t/a of P emitted in dairy production wastewater based on the 2019 milk production rate of $3x10^6$ kL/a.

The OMAFRA ice cream and cheese production dataset included useful P data from waste dairy material and detergent-containing wash water that were used to estimate overall dairy processing P waste values for these products. Published wastewater to production ratios for ice cream and cheese[201] and the concentrations of P in ice cream and cheese wastewater[202] were used to calculate an estimate of 0.7 t/a - 4.6 t/a of P in ice cream production wastewater, and 2 t/a - 270 t/a for cheese production. The sum of the ranges of low and high P flows in the wastewater from milk and dairy production is therefore 38 t/a – 434 t/a.

Figure 41 shows the estimated P flows (t/a) through the dairy industry. A large fraction of dairy products produced in Ontario are consumed in the province. These estimates suggests that approximately 1% to 14% of the P flows in dairy production is a component of its waste streams.

Figure 41. Phosphorus Flow (t/a) for Ontario's Dairy Industry



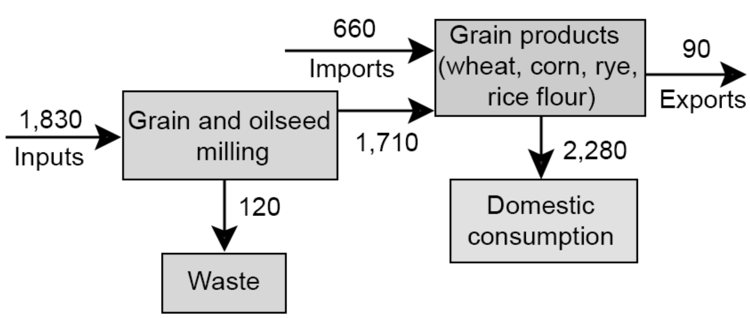
Grain and Oilseed Milling

Ontario processes a significant amount of grain and oilseed by milling products such as flour and oil. The P content in various grains and products was obtained from the Canadian Nutrient File.[203] For the purposes of this report, it was assumed that oil products have no P content, so they were not included in the analysis. Data for rice production was insufficient to include in this estimate. As rice production values are not known, the magnitude of this gap for P flows from the rice processing industry is unclear.

Figure 42 shows the estimated P flow for imports, exports, and grain and oilseed milling processes. The production data for rye flour, corn flour, oatmeal and pot and pearl barley were unavailable. Therefore, these production data were estimated using import, export, and domestic sales (referred to as "disappearance" data) provided from Statistics Canada's Supply and Disposition of Food in Canada. National import and export data were scaled down to Ontario using the provincial distribution for imports and exports (32.8 % for Ontario).[204]

It is estimated that 7% (~ 120 t/a) of P from grain and oilseed inputs (~1,830 t/a) is released during milling and is a component of waste streams. Due to the high uncertainties associated with this estimation method (see Appendix D), it is emphasized that these P flows are approximate estimates. Figure 42 shows that a total of 2,280 t/a of P is consumed as part of domestic grain consumption, while 90 t/a is exported.

Figure 42. Phosphorus Flow (t/a) for Ontario's Grain and Oilseed Milling Industry



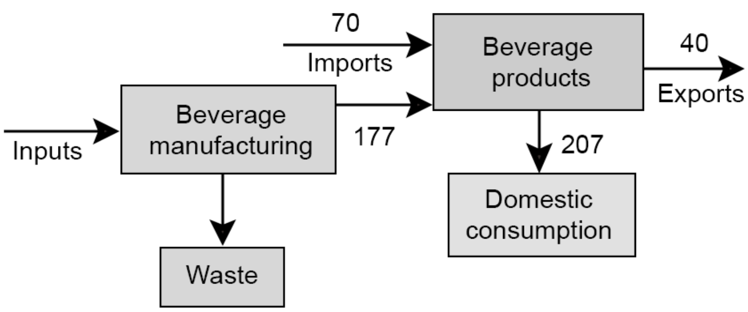
Beverage Manufacturing

Beverage manufacturing involves production and distribution of a range of beverages, including soft drinks, beer, wine, ciders, and spirits. Phosphoric acid is an additive to some types of soft drinks, while the grains and yeast used to produce beer, and the grapes or fruits for wine and cider production also contain P. As published data describing P flows through beer and fruit juice production were identified, a more detailed analysis of these specific sectors is presented in separate sections below.

The range of feedstock types and P concentrations for beverage production was considered too broad and detailed for this study. Instead, waste P flow estimates were made for beer, juice, and soft drink production. Estimates for total beverage imports and exports were available, and scaled from trade, supply, and disposition (sales) data. P concentration data were used to estimate the flows in these beverages. It should be noted that the most recent NPRI data for the beverage industry is from 2016 and it is not complete.

Figure 43 shows the estimated P flows (t/a) through the Ontario beverage manufacturing industry. There is an estimated 177 t/a of P from domestically produced beverage manufacturing and another 70 t/a from imported beverage products. Domestic consumption accounts for 207 t/a of P, with 40 t/a related to exports.

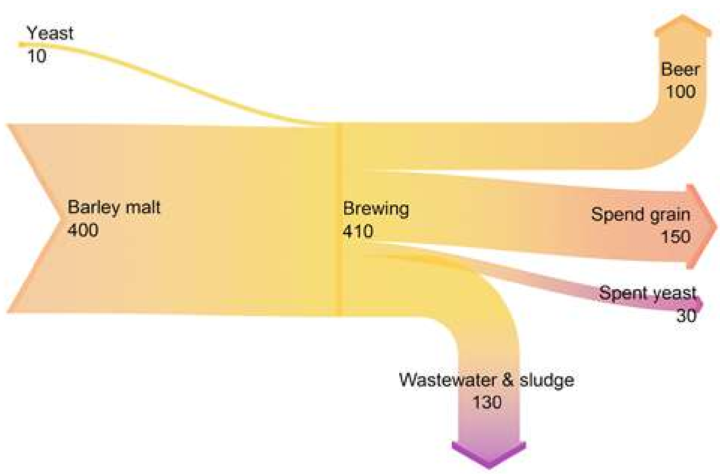
Figure 43. Ontario Phosphorus Flows (t/a) for the Beverage Manufacturing Sector



Breweries

A more detailed estimate of P flows in beverage production was calculated for beer. Mass balances for beer production were sourced from a publication by Krausová (2014).[205] The total P concentrations for the process flows were obtained from published literature.[206] The beer production data for Ontario (774 kL/a) were estimated from the import, export and consumption (i.e., domestic disappearance) data for Canada. These data were used to scale up the estimated P flows for the beer production industry in Ontario and are presented in Figure 44.

Figure 44. Phosphorus Flows (t/a) for Ontario Brewery Industry



*Note: Arrow widths are proportional to P flow magnitudes.

Fruit Juice

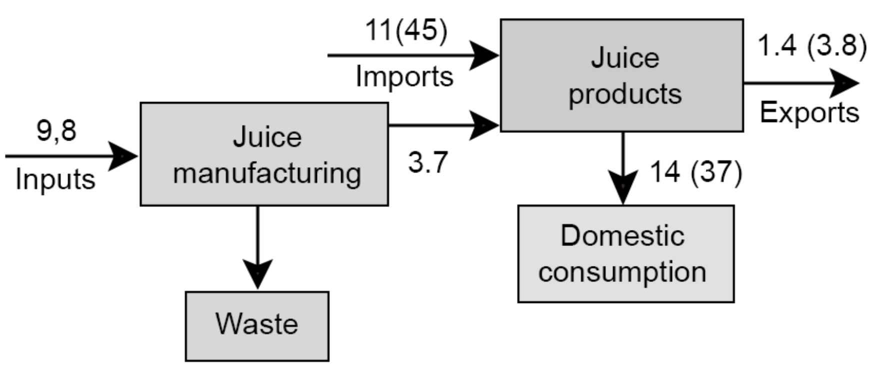
Apples, grapes and tomatoes are grown in Ontario and can be processed into juice and canned or frozen fruit. Citrus fruits are imported and processed into juices. The focus for this sector is on estimating P flows for apple, grape, tomato, and orange juices based on published supply, disposition (sales), and trade information. Canned and frozen fruit production data were not identified. The estimation method is further detailed in Appendix D.

The estimated P flow data for citrus juice production was separated from apple, grape, and tomato juice production because the reported orange juice production data were negative in value. It is assumed that this may be a consequence of no citrus production in Ontario. The negative values were included to offer an order of magnitude estimate of P flows in the fruit juice production industry.

Canadian import and export data were sourced from World Integrated Trade Solutions data. Trade Data Online[207] provided national and provincial trade dollar value data that were used to scale the Ontario imported fruit juice data. Import, export, and production amount data were multiplied by P concentration values for each juice type sourced from the Canadian Nutrient File. NPRI data for 2019 did not include a P waste stream for an identifiable juice producer. Waste P flows for juice production were therefore extrapolated from available apple juice mass balance and P component balance data.[208]

Figure 45 shows the estimated P flows through the Ontario fruit juice industry for apple, grape, and tomato juices, with the suspected values for orange juice noted in parentheses. P in raw materials for apple, grape and tomato juice was estimated to be 9.8 t/a, with domestic consumption accounting for 13.6 t/a. There is an estimated 11.3 t/a of imported apple, grape and tomato juice, and 1.4 t/a exported.

Figure 45. Phosphorus Flows (t/a) for Apple, Grape, Tomato, and Orange Juice Industries



Soft Drink Production

Wastewater produced by soft drink manufacturing was reported to be approximately 1.25 to 2 times the production volume.[209] Published P concentration ranges in soft drink wastewater were 20 – 40 mg/L.[210] With these data, the estimated P waste from 700 ML of soft drink production for 2019, was estimated to be 18 - 56 t/a.*

Data and Information Gaps

There were insufficient data to estimate many of the food processing P flows in Ontario. Unavailable information included production data for orange juice, canned and frozen fruits, vegetables and other canned products. P flow data for the meat production industry is considered in the agriculture section of this report (Section Three).

* calculated from Statistics Canada national import/export/consumption data and scaled to Ontario trade value data

5.2.5. Chemical Processing Industry

Ontario is home to Canada's largest chemical manufacturing sector, generating 40% of the country's total chemical production, with $18.6 billion of exported goods and $25.5 billion in shipments.[211, 212] Nine of the top 15 global chemical firms (by sales) have manufacturing operations in the province. Ontario's chemical sector encompasses a significant value chain – from industrial chemicals to synthetic resins, and from fertilizers and formulated products to petroleum refining.

P containing chemicals are imported to Ontario, some of which may be used in the food industry as additives, food preservation, food processing, and cleaning. The most significant use of P in the chemical industry is as part of synthetic fertilizers. P flows through what is termed the "general chemistry" industry were estimated, as well as the P wastes that are assumed to be generated by metal corrosion prevention processes.

Fertilizer Imports

P is not mined or refined in Ontario so the local production of P containing fertilizers is assumed to be negligible. This assumption is supported by the similarity of the values of imported P in fertilizer (56,774 t/a) and the 52,274 t/a 2016 P fertilizer sales in Ontario.[213] Table 16 shows estimates for P associated with fertilizers based on imports to Ontario. These data were compiled from World Integrated Trade Solutions and Government of Canada Trade Data Online.[214] The table points to monoammonium phosphate, diammonium phosphate and NPK (nitrogen/phosphorus/potassium) as the main P fertilizers imported to Ontario.

A complete list of P fertilizers and their estimated P contents is found in Appendix D. Fertilizers with unknown compositions were compared to similar fertilizers with known P contents, such as diammonium phosphate (20% P)[215] , monoammonium phosphate (27% P)[216] or NPK fertilizer (14% P).[217] Given these assumptions, the P flows associated with fertilizer imports are approximate estimates only.

Table 16. Annual Estimates of Phosphorus Fertilizers and Phosphorus Contents Imported to Ontario

Product	Imports to Canada (t/a)	Percentage of National Imports to Ontario	Ontario Imports (t/a)	P content (fraction)	P (t/a)
Fertilizers, mineral or chemical; diammonium hydrogenorthophosphate (diammonium phosphate)	118,820	1.3	1,545	0.2	309
Fertilizers, mineral or chemical; phosphatic, n.e.s. in heading no. 3103	12,040	5.1	614	0.2	123
Fertilizers, mineral or chemical; phosphatic, superphosphates	940	-	0	0	0
Fertilizers, mineral or chemical; containing the three fertilizing elements N, P and K	193,400	20.8	40,300	0.14	5,642
Fertilizers, mineral or chemical; ammonium dihydrogenorthophosphate (monoammonium phosphate) and mixtures thereof with diammonium hydrogenorthophosphate (diammonium phosphate)	1,401,000	10.9	153,000	0.27	41,310
Fertilizers, mineral or chemical; containing nitrates and phosphates	21,442	27.2	5,841	0.2	1,168
Fertilizers, mineral or chemical; containing the two fertilizing elements P and K	2,845	45.6	1,299	0.2	260
Fertilizers, mineral or chemical; containing the two fertilizing elements N and P, other than nitrates and phosphates	539,834	7.27	39,246	0.2	7,850
Estimated total P in fertilizers imported to Ontario (t/a)					**56,774**

The total estimated Ontario P flows (t/a) across the fertilizer industry in Ontario are presented in Figure 46. It is assumed that the imported P fertilizer masses are dictated by farmers ordering them for the next season. While there may be some P loss during re-packaging for local shipment, is it assumed to be very small.

The estimated P flow as fertilizer to agriculture (56,774 t/a) is close to the 56,291 t/a fertilizer P-flow estimate in Section 3.2. Fertilizer imports to Ontario are also used for other applications such as golf courses, commercial, and personal landscaping. The fraction of imported fertilizer used for agriculture is unknown.

Figure 46. Phosphorus Flows (t/a) for the Ontario Fertilizer Industry

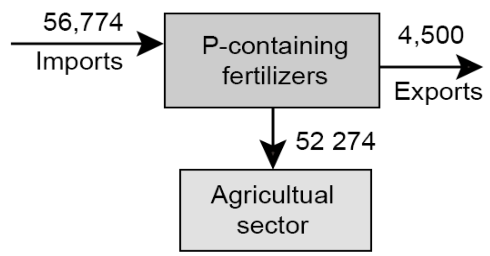
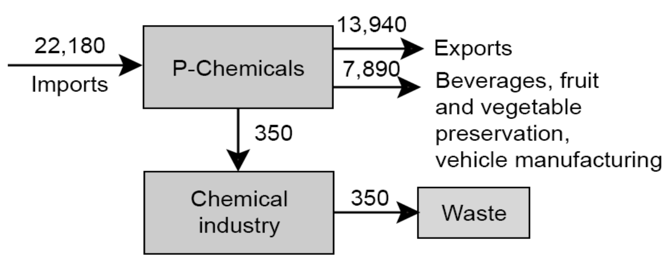


Figure 47. Phosphorus Flows (t/a) for the Chemical Manufacturing Industry



General Chemical Manufacturing

P, (poly)phosphoric acid, phosphates and phosphinates are the major P containing chemicals imported to Ontario. These chemicals have a range of uses, including for the manufacturing of beverages (e.g., phosphoric acid for cola production), food preservation, anti-corrosion treatment of vehicle parts, and other product manufacturing.

The amount of P in each imported chemical was calculated with the known mass fraction of P in each chemical and a known chemical formula (see Appendix D). Technical grade phosphoric acid is typically concentrated to 85%.[218] The flow in other P chemical imports was corrected by an assumed factor of 0.85 to account for impurities in technical grade chemicals.

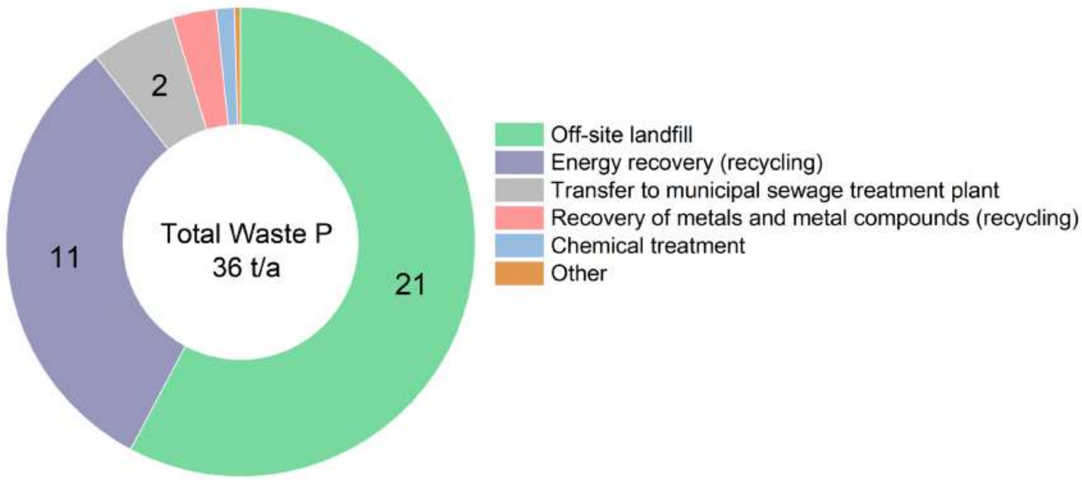
Figure 47 shows the estimated P flows for industrial chemical manufacturing in Ontario. The reported P inflow is equivalent to the P flows reported for this sector's waste streams. It is therefore assumed that negligible P is incorporated into the products being manufactured. P chemicals may serve different roles in overall chemical production processes, including as cleaning agents. There are no available data on the production of any P containing chemicals in Ontario, so it is assumed that they are not sold as products. Imported P chemicals are also used in other industries described in this report. However, the ratios of the imported P chemical masses to these other industries (e.g., food production and anti-corrosion metal processing) were not found. As over 7,700 t/a of P chemical are used by these industries, identifying the specific destinations of these P chemicals is considered to be an important next step.

5.2.6. Vehicle Manufacturing

As a global leader in the transportation and automotive industry, Ontario has expertise and leadership in automotive skilled trades, electrical vehicle production, and manufacturing and assembly.[219] The province has established itself as the second largest vehicle producing jurisdiction (by volume) in North America, and its transportation, motor vehicle, and parts industry accounts for a significant portion of the province's manufacturing output.

It was assumed that the major P uses for vehicle manufacturing include treating steel surfaces for corrosion resistance, and as cleaning agents. The magnitudes of these values as a fraction of the total chemical industry P flow are not known. An effective but hazardous corrosion resistance process involves contacting metal surfaces with hexavalent chrome (Cr(VI), a carcinogen) that is dissolved in an acid solution. To reduce impacts associated with using this anti-corrosion process, another chemical process was developed that uses a solution of hypophosphite (phosphinate, P(I)) and dissolved nickel (Ni(II)).[220, 221] Phosphinate is unstable, so it is created onsite by dissolving elemental white P (P(0)) in sodium hydroxide solutions. The type of P found in waste from the transportation industry and reported to the NPRI is assumed to be associated with this process. The chemical form of P in this waste is unknown, so its potential for recovery is also unknown. The NPRI vehicle manufacturing sector P-emission data are presented in Figure 48.

Figure 48. Phosphorus Flows (t/a) through the Vehicle Manufacturing Sector (2019)



5.2.7. Aquaculture

Aquaculture operations in Ontario provide 106 million meals (8,000 t) of farmed seafood yearly, contributing $122 million to the province's economy. The province produces brook trout, brown trout, arctic char, tilapia, Pacific white shrimp, barramundi, lake whitefish, baitfish species, and rainbow trout. P is an essential component of feed for aquaculture. Uneaten or excess feed and fecal matter from fish enter the environment from open-pen aquaculture in the form of particulate P that is deposited in the sediment in freshwater systems. It is estimated that 15% to 30% of applied feed is released as waste in aquaculture. Aquaculture effluent and wastes discharged from open-pen farming represents a P point source for aquatic environments, which can lead to polluted waters and sediments. While fish manure can be applied on land, this approach is limited by its heavy metal content.[222]

In 2019, the aquaculture industry in Ontario produced 5,574 t/a of rainbow trout and 313 t/a of other fish.[223] Lake-based, net-pen production in Georgian Bay and Lake Huron account for 90% of this production.[224] While overall production is relatively low, a 10% to 15% year-over-year growth in output has been projected for this industry.[225] The P concentration in rainbow trout is 226 mg P/100 g of raw fish.[226] This concentration allows for an estimation of 12 t/a P in rainbow trout production. The P in aquaculture waste has been estimated to be 10 kg P/t of fish produced.[227] Therefore, approximately 56 t/a P of rainbow trout aquaculture waste was estimated for 2019.

5.3 Database Analysis of Industrial Waste Streams

5.3.1 Method One: Upscaling to Determine Phosphorus Disposals and Releases

This section outlines an upscaling approach that is used to estimate P flows from Ontario manufacturing sectors and maps the estimated regional flows.

Methodology

The data sources used for the calculation of P flows the industrial sector are:

- **National Pollutant Release Inventory (NPRI)**[228] : Reporting facilities are identified by a 6-digit NAICS code (level 5 classification), their geographic coordinates, and number of employees. Data from the NPRI on P are available from 2003 onwards. For more information on reporting requirements under the NPRI, see p.26.
- **Industrial Wastewater Discharges (IWD)**[229] : Facilities are classified by sector, but this classification does not align directly with the NAICS. This database contains the amount of P released to water from 2004 onwards.

However, only the municipality, and not the coordinates of specific facilities are provided. Information from this database was used to scale up P emissions from industrial sectors reported by the NPRI.

- **Census data**[230, 231]: Statistics Canada's 2011 and 2016 census provided data on jobs by economic sector using a four-digit NAICS code (i.e., level 3 classification) within each census division (39 in Ontario). Census data was used for the purpose of upscaling P emissions from the industrial sector.

This approach used data from the NPRI as a primary source to identify the quantities, year, and location of P emissions by industrial facility. Facilities required to report to the NPRI are those that have more than 10 full-time employees, perform specific activities (e.g., incineration, wood preservation, wastewater treatment or fuel combustion), or manage substances above a certain threshold (i.e., more than 10 t/a of P). This means that the NPRI only contains data for a subset of facilities, including those that are largest in size, or manage more significant quantities of pollutants. In order to obtain a comprehensive and complete account of emissions in the province, it is important for the contribution from non-reporting facilities to also be estimated.

The approach followed to determine P flows from the industrial sector involved using data from the NPRI as a starting point and then determining an estimate for facilities that are not required to report. The number of employees at reporting facilities and the quantities of P released, disposed of and transferred were used to obtain a per-capita P coefficient by subsector, region, and year. This coefficient was then multiplied by the number of jobs (as reported in the census) in each industrial subsector, by region and year, to obtain an estimate of total releases, disposals, and transfers.

The following steps were taken in this upscaling process:

Determining P quantities from facilities reporting to the NPRI:

1. Data from facilities reporting to the NPRI was calculated first. The quantities of P released, disposed of, or transferred by facilities were summed and aggregated across census divisions by four-digit NAICS code (i.e., level 3 classification). These geographic and industrial classification resolutions were selected because they are the lowest available for jobs in the census data, allowing for comparison.

Determining P quantities for facilities not reporting to the NPRI:

2. The number of employees at NPRI-reporting facilities were also aggregated by census division and NAICS level
3. Jobs by NAICS level 3 and census division were obtained from the 2011 and 2016 census. Missing years were interpolated or extrapolated linearly.
4. An upscaling factor was used to account for facilities that are not required to report to the NPRI. The upscaling factor is as follows:

$$f_{y,g,m} = min\left[max\left(k_y \frac{J_{y,g,m}}{E_{y,g,m}}, 1\right), f_{max}\right]$$

Where:

$f_{y,g,m}$ is the upscaling factor for year (*y*), census division (*g*), industrial or manufacturing subsector (*m*)
$J_{y,g,m}$ is the number of census jobs determined in Step 3
$E_{y,g,m}$ is the number of employees from facilities reporting to the NPRI (Step 2)
f_{max} is an upper bound of the factor used to avoid extremely large values. A number of different values were tested and a value of 3 was deemed conservative to avoid overestimation.
k_y is a calibration coefficient calculated from IWD data

The rationale for using a calibration coefficient is to attenuate the ratio of census jobs to NPRI employees as they originate from different sources and are subject to different accounting methodologies so there could be a scaling discrepancy. This coefficient aims to capture that and is calculated per year using the subsector with the largest releases to water (i.e., paper manufacturing). Values from the IWD are considered as representing true total releases to water, and the calibration coefficient is calculated as follows:

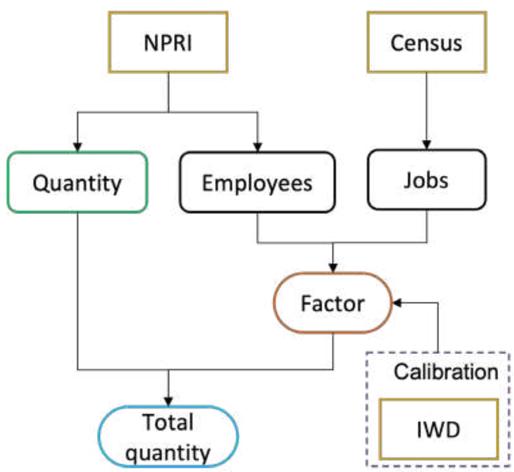
$$k_y = \frac{WaterReleases_y^{IWD}}{WaterReleases_y^{NPRI}} * \frac{E_{y,Prov,Paper}}{J_{y,Prov,Paper}}, \qquad \forall y.$$

Determining P quantities for facilities all facilities:

5. The factors from Step 4 are then multiplied by the quantities from Step 1 to obtain the upscaled values for releases, disposals or transfers.

Figure 49 provides a visual representation of the upscaling method used for this study.

Figure 49. Upscaling Method for Determining Phosphorus Flows from Industrial Facilities

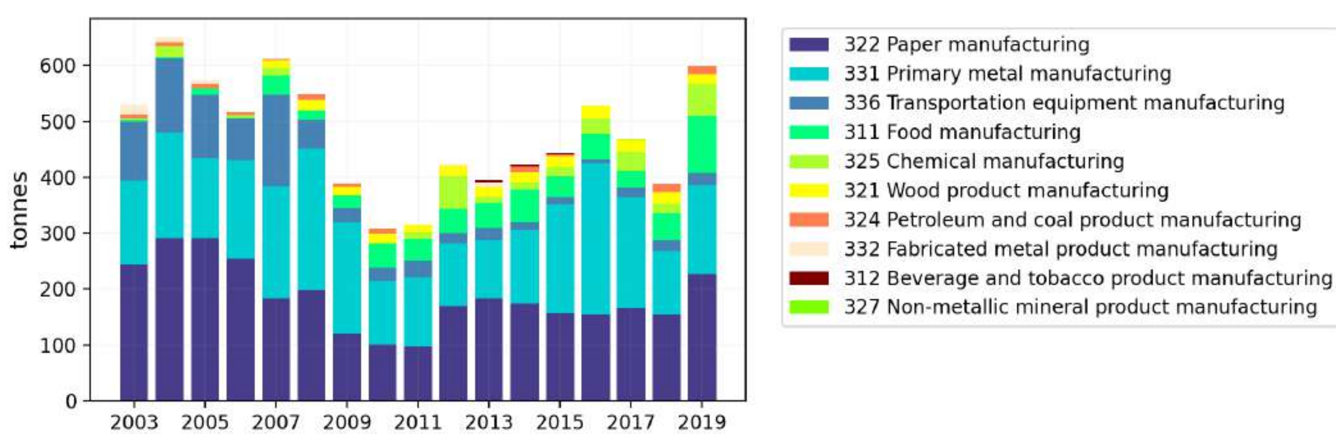


Phosphorus Flows from Industrial Facilities

Figure 50 shows that the most significant disposals of P from Ontario industrial facilities reporting to the NPRI are paper manufacturing and primary metal manufacturing. As such, these are the sectors with the greatest potential for the reuse and recovery of P. Total disposals are shown to have had an initial decline between 2008 and 2010, followed by a moderate increase from 2011 onwards.

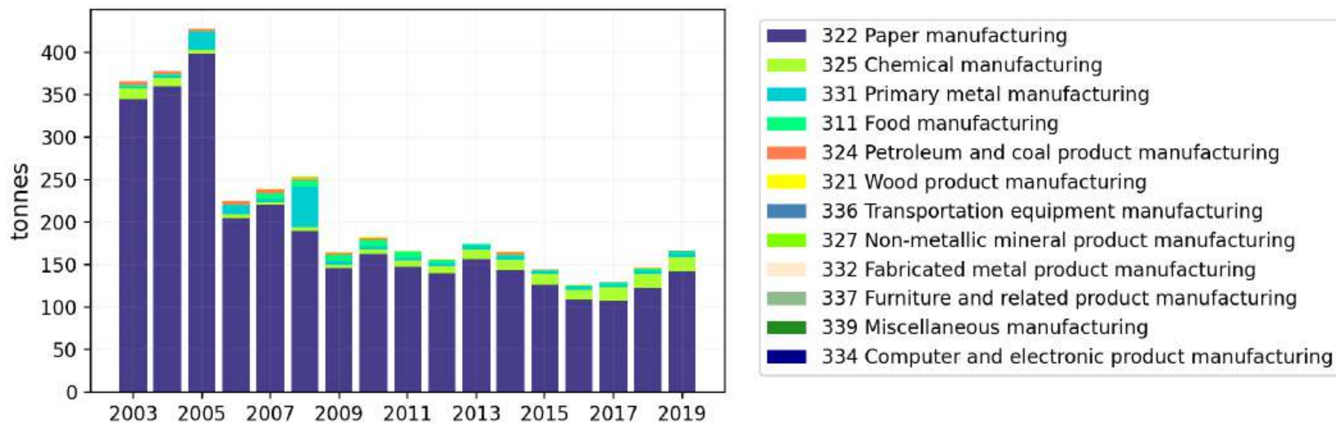
Figure 51 shows that in terms of total releases of P, paper manufacturing is by far the largest contributor. These quantities, which are presented at a more aggregated subsector level than those resulting from the upscaling process, point to paper manufacturing as the subsector with the greatest potential for P reuse and recovery. Total releases are shown to decrease significantly between 2005 and 2006 and remain relatively consistent from 2007 onwards.

Figure 50. Total Phosphorus Disposals by Industrial Manufacturing Sectors in Ontario (2003 – 2019)



*Note: Subsectors listed on the right appear ranked by the amount of P disposed of.

Figure 51. Total Phosphorus Releases by Industrial Sectors in Ontario (2003 to 2019)



*Note: Subsectors listed on the right appear ranked by the amount of P released.

Upscaled Industrial Disposals

In 2019, a total of 605.78 t/a of P were estimated to be disposed of from the overall industrial sector, using the upscaling approach. A total of 40% of these disposals were on-site and 60% were off-site. These quantities were calculated using a more disaggregated subsector level than shown in Figure 50 and Figure 51 to provide a more detailed view of emitting sectors. For this reason, the subsector names presented next in the upscaled quantities for disposals and releases may differ from those in these figures.

Table 17 outlines the largest contributors of P as upscaled disposals by subsector. The pulp, paper, and paperboard mills subsector contributed 37% (226.04 t/a) of P as disposals, while iron, steel and ferro-alloy manufacturing accounted for 22% (133.22 t/a). Table 18 outlines the census subdivisions where the largest disposals occur, with the top three being Thunder Bay, Durham and Middlesex. Thunder Bay is the location of several pulp, paper, and paperboard mills, including the largest complex in the country, while Durham is home to iron and steel mills and ferro-alloy manufacturing.

Table 17. Phosphorus Disposals by Subsector (2019)

Industry Subsector	Phosphorus (t)	Percentage (%)
Pulp, paper, and paperboard mills	226.04	37
Iron and steel mills and ferro-alloy manufacturing	133.22	22
Grain and oilseed milling	80.69	13
Basic chemical manufacturing	41.40	6.8
Motor vehicle manufacturing	24.09	4.0
Non-ferrous metal (excluding aluminum) production and processing	23.08	3.8
Dairy product manufacturing	20.17	3.3
Other subsectors	57.07	9.4
Total	**605.78**	**100.0**

Table 18. Phosphorus Disposals by Census Division and Industry Subsector (2019)

Census Division	Phosphorus (t)	Percentage (%)	Industry Subsector
3558 – Thunder Bay	159.7	26.4	Pulp, paper, and paperboard mills
3518 – Durham	112.5	18.6	Iron and steel mills and ferro-alloy
3539 – Middlesex	66.30	10.9	Grain and oilseed milling
3528 – Haldimand-Norfolk	41.40	6.8	Basic chemical manufacturing
3556 – Cochrane	32.56	5.4	Pulp, paper and paperboard mills
3537 – Essex	26.66	4.4	Grain and oilseed milling
3560 – Kenora	26.11	4.3	Veneer, plywood, and engineered wood
3552 – Sudbury	25.75	4.3	Pulp, paper, and paperboard mills
3554 – Timiskaming	23.08	3.8	Non-ferrous metal (except aluminum)
3525 – Hamilton	20.66	3.4	Iron and steel mills and ferro-alloy
3501 – Stormont, Dundas and Glengarry	20.17	3.3	Dairy product manufacturing
Other census divisions	50.89	8.4	-
Total	**605.78**	**100.0**	**-**

Upscaled Industrial Releases

In 2019, a total of 170.6 t/a of P were estimated to be released from the overall industrial manufacturing sector, using the upscaling approach. A total of 88% of these releases were to waterbodies, 9% to air, 3% to other media, and 0% to land.

Table 19 outlines the sectors that contributed the largest amounts of P as upscaled releases. The pulp, paper, and paperboard mills subsector was by far the most significant contributor, accounting for 82.7% (141.18 t/a) of P releases. Table 20 outlines the census subdivisions where the most significant releases occur, including Thunder Bay, Kenora and Sudbury.

Table 19. Phosphorus Releases by Industry Subsector (2019)

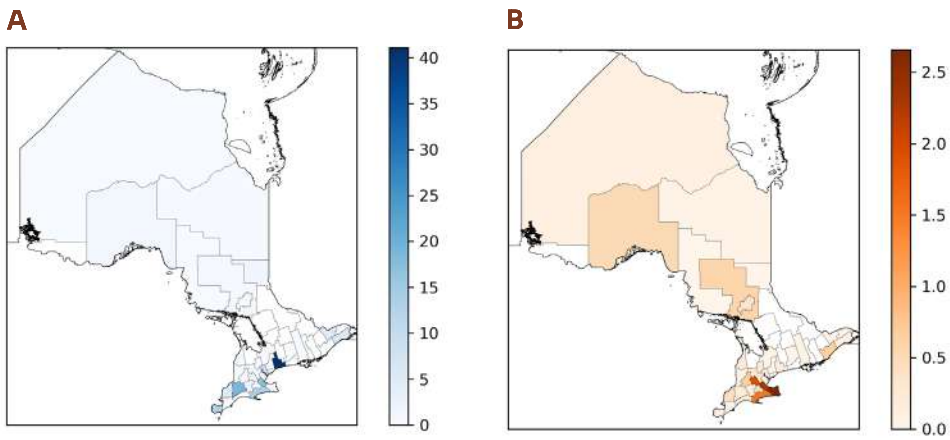
Industry Subsector	Phosphorus (t)	Percentage (%)
Pulp, paper, and paperboard mills	141.18	82.7
Pesticide, fertilizer and other agricultural chemical manufacturing	10.85	6.4
Basic chemical manufacturing	7.72	4.5
Other subsectors	11.01	6.4
Total	**170.76**	**100.0**

Table 20. Phosphorus Releases by Census Division and Industry Subsector (2019)

Census Division	Phosphorus (t)	Percentage (%)	Industry Subsector
3558 – Thunder Bay	61.15	35.8	Pulp, paper, and paperboard mills
3560 – Kenora	47.97	28.1	Pulp, paper, and paperboard mills
3552 – Sudbury	25.56	15	Pulp, paper, and paperboard mills
3556 – Cochrane	6.86	4	Pulp, paper, and paperboard mills
3526 – Niagara	47.97	28.1	Pulp, paper, and paperboard mills
Other census divisions	23.94	14	-
Total	**170.76**	**100.0**	-

Figure 52 shows the location of upscaled P disposals and releases from industrial manufacturing sectors by census division for 2019. The regions where P disposals and releases occur are primarily located in the north and southwest parts of the province.

Figure 52. Total Manufacturing Upscaled (A) Disposals and (B) Releases (2019) [kg/km²]

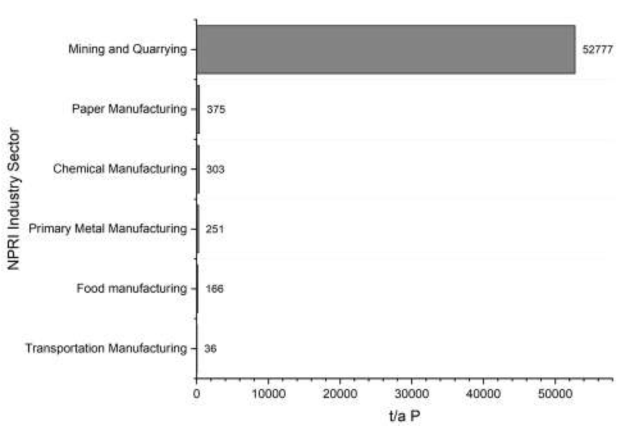


5.3.2 Method Two: Phosphorus Waste in Industrial Sectors

The 2019 NPRI P waste data in different industrial sectors include sub-classifications of waste destinations. In this section, the magnitudes of the P wastes in the different sub-categories for industrial sectors are presented and discussed. This section complements the overall P flow data estimates in Section 5.3.1.

Figure 53 shows P waste from key industrial sectors as reported to the NPRI in 2019. By far the largest P waste producers were mining sites.

Figure 53. Phosphorus Release Data for Ontario Industry Reported to the NPRI (2019)



Mining Waste

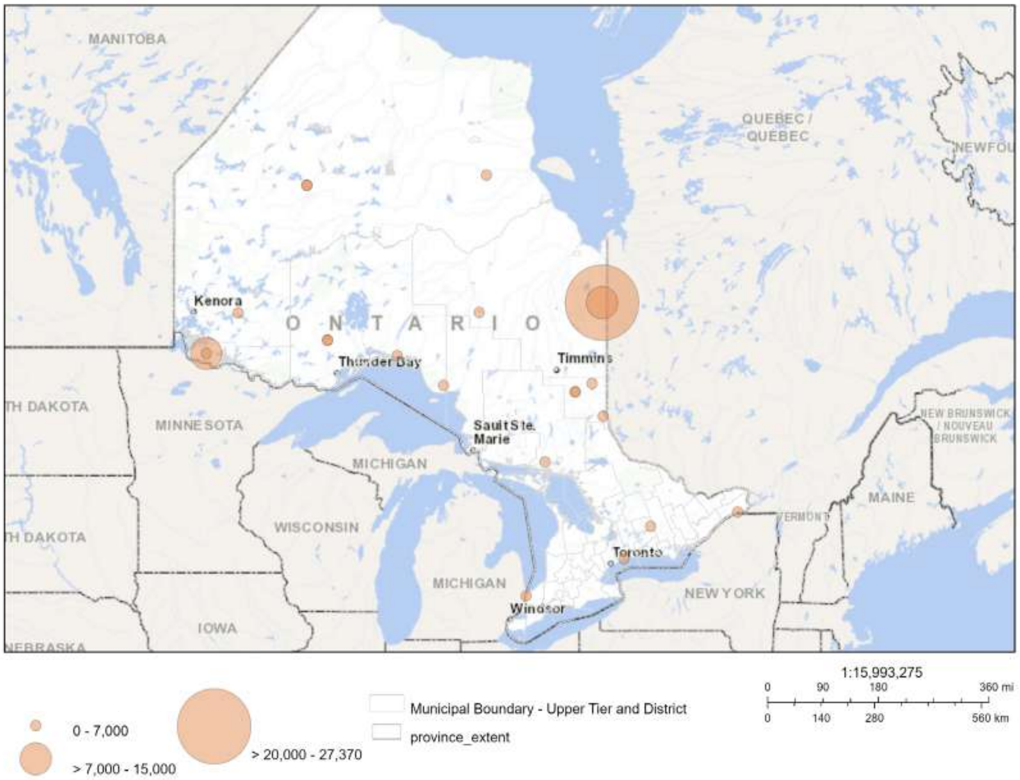
The mining industry in Ontario is active in diverse communities in Windsor, Goderich, Perth, Midland, Sudbury, Timmins, Red Lake, Kirkland Lake, Marathon, North Bay, and Attawapiskat. In 2020, Ontario generated $10.7 billion from mineral production.[232]

Northern Ontario was the site of a phosphate rock mine in Kapuskasing. While the mine closed in 2013, other mine sites in Northern Ontario generate a significant amount of waste rock and tailings that include P in amounts that are reported to the NPRI and *Ontario Toxics Reduction Act* - Reporting - Annual Reports.[233] The Detour gold mine[234], New Gold Rainy River mine[235] and DeBeers diamond mine, which closed operations in 2019[236], were the largest emitters of P in 2019.

Approximately 55,000 t/a of solid P waste from mining operations was reported to the NPRI in 2019. The P is in waste rock referred to as “tailings” — fine rocks produced by mineral processing and stored in tailings ponds — (~17,000 t/a) and from larger-sized waste rock (~36,000 t/a). An estimated 0.03 - 0.13 wt %P in these waste rock and tailings was calculated for the Detour and Macassa mining sites. The waste rock P concentrations are currently considered to be too low for economical P-recovery.

Figure 54 shows the significant magnitude of P in waste stored on-site at active mines in Northern Ontario as reported to the NPRI for 2019.

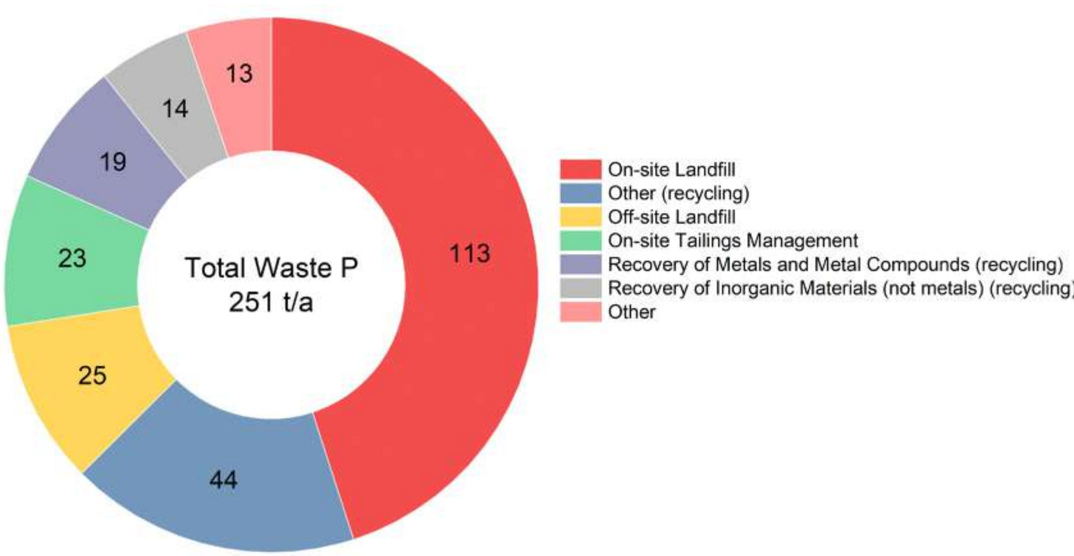
Figure 54. Phosphorus in On-site Storage at Active Mine Sites in Ontario (2019)



Phosphorus Waste for Primary Metal Manufacturing

Approximately 45% of P waste from metals manufacturing, including steel and other non-ferrous metals, was reported to be sent to landfill. On-site landfill was the largest P waste flow for this sector (113 t/a), followed by recycling (44 t/a) and off-site landfills (25 t/a). The slag by-product from steel production is not considered as a waste due to its reuse as a pozzolan feed for cement production.

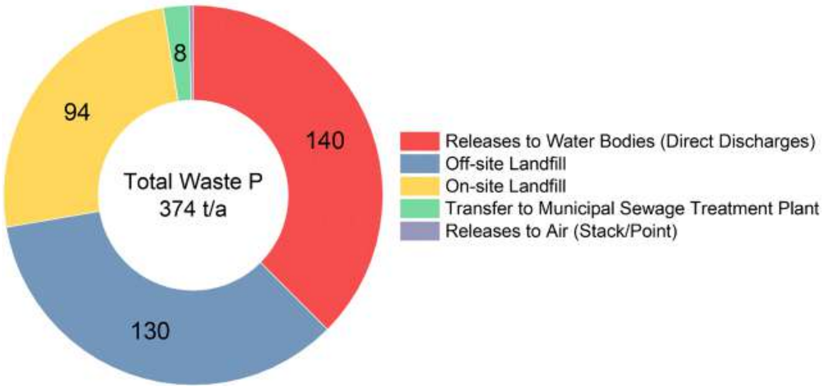
Figure 55. Phosphorus Flows (t/a) from Primary Metal Manufacturing by Waste Destination (2019)



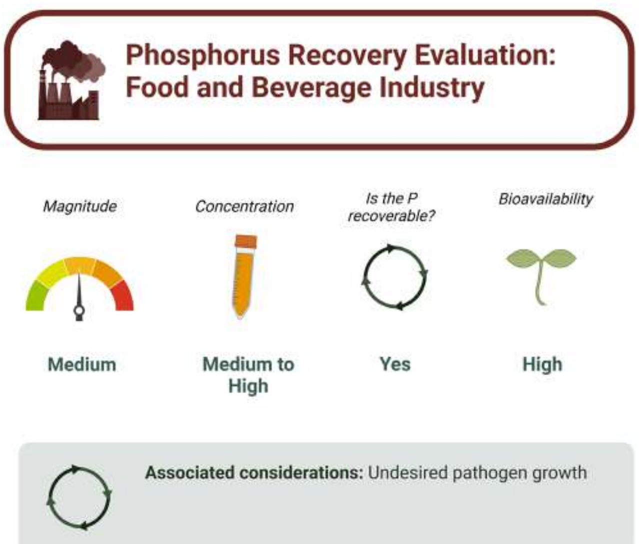
Paper Manufacturing

Figure 56 shows the destinations and amounts of P waste flows from paper manufacturing as reported to the NPRI in 2019. Approximately 60% (224 t/a) of P waste from paper manufacturing was sent to either on- or off-site landfill. Another 37% (140 t/a) was discharged to water. The upscaled estimate of P waste from paper manufacturing in Section 5.3.1 was less than 10 t/a lower than this estimate.

Figure 56. Phosphorus Waste Flows (t/a) from Paper Manufacturing by Waste Destination (2019)



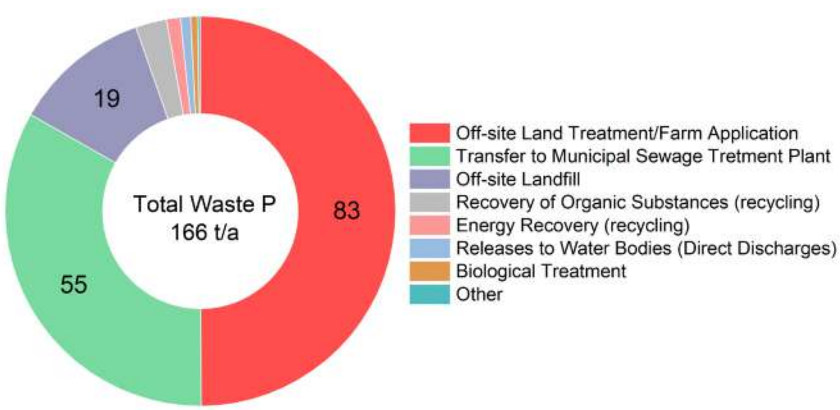
Food and Beverage Industry



The three food-related subsectors with the largest reported P wastes were grain and oilseed milling (120 t/a), dairy product manufacturing (37 t/a), and animal food production (10 t/a). NPRI data for 2019 were not available for beverage manufacturing. The NPRI P waste magnitude and destination values for food manufacturing are similar to the upscaled estimate (16 t/a) results in Section 5.3.1.

Figure 57 shows that approximately 50% (83 t/a) of the P waste from food manufacturing was applied to land, and 33% (55 t/a) was sent to municipal WWTPs.

Figure 57. Phosphorus Waste (t/a) from Food Manufacturing by Waste Destination (2019)



Chemical Manufacturing

Figure 58 shows P waste flows from chemical manufacturers as reported to the NPRI in 2019. The largest flow (145 t/a) was to recovery of organic substances (recycling). This might represent waste P in solvents that are sent to a third party to purify and return to the user. The total P flow values reported to the NPRI for 2019 (303 t/a) are similar to the 375 t/a estimate from the data estimate from import and export data, while the upscaled chemical manufacturing P waste estimate in Section 5.3.1 was 506 t/a. It is possible that the NPRI data underestimates the P waste magnitude, as smaller facilities may not meet the thresholds for mandated reporting.

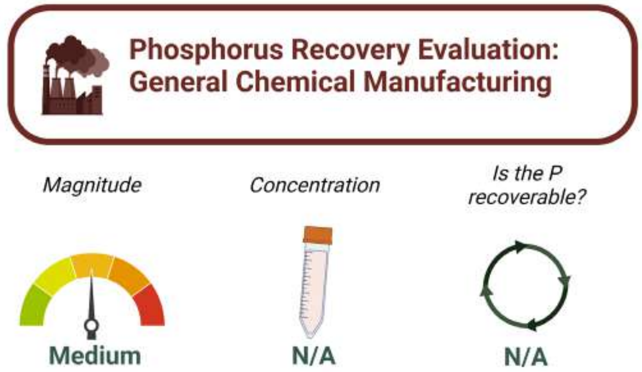
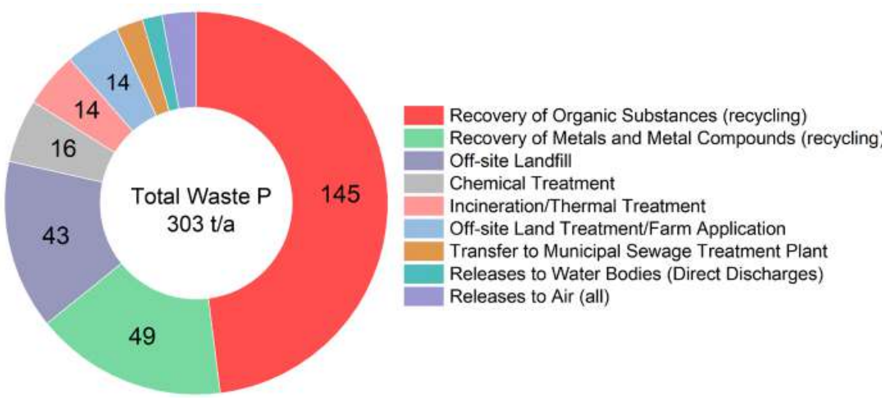


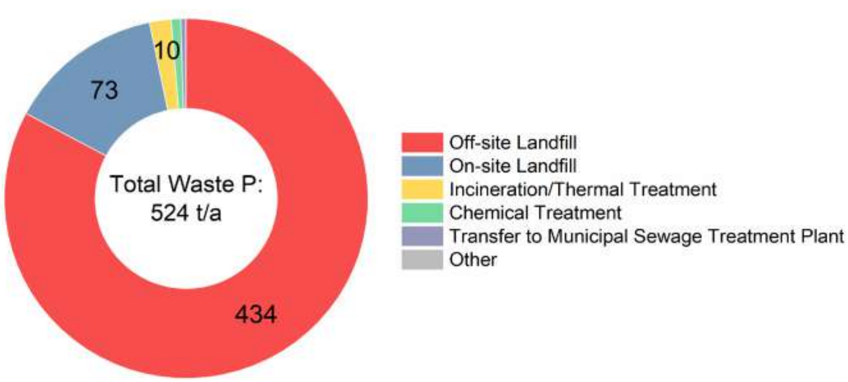
Figure 58. Phosphorus Waste (t/a) from Food Manufacturing by Waste Destination (2019)



Solid Industrial Waste

Figure 59 shows other solid industrial P containing waste flows reported to the NPRI in 2019. The P distribution shows that ~500 t/a were sent to on- or off-site landfills. The form of these P wastes is not known.

Figure 59. Phosphorus Waste from Solid Industrial Waste by Destination (2019)



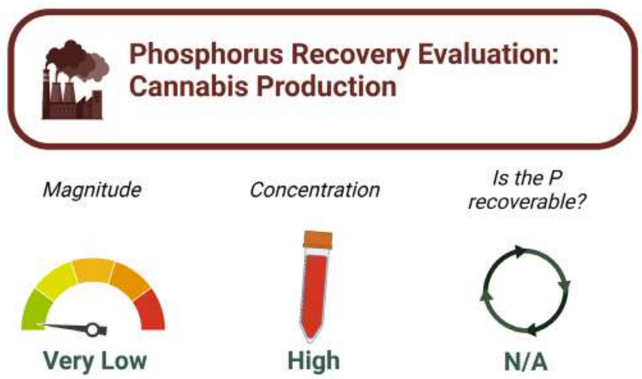
Electric Power Generation, Transmission and Distribution

Ontario currently generates 151 terawatt hours of electricity, comprising approximately 23% of all energy generated in Canada. The province has several diverse sources for electricity generation, the majority of which do not release P, including, 60% from nuclear, 26% from hydroelectricity, 7% from wind, and 2% from solar.[237] However, the remaining 4% of Ontario's electricity generation is sourced from natural gas and biomass combustion, the latter of which contains and releases P. Ontario's biomass combustion facilities are generally powered with wood waste, a process that releases stored P into the environment.[238]

In 2019, a total of 63 t/a of P was reported to the NPRI from electric power producers. Over 97% of the waste P was classified as "sent to on- and off-site landfill". It is assumed that this P is in the form of ash from combusted biomass.

Cannabis Production

Ontario has the largest number of registered cannabis businesses in Canada, with 112 establishments as of December 2020. In 2020-21, there were 99 million grams of cannabis sold in Ontario's recreational market, with $840 million in sales across retail stores and the Ontario cannabis store.[239] Cannabis crops are grown in various mediums, including soil, soilless, hydroponic, and deep-water culture. Essential nutrients that include P, are provided to the crop via traditional fertilization methods to the soil, or they are added as nutrient solutions to the hydroponic system.



Fertilizer use for cannabis cultivation is regulated under the *Fertilizers Act* and *Cannabis Regulations of Canada*.[240] The application of excess P is reported to be frequent among cannabis growers to promote flower development.[241] This contributes to liquid waste discharges in wastewater.[242]

The waste P produced by the hydroponic cannabis industry was not reported to the NPRI in 2019. Waste P available for recovery from cannabis production is dependent on the amount of the flow and the P concentration in purged hydroponic waters. An estimate of possible P waste flows from the Ontario cannabis industry was made based on the following assumptions:

- Approximately 2,780,000 commercial (not household) cannabis plants were reported by Statistics Canada in 2021.
- Approximately 37% of Canadian cannabis production industries were located in Ontario.[243]

Assuming equivalent establishment sizes, there were approximately 1,020,000 cannabis plants in Ontario.

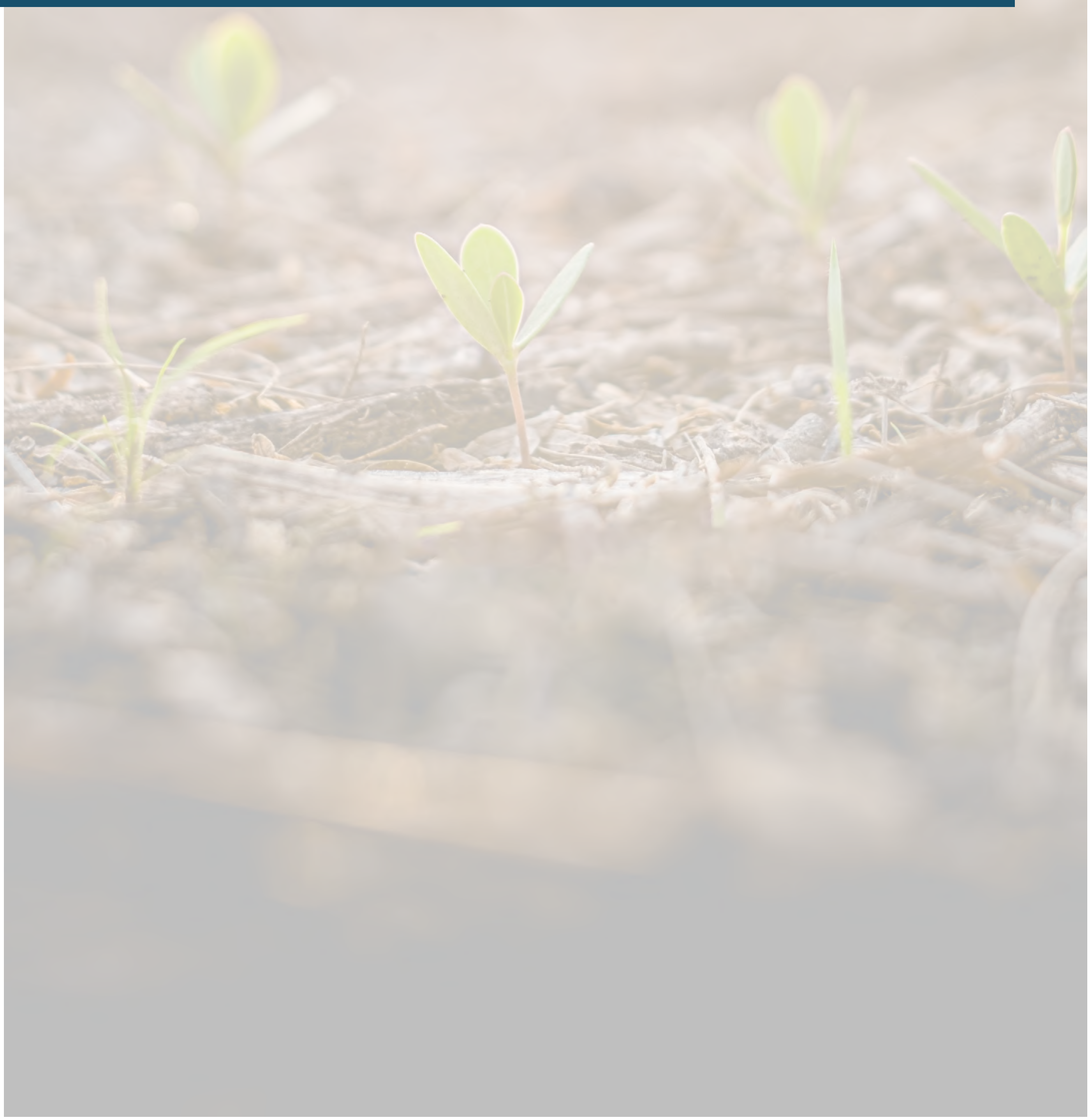
Table 21 shows the estimated P runoffs for each cannabis plant during its lifetime in different growing environments as a means of estimating P waste from cannabis cultivation.[244]

Table 21. Phosphorus Runoff from Cannabis Cultivation based on Growing Facilities Type

Nutrient	Outdoor Runoff (g/plant)	Indoor Runoff (g/plant)	Number of plants in ON	Total P runoff for outdoor cultivation (t/growing cycle)	Total P runoff for indoor cultivation (t/growing cycle)
Phosphorus	2.70 - 6.94	0.58 - 1.57	1,017,170	0.27 - 0.71	0.06 - 0.16

Section Six:

Opportunities and Next Steps



Opportunities and Next Steps

6.1 Summary of Findings

6.1.1 Agricultural Sector

- In 2019, P inflows and outflows associated with agricultural activities, including both livestock and crop production, were approximately 79,615 t/a and 70,437 t/a, respectively.
- The main inflows to the sector are in the form of synthetic fertilizers (56,291 t/a combined for open field crops and greenhouses) and livestock feed (21,815 t/a).
- The main P outflow (i.e., not including those transferred to another sector or activity) for the livestock sector is associated with manure production (30,583 t/a). Slaughterhouse waste had a P flow of 3,797 t/a in 2019.
- The P associated with animal imports for the province is estimated to be 1,509 t/a, while exports have a P flow of approximately 1,808 t/a.
- The most significant P outflows from crop production were as food products (42,823 t/a plus additional flows associated with meat, milk and eggs), crop residues (32,545 t/a), for ethanol production (6,203 t/a) and to the environment from erosion and runoff (5,022 t/a). The P in crop residues is typically transferred to the soil and that which is not taken up by plants may also find its way into the environment.
- P flows from greenhouses include inflows in the form of fertilizer (506.2 t/a) and outflows as agricultural products (403.1 t/a), GNF systems (103 t/a) and household septic systems used by the labour force living in the vicinity (2.6 t/a).

6.1.2 Urban Sector

- The P flow associated with WWTPs is estimated to be approximately 6,391 t/a (5,491 t/a solid and 900 t/a liquid). However, as noted in this report, this quantity should be used with caution as it may contain double counting where one WWTP may disposes of P by sending it to another WWTP. An estimated 1,445 t/a of P is attributed to waste from the province's septic systems.
- Stormwater runoff in urban areas can transport P from lawn fertilizer, sediment, leaves and landfill as it moves across land, eventually ending up in nearby bodies of water. The P transported by urban stormwater is affected by multiple factors, including the amount of rainfall, slope and the design of the urban drainage systems. The P flow through urban stormwater is estimated to be 881 t/a based on the use of an export coefficient of 119 kg/km2/year for the province.
- The average P content based on the maximum handling capacity of Ontario anaerobic digestion and composting facilities is 1,402 t/a and 2,118 t/a, respectively. The remainder of organic food waste goes to landfill due to a lack of handling capacity.

6.1.3 Industrial Sector

- P flows associated with the manufacturing sector were estimated to be approximately 775 t/a, of which 605 t/a are from disposals and 171 t/a are from releases.
- Sectors with the most significant P flows include:
    - Pulp, paper and paperboard mills
    - Iron and steel mills and ferro-alloy manufacturing
    - Grain and oilseed milling
    - Basic chemical manufacturing
- An estimated 55,000 t/a of solid P waste from mining operations was reported to the NPRI in 2019 in Ontario. However, the P in mining waste is naturally contained in the ore and is very dilute. This, combined with the remote location and expense to recover P from this ore point to is not being a suitable candidate for P recovery and reuse, particularly in the short-term.

- The largest inflow of P is associated with imports to the chemical industry (22,000 t/a). An estimated 11,700 t/a of P flows into the Ontario steel industry as raw materials, while approximately 2,610 t/a of P flows into the forestry industry.
- The chemical industry (22,180 t/a), dog and cat food manufacturing (8,400 t/a), steel (6,700 t/a as slag), dairy (3,110 t/a), grain and oilseed (2,370 t P/a) and forestry (2,260 t/a) industries were identified as those industries with the most significant P outflows.

6.2 Opportunities for Phosphorus Recovery and Reuse

The findings from this report point to the most significant P flows in the province being associated with agriculture. While key waste streams from agriculture include manure and slaughterhouse waste, a large amount of P is also found in the food products that leave the sector and which are consumed by citizens. In turn, this P eventually finds its way into various urban waste streams (e.g., municipal WWTPs, food and organic waste, septic systems).

The magnitude or concentration of P associated with the flows in the agriculture and urban sectors, along with their accessibility, point to their potential as promising options for NRR. A number of technologies aimed at recovering P from these flows are currently in development, being piloted or already in the market (see Table 1 and Appendix F). By contrast, solutions geared towards many of the various industries outlined in this report are not as advanced, which may be due in part to complexities related to implementation or the fact that these P flows are less significant in magnitude. However, this should not prevent decisions-makers, industry and a wide range of stakeholders in seeking solutions, where benefits can be demonstrated.

This section explores potential opportunities for recovery and reuse associated with the flows outlined in this report. It also spotlights technologies currently being piloted or available in the market, providing a set of practical examples that point to the feasibility of P recovery and reuse in Ontario.

6.2.1 Agricultural Recovery and Reuse Opportunities

Manure

While the concentration of P in manure is relatively low, the significant quantity produced results in a large P flow. Manure can be applied directly to the soil, but it is bulky and expensive to transport, making this option more suited to fields located in close proximity to where it is generated. Manure from farms also has the potential to be collected and processed using on-site NRR technologies, particularly at large, intensive livestock facilities that have the necessary scale. However, while the P in manure has the potential to be recovered and reused, it is present in both inorganic and organic forms. Inorganic P is not associated with organic materials, is water soluble and available for uptake by crops. It is mostly present in the liquid portion of manure or bonded to soluble minerals. Organic P is formed by is typically bound by animal or crop tissues and is found primarily in the organic fraction of manure (primarily solid), chemically bonded to carbon. Organic P requires a mineralization process to be converted to an inorganic form for uptake by crops.

Case Study: MagPi (Muddy River Technologies Inc.) (P Recovery and Reuse)

MagPi (Magnesium Phosphorus Innovation) is a P removal and harvesting technology created by Muddy River Technologies Inc. in Delta, British Columbia. MagPi was one of the top 10 technologies competing for the Everglades Foundation's George Barley Water Prize. MagPi is a four-stage electrochemical process that uses electric current to dissolve a magnesium anode to form magnesium ammonium phosphate (struvite), thus removing P in the form of a slow-release fertilizer. MagPi is used to harvest struvite on farms, from food processing plants, water, and wastewater treatment plants. MagPi equipment has been used to treat manures, sewage, greenhouse and food processing waste, and algae ponds, reducing total and dissolved P by up to 90%. With support from ECCC's Great Lakes Protection Initiative, Muddy River is currently demonstrating MagPi's recovery of P from dairy cattle manure at a farm in Alma, Ontario, in the Lake Erie Basin.

For more information, visit: www.muddyriver.ca

Case Study: Microwave-Advanced Activation-Oxidation Process (Boost Environmental Systems) (P Recovery and Reuse)

BOOST Environmental Systems is a Vancouver-based waste management company providing custom process design solutions for wastewater treatment plants, livestock farms, and food waste industries with enhanced energy and phosphorus recovery. BOOST's Integrated Waste Treatment System combines their Microwave Advanced Oxidation Process (MW-AOP) with their P recovery technology and methane production.[245] The MW-AOP liquifies waste solids ahead of the digestion process (i.e., it is installed upstream of an anaerobic digester), thereby enhancing the efficiency of the digestion process, and allowing for the use of smaller digesters, minimizing the total volume biosolids, and increasing biogas production, while reducing the associated operating costs. It is estimated that the MW-AOP can increase capacity at the anaerobic digester by more than double, while cutting energy usage by more than half and creating quality renewable natural gas (RNG) for use or sale to the grid. The technology is also estimated to shrink biosolids by approximately 75%.[246]

The process can be used for large dairy applications and for municipal WWTPs. The MW-AOP is space-efficient and removes 80% of total suspended solids in municipal sewage sludge and 40% of solids in liquid manure. A struvite process can also be added downstream of the anaerobic digester, making P available for recovery in the form of phosphate pellets, or struvite, using Ostara's Pearl® nutrient recovery technology. The resulting struvite can also contribute to revenue streams when being sold to the gardening sector or as part of a commercial agricultural fertilizer mix.

Pilot Studies

BOOST has piloted their MW-AOP technology for different applications, including tests at the UBC Dairy Education and Research Centre (Agassiz, BC), the Metro Vancouver Wastewater Treatment Plant (Delta BC), and a current 2-year study at the James Wastewater Treatment Plant (Abbotsford, BC).

With 525 cows on site, the UBC Dairy Education and Research Centre generates an output of ~7100 kg of P each year. BOOST's technology breaks down the solid portion of the manure and releases nutrients from the liquid portion. The MW-AOP process allows for the recovery of struvite (magnesium ammonium phosphate) to be converted into a slow-release fertilizer. This pilot proves that the novel technology is one of many feasible and sustainable ways to recover phosphorus as a means for efficient dairy waste management.

The James WWTP produces ~5,200 tonnes of biosolids per year, and this amount is expected to increase by 50% over the next 25 years. The installation of the MW-AOP system is predicted to reduce biosolids by an estimated 57%. BOOST technology use in a WWTP produces a solution rich in nutrients, like ammonia and phosphates, which can be recovered in the form of struvite. Additional integration of struvite recovery technology (i.e., Ostara's Pearl® nutrient recovery technology) has been considered for the project, which would provide estimated cost recovery in five to seven years.[247]

For more information, visit: https://boostenviro.com/

Slaughterhouse Waste

As previously noted, slaughterhouse waste contains a significant amount of P with the potential for recovery. Many slaughterhouses in Ontario discharge their wastewater into municipal systems after on-site treatment. Currently, P recovery from slaughterhouse wastewaters is performed through chemical precipitation using aluminum or iron compounds. The product obtained is a sludge containing the precipitated P and involving additional disposal costs. The use of commercial struvite production processes for the treatment of slaughterhouse wastewaters has been studied by the Australian Meat Processor Corporation*. In a 2018 study, chemical P precipitation was compared with struvite production, concluding that struvite precipitation might be feasible, provided appropriate economies of scale. This would help to avoid the use of the harmful chemicals required in traditional chemical precipitation processes and allow the P from slaughterhouse waste to be reused in the form of fertilizer.

Greenhouses

One of the main P outflows from greenhouses are discharges from GNF systems. The optimization of feedwater usage can be one of the most important ways to avoid P discharges to the environment, while also decreasing the volume of water required for P recovery and associated costs. Different processes have been proposed for P recovery at greenhouses, including the use of end-of-pipe wetlands or the implementation of bioreactors with the capacity to remove P from GNF discharge streams.[248] The use of precipitation processes for P recovery from greenhouse wastewaters have also been studied, with findings pointing to the potential for more that 90% of P to be recovered, primarily in the form of hydroxyapatite.[249]

Crop Residues

Straw and stover waste are commonly left in fields after harvesting for the purpose of improving the soil for crop production by supplying organic matter and nutrients, including P. While P recovery from crop residues is not well-developed, advances in processing techniques (e.g., thermal processes[250], chemical and supercritical extractions[251], the use of ionic liquids[252], etc.), point to potential future opportunities for recovery and reuse of P from straw and stover, and other crops.

Agricultural Fields

The reuse of P by plants is the predominant means of addressing legacy P in agricultural fields, as P recovery in this situation is challenging and unnecessary. The adoption of precision agriculture techniques where the appropriate amount of P (as synthetic fertilizer or manure) is applied to croplands at the correct time to reduce losses, is considered one of the most effective ways of reducing P releases from agricultural lands to the environment. When application rates are tailored to specific sites, this approach has been shown to decrease the amount of P required for application by 12% to 41%.[253] Despite challenges, the recovery of P from soil using tile drainage systems, such as the use of sorption materials or constructed wetlands, is also being explored.[254, 245]

Case Study: Vegetated Buffers and Vertical Wetlands (P Recovery)

Agricultural runoff — water that washes over fields that can contain pesticides, sediment and nutrients — is a prominent non-point source of P in waterways. Vegetated buffer strips comprised of grasses, shrubs, and trees can be installed at the boundaries between farmlands and bodies of water to protect the environment from the impacts associated with the pollutants found in runoff. As the runoff drains through the buffer strip, are intercepted by the vegetation.

According to the Land Application Standards in the *Nutrient Management Act of Ontario* (2002), nutrient application within an agricultural operation is prohibited unless there is a vegetated buffer zone 13-meters from the top of the nearest bank of the surface water.[256] A "vegetated buffer zone" is defined as an area with

*Australian Meat Processing Corporation (2018). Struvite vs traditional chemical phosphorus precipitation what option rocks? Retrieved from: https://www.ampc.com.au/

"a width of at least three metres" that "is maintained under continuous vegetated cover, including perennial grasses, trees, and forage crops". While buffer zones can play an important role in reducing the amount of pollutants, including nutrients, that reach waterbodies from agricultural lands, spatial constraints an make it difficult to incorporate them, particularly in small to medium sized farms. The application of vertical wetland systems in agricultural field boundaries may offer a space-efficient solution for farmers for run-off mitigation and nutrient-capture. Vertical wetland systems mimic the properties of natural wetlands by incorporating beneficial plant species as a filter bed. Scheduled harvesting of wetland plants, like cattails (Typha sp.) and reeds, provide opportunities to remove nutrients, like nitrogen and phosphorus captured from agricultural runoff, from the system. The Lake Winnipeg Bioeconomy Project is an example of where the use of biomass, including cattail and other marsh grasses, has been explored as a solid fuel to replace coal for rural heating.[257]

A number of studies have looked at the feasibility of nature-based technologies that are easy to manage and maintain, like vertical wetland systems. While typically used in urban or domestic context, their applicability for agricultural wastewater has also been explored. A combined analysis by Beasley et al. (2018) and design by Fischer et al. (2018) examined the feasibility for a vertical wetland project to collect agricultural runoff from tile drainage output in the Lower Thames area of the Lake Erie watershed.[258] The study identified the need for site-specific customization (e.g., substrates choices, use of native plant species) and acceptance by farmers as some of the constraints to implementing these structures. Cost reductions, lower maintenance and environmental outcomes are potential opportunities. It was estimated that the vertical wetland design had the potential to remove 3.37 kg of P yearly, under optimal conditions.[259]

6.2.2 Urban Recovery and Reuse Opportunities

Co-Digestion

Phosphorus-containing wastes can be a source of renewable energy like methane or hydrogen.[260] Anaerobic digestion is a process where bacteria break down organic matter (e.g., food scraps, manure, sewage sludge) in the absence of oxygen. The anaerobic digestion process produces biogas that is primarily composed of methane and carbon dioxide, and which can be used as an energy source similar to natural gas.[261] The solid residual can be applied to land or composted and used as an amendment for soil. Co-digestion refers to the simultaneous anaerobic digestion of multiple organic wastes in one digester, typically food and organic wastes processed alongside sewage sludge or agricultural wastes at WWTPs or large-scale farms, respectively.

Co-digestion projects leverage existing anaerobic digestion infrastructure to process organic waste and generate value through the production of biofuels and the recovery of nutrients, like P. There are a wide range of choices for co-digestion feedstocks, including restaurant or cafeteria food wastes, food processing wastes or by-products, fats, oil and grease (FOG) from restaurant grease traps, energy crops and crop residues. The process can be used to increase methane production from low-yielding or difficult to digest materials. Co-digestion also provides opportunities to generate revenue through the production of local organic non-mineral fertilizers, which can be marketed commercially without having to build new stand-alone facilities. The co-digestion of agricultural, sewage, food, and organic wastes provides additional benefits to municipalities with anaerobic digestion facilities, including the diversion of materials from landfills, the production of biogas and the incentive to economize conventional anaerobic digestion technology.

The Food and Organic Waste Policy Statement issued in 2018 references co-digestion, stating that "Municipalities are encouraged to plan for the management and beneficial use of biosolids, including considering new and enhanced biosolids processing technologies and co-management practices that support volume minimization and nutrient recovery."[262]

Case Study: Thermal Hydrolysis (P Recovery)

Lystek's Thermal Hydrolysis Process uses high-speed shearing, alkali, and low-pressure steam injection to disintegrate microbial cell walls and hydrolyses complex macromolecules into simpler compounds. The technology processes digested or undigested residuals into a biosolid fertilizer and multi-purpose hydrolyzed product. LysteGro® is a class A quality biosolid in the U.S. and a registered fertilizer with the California Department of Food and Agriculture and the Canadian Food Inspection Agency.

For more information, visit: https://lystek.com

Municipal Wastewater Treatment Plants

Case Study: Co-digestion at Wastewater Treatment Plants (P Recovery and Reuse)

It is estimated that only 20% of municipal WWTP potential for methane abatement is currently being used.[263] Ontario's Food and Organic Waste Framework's Policy Statement notes that "Existing wastewater treatment infrastructure may be considered for acceptance of source separated food waste, where there exists (or can be created, for example through approaches such as optimization, infrastructure upgrades or adoption of advanced technology) excess capacity to create high-value end products", like commercial fertilizers.[264] There is an opportunity for municipalities to leverage the existing capacity at WWTPs to reduce greenhouse gas emissions, capture the energy generated, and divert organic waste from landfills for co-digestion and nutrient recovery.[265] Municipalities divert organic waste from landfills and send it to WWTPs to be co-digested to produce biogas.

Recently, the Ontario Clean Water Agency and Ontario Water Consortium launched the Municipal Co-Digestion Initiative, joining municipalities, industry stakeholders, utilities, and regulators to shape the shift towards resource recovery and energy neutrality at WWTPs.[266] The City of Stratford, the Town of Petawawa, and the City of Cornwall are currently involved in the initiative, while other municipalities across Ontario have also begun to explore leveraging their existing WWTP anaerobic digester for co-digestion opportunities.[267]

The City of Cornwall's Strategic Priorities 2019-2022 outlines a co-digestion solution to municipal organic waste as an undertaking that would reduce energy usage and GHG emissions, while contributing to sustainability goals. In support of this goal, the City conducted two feasibility studies from 2020 to 2021 to explore, assess and establish the basis for further organic waste diversion and resource recovery, including through co-digestion at their WWTP.[268] The studies found that with the proposed co-digestion facility, biosolid production would increase, with the potential to use the biosolids as compost with an added pasteurization and screening system. Additional materials, like P, struvite, cellulose, and other minerals could also be extracted from the process.[269]

Case Study: Ostara Nutrient Recovery Technologies (P Recovery and Reuse)

Struvite (magnesium ammonium phosphate) mineralization and accumulation is a common problem within WWTPs, with a high associated cost to control and prevent build-up within their operations. If left untreated, struvite crystals form rock-like formations within WWTP infrastructure and can cause blockages or clog up the equipment. Preventing the damage caused by struvite precipitation in WWTP valves and pipes is another benefit of P recovery from these facilities.[270]

Ostara's proprietary Pearl® technology recovers nutrients from industrial, agricultural and municipal wastewater treatment streams and transforms them into granular fertilizers. Pearl® is a customizable and modular treatment solution that fits into main or side-stream operations, removing P from the treatment system by adding magnesium in a controlled pH setting. This allows the nutrients to crystallize into inorganic, slow-release fertilizer granules that are harvested, dried and bagged, and marketed as Crystal Green®.

Ostara's Waste Activated Sludge to Remove Internal Phosphorus (WASSTRIP®) technology is a value added to Pearl® for facilities that use anaerobic digestion. The WASSTRIP releases P upstream before it reaches the digester, improving nutrient removal and recovery, while also protecting equipment from struvite, improving dewaterability and reducing biosolids. Ostara operates internationally, with 23 Pearl® commercial systems worldwide, approximately 17 KT of annual fertilizer production, 400,000 hours of Pearl® system operational experience, and 13.3 million people serviced by Ostara's nutrient recovery system.[271]

In Canada, Ostara technology is currently used by the City of Saskatoon, SK, and EPCOR Water Services, in Edmonton, AB. The nutrient recovery system in Saskatoon's WWTP reportedly recovers about 300 tonnes of P-rich granular fertilizer each year. Ostara notes that WWTPs can anticipate a return on investment in the technology after five years of use, based on the associated reduction in operational costs (e.g., dewatering and disposal costs, biosolids management, energy use, maintenance and replacement costs associated with the accumulation of struvite) and additional revenues from the resale of the fertilizer product.[272] Ostara's Crystal Green meets the fertilizer specifications of the Canadian Food Inspection agency and is sold to farmers of broadacre crops primarily in Alberta, Manitoba, and PEI.[273] Crystal Green is currently being tested for yield and P in leachate by the University of Guelph, with support from ECCC's Great Lakes Protection Initiative and MITACs.

For more information, visit: www.ostara.com

Septic Systems

P recovery from septic systems would be difficult due to their simplicity and small scale. However, the environmental impact of P discharges into the environment can be mitigated by promoting the maintenance of these systems, as well as ensuring that they are not installed in vulnerable environments. In addition, certain consumer practices can contribute to reducing the potential for the release of P from septic systems, such as the use of P-free detergents.

Stormwater

Actions to manage P in stormwater are primarily related to reductions at the source (e.g., using appropriate lawn fertilizers, ensuring litter and pet waste is disposed of appropriately, etc.,). P releases from drainage systems can be mitigated by implementing retention systems prior to their discharge, such as artificial wetlands and other bioretention structures, and sand filters.

6.2.3 Industrial Recovery and Reuse Opportunities

Case Study: Co-digestion from Food and Beverage Processors (P Recovery and Reuse)

StormFisher Environmental is leading many co-digestion projects in Ontario, using their digestate technology for nutrient recovery from food and organic wastes. In alignment with Ontario's Food and Organic Waste Policy, StormFisher works with food processors (e.g., Maple Leaf Foods), brewing companies (e.g., Labatt) retailers, and waste hauler to process organics (municipal source separated organics; industrial, commercial, and institutional waste; packaged food waste; liquid food waste; and solid food waste) and produce renewable energy and a Canadian Food Inspection Agency registered granule and liquid fertilizer, called Cycle Organic and Cycle Liquid.

Case Study: Econse Water Purification Systems (P Recovery)

Econse Water Purification Systems' BrüClean, is an integrated treatment system designed for small and large craft breweries and brew pubs to process their wastewater. Many craft breweries in Ontario are located in rural areas outside of the service areas for WWTPs. BrüClean's small footprint is ideal for craft breweries, providing an on-site treatment solution for their wastewaters. BrüClean uses electrocoagulation, which involves a reactor and metal electrodes, in combination with liquid and solid separators to bind P. Econse was one of 10 semi-finalists in the George Barley Water Prize, and BrüClean has been installed at various craft breweries in Ontario, including Bench Brewery (Niagara) and Fenelon Falls Brewery (Kawartha Lakes Region). BrüClean's treatment provides an average reduction of P from 93 mg/L to 2.6 mg/L, after treatment.[274] The company's Water Purification System can be used for agricultural wash water and greenhouses, including those for growing cannabis. Crystal Green is currently being tested, with support from ECCC's Great Lakes Protection Initiative and MITACs, by the University of Guelph for yield and P in the leachate.

Case Study: Aqua Treatment Technologies

Aqua Treatment's three-celled AQUA Wetland System contains synthetic liners, sand/gravel medium, and cattail plants, while P is coprecipitated — a type of precipitation where soluble compounds in a solution are removed during the course of precipitation — with iron, aluminum, and calcium compounds in the root bed.[275] These systems have been implemented to treat sanitary sewage, winery wash water, agricultural wastewater, landfill leachate, and greenhouse irrigation leachate water in various locations in Ontario. A vertical flow constructed wetland designed and installed by Aqua Treatment Technologies for treating winery process water and domestic sewage was piloted at a winery in Niagara, Ontario. Conventional options for treating winery wastewater are considered ineffective due to their large organic load, and fluctuating quantity and quality of wastewater, dependent on the season and winery production schedule. Six-year period performance data from the pilot showed that average treatment efficiencies were 83% for TP.[276]

6.3 Select Policy Frameworks

While this report has highlighted the potential suitability of various P flows in Ontario for recovery and reuse and pointed to existing NRR technologies, barriers to their adoption and implementation remain. As is true with many emerging technologies, their viability will require that the social, environmental and financial needs of those using them are met. It has been shown that emerging technologies experience challenges breaking through, not because of the merits of the technology itself, but because associated regulations, infrastructure and user practices are aligned with an existing structure.

It has often been argued that the successful establishment of technologies that have a high social or environmental return, but perhaps a lower private return in the beginning, require a strong policy framework to support the transition during their initial adoption phase. Uncertainty and limited understanding of long-term benefits often plague innovation, increasing the challenges of bringing new technologies to market and generating sufficient enthusiasm for widespread adoption. This is an important consideration for NRR where capital costs may initially overshadow the significant long-term remediation costs that they help to avoid, along with the considerable benefits of reducing P from sources like agriculture. However, the increasing cost of synthetic fertilizers and the dependence on foreign imports of phosphate rock promise to dramatically influence the value proposition for NRR technologies in the near future and it will be important for Ontario, and Canada more broadly, to be prepared.

While a number of policy instruments have already been introduced globally to support NRR, with European nations shown to be early movers, P management strategies in Ontario to-date have focused primarily on preventative measures to limit its release into the environment.[277] A recommendation emerging from the 2018 NNRR conference in Toronto was the need to recognize P as a limited strategic resource, with a specific policy that would enable recovery and reuse within a sustainable national NRR framework, similar to what the EU has done. Identifying P as a key resource for food security has been critical for driving NRR technologies and strategies in the EU.

Despite the absence of a provincial or national framework specific to NRR, a number of enabling policies related to the circular economy, waste reduction and prevention of environmental impacts, including eutrophication, are being pursued in Canada and Ontario that can complement and be leveraged to support the successful deployment of NRR technologies. At the same time, certain policies have the potential to impact the magnitude of P flows for various sectors and as such, consideration should be given to how they may impact the future viability of NRR technologies.

While it is beyond the scope of this report to review existing policy and regulatory frameworks in detail, the following section outlines a select number that align with NRR and have the potential to guide or promote technology adoption in support of the circular economy, management of recovered resources or protection of the environment. This section focuses on the efforts of the federal and provincial governments however, there are a number of important initiative being pursued by a wide range of stakeholders. A more thorough policy review is recommended as a next step emerging from this report, in an effort to ensure the effective adoption of NRR technologies in Ontario, and more broadly, across Canada.

A list of additional policies and regulations that are more specific related to P or to NRR can be found in Appendix E.

6.3.1 Circular Economy

Waste-Free Ontario Act and Strategy for a Waste-Free Ontario: Building the Circular Economy

In 2016, Ontario made an important commitment to transitioning to a circular economy with the introduction of its *Waste-Free Ontario Act*, comprised of the *Resource Recovery and Circular Economy Act*, 2016 and *Waste Diversion Transition Act*, 2016. The *Waste-Free Ontario Act* is aimed broadly at tackling the issue of waste generation by increasing resource recovery and its introduction was accompanied by the release of the province's Strategy for a Waste-Free Ontario: Building the Circular Economy in 2017, which lays out Ontario's vision for a circular economy and goals of a zero-waste Ontario.[278]

The strategy recognizes the tremendous environmental and economic opportunities that exist from embracing a circular economy and nutrient recovery is considered as one of its resource recovery and waste reduction priorities. More specifically, NRR has the potential to play a key role in directly supporting a number of the aims outlined in the strategy, including:

- increasing the reuse and recycling of waste across all sectors of the economy
- increasing opportunities and markets for recovered resources
- promoting public education and awareness with respect to resource recovery and waste reduction
- promoting cooperation and coordination among various persons and entities involved in resource recovery activities and waste reduction activities[279]

The strategy also points to the importance of implementing modern regulatory approaches and promoting innovative best practices and technologies, and highlights support for recovered food and organic materials, which the province is furthering through its Food and Organic Waste Framework.[280]

Ontario Food and Organic Waste Framework and Food and Organic Waste Policy Statement

In 2018, Ontario released its Food and Organic Waste Framework in support of its Strategy for a Waste-free Ontario and the building of a circular economy. The framework is comprised of a Food and Organic Waste Action Plan and a Food and Organic Waste Policy Statement, and its overall goals include:

- Reducing food and organic waste
- Recovering resources from food and organic waste
- Supporting resource recovery infrastructure
- Promoting beneficial uses of recovered organic resources[281]

The province's Food and Organic Waste Policy Statement was issued in 2018 under section 11 of the *Resource Recovery and Circular Economy Act*. The statement highlights the importance of waste reduction and resource recovery of food and organic waste, in an effort to improve environmental outcomes, reduce GHG emissions and recover valuable nutrients in support of a circular economy.[282] It also states that "Reintegrating food and organic waste into the economy recovers the resources embedded in these materials. As additional food and organic waste recovery capacity is developed, markets and end-uses should be expanded and diversified through new and innovative approaches."[283]

It is important to note that the policy statement also points to the potential for it to be complemented by other future policy statements and actions, including provincial regulations, plans and guidelines or municipal policies and private sector initiatives. It is anticipated that as the province moves forward with its implementation of the strategies outlined in the policy statement, there will be impacts on the nature of the processing and use of food and organic wastes. This will in turn, have implications for the P flows associated with these materials and should be taken into consideration in planning for the adoption of NRR technologies.

6.3.2 Climate Change and Greenhouse Gas Emissions

A Healthy Environment and a Healthy Economy Plan

In 2020, the Government of Canada released its strengthened climate plan, A Healthy Environment and a Healthy Economy Plan. The plan outlines environmental and economic goals, including clean air, clean water and long-term job security, by building on the strengths and achievements of existing progress, while introducing a series of new federal measures. A total of 64 new or strengthened policies, programs and investments to cut pollution and build a stronger, cleaner, more resilient and inclusive economy are outlined.[284] More specifically, the plan commits the federal government to a number of initiatives and programs related to reducing emissions in the agricultural sector that may also align with the beneficial outcomes promised by NRR. These include:

- $25 million for an Agricultural Clean Technology Program
- $20 million for a Food Waste Challenge
- Over $19 million for biomass and bioproducts research clusters

To help farmers and food businesses continue to develop and implement clean practices that reduce GHG emissions and protect the land, water and air that they depend on for long-term sustainability, the plan also outlines a commitment to:

- An investment of $165.7 million over seven years to support the agriculture industry in developing transformative clean technologies and helping farmers adopt commercially available clean technology.
- Setting a national emission reduction target of 30% below 2020 levels from fertilizers and to work with fertilizer manufacturers, farmers, provinces and territories, to develop an approach to meet it. As outlined in the plan, improving how fertilizers are used through better products and practices will save farmers money and time and help protect Canada's land and water.[285]

These programs and targets could be leveraged to further support NRR technologies in the agricultural sector given their significant potential to contribute to protecting the land, water and air that farmers depend on and ensuring P does not end up in the environment.

Clean Fuels Fund

As a part of its commitments under the strengthened climate plan and to complement the Clean Fuel Standard, a $1.5 billion Clean Fuels Fund was also announced by the federal government in 2020. The fund will be administered by Natural Resources Canada (NRCan) and will seek to increase the production and use of low-carbon fuels in a manner that complements federal carbon pollution pricing, regulatory efforts and other federal programming.[286]

The Clean Fuels Fund includes a commitment of $30.4 million to support and enhance biomass supply chains that will in turn, support new or expanded clean fuel production. Stronger biomass supply chains have the potential to divert organic materials to new organic processing systems that will produce energy, but also have an organic materials output (e.g., digestate). It is noted that establishing domestic biomass feedstock infrastructure will benefit a wide range of stakeholders, including farmers, forest harvest operators, sawmills and municipal waste services, by creating new opportunities for underutilized waste. The important role that NRR technologies could play in supporting new organic processing systems should be considered.

6.3.3 Nutrient Loading and Management

Ontario is home to the Great Lakes — the largest group of freshwater lakes on Earth — and the region that has grown around the lakes accounts for more than 30% of Canada's population and seven of the country's largest cities. The lakes also directly provide drinking water for 60% of Ontarians. The Great Lakes Basin contains 40% of the country's economic activity, 25% of agricultural production and approximately half of its manufacturing activity.[287] This points to the importance of ensuring the lakes remain unaffected by the activities of those who rely on them.

Great Lakes Water Quality Agreement (1972, 1978, 1983, 1987 and 2012)

The Great Lakes have a long history of challenges related to nutrient loading. By the mid-20th century, P entering the Great Lakes primarily from agricultural and urban runoff, industrial discharges, untreated sewage, detergents and atmospheric deposits had helped to create the ideal conditions for the proliferation of algae. This was particularly true of the lower lakes and in the 1970s, Lake Erie was said to be "dying" due to significant algal blooms. Recognizing the need for a framework to coordinate efforts to manage and protect the Great Lakes, Canada and the U.S. signed the Great Lakes Water Quality Agreement (GLWQA) in 1972 to "restore and enhance water quality in the Great Lakes System."

Central to the 1972 GLWQA were commitments to limit P discharges into the lakes. The Agreement required the Parties to set basin-wide water quality benchmarks and review the design and operation of the region's water treatment infrastructure. While these efforts were initially successful, the continued threat of algal blooms across the Great Lakes pointed to shortcomings in the approach to addressing the issue under the Agreement. A number of additional measures under subsequent versions of the GLWQA were made to limit eutrophication, including maximum P loading targets introduced under the 1978 Agreement and further specifications for each lake in the 1983 supplement.

Despite these measures and early successes related to urban point sources, several issues have not yet been fully addressed or began to reoccur years later. The current 2012 GLWQA addresses nutrients, with a focus on P, under its nutrients annex (Annex 4), which guides efforts to manage P and other nutrients to minimize hypoxic zones, manage levels of blue-green algae to prevent the formation of harmful toxins, and to ensure that algae species in nearshore waters are consistent with those found in healthy aquatic ecosystems. To meet these goals, the U.S. and Canada have established binational P concentrations, loading targets and allocations, while also continuing to assess and implement programs and measures designed to reduce P loadings from point and nonpoint sources. Much of the effort under this Annex is directed towards achieving reductions of P loading to Lake Erie, which has experienced significant environmental and socio-economic impacts associated with harmful and nuisance algal blooms.

The GLWQA also addresses highly contaminated areas that have been designated as Areas of Concern (AOC). Once an AOC designation has been established, the beneficial uses of the area must be restored, which are addressed through the development and implementation of Remedial Action Plans (RAPs). Localized actions are then established to address the sources of contamination and remediate the area. This includes addressing areas that exhibit high concentrations of P, resulting in eutrophication or undesirable algae.

Canada-Ontario Agreement Respecting Great Lakes Water Quality Ecosystem Health (COA)

The *Canada-Ontario Agreement Respecting Great Lakes Water Quality and Ecosystem Health* (COA), initially signed in 1971, was established in response to growing public concern about the health of the lakes. The COA is the primary mechanism through which federal departments and provincial ministries work together to meet some of Canada's key obligations under the GLWQA.

The Canada-Ontario Lake Erie Action Plan was developed under the COA, which designates "more than 120 actions to help reduce how much phosphorus enters Lake Erie".[288] The action plan works to address P mismanagement by improving monitoring initiatives, establishing P loading limits and driving action through P reduction strategies. Furthermore, there is a focus on improving the scientific knowledge within this field to develop new and innovative practices and technologies that go beyond limiting P contamination and focus instead on recovery and reuse. The plan states that "Canada and Ontario will work with partners to explore opportunities to adopt innovative technologies that encourage phosphorus recovery and reuse".[289]

The plan also encourages investment in research and demonstration initiatives aimed at improving knowledge and understanding of the effectiveness of BMPs for reducing nutrient loss and improving efficiency in agricultural production. Funding has been provided to demonstrate GNF recycling and to research efforts aimed at the recovery of P from point and nonpoint sources, including support through the George Barley Water Prize — the Everglades Foundation's innovative technology competition to reduce and recovery P from waterbodies.[290] The prize challenged companies and academic institutions to develop and demonstrate how their next generation technology can help remove or prevent excess P in freshwater systems and has supported the advancement of a number of proprietary NRR technologies, including those from Canadian companies.[291]

Canada Water Agency

In December 2019, the federal government announced a commitment to establishing a new Canada Water Agency to "work together with the provinces, territories, Indigenous communities, local authorities, scientists and others to find the best ways to keep our water safe, clean and well-managed." The Prime Minister also directed the Minister of Environment and Climate Change to "develop further protections and take active steps to clean up the Great Lakes, Lake Winnipeg, Lake Simcoe and other large lakes."[292] The 2022 federal budget proposed to provide $43.5 million over five years, starting in 2022-23, and $8.7 million ongoing to ECCC to create the Canada Water Agency. The federal government's cross-Canada public consultation process and resulting Toward the Creation of a Canada Water Agency: Public & Stakeholder Engagement – What We Heard document noted that Canada is a leader in "sustainable agricultural water management" and "freshwater technology, innovation and infrastructure". It is anticipated that nutrients, including P, will be a key focus of the Canada Water Agency when implemented.

6.3.4 Summary

P is a finite and non-substitutable resource that is critical for food security. When not appropriately managed, it has the potential to contribute to significant environmental challenges, particularly in local waterbodies where it can support the growth of harmful algal blooms. However, P can also be physically conserved, with the potential to be recycled indefinitely. Given estimates that global reserves of high-quality phosphate rock could be depleted as soon as the next 30 - 40 years, discussions about the importance of P recovery and reuse are both timely and critical.

A better understanding of how P moves throughout the local economy can provide further understanding of P use and losses. This report has identified and estimated the amount of P flowing through relevant sectors of Ontario's economy as the starting point for further discussions about where efforts should be prioritized to support improved management of P, including through the effective deployment of NRR technologies. It has also highlighted relevant policy frameworks, programs and technologies in an effort to highlight where NRR can support existing commitments by governments, industry and other stakeholders. While this report has highlighted the fact that NRR is not likely to meet all of the province's P needs in the short-term, if prioritized now, it can play a critical role in addressing the issue of P scarcity in the future.

Appendices

Appendix A: Key Data Sources

Sector	Source	Dataset	Year	Geographic Scale
Agriculture	Agriculture and Agri-Food Canada	Poultry slaughter reports	1992-Present	National by Province
Agriculture	Agriculture and Agri-Food Canada	Red meat and livestock slaughter and carcass weights	1997-Present	National by Province
Agriculture	Health Canada	Nutrient Value of Some Common Foods	2015	N/A
Agriculture	Statistics Canada – Statistique Canada	Appendix G - Estimated number of households and average household size by domain, Canada	2016	National by Province
Agriculture	Statistics Canada – Statistique Canada	Cattle inventory on farms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Cattle statistics, supply and disposition of cattle	2000-Present	National by Province
Agriculture	Statistics Canada – Statistique Canada	Farm operating revenues and expenses, annual	2015-2020	National by Province
Agriculture	Statistics Canada – Statistique Canada	Fertilizer shipments to Canadian agriculture markets, by nutrient content and fertilizer year, cumulative data.	2006-Present	National by Province
Agriculture	Statistics Canada – Statistique Canada	Field crops and hay, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Field vegetables, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Fruits, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Greenhouse products and mushrooms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Hogs statistics, supply and disposition of hogs, semi-annual	2007-Present	National by Province
Agriculture	Statistics Canada – Statistique Canada	Households and the Environment: Table 12 — Sewer and septic system connections, by province	2011	National by Province
Agriculture	Statistics Canada – Statistique Canada	Land inputs, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Other livestock inventories on farms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Pig inventory on farms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Poultry inventories on farms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Canada – Statistique Canada	Red meat conversion factors	2013	N/A
Agriculture	Statistics Canada – Statistique Canada	Sheep inventory on farms, Census of Agriculture, 2011 and 2016	2011, 2016	National by Census Division
Agriculture	Statistics Netherlands	Standardised calculation methods for animal manure and nutrients. Standard data 1990–2008	1990-2008	National (Netherlands)
Agriculture	opendatasoft	Census divisions - Canada	2019	Ontario by Census Division
Agriculture	Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs	Available Nutrients and Value for Manure From Various Livestock Types	2013	Ontario
Agriculture	Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs	Horticultural Crops	Multiple ranges	Ontario, Ontario by county

Sector	Source	Dataset	Year	Geographic Scale
Agriculture	Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs	Ontario egg production	1998 - 2019	Ontario
Agriculture	Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs	Ontario milk shipments by county	2007 - 2019	Ontario by County
Industry	Statistics Canada – Statistique Canada	Supply and Disposition of Food in Canada	1960-2020	National
Industry	World Bank	World Trade Integrated Solutions	1988-2019	National
Industry	Environment and Climate Change Canada	National Pollutant Release Inventory	2003 - present	National by Province
Industry	Government of Canada	Trade Data Online	1990-present	National by Province
Industry	Government of Canada	Canadian Forest Service-Statistical Data	1990-2019	National and Provincial
Industry	Statistics Canada – Statistique Canada	Census jobs by economic sector at NAICS level 3	2011, 2016	National
Industry	Ontario Ministry of Environment Conservation and Parks of Ontario	Industrial Wastewater Discharges	2004-Present	Ontario
Urban	Environment and Climate Change Canada	Wastewater Systems Effluent Regulations	2013-Present	National
Urban	Ontario Ministry of Environment Conservation and Parks of Ontario	Municipal Treated Wastewater Effluent	2008-Present	Ontario

Appendix B: Phosphorus Flows in Ontario's Natural Environment

This report has highlighted the fact that the natural environment receives P from a wide range of sources, including from the agricultural, industrial, and urban (e.g., WWTPs) sectors. Due to the complexity of these flows, an estimate of their magnitude was beyond the scope of this study and should be considered for future work.

This section provides a very high-level overview of P flows in Ontario's atmosphere, natural waterbodies and forested areas based on findings in the literature. This information provides an estimate of these natural flows with the aim of better understanding the impact of anthropogenic activity on the amount of P found in the environment.

Atmospheric Deposition

The total P concentration of the atmosphere is low, and there are different P types, with mineral aerosols being dominant (82%).[293] A 2008 study by Mahowald et al. using a combination of data and modelling concluded that there is a global net P loss to the atmosphere from land, and a net ocean gain from atmospheric P. The P loss from land to the atmosphere is for many, but not all types of landscapes and locations.[294] The model also generated a figure of total net P estimates with different values for different regions. A net deposition to the approximate Ontario location was estimated to be 1 mg/(m^2a).

Tipping et al. (2014) reported on how three sources of P: local, biologically-sourced, fertilized farmland, and inorganic fine dust from deserts and soils, contribute to atmospheric P deposition and loss.[295] Atmospheric deposition of biologically-sourced and fertilized farmland P are thought to be locally sourced and deposited. This local P transfer has the potential to enrich local, P-poor ecosystems.

P inputs from the atmosphere are a combination of local transfer and more predominate long-range dust transfer. The estimated global average P deposition rates for the Ontario region, and the total flows for Ontario land (892,411 km^2) and water (158,654 km^2) are presented in Table B1. The table shows that the overall estimated P flows transported to Ontario's landscape by natural processes are approximately 244,000 t/a from air deposition.

Table B1. Global Estimate of Atmospheric Phosphorus Deposition (t/a) Scaled to Ontario Land and Water Areas (2014)

Phosphorus Type	g/(m^2a^1)	t/a (land)	t/a (water)	t/a (total)
Inorganic orthophosphate	0.014	125,000	2,200	127, 200
Filtered total phosphorus	0.019	170,000	3,000	173,000
Total phosphorus (TP)	0.027	240,000	4,300	**244,300**

Natural Waterbodies

There is significant variability in total P concentrations in natural water due to differences in the amount of phosphate at the surface, shore, or deeper in the water column, whether P-rich zooplankton were caught in the sample, the effect of ice, time of year, and sample collection, measurement and storage techniques. Natural waters receive P from the atmosphere and from agricultural, industrial, and WWTPs. Due to the complex flows of natural waters, an estimate of the impact of these P-flows to natural water concentrations is considered out of the scope for this report. This section outlines expected variations in measuring P concentration in a natural body of water, and how they are being reduced as sample collection and P measurement methods improve.

P data have an estimated 23% variation during the springtime, when meltwater displaces deeper, nutrient-rich lake water. A 2010 study by Clark et al. noted higher seasonal variation for polytrophic —continually available, high nutrient concentration — lakes[296], such as Lake of the Woods in Northern Ontario (ranging from ~ 20 to ~ 105 µg TP/L), and the Kawarthas near Peterborough. This points to a need for a clear understanding of sampling collection and measurement methods when interpreting P lake data.

Improved P measurement precision since 2002 (± 0.7 µg TP/L) by the Dorset Environmental Science Centre (DESC) generated TP data of 2.3 – 46 µg TP/L for 243 Precambrian Shield lake locations between 2003 and 2006, with many lakes reporting < 20 µg TP/L. The measurement error is given as 1 µg TP/L (2-50%).

Total Phosphorus in Ontario Waterbodies

A combination of physical characteristics and surrounding land use can contribute to P loading in natural waterbodies. The issue is further complicated by a changing climate, hydrological patterns and invasive species. As highlighted in this report, eutrophication in some lakes has promoted harmful blooms of cyanobacteria. There is broad consensus that the primary and most manageable driver of these impacts in many waterbodies (e.g., Lake Erie), is P.

The shared Ontario, Michigan, Ohio, Pennsylvania, and New York land borders with Lake Erie and Lake Ontario prevent the creation of simple and relevant P estimates for Ontario's natural waters. However, average P concentrations in the province's lakes are monitored by the Ontario Lake Partner Program — a volunteer-based, water-quality monitoring program coordinated by MECP, in collaboration with the Federation of Ontario Cottagers' Association (FOCA). P concentrations from Lake Partner Program monitoring locations across Ontario's lakes from 2002 to 2020 are presented in Figure B1.

Given the important agricultural industry in Ontario, it is anticipated that there are significant P flows from agricultural lands to natural waters. Culley and Bolton (1983) reported an average value of 0.188 mg TP/L for southwestern Ontario agricultural streams. It is not known how representative this is as a P flow that contributes to industry as an influent through process water.

Figure B1. Average Phosphorus Concentrations (µg/L) in Ontario by Lake Sample Location (2019)[297]

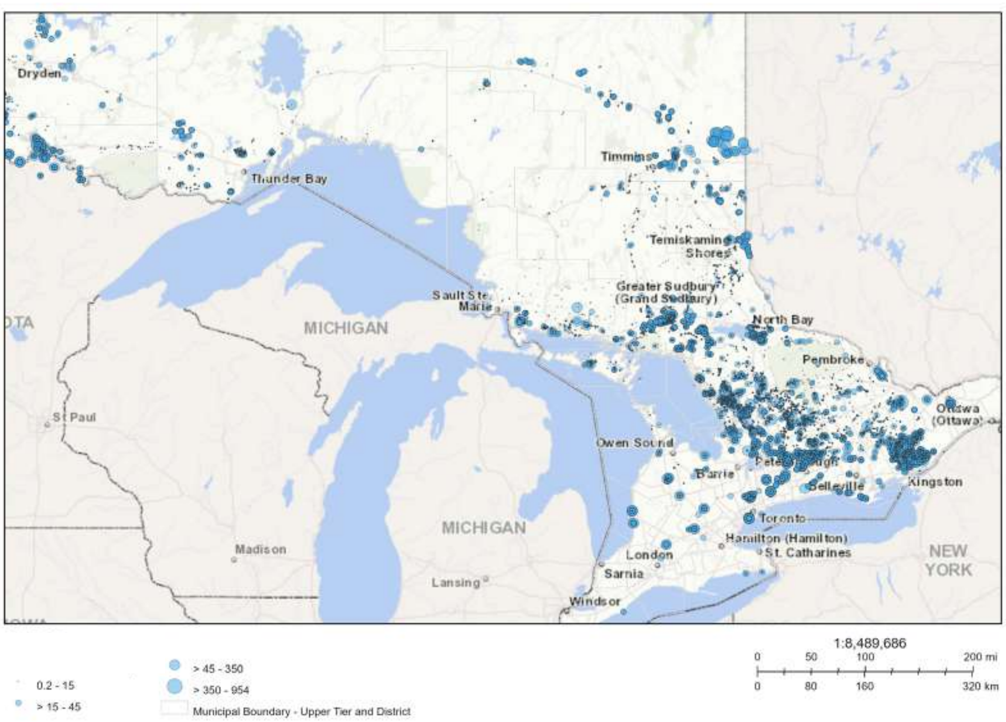
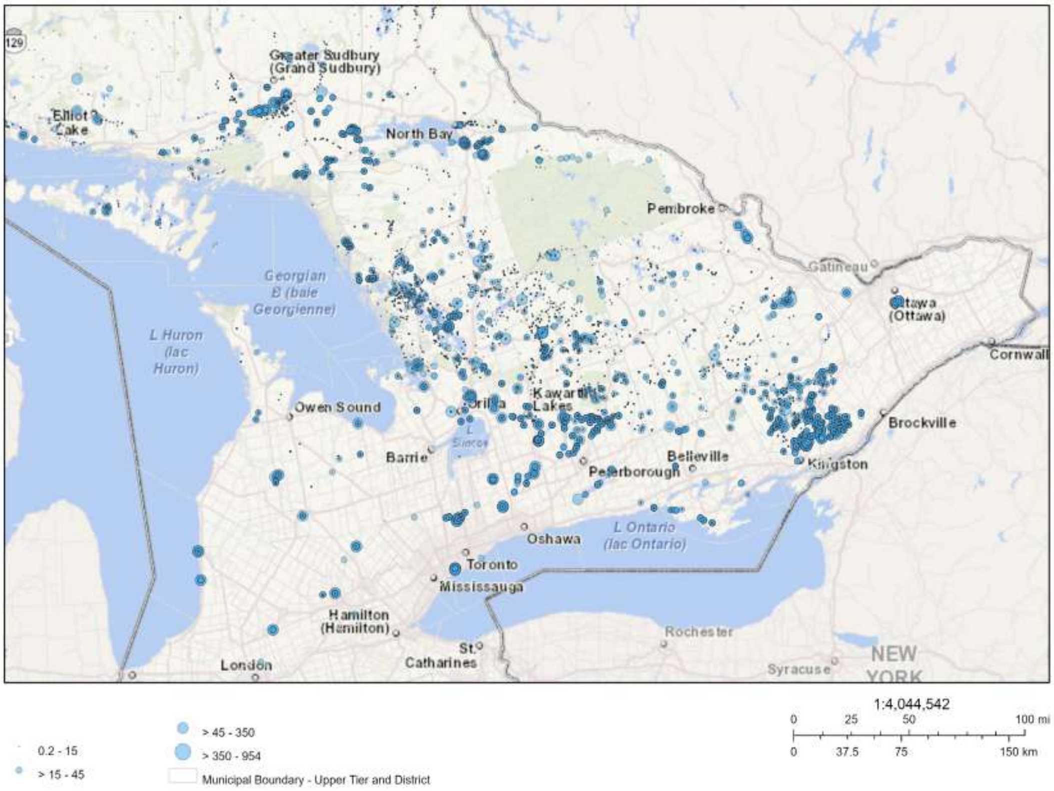


Figure B2. Average phosphorus concentrations (µg/L) in Southern Ontario by Lake Sampling Location (2019)



Impact of Western Ontario Geology and Agriculture on Phosphorus in Surface Water

The chemical composition of lake and natural surface waters is also affected by subsurface geology and geochemistry. This section discusses a report on the effect of two general till-plain — land that was covered with glacier debris from the previous ice age — types in western Ontario on soil TP and the flow of soluble reactive P in surface waters.

Plach et al. (2018) studied P runoff from soil types that are characteristic of two regions of Ontario:

- **Hummocky coarse-textured glacial till-plain**: Characteristic of northwestern Ontario, this soil type is alkaline, with a high acid soluble TP content (up to 91 %).
- **Lacustrine, fine-textured, glacial till-plain**: Common in southwestern Ontario, this till is more acidic, and the soil TP content is moderately soluble.

Differences in silt to clay ratios and the capacity for the soil to shrink and swell when dried or hydrated correlated to differences in P concentrations.[298]

The surface layer soluble P concentrations were generally lower than the recommended minimum 30 mg P/kg for coarse northwestern soils.[299] The fine-textured southwestern soils were at, or above, this minimum for agriculture. When treated, more P dissolved from the fine-textured soils than the coarse-textured soils. More inorganic P was dissolved with an acidic extraction from the coarse-textured soil than the fine-textured soil, which means that there may be more P that is unavailable to plants and runoff in these soil types. The soluble reactive P concentrations in surface runoff may be higher in the southwestern than the northwestern Ontario landscape.

Average Ontario soil P concentrations from the Great Lakes Basin published by Miller et al. (1982) was 733 ± 150 g P/kg soil. The study also determined that the surface soil clay content, percent crop area, and applied P correlated with reactive P in surface runoff. They measured a 0.098 mg/L mean soluble P concentration in runoff from 33 fields in Ontario. Approximately a decade later, Bowman et al. (1994) studied herbicide and nutrient run-off in rainfall simulations on soil from corn cropland and compared the results with field data. The soil used in the Bowman study contained more than 30 g P/kg soil. They reported 9.5 – 12 mg TP/L from their Ontario cropland runoff measurements and warned of eutrophication.[300]

Given the wide variations in soil type, history of fertilizer application, measurement technique and variation in P with time, scaling up P concentration values from different studies for Ontario cannot be done with any reasonable accuracy.

Forested Areas

Canada's National Forest Inventory reports 30 billion tonnes of above ground biomass in Canada's natural forests.[301] This value was scaled down for Ontario using the ratio of the forested area in Ontario to the forested area in Canada[302], arriving at an estimated 4.6 billion tonnes of above ground biomass in Ontario's forests. Assuming that the P content of wood is 0.01% (see Appendix D), there is an estimated 460,000 tons of P in Ontario forests. In 2019, approximately 2,000 tons of P was harvested within wood for use in the forestry industry.

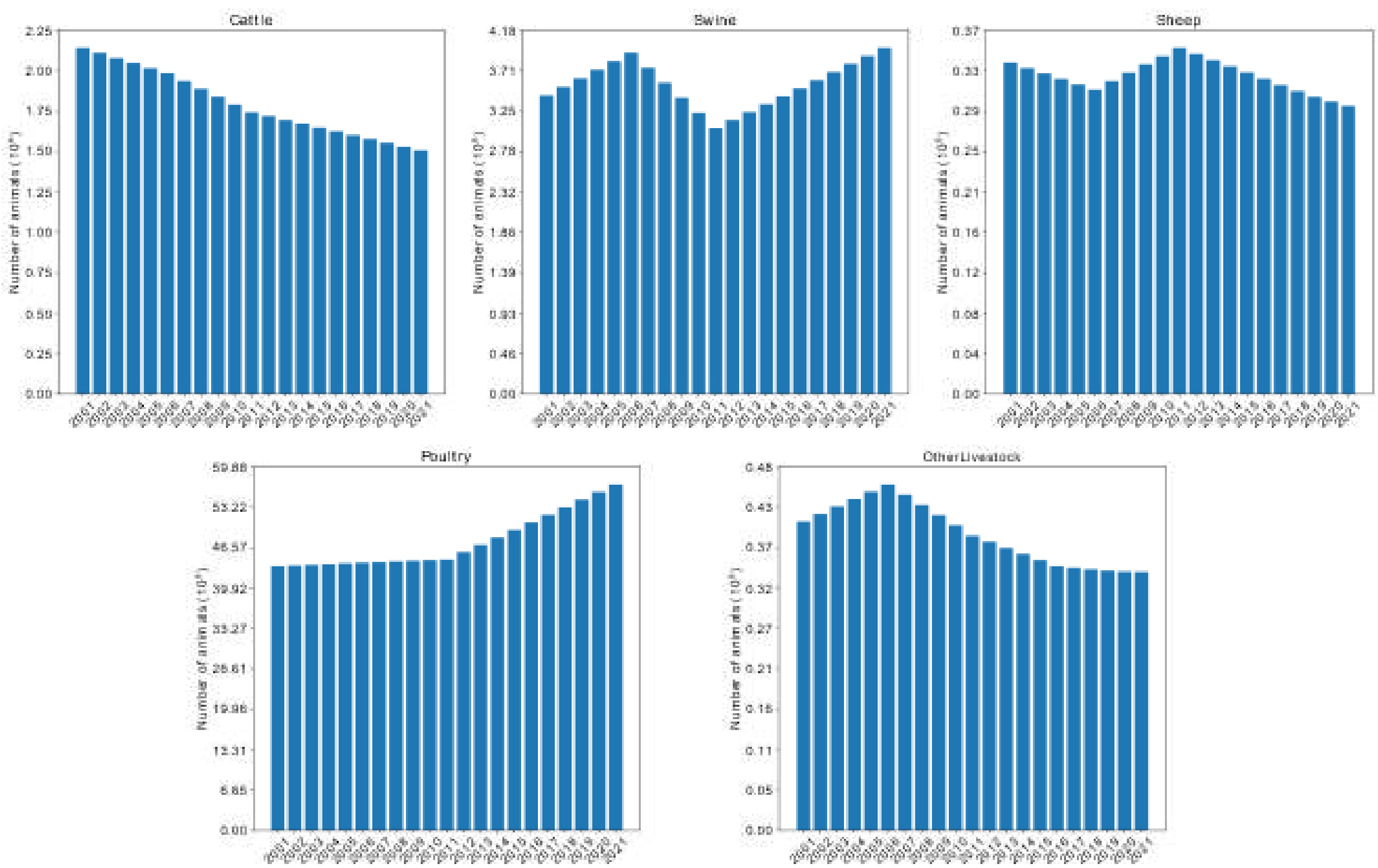
Appendix C: Additional Methodology & Data for Agricultural Sector

Livestock Census

Livestock census data is reported by Statistics Canada every five years (i.e., 2001, 2006, 2011 and 2016), using Dissemination Geography Unique Identifiers (DGUIDs). These identifiers are built based on 4 items combined in a unique DGUID:

- **Vintage**: four digits representing the year of data collection
- **Type of geographic areas covered by the dataset**: one character code, A or S denoting administrative or statistical areas respectively
- **Schema**: four digits denoting the kind of division considered (0003 denotes Census Division)
- **Geographic Unique Identifier (GEOUID)**: variable alphanumeric code assigned to each individual geographical division which in this case corresponds with the Census Divisions of Ontario identifier (a four digits code starting with “35”).[303] The GEOUID is extracted from the DGUID reported by the census using Pandas[304] to retrieve the number of animals of each type in each Census Division. The inventory of animals for the years between two consecutive Census of Agriculture has been estimated through a linear interpolation. Figure C1 shows the evolution of the livestock census in Ontario for the years 2001 to 2021.

Figure C1. Livestock Census in Ontario by Animal Type



Animal Production Cycles

The livestock census provides a snapshot of the number of animals in the region studied. We assumed that the number of animals reported is throughout the year (i.e., the animals culled are replaced by new ones). However, in the case of broilers and turkeys, the number of animals reported by the livestock census have been reduced by a factor of 0.68 (broilers) and 0.80 (turkeys), since these animals have life cycles of 43 and 80 days respectively, meaning barns are empty for 20 days between cycles.[305]

Animal Imports & Exports

The P flows for animals imported and exported are estimated based on the P content of each animal. The P content is estimated based on the weight of the live animal and the ratio of P to total weight $\left(\eta_{\text{P to live}_j}\right)$ as shown in Table C1.

$$P_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) = W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) \cdot \eta_{\text{P to live}_j}$$
$$j \in \{\text{Cattle, Calves, Hogs, Sheep}\}$$

Table C1. Phosphorus to Live Weight Ratios[306]

	Cattle	Hogs	Sheep
Phosphorus/Live weight (%)	0.74	0.53	0.52

Manure

Manure generation rates and composition for each type of animal based on life stage is shown in A-2.[307, 308, 309, 310, 311, 312, 313, 314] Manure production is estimated by combining the number of animals $(N_{animals})$ reported in the livestock census and the manure production rate of each type of animal (m), which is normalized by animals unit equivalents (AU), as shown below.

$$Manure\left(\frac{\text{kg}}{\text{day}}\right) = N_{animals_i}(\text{animals}) \cdot AU_{eq_i}\left(\frac{\text{AU}}{\text{animals}}\right) \cdot m_i\left(\frac{\text{kg}}{\text{day} \cdot \text{AU}}\right)$$
$$i \in \{\text{Beef Cow, Dairy Cow, Beef Calf, Dairy Heifer, Swine Mature, Swine Immature, Sheep, Lamb, Broiler, Pullet, Layer, Turkey, Horse, Goat, Rabbit, Mink, Bison, Llamas/Alpacas}\}$$

The amount of P contained in manure is calculated based on the composition reported for each type of manure in Table C2.

$$P_{manure}\left(\frac{\text{kg}}{\text{day}}\right) = Manure\left(\frac{\text{kg}}{\text{day}}\right) \cdot P_{total}(\%\text{wt})$$

Table C2. Manure Generation Rates and Composition for Different Types of Animals

Livestock type	Water (%)	Organic matter (%)	Ntotal (%)	Ptotal (%)	Ktotal (%)	Manure (kg/day/AU)	AUeq (AU/animals)
Dairy cow	87	10.98	0.59	0.08	0.2	37.88	0.74
Dairy heifer	83	13.04	0.48	0.09	0.21	29.95	0.94
Dairy calf	83	9.28	0.51	0.06	0.13	29.95	4
Beef cow	88	10.58	0.34	0.08	0.24	28.58	1
Beef calf	88	10	0.58	0.1	0.38	28.14	4
Swine mature	90	9.15	0.76	0.22	0.47	15.19	2.67
Swine (immature)	90	8.31	0.83	0.14	0.37	36.51	9.09
Layers	75	19.3	1.93	0.58	0.68	28.46	250

Livestock type	Water (%)	Organic matter (%)	Ntotal (%)	Ptotal (%)	Ktotal (%)	Manure (kg/day/AU)	AUeq (AU/animals)
Pullets	75	19.3	1.93	0.58	0.68	20.68	455
Broilers	75	19.09	1.09	0.32	0.62	37.21	455
Turkey (mature)	74	20.42	1.5	0.42	0.65	22.67	50
Turkey (immature)	74	20.42	1.5	0.42	0.65	20.33	67
Sheep	75	20.75	1.13	0.18	0.75	18.16	5
Lamb	75	20.75	1.13	0.18	0.75	18.16	7.14
Mink	54	45.8	3.28	1.82	0.79	42.74	150
Horses	85	11.92	0.6	0.13	0.37	23.38	0.91
Rabbits	54	46	1.22	0.87	0.57	51.64	50
Goat	68.8	31.2	1.06	0.37	1.03	20.94	5.88
Llamas/alpacas	69	31	0.71	0.38	0.24	12.49	3.5
Bison	78.9	21.1	0.4	0.07	0.07	44.88	0.91

Meat and Slaughter Products

Slaughterhouse facilities are part of meat processing plants in Ontario. Data on slaughterhouse facilities in Ontario were retrieved from licensing permits reported by the government. However, it should be noted that licensing for meat plants can be either federal or provincial[315], requiring that both kinds of facilities are accounted.

Cattle: The number of cattle slaughtered in federal and provincial facilities in the province of Ontario is retrieved from Agriculture and Agri-Food Canada (2021b), 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – federally inspected (Annual)' and 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – provincially inspected (Annual)' sections, respectively.

Calves: The number of calves slaughtered in federal and provincial facilities in the province of Ontario is retrieved from Agriculture and Agri-Food Canada (2021b), 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – federally inspected (Annual)' and 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – provincially inspected (Annual)' sections, respectively.

Pigs: The number of total hogs slaughtered in Ontario (including both federally and provincially licensed facilities) is retrieved from Agriculture and Agri-Food Canada (2021b) by combining the 'Origin of hogs slaughtered – federally and provincially inspected', 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – federally inspected (Annual)', and 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – provincially inspected (Annual)' sections.

Sheep and lambs: The number of sheep and lambs slaughtered in federally and provincially licensed plants is retrieved from Agriculture and Agri-Food Canada (2021b), 'Sheep and lamb slaughtered – federally inspected' and 'Cattle, veal cattle, hogs, sheep and lamb slaughtered – provincially inspected' sections respectively. However, for federally inspected facilities, the data reported is aggregated for Ontario and the western provinces. The number of sheep and lambs slaughtered in federally inspected facilities is estimated based on the ratio of animals culled in provincially licensed plants in Ontario to those in the western provinces for each year.

Goats: The number of sheep and lambs slaughtered in federally and provincially licensed plants is retrieved from Agriculture and Agri-Food Canada (2021b), 'Goats – federally and provincially inspected' section. Data is only available for 2014 onwards.

Chicken and turkeys: The total number of chickens and turkeys in Ontario (including both federally and provincially licensed facilities) is obtained from Agriculture and Agri-Food Canada (2021a).

The live weight of each animal slaughtered (W_{live}) is determined based on the average warm carcass weight $(W_{carcass_j})$ and the live to carcass weight ratio $(\eta_{\text{carcass to live}_j})$. The difference between the live weight and the carcass weight is assumed to be slaughterhouse waste.

$$W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) = W_{carcass_j}\left(\frac{\text{kg}}{\text{animal}}\right) \cdot \eta_{\text{carcass to live}_j}$$
$$W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) = W_{carcass_j}\left(\frac{\text{kg}}{\text{animal}}\right) \cdot \eta_{\text{carcass to live}_j}$$
$$j \in \{\text{Cattle, Calves, Hogs, Sheep and Lambs, Goats, Chicken, Turkeys, Rabbits}\}$$

The average warm carcass weights for cattle, calves, and hogs are obtained from Agriculture and Agri-Food Canada (2021b), 'Average Warm Carcass Weights of Federally Inspected Plants' section. For chicken and turkeys, weights are taken from Agriculture and Agri-Food Canada (2021a). Sheep and lamb weights are taken from Statista (2021) and goat weights are estimated from Farm & Food Care Ontario (2021). Tables C3 and C4 show the live to carcass weight conversion factors that were used.

Table C3. Average Warm Carcass weights by Animal Type

Animal type	2016	2017	2018	2019	2020
Cattle	411.36	401.051	398.97	408.4	403.38
Hogs	103.35	104.2	105.24	106.67	109.38
Calves	169.16	173.01	170.63	172.84	180.87
Sheep	19.7	19.7	19.7	19.7	19.7
Goat	14.19	14.19	14.19	14.19	14.19
Rabbit	1.25	1.25	1.25	1.25	1.25
Chicken	2.36	2.40	2.45	2.48	2.48
Turkey	10.98	10.75	10.72	10.77	11.04

Table C4. Carcass to Warm Carcass Ratios and Phosphorus to Warm Carcass Ratios

	Cattle	Hogs	Calves	Sheep	Goat	Rabbit	Chicken	Turkey
Carcass/warm carcass weight (%)	49	80	55	46	50	53	72	77
Phosphorus/warm carcass weight (%)	0.74	0.53	0.8	0.52	0.63	0.6	0.5	0.51

The P content of each animal is estimated based on the weight of the live animal and the ratio of P to total weight $(\eta_{\text{P to live}_j})$ reported in Table C4, as shown below. The P content for the carcass and for slaughterhouse waste were estimated proportionally based on the weight of each of these parts (i.e., carcass and slaughterhouse waste) over the animal live weight.

$$P_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) = W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) \cdot \eta_{\text{P to live}_j}$$
$$P_{carcass_j}\left(\frac{\text{kg}}{\text{animal}}\right) = P_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) \frac{W_{carcass_j}\left(\frac{\text{kg}}{\text{animal}}\right)}{W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right)}$$

$$P_{slaughterhouse\ waste_j}\left(\frac{\text{kg}}{\text{animal}}\right) = P_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right) \cdot \frac{W_{slaughterhouse\ waste_j}\left(\frac{\text{kg}}{\text{animal}}\right)}{W_{live_j}\left(\frac{\text{kg}}{\text{animal}}\right)}$$
$$j \in \{\text{Cattle, Calves, Hogs, Sheep and Lambs, Goats, Chicken, Turkeys, Rabbits}\}$$

Fertilizer Applied to Open Field Crops

P applied as fertilizer to open field crops $(P_{fertilizer_{field},Ontario})$ is estimated based on the inputs of fertilizer products containing P at provincial level.[316] P applied to non-field crops, including greenhouse and nursery crops, is not accounted for in P inputs to crop fields, so the phosphate applied to greenhouse crops is subtracted from the total phosphate shipments. This approach assumes that the P content of fertilizer used in different crops is similar.

$$P_{fertilizer_{openfield},Ontario} = P_{fertilizer_{total},\ Ontario} - P_{fertilizer_{greenhouse\ crops},\ Ontario}$$

The allocation of P applied to field crops to each census division $CD\left(P_{fertilizer_{openfield},CD}\right)$ is determined according to the fraction of fertilized area of each census division $(Area_{fertilized,CD})$ over the total fertilized area in Ontario $(Area_{fertilized,Ontario})$[317], deducting the areas corresponding to non-field crops, i.e., greenhouses crops $(Area_{greenhouse\ crops})$[318]. Areas reported are from the 2016 Census of Agriculture since these datasets include data for all census divisions.

$$P_{fertilizer_{openfield},CD} = P_{fertilizer_{openfield},Ontario} \cdot \frac{Area_{fertilized,CD} - Area_{greehouse\ crops,CD}}{Area_{fertilized,Ontario} - Area_{greehouse\ crops,Ontario}}$$

Fertilizer Applied to Non-field Crops

Due to the limited availability of data, it is assumed the P applied to greenhouses was equal to the P uptake by greenhouse vegetables (tomatoes, peppers, and cucumbers)[319], which represent the lower bound for P supply to greenhouse crops.

$$P_{fertilizer_{greenhouse\ crops},\ Ontario} = P_{uptake_{greenhouse\ crops},Ontario}$$

The allocation of P applied to non-field crops for each census division $\left(P_{fertilizer_{greenhouse},CD}\right)$ is determined according to the fraction of the non-field crop area $(Area_{greenhouse\ crops,CD})$ over the total area of greenhouse and nursery crops in Ontario $(Area_{greenhouse\ crops,Ontario})$.

$$P_{fertilizer_{greehouse},CD} = P_{fertilizer_{greehouse},Ontario} \cdot \frac{Area_{greehouse\ crops,CD}}{Area_{greehouse\ crops,Ontario}}$$

Phosphorus Uptake by Crops

P taken by the crops grown in each census division $(P_{uptake_{CD}})$ for both open fields and greenhouses is based on the P content of each type of crop $(P_{uptake_{Plant}})$. Crops are categorized according to field crops, field vegetables, fruits and berries, silage and forage crops, and vegetables grown in greenhouses.[320, 321]

The crops grown in each Ontario census division are estimated by combining the land devoted to each type of plant in each census division $(Area_{Plant,CD})$ reported by Statistics Canada[322, 323, 324] with its specific yield $(Yield_{Plant})$[325], as shown below. For the case of the production of fruits, berries, and greenhouse vegetables, production data reported by OMAFRA at census division level has been considered[326], simplifying the estimation procedure. For field crops, grain, and straw and stover, fractions are differentiated as straw and stover remains in the fields after harvesting. Yield and P content values are reported in Table C5.

$$P_{uptake_{CD}} = P_{uptake_{Plant}} \cdot Area_{Plant,CD} \cdot Yield_{Plant}$$

Table C5. Yield and Phosphorus Content Values of Different Crops

Crop	Plant part	Dry wt. (lb/bu)	Typical yield (yield unit/acre)	Yield unit	N (%wt)	P (%wt)	K (%wt)
Flax	Grain	56	15	bushel	4.09	0.55	0.84
Flax	Straw/Stover		1.58725	metric tonne	1.24	0.11	1.75
Buckwheat	Grain	48	30	bushel	1.65	0.31	0.45
Buckwheat	Straw/Stover		0.4535	metric tonne	0.78	0.05	2.26
Corn	Grain	56	120	bushel	1.61	0.28	0.4
Corn	Straw/Stover		4.0815	metric tonne	1.11	0.2	1.34
Oats	Grain	32	80	bushel	1.95	0.34	0.49
Oats	Straw/Stover		1.814	metric tonne	0.63	0.16	1.66
Rye	Grain	56	30	bushel	2.08	0.26	0.49
Rye	Straw/Stover		1.3605	metric tonne	0.5	0.12	0.69
Sorghum	Grain	56	60	bushel	1.67	0.36	0.42
Sorghum	Straw/Stover		2.721	metric tonne	1.08	0.15	1.31
Wheat	Grain	60	40	bushel	2.08	0.62	0.52
Wheat	Straw/Stover		1.3605	metric tonne	0.67	0.07	0.97
Canola	Grain	50	35	bushel	3.6	0.79	0.76
Canola	Straw/Stover		2.721	metric tonne	4.48	0.43	3.37
Soybeans	Grain	60	35	bushel	6.25	0.64	1.9
Soybeans	Straw/Stover		1.814	metric tonne	2.25	0.22	1.04
Sunflower	Grain	25	44	bushel	3.57	1.71	1.11
Sunflower	Straw/Stover		3.628	metric tonne	1.5	0.18	2.92
Alfalfa	Forage		3.628	metric tonne	2.25	0.22	1.87
Wheatgrass	Forage		0.907	metric tonne	1.42	0.27	2.68
Apples	Fruit		10.884	metric tonne	0.13	0.02	0.16
Peaches	Fruit		13.605	metric tonne	0.12	0.03	0.19
Pears	Fruit		-	-	-	0.01	-
Plums and prunes	Fruit		-	-	-	0.02	-
Cherries (sweet)	Fruit		-	-	-	0.02	-
Cherries (sour)	Fruit		-	-	-	0.02	-
Apricots	Fruit		-	-	-	0.023	-
Strawberries	Fruit		-	-	-	0.023	-
Raspberries	Fruit		-	-	-	0.03	-
Tomatoes	Fruit		19.954	metric tonne	0.3	0.04	0.33
Alfalfa haylage	Silage		4.535	metric tonne	2.79	0.33	2.32
Corn silage	Silage		6.349	metric tonne	1.1	0.25	1.09
Forage sorghum	Silage		5.442	metric tonne	1.44	0.19	1.02
Sugar beets	Beet		18.14	metric tonne	0.2	0.03	0.14
Bell peppers	Vegetable		8.163	metric tonne	0.4	0.12	0.49
Dry beans	Vegetable		0.4535	metric tonne	3.13	0.45	0.86
Cabbage	Vegetable		18.14	metric tonne	0.33	0.04	0.27

Crop	Plant part	Dry wt. (lb/bu)	Typical yield (yield unit/acre)	Yield unit	N (%wt)	P (%wt)	K (%wt)
Carrots	Vegetable		11.791	metric tonne	0.19	0.04	0.25
Celery	Vegetable		24.489	metric tonne	0.17	0.09	0.45
Cucumbers	Vegetable		9.07	metric tonne	0.2	0.07	0.33
Lettuce (heads)	Vegetable		12.698	metric tonne	0.23	0.08	0.46
Onions	Vegetable		16.326	metric tonne	0.3	0.06	0.22
Peas	Vegetable		1.3605	metric tonne	3.68	0.4	0.9
Potatoes	Vegetable		13.1515	metric tonne	0.33	0.06	0.52
Snap beans	Vegetable		2.721	metric tonne	0.88	0.26	0.96
Sweet corn	Vegetable		4.9885	metric tonne	0.89	0.24	0.58
Sweet potatoes	Vegetable		6.349	metric tonne	0.3	0.04	0.42
Table beets	Vegetable		13.605	metric tonne	0.26	0.04	0.28
Pumpkin	Vegetable		-	-	-	1.17	-
Asparagus	Vegetable		-	-	-	0.05	-
Broccoli	Vegetable		-	-	-	0.055	-
Cauliflower	Vegetable		-	-	-	0.043	-
Rutabaga	Vegetable		-	-	-	0.055	-
Radishes	Vegetable		-	-	-	0.02	-

Appendix D: Additional Methodology & Data for Industry Sector

Table D1. Methodology for Estimating Phosphorus Flows through Ontario's Steel Industry

Flow(s)	Source	Estimations	Assumption	Exceptions
Imports and Exports	World Integrated Trade Solutions	National data scaled down using dollar value data from Trade Data Online, Gov. of Canada.	N/A	Cheminfo Services Inc., 2019 was used for Ontario steel import and export 2017 Data*
Interprovincial Imports	Statistics Canada, interprovincial and international trade flows (dollars)	Mass of interprovincial imports of iron ore and coal is estimated from dollars using the 2019 mass: 2018 dollars ratio for imports. P estimated from mass.	There is negligible change between the 2018 and 2019 interprovincial imports of iron ore and coal	
Raw Material in Flow (iron ore and steel)	N/A	1,300 kg of iron ore and 600 kg of coal used per ton of steel production[327]	N/A	
Mineral resources (iron ore and coal) that go to 'Transport, Chemical and Other Industries'	N/A	N/A	Assume that all P in minerals not used by the steel industry is going to 'Transport, Chemical and Other Industries'	
Steel Production	Cheminfo Services Inc., 2019 and company webpages	Capacity data scaled down to production data using the production to capacity ratio in Canada in 2017, where the production was unknown	Assumed that the steel production from mini mills that are not listed in NPRI is negligible	
Slag Production	N/A	200 kg of slag produced per ton of steel[328]	Assume P that is not in the waste or steel must be in the slag.	
Domestic Steel Consumption	N/A	N/A	Assume disappearance is equal to domestic consumption (imports + production - (waste + exports))	
Domestic Slag Consumption	N/A	N/A	Assume disappearance is equal to domestic consumption (imports + production - (waste + exports))	
Steel scrap	N/A	1,100 kg of steel scrap input per tonne of steel production using EAF[329]	N/A	

Table D2. Annual Ontario Steel Production Data and Estimated Phosphorus Content

Steel Producers	Quantity for Ontario (t/a)	Product Phosphorus Percentage (%)	Phosphorus in Steel Products (t/a)
ArcelorMittal Dofasco G.P. (factory: Dofasco Hamilton)	3,300,000	0.01	330
Algoma Steel Inc.	2,350,000	0.01	235*
Stelco Inc.	2,100,000	0.01	210*
Gerdau Ameristeel Corporation (factory: Gerdau Ameristeel Corporation, Whitby Mill)	830,000	0.01	83*
Total	**8,580,000**	**0.01**	**858**

*Estimated by calculating 87% of company capacity, which is the ratio of the annual steel production in Canada (13,614 kt) and the steel production capacity in Canada (15, 600 kt) in 2017.[330]

Table D3. National Import and Export Data[331] and Respective Provincial Distribution of Trade Flows[332] for the Steel Industry

Commodity	National Imports (kg)	National exports (kg)	Imports to Ontario (%)	Exports from Ontario (%)
Iron ores and concentrates; non-agglomerated	8,192,580	-	1.04	-
Iron ores and concentrates; agglomerated (excluding roasted iron pyrites)	8,415,100	-	100	-
Coal; bituminous, whether or not pulverised, but not agglomerated	6,740,120	-	81.5	-
Coke and semi-coke; of coal, lignite or peat, whether or not agglomerated; retort carbon	1,297,620	-	80.95	-
Slag, granulated (slag sand); from the manufacture or iron or steel	62,827	210,198	48.7	95.4
Slag, dross; (other than granulated slag), scalings and other waste from the manufacture of iron or steel	194,781	194,781	36.33	74.22

Table D4. Interprovincial Import Data for the Steel Industry (2018)

Interprovincial Imports	Dollar Value x1000	Mass (t)
Iron ores and concentrated	469,826	3,876,854
Coal	60,300	560,771

* Interprovincial and international trade flows, basic prices, detail level, Gov. of Canada
**Mass was estimated from monetary value using the following formula:

Dollar value of international imports of iron ore & concentrates in 2018 = $1,030,130
Dollar value of international imports of coal & coke in 2018 = $724,768
Masses of iron ore & concentrates and coal & coke in 2019 were calculated using the data in Table D3.

Table D5. Phosphorus Content in Ontario Wood Sources by Species

Wood species	Percentage use in forestry industry (%)[333]	P content (%)[334]
Conifers	73	0.01
Deciduous	27	0.02
Mass-Weighted Average		0.01

Table D6. Imports and Exports of Wood Products for Ontario (2019)[335]

Type of Flow	Item	Quantity (t/a)
Imports	Primary wood	382,459
	Pulp and paper	1,886,954
	Fabricated wood products	2,281,476
Exports	Primary wood	510,597
	Pulp and paper	1,363,780
	Fabricated wood products	6,440,214

* Some data was originally measured in meters cubed and converted to tonnes by multiplying by the density of wood (1.5 t/m^3).[336]

Table D7. Imports and Exports of Wood Products for Ontario (2019)[337]

Type of Data	Item	Canada	Ontario
Production	Wood-fabricated materials (m^3)	67,085,782	15,494,485
Production	Pulp and paper products (t)	20,689,000	6,062,291
Revenue of goods produced	Wood-fabricated materials (dollars)	$35,814,788,000	$5,514,648,000
Revenue of goods produced	Pulp and paper products (dollars)	$30,592,308,000	$8,964,158,000

*Ontario production values were estimated with the following formula:

$$Production\ (ON) = \frac{Revnue\ (ON)}{Revenue\ (CAN)} \times Production\ (CAN)$$

Table D8. Volume of Wood Harvested in Ontario (2010 - 2018)[338]

Year	Wood volume (m3)
2018	13,980,018
2017	15,176,833
2016	15,123,867
2015	15,828,853
2014	15,714,582
2013	15,547,833
2012	14,356,210
2011	14,309,538
2010	15,287,393
Average (2019 estimate)	**15,036,125**

Table D9. Interprovincial Trade Flows of Primary Wood Products to and from Ontario (2018)

Interprovincial Flows	Dollar value (x1000)	Estimated mass (t)
Primary wood products - imports	126,057	1,260,570
Primary wood products - exports	152,670	1,526,700

*Interprovincial and international trade flows, basic prices, detail level, Gov. of Canada
**Mass was estimated from monetary value using Eq. A-Y:

$$Interprovincial\ mass\ flow = \frac{Intenational\ import\ mass}{\ } \times Interprovincial\ flow\ monetary\ value$$

Dollar value of international imports of primary wood products in 2018 = $ 26,900,175[339]
Mass of international imports of primary wood products, 2018 = 259,057 tonnes[340]

Table D10. Methodology used to Estimate Phosphorus flows through Ontario's Forestry Industry

Flow(s)	Source	Estimations	Assumption
Wood harvested in Ontario	Canadian Forest Service (volume)	Volume of harvested wood in 2019 estimated by averaging the volume of harvested wood from 2010-2018. Mass was calculated from volume by multiplying by the wood density.	
Imports and exports (wood fabrication)	Canadian Forest Service (mass)	P content estimated using a 0.01 % P in wood[341]	
Interprovincial imports and exports	Statistics Canada, interprovincial and international trade flows (dollars)	Wood mass estimated from dollars using the mass: dollars ratio for imports. P was estimated from mass.	
Wood-fabricated products	Canadian Forest Service (mass)	P estimated from product masses	
Waste (pulp & paper and wood fabrication)	NPRI		
Wood fabricated production inputs	N/A	The total of wood fabrication products and waste	
Pulp & paper inputs	N/A	Total P input to the forestry industry, subtract wood fabrication inputs	
Pulp & paper products	N/A	Subtract waste from Inputs into pulp & paper industry	

Table D11. Phosphorus Flows in Dairy Production Wastewater

Flow(s)	Source	Estimations	Assumption
Imports and Exports	World Integrated Trade Solutions	National data scaled down using dollar value data from Trade Data Online, Gov. of Canada.	N/A
Raw materials	N/A	Currently, we are unable to estimate raw materials for other dairy products	N/A
Dairy production	Supply-disposition data from Statistics Canada	Production was estimated using import, export, waste and domestic disappearance data provided in the supply-disposition file.	
National data were scaled down by 41.6%, which is the percentage of Ontario's total revenue for dairy products manufacturing.	N/A		
Domestic dairy consumption	N/A	N/A	Assume disappearance is equal to domestic consumption
Waste	N/A	P in ice cream and cheese production wastewater was estimated in Table D30. Based on the production, the P amount in milking facility effluent was estimated (Table D29).	Calculation based on the estimated production

Table D12. Ontario Production of Dairy Products (2019)

Commodity	CA Imports (thousand Kilolitres or Tonnes)	Import % corresponding to ON	CA Exports (thousand Kilolitres or Tonnes)	Export % corresponding to ON	CA Production* (thousand Kilolitres or Tonnes)	ON Imports (thousand Kilolitres or Tonnes)	ON Exports (thousand Kilolitres or Tonnes)	ON Production (thousand Kilolitres or Tonnes)	P kg/000'kL or 000' Tonne of product edible portion	P in ON Imports (Tonne)	P in ON Exports (Tonne)	P in ON Production (Tonne)
Butter	--	--	--	--	116.15	--	--	48.3	300	0.0	0.0	14.5
Buttermilk	--	70.8%	--	5.2%	11.82	--	--	4.9	920	0.0	0.0	4.5
Cereal cream 10%	--	--	--	--	116.17	--	--	48.3	1000	0.0	0.0	48.3
Cheese sum	30.45	42.4%	9.85	71.0%	567.63	12.9	7.0	235.9	4000	51.6	28.0	943.6
Ice Cream and Other Edible Ice, Whether or Not Containing Cocoa	--	46.3%	0.27	84.1%	67.66	--	0.2	28.1	1000	0.0	0.2	28.1
Milk and Cream Sweetened - Concentrated - Not in Powder	0.01	10.3%	0.39	3.5%	2.32	0.001	0.01	1.0	3270	0.0	0.0	3.2
Milk and Cream Unsweetened - Concentrated - Not in Powder	--	92.8%	0.18	1.1%	0	--	0.002	0.0	3270	0.0	0.0	0.0
Milk powder sum	4.57	86.8%	65.86	17.7%	168.12	4.0	11.7	69.9	9700	38.5	113.1	677.7

Commodity	CA Imports (thousand Kilolitres or Tonnes)	Import % corresponding to ON	CA Exports (thousand Kilolitres or Tonnes)	Export % corresponding to ON	CA Production* (thousand Kilolitres or Tonnes)	ON Imports (thousand Kilolitres or Tonnes)	ON Exports (thousand Kilolitres or Tonnes)	ON Production (thousand Kilolitres or Tonnes)	P kg/000'kL or 000' Tonne of product edible portion	P in ON Imports (Tonne)	P in ON Exports (Tonne)	P in ON Production (Tonne)
Milk/ Cream, Not Concentrated or Sweetened (<2% Fat)	--	56.8%	--	12.6%	179.49	--	--	74.6	980	0.0	0.0	73/1
Milk/ Cream, Not Concentrated or Sweetened (2-6% Fat)	--	58.2%	--	78.6%	1600.85	--	--	665.3	870	0.0	0.0	578.8
Powder whey	1.3	60.7%	--	15.3%	64.6	0.8	--	26.8	9000	7.1	0.0	241.6
Processed cheese	1.05	53.5%	0.11	18.8%	67.13	0.6	0.02	27.9	6000	3.4	0.1	167.4
Products Consisting of Natural Milk Constituents	1.76	49.2%	1.08	6.7%	204.9	0.9	0.1	85.2	1000	0.9	0.1	85.2
Table cream 18%	--	--	--	--	144.41	--	--	60.0	840	0.0	0.0	50.4
Whipping cream 32% or 35%	--	--	--	--	59.39	--	--	24.7	620	0.0	0.0	15.3
Yogurt	0.55	31.8%	9.24	95.6%	374.38	0.2	8.8	155.6	850	0.1	7.5	132.3
Total										**101.6**	**149.1**	**3,064.0**

Table D13. Cleaning Water Demand in Milking Facilities[349]

	Automatic Milking System	Herringbone Milking Parlour
L cleaning water/L milk produced	0.8	1.3

Table D14. Milking Facility Cleaning Water Phosphorus Concentration and Amount Estimates

Phosphorus in dairy wastewater[350]	ON milk production (kL/a)[351]	ON cleaning water demand (000 kL/a)	P in ON cleaning water effluent (t/a)
15-42 mg P/L	3,011,118	2,420 – 3,914	36-164

Table D15. Phosphorus Concentrations and Mass Estimates for Wastewater from the Production of Dairy Products

Product	Cheese	Ice Cream
kg wastewater/kg milk[352]	1.63 - 5.70	0.80 - 5.60
kg wastewater/kg milk (avg)[353]	3.14	2.8
ON 2019 production (t/a)	169.3	28.1
Wastewater P concentration (g/L)[354]	0.005 – 0.28	0.014
Wastewater mass (kt/a)	276 - 965	47 - 331
P mass in wastewater (t/a)	2 - 270	0.7 - 4.6

Table D16. Imports, Exports, Production and Consumption of Grain and Oilseed Products in Canada[342]

Commodity	Import (kt)	Export (kt)	Consumption (kt)	Production (kt)
Wheat flour	89.69	184.16	N/A	2545.51
Rye flour	0.69	1.87	8.05	9.23*
Oatmeal and rolled oats	10.34	458.89	178.26	626.81*
Corn flour and meal	66.76	47.31	20.81	1.36*
Rice	314.85	13.8	-	-
Pot and pearl barley	0	0	17.59	17.59*

*These production values are estimated using Eq. A-Z.

$$Production = imports - consumption - exports$$

Table D17. Phosphorus Value of Edible Portion of Commodities[343]

Commodity	Wheat flour	Rye flour	Oatmeal and rolled oats	Corn flour and meal	Rice	Pot and pearl barley
P-value (mg P/100 g of edible portion)	116	207	352	99	264	264

Table D18. Import and Export Distribution for Products from the Grain and Oilseed Industry[344]

Commodity	Imports to Ontario (%)	Exports from Ontario (%)
Wheat flour	77.18	25.29
Rye flour	64.91	0
Oatmeal and rolled oats	42.64	1.39
Corn flour and meal	84.66	1.35
Rice	60.58	39.12

Table D19. Methodology used to Estimate Phosphorus Flows through Ontario's Grain and Oilseed Industry

Flow(s)	Source	Estimations	Assumption	Exceptions
Imports and Exports	Supply-disposition data from Statistics Canada	National data scaled down using provincial distribution from Trade Data Online, Gov. of Canada.	N/A	
Production	Supply-disposition data from Statistics Canada	Production data for rye flour, corn flour, oatmeal and pot and pearl barley are confidential. Production was estimated using import, export, waste and domestic disappearance data provided in the supply-disposition file.		
Domestic P consumption in products	N/A	N/A	Domestic P consumption was estimated by: P imports + P production - P exports.	
Raw materials	N/A	N/A	P in raw materials was estimated by P production + P waste	

Table D20. Methodology used to Estimate Phosphorus Flows through Ontario's Beverage Manufacturing Industry

Flow(s)	Source	Estimations	Assumption
Imports and Exports	World Integrated Trade Solutions	National data scaled down using dollar value data from Trade Data Online, Gov. of Canada.	N/A
Raw materials	N/A	Raw material for the brewery was estimated based on brewing process mass balance which is in Table C10. Currently, we are unable to estimate raw materials for other beverage products	N/A
Beverage Production	Supply-disposition data from Statistics Canada	Production data including ale, beer, stout and porter/ ciders, cooler and other refreshment beverages/ distilled spirits/ wines/ soft drinks. Production was estimated using import, export, waste and domestic disappearance data provided in the supply- disposition file.	
Domestic beverage Consumption	N/A	N/A	Assume disappearance is equal to domestic consumption
Waste	N/A	Waste for the brewery was estimated based on brewing process mass balance which is in Table B19. The P amount in soft drink manufacturing effluent was estimated based on the production (Table B18).	Calculation based on the estimated production

Table D21. Ontario Beverage Production Data

Commodity	CA Imports (1000 kL)	Import% to ON	CA Exports (1000 k)L	Export% for ON	CA Domestic consumption (1000 kL)	CA Production* (1000 kL)	ON Imports (1000 kL)	ON Exports (1000 kL)	ON Production (1000 kL)	P mg/L of product edible portion	P in ON Imports (t)	P in ON Exports (t)	P in ON Production (t)
Ale, beer, stout and porter	372	0.4	165	0.7	2,380	2,008.3	145	116	773	130	18	15	100
Ciders, cooler and other refreshment beverages	70	0.5	22	0.1	203	132	37	1.5	51	70	2.6	0.1	3.6
Distilled spirits	23	0.4	164	0.7	336	312	10.4	112	120	70.0	0.7	7.8	8.4
Wines	415	0.3	95	0.5	614	199	131	47.3	76.7	200	26	9.5	15
Soft drinks	513	0.6	171	0.6	2,332	1,818	308	96	700	70	22	6.7	49
Total											**70**	**39**	**177**

* Production = Domestic consumption + Exports - Imports
**CA - Canada; ON - Ontario

Table D22. Phosphorus Flow Estimations for 1 L of Average Beer Production

Components	Barley malt (kg)	Yeast (kg)	Spent grain (kg)	Beer (L)	Spent yeast (kg)	Wastewater (L)
For 1 L of beer	0.18	0.01	0.21	1.00	0.02	2.0
Dry mass%	0.95	0.15	0.2	0	0.15	0
P concentration	0.3 wt%	1.5 g / 100 g	0.46 wt%	130 mg/L	15 g / kg dry mass	30 - 100 mg/L
g P/L beer	0.51	0.015	0.19	0.13	0.04	0.06 - 0.20

Estimates for P flows for basic brewing process streams were calculated from a description of the basic brewing process in Krausová (2014).[345]

Table D23. Phosphorus Flow Estimations for 774 kL/a Beer Production in Ontario

Phosphorus Flows	Barley malt	Yeast	Spent grain	Beer	Spent yeast	Wastewater
kt/a	0.40	0.01	0.15	0.10	0.03	0.05 - 0.15

Table D24. Methodology used to Estimate Phosphorus Flows through Ontario's Juice Manufacturing Industry

Flow(s)	Source	Estimations	Assumption
Imports and Exports	World Integrated Trade Solutions	National data scaled down using dollar value data from Trade Data Online, Gov. of Canada.	N/A
Raw materials	N/A	Raw material for juice production was estimated based on apple juice production mass balance (Table C23).	N/A
Juice production	Supply-disposition data from Statistics Canada	Production data include apple juice, orange juice, grape juice and tomato. Production was estimated using import, export, and provided in the supply- disposition file and food availability per person data. National data were scaled down by 41.2%, which is the percentage of Ontario's total revenue for fruit and vegetable preserving and specialty food manufacturing.	N/A
Domestic juice consumption	N/A	N/A	Assume disappearance is equal to domestic consumption
Waste	N/A	The P amount in juice manufacturing effluent was estimated based on the production (Table D24).	Calculation based on the estimated production

Table D25. Phosphorus Flows in Ontario Juice Production

	Apple juice	Grape juice	Orange juice	Tomato juice
CA food availability per person (L/a)	4.1	3	9.1	0.5
ON total available product (t/a)	62.6	46.2	138.8	8
CA imports (t/a)	179	75.5	354.1	1.1
CA export (t/a)	13.5	5	17.3	0.5
ON Imports%	0.3	0.6	0.6	0.9
ON Exports%	0.8	0.4	0.8	0.9
ON Imports (t/a)	55.5	43.8	199.3	1
ON Exports (t/a)	11.4	2	13.9	0.5
ON juice production (t/a)	18.5	4.4	-46.7	7.5

	Apple juice	Grape juice	Orange juice	Tomato juice
P in product (g P/kg)	90	140	170	190
P in ON Imports (t/a)	5	6.1	33.9	0.2
P in ON Exports (t/a)	1	0.3	2.4	0.1
P in ON Production (t)	1.7	0.6	-7.9	1.4

*CA - Canada; ON - Ontario

Table D26. Mass Balance of Apple Processing into Apple Juice[346]

Components	Apple (kg)	Apple pomace (kg)	Production residue (kg)
For making 1 L of apple juice	2.07	0.69	0.34
P concentration	110 mg P/kg	--	--
g P/L apple juice	0.23	0.14*	

Table D27. Phosphorus Flows in Juice Manufacturing Based on Apple Juice

Juice product	Apple juice	Grape juice	Orange juice	Tomato juice
ON juice production (t/a)	18.47	4.4	-46.69	7.5
ON total raw materials	38.23	9.11	-96.65	15.53
P in product (g P/kg)	90	140	170	190
P in raw material (g P/kg)	110	200	120	240
ON total P in the product (t/a)	1.66	0.62	-7.94	1.43
ON total P in raw material (ta)	4.21	1.82	-11.6	3.73
ON total P in waste (t/a)	2.54	1.21	-3.66	2.3

Table D28. Estimation of Phosphorus in Soft Drink Manufacturing Wastewater (2019)

Soft drink production	Wastewater volume[347]	Wastewater phosphorus concentration[348]	Total soft drink production (ON)	Phosphorus content in soft drink production wastewater
1 L	1.25 - 2 L	20 - 40 mg/L	701 000 kL/a	18 - 56 t/a

Table D29. Annual Estimates of Phosphorus Fertilizers and Phosphorus Contents Exported from Ontario

Code	Product	Exports-Canada (t/a)	Percentage of exports from Ontario	Exports-Ontario (t/a)	P content (fraction)	P (t/a)
310530	Fertilizers, mineral or chemical; diammonium hydrogenorthophosphate (diammonium phosphate)	4,326	12.85	556	0.2024	113
310390	Fertilizers, mineral or chemical; phosphatic, n.e.s. in heading no. 3103	520	30.66	159	0.2	32
310310	Fertilizers, mineral or chemical; phosphatic, superphosphates	2	0	0		0
310520	Fertilizers, mineral or chemical; containing the three fertilizing elements nitrogen, phosphorus and potassium	64,296	34.98	22,491	0.1408	3,167
310540	Fertilizers, mineral or chemical; ammonium dihydrogenorthophosphate (monoammonium phosphate) and mixtures thereof with diammonium hydrogenorthophosphate (diammonium phosphate)	3,096	64.14	1,986	0.27	536
310551	Fertilizers, mineral or chemical; containing nitrates and phosphates	1,070	12.4	133	0.2	27
310560	Fertilizers, mineral or chemical; containing the two fertilizing elements phosphorus and potassium	2,899	22.04	639	0.2	128
310559	Fertilizers, mineral or chemical; containing the two fertilizing elements nitrogen and phosphorus, other than nitrates and phosphates	6,848	39.37	2,696	0.2	539
	Estimated Total P in Fertilizers exported from Ontario					**4,541**

Table D30. Annual Import Estimations of Phosphorus Chemicals and Estimated Masses

HS Code	Product	Imports-Canada (t/a)	Percentage Imports to Ontario (%)	Imports - Ontario (t/a)	P Content (fraction)*	Ontario Imports (t/a)
280920	Phosphoric acid and polyphosphoric acids	125,080	47.74	59,700	0.32	19,100
280470	Phosphorus	1,627,450	90.87	1,480	1	1,480
283510	Phosphinates (hypophosphites) and phosphonates (phosphites)	978,590	28.82	282	0.48	135
283522	Phosphates; of mono- or disodium	1,384,770	68.23	945	0.24	227
283524	Phosphates; of potassium	3,550,340	50.45	1,790	0.15	269
283526	Phosphates; of calcium n.e.s. in item no. 2835.25	9,188,350	30.27	2,780	0.2	556
283531	Polyphosphates; sodium triphosphate (sodium tripolyphosphate)	7,307,700	49.08	3,590	0.28	1,000
283525	Phosphates; calcium hydrogenorthophosphate (dicalcium phosphate)	1,759,190	46.27	814	0.18	147
283529	Phosphates; n.e.s in item no. 2835.2	2,173,060	82.87	1,800	0.2	360
283539	Polyphosphates; (other than sodium triphosphate (sodium tripolyphosphate))	18,748,000	52.92	9,920	0.28	2,778
280910	Diphosphorus pentoxide	104,376	31.12	32	0.44	14.3
	Estimated total P in chemicals imported to Ontario (t/a)					**26,100**

*The P content is calculated from the ratio of the equal to molar mass of P/molar mass of chemical
*The total P in imported chemicals was multiplied by a factor of 0.85 to account for 85 % concentration of phosphoric acid, and possible other impurities in the other chemical forms.

Table D31. Annual Export Estimations of Phosphorus Chemicals and Estimated Masses

Code	Product	Exports-Canada (t/a)	Percentage Exports from Ontario	Exports - Ontario (t/a)	P content (fraction)	P (t/a)
280920	Phosphoric acid and polyphosphoric acids	5,637	71.52	4,032	0.32	1,290
251010	Natural calcium phosphates, natural aluminum calcium phosphates and phosphatic chalk; unground phosphorus	2,121	100	2,121	0.2	424
25102	Natural calcium phosphates, natural aluminum calcium phosphates and phosphatic chalk; ground	297	0	0		0
280470	Phosphorus	0	0	0	1	0
283510	Phosphinates (hypophosphites) and phosphonates (phosphites)	30	60.93	18	0.48	9
283522	Phosphates; of mono- or disodium	630	97.69	615	0.24	148
283524	Phosphates; of potassium	440	96.51	425	0.15	64
283526	Phosphates; of calcium n.e.s. in item no. 2835.25	150	100	150	0.2	30
283531	Polyphosphates; sodium triphosphate (sodium tripolyphosphate)	29,682	99.91	29,655	0.28	8,303
283525	Phosphates; calcium hydrogenorthophosphate (dicalcium phosphate)	58	63.21	36	0.18	7
283529	Phosphates; n.e.s in item no. 2835.2	272	99.99	272	0.2	54
283539	Polyphosphates; (other than sodium triphosphate (sodium tripolyphosphate))	22,003	99.48	21,889	0.28	6,129
280910	Diphosphorus pentoxide	0		0	0.44	0
	Estimated Total P in Chemicals exported from Ontario	0		0		**16,457**

Table D32. Examples of Phosphorus in Mining Waste (2019)

Category	Value	Reference
Detour Gold Corporation		
Total waste rock (t)	85,000,000	Detour gold news release (Detour Gold Reports Q4 and FY 2019 Production Results)
P in waste rock (t)	27,370	NPRI
P concentration (wt%)	0.03%	
Total tailing (t)	33,866,254	Kirkland Lake Gold sustainability report 2019
P in tailing management (t)	9,211	NPRI
P concentration (wt%)	0.03%	
Kirkland Lake Gold: Macassa Mine		
Total tailing (t)	361,231	Kirkland Lake Gold sustainability report 2019
P in tailing management (t)	468	NPRI
P concentration (wt%)	0.13%	

Table D33. Estimation Method and Data Sources for Ontario Pork and Beef Production

Flow	Year	Source	Link
ON Pork imports and exports	2009-2021	Statistics Canada, International Trade Statistics	http://www.omafra.gov.on.ca/english/stats/trade/pig_pork.xlsx
ON Beef imports and exports	2009-2021	Statistics Canada, International Trade Statistics	http://www.omafra.gov.on.ca/english/stats/trade/cattle_beef.xlsx
Food availability	1960-2020	Statistics Canada, Table 32100054; Formerly CANSIM Table 002-0011	https://open.canada.ca/data/en/dataset/a683c640-b5fd-48f8-a0f1-d619b8f7e04c
Ontario population	1946-2021	Statistics Canada, Table: 17-10-0009-01 (formerly CANSIM 051-0005)	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901

Assumption:
production = total food availability + exports from ON - import into ON
total food availability = food availability per person x ON population

Table D34. Ontario Food Production and Phosphorus for Each Product (2019)

*Production values from OMAFRA or Statistic Canada (Tables D31 and D35). The P concentration “Phosphorus (g/kL or g/t)” is from the Canadian Nutrient File. The “Total Phosphorus in the product (t/a)” is calculated from the production and P concentration values.

Product	Category	2019 Production	Unit	Phosphorus (g/kL or g/t)	Total Phosphorus in product (t/a)
Winter Wheat	Cereals	1,371	kT	2,880	3,947
Oats	Cereals	105	kT	4,450	466
Barley	Cereals	134	kT	2,640	354
Mixed Grain	Cereals	93	kT	1,500	139
Grain Corn	Cereals	8,641	kT	720	6,221
Fodder Corn	Cereals	4,743	kT	720	3,415
Spring wheat	Cereals	151	kT	3,320	502
Total aquaculture	Fish and seafood	5,901	tonne	2,400	14.2
Apple	Fruits	147,132	tonne	80	11.8
Apricot	Fruits	0	tonne	230	0.0
Blueberry	Fruits	785	tonne	120	0.1
Grape	Fruits	82,788	tonne	100	8.3
Nectarine	Fruits	2,673	tonne	260	0.7
Peach	Fruits	16,814	tonne	200	3.4
Pear	Fruits	3,410	tonne	110	0.4
Sweet cherry	Fruits	793	tonne	210	0.2
Sour cherry	Fruits	3,426	tonne	160	0.5
Plum & prunes	Fruits	2,479	tonne	160	0.4
Raspberry	Fruits	747	tonne	290	0.2
Strawberry	Fruits	6,679	tonne	240	1.6
Total prok	Meat	366	kT	2,130	780
Total beef	Meat	352	kT	1,870	659
Chicken	Meat	439,577	tonne	1,510	664
Turkey	Meat	72,269	tonne	1,470	106
Milk	Milk and egg	3,011,118	kL	870	2,620
Egg	Milk and egg	302,724	000 dozens	0	218
Soybeans	Oilseed	3,708	kT	7,040	26,105
Canola	Oilseed	42	kT	0	317
Beans (green & wax)	pulses	33,907	tonne	4,000	136
Green peas	pulses	24,774	tonne	1,080	26.8
White Beans	pulses	56	kT	3,010	170
Coloured Beans	pulses	68	kT	4,000	272
Beets	roots	16,514	tonne	400	6.6
Carrots	roots	186,945	tonne	350	65.4
Dry onion	roots	96,504	tonne	290	28.0
Radishes	roots	4,047	tonne	200	0.8
Rutabagas	roots	21,748	tonne	530	11.5
Maple Syrup	Sugar	2,282	kL	30	0.1
Honey	Sugar	3,612	tonne	40	0.1
Sweet potato	tuber	13,240	tonne	470	6.2
Potatos	tuber	304,152	tonne	570	173

Greenhouse peppers	Vegetables	99,453	tonne	200	19.9
Greenhouse cucumber	Vegetables	299,554	tonne	240	71.9
Greenhouse tomato	Vegetables	185,170	tonne	240	44.4
Asparagus	Vegetables	7,511	tonne	520	3.9
Broccoli	Vegetables	13,059	tonne	660	8.6
Cabbage	Vegetables	55,510	tonne	260	14.4
Cauliflower	Vegetables	5,740	tonne	440	2.5
Celery	Vegetables	13,489	tonne	240	3.2
Cucumbers and Gherkins	Vegetables	40,020	tonne	240	9.6
Eggplant	Vegetables	1,380	tonne	240	0.3
Kale	Vegetables	1,578	tonne	920	1.5
Pepper	Vegetables	39,896	tonne	200	8.0
Pumpkin & Squash	Vegetables	77,483	tonne	440	34.1
Spinach	Vegetables	1,920	tonne	490	0.9
Sweetcorn	Vegetables	100,196	tonne	890	89.2
Tomato	Vegetables	469,518	tonne	240	113
Mushroom	Vegetables	66,687	tonne	860	57.4

Table D35. Mass Loss Factors for Different Food Types along the Food Supply Chain (FAO)[355]

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket, Retail	Consumption
Cereals	0.02	0.02	0.05	0.02	0.27
Roots and tubers	0.2	0.1	0.15	0.07	0.3
Oilseeds and pulses	0.12	0	0.05	0.01	0.28
Fruits and vegetables	0.2	0.04	0.02	0.12	0.28
Meat	0.035	0.01	0.05	0.04	0.11
Fish and seafood	0.12	0.005	0.06	0.09	0.33
Milk	0.035	0.005	0.012	0.005	0.15
Average	**0.10**	**0.03**	**0.06**	**0.05**	**0.25**

Table D36. Ontario Phosphorus Mass Losses along the Food Supply Chain for Selected Foods (2019)

Food Type	Total P in Initial production (t/a)	TP Loss in Agricultural production (t/a)	TP Loss in Postharvest handling and storage (t/a)	TP Loss in Processing and packaging (t/a)	TP Loss in Distribution: Supermarket, Retail (t/a)	TP Loss in Consumption (t/a)
Sugar	0.076	0.008	0.002	0.004	0.003	0.015
Tuber	22.19	4.44	1.77	2.40	0.95	3.79
Roots	434.68	62.24	10.08	27.19	7.98	93.04
Fish and seafood	512.23	10.24	10.04	24.60	9.35	123.66
Pulses	737.10	88.45	0.00	32.43	6.16	170.81
Vegetables	748.21	149.64	34.34	31.57	57.29	135.57
Fruits	48.47	8.41	1.11	1.34	4.12	9.98
Meat	2,180.71	76.66	21.09	104.10	79.28	209.18
Milk and egg	2,824.78	98.87	14.16	36.54	16.87	394.91
Cereals	14,839.13	296.78	290.85	712.58	270.78	3,582.39
Oilseed	29,894.43	3,567.81	1.11	1,307.90	249.09	6,907.01
Total	**52,242.00**	**4,363.55**	**384.56**	**2,280.64**	**701.86**	**11,630.37**

Table D37. Data Sources for Ontario Agricultural Production

Products	Year	Sources used	Link
Finfish and shellfish	1991-2020	Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value	https://doi.org/10.25318/3210010701-eng
Apple	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/apple.xlsx
Apricot	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/apricot.xlsx
Blueberry	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/blueberry.xlsx
Grape	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/grape.xlsx
Nectarine	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/nectarine.xlsx
Peach	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/peach.xlsx
Pear	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/pear.xlsx
Sweet cherry	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/sourcherry.xlsx
Sour cherry	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/sourcherry.xlsx
Plum and Prunes	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/plumprunes.xlsx
Raspberry	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/raspberry.xlsx
Strawberry	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/strawberry.xlsx
Asparagus	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/asparagus.xlsx

Products	Year	Sources used	Link
Beans (green & wax)	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/beans.xlsx
Beets	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/beets.xlsx
Broccoli	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/broccoli.xlsx
Cabbage	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/cabbage.xlsx
Carrots	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/carrots.xlsx
Cauliflower	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/cauliflower.xlsx
Celery	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/celery.xlsx
Cucumbers and Gherkins	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/cucumber.xlsx
Dry onion	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/dryonion.xlsx
Eggplant	2018-2021	Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/greenpeas.xlsx
Green peas	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/greenpeas.xlsx
Kale	2018-2021	Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/cabbagekale.xlsx
Pepper	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/pepper.xlsx
Pumpkin & Squash	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/pumpkin.xlsx
Radishes	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/radishes.xlsx
Rutabagas and Turnips	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/rutabagas.xlsx
Spinach	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/spinach.xlsx
Sweetcorn	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/sweetcorn.xlsx
Sweet potato	2018-2021	Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/sweetpotato.xlsx
Tomato	1979-2021	Agricultural Statistics for Ontario, OMAFRA; Fruit and Vegetable Survey, Statistics Canada	http://www.omafra.gov.on.ca/english/stats/hort/tomato.xlsx
Greenhouse tomatoes	1979-2020	Statistics Canada, CANSIM table no: 32-10-0456-01	http://www.omafra.gov.on.ca/english/stats/hort/ghtomato.xls
Greenhouse cucumbers	1979-2019	Statistics Canada, CANSIM table no: 32-10-0456-01	http://www.omafra.gov.on.ca/english/stats/hort/ghcucumber.xls
Greenhouse peppers	1993-2020	Statistics Canada, CANSIM table no: 32-10-0456-01	http://www.omafra.gov.on.ca/english/stats/hort/ghpepper.xls
Mushrooms	1983-2020	Statistics Canada, CANSIM table no. 32-10-0356-01	http://www.omafra.gov.on.ca/english/stats/hort/mushroom.xlsx
Potatoes	1984-2021	Statistics Canada, CANSIM table no. 32-10-0358-01	http://www.omafra.gov.on.ca/english/stats/hort/potato.xlsx
Winter Wheat	2004-2020	Statistics Canada: Field Crop Reporting Series	http://www.omafra.gov.on.ca/english/stats/crops/ctywwheat2004_20.xlsx

Products	Year	Sources used	Link
Oats	2004-2020	Statistics Canada: Field Crop Reporting Series	http://www.omafra.gov.on.ca/english/stats/crops/ctyoats2004_20.xlsx
Barley	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctybarley2004_20.xlsx
Mixed Grain	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctymixed2004_20.xlsx
Grain Corn	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctygcorn2004_20.xlsx
Soybeans	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctysoy2004_20.xlsx
White Beans	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctywbeans2004_20.xlsx
Fodder Corn	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctyfcorn2004_20.xlsx
Spring wheat	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctyswheat2004_20.xlsx
Canola	2004-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctycanola2004_20.xlsx
Coloured Beans	2005-2020	OMAFRA calculations adapted from Statistics Canada	http://www.omafra.gov.on.ca/english/stats/crops/ctycbeans2005_20.xlsx
Chicken	1998-2020	Statistics Canada. Table 32-10-0118-01	http://www.omafra.gov.on.ca/english/stats/livestock/poultry.xlsx
Turkey	1998-2020	Statistics Canada. Table 32-10-0117-01	http://www.omafra.gov.on.ca/english/stats/livestock/poultry.xlsx
Milk	2007-2020	OMAFRA; Dairy Farmers of Ontario.	http://www.omafra.gov.on.ca/english/stats/dairy/shipment.xlsx
Egg	1998-2020	Statistics Canada. Table 32-10-0119-01	http://www.omafra.gov.on.ca/english/stats/livestock/eggs.xlsx
Honey	1982-2021	Statistics Canada, CANSIM table no. 32-10-0353-01	http://www.omafra.gov.on.ca/english/stats/hort/honey.xlsx
Maple syrup	1982-2021	Statistics Canada, CANSIM table no. 32-10-0354-01	http://www.omafra.gov.on.ca/english/stats/hort/maple.xlsx

Appendix E: Select Policies and Programs related to Phosphorus

Government	Policy or Program	Year	Description
Governments of Canada and the U.S.	Great Lakes Water Quality Agreement	1972 Revised in 1978, amended in 1983 and 1987, and updated in 2012	▪ Binational agreement between Canada and the U.S. to restore and enhance water quality in the Great Lakes Basin. Annex 4 of the Agreement focuses specifically on coordinating binational actions to manage P (and other nutrients, if warranted) concentrations and loadings in the Great Lakes waters.
Government of Canada and Province of Ontario	Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health	1971 Amended in 1994, 2002,2007, 2014, 2021	▪ The Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (COA) is a federal-provincial agreement supporting the restoration and protection of the Great Lakes. It is the means by which Canadian federal departments interact with Ontario provincial ministries to meet Canada's obligations under the GLWQA. ▪ Annex 1 of 2021 COA strives to attain the sustainable use of nutrients for the continued health and productivity of the Great Lakes ecosystem, with a focus on Lake Erie. ▪ Annex 3 commits to reducing excess nutrient and contaminant loadings from stormwater and wastewater collection and treatment systems and supporting innovative practices and technologies that result in improved environmental protection, including P recovery and reuse.
Environment and Climate Change Canada and the Ontario Ministry of the Environment, Conservation and Parks	Bay of Quinte Remedial Action Plan	1985	▪ The Bay of Quinte was designated an Area of Concern (AOC) in 1985 under the GLWQA. A Remedial Action Plan (RAP) is required for AOCs to measure progress against Beneficial Use Impairments before they can be delisted. The development of a long-term Phosphorus Management Plan is one of the last remaining activities before the bay can be considered for delisting and is currently being developed.
Environment and Climate Change Canada, U.S. Environmental Protection Agency, Ontario Ministry of the Environment, Conservation and Parks	Lakewide Action and Management Plans	1987 Amended in 2012	▪ Lakewide Action and Management Plans (LAMPs) are binational, five-year, ecosystem-based strategies for restoring and protecting the water quality of each of the five Great Lakes and their respective connecting river systems. ▪ LAMPs include nutrient strategies and action plans that work to limit the loss of nutrients into the environment and the resulting contamination of freshwater sources.
Environment and Climate Change Canada, Agriculture and Agri-Food Canada, Ontario Ministry of the Environment, Conservation and Parks, Ontario Ministry of Natural Resources and Forestry, Ontario Ministry of Agriculture, Food and Rural Affairs	Canada-Ontario Lake Erie Action Plan	2018	▪ Developed jointly by federal and provincial agencies, the Canada-Ontario Lake Erie Action Plan sets out a path for reducing P loading in Lake Erie with the goal of decreasing the presence of harmful and nuisance algal blooms, as well as the zones of low oxygen (hypoxia) that threaten both the ecosystem and human health. ▪ The action plan recognizes that ongoing research to reduce, recycle and recover P from point and non-point sources will be important for achieving the targets.
Ontario Ministry of the Environment, Conservation and Parks	Lake Simcoe Protection Plan	2009 Updated 2020	▪ This plan is designed to protect and restore the ecological health of Lake Simcoe and includes a focus on reducing P loading, including through the development of a comprehensive Phosphorus Reduction Strategy.

Government	Policy or Program	Year	Description
Ontario Ministry of the Environment, Conservation and Parks	Lake Simcoe Phosphorus Reduction Strategy	2016 Updated 2021	▪ This strategy is critical to achieving the ambitious and aggressive reductions in P needed to restore the Lake Simcoe's water quality and ecological health. ▪ The strategy discusses the reuse of treated wastewater effluent and stormwater runoff.
Ontario Ministry of the Environment, Conservation and Parks	Ontario's Great Lakes Strategy	2016 Updated 2021	▪ This strategy outlines Ontario's priorities for maintaining the health and wellbeing of the Great Lakes. ▪ ▪he strategy notes a commitment to decreasing reliance on P imports and improving efficient use of P for improved soil management and crop growth, through supporting opportunities to pilot new and innovative technologies for enhanced and improved nutrient recycling, including P recovery from sewage, manure, and compost
Province of Ontario	Great Lakes Protection Act	2015 Amended 2020, 2021	▪ The purpose of this Act is to protect and restore the ecological health of the Great Lakes-St. Lawrence River Basin, including through the elimination or reduction of harmful pollutants; and to create opportunities for individuals and communities to become involved in the protection and restoration of the ecological health of the Great Lakes-St. Lawrence River Basin.
Government of Canada	Fertilizers Regulations under the Fertilizers Act, 1985	2006 Amended in 2007, 2009, 2011, 2012, 2013, 2015, 2020	▪ The *Fertilizers Act* and Fertilizers Regulations require that all regulated fertilizer and supplement products imported into or sold in Canada must be safe for humans, plants, animals, and the environment. They must also be properly labelled to ensure safe and appropriate use. ▪ As P is a primary component in fertilizer, this regulation optimizes P application in fields to limit its loss to the environment.
Agriculture and Agri-Food Canada and the Ontario Ministry of Agriculture, Food and Rural Affairs	Canada-Ontario Environmental Farm Plans	1993	▪ Environmental Farm Plans (EFP) are voluntary assessments prepared by farm families to increase their environmental awareness in up to 23 different areas on their farm. Through the EFP, farmers highlight their farm's environmental strengths, identify areas of environmental concern, and set realistic action plans with timetables to improve environmental conditions. ▪ Voluntary workshops held by Ontario Soil and Crop Improvement Association address P loss.
Province of Ontario	Waste-Free Ontario Act	2016	▪ Comprised of the Resource Recovery and Circular Economy Act, 2016 and the *Waste Diversion Transition Act*, 2016 ▪ Establishes Ontario's commitment to transitioning to a circular economy by increasing the recovery and reuse of resources and references nutrient reuse.
Ontario Ministry of the Environment, Conservation and Parks	Strategy for a Waste-Free Ontario: Building the Circular Economy	2017 Updated 2021	▪ This strategy outlines objectives and actions for achieving zero waste and a circular economy. ▪ The recovery of nutrients, such as digestate from anaerobic digestion, is considered diversion under the strategy.

Government	Policy or Program	Year	Description
Ontario Ministry of the Environment, Conservation and Parks	Food and Organic Waste Framework	2018 Updated 2021	▪ The Food and Organic Waste Framework is comprised of the Food and Organic Waste Action Plan and the Food and Organic Waste Policy Statement. ▪ The Framework discusses the importance of not being limited to recovering nutrients and resources at the end-of-life stage in an effort to move towards a truly circular economy.
Ontario Ministry of the Environment, Conservation and Parks	Food and Organic Waste Policy Statement	2018 Updated 2021	▪ Issued under section 11 of the Resource Recovery and Circular Economy Act, this statement provides direction for increasing waste reduction and resource recovery of food and organic waste, by 2025. ▪ Waste reduction and resource recovery of food and organic waste is noted to recover valuable nutrients, thus fostering a circular economy.
Ontario Ministry of the Environment, Conservation and Parks	Provision and Operation of Phosphorus Removal Facilities at Municipal, Institutional and Private	2016 Updated 2021	▪ This guideline ensures that P removal facilities are installed and properly operated at municipal, institutional and private sewage treatment works to minimize water quality issues and associated eutrophication problems caused by excessive P levels in receiving water bodies.
Ontario Ministry of the Environment, Conservation and Parks	Determination Of Treatment Requirements for Municipal and Private Sewage Treatment Works	2016 Updated 2021	▪ This guideline outlines requirements for the treatment of municipal and private sewage discharge in surface waters. ▪ In determining that all sewage treatment works shall provide secondary treatment, the guideline notes consideration for the possibility of more stringent future P removal requirements and the capability of secondary sewage treatment processes to be upgraded to meet such requirement.
Ontario Ministry of the Environment, Conservation and Parks	Procedures for sampling and analysis requirements for municipal and private sewage treatment works (liquid waste streams only)	2016 Updated 2021	▪ This document helps evaluate non-industrial sewage treatment works for compliance. ▪ This document provides procedures for evaluating non-industrial sewage treatment works for compliance.
Province of Ontario	Nutrient Management Act	2002 Amended 2021	▪ This act provides for the management of materials containing nutrients in ways that will enhance protection of the natural environment and provide a sustainable future for agricultural operations and rural development. ▪ The act helps to match nutrient application to crops' fertility needs and to keep excess nutrients and pathogens out of waterways.
Ontario Ministry of Agriculture, Food, and Rural Affairs	Nutrient Management Strategy	2002 Updated 2021	▪ The *Nutrient Management Act* (2002) requires any building project relating to livestock housing or manure storage facility to have an approved Nutrient Management Strategy (NMS) before a building permit will be issued. This applies to all farms that generate more than five nutrient units and are proposing to build, expand or renovate.
Various Municipalities	Municipal By-laws	2019	▪ Various municipalities across the province have by-laws that outline limits on what can be discharged into the sewers system and natural watercourses, including the release of P.

Appendix F: Selected Phosphorus Recovery and Reuse Technologies

Process	Input Materials	Output Materials	Description	Links
Agriculture				
Phosphate Hydrolysing Enzymes	**Rural Nonpoint Source (RNPS)** Organic and Inorganic P from manwure, crop residues, and organic wastes	P fertilizer	The PhosFarm project is led by a European partnership to develop a controlled enzymatic mineralization method to sustainably recover P from agricultural wastes. Inorganic phosphate is isolated from liquid manure, digestate and other agricultural waste by binding special enzymes to suitable carriers. These catalysts react with the resource, forming a solid phase and a liquid fraction that contains the dissolved phosphate. This can be precipitated as magnesium ammonium phosphate or calcium phosphate. These salts can be applied directly as fertilizer.	PHOSFARM Grant/Project Info (EU) PRESS RELEASE EC-funded PhosFarm Project
Silage Leachate Runoff Treatment	**Rural Point Source (RPS)** Silage Effluent	P captured in filter media	Silage leachate can be directed through slag and Phosphix filters to capture P.	Managing Silage Effluent in Ontario Bray and Ward, 2020 Managing Silage Effluent OMAFRA PHOSPHIX
Nutrient Recovery Technology for Livestock Farms	**RNPS** Manure	P fertilizer	Ostara's nutrient recovery technology removes P to create a fertilizer that also simplifies digestate management through improved nutrient balance.	https://ostara.com/livestock-farms/
Pyrolysis	**RPS & Urban Point Source (UPS)** Manure, human excreta, high-P plants grown on P-enriched sites (P mines, agricultural soils, stormwater basins, and P polluted lakes)	P-enriched biochar (used directly as soil amendment or further processed through chemical retrieval of P)	A thermochemical treatment that breaks down organic P to produce biochar. Feedstock is exposed to high temperatures using small-sized stoves, up to industrial-scale pyrolysis equipment.	IISD Nutrient Recovery and Reuse in Canada
Industry				
Magnetic Separation in Industrial Slag	**UPS** Iron and Steelmaking Slag	Process reviewed in Matsubae-Yokoyama et al. 2009 estimated 3.1 mass% as P_2O_5	Magnets are used to separate metals from the P in slag. P occurs in an enriched crystal phase within a FeO-CaO-SiO2 matrix. These two materials have different magnetic properties and can be separated using a strong magnetic field. The P-free residual slag can be recycled back into the industrial processing, while P can be further processed for reuse.	Jeong et al. 2009 Recovery of Manganese and Phosphorus from Dephosphorization Slag Matsubae-Yokoyama et al. 2009

Process	Input Materials	Output Materials	Description	Links
Urban				
Struvite Crystallization	**UPS** Wastewater *Only applicable to WWTPs with biological P removal, usually with sludge digestion	Struvite Fertilizer	Struvite is a solid precipitate of magnesium, phosphate, and ammonium. The crystals contain a significant amount of P, providing fertilizing properties. Struvite production can be controlled within a fluidized reactor. Struvite is a multi-elemental fertilizer, the production of which does not align with agricultural practices and infrastructure developed to handle single-element nutrients that are configured for crop needs and soil type. Struvite is currently produced in limited volume and as such, may be better suited to consumer home and garden markets. Ostara Pearl technology can be added to a WWTP main or side-stream operation to produce struvite through their proprietary Pearl® fluidized reactor and WASSTRIP process (Waste-Activated Sludge Stripping to Remove Internal Phosphorus) to recover P and N.	Ostara
Enhanced Biological P Removal (EBPR)	**UPS** Activated Sludge In WWTPs	P	EBPR is the uptake of P by phosphorus accumulating organisms (PAOs), bacterial communities used to process sludge in WWTPs. PAOs store food under anaerobic conditions and then process the stored food once under aerobic conditions.	Enhanced Biological Phosphorus Removal
Thermal Hydrolysis Process	**UPS** Wastewater	Fertilizer (LysteGro®)	Lystek's Thermal Hydrolysis Process uses high-speed shearing, alkali, and low-pressure steam injection to disintegrate microbial cell walls and hydrolyses complex macromolecules into simpler compounds. The technology processes digested or undigested residuals into a biosolid fertilizer and multi-purpose hydrolyzed product, which has Canadian Food Inspection Agency and U.S. government approval as fertilizer . The process disintegrates microbial cell walls and hydrolyses complex macromolecules into simpler compounds, creating a pathogen free, high solids liquid product with low viscosity.	Lystek Zaman et al., 2019 Enhanced biological phosphorus removal using thermal alkaline hydrolyzed municipal wastewater biosolids
Biochar and Activated Carbon	**UPS** Sewage sludge, Wastewater	P Soil amendment	Biochar is a porous carbonaceous material (aka char, charcoal, black carbon) used in P recycling to adsorb P. It is made from any organic material, including rice husk, straw, manure, and other agricultural wastes.	Dai et al. 2020 Utilization of biochar for the removal of N and P Vikrant et al. 2018 Engineered biochar for the removal of P in water and wastewater

Process	Input Materials	Output Materials	Description	Links
Urban				
Nanostructured PO¬4 Sorption Media	**UPS & Urban Nonpoint Sources (UNPS)** Wastewater, agricultural runoff, lakes, streams, and in food processing plants.	Precipitate (Ca_3PO_4)	P is recovered as PO_4 ions, which can be removed from the sorption media. Precipitation forms Ca_3PO_4 (high P content) which can be used to make fertilizer, phosphoric acid, etc. MetaMateria Technologies markets a highly porous ceramic product containing iron-oxyhydroxide nanocrystals.	MetaMateria Phosphorus Management
Nanofiltration	**UPS & RPS** Natural surface waters, liquid agricultural feed, industrial wastewater, pretreated sewage sludge	Suspended and dissolved P	Use of nanofiltration membranes (NF and NF90), sieving (ultrafiltration), and diffusion (reverse osmosis) for P-permeation. Dissolved material is retained as water flows through the membrane while suspended. Nanofiltration removes 96% of P when treating natural surface waters.	Lee et al. 2013 Performance studies of P removal using cross-flow nanofiltration
Hybrid Ion Exchange Nanotechnology	**UPS** Wastewaters	Liquid fertilizer (3-0.28-3) used in hydroponic lettuce growing	Hybrid ion exchange (HIX) nanotechnology has successfully been applied at scale to recover nutrients from a variety of wastewaters. The resulting product after recovery and reconcentration is a N–P–K liquid fertilizer, 3–0.28–3, which is being used for hydroponic lettuce growing. Ion Exchange Nanotechnology is also being investigated for harvesting P for the rapidly expanding lithium battery production market.	Vaneeckhaute and Weinberg, 2017 IISD Nutrient Recovery and Reuse in Canada
Co-digestion (Food Waste Nutrient Recovery and Reuse)	**UPS** Organic Waste	Fertilizer	On-farm anaerobic digesters that co-digest nutrient rich materials, like food and organic waste with agricultural materials or wastewater sludge. The process uses microorganisms to break down the biodegradable materials in anaerobic (no oxygen) conditions, while biogas and nutrients are recovered. StormFisher offers an organic waste management solution for solids, packaged materials, liquids, and retail food waste.	IISD Nutrient Recovery and Reuse in Canada StormFisher
Microwave Enhanced Advanced Oxidation Process (MW-AOP)	**UPS & RPS** Municipal Wastewater, Agricultural Waste (e.g., dairy and swine wastes), and other Organic Wastes (e.g., food processing)	Struvite	BOOST Environmental's Integrated Waste Treatment System (MW-AOP) combines microwave irradiation and a key oxidant to disintegrate solids for both energy (anaerobic digestion) and nutrient recovery (struvite crystallization). The process liquifies waste solids ahead of the digestion process, increasing digestion efficiency and biogas production. The MW-AOP reduces 80% of TSS in municipal sewage sludge and 40% of solids in liquid manure.	BOOST Municipal Wastewater BOOST Agricultural Waste BOOST Waste Management

Process	Input Materials	Output Materials	Description	Links
Electrocoagulation	Wastewater	Fertilizer	Electrocoagulation involves a reactor and metal electrode, in combination with liquid and solid separators to bind P.	Econse Water Purification System https://econse.com/case-studies/
Phosphex™ (U of Waterloo)	Surface water, wastewater, and septic system effluent	Residual P can be used as construction materials, agricultural amendments, or ballast for road construction	Gravity-driven system using proprietary compound, Phosphex™ and Basic Oxygen Furnace Slag (by-product of steel production) to promote adsorption and precipitation reactions. The Phosphex technology can be installed as a vertical barrier in the pathway of horizontally flowing contaminated water sources or within an enclosed treatment container.	https://uwaterloo.ca/research/waterloo-commercialization-office-watco/business-opportunities-industry/phosphextm-treatment-and-removal-phosphorous-water
BioPhree® (Green Water Solutions Inc.) *	Agricultural runoff, surface waters	Fertilizer	BioPhree is a proprietary composite resin (hybrid ion exchange resin impregnated with iron oxide) with high affinity to adsorb P compounds. The absorption material captures P until saturation is reached, which, depending on the system, can take several weeks to months. Once the material is saturated, the P is washed off, and the material is reused. The cleaning solution is also reusable in the next regeneration cycle. The concentrated P is recaptured by a nanofiltration process.	https://www.watertoday.ca/ts-bg-barley-prize-q&a-greenwater-solution.asp https://www.balticwaterhub.net/innovation/aquacare-biophree

Appendix G: Additional Information and Calculations for Figure 6 and Figure 7

Figure 6 in this report shows the magnitude and flow of P in Ontario's key agriculture and industry sectors. Figure 7 shows the aggregated inflows, outflows and losses for the agricultural, industrial and urban sectors. It is important to note that only a selected number of the flows from these sectors have been included in these figures in order to simplify the presentation of this information. These figures are meant to provide a high-level overview of the scale of P flows in the province as a means of summarizing the more detailed information found throughout this report. This appendix provides further detail about the magnitudes used to create Figure 6 and Figure 7.

"Crop residues" in Figure 6 represent the amount of P in stalks, stover, and other crop materials that are left in the field over the course of one year. It is assumed that the P in crop residues is bioavailable for crop uptake within one year. The reuse of P in manure as a fertilizer for agricultural production is more complex than the uptake associated with crop residues, due to the variation in location and magnitudes of manure production across the province. For the purposes of this report, it was assumed that all manure produced in Ontario is distributed to agricultural fields. However, in practice, this distribution is not uniform and P loss can occur from manure directly to natural waters. This loss is not currently measured or estimated.

Where more than one approach was used to determine a P flow in this report, each of the final estimates is included within the appropriate section of the report. However, only one of these estimates was used for the purposes of creating Figure 6 and Figure 7. Overall, there was more data available for the agricultural sector than for the industrial and urban sectors. More data and research are required to better understand P flows for these sectors. Table G1 shows the specific values from the agriculture and industry sectors that were used to create Figure 6, along with their respective locations in the report. These values were also used in Figure 7, along with those from the urban sector (see Table G2).

Table G1: P Flow Estimates from Agriculture and Industry used in Figure 6

P Flow	Magnitude (t/a)	Location of Estimation Details in Report
INFLOWS		
Agriculture		
Fertilizer	56,291	Section 3.2 - Figure 10 – Fertilizer (open field = 55,785 t/a, greenhouses = 506 t/a) Section 3.3.2 – Figure 17 – Fertilizer (open field) Section 3.3.2 – Figure 18 – Fertilizer (greenhouses) Section 3.3.2 – Synthetic Fertilizer and Greenhouse Crops
Livestock Feed Imports	21,815	Section 3.2 - Figure 10 – Livestock feed imports Section 3.3.1 – Livestock Feed
Animal Imports	1,509	Section 3.2 - Figure 10 – Animal Imports Section 3.3.1 - Animal Imports & Exports (Table 2)
Total Agriculture	**79,615**	
Industry		
Chemical Imports	22,180	Section 5.2.5, Appendix D, Table D-26
Steel	11,700	Section 5.2.2 – Figure 37 - Iron ore and coal (8400 t/a), interprovincial imports (2600 t/a), steel imports (500 t/a), steel scrap (200 t/a)
Forestry	2,610	Section 5.2.3 – Figure 38 - Harvested wood (2 260 t/a), imported fabricated wood products (230 t/a), pulp and paper imports (80 t/a), wood imports (40 t/a)
Total Industry	**36,490**	
TOTAL INFLOWS	**116,105**	

REUSE (INFLOW & OUTFLOW)		
Agriculture		
Crop Residues	32,545	Inflow and Outflow from Crop Production Section 3.2 - Figure 10 Section 3.3.2 – Crop Production Sector
Livestock Feed	22,350	Outflow from Crop Production, Inflow to Livestock Section 3.2 - Figure 10 – Crops for livestock feed Section 3.3.1 – Livestock Feed
Manure	30,583	Outflow from Livestock, Inflow to Crop Production Section 3.2 - Figure 10 Section 3.3.1 – Manure (Table 6)
Total Agriculture	**85,478**	
TOTAL REUSE	**85,478**	
OUTFLOWS		
Agriculture		
Crop Food Products	43,226 (open field crops = 42,823 t/a, greenhouse crops = 403 t/a)	Section 3.2 - Figure 10 – Open-Field Food Products Section 3.3.2 – Figure 17 – Grains, beans, beets and potatoes (40,901.6 t/a), Field vegetables (1,800.5 t/a), Fruits and berries (120.8 t/a) Section 3.3.2 – Figure 18 - Greenhouse crops
Meat	7,077	Section 3.2 - Figure 10 - Meat Section 3.3.1 – Meat (Table 9)
Milk & Eggs	3,197 (milk = 2,830, eggs = 367)	Section 3.2 - Figure 10 – Milk and Eggs Section 3.3.1 - Milk and Eggs
Animal Exports	1,808	Section 3.2 - Figure 10 – Animal Exports Section 3.3.1 - Animal Imports & Exports (Table 2)
Ethanol Production	6,203	Assumed output (recycling fraction unknown) Section 3.3.2 - 33 % of Ontario's corn production
Total Agriculture	**61,511**	
Industry		
Chemical Exports	13,940	Section 5.2.1 – General Chemical Manufacturing - Figure 47
Total Industry	**13,940**	
TOTAL OUTFLOWS	**75,451**	
WASTE/LOSSES		
Agriculture		
Greenhouse Releases	106	Section 3.2 - Figure 10 – Greenhouse Releases Section 3.3.2 – Figure 18 – Greenhouse nutrient feedwater release (103.1 t/a) and Greenhouse labour force (2.6 t/a)
Environment	5,022	Section 3.2 - Figure 10 – P Losses Section 3.3.2 - Figure 17 – P Losses
Legacy P	9,179	Section 3.2 - Figure 10 – Legacy P Section 3.2.2 – Figure 17 – Legacy P
Slaughterhouse Waste	3,797	Section 3.2 - Figure 10 – Slaughterhouse Waste Section 3.3.1 – Slaughterhouse Waste (Table 10)
Total Agriculture	**18,104**	
Industry		
Industrial Waste	605	Section 5.3.1, Table 17
Total Industry	605	
TOTAL WASTE/LOSSES	**18,709**	

In addition to those outlined above for Figure 6, the following estimates were used to determine the overall estimates for the urban sector as outlined in Figure 7.

Table G2: P Flow Estimates from the Urban Sector used in Figure 7

P Flow	Magnitude (t/a)	Location of Estimation Details in Report
INFLOWS		
Imports post distribution	4,655	Section 4.3 - Figure 34 – Municipal Food and Organic Waste
Local distribution	10,824	Section 4.3 - Figure 34 – Municipal Food and Organic Waste
Processing/distribution loss	3,048	Section 4.3 - Figure 34 – Municipal Food and Organic Waste
TOTAL INFLOWS	**18,527**	
OUTFLOWS		
WWTP (solids)	5,491	Section 4.2 - Municipal Wastewater Treatment Plants
Uptake	2,591	Section 4.3 – Municipal Food and Organic Waste
Compost	2,032	Section 4.3 – Figure 34 – Municipal Food and Organic Waste
TOTAL OUTFLOWS	**1,402**	Section 4.3 – Figure 34 – Municipal Food and Organic Waste
Total Outflows	**11,602**	
WASTE/LOSSES		
Landfill	601	Section 4.3 – Figure 34 – Municipal Food and Organic Waste
Septic	1,445	Section 4.4 – Septic Systems
WWTP release	900	Section 4.2 - Municipal Wastewater Treatment Plants
TOTAL WASTE/LOSSES	**2,946**	

Appendix H: Database Comparisons

Comparison of National Pollutant Release Inventory and Industry Wastewater Discharge Database

Ontario companies in nine industrial sectors are required to sample and report direct wastewater discharges to the MECP based on the provincial *Effluent Monitoring and Effluent Limits* (EMEL/MISA) *Regulation*. Table H1 compares data from the provincial Industrial Wastewater Discharge (IWD) dataset[356] with the P flow release to water data reported to the NPRI. This comparison shows that fewer companies reported their P waste flow to waterbodies data to the NPRI than the IWD, supporting the possibility that NPRI waste data underestimates P waste flows to waterbodies.

Table H1. Comparison of Direct Phosphorus Discharges to Waterbodies (2019)

<table>
<tr><th colspan="2" rowspan="2">Sector</th><th colspan="2">Industrial Wastewater Discharge Database</th><th colspan="3">National Pollutant Release Inventory (Direct Discharges to Waterbodies)</th></tr>
<tr><th>No. of facilities reporting</th><th>Total P (t/a)*</th><th>No. of facilities reporting direct water discharge</th><th>Number of facilities reporting</th><th>Total P (t/a)</th></tr>
<tr><td colspan="2">Iron and steel</td><td>1</td><td>0.8</td><td>2</td><td>4</td><td>1.2</td></tr>
<tr><td colspan="2">Metal casting</td><td>1</td><td>0.03</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td colspan="2">Petroleum refineries</td><td>6</td><td>11.3</td><td>0</td><td>2</td><td>0</td></tr>
<tr><td colspan="2">Electric power generation</td><td>1</td><td>0.08</td><td>0</td><td>2</td><td>0</td></tr>
<tr><td colspan="2">Pulp and paper</td><td>10</td><td>140.5</td><td>5</td><td>8</td><td>139.9</td></tr>
<tr><td rowspan="2">Chemical manufacturing</td><td>Organic chemicals</td><td>8</td><td>2.7</td><td rowspan="2">3</td><td rowspan="2">13**</td><td rowspan="2">5.1</td></tr>
<tr><td>Inorganic chemicals</td><td>5</td><td>2.3</td></tr>
<tr><td colspan="2">Total</td><td>32</td><td>157.7</td><td>10</td><td>29</td><td>146.2</td></tr>
</table>

*Assumption: continuous production

** Not including fertilizer companies

Comparison of National Pollutant Release Inventory Direct Water Release Data and Municipal Treated Wastewater Effluent Data

Municipal WWTP volumetric water release and P concentrations are voluntarily reported on an monthly basis to the Ontario Municipal Treated Wastewater Effluent Database (MTWE).[357] Annual total P emission data are voluntarily reported to the NPRI. To compare the P emission results from these two databases, the total annual P releases to water for all WWTPs in each census division were compared.

The reported monthly volumetric emission flowrates and total P concentration in unfiltered effluent to the MTWE were summed over 2019. These values are expected to be underestimated due to some missing monthly data, and some incomplete database entries. Table H2 shows that the summed MTWE total P release data are within 10 % of the NPRI annual reported P release to water data. Therefore, it is possible that the NPRI data total P direct water release data are underreported.

Table H2. NPRI (direct to water discharge) and MTWE reported total phosphorus (t/a) 2019 emissions

Ontario Census Division	MTWE (t/a)	NPRI (t/a)	Ontario Census Divison	MTWE (t/a)	NPRI (t/a)
Algoma	7.16	3.8	Niagara	28.15	29.5
Brant	3.75	2.86	Nipissing	7.92	7.82
Bruce	0.69	0	Northumberland	1.16	0
Chatham-Kent	4.96	0	Ottawa	85.86	85
Cochrane	7.05	3.99	Oxford	4.04	1.95
Dufferin	0.52	0.31	Parry Sound	0.2	0
Durham	60.62	59.64	Peel	162.63	122.11
Elgin	4.4	3.92	Perth	1.62	0
Essex	26.63	19.51	Peterborough	3.66	3.54
Frontenac	15.56	0	Prescott and Russell	5.01	0
Grey	3.8	1.87	Prince Edward	0.15	0
Haldimand-Norfolk	2.85	0	Rainy River	0.74	0
Haliburton	0.04	0	Renfrew	3.86	0
Halton	17.62	17.93	Simcoe	7.23	2.35
Hamilton	71.15	71.76	Stormont, Dundas and Glengarry	8.93	6.41
Hastings	1.7	2.11	Sudbury	14.13	0
Huron	1.67	0	Thunder Bay	8.96	7.47
Kawartha Lakes	0.47	0	Timiskaming	2.34	1.34
Kenora	2.75	0	Toronto	283.78	292.52
Lambton	6.62	5.36	Waterloo	14.92	0
Lanark	1.18	0	Wellington	3.25	0
Leeds and Grenville	3.25	2.7	York	0.23	0
Lennox and Addington	0.9	0			
Manitoulin	0.01	0			
Middlesex	32.14	27.63			
Muskoka	0.61	0			
Total				**926.89**	**783.4**

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