

MAPPING VIRUTAL WATER in CANADA'S PRAIRIES: A  
Comparison between Prairie Virtual Water Demands and  
Renewable Supply

by

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A THESIS

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## **An Abstract of the Thesis of**

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**Title: Mapping Virtual Water Use in Canada's Prairies: A Comparison between Prairie  
Virtual Water Demands and Renewable Supply**

Approved:   
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Katharine "Katie" Meehan

Canada is often perceived as a water-rich nation. However, in the prairie provinces of Alberta, Saskatchewan and Manitoba, water is in lower supply. These provinces are also home to about 85 percent of the country's agriculture, which consumes the largest amount of water of any industry in the country. In this thesis, I first analyze the water demands from potential evapotranspiration and virtual water demands from nine of Canada's primary agricultural products (beef, pork, chicken, wheat, canola, soy, oats, barley, and corn). I subsequently compare these demands with the renewable supplies of water from precipitation and streamflow to show that the prairies are approaching on the maximum hydrologic capacity of their environment.

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## Introduction

“My country’s bigger than most,  
And if asked I boast...

Although we don’t have history...  
Still what we’ve got’s glorious.

We’ve got rocks and trees, and trees and rocks,  
and rocks and trees, and trees and rocks,  
and rocks and trees, and trees and rocks,  
and rocks and trees, and trees and rocks,  
and water.”

- The Arrogant Worms, Canadian Folk Band, 1999

Every minute, Canada exports more than 45 Olympic swimming pools worth of water. Annually, this adds up to more than enough water to cover the entire Trans-Canada highway 341 stories high. This water export, however, is not in the form of dihydrogen monoxide (H<sub>2</sub>O). Instead, it is *embedded* in products that it exports -- a concept called *virtual water* (Allan, 1993; Hoekstra & Hung, 2002). Canada boasts the world’s fourth largest *net virtual water loss* -- meaning that the quantity of water used to produce the country’s exports greatly outpaces what it brings in as imports (Hoekstra & Chapagain, 2008). Most of these exports are agricultural products. Water-intensive meats like beef and pork as well as crops like wheat and canola are some of Canada’s thirstiest exports.

These facts contrast with stereotypes about Canada’s water abundance. Even Liberal politicians claim that Canada has plenty of water to spare, pointing to the

millions of lakes that cover the country's surface.<sup>1</sup> These lakes are estimated to be between two to three million in quantity -- more than the rest of the world combined (CIA, 2011). Environment Canada (2013) says that there are more than 30 thousand lakes larger than three square kilometers, and that more than seven percent of Canada's surface is covered with lakes. Raymond Chrétien, Canada's former ambassador to the US, once declared that Canada has "20 per cent of the world reserves of fresh water"(Chrétien, 1999). David Anderson, former Minister of the Environment in Prime Minister Jean Chrétien's government, stated that "Canada has the world's largest supply of fresh water"(Anderson, 1999).<sup>2</sup>

Public perceptions of Canada's water supply also reflect these viewpoints. This belief in a national abundance of water is culturally pervasive, partially because water helps to define Canadian national identity. The Arrogant Worms' (1999) comic Canadian folk song offers such an example. Former Prime Minister William Lyon Mackenzie King (1936) echoed this point that environmental geography defines Canadian national identity by saying, "If some countries have too much history, we have too much geography." On Environment Canada's (2010) website, the section on "Water and Society" states, "Water has played, and continues to play, a special role in the growth of our nation and is an integral part of the Canadian identity."

Academics in the water management community have also documented this relevance of water to Canadian identity. Christensen and Lintner's (2007, page 219) title one of their writings on water rights transfer in Canada as "Trading our Common

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1 "Liberal" refers to the Liberal Party of Canada -- Canada's centrist party, comparable to the Democrats in the US.

2 Raymond Chrétien was the Canadian Ambassador to the US under Jean Chrétien, the prime minister. Raymond was Jean's nephew, hence the same last names.



Heritage?” Andrew Biro (2007, page 322, emphasis original) echoes Prime Minister William Lyon Mackenzie King, saying that “*who* we are is profoundly shaped by the *where* in which we find ourselves” when he argues that water defines national identity. Karen Bakker (2007, page 15) adds that “images of pristine... water are central to concepts of Canadian identity.”

This sense of national identity around hydrologic geography has resulted in an apprehension to share water, especially with the United States. In February of 1999, the Canadian Parliament unanimously voted to ban bulk exports of water (Maravilla, 2001).<sup>3</sup> Bulk water exports refer to the transfer of water in *water form* (non-virtual). Such exports can happen through tankers, pipelines, trucks, or other means. The Canadian parliament voted again in 2002 to ban bulk water transfers between “boundary water” basins (Amendment to International Boundary Waters Treaty Act, S.C. 2002, c. 6.; Lasserre, 2007). The unanimity of the decision to ban these transfers reflects the general sentiment of the Canadian public on the issue. Canadians feel a sense of “Hydrological Nationalism”(Biro, 2007). This nationalist sentiment is not new, as Canada has been rejecting water diversion projects from the US since before 1952, when the US proposed the North American Water & Power Alliance. This project aimed to transfer water from BC and the Northern Territories to the Great Lakes, the Mississippi, and California. And the current southwestern shift of US populations into

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<sup>3</sup> This ‘ban’ is not a federal mandate. Instead, it provided for provinces to voluntarily participate in banning bulk water export through interbasin transfers. All territories and provinces participate in this ‘ban’ and have their own legislation prohibiting export. The only exception is New Brunswick, which does not export water but does not ban it either. Conservationist groups such as the Council of Canadians warn that provinces could opt to initiate bulk water transfers. Such an initiation could create a legal patchwork and provide for a NAFTA challenge to open up the rest of Canada to bulk export (Patterson, 2011).

cities reliant on the Colorado River has sparked fears that Canada may be expected to supply water where this river is no longer able (Lassere, 2007).

Most recently, the Conservative Party of Canada -- the country's most pro-unregulated trade party -- proposed the Transboundary Waters Protection Act, which would reaffirm the country's prohibition on bulk water trade. When arguing in favor of the bill, the Conservative Minister of Foreign Affairs said that he and the Harper government would support the bill's efforts to "stop the Americans from stealing all our clean water"(Baird, 2013).<sup>4</sup> While Canadians are adamantly opposed to exporting their water in water form, they lose millions of gallons every day to the United States through virtual water export, causing the Council of Canadians to call virtual water the country's "leaky exports"(Rahman, 2011).

## **Research Questions**

Building on previous research on virtual water and the physical geography of Canada's prairies, I explore the following questions: How much water is consumed through agriculture and which specific products represent the largest virtual water demand? How is this demand spatially distributed? And how does this demand compare with the quantity of water available in nearby renewable sources? I use the following data sources to calculate the water balance in the prairie regions:

- Virtual water footprints of nine different agricultural products (beef, pork, chicken, wheat, canola, soy, oats, barley, and corn)
- Acreage of each of those agricultural products by agricultural regions (groupings

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<sup>4</sup> This bill was also motivated by concerns that the US was exceeding its permitted withdrawals from the Great Lakes. This bill would increase the inspections for corporations that withdraw from the Great Lakes and subject violators to fines (Transboundary Waters Protection Act, S.C. 2013, c. 383.)

of census districts for farms)

- Potential evapotranspiration and precipitation rasters
- Major rivers and their discharge volumes

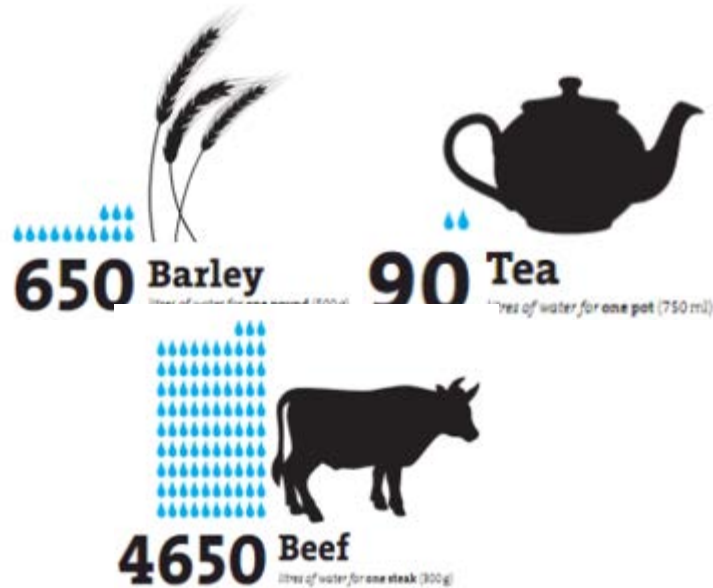
I display the findings spatially using ArcMap and compare demand (from agriculture) with supply using the UN's System of Environmental Economic Accounting for Water (SEEA). This accounting mechanism, to be explained more extensively in the methods section of this thesis, provides a simple way to compare variables like inflows from rivers with anthropogenic demands.

### **Defining Key Terms**

Originally coined by Tony Allan (1993),<sup>5</sup> virtual water refers to the water that is 'embedded in' -- or required to produce -- various commodities. Kekeritz's (2007) visualizations (Figures 1 through 3) offer examples of global averages of virtual water footprints for several food products. These figures are based on data from Mekonnen and Hoekstra (2011).

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<sup>5</sup> Tony Allan is an emeritus professor of geography at King's College in London and winner of the Stockholm Water Prize for his work on the topic of virtual water.



Figures 1, 2, and 3: Global Average Virtual Water Footprints of Barley, Tea, and Beef

Sources: Graphics by Kekeritz (2007) and data from Mekonnen & Hoekstra (2011).

Virtual water trade is a mechanism to account for the amount of water lost or gained through commerce. This ‘trade’ of virtual water refers to the exchange of goods with embedded virtual water values. Currently, no agreements or regulations exist to account for virtual water in traded commodities. Unlike carbon markets, virtual water has no official cost assigned to it. In an analysis by Mekonnen and Hoekstra (2011), the value of the virtual water footprints of industrial products varies by country. On average, Canadian industrial products use about 45 cubic meters of water for each 1000 US dollars of value. Comparatively, Japanese products fetch the same value at only 4 cubic meters. This variation in the value of a cubic meter of virtual water by country is a testament to the lack of a consistent price, and the lack of formal agreements to ‘trade’ it.

By way of example, the average virtual water footprint of a cup of coffee is 140 liters. In their report, Hoekstra and Chapagain (2003) calculated the per-hectare virtual

water footprint of coffee cherries, and then increased the virtual water value by adding the water cost of pulping, fermenting, soaking, washing, hulling, and roasting, among other parts in the process, until they reduced the per-hectare value to that of the average 125 ml amount that an individual would consume. Ultimately, they found that growing the crop itself only accounted for a little more than 13 percent of the footprint, while processing that into its final roasted form took the remaining 87 percent of the water in the operation. This processing, however, increased the footprint not because of energy requirements. Instead, at each stage of processing the coffee cherries, more of the coffee plant was lost, increasing the water footprint per volume of coffee (Hoekstra and Chapagain, 2003).

*Renewable water* refers to water resources that are consistently being recharged. Such resources include precipitation and streamflow. To offer a contrasting example, groundwater, lake water, and wetland water are all *nonrenewable* sources of water, because they can only be replenished at the cost of other renewable sources. Examples of this include precipitation percolating down into groundwater or lakes like Lake Winnipeg being refilled by the outflow from the Saskatchewan River.

### **Canadian Hydrology and Institutional Context**

The breakdown of non-virtual water in Canada is as follows:

- 14 percent of Canada's surface area is covered in wetlands (Day and Quinn, 1999). Almost all of these are in the north, as the southern ones were mostly drained to make room for human settlements.
- More than 7 percent of Canada's surface area is covered in lakes (Environment Canada, 2010).

- 2,902 cubic kilometers of water represents the country's annually renewable supply (although 60 percent of this flows north into the Arctic and 11 percent of the remainder flows into the Atlantic through the St. Lawrence) (CIA, 2011; Environment Canada, 2013).

Data on groundwater is sparse and varies by province. Environment Canada maintains information on how much drinking water for each province comes from groundwater, but they do not have publically available data on the quantity or location of groundwater. However, the province of Alberta has done extensive work in recent years to map their groundwater (Alberta Environment, 2010). Their findings show that Alberta has 40,000 cubic kilometers of groundwater. However, these same studies reveal that only 0.01 percent of their province's groundwater is "recoverable" -- reducing the amount to 4000 cubic meters (Alberta Water Portal, 2013).<sup>6</sup>

Comparatively, the water footprint of a tonne of Canadian beef is 9946 cubic meters (Mekonnen & Hoekstra, 2011). Outside of Alberta, there is little research on groundwater quantity. According to Nowlan (2005, page 10) of the World Wildlife Fund, Canada lacks accounts of the water stored as groundwater, calling this information "virtually unknown."

Because of the great volume of water stored in Canada's lakes, the country as a whole has acquired a reputation for having more than enough water to sustain not only its own needs, but those of other nations as well. This misconception is based on the volume of fresh water in all of Canada's lakes, which amounts to "20 percent of the water in all of the world's lakes"(Environment Canada, 2005). Canada inherited this

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<sup>6</sup> Day and Quinn point out that accessibility to groundwater is limited by "the preponderance of permafrost, shallow soils and impermeable crystalline bedrock" and claim that Canada has no large aquifer like the Ogallala from which to draw water at a large scale (Day and Quinn, 1999, page 4).

lake water from the melting of the Laurentide Ice Sheet at the end of the last ice age. As two geographers put it, these lakes are “a one-time gift of the recession of the Pleistocene ice fronts; they are not renewable, except at a cost to the rivers that feed and drain them”(Day and Quinn, 1991, page 4). However, Canada’s *renewable* supply of water, present mostly in streamflow and precipitation, represents 6.5 percent of the world’s supply. Unfortunately, this water is spatially isolated from the majority of Canada’s thirsty industries and population. While 85 percent of Canadians live within 300 kilometers of the southern border, 60 percent of the renewable supply of water runs northward. This separation reduces the amount of water easily available to 2.6 percent of world supply (Sprague, 2007).

Because the North American Free Trade Agreement (NAFTA) defines “‘ordinary natural water of all kinds (other than sea water)’ as a tradable good”(Conca, 2006, page 224), Canada has found itself in a position where it could export its water to the United States. NAFTA prohibits limitations that discriminate against international trade and provides for processes to subject a member country to fines and other sanctions in the case that it enacts laws that do. In order to prevent bulk water exports under this agreement, the Canadian government has placed restrictions on *interbasin transfers* that do not relate to hydroelectric power and applied said rule both nationally and internationally. While this law has definite environmental benefits, such as reducing the movement of invasive species, it has compromised the government’s ability to divert water for municipal use and irrigation. Such restrictions mean that moving water from the north to the thirstier Canadian south comes with political and hydrological consequences -- such as chapter 10 and 11 challenges under NAFTA. Of the interbasin

transfers that do occur in Canada, 97 percent are for hydroelectric power. Only three percent are for irrigation and municipal use -- an amount that has managed to slip by the federal and provincial prohibitions. To attempt to establish a large-scale diversion of water from the St. Lawrence or any of the larger northern rivers to the thirsty prairies could open the floodgates to NAFTA challenges from the United States (Lassere, 2007).

### **Water in the Canadian Prairies**

Not only does Canada have less available freshwater than is often perceived by analysts of global water distribution, but within the prairie provinces of Alberta, Saskatchewan, and Manitoba, water demands are high while renewable supply is comparatively low. Both climatic and anthropogenic causes create this hydrologic predicament. Climatic variables include lower levels of precipitation and streamflow compared to the rest of Canada, as well as higher rates of potential evapotranspiration, meaning that water evaporates from land surfaces and transpires from plants faster than it does in the north. For example, average precipitation in the prairie regions is 454 mm (McGinn and Shepherd, 2003), while Canada's average is 535 mm (Phillips, 1990). This lower precipitation, combined with higher potential evapotranspiration (average of 640 mm in the prairies compared with 430 mm as a national average), means that most of the prairies have naturally occurring water deficits (Zomer, 2008).

Meanwhile these prairie regions are also home to the country's most water-intensive industries (Harker, 2013). Figure 4 shows that these kinds of water withdrawals contribute to Canada's large virtual water footprint. When products from these sectors are exported, they contribute to Canada's 'net annual water loss' (or the amount of virtual water that leaves the country as exports subtracted by the amount of



virtual water that enters as imports) of 43 million cubic kilometers (Hokestra and Chapagain, 2008).

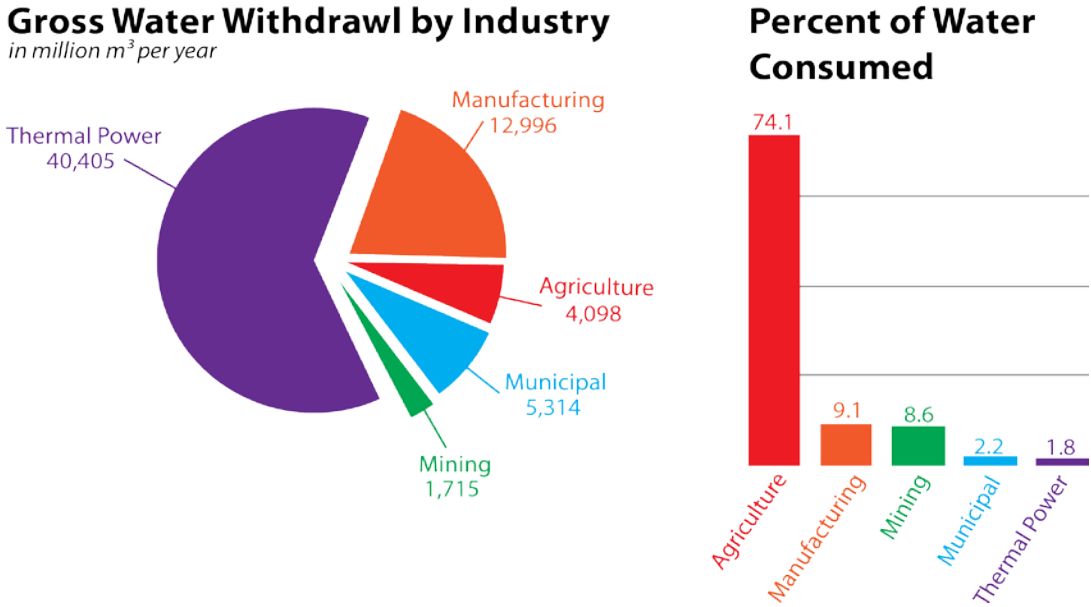


Figure 4: Water Withdrawals v. Consumption

Source: Graphic by Author, data from Shrubsole and Draper, (2007). These numbers represent non-virtual water.

Unlike in Canada, the federal government of the United States has justified its intervention in water management with the Interstate Commerce Clause in Article 1, Section 8 of the Constitution (U.S. Const. art. I, § 8). The argument has been that water plays a part in interstate commerce and can be regulated as such. In Canada, federal authority isn't as expansive. Under section 92A of the Canadian Constitution Act, the provinces have the “Exclusive Powers” to manage non-renewable natural resources, meaning that groundwater, wetlands and lakes are difficult for the federal government to manage, except as they relate to federal authorities such as fisheries and navigation (Constitution Act, 1982, 92A). Additionally, according to Karen Bakker (2007, page 4), the provinces are charged with the authorities over “water resources and water supply,”

putting renewable sources like rivers into a legal grey area. Figure 5 shows this federalist division of natural resource responsibilities, which have led to municipal management of water supplies. Generally, courts have found that provinces maintain authority over “water management” but that the national government may intervene when it has authority, such as endangered species or pollution. As a result, thirsty provinces would need to overcome more legal hurdles to access water from neighboring provinces if their supply runs low.

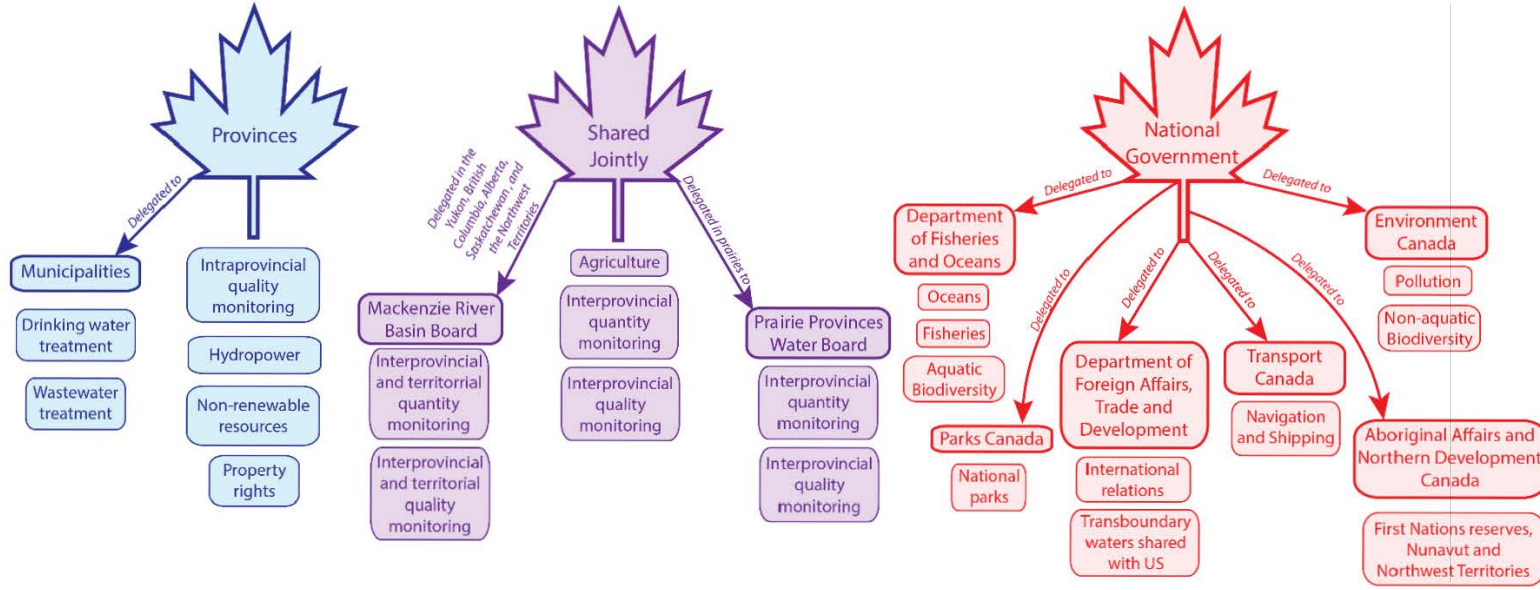


Figure 5: Federalist distribution and delegation of water authorities.

Sources: Graphic by Author, data compiled from Environment Canada (2010; 2013), Saunders and Wenig (2007), Fisheries and Oceans (2011).

The prairies' agreement on the establishment of the Prairie Provinces Water Board of 1948 also reveals an apprehension to engage in adversarial legal battles over control of water resources -- unlike the legal battles seen in the United States over the Colorado River. The post-cursor of this board has been the Master Agreement on Apportionment of 1969, in which the province of Alberta agreed to use no more than 50 percent of water from any river shared with Saskatchewan. The Federal Government of Canada has joined these agreements as a signatory but involved itself very little role in their negotiation. Both of these agreements were decided by negotiation rather than litigation -- largely due to cultural preferences, but also from to a lack of political laws guiding authority and ownership of trans-provincial waters.

No province is at greater risk of running a water deficit than Alberta. According to the Alberta Water Portal, a nonprofit organization that does research on the province's water, Alberta contains only 2.2 percent of Canada's water (Alberta Water Portal, 2013). Northern river basins such as the Peace, Athabasca, and Mackenzie hold 87 percent of Alberta's renewable water, leaving only 13 percent in southern basins like the Saskatchewan (Alberta Environment, 2010). Alberta also suffers from the rainshadow effect, whereby British Columbia intercepts most of the water coming in from the Pacific, thanks to the Rocky Mountains. The southern half of the province (where most of the province's population resides) has some of the highest potential evapotranspiration rates in the country (783 mm, in the province's three southernmost agricultural regions).

Because of these hydrologic, climatic, and anthropogenic factors, the prairie

provinces are particularly relevant subjects for investigation of water budgeting and virtual water.<sup>7</sup> And unlike the agricultural regions of southern Ontario and Quebec, the prairies have naturally occurring water deficits, whereby potential evapotranspiration exceeds precipitation. They also lack the massive annual flow of the St. Lawrence River, which drains from Lake Ontario into the Atlantic Ocean. The prairie region's commerce is important because this region withdraws large amounts of water for agriculture. 75 percent of all water withdrawn for Canadian agriculture is withdrawn from hydrologic features in this region (Harker, 2013). Figure 6 contextualizes the region as well as its physical water balances.

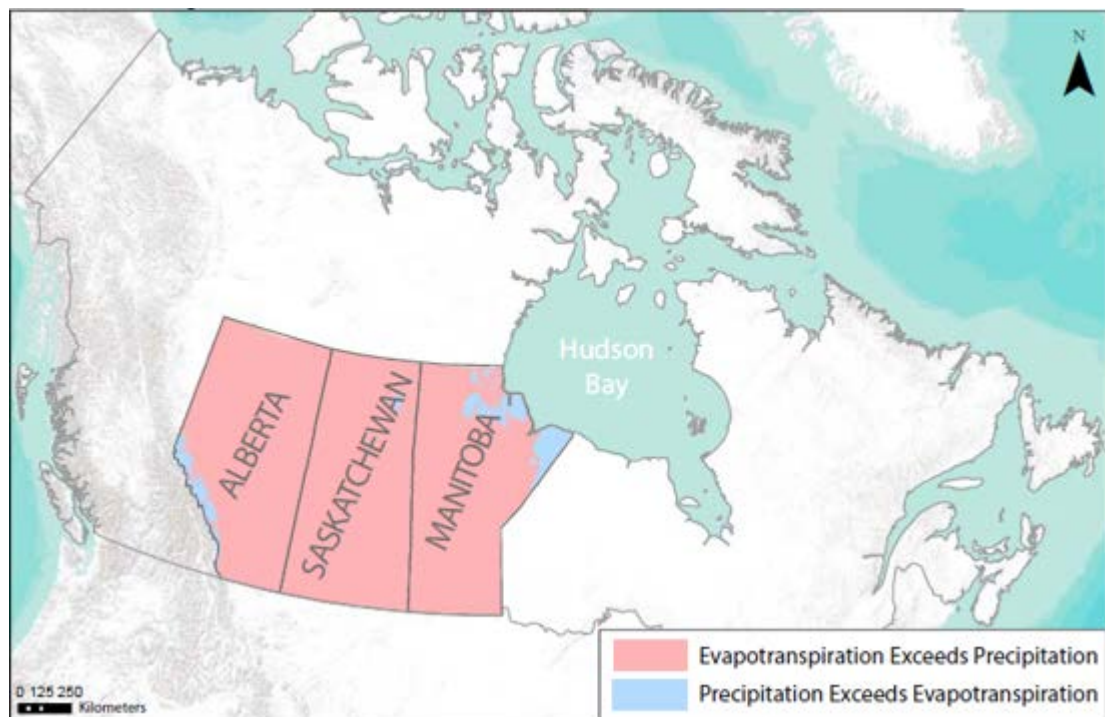


Figure 6: Annual Physical Water Balance

Sources: Graphic by Author, data from Zomer et al (2008, 2007), CIGAR CSI (2008).

<sup>7</sup> Most of Canada's agriculture comprises of grains and oilseeds (37%), red meats (27%), dairy (12%), horticulture (9%), and poultry & eggs (8%) (Canadian Federation of Agriculture, 2007).

<sup>7</sup>(47% meat (15% of blue water withdrawals), 46% plants (85% of blue water withdrawals)) (Environment Canada, 2013)

## Literature Review

### Virtual Water

The concept of virtual water originated from Israeli economists in the mid-1980s who became critical of their country's virtual water deficit, arguing that agriculture was consuming 60 percent of the country's scarce water resources (Allan, 2003). Allan (1997) uses the Middle East and North Africa (MENA) as an example of a region where water inputs (from precipitation, soil moisture and inflow) are only sufficient to satisfy demands for domestic water use. He adds that it has been hydrologically impossible to satisfy the agricultural needs of the region's population since 1970. Hoekstra and Hung (2002) found that since then, many MENA countries have reached net virtual water surpluses, relying on greater import of water-intensive products. For MENA, less than 12 percent of the region's virtual water footprint is supplied locally. More than 40 percent is provided by North America and Western Europe. Comparatively, North America supplies about 37 percent of its virtual water footprint (Hoekstra and Chapagain, 2008). To supply these virtual water exchanges, many nations have developed *net virtual water losses*. The countries with the largest annual losses in virtual water are the United States (92 km<sup>3</sup>), Australia (57 km<sup>3</sup>), Argentina (47 km<sup>3</sup>), and Canada (43 km<sup>3</sup>) (Hoekstra & Chapagain, 2008).

The debate around virtual water in water management literature formerly revolved around the term itself. Merrett (2003) argued that Allan incorrectly uses the term 'virtual' to describe virtual water, claiming that virtual water is in no way 'virtual' (since it represents water that is *real*, not digitally composed of zeros and ones). He also argued that the use of virtual water as an accounting mechanism for water can result in

miscalculations for bulk water transfers -- a concern that has largely been resolved by Falkenmark (1998, 2003) and Hoekstra & Chapagain's (2008) trifurcation of the concept into blue, grey, and green water and calculating values between those three categories.<sup>8</sup> Figure 7 visualizes this trifurcation, while also showing the differing virtual water footprints between corn and beef. Allan (2003, page 4) has argued that the 'virtual' descriptor in virtual water is simply a metaphor that has succeeded in capturing the "attention of the water managing community."

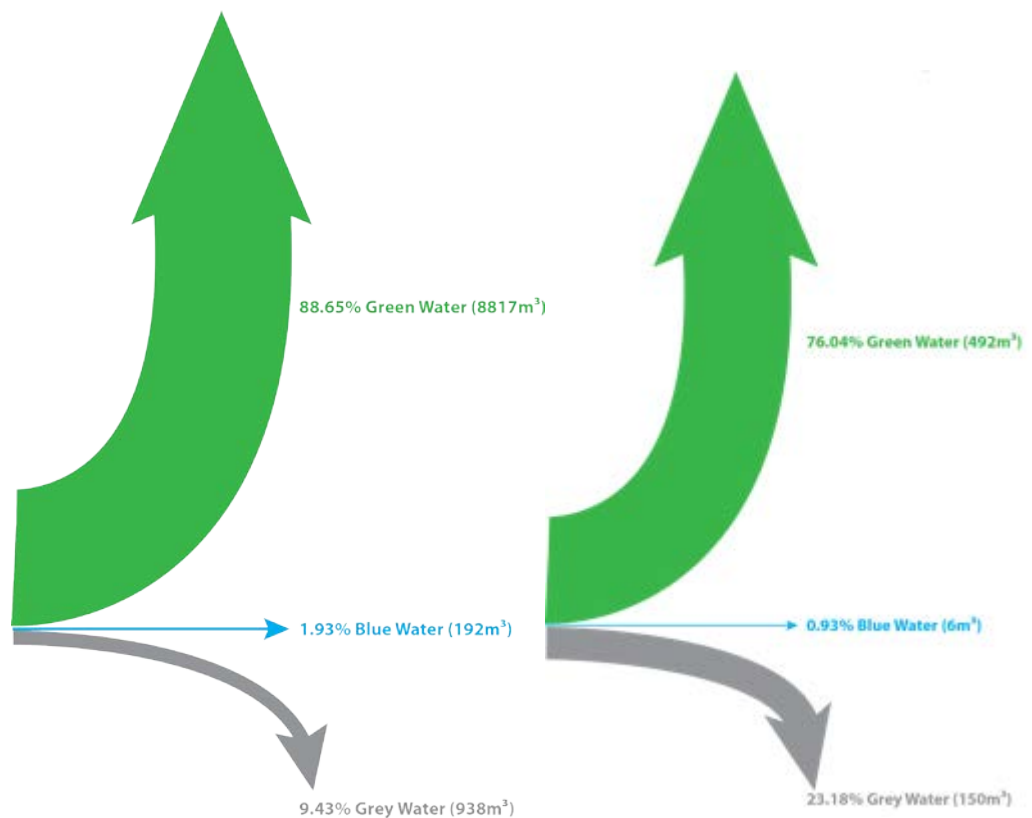


Figure 7: Virtual Water Footprint Breakdowns for Beef and Corn

Beef is on the left and corn is on the right. Source: Graphic by Author, data from Mekonnen and Hoekstra (2011).

The term did not gain popularity until Arjen Hoekstra, who at the time worked

<sup>8</sup> Green, blue, and grey water are classifications of water under the 'umbrella' of virtual water. A product's virtual water footprint is the sum of these three classifications.

at UNESCO's Institute for Water Education (IHE), expanded on the concept to encompass 'virtual water footprints' of various commodities. In 2004, he and Ashok Chapagain modeled the water "consumption and trade" for 140 of the 200 world economies. Their models divided water footprints into two categories: blue water and green water (Hoekstra & Chapagain, 2004). Green water, simply put, is water provided by the environment. This includes rainwater that falls on crops, soil moisture, and other sources of water that naturally occur where they are needed. Blue water refers to surface or groundwater that is moved by humans (i.e. irrigation, pipeline, plumbing, etc.). In recent years, Hoekstra and Chapagain have included another type of water in their models: grey water, which refers to "volume of water needed to dilute a certain amount of pollution."<sup>9</sup> By using these breakdowns of water, they have modeled 'virtual water footprints' (Hoekstra and Chapagain, 2008, page 4).

Now, the term 'virtual water' is more commonly utilized by researchers in water governance, management, and accounting, and much of the literature has moved beyond linguistic debate and onto accounting for virtual water and using such findings as tools for conservation. Hoekstra and Hung (2002) were the first to begin using virtual water to account for the footprints of specific products and nations, and have since allied with researchers in economics, business, accounting, geography, and other fields to develop this field of virtual water accounting (Hoekstra & Chapagain, 2008; Godfrey & Chalmers, 2012).

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<sup>9</sup> In this thesis, "grey water" refers exclusively to water for diluting pollution. In a large amount of water policy and conservation literature, it may refer to water that is recycled (ie using water from a shower to flush a toilet). This definition is not used in this writing.



## **Canada and the Prairies**

Generally, hydrologic research on Canada's prairies has focused on climate and other physical variables affecting water. Examples of this include topics like natural wetland oscillation (van der Valk, 2005), saline lake chemistry (Bierhuizen, 1985), and duck nesting patterns (Greenwood, 1995). Studying water as it relates to humans in the region, however, has been a more recent phenomenon (with the exception of historians documenting droughts). Gan (2000), reviews literature showing that the prairies have historically been subject to droughts. Severe droughts since the 1930s have repeatedly interrupted prairie agriculture (Godwin, 1986; Ripley, 1988; Arthur and Chorney, 1989). During the winter, precipitation drops to less than 25 mm per month while the region's greatest precipitation occurs in the spring and summer (Gan, 2000). Climate scientists point out that the region's average temperature increased 0.9° C between 1895 and 1991 (Gullet and Skinner, 1992) -- leading to increased climate variability, especially for precipitation. These increasing temperatures also risk reducing annual snowmelt, which occurs in spring at the beginning of each growing season. The consensus among these researchers is that the prairies are getting warmer and drier.

Schindler (2006) offers a more alarming description of the prairies, using the phrase "impending water crisis" to describe the future of the region. His investigation also offers a visualization of the declining streamflow in the region. Most relevant to my research are his findings on the Saskatchewan River, which he shows to have decreased in annual discharge from 100 km<sup>3</sup> in 1910 to less than 20 km<sup>3</sup> in 2000. While there is little controversy among researchers around the dryness and changing climate of

the prairies, the clearest distinction exists between those that are more apt to default their explanation of this climate to greenhouse gas emissions.

Other researchers, like Gan, are more conservative in their assessment, stating the climate change is probably the culprit, but leaving room for discourse in his conclusions. Absent from the literature are the anthropogenic effects of agriculture on the region's water supply.

## Methods

This research employs use of GIS to map and compare both physical and virtual water demand with physical water supply in Canada's prairie regions. This analysis amounts to use of a simplified and spatial version of the UN's System of Environmental Economic Accounting for Water (SEEAW). It is the sum of inflows, precipitation, and returns from anthropogenic uses, subtracted by outflows, evapotranspiration, and anthropogenic demands. As a formula, these relationships are expressed as:

$$\text{Inflows} + \text{Precipitation} - \text{Outflows} - \text{Evapotranspiration} - \text{Human Demand} + \text{Human Returns} = \text{Amount of water in inland water system}$$

In this formula, human demand refers to the virtual water footprint of all production and use within a designated geographic area, while human returns refer to the water that may be extracted from the natural environment and returned to the area (ie water used for cooling fluid at a nuclear plant then discharged into a river). Visually, this concept is reiterated in Figure 8 below. GIS is used to map Canada's virtual water footprints throughout agricultural regions and compare these with inflow values from nearby rivers.

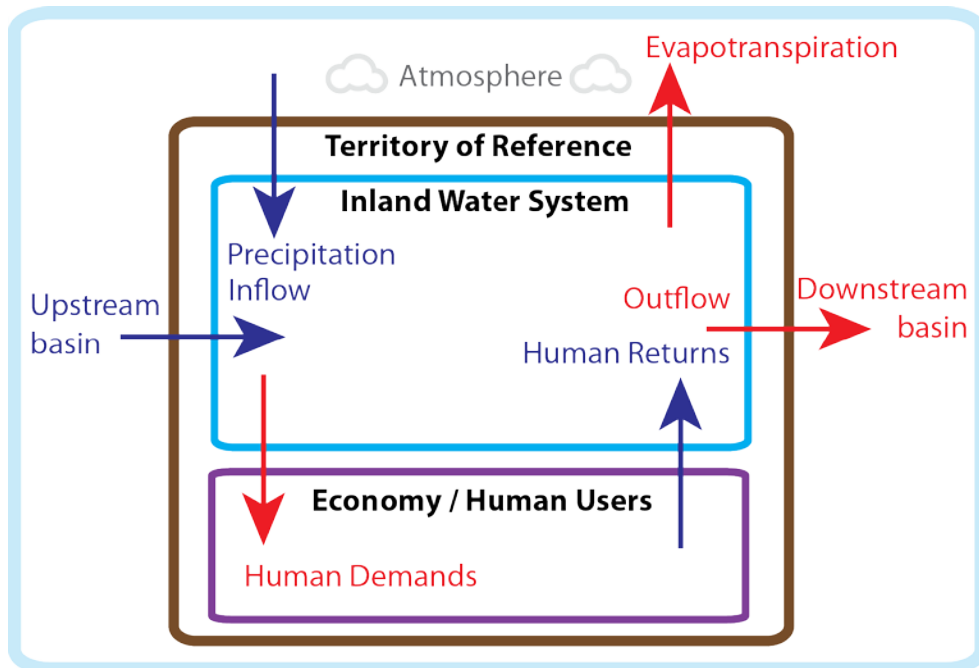


Figure 8: System of Environmental Economic Accounting for Water, Simplified

Source: Graphic by Author, concept by UN Statistics Division (2007).

Because the Prairie Provinces almost unanimously have potential evapotranspiration rates that exceed precipitation, more focus is placed on blue and grey water and streamflow (outflow and inflow). Mapping demand (blue and grey virtual water) against supply (inflow from nearby rivers) shows which agricultural regions and products are most culpable for water scarcity in the region, while also showing how much room for growth there is until water budgets hit zero.

This project investigates the effect of water demands from agriculture on Canada's Prairie Provinces (Alberta, Saskatchewan, and Manitoba), exempting industry from the investigation due largely to the difficulty associated with data acquisition (most industrial data is proprietary) and the lower water use compared to agriculture. Use of SEEAW to calculate water balances for municipalities entails multiplying their populations by their per-capita annual water footprints. Municipalities do not constitute

a large consumer of water, as they produce far less than agriculture and return almost all of what they use to the environment. Their utilization in this analysis is for comparison to agriculture, but does not factor into the total water deficits in the region. For agricultural districts, I analyze nine of Canada’s most produced agricultural products (beef, pork, chicken, wheat, canola, soy, oats, barley, and corn) by multiplying the amount produced in the most recent year for which data is available (2011) in each agricultural region by their corresponding virtual water footprints. Data on agricultural products and the amount produced comes from the Canadian Agricultural Census. Hoekstra and Mekonnen (2011) provide data on the corresponding virtual water footprints of those products. These calculated demands are displayed spatially and constitute the values for the *human demand* variable in the equation above.

Table 1 gives information on each of the agricultural products used in this analysis as well as justification for why each one was used.

<b>Agricultural Product</b>	<b>Reason for Inclusion in Analysis</b>
Beef	Largest water user of all agricultural products. Virtual water footprint of 9946 cubic meters per tonne (Mekonnen and Hoekstra, 2011). Almost 82 percent of beef production is in the prairies. Red meats constitute 27 percent of Canada’s agricultural production (Canadian Federation of Agriculture, 2007). <sup>10</sup>
Pork	Second largest water user of all agricultural products. Virtual water footprint of 4340 cubic meters per tonne (Mekonnen and Hoekstra, 2011). Almost 42 percent of pork production is in the prairies.

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10 While most beef is produced in the prairies, Canada’s dairy cattle are concentrated in Ontario and Quebec (more than 70 percent). Only 15 percent are in the prairies (Statistics Canada, 2011). Dairy is also difficult to calculate because of the processing that occurs between the extraction from cattle and conversion into a consumer product, potentially leading to representing its water demands with spatial inaccuracy. The virtual water footprint of the least processed milk in Mekonnen and Hoekstra’s calculations is 1248 m<sup>3</sup> per tonne.

Poultry	Poultry and eggs together constitute eight percent of Canada's agricultural production (Canadian Federation of Agriculture, 2007). Eggs, however, were excluded due to the fact that more than 75 percent of them are produced outside of the prairies <i>and</i> because their virtual water footprint is lower than that of poultry (by about 236 m <sup>3</sup> per tonne) (Mekonnen and Hoekstra, 2011; Statistics Canada, 2011).
Wheat	The prairies produce about 94 percent of all wheat grown in Canada. Wheat also boasts a VWFP of 3403 m <sup>3</sup> per tonne. Grains (and oilseeds) like wheat constitute 37 percent of Canada's agriculture (Mekonnen and Hoekstra, 2011; Canadian Federation of Agriculture, 2007).
Canola/ Rapeseed	Almost 99 percent of all canola grown in Canada comes from the prairies. Each tonne of canola uses 3070 m <sup>3</sup> of water. Oilseeds (and grains) like canola constitute 37 percent of Canada's agriculture (Mekonnen and Hoekstra, 2011; Canadian Federation of Agriculture, 2007).
Soy	Soy is one of Canada's major crops. However, less than 19 percent of it is produced in the prairies. Almost 98 percent of the remaining soybeans grown in Canada come from Ontario and Quebec (Statistics Canada, 2011).
Oats	Almost 88 percent of all oats grown in Canada come from the prairies (Statistics Canada, 2011).
Barley	More than 93 percent of all barley grown in Canada comes from the prairies (Statistics Canada, 2011).
Corn	Corn is one of the major crops produced in Canada. However, only 11 percent of Canada's corn comes from the prairies. Ontario and Quebec produce about 87 percent of the country's corn (Statistics Canada, 2011). Because corn is largely used for animal feed, this spatial disjunction between production and use represents an already existing alleviation on the amount of water demanded by animal agriculture in the prairies.

Table 1: All Nine Agricultural Products and Reasoning for their Inclusion

## **Calculating Agricultural Water Demands**

This research employs use of several simple python (the programming language used to calculate values in ArcMap's field calculator) functions and basic arithmetic to calculate virtual water demands in the Prairie Provinces. It relies on data from Mekonnen and Hoekstra (2011). These data utilize Hoekstra and Chapagain's (2008) method of estimating the virtual water content of an agricultural good. The variables that this method employs are crop yield and the amount of water that a crop requires to grow at the certain location. The latter value is derived from soil water, precipitation, irrigation, evapotranspiration and assumes "ideal growth conditions"(Hoekstra and Chapagain, 2008, page 10).

For the water footprints of beef, poultry and pork, Mekonnen and Hoekstra (2011) have aggregate amounts for blue, grey, and green water footprints for all of Canada for each tonne of meat produced. The data offered by Statistics Canada from the Canadian Agricultural Census (Statistics Canada, 2011) for these animals was population within each agricultural region -- not necessarily the amount produced per year. In order to determine this value, I used aggregate data from another series of reports from Statistics Canada on total production of each of these animal meats in tonnes on an annual basis, and used the populations within agricultural districts compared to the total populations for all of Canada to find values of meat production proportional to the populations of each district.

To calculate for meat products, I did the following:

- Find the amount of animals that are converted into each meat in each agricultural region. (Specific agricultural regions will be referenced frequently in this section. To locate them, refer to Figure 9).
- Use that quantity of animals to solve for tonnes of meat produced in each agricultural region
- Convert tonnes to cubic meters of water
- Convert cubic meters to cubic kilometers



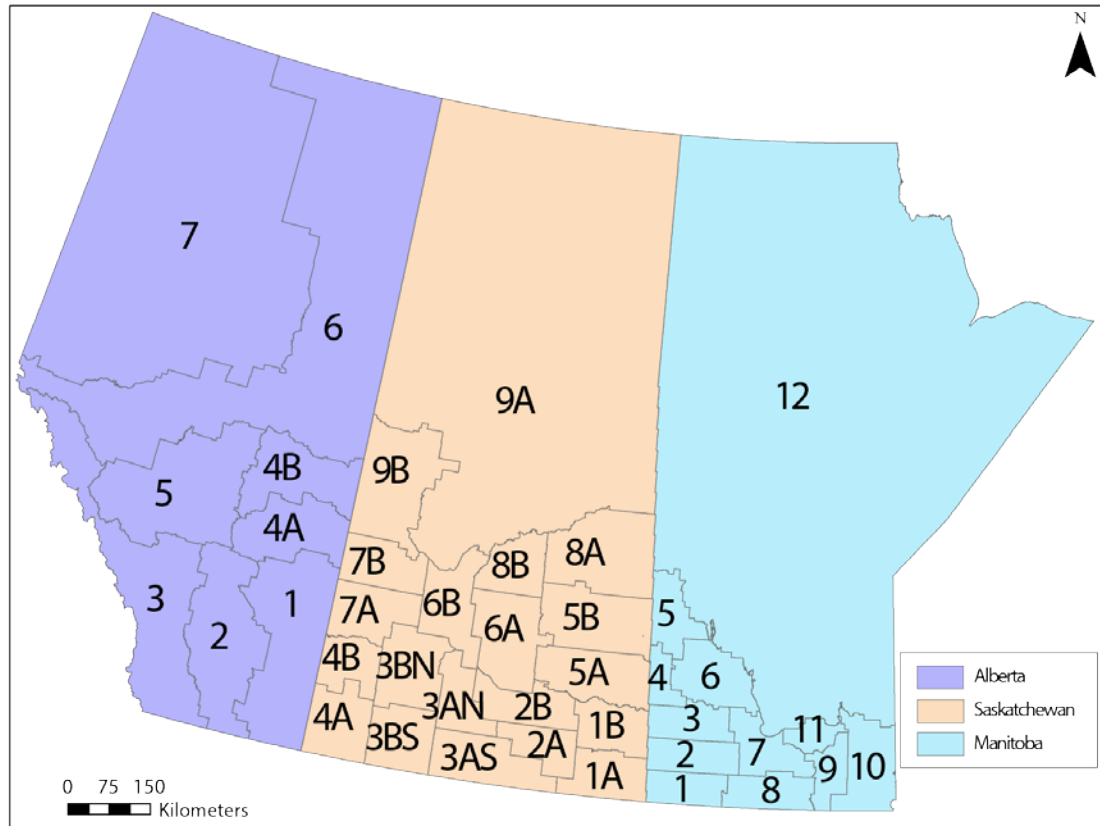


Figure 9: Map of Canadian Agricultural Regions by Province.

Source: Graphic by Author, data from Statistics Canada (2012).

For example, in 2011, Canada as a whole produced 1,953,550 tonnes of beef. In the same year, Canada had a total of 3,849,368 beef cattle at the time of the census. And Alberta Agricultural Region 4A had 148,224 cattle at the time of the census. With these data points, I was able to solve for the amount of beef produced by that agricultural region with the following equation:

$$148,224 \text{ cattle} / 3,849,368 \text{ cattle} = a / 1,953,550 \text{ tonnes. Solve for } a$$

$$a = 75,223.51596417905 \text{ tonnes}$$

Unfortunately, the data would be more accurate had the census data simply been tonnes of beef produced in that agricultural region. This method was merely a way of working

with available data. Potential errors from this workaround include inaccuracies from cattle being produced in one region and slaughtered in another as well as year-to-year inconsistencies (i.e. a cattle being born and counted one year but slaughtered another).

Once I had data on tonnes of each meat produced in each agricultural region, I converted it into virtual water footprints. I used only blue and grey water in this calculation, as green water would have already been calculated in the potential evapotranspiration from crops used as animal feed. Its inclusion would have led to double-counting water demands. Blue and grey water also have this risk (because crops also create runoff from fertilizers and pesticides as well as intake water from irrigation) of double counting, however it is less large because most of these are used for diluting runoff from pollution produced by animals as well as for their drinking supply. Because the virtual water data on animal products is only on aggregate country-wide averages, all provinces and regions used the same formula:

Amount of meat produced in tonnes \* sum of blue and grey virtual water footprints of that product = total virtual water footprint for that product in that agricultural region

For the previous example, that equation would look like this:

$75,223.51596417905 \text{ tonnes} * 1130 \text{ m}^3 \text{ per tonne} = 85,002,573.03952233$

I would subsequently convert this value to cubic kilometers:

$85,002,573.03952233 \text{ cubic meters} * 10^{-9} = 0.085002573 \text{ cubic kilometers}$

After calculating this data on animals, I moved onto crops. The crops that I decided to include were wheat, canola, soy, oats, barley, and corn. A more exhaustive analysis would include all crops available from the Canadian Agricultural Census

(which includes everything from cabbage and wheat to Christmas trees and maple syrup). To calculate the virtual water footprints of each agricultural region from each of these crops, I used the Canadian Agricultural Census data to get the amount of acres devoted to that crop within each agricultural region. To convert this data to virtual water footprints, I used the following process:

- Find the amount of acres devoted to that crop in each agricultural region
- Convert acres to bushels using the Canadian government's data on crop output
- Convert bushels to tonnes
- Convert tonnes to cubic meters of water
- Convert cubic meters to cubic kilometers

For example, Manitoba Agricultural Region 8 had 515,010 acres of wheat in 2011. With this acreage, I used the average national bushels per acre (Statistics Canada, 2013), in this case 42.1 bushels per acre for wheat in 2011, to convert acres to bushels.<sup>11</sup>

Subsequently, I used the Government of Alberta's Agriculture and Rural Development bushel per tonne conversions to find how many tonnes of each agricultural product were produced in each agricultural region. The equation worked as follows:

$$\text{Bushels of crop} \div \text{amount of bushels per tonne} = \text{tonnes of crop}$$

With the previous example of Manitoba wheat, this would work as follows:

$$515,010 \text{ bushels} \div 36.7440 \text{ bushels per tonne} = 14,016.1659 \text{ tonnes}$$

With a tonne value, I could convert to virtual water. Unlike animal products, Mekonnen and Hoekstra's (2011) data differentiates virtual water footprints of crops not only by

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<sup>11</sup> The conversion worked as follows:  $515,010 * 42.1 = 21,681,921$  Acres \* bushels per acre = bushels

country, but also by province. This allowed for more accurate virtual water footprint values but also meant more complex calculations for unit conversions.

The equation for conversion of crops varied by province:

Tonnes of crop  $\times$  sum of that crop's blue and grey virtual water footprints for the agricultural region's province = virtual water footprint for that crop in that agricultural region in cubic meters

Converting this value to cubic kilometers adds one extra step:

Virtual water footprint for that crop in that agricultural region in cubic meters  $\times 10^{-9}$  = virtual water footprint for that crop in that agricultural region in cubic km

Because of this provincial variation, I employed the use of an if/else statement in python when calculating these values using ArcMap's field calculator. To continue with the wheat example:

14,016.1659 tonnes  $\times$  175.897959096223 cubic meters per tonne =

2,465,414.976164076 cubic meters

2465414.976164076 cubic meters  $\times 10^{-9}$  = 0.00246541498 cubic km

Once I had calculated all of the virtual water footprints for all nine of the agricultural products for which I was accounting, I found the sum of all these virtual water footprints. At this point, each agricultural region having a virtual water demand value, I used a select by location to select all agricultural regions with at least half of their area located within the Saskatchewan River basin. I exported these regions as a new layer and used ArcMap's statistics tool to find the sum of water demand from all of these regions.

## Calculating Municipal Water Demands

Calculating municipal water demands was much simpler than calculating that of agriculture. It only required two pieces of data: population and per capita water use for municipalities' corresponding population (municipalities with greater populations tend to have lower per capita water use). The process was as follows:

- Determine the populations of each municipality
- Multiply those populations by their corresponding per capita water use

I used a shapefile of Canada's cities and towns and multiplied the population values from the Canadian census by Environment Canada's data on per capita water use. This required an if/else statement similar to that in calculating crop footprints to allow for one field calculation to calculate for municipalities of varying populations. The formula looked like this:

$$\text{Population of municipality} \times \text{Per capita water footprint for corresponding population} = \text{Municipal water footprint for that city}$$

For Edmonton, Alberta, the calculation worked like this:

$$730,375 \text{ people} \times 140.62 \text{ cubic meters per year per person} = 102,705,332.5$$

Converted to cubic kilometers, this comes to:

$$102,705,332.5 \times 10^{-9} = 0.102705332 \text{ cubic km}$$

In Python, the code looked as follows:

```
def find_water_use(population):
    population = int(population)
    pop_for_math = population*365.25*0.001*0.000000001
    if population <= 1000:
        return pop_for_math*756
    elif population > 1000 and population <= 2000:
        return pop_for_math*528
    elif population > 2000 and population <= 5000:
        return pop_for_math*712
    elif population > 5000 and population <= 50000:
```

```
    return pop_for_math*570
elif population > 50000 and population <= 500000:
    return pop_for_math*489
else:
    return pop_for_math*497
```

```
find_water_use( !CSD_POP01! )
```

Both of these municipal and agricultural values were mapped using point symbols (preferable over choropleth for showing totals) that this investigation refers to as ‘bubbles.’ Agricultural information was in polygon format, meaning that it covered an area, while municipal information was represented by points, locating each municipality at a particular x,y coordinate on the map. This method, which employed discrete, vector data on population, risked overlooking rural, non-agricultural water users. Since these values are very low, however, they do not constitute very much of the region’s water use and may even be negligible.

## Findings

Animal agriculture tends to have the greatest virtual water footprint, especially when green water is included. The exception to this is poultry, which is more efficient in terms of virtual water than canola and wheat -- a biological anomaly because species higher on the food chain generally require more water. For a chicken, this means the water for the chicken as well as the water to grow the food that the chicken eats. This abnormality is largely attributable to the industrialization of poultry farms. According to the popular documentary, *Food Inc.* (2009), a chicken now grows twice the size in half the time compared to a counterpart in 1950. Farmers have reached such efficiency with the help of selective breeding as well as growth hormones. While a tonne of poultry in Canada takes 1777 cubic meters of water to produce, in Russia, which bans many of the growth hormones used in North America, the same amount of chicken takes 5052 cubic meters (Mekonnen and Hoekstra, 2011). Figure 10 shows the virtual water footprints of all nine of the agricultural products I examined in this research.

## Highest Water Usage

*in m<sup>3</sup> per tonne*

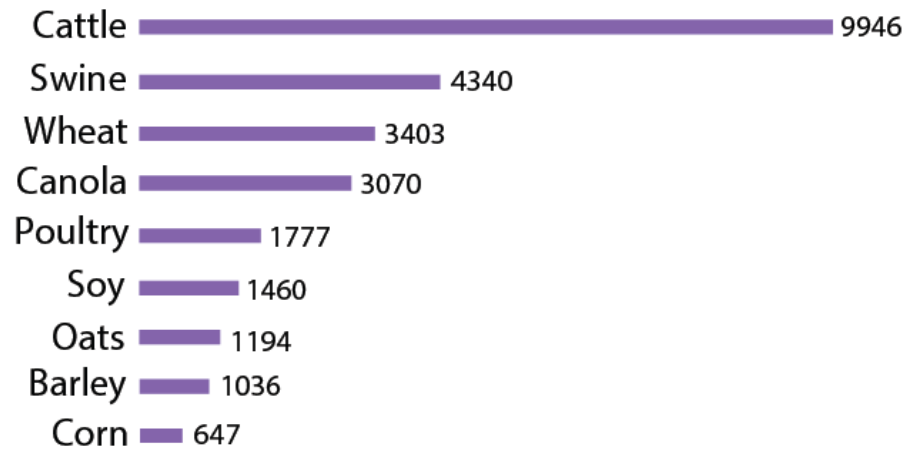


Figure 10: Graph of Virtual Water Footprints for the Nine Investigated Products for Canada

Source: Graphic by Author, data from Mekonnen and Hoekstra (2011)

The agricultural regions that consume the most water tend to be large wheat and canola producers. Notably, Alberta Agricultural Region 2, whose virtual water footprint from agriculture is about 1.04 km<sup>3</sup>. These two crops alone account for more than 63 percent of the agricultural water used in the region. Barley and corn also play a large role in demanding water in this region, at 13 and 10 percent of demand, respectively. For the province as a whole, the biggest water guzzlers are wheat (37%), canola (26%), barley (13%), and beef (12%). Saskatchewan's agricultural demands don't appear as large, mostly because the regions' represent smaller areas. Wheat and canola represent the most water-demanding crops in Saskatchewan as well, together representing more than 77 percent of Saskatchewan's total agricultural virtual water footprint. In Manitoba, the largest consumers of water are canola (28%), wheat (26%) and pork (16%). The fact that, despite their massive virtual water footprints, animal products have not appeared as any of the biggest water consumers in any of these provinces is



evidence that the footprints of animal products can more easily be spatially distributed, since the grain used as feed can be grown elsewhere -- largely in southern Ontario and Quebec as well as the corn belt in the US. Under the changes in tariffs with the EU under CETA, economists estimate a doubling in the size of the canola industry (largely powered by agrifuel demands in Europe) and additional growth of the wheat sector, as tariffs on the two products are eliminated over a seven-year period (Johnson, 2013). Unlike animal agriculture, crops are harder to move north because of their dependence on insolation, making room for new research to investigate: Where should this new agriculture go if it can't go north?

The presence of more than 964 thousand acres of wheat and over a million acres of canola in Alberta Agricultural Region 7 (one of the northernmost agricultural regions in Alberta) suggests that these two products grow well in the cold north. If the environmental impacts are minimal, then it would be possible to move many of these thirsty crops north to depend on the Peace or even Mackenzie River, alleviating the stress placed on the Saskatchewan River in southern Alberta. This move should not be done hastily, however, since spatial expansion of agriculture in the north would require deforestation -- something that was not required in the dry plains of the southern prairies.

Agriculture uses significantly more water than municipalities. When classifying data proportionally, even the largest municipalities in the region had water footprints lower than most agricultural regions. Non-metropolitan towns appeared as specs on the map (see Figure 11). This prompted the use of natural breaks classification for the data, distorting proportional sizing but making that the final geovisualization more human-

readable. According to a report by Environment Canada (2011) on municipal water use, Calgary, the most populous prairie city used between 0.15 and 0.20 km<sup>3</sup> of water in 2011 (returning almost all of this as treated effluent). Comparatively, Alberta Agricultural Region 3, a median region in regards to water use, used 0.47 km<sup>3</sup> of water in the same year -- more than twice as much as the region's most populous city (Statistics Canada, 2011). Of the prairie's 40 agricultural provinces, only eight used less water (from these nine products) than the municipality of Calgary.<sup>12</sup> Additionally, six of these regions are located in Manitoba -- the least agricultural of the Prairie Provinces. Figure 11 illustrates these spatial variations in water balances.

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<sup>12</sup> Depending on whether or not the 0.15 or 0.20 km<sup>3</sup> number is used, this number could increase to nine agricultural regions, because Saskatchewan Agricultural Region 4B's agricultural water footprint was 0.18 km<sup>3</sup>.

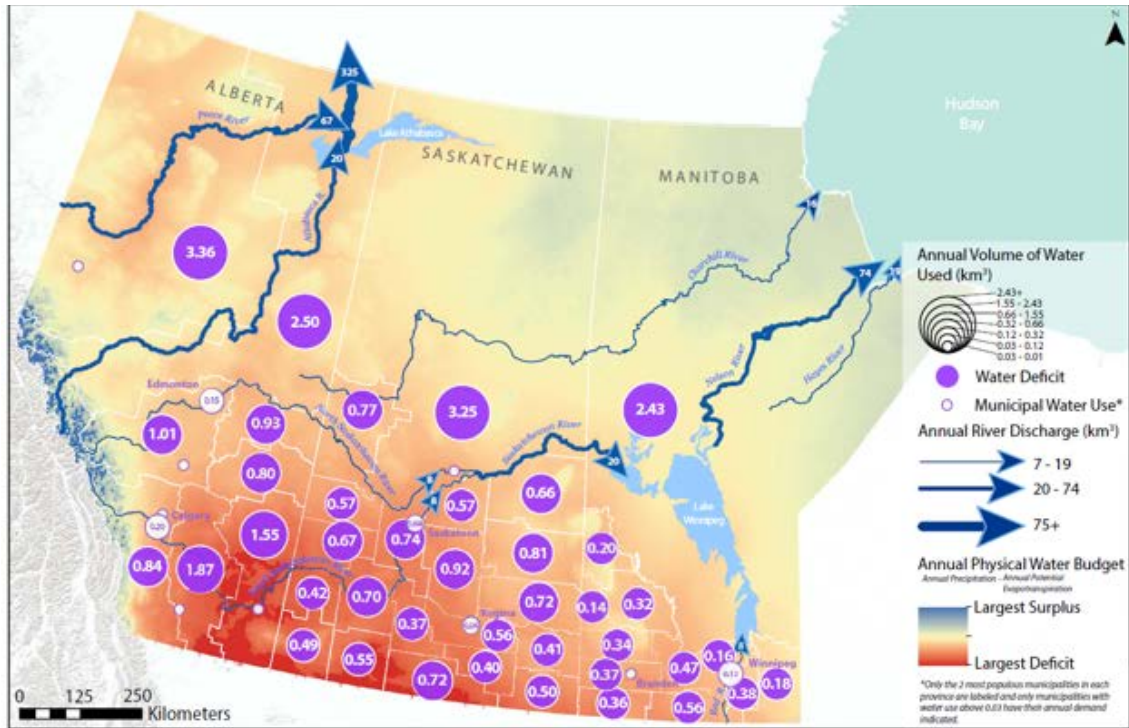


Figure 11: Water Deficits by Agricultural Census Region

Sources: Graphic by Author, data from CIGAR CSI (2008); worldgrids.org & Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. (2005); Mekonnen & Hoekstra (2011); Statistics Canada, (2011, 2012); Environment Canada, (2009); Alberta Agricultural and Rural Development, Global Runoff Database Center (2007); ESRI, USGS, NOAA, (2014).

Alberta's heavy reliance on irrigation is reflected in the green and blue water footprints of the province's crops. Lower precipitation and greater evapotranspiration reduce the amount of green water available, motivating this reliance on irrigation, which increases blue water demands. As an example, one tonne of corn grown in Alberta requires 314 m<sup>3</sup> of green water, 316 m<sup>3</sup> of blue water, and 143 m<sup>3</sup> of grey water. The breakdown for the same amount of corn from Manitoba is 563 green, 4 blue, and 171 grey. This comparison is visualized in Figures 12.

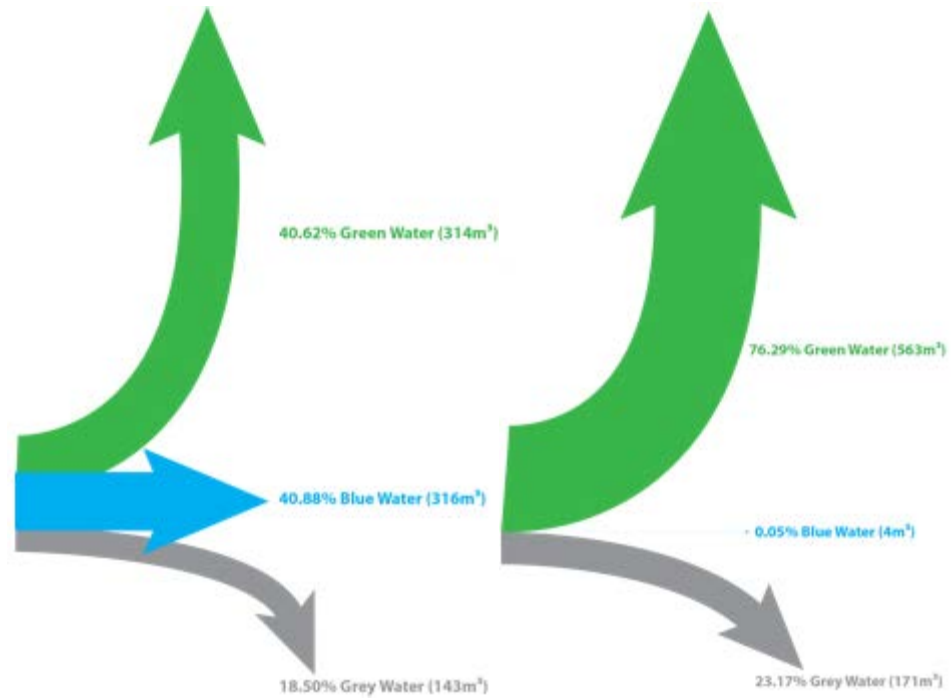


Figure 12: Comparison of Alberta and Manitoba Corn Virtual Water Footprint Breakdowns

Alberta corn is on the left. Manitoba corn is on the right. Both breakdowns represent one tonne of corn. Source: Graphic by Author, data from Mekonnen and Hoekstra (2011).

The Saskatchewan and Assiniboine River Basins are the most at risk of falling into water deficits. The agricultural water demands in the Assiniboine river basin exceed the river's annual flow, while the agricultural water demands in the Saskatchewan and Assiniboine river basins ( $8.66 \text{ km}^3$ ) reach about half of the Saskatchewan's annual flow ( $19.94 \text{ km}^3$ , or  $21.36 \text{ km}^3$  for both the Saskatchewan and Assiniboine). When using the UN's SEEAW, the water deficits by agricultural region become even larger. In the Saskatchewan and Assiniboine river basins together, the total deficit (without factoring in inflow from these rivers) is  $16.97 \text{ km}^3$ . Agricultural regions with large spatial areas have much larger deficits than the smaller, southern ones, as the natural deficits between precipitation and potential evapotranspiration

inflates the SEEAW differences. These SEEAW differences are depicted in the previous map.

These SEEAW measurements exempt the inflow/outflow from their totals. Instead, a value with this data was calculated for the entire Saskatchewan and Assiniboine river basins. The total value for both basins is 16.97 km<sup>3</sup>, meaning that the annual flow of the Saskatchewan of about 19.94 km<sup>3</sup> leaves little room for agricultural expansion in the region. This finding is especially problematic because of Schindler (2006) and Gan's (2000) analyses. Their research shows that while climate change will cause precipitation to become more infrequent (but more intense when it does occur). Schindler also shows that the discharge of the Saskatchewan River has been falling since 1910 -- and that it continues on a downward trend. These findings mean that the increased demands for water from agricultural products will have to compete for a shrinking supply of water, if they are located in this region.

Because of the large demands placed on the surface water supplies in this region, municipalities and farmers have also utilized groundwater. Groundwater, like lakes, constitutes a non-renewable resource.<sup>13</sup> In a 1988 report by the Science Council of Canada (page 12), the authors stated that "nearly all the water used" for livestock production comes from groundwater. Environment Canada echoed this point in 2013, indicating that little has changed, except that more animal agriculture relies on the resource than before. Environment Canada adds that many surface waters are too contaminated to be legally used for washing and irrigating crops, causing crop farmers to increasingly turn to groundwater. Many municipalities also utilize groundwater.

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<sup>13</sup> While it is arguable that groundwater is renewable because it is recharged, this recharge rate is much slower than that of surface water.

About 42 percent of Saskatchewanians rely on groundwater for domestic use. Municipal water use is usually of little consequence, since 97.8 percent of it is returned to waterways. However, when the municipal supply comes from groundwater, it presents another issue. These withdrawals are not returned to the ground. Instead, municipalities discharge them into surface waterways, meaning that almost 100 percent of withdrawn groundwater is lost from the aquifer.

Researchers have also warned that prairie groundwater is at an increasing risk of contamination. Oil, gas, and mining operations as well as pesticides, fertilizers, and animal waste have already begun to leach downward into groundwater (Science Council of Canada, 1988). According to the UN Food and Agriculture Organization (2012) and Alberta Agriculture and Rural Development (2005), for the province of Alberta, the areas most at risk of groundwater contamination are occupied by the greatest density of cattle rearing.

### **International Trade and Global Economic Integration**

Integration with the global economy via trade agreements has provided for the growth of Canada's virtual water footprint. Because of Canada's small population (less people live in Canada than in the entire state of California), most demand for agricultural products comes from outside of the country. As figure 13 shows, just looking at pork and beef exports -- the country's two most water-intensive agricultural products -- shows an increase in production following the approval of NAFTA.<sup>14</sup>

Much the same way that NAFTA boosted Canada's agricultural exports in 1994, newly proposed and approved trade agreements will have the same effect. The Canada-

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<sup>14</sup> Beef and pork are the biggest water users when their feed crops are included in their virtual water footprints. When these are not included, wheat and canola outpace them as the biggest water users.

EU Comprehensive Economic and Trade Agreement (CETA) will increase Canada's pork quotas for export to the EU from 6,000 to 75,000 tonnes and its beef quota from 15,000 to 65,000 tonnes (CBC, 2013). Other agreements like the Transpacific Partnership (not yet approved) and the Canada-South Korea Free Trade Agreement have no quotas, and allow Canadian water-intensive products to be exported to other member countries much the same way they are to the US and Mexico under NAFTA.

### Annual Canadian Cattle and Hog Production

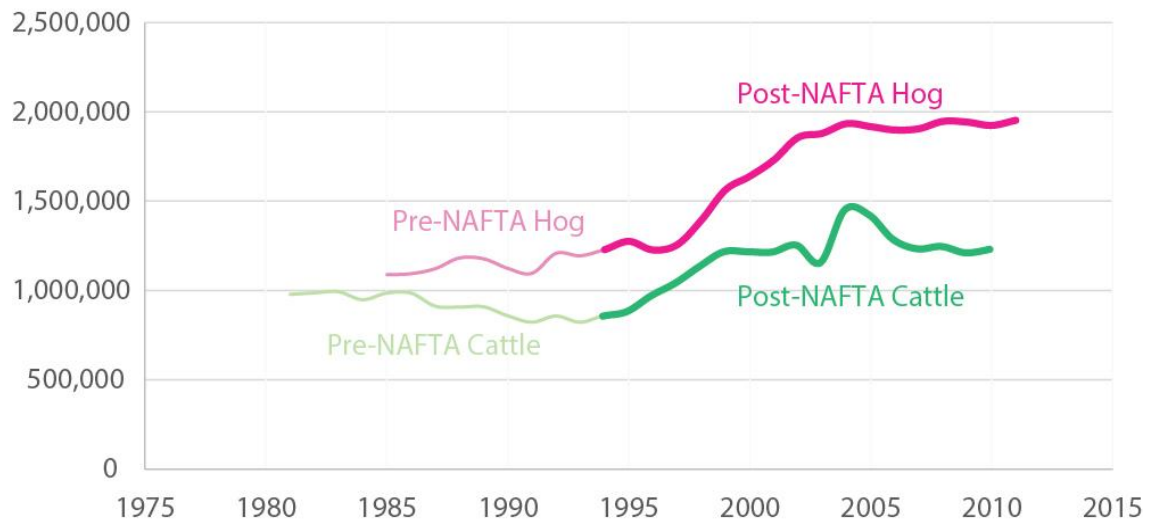


Figure 13: Annual Canadian Cattle and Hog Production in metric tonnes per year  
 Source: Graphic by Author, data from Statistics Canada, (2011, 2012).

Placement of the growing agricultural demand within the Saskatchewan or Assiniboine river basins, especially in Alberta, would risk putting Alberta's use of water from the Saskatchewan River above the 50 percent of annual flow it is permitted under the Master Agreement on Apportionment.

Manitoba is at the least risk of exceeding its water budget, because it is almost entirely outside of the Saskatchewan river basin while also benefiting from lower agricultural demands (due to less agricultural products being produced there).

## **Limitations**

The most obvious limitation to using virtual water is its somewhat narrow focus on water *quantity*. It does not consider *quality*. While the addition of grey water to the discourse on virtual water slightly ameliorates this problem, this category only focuses on water used to dilute pollution -- not bodies of water that are rendered unusable because of pollution. Schedule 2 of the Canadian Fisheries Act establishes “tailings impoundment areas” which regulations define as water bodies that “the owner or operator of a mine may deposit or permit the deposit of waste rock or an effluent that contains any concentration of a deleterious substance and that is of any pH” (Fisheries Act, 2002). Especially astounding about this waste disposal policy is the fact that Canada is the world’s second biggest uranium producer, meaning that much of this toxic waste is radioactive (Trade Tech, 2014). Most of these “tailings impoundment areas,” however, are in the Canadian north. In the southern prairies, pesticide and fertilizer runoff is affecting water bodies like lakes and wetlands (Donald, 1999). Recently, researchers have found that toxic compounds from the tar sands are leaching into the nearby Athabasca River (Kelly, Schindler, Hodson, Short, Radmanovich & Nielsen, 2010). Such matters of water *quality*, despite their effects on the availability of clean water, are not documented in virtual water accounting.

Another limit to this analysis is the reliance on potential evapotranspiration (PET) instead of actual evapotranspiration. The decision to use PET was motivated by data availability. However, the weakness of this data is that water only evaporates from land surfaces or transpires from plants if it is there in the first place. Since the surface



of the prairies is not always covered with water, it is safe to assume that actual evapotranspiration would be lower.

This research also uses annual data, rather than seasonal information. Most of this agriculture occurs in the spring, when the amount of water that enters the region is greater. Precipitation is usually higher in this season, meaning that the balance between precipitation and PET is more favorable for crops. This season also marks the time of snowmelt; large amounts of water become available after the winter and water runs down from the Rocky Mountains in greater-than-average quantities. A more extensive analysis of prairie water balances, then, would take a seasonal approach, rather than an annual one.

Finally, using only nine agricultural products was a major limitation in this analysis. While inclusion of all products in the Canadian agricultural census may have been unnecessary, many products with large virtual water footprints such as rye and flaxseed which are also largely produced in the prairies were excluded from this analysis. Inclusion of these products would improve the analysis by giving more and better data on the virtual water footprints of each agricultural region.

## Conclusion and Recommendations

Overall, these findings show that within the prairies, agriculture is the largest user of water. My analysis has determined that the Saskatchewan and Assiniboine river basins are most at risk of falling into water deficits, especially if agricultural expansion from trade combines with increased precipitation variability from climate change. This agricultural analysis shows that anthropogenic actions contribute to the water quantity circumstance in the prairies. Such findings expand on the more physical approach that has been used to analyze the region's water predicament.

As mentioned earlier, I structured my research around the following questions. A brief summary of my findings for each question follows:

1. How much water is consumed through agriculture and which specific products represent the largest virtual water demand?
2. How is this demand spatially distributed?
3. And how does this demand compare with the quantity of water available in nearby renewable sources?

Prairie agriculture consumes about  $8.66 \text{ km}^3$  of water per year. Beef, pork, wheat and canola represent the largest virtual water demands. The largest consumers of water are located in south-central Saskatchewan and the southern half of Alberta. These locations present a problem for the Saskatchewan and Assiniboine river basins, whose combined annual flows are about  $21.36 \text{ km}^3$ . Potential evapotranspiration amounts to about  $8.31 \text{ km}^3$  in the region, leaving about  $13.05 \text{ km}^3$  of water in the SEEAW balance. Subtracting the agricultural demands in this region from this total leaves  $4.39 \text{ km}^3$  as the water surplus. Because the spatial distribution of agricultural demands places stress on

the nearby waterways, I explain in the *Policy Implications* section of this thesis how government regulations and incentives can ameliorate this stress.

As it relates to advancements in geography, these research and findings offer a spatial means of accounting for water consumption by looking at products and their geographies. Much of the accounting that currently takes place is done under the Master Agreement on Apportionment, which looks more closely at water quantity than quality. To do these measurements, water stations look at discharge at different locations along the rivers, observing increases or decreases in flow as humans and evaporation withdraw from the rivers. Because a certain amount of grey water must be devoted to pollution dilution, this quantity-based approach limits the ability of the Prairie Provinces Water Board to enforce its requirement that 50 percent of the Saskatchewan river's flow reach the province of Saskatchewan; some of that flow may be devoted to allowing water to flow into Lake Winnipeg at low enough pollution concentrations.<sup>15</sup> While others have contributed to virtual water accounting, use of GIS to map virtual water demands and compare them to actual water supply shows which products in which places are the biggest consumers of water. These findings, subsequently, can contribute to policy -- potentially catalyzing the reorganization of water-intensive crops into more water-rich regions.

These findings also inform the virtual water literature by providing a methodological framework for pinpointing water demand by particular commodities. Mekonnen and Hoekstra (2011) have created raster grids based on a combination of the

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<sup>15</sup> To clarify the purpose of grey water: Some of the water used for grey water may return to the river and be reusable downstream. However, if too much water is withdrawn, it could (and in many cases already does) have a negative impact on wildlife and downstream ecosystems, while also being too polluted to be suitable for human use.

FAO's estimated locations of cropland as well as Monfreda et al's (2008) analysis of the 2000 Global Land Cover Project. Monfreda et al analyzed this global land cover to find both where agriculture was located as well as how much crop agriculture was located within each raster cell. Mekonnen and Hoekstra subsequently used this data with their estimations of crop virtual water footprints, trifurcated into green, blue and grey. Their research resulted in maps for each footprint based on the 2000 data. By contrast, this research relied on the 2011 Canadian agricultural census, which offers more recent and spatially-specific data, while also accounting for agriculture that is more difficult to observe via remote sensing (which the Global Land Cover Project employed). Such land use-based distribution of virtual water footprints has difficulty locating sites where agriculture may be abnormally concentrated, such as concentrated animal feeding operations. It cannot easily differentiate between agricultural land use, so slaughterhouses and grazing land could not be easily distinguished, despite their different concentrations of agricultural production and virtual water demand. Reliance on census data allowed me to overcome this challenge, since I was not reliant on land cover but rather on surveys on the actual number of each agricultural product produced.

Visualizing this data within agricultural regions rather than raster cells provided for greater accuracy because the virtual water footprints were mapped by geographic subdivisions within which animal populations and crop productions were surveyed (via the Canadian Census). While distributions are estimated as accurately as possible with rasters, the ability to use this datatype to display the spatial organization of virtual water demands is limited by the fact that Statistics Canada does not collect data at such a scale. Mapping virtual water demands by agricultural region eliminated the need to

interpolate data via estimations. Since population and production data for agricultural products was already gathered, there was no need to estimate values at various spatial locations (as would have been necessary with a raster dataset).

In terms of water's cultural relevance to Canada, the large amount of water lost in virtual form reveals a national dissonance: while Canadians are protective of their water, they do not pay attention to the amount embedded or lost in commodities -- especially agricultural products. Water richness is one of Canada's comparative advantages in the global economy. However, as this research shows, water is being consumed in a spatially disjunct manner: the thirstiest products are being produced in the driest parts of the country. To maximize on this advantage, water should be conserved where it is in lower supply.

### **Policy Implications**

Northern Rivers such as the Athabasca and Peace Rivers have large surpluses and could serve as relocation sites for the agriculture that is currently in southern Alberta. Of the potential solutions I present in this section, most politically palatable for the ruling Conservative Party of Canada would be incentivizing the movement of this agriculture northward into the Athabasca, Peace, and McKenzie River Basins. Part of the recent conversations about beef and pork to be exported under the new Canada-EU CETA have dealt with how Canada will begin producing larger amounts of hormone-free meats, since the EU prohibits use of growth hormones. Because these animals will not grow as fast without use of these hormones, their virtual water footprints will be greater -- making them better suited for the Canadian north, where renewable water is more plentiful.

Additionally, more division of the northern agricultural regions would assist in data analysis. For example, most of the agriculture in Alberta Agricultural Regions 6 and 7 is along the southern Athabasca and central Peace rivers, respectively. Saskatchewan Agricultural Region 9A is the about the same size as all of the province's other agricultural regions combined. And Manitoba Agriculture Region 12 takes up almost all of the province's surface area and includes all four of the province's largest rivers. Breaking apart these regions would assist in locating agriculture as well as comparing Canadian Agricultural Census data with inflows and outflows from rivers.

For policies, these Agricultural Regions could serve as tools to incentivize movement of farms northward. Environment Canada, as well as provincial environmental agencies like Alberta Environment, could offer incentives (tax benefits, grants, etc) to farmers that relocate away from the Saskatchewan and Assiniboine river basins. If demands on water begin to exceed renewable supply and force industries to begin drawing from nonrenewable sources (like groundwater or lakes), new regulations should be implemented to cap the amount of water that can be used within designated spatial areas. Virtual water accounting methods used in this research to convert agricultural products to virtual water footprints could be used to find these caps and translate them into limits on agricultural production -- a measurement with which farmers could more easily comply.

However, this movement northward would require more fuel for transport, as well as more infrastructure (roads, railways, bridges, etc) to move products south to the more urban export and processing centers. Because of the flat topography of the southern prairies as well as their lack of forested area makes them more suitable for

agriculture than the cold and more densely vegetated north. For this reason, I recommend more comprehensive policy changes to prevent demand for water in the Saskatchewan and Assiniboine river basins from outstripping supply.

The first of these regulations is a realignment of the national government's focus on international trade. While Canadians may benefit from a diversified trade portfolio (the US currently represents a large portion of Canada's trade), this diversification should not come at the expense of Canada's natural environment. Attempts to broaden this trade should focus on products that have smaller or positive environmental impacts and virtual water footprints, and on commodities that are produced in less hydrologically sensitive areas. A *Wall Street Journal* (Menon, 2013) article quoted an economist saying that the Canada-EU deal was "basically cheese for beef" – referring to the fact that it would increase Canada's beef production (largely in Alberta and the rest of the prairies) at the expense of its dairy farmers (largely in southern Ontario and Quebec). This geographic shift westward means moving water demands away from the St. Lawrence (with an annual flow of 318 km<sup>3</sup>) and potentially into the Saskatchewan or Assiniboine River Basins (21.36 km<sup>3</sup>) (Environment Canada, 2013).

The federal government of Canada could also ameliorate this hydrologic situation by shifting its focus away from eliminating or increasing quotas on agricultural products like beef, pork, canola, and wheat. These products, of the nine researched, have the greatest virtual water footprints. Increasing market-based incentives to produce crops with lower virtual water footprints (corn, soy, etc) by increasing their export quotas could shift production away from crops with greater

virtual water footprints. Additionally, while agricultural consumes almost 75 percent of its water withdrawals, other industries return a greater percentage. Focusing on growing exports from other, more sustainable sectors, such as clean energy, could reduce the country's annual virtual water losses.

To conserve groundwater, I recommend employing conjunctive management as well as stricter and enforceable water quality standards for surface waters. Conjunctive management entails managing surface and groundwater more jointly and employing such practices as turning to groundwater during droughts and reinserting surface water into aquifers to replenish withdrawn supplies (Blomquist et al, 2001). This type of management would reduce the risk of overdrawing groundwater and would shift use of water towards surface waters when supply is greater. In order to make this transition, though, surface waters must be clean enough so that they can be used safely to water and clean crops. As stated earlier, surface waters (especially those further east from the Rocky Mountains) are too contaminated to be used for this purpose (Environment Canada, 2013). As a result, stricter water quality standards and enforcement mechanisms would make such conjunctive management easier to implement (because more water users could rely on surface waters rather than groundwater).

New policies will become necessary to conserve water in the Saskatchewan and Assiniboine River basins. Without such rules, political disputes around the Master Agreement on Apportionment (MAA) will arise. Environment Alberta (2003, page 4) warns that the sum of allocated water plus the water demanded from anticipated growth plus water needed to support the aquatic environment is “more water than is available.” If farmers use all the water to which they are entitled, the federal government may step



in to protect wildlife. And if water levels drop further, the province of Saskatchewan could challenge Alberta at the Prairie Provinces Water Board for consuming more than its fair share. These existing agreements and regulations, then, require that both the Canadian federal government as well as provincial governments enact binding rules to conserve water, and ensure its availability for Canadians and wildlife that need it, regardless of geography.

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