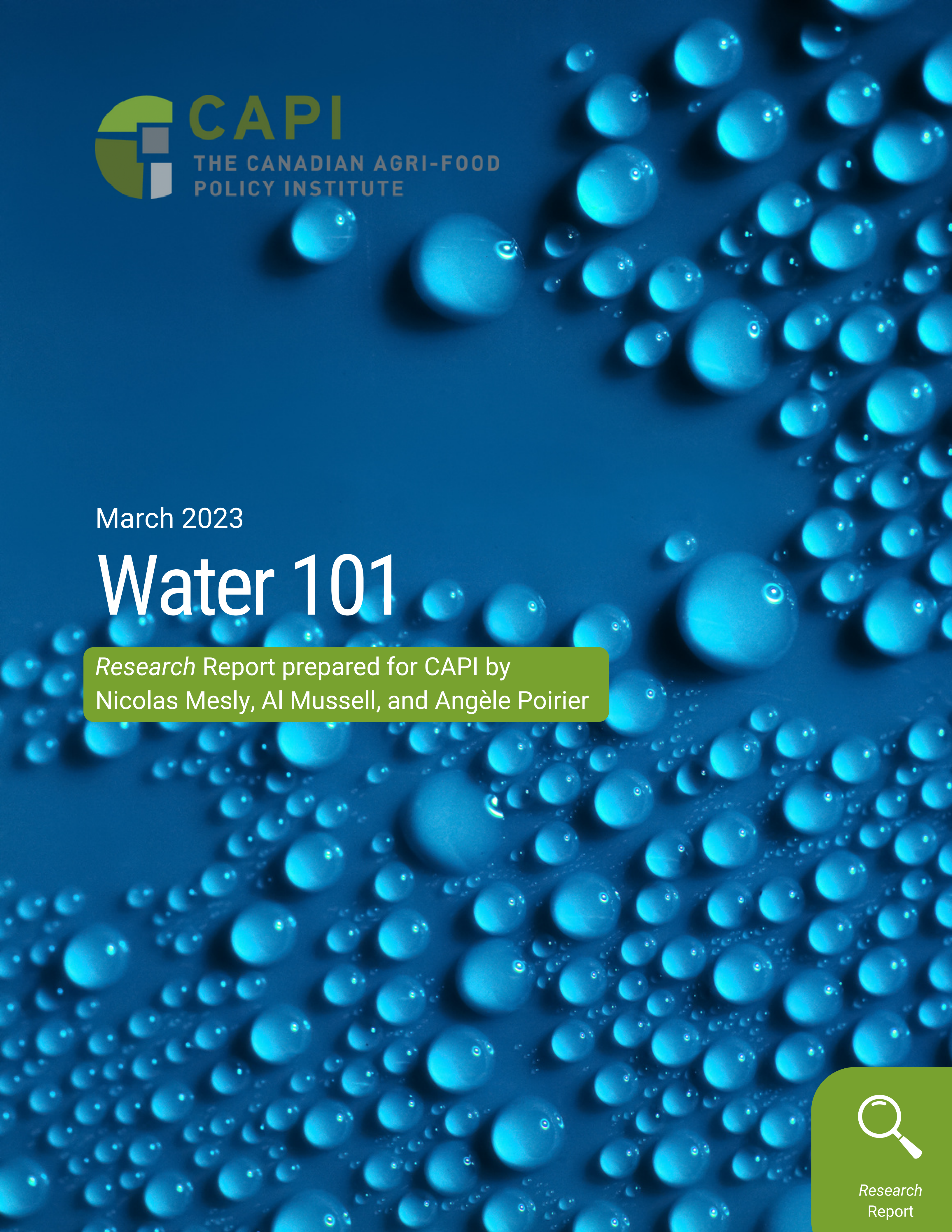

CAPI
THE CANADIAN AGRI-FOOD POLICY INSTITUTE

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Water 101

Research Report prepared for CAPI by
Nicolas Mesly, Al Mussell, and Angèle Poirier

Research Report

The Canadian Agri-Food Policy Institute
960 Carling Avenue, CEF Building 60
Ottawa, ON K1A 0C6
www.capi-icpa.ca

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Note from CAPI

Because water is a common resource which is essential to life, it is usually governed by central planners and not left to the free market, excepting rare occasions. Water-related policies intersect with areas such as monitoring and reporting, international trade, and of course, agriculture. As an advancer of agricultural policy solutions, CAPI offers *Water 101* to present the general state of water in Canada, its importance to Canadian agriculture and food processing, and implications for domestic and international policy.

This report is the first in a series of reports which will tackle the complex issue of water as it relates to agriculture, food security, and governance. This series – and related products such as webinars and data visualizations – are being produced with the help of CAPI's Distinguished Fellow Nicolas Mesly, an award-winning journalist, photographer, and agronomist.

Key takeaways

- Water, unlike many other inputs in food production, can neither be created nor destroyed. However, amid a growing global demand for food, water availability and quality are growing concerns.
- Compared to other countries, Canada is endowed with enough water to sustain significant agri-food exports. A relatively small share of Canada's water withdrawals are used in food production and manufacturing.
- Water and electricity are among the most important inputs in food processing. Canada is an attractive place for food processing investment with its abundance of water and low electricity rates, especially hydroelectricity in Quebec.
- Because water flows across borders (provincial and national), water is a shared jurisdiction between multiple levels of government. Multiple different transboundary agreements exist, but they are not always renewed or enforced.

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List of acronyms and initialisms

AAFC	Agriculture and Agri-Food Canada
AWC	Alberta Water Council
BMP	beneficial management practice
CAP	Canadian Agricultural Partnership
CBM	coalbed methane
CSIDC	Canada-Saskatchewan Irrigation Diversification Centre
CWN	Canadian Water Network
ECCC	Environment and Climate Change Canada
ENR	Environment and Natural Resources Canada
FAO	Food and Agriculture Organization of the United States
GLWQA	Great Lakes Water Quality Agreement
IJC	International Joint Commission
INRS	Institut national de la recherche scientifique
LCBP	Lake Champlain Basin Program
MAA	Master Agreement on Apportionment
MELCC	Ministère de l’Environnement et de la Lutte contre les changements climatiques (Québec)
NGO	non-governmental organization
OBWB	Okanagan Basin Water Board
P_2O_5	phosphorus pentoxide
PGMN	Provincial Groundwater Monitoring Network
PPWB	Prairie Provinces Water Board
SCAP	Sustainable Canadian Agricultural Partnership
WPAC	watershed planning and advisory council
WSA	Water Security Agency [Saskatchewan]

1. Introduction

The availability and quality of water is increasingly a global concern, the result of a growing population, economic growth, a warming climate, and current/past water management practices. Leaders and global organizations are increasingly recognizing that water has a role to play in the fight against climate change. For the first time ever, water was on the agenda of COP, the United Nations' yearly convention on climate change, which took place in Egypt in November 2022 and was named "the water COP" (Suga, 2022).

Water is neither created nor destroyed; however, it can be denatured, contaminated, changed in state, transported across distances, and locally depleted. As an agricultural producer and major exporter, Canada's use and secure access to water resources is a key element of sustainability. Excessive and locally exploitative water use can put agriculture in conflict with other water users such as the energy sector, municipalities, and Indigenous communities as well as with environmental protection. Within the agri-food sector itself, competition can arise between stakeholders such as producers of specialty crops, food processing plants, and water and beverage companies. Water use efficiency and the sources of water used in agriculture reflect on Canada's agricultural sustainability and the perception of its products marketed abroad.

The current and future global contexts sharpen the focus on the demands for effective water management and policy in Canada. It is broadly acknowledged that intensification – producing more from an existing land base – is more sustainable than bringing new land under cultivation. Intensification of existing agricultural land involves more precise management of inputs, including water, such as through improved irrigation systems, and conversely drainage management to support crop yields.

Climate change and its effect on agricultural production (including animal production) places further demands on effective water management. This is very tangible in Canada: the 2019 harvest in various parts of Canada will be remembered as the "harvest from hell" with persistent and exceptionally wet, cold, and windy conditions. In 2021, western Canada suffered a severe drought that significantly reduced crop yields and production; this was followed, in November 2021, by intense and catastrophic flooding in the lower mainland of BC. A warming climate increases growing degree days, creating the prospect of increased yields and the feasibility of agriculture in more northern areas, but with new demands on water. The warming climate also accelerates the water cycle, with the effect of both increasing evaporation rates and the demands for water in cooling and other purposes. In turn, the water cycle is tied to the carbon and nitrogen cycles that influence climate change. In a situation of increased variability in growing conditions that challenges growth and stability in agriculture, means of planning, conserving, and allocating water loom larger.

More broadly, the global situation has been shifting away from relative abundance in food – in which important risks are farm product surpluses, low farm prices, and low or unstable farm incomes – to relative scarcity, in which important risks are food security, affordable food prices, highly variable farm incomes. The prospect of continued robust food demand coupled with simultaneous extreme climate events and geopolitical and agri-food trade disruptions (notably, the invasion of Ukraine by Russia on February 24th, 2022) will increasingly threaten agricultural production and food security. In this environment, management of efficiencies and safeguards on natural resources supporting agriculture will be incumbent, water resources chief among them.

The purpose of this paper is to provide an overview of agriculture and water use in Canada – in particular, surveying sources of water drawn upon by agriculture in Canada and extent of use, the movement of water embodied in agri-food trade, and the governance of water resources in Canada. Subsequent papers in this series will perform case studies and will highlight the need for a national water strategy to mitigate food security threats and climate change aggravators.

Table 1. Statistical metrics.

withdrawal	Water drawn from a source, whether or not it is used (Gleick, 2011, p. 221).
virtual water	The amount of water required to produce an agri-food product (including irrigation, processing, and water contained in the final product).
virtual water trade	The amount of virtual water which crosses international borders through agri-food trade.

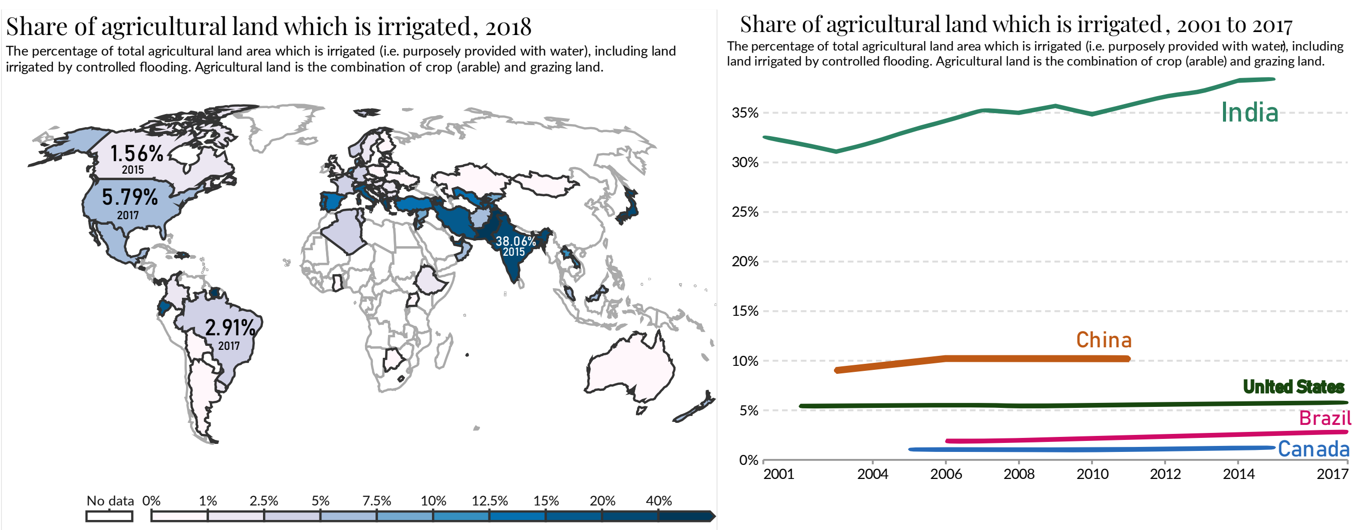
2. Irrigation

Irrigation is a source of agricultural water for crops and livestock from either stored sources (groundwater and reservoirs), dams, or surface water. Irrigation may be done to compensate for a lack of natural precipitation, to ensure uniformity in moisture levels for crops or water for animals, or to foster the growth of high-value crops (especially in southern Ontario) which would not otherwise thrive in Canada. Irrigation also provides water for livestock.

As pictured in Figure 1, a relatively small share of Canada's total agricultural land is irrigated (1.56%); the same is true for Brazil (2.91%) who, like Canada, is a large food net exporter (Ritchie & Roser, 2017). The United States' share of irrigated farmland is somewhat higher (5.79%) but has remained stable since 2001 (panel B). India has one of the highest shares of irrigated agricultural land (38.06%) and this share has increased from the low 30s in 2001 to nearly 40 percent in 2017 (panel B).

Figure 1. Irrigation around the world.

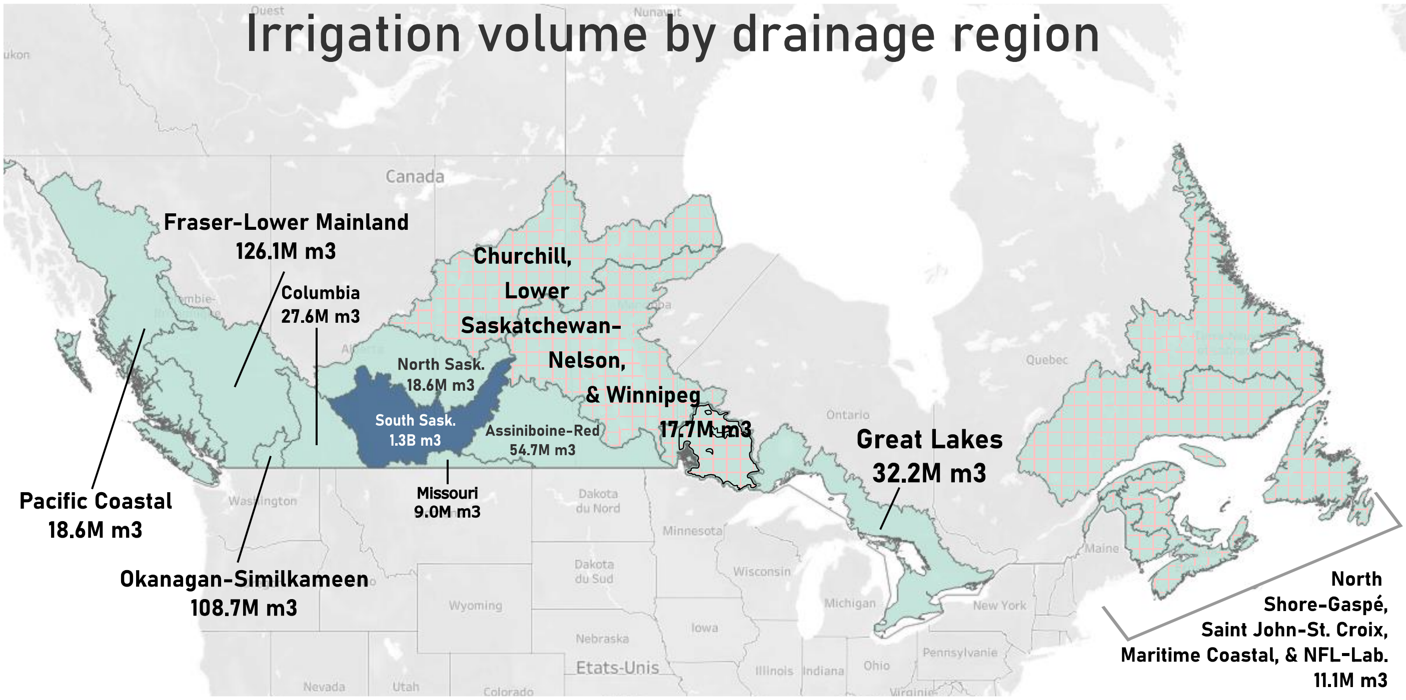
(A) (B)



Source: Ritchie, H., & Roser, M. (2017). Water Use and Stress. Our World in Data. https://ourworldindata.org/water-use-stress.
Images produces internally.

While Canada has a small share of irrigated agricultural land, it is geographically concentrated. The largest irrigation volumes are in Alberta and Saskatchewan for field crops and forage crops. This may be driven by the semi-arid climates which exist in southern Saskatchewan and south-central Alberta. Small clusters of irrigated land exist in Ontario and British Columbia, primarily for horticultural crops.

Figure 2. Irrigation volumes by drainage region, m^3, 2020.



Data source: Statistics Canada. (2021, December 13). Irrigation volume by province and drainage region. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810023901.
Image produced internally.

Irrigation requires infrastructure such as pipelines, canals, storage reservoirs, and electricity. Alberta, the province with the highest irrigation volumes (Statistics Canada, 2021), has 12 irrigation districts which manage 8,000 kilometres of pipelines and canals to water 625,000 hectares in the province (Alberta WaterPortal Society, 2021). The purpose of the districts is to allocate water and maintain the irrigation infrastructure of each district (Alberta King's Printer, 2000). It is estimated that irrigation districts generate $5.4 billion in economic activity each year, or 28% of Alberta's agri-food gross domestic product (Alberta WaterPortal Society, 2022b).

Saskatchewan has a less expansive irrigation district scheme, with 30 districts covering 42,000 hectares (Government of Saskatchewan, 2023, sec. 1). These districts are designed to offer and promote irrigation services, ensure sustainable irrigation, and manage irrigation infrastructure (The Irrigation Act, 2020, sec. 2(9)). The Canada-Saskatchewan Irrigation Diversification Centre (CSIDC) exists in Outlook, Saskatchewan, to promote irrigation as a means of growing high-value crops such as dry bean and seed potato (AAFC, 2019).

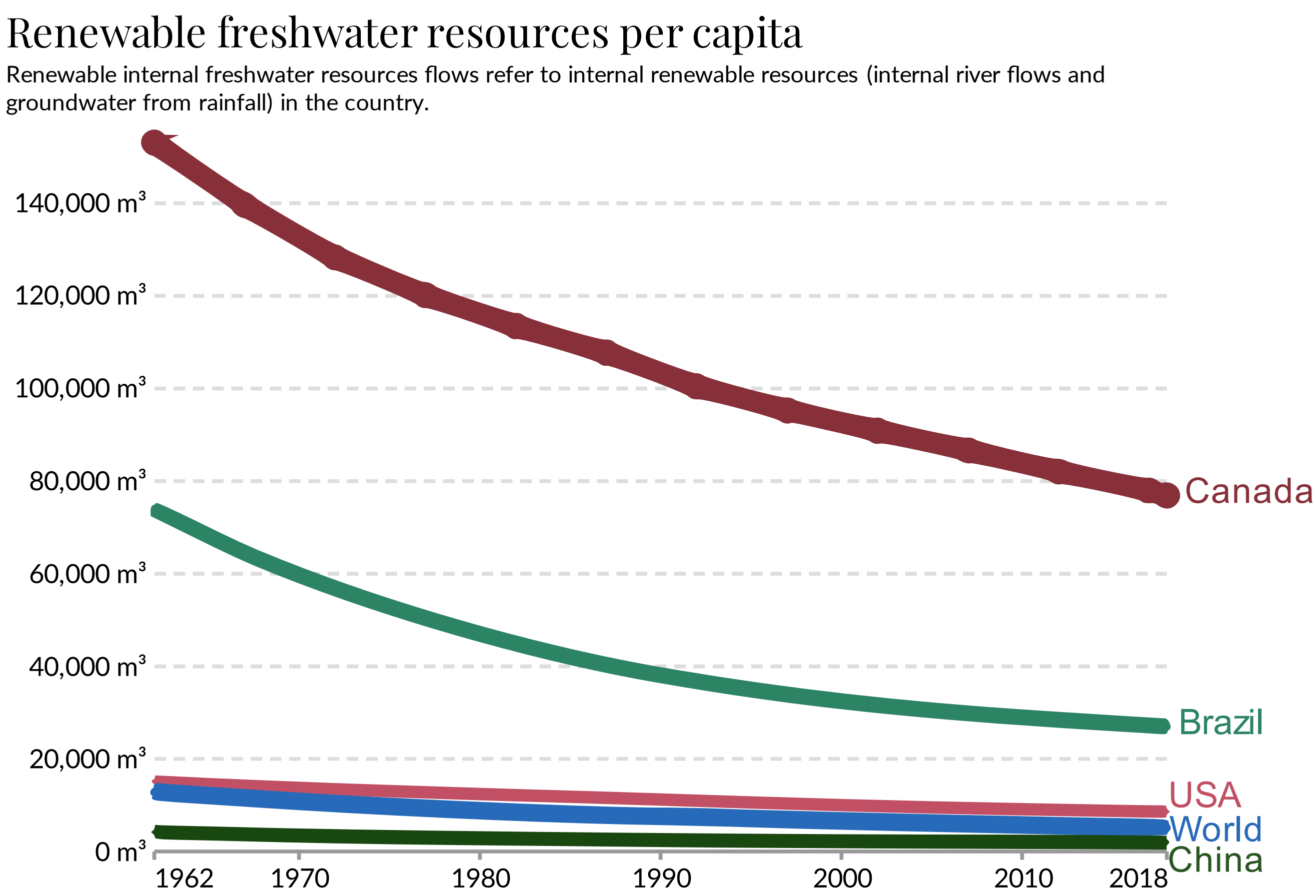
2.1. Freshwater resources

Freshwater withdrawals refer to freshwater (naturally non-salty water from either groundwater or surface water, such as lakes and rivers) taken from a source, whether or not the water is actually used; for agriculture, this includes irrigation of crops and livestock watering (Gleick, 2011, p. 221). Globally, approximately 70 percent of total freshwater withdrawals are for agriculture (Gleick, 2014, p. 5). Canada's agricultural sector has one of the lowest withdrawal rates in the world: 12% of all freshwater withdrawals in Canada are for agriculture, compared with 41% in the United States and 55% in Brazil, another large food net exporter (*ibid.*). What is different about agriculture, however, is that the majority of water withdrawals are not returned to source, unlike other sectors such as energy and manufacturing (ECCC, 2017).

Irrigation is closely tied to yield and production around the world (Ritchie & Roser, 2017) and is generally more important in the Southern Hemisphere. Despite relatively low shares of irrigated agricultural land, Canada and the USA have had high production and yield levels and have consistently been net exporters of food products. Brazil, another large net-exporter of food, has a high freshwater use rate in agriculture.

The high levels of food production in these countries (despite low levels of irrigation) may be connected to high levels of freshwater availability. Canada has one of the highest levels of renewable freshwater resources in the world (76,897 m^3/person/year in 2018), compared with 8,622 m^3/person/year in the USA and the world average of 5,658 m^3/person/year (Ritchie & Roser, 2017). One thing which per-capita water measurements do not divulge is whether water is equitably distributed across a given country's population.

Figure 3. Renewable freshwater resources per capita.

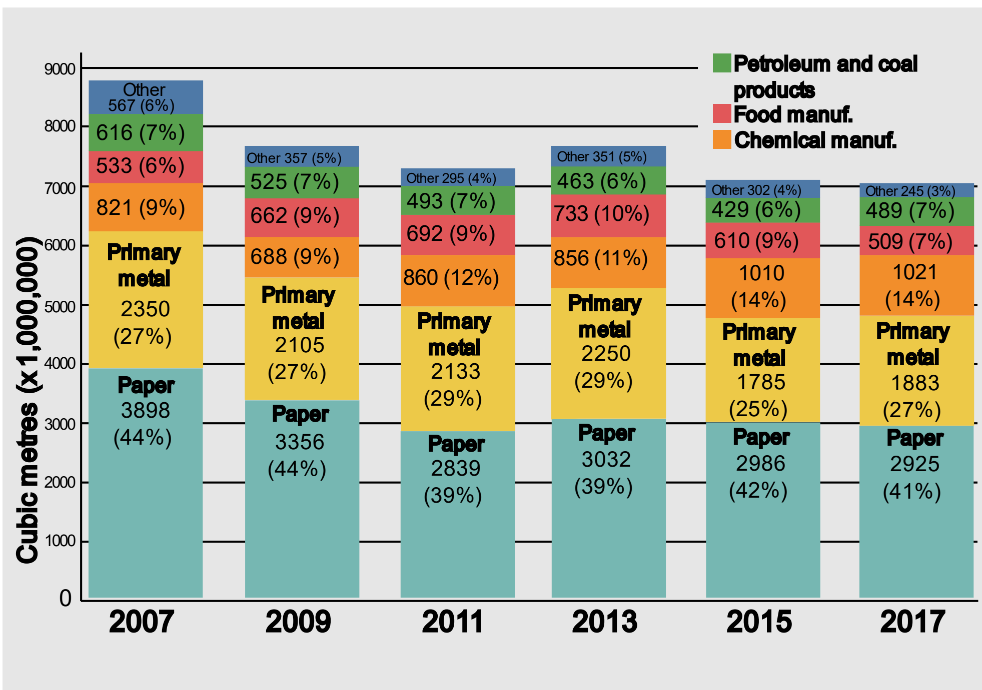


Source: Ritchie, H., & Roser, M. (2017). Water Use and Stress. Our World in Data. https://ourworldindata.org/water-use-stress.
Image produced internally.

3. Food processing in Canada

In addition to agricultural production use in crop irrigation and livestock watering, food processing can also be considered an agricultural use of water. Figure 4 shows that water intake for food manufacturing (red segments) makes up a relatively small portion (7 percent in 2017) of all manufacturing water intake. In addition, the largest source of water intake for food processing is municipal freshwater (dark blue), followed by self-supplied surface water (Statistics Canada, 2023). Both figures reveal that total water intake for food manufacturing has been decreasing since 2013, from 733 million cubic metres to 509 million in 2017. This may be explained by large food processors adopting technology to reduce total water consumption in recent years without decreasing production, as in the case of Kraft Heinz and Maple Leaf Foods (Maple Leaf Foods, 2021). Most large food manufacturing companies have also set water use efficiency targets and are working toward them in various ways: turning off water systems during non-production and non-sanitation hours (Maple Leaf Foods, 2021, p. 105), reducing irrigation by switching to water stress-tolerant crops (McCain Foods Ltd., 2022, p. 1), or capturing and recycling water vapour from fryers.

Figure 4. Water intake by industry, Canada, 1,000,000 m^3.



Data source: Statistics Canada. (2022). Water intake in manufacturing industries, by source and industry. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810004001.
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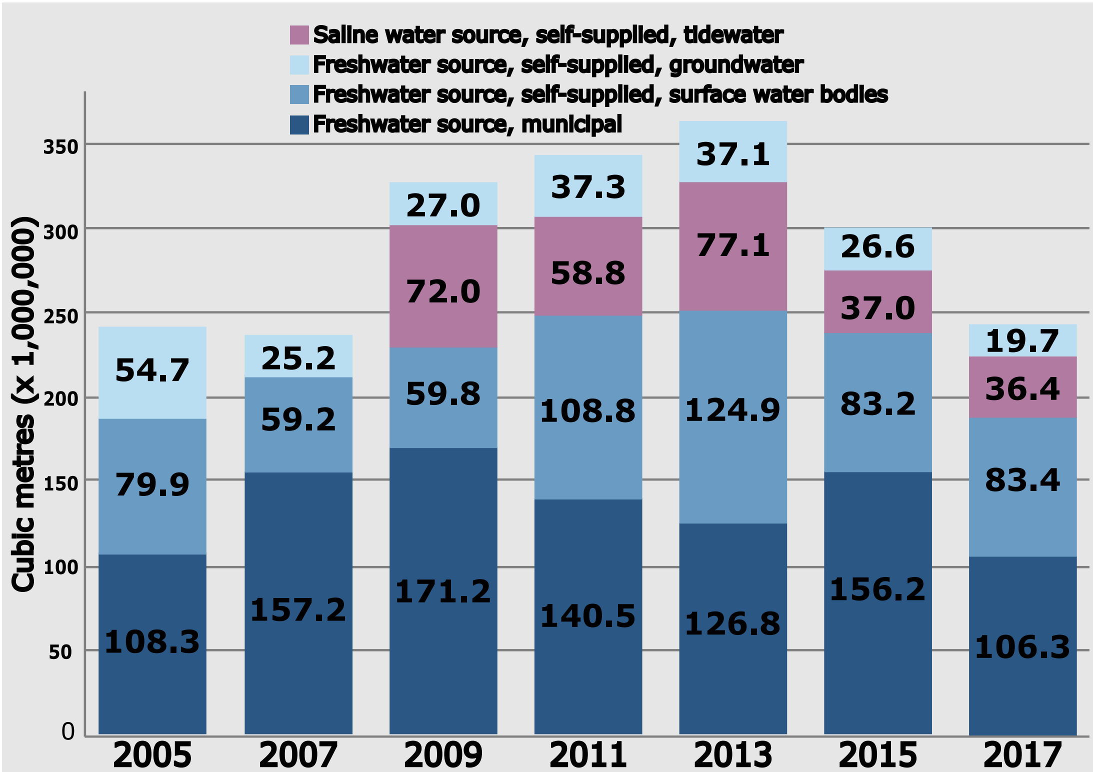
Figure 5. Water sources in food manufacturing, 1,000,000 m^3.



Data source: Statistics Canada. (2022). Water intake in manufacturing industries, by source and industry. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810004001.
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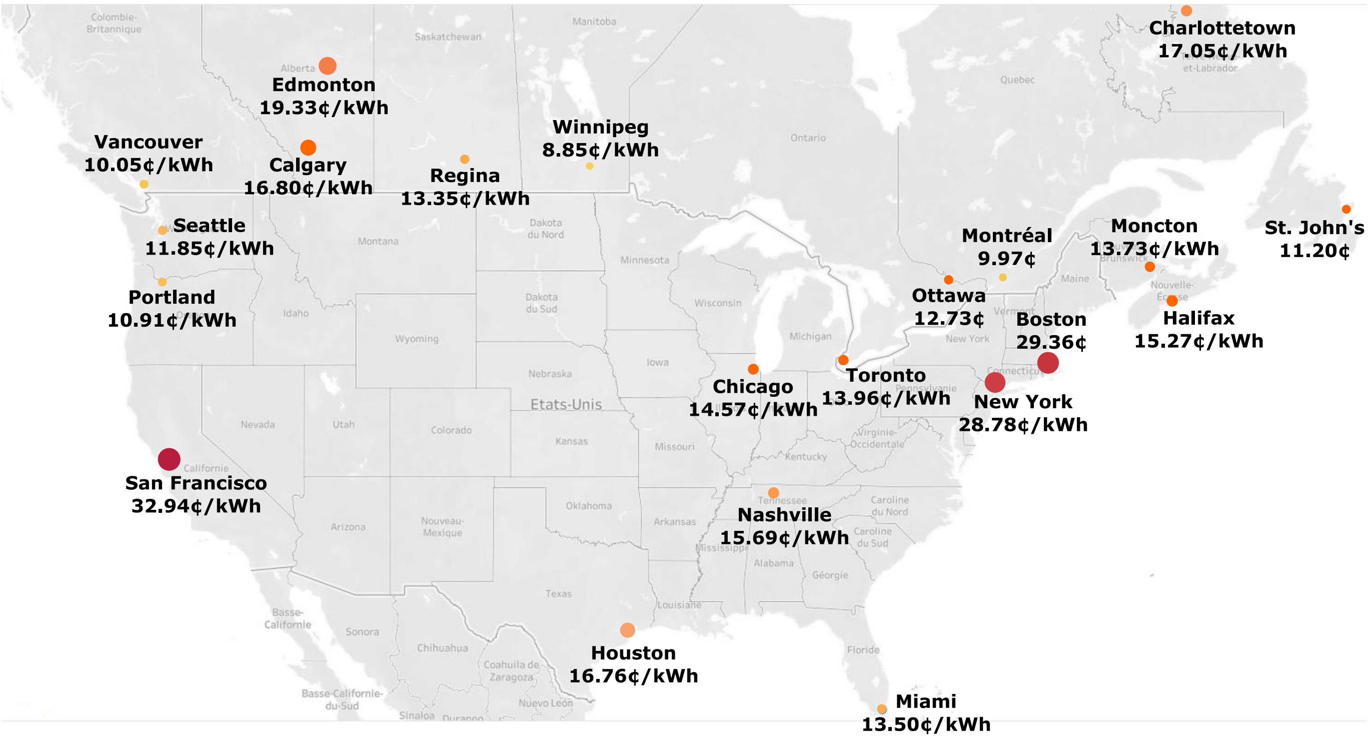
3.1. Hydroelectricity

If water is a major input in food processing, another major input is electricity. Canada has a comparative advantage of extensive hydro-electric generating capacity, with concomitantly low electricity costs; as a result, food processing plants in Canada (especially, eastern Canada) have had the lowest operating costs in North America (The Boyd Company, 2016, pp. 1, 4). Average electricity costs for medium-power customers (the average of 500 to 2,500 kilowatts) are displayed below. The lowest electricity rates are in Quebec, at 9.97¢ per kilowatt-hour (Montreal). Just across the border from Quebec, Boston and New York have some of the highest electricity rates, at nearly 30¢ per kilowatt-hour (Hydro Québec, 2022).

Figure 6. Average electricity rates for medium-power customers, 2022.



Data source: Hydro Québec. (2022). Comparison of Electricity Prices in Major North American Cities 2022 (p. 84). https://www.hydroquebec.com/data/documents-donnees/pdf/comparison-electricity-prices.pdf?v=2022
Image produced internally.

Low electricity costs make Canada an appealing location for investments in the food processing industry. For instance, Roquette, a French company, chose Manitoba as the location of the world's largest pea processing plant partly because of access to sustainable hydroelectricity and water, which is used in abundance to extract protein from peas (Food Processing Technology, 2018). According to some North American food processors, water and electricity are the pillars of competitiveness in the Canadian agri-food sector. The map shows that the Great Lakes area is the most competitive in terms of electricity rates in Canada.

"This increase in electricity rates is not sustainable. It means less money for short- and medium-term investments for our businesses, for research and development, and to cover environmental expenses. Moreover, this increase makes our companies less competitive with the rest of Canada and internationally."

– Dimitri Fraeys, CTAQ

Read more about water-related concerns in Québec in case study #1, "Water, a source of concern for agricultural producers and agri-food processors in Québec," [link on title, please] by Nicolas Mesly. Other case studies will follow in this series.

Hydroelectricity is the most efficient of all energy sources in Canada, converting 90 percent of water's available energy into useable energy. Water is also a renewable resource; this makes hydroelectricity a low-carbon and sustainable energy source. However, water is only renewable and available if it is managed appropriately. Hydroelectricity generation requires significant investments such as dams, miles of conduit, and human capital. Careful stewardship of resources – both natural and built – will be necessary to ensure that Canada retains its competitive advantage of low hydroelectricity costs.

4. Virtual water footprint

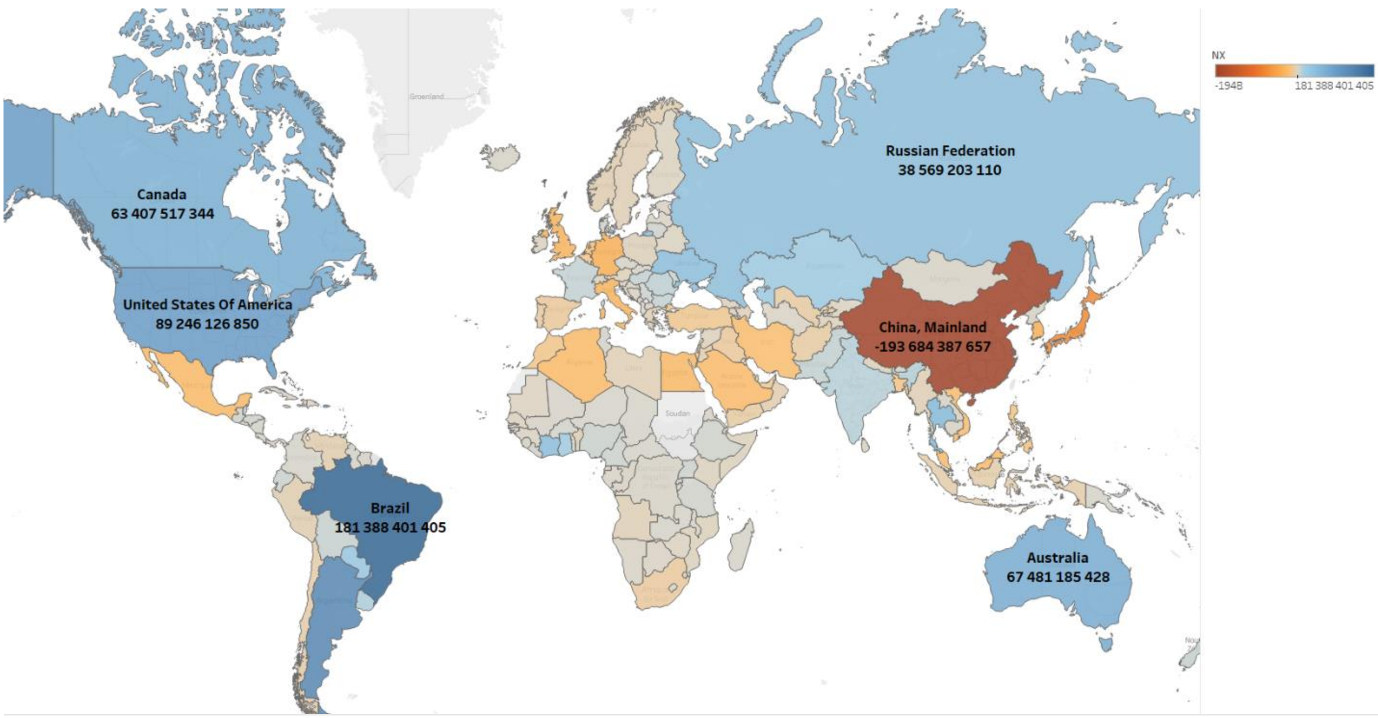
The concept of the water footprint is based on the amount of water that is “used” by a given industry or activity, such as producing food, and thus implicitly embedded in products. Virtual water accounts for the water content of the final product as well as the water used in the production process and embodied in the product.

For example, the water embodied in corn has a global average water footprint of 1,222 litres per kilogram; the global average water footprint of groundnuts (in shell) is about 2,782 litre/kg.

The concept of the virtual water footprint can be especially useful when looking at agri-food trade to get a sense of global water balances. Using the example above, a country that exports 1 kg of corn and imports 1 kg of groundnuts is a net importer of 1,560 litres of virtual water (2,782 L minus 1,222 L), representing the domestic water resources saved by importing in lieu of producing the product itself.

The map shows that Canada is a small net exporter of virtual water: 63B cubic metres, compared with Brazil’s 181B cubic metres, the world’s largest net exporter of virtual water. In contrast, China – a large producer but also a large agri-food net importer – is the world’s largest virtual water net importer at 193B cubic metres (*ibid.*). The US, a large producer and exporter, is also a net water exporter (89B cubic metres) (*ibid.*). Most of Europe is a net water importer apart from France (6.5B cubic metres net exported) (*ibid.*).

Figure 7. Virtual water net exports, m3 (crops: 2016; animal products: 2020[1])



Data source: Water to Food. (2021). Download—CWASI Database. https://www.watertofood.org/download.
Image produced internally.

Canada’s status as a net exporter of virtual water may be explained in part simply due to its large export quantities of canola and wheat: globally, oilseeds are responsible for the most traded water (43 percent), followed by cereals (17 percent). Brazil, the largest net exporter of virtual water, exports mostly soybeans (45% of all virtual water exports), followed by maize (13%), “luxury foods” which are mostly sugar and coffee (21%), and cereals (14%) (FAO, 2022).The United States’ virtual water exports are in the form of soybeans (33%), wheat

[1] The most recent figures from the CWASI database were 2016 for crop products, 2020 for animal products. The 2016 and 2020 data are therefore summed together to create the map, which was created internally using Tableau, a data visualization software.

(17%), maize (12%), and meat (12%). China, the world's largest virtual water importer, imports water mostly in the form of soybeans (60%), followed by cereals (13%) and seeds (for example, sunflower seeds, mustard seeds, et cetera) and oils (12%) (*ibid.*).

When measuring the water footprint of commodities, UNESCO has published measurements in volume of water per weight of output; smaller is "better" if the goal is water conservation (Mekonnen & Hoekstra, 2010). Water usage is greatest in the production of beef (15,415 litres per kilogram of meat), while cereals and oilseeds are in the bottom six on the list, at 2,364 and 1,644 litres per kilogram (*ibid.*). Sheep meat has the second-highest water footprint at 10,411 litres per kilogram.

The reason for the high water footprints of bovine and sheep meat is the unfavourable feed conversion efficiency: these animals require a relatively high amount of input (daily feed per animal) per output (kilograms of meat produced yearly per animal) (Mekonnen & Hoekstra, 2010, pp. 5, 12). Water footprint values also vary by country according to water requirements for crops and livestock because this system has far lower blue (surface and ground) water and grey (polluted) water footprints than the industrial system (*ibid.*, p.24). Australia, known for its sheep and goat meat exports, grazes almost all of its sheep and goats (Mekonnen & Hoekstra, 2010, tbl. 4).

Figure 8. Water footprint by commodity.

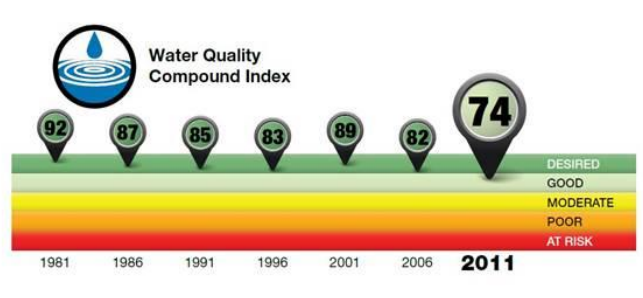
Item	Cubic metres per ton
Sugar crops	197
Vegetables	322
Starchy roots	387
Fruits	962
Cereals	1,644
Oil crops	2,364
Pulses	4,055
Nuts	9,063
Milk	1,020
Eggs	3,265
Chicken meat	4,325
Goat meat	5,521
Butter	5,553
Pig meat	5,988
Sheep meat	10,411
Bovine meat	15,415

Source: Mekonnen & Hoekstra. (2010a). Water footprint of crop and animal products: A comparison. https://waterfootprint.org/en/water-footprint/product-water-footprint/water-footprint-crop-and-animal-products/

5. Water monitoring in Canada

As a matter of food and national security, it is essential for a nation to monitor the quality and quantity of water, both ground and surface. Canada's Water Quality Agri-Environmental Performance Index monitors water quality on agricultural lands by testing for nitrogen, phosphorus, coliforms, and pesticides in water on agricultural land. These tests can be from well water (groundwater), drinking water (ground or surface origin), or lakes and rivers (surface water). The Water Quality Index has generally decreased over time, from 92 ("desired") in 1981 to 74 ("good") in 2011. (The overall water quality index has only been updated to 2011 because pesticide data, one of the components, are not available for 2016 due to a delay in proprietary data used in the model.) For a more detailed discussion of nitrogen and phosphorus, see section 5.3. Agricultural use of nitrogen and phosphorus.

Figure 9. Water quality index.



Source: Agriculture and Agri-Food Canada. (2016, July 11). Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4 [Fact sheet]. https://agriculture.canada.ca/en/agriculture-and-environment/agri-environmental-indicators/environmental-sustainability-canadian-agriculture-agri-environmental-indicator-report-series-report.

5.1. Groundwater quality and quantity

Groundwater is water below the surface of the ground, such as wells and aquifers. Provinces oversee groundwater quality and quantity monitoring, usually at the watershed level.

The importance of groundwater monitoring in Canada was highlighted in the Walkerton, Ontario crisis in 2000. A combination of manure and heavy spring rains resulted in runoff and the contamination of the town's drinking water and the death of seven people. Given the gravity of these consequences, the importance of monitoring groundwater cannot be overstated.

British Columbia's groundwater monitoring network contains 226 wells (mostly owned by the government), some of which have been monitored since 1961. In 2019, the level of groundwater was found to be rapidly declining at 9 percent of wells (Environmental Reporting BC, 2019). In the Okanagan watershed, 55 percent of water is used for agriculture. In response to growing demand for water, the Okanagan Water Supply & Demand Project was undertaken from 2005 to 2010 and resulted in agricultural water demand models for not only the Okanagan, but also the Similkameen, Nicola, and Lower Fraser valleys.

Alberta's groundwater observation network is comprised of about 250 wells which are maintained by Alberta Environment staff (Alberta Water Portal Society, 2022). The Government with the help of partners also collects groundwater and surface water samples and compiles them into a risk index which can be viewed in the agricultural land resource atlas in ArcGIS. The water quality risk is composed of metrics of livestock inventory, crop production, agrochemical use, aquifer vulnerability, and moisture levels (*ibid.*).

Notable conflict has arisen in Alberta over groundwater contamination linked to the oil and gas industry. Concerns are concentrated in the south-eastern part of the province where coalbed methane (CBM) wells are common (Humez et al., 2016). Leaked methane from CBM wells, when dissolved in drinking water, is highly flammable and is suspected to cause livestock fatalities (Mesly, 2007). Methane is ubiquitous in Alberta's shallow groundwater, with concentrations increasing with well depth (Humez et al., 2016). Over 600,000 Albertans rely on groundwater for drinking and most landowners have at least one oil or gas well on their property (Alboiu & Walker, 2019), although not all are CBM wells.

Saskatchewan's groundwater is monitored by the Saskatchewan Water Security Agency (WSA) through the Groundwater Level Observation Well Network (Saskatchewan Water Security Agency, 2022b). The WSA also operates 72 dams in Saskatchewan to ensure there is enough water available for agriculture, municipal, and industrial uses (Saskatchewan Water Security Agency, 2022a).

Manitoba's groundwater is monitored by the Ministry of Environment, Climate and Parks (Manitoba Environment, Climate and Parks, 2022). In a 2019 report, 16 percent of wells in rural Manitoba were found to have exceeded the maximum recommended nitrate level (Manitoba Sustainable Development, 2019).

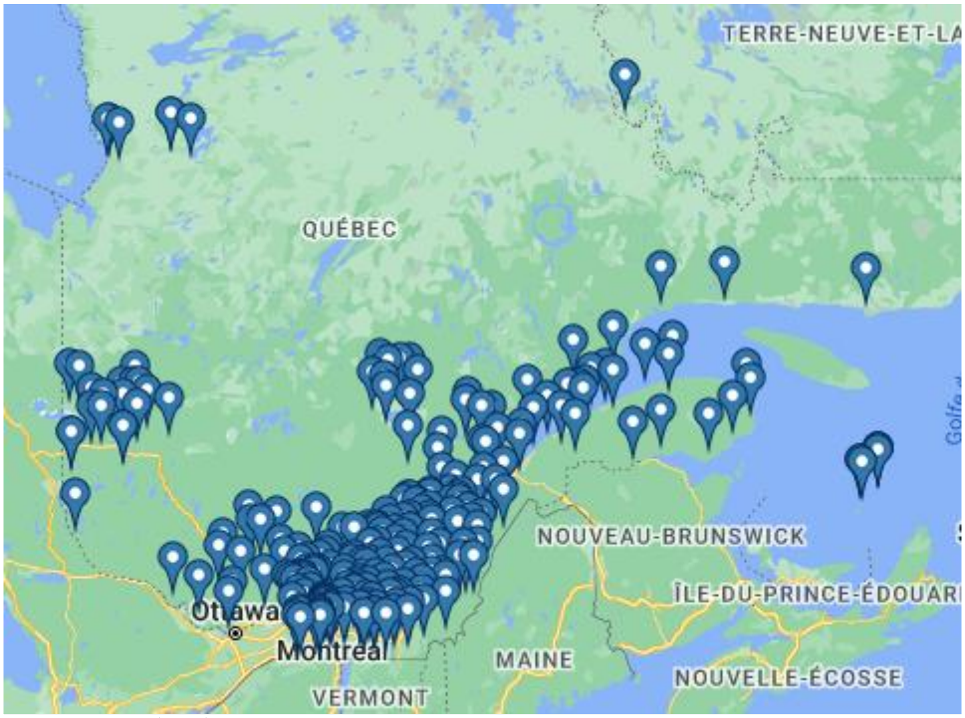
Ontario's Provincial Groundwater Monitoring Network (PGMN) Program is a network of wells in the province which are tested for water level and quality (Ontario, 2022a). The data are available to the public on the provincial government website (Ontario, 2022c). The map below shows the locations of the wells in the network which are mostly on public land (426) with some on private land (95) (*ibid.*). Ontario's 36 different conservation authorities are responsible for collecting data, maintaining the wells, and monitoring the equipment in their jurisdictions (Nottawasaga Valley Conservation Authority, 2020a).

Figure 10. Ontario wells in the Provincial Groundwater Monitoring Network.

Source: Ontario. (2022a). Map: Provincial Groundwater Monitoring Network. Ontario.ca. http://www.ontario.ca/page/map-provincial-groundwater-monitoring-network

Quebec's groundwater monitoring network contains 263 wells (pictured below), mostly in the southern region of the province near the Saint Lawrence River (Québec, 2022a). The Ministry of Environment, with help from the *Institut national de la recherche scientifique* (INRS, an academic research institute in Quebec), reports regularly on the Saint Lawrence River region (*ibid.*). Occasionally, the Ministry conducts special studies on water quality in agricultural areas: for instance, a 2004 study found that nitrates were higher in groundwater in intensive agricultural zones than in moderate intensity zones (Rousseau et al., 2004, p. 9).

Figure 11. Quebec groundwater monitoring network.

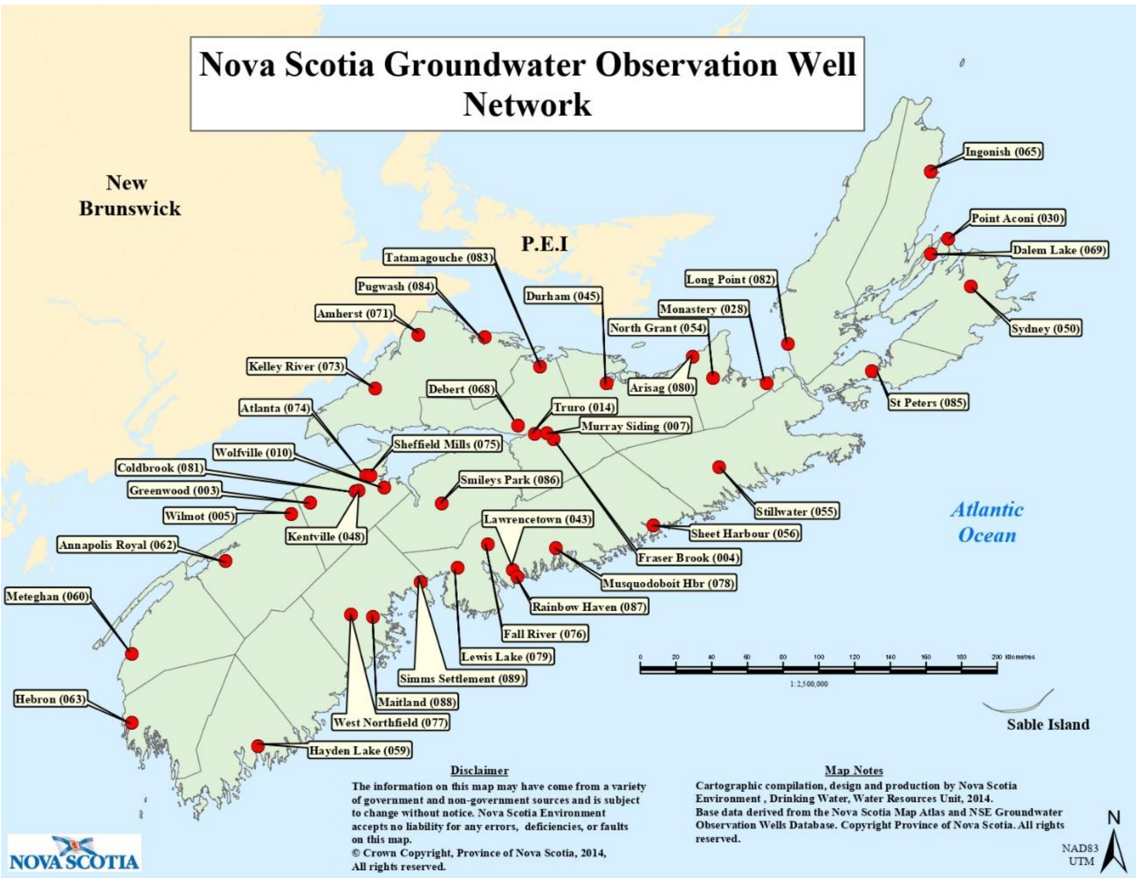


Source: Québec. (2022). Réseau de suivi des eaux souterraines du Québec.
https://www.environnement.gouv.qc.ca/eau/piezo/index.htm

The New Brunswick Department of Environment monitors and reports on groundwater quantity and quality using data from 8,786 domestic water wells drilled since 1994 (New Brunswick Department of Environment, 2008, p. iii). Although only five percent of the province's land mass are considered agricultural and only two percent are used for crop production (C. New Brunswick, 2022), some research has been done on the correlation between agriculture and nitrates in groundwater, specifically in areas with intensive potato farming (Chow et al., 2011; Richards et al., 1990).

Nova Scotia's department of Environment and Climate Change monitors groundwater quality and quantity and provides reports, databases, and maps (Nova Scotia Department of Environment and Climate Change, 2022a). The province's network has 40 wells, pictured below (Nova Scotia Department of Environment and Climate Change, 2022b). The latest comprehensive report available on the website stated that only one well in the province had high nitrate levels and was located in an agricultural area (Nova Scotia Environment, 2015). More reports are available for specific locations and initiatives such as the nitrate monitoring program in Kings County, the most intensively farmed region in Nova Scotia (Nova Scotia Department of Environment and Climate Change, 2012).

Figure 12. Nova Scotia Groundwater Observation Well Network.



Source: Nova Scotia Department of Environment and Climate Change. (2022b). Groundwater Observation Well Network | Groundwater. https://novascotia.ca/nse/groundwater/groundwaternetwork.asp

Prince Edward Island has a network of 14 wells which are monitored for groundwater quantity (Prince Edward Island, 2022). Livestock and agricultural irrigation are the province's smallest users of groundwater (5.5 percent and 2.2 percent), compared with 46 percent residential use and 35 percent industrial use (Prince Edward Island, 2019). Although there is no governmental initiative or reporting specifically on agriculture and water quality, monitoring and research work has been done assessing links between potato production systems to nitrate leaching in the province especially in the non-growing season (Liang et al., 2020).

In Newfoundland and Labrador, approximately five percent of drilled wells are sampled regularly (n≈1,310) for quality and contaminants; the results are posted online (Newfoundland and Labrador, 2020). No agriculture-specific reports or initiatives appear to exist in Newfoundland and Labrador.

5.2. Surface water quality and quantity

Surface water describes any body of water above ground, including lakes, rivers, and streams, and wetlands. Nutrient runoff from fertilized fields and pastures, as well as pathogens from waste water treatment plants, can collect in surface water bodies to be later withdrawn, posing threats to human, animal, and plant health. Excess nutrients from agriculture and chemicals from municipalities contribute to the growth of blue-green algae in watersheds across Canada. Refer to section 5.3. Agricultural use of nitrogen and phosphorus," for more on nutrient runoff from agriculture.

British Columbia has a network of approximately 116 surface water quality monitoring sites, 40 of which are deemed "federal-provincial, and 76 in the B.C. lake monitoring network (British Columbia, 2022). The 76 lake monitoring sites cover 53 lakes and are sampled by volunteers under the direction of the provincial government (B.C. Ministry of Environment and Climate Change Strategy, 2022). A summary report prepared for the Province covering the years 2015 through 2020 showed that most B.C. lakes were prone to nuisance cyanobacteria blooms due to their ratios of nitrogen to phosphorus (Larratt Aquatic Consulting, 2020, p. 2). Quamichan Lake on Vancouver Island had the most dangerous levels; this lake is in a watershed heavily impacted by urban development and agriculture (Larratt Aquatic Consulting, 2020, p. 21). In the Okanagan Valley, B.C.'s densest agricultural region, algal blooms (caused by municipal waste water) have been a concern in surface waters (Okanagan Water Stewardship Council, 2008, p. 36). The region therefore started a grant program to upgrade municipal facilities, which resulted in a 92.5 percent decrease in phosphorus inputs into lakes (*ibid.*). Nitrate and phosphorus pollution were the key drivers of the creation of the Okanagan Basin Water Board (OBWB) in 1970 (Okanagan Water Stewardship Council, 2019, p. 29). The OBWB convenes experts, provides thought leadership on water management, and resources for farmers (Okanagan Basin Water Board, 2022).

Saskatchewan's Water Security Agency monitors surface water at 27 primary water stations (Saskatchewan, 2022). Saskatchewan's ten rivers were sampled from 2019 to 2021 and were deemed as "good" or "excellent" (Saskatchewan Water Security Agency, 2022a).

The Prairie Provinces Water Board (PPWB) is a long-standing federal-provincial governance mechanism that helps manage shared water between Alberta, Saskatchewan, and Manitoba. The PPWB administers a formal agreement between the jurisdictions (Master Agreement on Apportionment or MAA) which was signed in 1969. The PPWB conducts water quantity and quality monitoring, paid for by Environment and Climate Change Canada (Prairie Provinces Water Board, 2022). The PPWB reports annually to governments, including on apportionment (the amount of water that must be passed from each jurisdiction to the downstream jurisdiction). The PPWB reported on long-term trends in water quality at 12 transboundary river reaches, measuring (among other things) total nitrogen and total phosphorus in the rivers (PPWB Committee on Water Quality, 2018).

At the Alberta/Saskatchewan boundary, total nitrogen levels were either stable (two rivers) or decreased (one river) at three of the six rivers; the other three increased in total nitrogen levels from 1993 to 2013 (Cold Lake), from 1967 to 2013 (Red Deer), or from 1970 to 2013 (South Saskatchewan) (PPWB Committee on Water Quality, 2018). The improvements in nitrogen were attributed to wastewater improvements made in Edmonton in 2001 (*ibid.*). Total phosphorus either decreased or remained stable at all six locations (*ibid.*).

At the Saskatchewan/Manitoba boundary, total nitrogen increased at four of six locations: Assiniboine, Carrot, Qu'Appelle, and Red Deer (*ibid.*). The main sources of total nitrogen and total phosphorus in the Carrot River are believed to be agriculture and forests (*ibid.*). Total phosphorus increased in two rivers: Carrot and Red Deer (*ibid.*).

The Nelson River drainage area spans Manitoba, Saskatchewan, and Alberta and contains 70% of Canada's cropland (471,000 km2) (Water Science and Technology Directorate, 2011, p. 19). Based on 2004-2006 sampling, seven of the country's nine hyper-eutrophic sites were in the Nelson River drainage area which means that total phosphorus concentrations were in the highest measured category: over 0.1 milligrams per litre (Water Science and Technology Directorate, 2011, pp. 38, 4). In 2016, it was reported that phosphorus levels had not meaningfully changed since 1999. This was based on water testing at five sites in the Nelson River water basin in northern Manitoba: two sites in Lake Winnipeg and its three largest tributaries (the Saskatchewan River, the Red River, and the Winnipeg River) (Environment and Climate Change Canada, 2018).

Lakes in the Prairies may be more susceptible to eutrophication because its waters are "harder": they have higher sulphur content and lower iron content than lakes in other parts of North America. These attributes encourage the accumulation of phosphorus in bottom sediment where it may later be mobilized, move up the water column, and cause algal blooms (Letwas et al., 2014, p. 25).

Ontario's Provincial Stream Water Quality Monitoring Network has approximately 338 stations (Ontario, 2022b) which are sampled by staff from individual watershed authorities (Nottawasaga Valley Conservation Authority, 2020b). The latest data available on surface water test results are from 2020 (Ontario, 2022b) and reveal continued concern in the Great Lakes as nitrogen concentrations rose rapidly from 1990 to 2006 (Water Science and Technology Directorate, 2011). Lakes Erie and Ontario ranked in the top three for nitrogen concentrations in Canada in 2006 (*ibid.*). In 2014, blue-green algae blooms near Toledo – the Ohio city nearest Lake Erie – caused toxicity in the drinking water, affecting half a million people for approximately 48 hours until the city was able to enhance its treatment system (Alliance for the Great Lakes, 2019; Sifferlin, 2014a, 2014b). Several Ohio watersheds which drain into Lake Erie have imposed limits on phosphorus levels in the water which may run off from local pig farms or from pig manure applied to field crops (Hopkins, 2020).

Some areas in the Maritime provinces have had issues with both phosphorus and nitrogen contamination of surface water. For instance, all ten rivers in Prince Edward Island's monitoring network have shown steadily increasing nitrate levels despite relatively stable potato production since 2008 (PEI Department of Environment, Energy and Climate Action, 2021). In addition, cranberry farming in Newfoundland and Labrador has been associated with pesticides in surface water, although continued implementation of BMPs was suggested to make cranberry farming more sustainable (Carey, 2017).

5.3. Agricultural use of nitrogen and phosphorus

Nitrogen and phosphorus are of particular concern because they are the most limiting factors to crop growth, but they are also the water contaminants with the strongest link to agriculture. Nitrogen can leach into groundwater and contribute to surface water eutrophication (Huang et al., 2017), and can produce atmospheric nitrogen emissions. Phosphorus also contributes to eutrophication and its symptoms: hypoxic zones and toxic algae blooms in freshwater (Canadian Water Network, 2018, p. 10). Traditionally, phosphorus was thought to be the main cause of eutrophication, but that view has been challenged and it is now becoming known that nitrogen is also a significant driver (Burton & Armstrong, 2020).

AAFC publishes an index of risk of water contamination, with 100 representing no risk. Of the four components of Canada's national water index (nitrogen, phosphorus, coliforms, and pesticides), the greatest contributor to the decrease from 1981 to 2011 was nitrogen, with a decline (1981 to 2016) from 88 to 74 (AAFC, 2021a). The risk of nitrogen contamination worsened the most in Alberta (the Red Deer and Qu'Appelle river basins), Saskatchewan, and Manitoba (the Carrot River and South Saskatchewan river basins) (AAFC, 2021a, fig. 3). Notably, the level of total nitrogen has increased in the Red Deer River basin, which runs from northern Saskatchewan to southern Alberta, from 1967 to 2013 (PPWB Committee on Water Quality, 2018, tbls. 1 and 4).

Phosphorus has the lowest score in Canada's Water Quality Index and has never been in the "desired" category (AAFC, 2021b). Southern Manitoba and southern Ontario were the highest risk regions in terms of water contamination by phosphorus (AAFC, 2021c).

Figure 13. Index of risk of water contamination, by component (AAFC).

	1981	1986	1991	1996	2001	2006	2011	2016
Nitrogen	88**	85**	87**	79*	64*	81**	69*	74*
Phosphorous	75*	71*	72*	69*	70*	68*	68*	73*
Coliforms	80**	82**	81**	78*	77*	76*	79*	80**
Pesticides	88**	86**	86**	88**	86**	85**	71*	-
*GOOD (60-79) **DESIRED (80-100)								

In 2018, the Canadian Water Network released a report identifying beneficial management practices (BMPs) that can minimize phosphorus run-off from agricultural lands. The most effective BMPs were crop residue management, conservation tillage, and cover crops. Planting perennial or permanent crops (such as hay and pasture) have also been recognized as a BMP because they can prevent the application of phosphorous fertilizer in the first place, thus avoiding the risk of water contamination (Veliz et al., 2022, p. 3).

From an operational perspective, farmers are incentivized to minimize the application of fertilizer and maximize its effectiveness in order to maximize profitability. Preventing runoff and nutrient leaching also reduces the need for future replenishment. As a means to achieving this, BMPs and regenerative agriculture are increasingly being advanced by large agribusiness firms such as Cargill and General Mills with targets on biodiversity, soil, and water (Cargill, 2019; General Mills, 2023).

In Quebec, producers must provide a yearly report on phosphorus in order to be eligible to receive government funding or to participate in programs such as AgriInvest In addition to BMPs, most provinces also monitor or regulate the application of nitrogen, phosphorus, or manure. The regulation of manure application may have been motivated by the death of seven people in the Walkerton, Ontario crisis, caused by E. coli bacteria associated with manure runoff on a nearby farm (Salvadori et al., 2009).

Restrictions on nitrogen, phosphorus, or manure vary greatly between provinces: for instance, Alberta is the only province which mandates that manure be incorporated after spreading (Reid et al., 2019, tbl. 3). British Columbia is the only province which mandates soil testing (*ibid.*). In Quebec, producers must provide a yearly report on phosphorus in order to be eligible to receive government funding or to participate in programs such as AgriInvest (Quebec, 2022). Some similarities between provinces do exist: many provinces prohibit or restrict the application of manure during the winter months (Reid et al., 2019, tbl. 3). A summary of agricultural nutrient management by province is provided below (*ibid.*).

BMP

"This fund [the Blue Fund announced by the Quebec Premier] would serve, among other things, to support farmers by establishing riparian buffer strips to control non-point source pollution from fertilizers or pesticides."

Read more about water issues in a Perspective *Report by Nicolas Mesly: "Water, a source of concern for agricultural producers and agri-food processors in Québec". Other case studies will follow in this series.*

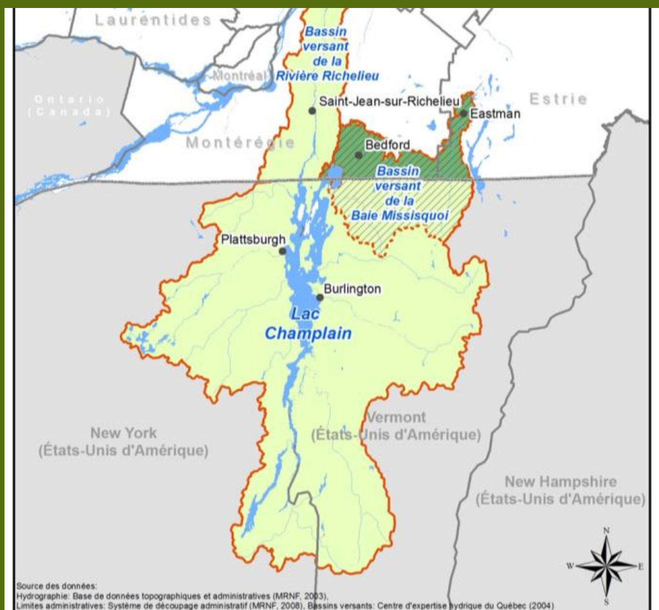
Figure 14. Summary of provincial nutrient management regulations.

Prov.	Regulation	Size of livestock operation	Max. P_2O_5 appl. rate	Other P restrictions	Reference
BC	Code of Practice for Agricultural Environmental Management, B.C. Reg 8/2019	Farm area > 5 hectares; located in vulnerable aquifer recharge area; nitrate test for field is 100 kg N/hectare or more	By 2026, STP limit of 300 ppm By 2027, all P-affected areas with an amended threshold will have STP limit of 100 ppm	P soil test every 3 years No spreading in high-precipitation area 1 Nov. to 1 Feb.	(British Columbia, 2019; BC Reg 8/2019 | Code of Practice for Agricultural Environmental Management, 2019; British Columbia Ministry of Agriculture, 2017; McDougall, 2010)
AB	Agricultural Operation Practices Act, RSALB, 2000 Manure Characteristics and Land Base Code, 2006	Large CFOs (>350 animal units) require approval CFOs in operation before 2002 exempt	Limits on N and soil conductivity rather than P	Manure is incorporated within 48 hours unless forage or direct seeded crops Application on frozen ground only with permit	(Agricultural Operation Practices Act, 2000; Manure Characteristics and Land Base Code, 2006; Alberta Agriculture and Food, 2007)
SK	The Agricultural Operations Regulations (1996)		No strict numeric limitations on P applications		(Agricultural Operations Regulations, A-12.1 Reg 1, 1996)
MB	Livestock Manure and Mortalities Management Regulation. Man Reg 62/2008	No new or expanding (<5 animal units) operations allowed in areas where annual manure P > 2x crop removal	If 60-120 ppm Olsen STP, no application >2x annual crop removal rate If 120-180 ppm Olsen STP, no application > annual crop removal rate	No application of P or N to land within nutrient buffer zone No application 10 Nov. to 10 Apr., subject to the director	(Man Reg 62/2008 | Nutrient Management Regulation | CanLII, 2008; Livestock Manure and Mortalities Regulation, Amendment, 2009)
ON	O. Reg. 267/03 (Sections 52, 92)	Farms with >300 NU (1 NU = 55 kg P) must comply with regulations	P application limited to: Crop production requirements +85 kg/hectare P2O5 per 5 yr; or Crop removal + 390 kg/hectare P2O5 per 5 yr	For regulated farms: No application where Olsen STP > 101 mg/kg No application 1 Dec. to 31 Mar. or when ground frozen	(O. Reg. 267/03: GENERAL | Nutrient Management Act, 2003)
QC	Agriculture Operations Regulation (2002), Quebec Reg 695/2002	Farms that generate >1600 kg manure P	Maintain P saturation (P/Al) < 7.6% for soil with clay >30% and <13.1% for clay content <30%	Yearly P report to the minister Winter spreading prohibited (1 Oct. to 1 Apr.)	(Agricultural Operations Regulation, 2002)
NB	The Livestock Operations Act (1998) New Brunswick Reg 99-32	NMP required for: New operations with >20 livestock or >200 poultry Existing livestock operations undergoing 10-fold expansion or more	No strict numeric limit on P loading		(NB Reg 99-32 | General Regulation, 1999; Livestock Operations Act, 1998; New Brunswick, 2007)
NL	No relevant legislation			BMPs suggested	(Newfoundland and Labrador, 2022)
NS	No relevant legislation			BMPs suggested	(Crozier & Moerman, 2004; Nova Scotia, 2017)
PEI	No relevant legislation				(Prince Edward Island, 2018)
ppm, parts per million | CFO, concentrated feeding operation | STP, soil test P | NMP, nutrient management plan					

Source: Reid et al., 2019. (Tbl. 3). Addressing Imbalances in Phosphorus Accumulation in Canadian Agricultural Soils. Journal of Environmental Quality, 48(5), 1156–1166. https://doi.org/10.2134/jeq2019.05.0205

CASE STUDY #1: QUÉBEC

Figure 15. Lake Champlain



Source: Organisme de bassin versant de la baie Missisquoi. (2014). Gestion transfrontalière des eaux—OBVBM. Organisme de bassin versant de la baie Missisquoi. https://obvbm.org/territoire/gestion-transfrontaliere-des-eaux/

The province of Quebec is the country's leading producer of milk and pork, and 75% of the grain produced in the province, principally corn and soybeans, is used for animal feed. But agricultural development has come with a price: it is affecting the quality of the province's waterways.

"Two thirds of the phosphorus found in many of Quebec's waterways comes from farm fertilizers used in fields. The intensification of livestock farming over the past few decades, combined with intensive corn and soybean crops planted and harvested with increasingly heavy machinery, has caused soil compaction, which has led to runoff and soil erosion. All this, combined with excessive land drainage, leads to high loads of phosphorus, pesticides, sediments and coliforms in streams, rivers and lakes, including the St. Lawrence River," explains Aubert Michaud, a researcher and water quality expert who recently retired from the Research and Development Institute for the Agri-Environment (IRDA).

Some watersheds are heavily affected by agricultural pollution. This is the case for the Missisquoi Bay watershed of Lake Champlain, a popular tourist region on both sides of the border whose waters are shared by Quebec and Vermont. The Quebec portion has 630 agricultural businesses that occupy 30% of this territory, while Vermont agriculture occupies 24%. The territory is crossed by several rivers (see map). The problem is that an increase of blue-green algae (cyanobacteria) due to excess phosphorus has turned the bay and parts of the lake into what amounts to a disgusting soup for the 50,000 seasonal and permanent residents of Quebec and Vermont.

In 2002, the governments of Quebec and Vermont signed an agreement to work together to reduce the amount of phosphorus in the lake in order to clean it up, with Quebec sharing 40% of the responsibility and Vermont, 60%. While progress has been made since then, the target phosphorus concentration of 25 micrograms per litre of water, necessary to prevent eutrophication of the lake, has never been reached. The agreement expired in December 2016 and was renewed by authorities five years later, in 2021, explains Pierre Leduc, President of the *Organisme du bassin versant Baie Missisquoi* (Missisquoi Bay Watershed Organization).

Source: Mesly, Nicolas. (2023). Water, a source of concern for agricultural producers and agri-food processors in Quebec. [Case study]. Other case studies will follow in this series. [insert Link here].

6. Water governance in Canada

Water is a shared responsibility in Canada. Water governance is primarily a provincial jurisdiction, with federal government responsible for the oceans and any water on federal lands (such as lakes in national parks), First Nations reserves, and Nunavut and the Northwest Territories (Environment and Climate Change Canada, 2016). Areas of shared responsibility which require a greater degree of cooperation include significant national water issues, health-related issues, and, notably, agriculture (Environment and Climate Change Canada, 2016).

6.1. Transboundary water agreements in Canada

Transboundary water agreements are necessary to ensure cooperation between jurisdictions which share a water resource. Entities such as the Prairie Provinces Water Board and the International Joint Commission exist to oversee transboundary water crossing borders between provinces and between Canada and the United States. The table below lists some of the more notable transboundary water agreements which exist between provinces and between Canada and the United States.

Figure 16. Water quality/quantity commitments and transboundary agreements, by jurisdiction.

Jurisdictions	Boundaries	Targets or commitments	Transboundary agreements	Related entities
Canada, United States	National and provincial	Prevent or resolve disputes, make recommendations	Boundary Waters Treaty (1909)	International Joint Commission (ensued from the Treaty)
Canada, Alberta, Manitoba, Saskatchewan	Provincial	Quality: N, P, pesticides, metals, major ions, etc.	Master Agreement on Apportionment (1969)	Prairie Provinces Water Board
Canada, BC, NWT, Yukon Territory, Alberta, Saskatchewan	Provincial and territorial	Recommending uniform objectives for water quality and quantity	Mackenzie River Basin Transboundary Waters Master Agreement (1997)	Mackenzie River Basin Board
Canada, United States	National	Nine quality indicators: nutrients and algae, drinking water, groundwater, toxic chemicals, fish consumption, habitat and species, watershed impacts and climate trends, and beaches	Great Lakes Water Quality Agreement (1972)	Governments of Canada and the United States
Ontario, Québec, Illinois, Michigan, New York, Indiana, Minnesota, Ohio, Pennsylvania, Wisconsin	Provincial, national, and state	Overseeing each jurisdiction's water management program	Great Lakes-St. Lawrence Agreement and Compact (2005)	The Great Lakes-St. Lawrence Governors & Premiers
Quebec, New York, Vermont	National and state	Quality: P	New York-Quebec-Vermont Water Quality Agreement (1993)	Lake Champlain Phosphorus Reduction Task Force; Missisquoi Bay Phosphorus Reduction Task Force
Canada (British Columba), United States	National	Targets for fish and flood control, infrastructure (bridges, roads, parks), and power generation	Columbia River Treaty (1961)	United States Army Corps of Engineers, Bonneville Power Administration (US), BC Hydro

Sources:
(1) ECCC. (2022, September 2). *Canada-US boundary waters treaty*. Environment and Climate Change Canada.
(2) Prairie Provinces Water Board. (2021, September 24). *PPWB Water Quality Agreement*.
(3) Mackenzie River Basin Board. (2022b). *Mackenzie River Basin Transboundary Waters Master Agreement*.
(4) Binational.net. (2022b). *State of the Great Lakes 2022*. https://binational.net/2022/07/29/sogl-edgl-2022/
(5) Great Lakes Governors and Premiers. (2023). *Great Lakes Agreement and Compact*.
(6) Missisquoi Bay Phosphorus Reduction Task Force. (2000). *A division of responsibility between Québec and Vermont for the reduction of phosphorus loads to Missisquoi Bay*.
(7) British Columbia. (2023). Columbia River Treaty. https://engage.gov.bc.ca/columbiarivertreaty/faqs/

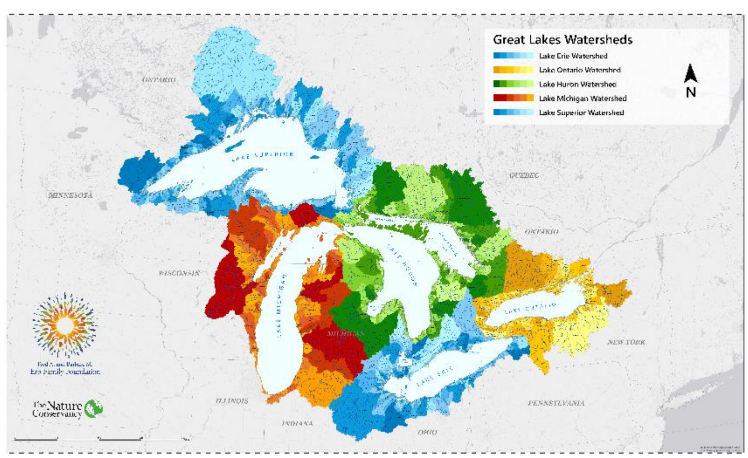
The Mackenzie River Basin Transboundary Waters Master Agreement pertains to the Mackenzie River watershed basin which accounts for 20 percent of Canada's land mass (Alberta Water Portal Society, 2014). The Master Agreement was signed in 1997 between British Columbia, the Northwest Territories, Yukon Territory, Alberta, Saskatchewan, and Canada (Mackenzie River Basin Board, 2022b). Its purpose was to facilitate bilateral water agreements between its members (*ibid.*). Four bilateral agreements have come to fruition under the Master Agreement: Alberta/NWT, BC/Yukon, BC/NWT, and Yukon/NWT (Mackenzie River Basin Board, 2022a). Some of the commitments of the Mackenzie River Basin Board are: recommending uniform guidelines for water quality and quantity monitoring; resolving disputes; meeting at least once a year; and publishing a report on the aquatic ecosystem once every five years (Governments of Canada, British Columbia, Alberta, Saskatchewan, and the Northwest Territories, 1997, p. 5).

The Prairie Provinces Water Board (PPWB) was originally formed in 1948 as a partnership between Alberta, Saskatchewan, Manitoba, and Canada to provide recommendations on transboundary water management and allocation (Prairie Provinces Water Board, 2022). In 1969, the Master Agreement on Apportionment (MAA) was signed and it reconstituted the PPWB to administer the agreement and oversee the equitable sharing and management of transboundary waters for 12 river reaches crossing the two provincial borders; the (Prairie Provinces Water Board, 2021). The MAA includes specific acceptable limits for nutrients, major ions, metals, pesticides, radioactivity, and other water quality metrics, with differing limits for each river (Prairie Provinces Water Board, 1992).

> **"The agreement [between eight American States, Ontario, and Québec] was prompted by concerns about massive exports of water from the Great Lakes to supply cities in the central and southern United States, and to California, where it would be used for irrigation."**
>
> **– Frédéric Lasserre**
>
> *Read more about water-related concerns in Québec in case study #1, "Water, a source of concern for agricultural producers and agri-food processors in Québec," by Nicolas Mesly. Other case studies will follow in this series.*

The International Joint Commission (IJC) is the largest entity overseeing transboundary waters in Canada. Guided by the Boundary Waters Treaty of 1909, the Commission is responsible for approving projects affecting water that flows across the Canada-US border (such as dams and bridges), and overseeing any transboundary problems that may arise (IJC, 2018b). Water quality also falls under the purview of the IJC (*ibid.*) and it has contributed to water clean-up through the Great Lakes Water Quality Agreement (IJC, 2018a).

The Great Lakes Water Quality Agreement (GLWQA) was first signed between Canada and the US in 1972 (Binational.net, 2022a). The five Great Lakes – Superior, Michigan, Huron, Erie, and Ontario – are surrounded by the provinces of Ontario and Quebec and by the states of Minnesota, Wisconsin, Michigan, Ohio, Pennsylvania, and New York. The parties to the GLWQA monitor and report yearly on nine priority outcomes in the five Great Lakes: nutrients and algae, drinking water, groundwater, toxic chemicals, fish consumption, habitat and species, watershed impacts and climate trends, and beaches (Binational.net, 2022b). There are ten Annexes in the GLWQA for which sub-committees must report to the Great Lakes Executive Committee (*ibid.*). The Annexes which are most relevant to agriculture are Annex 4 (nutrients) and Annex 8 (groundwater) (*ibid.*).



In the GLWQA's latest report (July 2022), Lake Superior scored the highest in terms of nutrient levels and harmful algal blooms, while Lake Erie scored the worst (Binational.net, 2022b, p. 20). Historically, this Lake has been particularly plagued with water quality impairment due to runoff from agricultural lands. Phosphorus runoff from the Western

Lake Erie watershed and the Huron-Erie corridor cause nuisance algal blooms and hypoxia (lack of oxygen) in Lake Erie (Macrae et al., 2021, p. 530). Notably, in its first triennial progress report, the IJC recommended that governments enact enforceable standards on the application of agricultural fertilizer and animal waste around Lake Erie, along with incentives for producers to reduce phosphorus runoff (International Joint Commission, 2017, p. 20). In 2018, Canada released the Lake Erie Action Plan to reduce the amount of phosphorus entering the Lake, including nutrient and manure management, soil management, and drainage (Canada, 2018). Progress has been made regarding water quality in Lake Erie through farm-level adoption of BMPs, but opportunities exist to tailor BMPs to farmers' regional conditions (Macrae et al., 2021, p. 530).

Lakes Huron and Michigan tied for the second-lowest scores in nutrients and harmful algal blooms, but while Lake Erie has too much phosphorus, these two lakes have too little phosphorus (Binational.net, 2022b, p. 20). Below-optimal levels of phosphorus can lead to a deficit of healthy algae required to support healthy lake and fishery ecosystems (Binational.net, 2022b, p. 19). However, Cladophora, a harmful algal bloom which can cause botulism outbreaks, can persist even in low-phosphorus environments (Binational.net, 2022b, p. 21). Lakes Huron and Michigan both have excessive Cladophora (*ibid.*). Notably, the Healthy Lake Huron initiative was launched in 2011 to improve the environmental health of Lake Huron (Healthy Lake Huron, 2022). No parallel initiative appears to exist strictly for Lake Michigan.

State of the Great Lakes (nutrients and algae), 2022.

Sub-indicators supporting the Nutrients and Algae assessment					
Sub-Indicator	**Lake Superior**	**Lake Michigan**	**Lake Huron**	**Lake Erie**	**Lake Ontario**
Nutrients in Lakes	Good & Unchanging	Fair & Unchanging	Fair & Unchanging	Poor & Unchanging	Fair & Unchanging
Harmful Algal Blooms: nearshore & embayments	Good & Undetermined	Fair & Unchanging	Fair & Unchanging	Poor & Improving	Good & Unchanging
Cladophora	Good & Unchanging	Poor & Unchanging	Fair & Undetermined	Poor & Unchanging	Poor & Undetermined

Source: Binational.net. (2022b, p. 20). State of the Great Lakes 2022. https://binational.net/2022/07/29/sogl-edgl-2022/

To the east of the Great Lakes lies the Lake Champlain watershed, crossing into Quebec and the states of New York and Vermont (see Figure 15 in the case study section). In 1990, the Lake Champlain Basin Program (LCBP) was formed to protect Lake Champlain, designated as a resource of national significance (Lake Champlain Basin Program, 2021, p. 2). Every three years, a State of the Lake report is published, providing measurements on indicators such as nutrient loads and contaminants (Lake Champlain Basin Program, 2021, p. 1). Every seven years, an action plan is released (called Opportunities for Action), identifying objectives for watershed restoration and protection (Lake Champlain Basin Program, 2022a). The most recent action plan (2022) has as one of its objectives to implement recommendations from the 2000 report from the Missisquoi Bay bi-national phosphorus reduction task force (Lake Champlain Basin Program, 2022c, p. 38). The Missisquoi Bay watershed, which straddles Vermont and Quebec, has gained attention because of higher nutrient loads than other watersheds (Lake Champlain Basin Program, 2022c, p. 28). In 2002, Vermont and Quebec signed an agreement to jointly reduce the amount of phosphorus in the Missisquoi Bay watershed – 40% for Quebec and 60% for Vermont (Québec, 2022b) – to a target of 0.025 milligrams per litre of total phosphorus in the Bay by 2016 (Québec, 2002). The target was not met by 2016 but the commitment was renewed in 2021 (Lake Champlain Basin Program, 2022b).

7. Conclusion

This report serves as a primer on the complex topic of water resources and governance in Canada especially as it relates to agricultural activities. Canada's climate, land base, and water availability make it well suited for food production, but agriculture accounts for a relatively small share of freshwater withdrawals. However, water resources are subject to degradation, an unintended consequence from agriculture.

Past government programs, such as the 2018-2023 Canadian Agricultural Partnership (CAP) subsidized many water stewardship efforts including rebates for on-farm dugouts and wells intended for agricultural use (Saskatchewan, 2023). The now-defunct Prairie Farm Rehabilitation Administration (PFRA), disbanded in 2012, planned large-scale water infrastructure projects such as irrigation and canals and facilitated on-farm management through workshops and other initiatives (PFRA, 1997; Western Economic Diversification Canada, 2020). The new Sustainable Canadian Agricultural Partnership (SCAP), in effect 2023 to 2028, contains the Resilient Agricultural Landscape Program which will provide funds to, among other things, local watershed health initiatives (AAFC, 2022c; Manitoba Association of Watersheds, 2023). BMPs, programs, and policies exist at every level of government to address water supply and quality.

However, Canada has no overarching, national water management strategy. Provinces have various approaches regarding governance issues such as entitlements, fees, and reporting. Some jurisdictions have more recent reports or provide analysis more relevant to agriculture than others. Given the variability of resources, agricultural activity, and priorities of each province, many different policies and water quality outcomes are possible across the country. A synthesized approach to water quality monitoring and reporting would help inform prevention and mitigation efforts, especially in water quality degradation related to agriculture.

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