

Impacts to Great Lakes agriculture and water use under changing climate conditions

Phase 1 summary report coinciding with the data dashboard presented at:
www.glc.org/work/agriculture

Table of Contents

| | |
|---|----|
| Table of Contents..... | 1 |
| Acknowledgments..... | 3 |
| Executive Summary..... | 3 |
| Overview..... | 4 |
| Growing the understanding of agriculture in the Great Lakes basin and region..... | 4 |
| Current Conditions..... | 5 |
| Agricultural land use across the region..... | 5 |
| Major commodities in the Great Lakes states and provinces..... | 6 |
| Agricultural land use within the basin..... | 7 |
| Agricultural water use..... | 7 |
| Future Conditions..... | 7 |
| Growing Degree Days..... | 7 |
| Plant Hardiness Zones..... | 9 |
| Drought Severity..... | 11 |
| State and Provincial Summaries..... | 13 |
| Illinois..... | 13 |
| Indiana..... | 13 |
| Michigan..... | 14 |
| Minnesota..... | 15 |
| New York..... | 15 |
| Ohio..... | 17 |
| Pennsylvania..... | 17 |
| Wisconsin..... | 18 |
| Ontario..... | 18 |
| Québec..... | 19 |
| Appendix..... | 20 |

Acknowledgments

The Great Lakes Commission (GLC) thanks its many partners, including colleagues in state and provincial agencies and state climatologists for their direction on the scope of this Phase 1 effort, and their expert feedback as data was added to the dashboard. The GLC also thanks The Joyce Foundation for its continued support of the Great Lakes and this work.

Executive Summary

The Great Lakes Commission (GLC) has long recognized the importance of agriculture for its party jurisdictions¹, with agriculture specifically referenced in the [Great Lakes Basin Compact](#) which formed the GLC in 1955.² A 1996 GLC effort produced an extensive *Agricultural Profile of the Great Lakes Basin: Characteristics and Trends in Production, Land-Use, and Environmental Impacts*.

Since 2023, when a new [strategic plan](#) was adopted, Great Lakes Commissioners have considered how changing climate conditions will affect the region’s agricultural production and water use. At the GLC’s 2024 Semiannual Meeting, a policy resolution was adopted on [Understanding Impacts to Great Lakes Agriculture and Water Use Under Changing Climate Conditions](#).

With support from The Joyce Foundation, the GLC has worked with experts from around the Great Lakes region to build a “coordinated scientific, technical, and economic understanding of current or baseline conditions for agricultural production in the Great Lakes basin,” as called for in the 2024 resolution, in an interactive data dashboard.³ Initial findings indicate that by both acreage and market value, corn and soybeans are the primary products raised in the region. However, when looking solely at market value the regional and national importance of livestock agriculture and specialty crops become increasingly apparent.

In conversations with climate experts it was noted that the region is one of the most diverse globally for the sheer number of products grown. This is especially true for specialty crops⁴. The dashboard’s commodity tab enables users to explore the 89 unique products grown in the region, including field grown crops, crops grown under protection in greenhouses or hoopouses, livestock, poultry, and even bees. Experts also shared unique aspects of their respective jurisdictions’ agricultural products, including:

- Northeast Indiana is a leading supplier of the ducks served at restaurants across the U.S.
- Michigan is famous for cherries, but is also a leading producer of Christmas trees.
- Pennsylvania grows a lot of grapes along the southern shore of Lake Erie.
- Ontario is leading the way in mushroom cultivation.
- Sugar beets are now mostly grown in Michigan and Minnesota.

¹ Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin with the provinces of Ontario and Québec.

² Article I: The purposes of this compact are, through means of joint or cooperative action . . . To advise in securing and maintaining a proper balance among industrial, commercial, *agricultural*, water supply, residential, recreational, and other legitimate uses of the water resources of the Basin. Great Lakes Basin Compact, 1955. Emphasis added.

³ Details on dashboard development and data management protocols are included within the Appendix.

⁴ Verbal discussion between GLC staff and state climatologists, August 14, 2025.

It is clear that many of these products are critical for the communities that produce them, but it is not clear what will happen as temperature and precipitation patterns change. Information presented within the dashboard's climate tab and discussions with climatologists indicate that conditions are projected to be steady through mid-century, except for localized impacts arising from severe weather. However, by the end of the century, models depict drought conditions.

This project's next phase of work, also supported by The Joyce Foundation, will strive to understand which of the region's crops require the most water and how patterns in irrigation may shift in the future. The GLC also intends to further analyze how Great Lakes basin jurisdictions perceive risks associated with agriculture production, especially those that are critical to community economies and identities.

Overview

Growing the understanding of agriculture in the Great Lakes basin

At its 2024 Semiannual Meeting, the Great Lakes Commission (GLC) adopted a policy resolution on [Understanding Impacts to Great Lakes Agriculture and Water Use Under Changing Climate Conditions](#). With support from The Joyce Foundation, the GLC is working with experts from around the Great Lakes region to answer key questions raised by the resolution, including:

- What are the current or baseline conditions for agricultural production within the Great Lakes basin?
- What might be grown in the future under changing climate conditions?
- What does the future hold for agricultural water use within the basin?

In the first phase of this project, the GLC has strived to answer the first question by representing current conditions in an interactive data dashboard.⁵ Information was also gathered to understand what is known about carbon storage on agricultural land and potential ramifications for flood and drought resilience. Finally, the GLC has developed resources exploring similarities and differences between Great Lakes jurisdictions, with respect to agriculture and management of groundwater resources. All materials are accessible at www.glc.org/work/agriculture.

⁵ Details on dashboard development and data management protocols are included within the Appendix.

Current conditions

Agricultural land use across the region

Agriculture is a significant industry and land use across the Great Lakes-St. Lawrence River region. This is particularly true in the Great Lakes region's westernmost states.

Amounts and types of agricultural land by state/province (millions of acres). Pie chart size corresponds to amount of agricultural land.

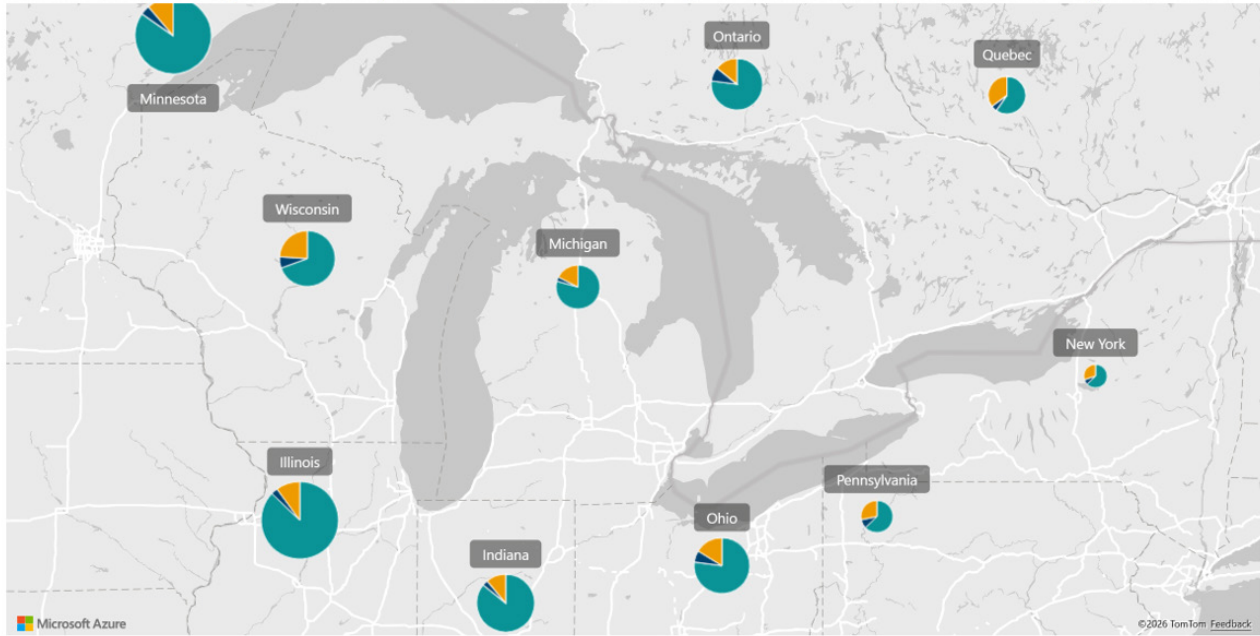


Figure 1. Amounts and types of agricultural land by state/province (millions of acres). Pie chart size corresponds to the amount of agricultural land within the entire state/province.

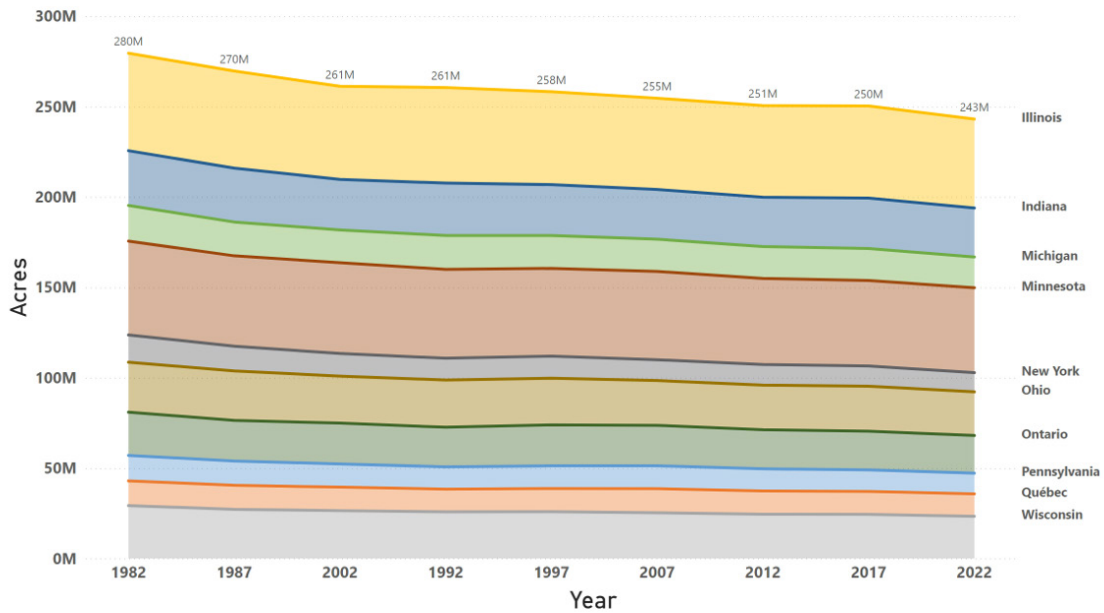
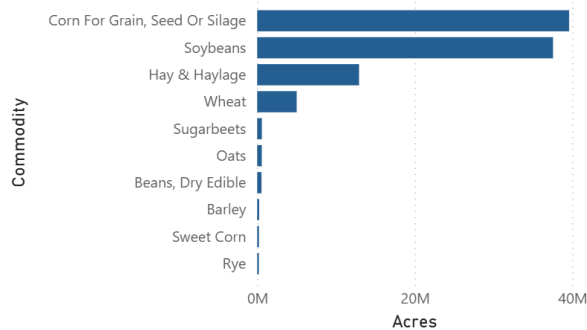


Figure 2. Agricultural land over time in the Great Lakes state and provinces.

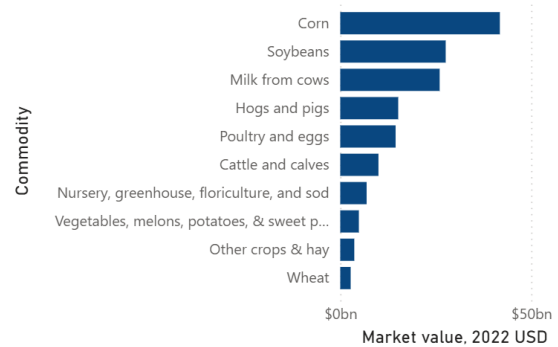
Major commodities in the Great Lakes states and provinces

The Great Lakes region is a major agricultural producer, with corn, soybeans, and wheat being the dominant crops. Other important commodities include dairy, fruit (e.g., apples, cherries, and blueberries), vegetables, potatoes, and sugar beets. The region also produces significant amounts of livestock beyond dairy production.

Top 10 Agricultural Crops by Acreage



Top 10 Agricultural Products by Market Value of Products Sold



Figures 3 and 4. Great Lakes region commodities by acreage and market value.

Agricultural land use within the basin

Approximately 26% of the land cover in the Great Lakes basin was classified as agriculture in 2021, ranging from 1% in the Lake Superior basin to 61% in the Lake Erie basin. The net change in agricultural land has been small in recent decades, with conversion of agricultural to developed land cover offset by conversion of natural to agricultural land. In the region overall, agricultural land area has decreased slowly from approximately 158 million acres in 1982 to 136 million acres today, a decline of 14% over the last 40 years. Data is not yet available to understand pressures on agricultural land arising from renewable energy production (e.g., solar and wind) or data center development.

Agricultural water use

A 2015 estimate of rainfed versus irrigated agriculture found that less than 4% of cropland in the Great Lakes basin is irrigated⁶. As was reported to the GLC's [Great Lakes Regional Water Use Database](#), approximately 700 million gallons of water were withdrawn from the Great Lakes basin per day for irrigation and livestock watering. The database does not provide a complete picture of agricultural water use in the basin; however, as the self-supply irrigation water use sector includes irrigation of recreational lands such as parks and golf courses in addition to irrigation assisting in the growing of crops or pastures. The livestock sector includes self-supplied water used by animals as well as water used in fish hatchery operations. During the next phase of this project, the GLC will work with its party jurisdictions to dig deeper into the existing data for a more precise picture of agricultural water use.

Future conditions

In the future, growing seasons are forecast to last longer while increased atmospheric carbon dioxide, changing temperature and precipitation regimes, more frequent and intense severe weather, and increased pests and pathogens are expected to have a mixture of effects on crop distributions and yields. For this first phase of work, the dashboard presents model results⁷ from the Northern Institute of Applied Climate Science (USDA Forest Service, Northern Research Station) that show how three metrics – growing degree days, plant hardiness zones, and cumulative drought severity – are projected to change. For each metric, 30-year projections are included under two scenarios representing “low” and “high” levels of climate change. The dashboard's county-level maps illustrate the range of possible futures and highlight areas that may see the greatest changes.

Growing Degree Days

Growing degree days (GDDs), also called heat units, are a way to measure how much heat plants receive over time. They're calculated by looking at how much the average daily temperature rises above a chosen baseline. For the data shared within the dashboard, the baseline is 5 °C (41 °F), since most plants grow

⁶ The Landsat-Derived Global Rainfed and Irrigated-Cropland Product 9LGRIP) maps the world's agricultural lands by dividing them into irrigated and rainfed croplands using Landsat 8 time-series satellite sensor data for the 2014-2017 period to create a nominal 2015 product.

⁷ Matthews, Stephen N.; Iverson, Louis R.; Peters, Matthew P.; Prasad, Anantha M. 2018. Assessing potential climate change pressures across the conterminous United States: mapping plant hardiness zones, heat zones, growing degree days, and cumulative drought severity throughout this century. RMPA-NRS-9. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 31 p. <https://doi.org/10.2737/NRS-RMAP-9>.

very little below that temperature. For example, if the average temperature on a given day is 21 °C (70 °F), that day contributes 16 growing degree days.

In general, more GDDs mean faster plant growth. But too much heat can cause crops to mature too quickly, experience stress, or become more vulnerable to pests – all of which can lower yields. Rising annual GDDs are expected to reduce yields for major U.S. crops such as corn, soybeans, sorghum, and wheat.⁸

Likely impacts on Great Lakes agriculture

Agricultural patterns

- Increased GDDs may push farmers to select more heat-tolerant or long-season varieties of existing crops.
- Crops that previously required more warmth, such as certain grape varieties and vegetable crops, may be able to expand northward. However, suitability for less heat-tolerant crops such as oats and spinach could decrease.
- Increased GDDs may also present opportunities to introduce new warm-season crops, although this depends on additional factors such as markets and soils.
- Overall, the region may see gradual diversification toward crops that benefit from longer, warmer growing seasons, but also increased heat-related stress.

Productivity

Field crops: A longer growing season can allow for earlier planting and, in some cases, the option to use longer-season varieties with the potential to produce higher yields under the right conditions. However, excess heat during sensitive stages (e.g., pollination for corn) can reduce yields. More rapid accumulation of GDDs can also cause crops to mature too quickly, shortening grain-filling periods and reducing productivity. Warmer conditions also increase the geographic range and pressure from certain pests such as the corn flea beetle and stink bugs, resulting in decreased yields.

- Dairy and forage crops: Longer warm seasons may allow additional cuttings of some forages. At the same time, higher summer temperatures can stress cool-season forages, reducing their quality. Heat stress also affects dairy cattle directly, lowering milk production.
- Specialty crops (e.g., apples, cherries, grapes): Many of these crops depend on stable spring temperatures. More heat can delay or disrupt flowering and increase frost vulnerability if plants break dormancy too early.

Water use

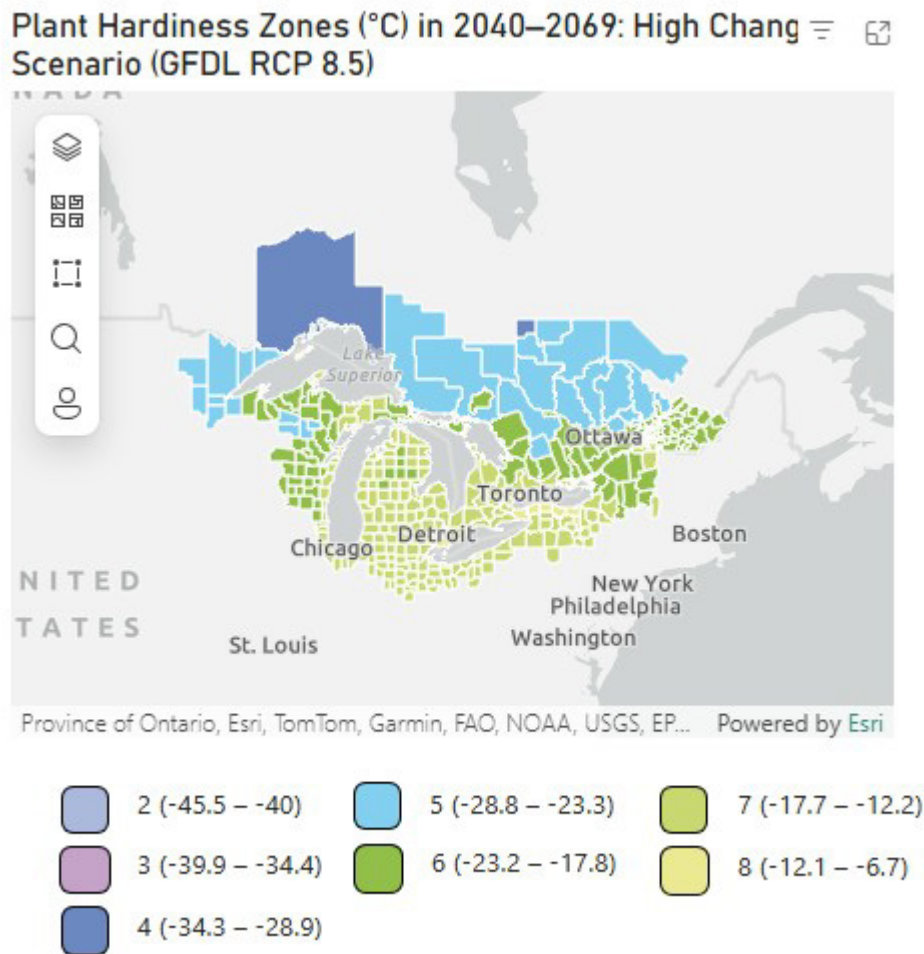
- Increasing GDDs generally mean warmer conditions, which increase crop water demand. Likely impacts include higher evapotranspiration rates (meaning crops lose more water and require more irrigation where it is available) and greater moisture stress during midsummer, especially during dry periods, potentially reducing yields without supplemental irrigation.

⁸ Kukul, M.S., & Irmak, S. (2018). U.S. agro-climate in 20th century: Growing degree days, first and last frost, growing season length, and impacts on crop yields. *Scientific Reports*, 8(1), 6977.

Plant Hardiness Zones

Plant hardiness zones (PHZs) are geographic areas defined by the lowest temperature reached each year. The zones modeled below are based on the 30-year average of annual minimum temperatures in 10 °F (5.56 °C) increments. Because each plant can only tolerate certain levels of winter cold, these zones provide a general guide to where certain crops or species can survive.

According to climate models, PHZs across the Great Lakes region are projected to shift substantially over this century. Minimum winter temperatures are expected to increase by an average of 3.5 °C in the low-change scenario and 11.5 °C in the high-change scenario by late century (2070-2099).⁹



⁹ Matthews, Stephen N.; Iverson, Louis R.; Peters, Matthew P.; Prasad, Anantha M. 2018. Assessing potential climate change pressures across the conterminous United States: mapping plant hardiness zones, heat zones, growing degree days, and cumulative drought severity throughout this century. RMPA-NRS-9. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 31 p. <https://doi.org/10.2737/NRS-RMAP-9>.

Likely impacts on Great Lakes agriculture

Shifting distributions for agricultural commodities

- As PHZs move northward, many parts of the Great Lakes region may become suitable for less cold-tolerant species. For example, 40 years ago much of Michigan fell within plant hardiness zones 4 and 5, and vineyards in the state were split roughly 50/50 between European *Vitis vinifera* grapes and more cold-hardy European-American hybrids.¹⁰ As more of Michigan has warmed into zone 6 (and viticultural practices have advanced), more Michigan vineyards have been able to shift from cold-hardy hybrids to prestige varieties like Riesling, Chardonnay, and Cabernet.
- However, the ability to adopt new crops will still depend on a wider range of climate risks. Increasing drought, heat waves, and damaging “false spring” events will continue to challenge perennial crops and may slow transitions to new species or varieties.¹¹
- While suitable areas will expand for some crops, chilling requirements for perennial crops such as cranberries, which grow in zones 2-7, will be increasingly difficult to satisfy. Because perennial species require long-term investment, such as specialized cranberry bogs that are costly to establish and cannot be easily moved, adaptation poses challenges. Growers cannot simply migrate northward or switch to more heat-tolerant crops without major financial losses.

Expansion of pests and pathogens

- Just as some crops migrate northward, certain pathogens, pests, and invasive species will also be able to expand northward into areas where they were previously thermally limited. For example, corn earworm – a highly damaging pest of corn, soybeans, tomatoes, and other crops – currently struggles to overwinter in much of the Great Lakes region. Less extreme winter temperatures are expected to increase pest survival and support a broader northward range.¹²

Changing crop insurance standards

- PHZs play a role in how both growers and insurers assess climate-related risk. In the U.S., USDA plant hardiness zones are used to establish certain standards for federally subsidized crop insurance. Geographic shifts in PHZs will likely impact which planting decisions are incentivized and disincentivized in each area by the crop insurance system.¹³ Crop insurance standards also guide research priorities and influence long-term agricultural investment.

¹⁰ <https://www.canr.msu.edu/news/the-evolution-of-michigan-viticulture-and-pruning-systems>

¹¹ McKenney, D.W.; Pedlar, J.H.; Lawrence, K.; DeBoer, K.; & MacDonald, H. (2025). Updated plant hardiness zones for Canada and assessment of change over time. *Scientific Reports*, 15(1), 22774.

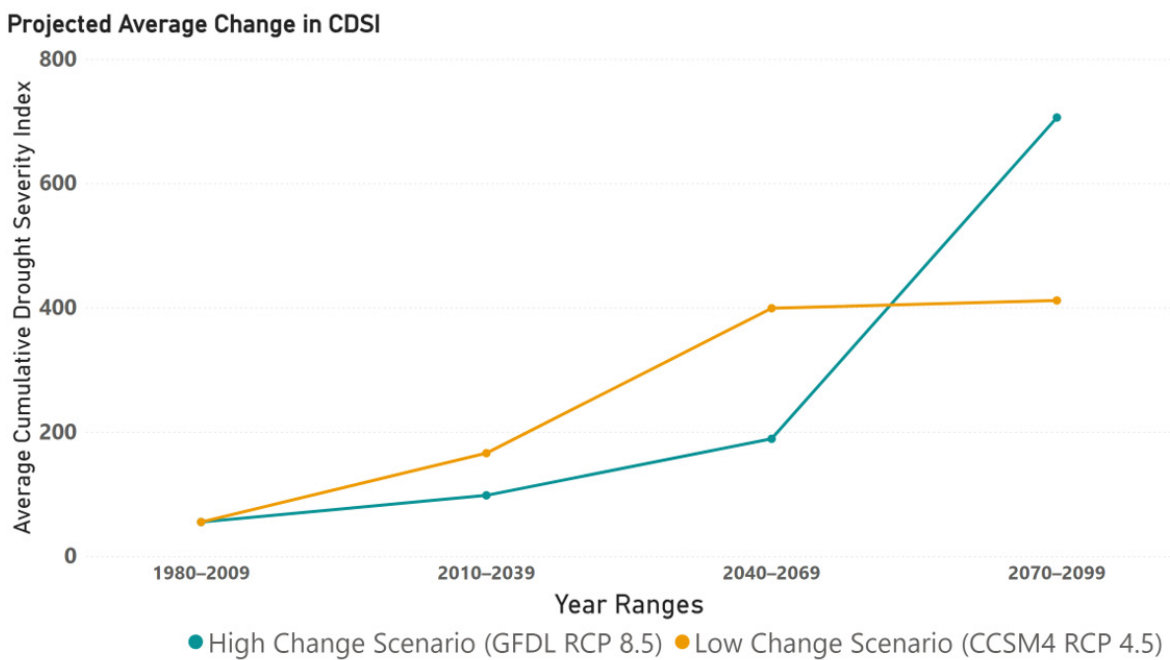
¹² Lawton, D.; Huseth, A.S.; Kennedy, G.G.; Morey, A.C.; Hutchinson, W.D.; Reising, D.D. & Zuefle, M. (2022). Pest population dynamics are related to a continental overwintering gradient. *Proceedings of the National Academy of Sciences*, 119(37), e2202230119.

¹³ Jaworski, A. (2016). Encouraging climate adaptation through reform of federal crop insurance subsidies. *NYUL Rev.*, 91, 1684.

Drought Severity

The frequency and intensity of droughts experienced in an area can be assessed by calculating a cumulative drought severity index (CDSI). The CDSI values shown below are derived from the occurrence and intensity of monthly drought events in the climate model data, where moderate, severe, and extreme drought conditions are weighted 1, 2, or 3x, respectively, and summed. The range of CDSI values for the 360 months in a 30-year period can therefore range from 0 (no months with any drought) to 1080 (every month has an extreme drought, with a weighted score of $12 \times 30 \times 3 + 1080$).

The Great Lakes region is projected to have more frequent or more intense droughts by the end of the century in both the low-change and high-change scenarios visualized within the dashboard.



Likely impacts on Great Lakes agriculture

Greater crop moisture stress and yield losses

- More severe or frequent droughts increase the likelihood that crops experience water shortages during key growth stages. Even short “flash droughts” can cause large losses when they coincide with sensitive crop periods.

- Corn and soybeans, the region's top two commodities by both area and market value, are especially sensitive during pollination and pod-filling; drought during these windows can sharply reduce yields.¹⁴
- Reduced soil moisture during drought periods can also increase soil temperature, causing heat stress to plants on top of moisture stress.¹⁵

Increased irrigation demand and expansion of irrigation in places where historically unneeded

- As the region's water use data shows, agriculture in the Great Lakes is primarily rain-fed. However, increasing drought severity will expand the need for supplemental irrigation where groundwater or surface water is available and incentivize farmers to invest in irrigation systems in areas where it has not traditionally been used.
- More severe droughts will also increase demand in other water use sectors such as municipal systems and industry, increasing competition for water. Notably, the hottest summer months when the use of agricultural irrigation is greatest are also when water demand peaks for data center cooling.¹⁶

Increased livestock heat stress and water needs

- Drought and associated heat events lead to reduced milk production in dairy cattle and increased water needs for cooling and animal hydration.¹⁷ While livestock operations use less water than crop irrigation, that water is needed year-round rather than only during peak summer months. Also, the consolidation of dairy farms is likely to continue, centralizing water use and potentially creating water demand hotspots.¹⁸

Impact on perennial systems

- Fruit trees, vineyards, and perennial crops are especially sensitive to prolonged moisture deficits because their root systems must sustain multiple years of productivity.¹⁹
- Likely effects of increased drought on these systems include smaller fruit size, reduced quality, increased drop (abscission); greater need for irrigation infrastructure (e.g., drip systems, water storage); and long-term tree or vine stress that can reduce yields for multiple years.

¹⁴ <https://extension.psu.edu/managing-crops-during-a-severe-drought-q-and-a>

¹⁵ Williams, A.P.; Cook, E.R.; Smerdon, J.E.; Cook, B.I.; Abatzoglou, J.T.; Bolles, K. & Livneh, B. (2020). Large contribution from anthropogenic warming to an emerging North American megadrought. *Science*, 368(6488), 314-318.

¹⁶ Alliance for the Great Lakes. (2025). A finite resource: Managing the growing water needs of data centers, critical minerals mining, and agriculture in the Great Lakes region. https://greatlakes.org/wp-content/uploads/2025/08/AGL_WaterUse_Report_Aug2025_Final.pdf

¹⁷ Cartwright, S. L., Schmied, J., Karrow, N., & Mallard, B. A. (2023). Impact of heat stress on dairy cattle and selection strategies for thermotolerance: a review. *Frontiers in veterinary science*, 10, 1198697.

¹⁸ U.S. Department of Agriculture, Economic Research Service. (2020). Consolidation in US dairy farming (Economic Research Report Number 274). <https://ers.usda.gov/sites/default/files/laserfiche/publications/98901/ERR-274.pdf>

¹⁹ Haigh, T. R., Otkin, J. A., Woloszyn, M., Todey, D., & Felkley, C. (2022). Meeting the drought information needs of Midwest perennial specialty crop producers. *Journal of Applied Meteorology and Climatology*, 61(7), 839-855.

State and Provincial Summaries

Illinois

As of the 2022 Census of Agriculture, Illinois had approximately 71,100 farms with a total of 26.3 million acres of farmland. The market value of agricultural products sold totaled more than \$26.4 billion, which ranks sixth nationally. Grain and oilseed production is an important industry in Illinois; as of 2022, it ranks first in the nation for soybeans and oil crops and second for corn by cash receipts. In addition, it ranks fourth in the nation for hogs.

Average annual temperatures have increased by 1.7°F in Illinois between 1979 and 2021, while annual precipitation has risen significantly (+5.7”) and extreme precipitation events have become more frequent (+1.5 days). Over that same period, the growing season has lengthened by 10.4 days. These changes represent opportunities to plant alternative varieties of crops and additional time for growth and harvest, but also increased risks, including damage from pests, diseases, and spring freeze injury. Warmer winter temperatures may also mean that chill hours for fruit crops are not met.

References

2022 Census of Agriculture State Profile – Illinois

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Illinois/cp99017.pdf

Giesting, K., Ontl, T., Baule, W., Shannon, D., Andresen, J., Wilson, A. B., Nowatzke, L., & Todey, D. (2022). Climate Change Impacts on Illinois Agriculture. Ames, Iowa: United States Department of Agriculture Climate Hubs and Great Lakes Research Integrated Science Assessment.

https://www.climatehubs.usda.gov/sites/default/files/2022_ClimateChangeImpactsOnIllinoisAgriculture_0.pdf

Farm Income and Wealth Statistics - Cash receipts by commodity State ranking

https://data.ers.usda.gov/reports.aspx?ID=4058#P55bc36a7fb71489799db85214b38ad3b_84_251iT0R0x137

Indiana

As of the 2022 Census of Agriculture, Indiana had approximately 53,600 farms with a total of 14.6 million acres of farmland. The market value of agricultural products sold totaled more than \$18 billion, which ranks ninth nationally. Poultry is an important industry in Indiana, which ranks third nationally for both eggs and turkeys on a cash receipts basis, as well as grain and oilseed production (fourth in the nation for soybeans and oil crops).

Average annual temperatures increased by 2°F in Indiana between 1979 and 2021, while annual precipitation has risen significantly (+7.3”) and extreme precipitation events have become more frequent, with an increase of 1.7 days annually. Over that same period, the growing season has lengthened by 13 days. These changes represent opportunities to plant alternative varieties of crops and additional time for

growth and harvest, but also increased risks, including damage from pests, diseases, and spring freeze injury. Warmer winter temperatures may also mean that chill hours for fruit crops are not met.

References

2022 Census of Agriculture State Profile – Indiana

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Indiana/cp99018.pdf

Bendorf, J., Schmitz, H., Nowatzke, L., Baule, W., Andresen, J., Wilson, A. B., & Todey, D. (2024). Climate Change Impacts on Indiana Agriculture. Ames, Iowa: United States Department of Agriculture Climate Hubs, Purdue University Climate Adaptation Partnership and Great Lakes Research Integrated Science Assessment.

https://www.climatehubs.usda.gov/sites/default/files/2022_ClimateChangeImpactsOnIllinoisAgriculture_0.pdf

Farm Income and Wealth Statistics - Cash receipts by commodity State ranking

https://data.ers.usda.gov/reports.aspx?ID=4058#P55bc36a7fb71489799db85214b38ad3b_84_251iT0R0x137

Michigan

As of the 2022 Census of Agriculture, Michigan had approximately 45,600 farms with a total of 9.5 million acres of farmland. The market value of agricultural products sold totaled more than \$12.2 billion, which ranks 17th nationally. In addition to its staple commodities of dairy products, corn, and soybeans, the fruit, vegetable and flower industries are especially important in Michigan; as of 2022, it ranks first in the nation for asparagus, second for apples, cucumbers, and squash; third for floriculture; fourth for blueberries, cherries, potatoes, and sugar beets; and fifth for cabbage on a cash receipts basis.

Average annual temperatures have increased by 1.8°F in Michigan between 1979 and 2021, while annual precipitation has also increased (+4.6”) and extreme precipitation events > 2.0 inches have become slightly more frequent (+0.6 days). Over that same period, the growing season in Michigan has lengthened by 5.8 days. These changes represent opportunities to plant alternative varieties of crops and additional time for growth and harvest, but also increased risks, including damage from pests, diseases, and spring freeze injury. Warmer winter temperatures may also mean that chill hours for fruit crops are not met.

References

Jean, M., Bendorf, J., Baule, W., Andresen, J., Wilson, A. B., Nowatzke, L., Todey, D., & Ontl, T. (2024). Climate Change Impacts on Michigan Agriculture. Ames, Iowa: United States Department of Agriculture Climate Hubs and Great Lakes Research Integrated Science Assessment.

2022 Census of Agriculture State Profile – Michigan

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Michigan/cp99026.pdf

Farm Income and Wealth Statistics - Cash receipts by commodity State ranking

https://data.ers.usda.gov/reports.aspx?ID=4058#P55bc36a7fb71489799db85214b38ad3b_84_251iT0R0x137

Minnesota

As of the 2022 Census of Agriculture, Minnesota had approximately 65,500 farms with a total of 25.4 million acres of farmland. The market value of agricultural products sold totaled approx.\$28.5 billion, which ranks fifth nationally. In addition to its key crops of corn and soybeans, for which it ranks third and fourth in the nation, respectively, Minnesota is a national leader for a diverse array of crops. It ranks first in the nation for green peas and sugar beets, second for oats, hogs, and turkeys, and third for canola, dry beans, oil crops, and sunflower (2022 cash receipts).

Average annual temperatures have increased by 1.2°F in Minnesota between 1979 and 2021, while annual precipitation has also increased (+2.8”) and extreme precipitation events > 2 inches have become slightly more frequent (+0.8 days). Over that same period, the growing season in Minnesota has not increased. These changes are smaller than those seen in the southern Great Lakes states, but they are already impacting agriculture and are forecasted to increase. They represent future opportunities to plant alternative crops or alternative varieties of crops through additional time for growth and harvest, but also increased risks, including damage from pests, diseases, drought, heat stress, and spring freeze injury. Warmer winter temperatures may also mean that chill hours for fruit crops are not met.

References

Roop, H. A., Meyer, N., Klinger, G., Blumenfeld, K., Liess, S., Farris, A., Boulay, P., Baule, W., Andresen, J., Bendorf, J., Wilson, A. B., Nowatzke, L., Todey, D., & Ontl, T. (2024). Climate Change Impacts on Minnesota Agriculture. Ames, Iowa: United States Department of Agriculture Climate Hubs, University of Minnesota Climate Adaptation Partnership and Great Lakes Research Integrated Science Assessment.

2022 Census of Agriculture State Profile – Minnesota

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Minnesota/cp99027.pdf

New York

As of the 2022 Census of Agriculture, New York had approximately 30,600 farms with a total of 6.5 million acres of farmland. The market value of agricultural products sold totaled more than \$8 billion, which ranks 26th nationally. Dairy products and cattle are the biggest industries in New York (2022 cash receipts), Fruits, vegetables, and specialty products are also important; the state ranks second in the nation for maple products, third for apples and snap beans, and fifth for squash.

Average air temperature statewide increased by almost 2.6°F from 1901 to 2022, and the warmest 10-year periods in recorded history have occurred since 2000. Observed temperature increases have been largest in the winter, followed by spring and fall, all of which leads to a lengthening of the growing season. New York's growing season increased by 11.5 days over the period from 1895 to 2020. Total annual precipitation and the number of extreme precipitation events have also increased over the last several decades. These changes represent both opportunities to plant alternative varieties of crops and utilize

additional time for growth and harvest, and also increased risks, including damage from pests, diseases, extreme weather events, heat stress, and spring freeze injury.

Since 1994, New York has been assisting farmers in addressing and preventing potential water pollution from agricultural activities through the Agricultural Nonpoint Source Abatement and Control (AgNPS) Program. The AgNPS Program awards water quality protection projects that focus on environmental planning and best management practice systems, including conservation measures such as nutrient management through manure storage, vegetative buffers along streams, and conservation cover crops. To date, the AgNPS Program has awarded over \$275 million through 30 rounds of funding to on-farm projects across the state to protect and conserve water resources.

In 2015, New York established the Climate Resilient Farming (CRF) Program to help farmers reduce agricultural greenhouse gas emissions, increase carbon sequestration in soils and perennial vegetation, and improve on-farm water management to increase farm resiliency in the face of a changing climate. To date, the CRF Program has awarded \$69 million to 570 farms across New York. Cumulatively these projects will help to reduce emissions by 574,000 metric tons of carbon dioxide equivalents per year and aid in the resiliency of farmland to withstand the increased climate risks such as damage from extreme precipitation, heat stress, and spring frost damage.

The CRF and AgNPS Programs are just two of the agriculture-based conservation programs that function as part of the Agricultural Environmental Management (AEM) framework, a broader effort that helps farmers achieve higher levels of environmental stewardship and more efficient, cost-effective farming systems. County Soil and Water Conservation Districts use the AEM framework to assist interested farmers through planning and implementation to make science-based and cost-effective decisions. As a result, farmers can meet business goals while conserving the state's natural resources.

References

Aller, D., Chatrchyan, A.M., Calixto, A., Cummings, J., Ortiz-Bobea, A., Peck, G., Schouten, J., Weikert, B., Wolters, E. and Stevens, A., 2024. *New York State Climate Impacts Assessment Chapter 03: Agriculture* (Vol. 1542, No. 1, pp. 146-213).

2022 Census of Agriculture State Profile – New York

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/New_York/cp99036.pdf

<https://agriculture.ny.gov/soil-and-water/agricultural-nonpoint-source-abatement-and-control>

<https://agriculture.ny.gov/soil-and-water/climate-resilient-farming>

<https://agriculture.ny.gov/soil-and-water/agricultural-environmental-management>

Ohio

As of the 2022 Census of Agriculture, Ohio had approximately 76,000 farms with a total of 13.6 million acres of farmland. The market value of agricultural products sold totaled more than \$15.4 billion, which ranks 11th nationally. In terms of cash receipts, Ohio's key crops are soybeans, corn, and animal products, especially eggs, for which Ohio is ranked second in the nation.

Average annual temperatures have increased by 2.2°F in Ohio between 1979 and 2021, and seven of the 10 warmest years on record have occurred since 1990. Annual precipitation has also risen significantly (+7.0”), and extreme precipitation events have become more frequent, with an increase of one day annually. Over that same period, the growing season has lengthened by 13.1 days. These changes represent opportunities to plant alternative varieties of crops and additional time for growth and harvest, but also increased risks, including damage from pests, diseases, and spring freeze injury. Warmer winter temperatures may also mean that chill hours for fruit crops are not met.

References

Wilson, A. B., Beers, L., Brown, C., McMichael, R., Bendorf, J., Baule, W., Nowatzke, L., Andresen, J., & Todey, D. (2024). *Climate Change Impacts on Ohio Agriculture*. Ames, Iowa: United States Department of Agriculture Climate Hubs, and Great Lakes Research Integrated Science Assessment.

2022 Census of Agriculture State Profile – Ohio

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Ohio/cp99039.pdf

Pennsylvania

As of the 2022 Census of Agriculture, Pennsylvania had approximately 49,000 farms with a total of seven million acres of farmland. The market value of agricultural products sold totaled more than \$10 billion, which ranks 20th nationally. In terms of cash receipts, Pennsylvania's key commodities are livestock and animal products. It also ranks first in the nation for mushrooms and fourth for apples and oats.

Average annual temperatures and annual precipitation in Pennsylvania have both increased over the last several decades, and both trends are expected to continue throughout the 21st century. Overall, agriculture in Pennsylvania may benefit through a lengthening growing season and the opportunity to cultivate warmer-weather crops, such as peaches. However, this comes with increased risks from pests and diseases. Animal agriculture is also expected to be impacted. For instance, milk production decreases if milking cows are under heat stress.

References

Pennsylvania Climate Action Plan 2024

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Pennsylvania/cp99042.pdf

Wisconsin

As of the 2022 Census of Agriculture, Wisconsin had approximately 58,500 farms with a total of 13.8 million acres of farmland. The market value of agricultural products sold totaled more than \$16.7 billion, which ranks 10th nationally. Wisconsin's key crops are staples like corn and soybeans and animal products like dairy (ranked second in the nation), cattle and eggs. The state also has strong fruit and vegetable industries and ranks first in the nation for cranberries, second for snap beans and third for carrots, cucumbers, green peas, and potatoes.

Average annual temperatures have increased by 1.6°F in Wisconsin between 1979 and 2021. Annual precipitation has also risen significantly (+4.9"), and extreme precipitation events have become more frequent (+1.1 days/year). Over that same period, the growing season has lengthened by 8.3 days. These changes represent opportunities to plant alternative varieties of crops and additional time for growth and harvest, but also increased risks, including damage from pests, diseases, and spring freeze injury. Other impacts on Wisconsin agriculture include decreased dairy herd milk production during extreme heat events and damage to alfalfa, winter cereals and cranberry crops due to less reliable winter snow and ice cover.

References

Kucharik, C., Mayerfeld, D., Dawson, J., Walling, S., Young, K., Baule, W., Nowatzke, L., Bendorf, J., Andresen, J., Todey, D., Wilson, A., & Ontl, T. (2023). Climate Change Impacts on Wisconsin Agriculture. Ames, Iowa: United States Department of Agriculture Climate Hubs, University of Wisconsin-Madison, Clean Wisconsin, and Great Lakes Research Integrated Science Assessment.

https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Wisconsin/cp99055.pdf

Ontario

In 2021, approximately 48,300 farms in Ontario generated over \$18.8 billion CAD in cash receipts. Primary agricultural production in Ontario is quite diverse, with the province producing over 200 commodities on 11.76 million acres of agricultural land. Dairy, vegetable, and soybean production are the top earning commodities by farm receipts in Ontario as of 2021. Ontario is also the leading greenhouse vegetable producer in Canada.

Changing climate is already impacting agricultural production across Ontario, with impacts expected to continue and amplify in the future. Mean annual temperature in the province increased by 1.3°C between 1948 and 2016, with mean annual precipitation increasing by 9.7% over the same period. Research suggests that Ontario's changing climate could present opportunities for field crop production driven by longer growing seasons, milder winters, and fewer frost days. However, the benefits are likely to be offset by risks associated with increased frequency and intensity of extreme weather events, variability in seasonal temperatures, and changing precipitation patterns at critical crop development phases.

References

Ontario Provincial Climate Change Impact Assessment Technical Report, January 2023

<https://www.ontario.ca/files/2023-11/mecp-ontario-provincial-climate-change-impact-assessment-en-2023-11-21.pdf>

Québec

Québec had approximately 29,400 farms and generated over \$11 billion CAD in farm cash receipts in 2021. The province is among Canada's leaders in several agricultural commodities including maple, dairy cows, pigs and cranberries. Dairy, pig and oilseed farms make up most farm revenues. In 2021, Québec accounted for 89.1% of the maple taps in Canada and reported more cranberry acreage than any other province.

By 2050, average annual temperatures in southern Québec are expected to rise by 2-4°C compared to historical values observed between 1981 and 2010. A longer, warmer growing season has potential benefits, such as increased productivity of certain crops and the opportunity to introduce new commodities and varieties. However, the projected changes also carry increased risks, such as winter mortality of perennial forage crops, surface runoff and soil erosion during extreme precipitation events, and decreased productivity due to heat stress to crops and livestock.

In response to increasing drought episodes, Québec is launching a [pilot project for active water-withdrawal management](#) to modernize practices and balance essential needs, economic activities, and ecosystem protection. Implemented in the Centre-du-Québec region, the initiative will assess the feasibility of adjusting major users' water withdrawals in real time according to available river flow, including temporary reductions or suspensions during critical low-water periods. The Ministry of the Environment, the Fight Against Climate Change, Wildlife and Parks will first produce a detailed overview of water use and define management parameters with voluntary partners, while testing communication tools to share flow information. The project's results, expected in 2028, will help determine whether this approach should be expanded to other regions.

Through a collaboration with the Ouranos consortium, Québec is working on the [QcClim'Eau](#) initiative that aims to integrate cutting-edge hydro climatology into regulatory decisions concerning flood zones, river mobility, and water withdrawal authorizations. Its two main goals are to quantify the impacts of climate change on water availability, water demand, flooding, and river dynamics, and to strengthen stakeholders' ability to understand and use this knowledge to adapt water and land management to emerging climate realities.

References

<https://www150.statcan.gc.ca/n1/pub/96-325-x/2021001/article/00005-eng.htm>

<https://www.ouranos.ca/en/news/2024-09-25/quebec-food-system-climate-change>

Appendix

Data sources and methodology for the ‘Agriculture in the Great Lakes’ data dashboard

A. Background

To support the understanding of baseline conditions in the Great Lakes region for agricultural production and water use, we acquired relevant census, satellite, monitoring and modeling data from federal agencies and other reputable sources. Using web-based data processing tools, these datasets are presented as a dashboard of interactive data visualizations that users can “drill down” into for more specific data views. This appendix describes the criteria for including datasets in the dashboard and the workflows for data processing.

B. Criteria for metric inclusion

B.1 Relevance

Potential dashboard metrics were considered to be relevant to the dashboard’s overall aim of better understanding climate-related risks and impacts to the Great Lakes basin agricultural sector if they mapped to one of the following topics, guided by the 2024 GLC resolution, *Understanding Impacts to Great Lakes Agriculture and Water Use Under Changing Climate Conditions*:

1. Agricultural production in the region
 - a. Acres in production
 - b. Product types and yield
2. Agricultural water use
 - a. Volume of water used for agricultural purposes
 - b. Irrigated acres by crop
3. Climate dependencies
 - a. Requirements for individual species (water, temperature, light) that limit their distribution
 - b. Expected changes in the climate parameters that limit crop ranges

B.2 Coverage

The dashboard aims to provide information both for the hydrological Great Lakes basin and for Great Lakes states and provinces jurisdiction-wide. A second criterion for inclusion in the dashboard was that potential metrics should have significant geographic coverage. When possible, we utilized datasets that were available across all of the states and

provinces. This allows comparisons between (and within) jurisdictions, lake basins, and latitude ranges, allowing the identification of challenges and opportunities for specific areas within the region.

In some cases, similar but not fully consistent data are available for different parts of the region, such as the US and Canada versions of the Census of Agriculture. In these cases, we harmonized the data to the extent possible to increase consistency across the region and documented the changes made for the purpose of harmonization. Some satellite-derived products do not extend to the latitudes of the northernmost parts of Ontario and Quebec, resulting in those northern census divisions being missing from the maps based on those products. A relatively small fraction of the total agricultural production in Ontario and Quebec is located in those census divisions.

B.3 Data Quality and Currency

A key aspect of the dashboard is the curation of high-quality metrics, i.e., metrics that provide an unbiased measure of some component of the agriculture/climate/water nexus. We relied on accuracy assessments when available as well as the opinion of partners in the states and provinces with subject matter expertise. Priority was given to datasets that have been included in peer-reviewed publications, grey literature reports, or open access databases that describe the methodology used, and/or that were recommended by SME partners.

We also prioritized datasets that are as up-to-date as possible. Datasets for which the most recent information is greater than ten years old were typically excluded unless no equivalent, more recent data were available. In addition, we primarily included datasets from longer-term programs that have a high likelihood of being updated regularly in future, so that the database can be updated periodically and remain relevant. Datasets from academic publications that are unlikely to be converted into ongoing data collection programs were only included when they addressed a key gap.

C. Data Sources

The data shared through the dashboard represent the compilation of several source datasets. The data sources are summarized below in Table A1.

C.1 Census data

We compiled and harmonized federal agricultural census data from the US and Canada collected from 1996-2022 to calculate the areas grown or quantity produced for individual commodities in the Great Lakes states and provinces.

Table A1: Summary of dashboard data sources.

| Page | Dashboard component | Data Source(s) | Appendix section(s) |
|---------------------|---|--|---------------------|
| Home | Pie chart: Amounts and types of agricultural land by state/province | 2022 US Census of Agriculture; Statistics Canada. Table 32-10-0249-01 Land use, Census of Agriculture, 2021 | C.1 |
| | Area chart: Agricultural Land over Time | 2022 US Census of Agriculture; 2021 Census of Agriculture – Canada | C.1 |
| | Bar chart: Top 10 Agricultural Crops by Acreage | 2022 US Census of Agriculture; 2021 Census of Agriculture – Canada | C.1 |
| | Bar chart: Top 10 Agricultural Crops by Market Value of Products Sold | 2022 US Census of Agriculture; Statistics Canada Table 32-10-0046-01 Farm cash receipts, quarterly (x 1,000) | C.1 |
| Commodity | Map | 2022 US Census of Agriculture; 2021 Census of Agriculture – Canada | C.1 |
| | Column chart | U.S. Census of Agriculture, 1997-2022; Census of Agriculture - Canada, 1996-2021 | C.1 |
| Jurisdiction | Map: Top commodity by acreage in each county/census division | 2022 US Census of Agriculture; 2021 Census of Agriculture – Canada | C.1 |
| | Narrative text | Various; see details | C.2 |
| | Bar chart: Top 5 Commodities by Acreage | 2022 US Census of Agriculture; 2021 Census of Agriculture – Canada | C.1 |
| | Bar chart: Top 5 Commodities by Cash Receipts | 2022 US Census of Agriculture; Statistics Canada Table 32-10-0046-01 Farm cash receipts, quarterly (x 1,000) | C.1 |
| Watershed | Map: Satellite-based crop acreage by sub-basin | USDA Crop Sequence Boundaries, 2021; Canadian Annual Crop Inventory, 2022 | C.3 |
| | Map: Irrigated vs. rainfed agricultural land | Landsat-derived Global Rainfed and Irrigated Cropland Product (LGRIP) version 001 | C.3 |
| | Map: Basin boundaries for Great Lakes Water Use Database | USGS Watershed Boundary Dataset | C.4 |
| | Stacked bar charts and stacked area chart: withdrawal amounts | Great Lakes Water Use Database | C.4 |
| | Map: Agricultural irrigation in the US Ag Census | 2022 US Census of Agriculture | C.1 |
| Climate | All climate page components | Matthews et al. climate change pressure maps | C.5 |

C.1.1 Data acquisition

C.1.1.1 US Census of Agriculture

County-level US Census of Agriculture data was downloaded in tabular format using the USDA NASS Quick Stats tool (<https://quickstats.nass.usda.gov/>). All downloads were filtered using the eight Great Lakes states for the State field. The map on the Commodities tab represents 2022 census data, while data from all censuses from 1997-2022 were acquired for the charts showing change over time. The Census of Agriculture is conducted every 5 years, so this represents the 6 most recent censuses. Commodities were downloaded at both the county and state scales; county because this allowed us to develop a higher-resolution map, and state because it allowed us to calculate statewide totals more accurately due to the privacy redactions in county-level data. Additional filters were applied to different commodity sectors and groups as follows:

Table A2: Filters used to download data from USDA Quick Stats

| Geographic Level | Sector | Group | Data Item |
|-------------------------|--------------------|-----------------------------------|---|
| <i>County and State</i> | Animals & Products | Livestock | Inventory |
| | | Poultry | Inventory |
| | | Specialty | Inventory |
| | Crops | Field Crops | Acres Harvested |
| | | Fruit & Tree Nuts | Acres Grown or Acres Bearing & Non-Bearing |
| | | Horticulture | Acres in Production (for products grown in the open); Sq. ft. in Production (for products grown under protection) |
| Vegetables | | Acres Harvested | |
| <i>Watershed</i> | Animals & Products | Livestock | Inventory |
| | Economics | Farms & Land & Assets - Ag Land | Acres |
| | | Farms & Land & Assets - Practices | Conservation Tillage Acres |

Aquaculture products are not currently included in the dashboard. Animal products (dairy, wool, eggs, honey) were not included in the mapped data but were included in state-level statistics and 'Top X Commodity' bar charts.

C.1.1.2 Census of Agriculture – Canada

Like the U.S., a Census of Agriculture is conducted once every 5 years in Canada by Statistics Canada. The cycle for the Canadian census is offset by 1 year from the American cycle, so that the most recent data available at this time are from the 2021 census. To look at change over time, data was downloaded for the 6 most recent censuses (1996-2021). The geographic areas used for mapping are the census divisions, the finest scale census data available and the nearest equivalent to U.S. counties. For the 2021 and 2016 censuses, data was downloaded from the [Census of Agriculture: Data Linked to Geographic Boundaries](#) page (Statistics Canada 2021). Data for 1996-2011 was downloaded from Borealis, the Canadian dataverse repository (Statistics Canada 1996, 2001, 2006, 2011).

C.1.2 Harmonization of census data

Time series

Because the US and Canada 5-year census of agriculture cycles are offset by 1 year, censuses separated by 1 year were combined in charts showing change over time. For example, in the stacked bar chart on the Commodity page showing area over time for a given commodity in each state/province, the years given are 1997, 2002, ... 2022, but these actually represent the 1996, 2001, ... 2021 censuses for the Ontario and Quebec sections of the chart.

Commodity groups

The US and Canada censuses name and organize agricultural commodities slightly differently. Each country also sometimes changes the names of agricultural commodities or how they are grouped together. For example, ginger was considered a field crop up until the 2017 census, when it was reclassified as a vegetable. This means that data are sometimes more granular for one country than for the other; Canada has specific data for cranberries, whereas in the US census cranberry data is included within the “Other Berries” category. At the county/census division level of detail, it is difficult to combine data for individual commodities into more general groups in order to make the grouping consistent across countries because in both Canada and the US, redactions are applied to prevent the disclosure of data for any specific farm operation in order to protect the confidentiality of individual producers. As a result, mapped quantities that represent the combination of multiple commodities may be underestimates.

Table A3 summarizes the commodity groups, subgroups, and individual commodities mapped in the dashboard, as well as the specific data items from each country’s census that were included in each commodity. Where the name of the data item for an individual commodity has changed over time, all names are included. In some cases, an individual

commodity is grouped into an 'other' category even though it is included in both countries' censuses because it is a recent addition to one census. For example, ducks are included in 'other poultry' because they were included in this category in the Canada census until 2021.

Table 3: Commodities, subgroups and groups mapped in the dashboard, and the data items in the US and Canada Censuses of Agriculture that they included.

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---------------------------------------|-----------------|-------------------------------------|--------|--------------------------------|--|
| Cultivated Christmas trees | Christmas trees | Christmas trees | Acres | Canada | Total Area Of Christmas Trees Grown For Sale - Acres |
| | | | | USA | Cut Christmas Trees - Acres In Production |
| Fruits, tree nuts, and berries | Berries | Blueberries | Acres | Canada | Blueberries Total Area - Acres |
| | | | | | Blueberries Under Cultivation - Acres |
| | | | | USA | Blueberries - Acres Grown |
| | | | | | BLUEBERRIES, TAME - ACRES GROWN |
| | | | | | BLUEBERRIES, WILD - ACRES GROWN |
| | | | | | BLUEBERRIES, TAME - ACRES HARVESTED |
| | | BLUEBERRIES, WILD - ACRES HARVESTED | | | |
| | | Cranberries | Acres | USA | Cranberries - Acres Grown |
| | | | | | Cranberries - Acres Harvested |
| | | | Canada | Cranberries Total Area - Acres | |
| Cranberries Under Cultivation - Acres | | | | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|----------|--------------------|--------|---|--|
| Fruits, tree nuts, and berries (cont'd) | Berries | Raspberries | Acres | Canada | Raspberries Total Area - Acres |
| | | | | | Raspberries Under Cultivation - Acres |
| | | | | USA | Raspberries - Acres Grown |
| | | | | | Raspberries - Acres Harvested |
| | | Strawberries | Acres | Canada | Strawberries Total Area - Acres |
| | | | | | Strawberries Under Cultivation - Acres |
| | | | | USA | Strawberries - Acres Grown |
| | | | | | Strawberries - Acres Harvested |
| | Fruit | Apples | Acres | Canada | Apples Total Area - Acres |
| | | | | USA | Apples - Acres Bearing & Non-Bearing |
| | | | | Canada | Apricots Total Area - Acres |
| | | | | | USA |
| | | Sour/Tart Cherries | Acres | Canada | Cherries (Sour) Total Area - Acres |
| | | | Acres | USA | Cherries, Tart - Acres Bearing & Non-Bearing |
| Sweet Cherries | | Acres | Canada | Cherries (Sweet) Total Area - Acres | |
| | | Acres | USA | Cherries, Sweet - Acres Bearing & Non-Bearing | |

| Group | Subgroup | Commodity | Unit | Census | Data_item | |
|---|----------|--------------------------------|--------------------------------|--------|--|--|
| Fruits, tree nuts, and berries (cont'd) | Fruit | Grapes | Acres | Canada | Grapes Total Area - Acres | |
| | | | Acres | Canada | Grapes Under Cultivation - Acres | |
| | | | Acres | USA | Grapes - Acres Bearing & Non-Bearing | |
| | | Peaches | Acres | Canada | Peaches Total Area - Acres | |
| | | | | USA | Peaches - Acres Bearing & Non-Bearing | |
| | | Pears | Acres | Canada | Pears Total Area - Acres | |
| | | | | USA | Pears - Acres Bearing & Non-Bearing | |
| | | Plums & Prunes | Acres | Canada | Plums And Prunes Total Area - Acres | |
| | | | | USA | Plums & Prunes - Acres Bearing & Non-Bearing | |
| | | Other fruits, berries and nuts | Other fruits, berries and nuts | Acres | Canada | Calculated by GLC - all fruits, berries and nuts minus commodities included separately |
| | | | | | USA | Calculated by GLC - all fruits, berries and nuts minus commodities included separately |

| Group | Subgroup | Commodity | Unit | Census | Data_item | |
|---|-------------------------------|-------------------|-------------------|--------|--------------------------|--|
| Grains, oilseeds, dry beans, and dry peas | Barley | Barley | Acres | Canada | Barley - Acres | |
| | | | | USA | Barley - Acres Harvested | |
| | Beans and Peas, Dry Edible | Beans, Dry Edible | Beans, Dry Edible | Acres | Canada | Dry White Beans - Acres |
| | | | | | | Faba Beans - Acres |
| | | | | | | Fava Beans - Acres |
| | | | | | | Other Dry Beans - Acres |
| | | | | | | Chick Peas - Acres |
| | | | | | | Lentils - Acres |
| | | | | | USA | Beans, Dry Edible, (Excl Chickpeas & Lima) - Acres Harvested |
| | | | | | | Beans, Dry Edible, (Excl Lima), Incl Chickpeas - Acres Harvested |
| | | | | | | Beans, Dry Edible, Lima - Acres Harvested |
| | | | | | | Chickpeas - Acres Harvested |
| | | | | | | Lentils - Acres Harvested |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--|-------------------------------------|--------------------------------|-------|--------------------------|---|
| Grains, oilseeds, dry beans, and dry peas (cont'd) | Beans and Peas, Dry Edible (cont'd) | Peas, dry edible | Acres | Canada | Dry Field Peas - Acres |
| | | | | USA | Peas, Dry Edible - Acres Harvested |
| | | Peas, dry edible (cont'd) | Acres | USA | Peas, Dry, Southern (Cowpeas) - Acres Harvested |
| | Corn | Corn for grain, seed or silage | Acres | Canada | Corn For Grain - Acres |
| | | | | | Corn For Silage - Acres |
| | | | | | Total Corn - Acres |
| | | | | USA | Corn, Grain - Acres Harvested |
| | | | | | Corn, Silage - Acres Harvested |
| | | | | | Corn, Traditional Or Indian - Acres Harvested |
| | Soybeans | Soybeans | Acres | Canada | Soybeans - Acres |
| | | | | USA | Soybeans - Acres Harvested |
| | Wheat | Wheat | Acres | Canada | Wheat (Total) - Acres |
| | | | | USA | Wheat - Acres Harvested |
| | Oilseeds | Canola/rapeseed | Acres | Canada | Canola (Rapeseed) - Acres |
| USA | | | | Canola - Acres Harvested | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--|-------------------|--------------------------|-------|----------------------------|---------------------------------|
| Grains, oilseeds, dry beans, and dry peas (cont'd) | Oilseeds (cont'd) | Canola/rapeseed (cont'd) | Acres | USA | Rapeseed - Acres Harvested |
| | | | Acres | Canada | Flaxseed - Acres |
| | | Acres | USA | Flaxseed - Acres Harvested | |
| | Oilseeds (cont'd) | Mustard seed | Acres | Canada | Mustard, Seed - Acres Harvested |
| | | | Acres | USA | Mustard Seed - Acres |
| | | Safflower | Acres | Canada | Safflower - Acres |
| | | | Acres | USA | Safflower - Acres Harvested |
| | | Sunflower | Acres | Canada | Sunflowers - Acres |
| | | | Acres | USA | Sunflower - Acres Harvested |
| | Other Grains | Buckwheat | Acres | Canada | Buckwheat - Acres |
| | | | Acres | USA | Buckwheat - Acres Harvested |
| | | Oats | Acres | Canada | Oats - Acres |
| | | | Acres | USA | Oats - Acres Harvested |
| | | Rye | Acres | Canada | Total Rye - Acres |
| | | | Acres | USA | Rye - Acres Harvested |
| | | Triticale | Acres | Canada | Triticale - Acres |
| | | | Acres | USA | Triticale - Acres Harvested |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--------------------------|--------------------|------------------------------------|--|---|--|
| Greenhouse and mushrooms | Greenhouse | Greenhouse - flowers | Square feet | Canada | Cut Flowers - Square Feet |
| | | | | | Greenhouse Flowers |
| | | | | | Potted Plants, Indoor Or Outdoor - Square Feet |
| | | USA | Floriculture Totals, Under Protection - Sq Ft In Production | | |
| | | Greenhouse - fruits and vegetables | Square feet | Canada | Greenhouse Vegetables |
| | | | | | Total Greenhouse Fruits And Vegetables - Square Feet |
| | USA | | Fruit Totals, Under Protection - Sq Ft In Production | | |
| | | | VEGETABLE TOTALS, INCL FRESH CUT HERBS, UNDER PROTECTION - SQ FT IN PRODUCTION | | |
| | Greenhouse - other | Square feet | Canada | Other Greenhouse Products | |
| | | | | Other Greenhouse Products - Square Feet | |
| USA | | | Nursery Totals, Under Protection - Sq Ft In Production | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|-----------------------------------|---------------------|-----------------------------|-------------|---------------------------------|--|
| Greenhouse and mushrooms (cont'd) | Greenhouse (cont'd) | Greenhouse – other (cont'd) | Square feet | USA | AQUATIC PLANTS, UNDER PROTECTION - SQ FT IN PRODUCTION |
| | | | | | BULBS & CORMS & RHIZOMES & TUBERS, DRY, UNDER PROTECTION - SQ FT IN PRODUCTION |
| | | | | | Hemp, Industrial, Under Protection, Clones & Transplants - Sq Ft In Production |
| | | | | | Hemp, Industrial, Under Protection, Complete Grows - Sq Ft In Production |
| | | | | | Hemp, Industrial, Under Protection, Seed - Sq Ft In Production |
| | | | | | FLOWER SEEDS, UNDER PROTECTION - SQ FT IN PRODUCTION |
| | | | | | PROPAGATIVE MATERIAL, UNDER PROTECTION - SQ FT IN PRODUCTION |
| | Mushrooms | Mushrooms | Square feet | Canada | Total Growing Area For Mushrooms - Square Feet |
| | | | USA | Mushrooms - Sq Ft In Production | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--------------------------------|-----------|--|--------|---------------------------------|--|
| Livestock, poultry and bees | Honeybees | Honeybees, number of colonies | Number | Canada | Bees, Number Of Colonies |
| | | | | | Honeybees - Number Of Colonies |
| | | | | USA | Honey, Bee Colonies - Inventory, Measured In Colonies |
| | Cattle | Beef cows | Number | Canada | Beef Cows - Number |
| | | | | USA | CATTLE, COWS, BEEF - INVENTORY |
| | | Dairy cows | Number | Canada | Dairy Cows - Number |
| | | | | USA | CATTLE, COWS, MILK - INVENTORY |
| | | Cattle excluding cows | Number | USA | CATTLE, (EXCL COWS) - INVENTORY |
| | | | | Canada | Cattle excluding calves - Number |
| | | Total cattle and calves | Number | Canada | Total Cattle And Calves - Number |
| | USA | | | Cattle, Incl Calves - Inventory | |
| | Poultry | Chickens (Total hens and chickens) | Number | Canada | Total Hens And Chickens - Number Of Birds |
| | | | | USA | Chickens - Inventory |
| | | | | | Chickens, Layers - Inventory |
| | | | | | Chickens, Broilers - Inventory |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--------------------------------------|------------------|---|--------|-------------------------------------|--|
| Livestock, poultry and bees (cont'd) | Poultry (cont'd) | Chickens (Total hens and chickens) (cont'd) | Number | USA | Chickens, Pullets, Replacement - Inventory |
| | | Turkeys | Number | Canada | Turkeys - Number Of Birds |
| | | | | USA | Turkeys - Inventory |
| | | Other poultry | Number | Canada | Ducks - Number |
| | | | | USA | Ducks - Inventory |
| | | | | Canada | Geese - Number |
| | | | | USA | Geese - Inventory |
| | | | | USA | Chukars - Inventory |
| | | | | USA | Emus - Inventory |
| | | | | USA | Guineas - Inventory |
| | | | | USA | Ostriches - Inventory |
| | | | | USA | Partridges, Hungarian - Inventory |
| | | | | USA | Peafowl, Hens & Cocks - Inventory |
| | | | | USA | Pheasants - Inventory |
| | | | | USA | Pigeons & Squab - Inventory |
| | USA | | | Poultry, Other - Inventory | |
| | USA | | | Quail - Inventory | |
| | USA | Rheas - Inventory | | | |
| | Canada | Other Poultry - Number Of Birds | | | |
| | Equine | Donkeys | Number | Canada | Donkeys - Number |
| | | | | USA | Equine, Mules & Burros & Donkeys - Inventory |
| Horses and ponies | | Number | USA | Equine, Horses & Ponies - Inventory | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--|-----------------|-------------------------------|--------|--------------------------------|-------------------------------------|
| Livestock, poultry and bees (cont'd) | Equine | Horses and ponies | Number | Canada | Horses And Ponies - Number |
| | Goats | Goats | Number | Canada | Goats - Number |
| | | | | USA | Goats - Inventory |
| | Pigs | Total Pigs | Number | USA | Hogs - Inventory |
| | | | | Canada | Total Pigs - Number |
| | Other livestock | Bison | Number | Canada | Bison (Buffalo) - Number |
| | | | | USA | Bison - Inventory |
| | | Deer (Excluding Wild Deer) | Number | Canada | Deer (Excluding Wild Deer) - Number |
| | | | | USA | Deer - Inventory |
| | | Elk | Number | Canada | Elk - Number |
| | | | | USA | Elk - Inventory |
| | | Llamas and alpacas | Number | USA | Llamas - Inventory |
| | | | | USA | Alpacas - Inventory |
| | | | | Canada | Llamas And Alpacas - Number |
| | | Mink | Number | Canada | Mink - Number |
| | USA | | | Mink, Live & Pelts - Inventory | |
| | Rabbit | Number | Canada | Rabbit - Number | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--------------------------------------|--------------------------|---------------------------------|--------------------------------|--------|--|
| Livestock, poultry and bees (cont'd) | Other livestock (cont'd) | Rabbit (cont'd) | Number | USA | Rabbits, Live - Inventory |
| | | Wild boars | Number | Canada | Wild Boars - Number |
| | Sheep | Total sheep and lambs | Number | USA | Sheep, Incl Lambs - Inventory |
| | | | | Canada | Total Sheep And Lambs - Number |
| Nursery, floriculture, and sod | Floriculture totals | Floriculture totals in the open | Acres | USA | Floriculture Totals, In The Open - Acres In Production |
| | | | | Canada | Estimates of field-grown cut flowers area |
| | Nursery totals | Nursery totals in the open | Acres | Canada | Total Area Of Nursery Products - Acres |
| | | | | USA | Nursery Totals, In The Open - Acres In Production |
| | Sod | Sod | Acres | Canada | Total Area Of Sod Under Cultivation For Sale - Acres |
| | | | | USA | Sod - Acres Harvested |
| | | | | | Sod, In The Open, Harvested Or Intended For Sale In Future Years - Acres In Production |
| | Other crops and hay | Grasses & Legumes Totals, Seed | Grasses & Legumes Totals, Seed | Acres | Canada |
| USA | | | | | Grasses & Legumes Totals, Seed - Acres Harvested |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|------------------------------|---------------|--------------------------------|--------|------------------------------|--|
| Other crops and hay (cont'd) | Hay & Haylage | Alfalfa | Acres | Canada | Alfalfa And Alfalfa Mixtures - Acres |
| | | | | USA | Hay, Alfalfa - Acres Harvested |
| | | All other hay and fodder crops | Acres | Canada | All Other Tame Hay And Fodder Crops - Acres |
| | | | | USA | Hay & Haylage - Acres Harvested |
| | | | | | Hay & Haylage (Excl. Alfalfa) - Acres Harvested |
| | | | | | |
| | Hemp | Hemp | Acres | Canada | Hemp - Acres |
| | | | | USA | Hemp, Industrial, In The Open, Fiber - Acres Harvested |
| | | | | | Hemp, Industrial, In The Open, Floral - Acres Harvested |
| | | | | | Hemp, Industrial, Grain, In The Open - Acres Harvested |
| | | | | | Hemp, Industrial, In The Open, Other Usage - Acres Harvested |
| | | | | | Hemp, Industrial, In The Open, Seed - Acres Harvested |
| Sugarbeets | Sugarbeets | Acres | Canada | Sugar Beets - Acres | |
| | | | USA | Sugarbeets - Acres Harvested | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|--|-------------------|-------------------|-------|--------|--------------------------------------|
| Other crops and hay (cont'd) | Other field crops | Other field crops | Acres | Canada | Tobacco - Acres |
| | | | | | Canary seed |
| | | | | | Caraway |
| | | | | | Other field crops - Acres |
| | | | | USA | Tobacco - Acres Harvested |
| | | | | | Hops |
| | | | | | Camelina |
| | | | | | Emmer & Spelt |
| | | | | | Wild Rice |
| | | | | | Herbs, Dry - Acres Harvested |
| | | | | | Field crops, other - Acres harvested |
| Vegetables, melons, potatoes, and sweet potatoes | Potatoes | Potatoes | Acres | Canada | Potatoes - Acres |
| | | | | USA | Potatoes - Acres Harvested |
| | Vegetables | Asparagus | Acres | Canada | Asparagus Non-Producing - Acres |
| | | | | | Asparagus Producing - Acres |
| | | | | USA | Asparagus - Acres Harvested |
| | | | | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|------------------|-------|--------|--------------------------------------|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Beans, fresh | Acres | Canada | Green And Wax Beans - Acres |
| | | | | USA | Beans, Green, Lima - Acres Harvested |
| | | | | | Beans, Snap - Acres Harvested |
| | | Beets | Acres | Canada | Beets - Acres |
| | | | | USA | Beets - Acres Harvested |
| | | Broccoli | Acres | Canada | Broccoli - Acres |
| | | | | USA | Broccoli - Acres Harvested |
| | | Brussels sprouts | Acres | Canada | Brussels Sprouts - Acres |
| | | | | USA | Brussels Sprouts - Acres Harvested |
| | | Cabbage | Acres | Canada | Cabbage - Acres |
| | | | | | Chinese Cabbage - Acres |
| | | | | USA | Cabbage, Chinese - Acres Harvested |
| | | | | | Cabbage, Head - Acres Harvested |
| | | | | | Cabbage, Mustard - Acres Harvested |
| | | Carrots | Acres | Canada | Carrots - Acres |
| | | | | USA | Carrots - Acres Harvested |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|-------------|-------|--------|--|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Cauliflower | Acres | Canada | Cauliflower - Acres |
| | | | | USA | Cauliflower - Acres Harvested |
| | | Celery | Acres | Canada | Celery - Acres |
| | | | | USA | Celery - Acres Harvested |
| | | Cucumbers | Acres | Canada | Cucumbers - Acres |
| | | | | USA | Cucumbers - Acres Harvested |
| | | Garlic | Acres | Canada | Garlic - Acres |
| | | | | USA | Garlic - Acres Harvested |
| | | Ginseng | Acres | Canada | Ginseng - Acres |
| | | | | USA | Ginseng - Acres Harvested |
| | | Lettuce | Acres | Canada | Lettuce - Acres |
| | | | | USA | Lettuce - Acres Harvested |
| | | Onions | Acres | Canada | Dry onions - Acres |
| | | | | | Onions (dry, yellow, Spanish, cooking, etc.) |
| | | | | | Dry onions, yellow, Spanish, cooking, etc. |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|-------------|-------|--------|--|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Onions | Acres | | Dry Onions, Yellow, Spanish, Cooking, Etc. - Acres |
| | | | | | Green or bunching onion, shallots - Acres |
| | | | | | Shallots, green and seed onions |
| | | | | | Shallots, green onions |
| | | | | | Shallots and green onions |
| | | | | | Shallots And Green Onions - Acres |
| | | | | USA | Onions, Dry - Acres Harvested |
| | | | | | Onions, Green - Acres Harvested |
| | | Peas, fresh | Acres | Canada | Green peas |
| | | | | | Green Peas - Acres |
| | | | | USA | Peas, Chinese (Sugar & Snow) - Acres Harvested |
| | | | | | Peas, Green, (Excl Southern) - Acres Harvested |
| | | | | | Peas, Green, Southern (Cowpeas) - Acres Harvested |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------------|-----------------------|-------|--------|----------------------------------|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Peppers | Acres | Canada | Peppers |
| | | | | | Peppers - Acres |
| | | | | USA | Peppers, Bell - Acres Harvested |
| | | | | | Peppers, Chile - Acres Harvested |
| | | Radishes | Acres | Canada | Radishes - Acres |
| | | | | | Radishes |
| | | | | USA | Radishes - Acres Harvested |
| | | | | | Daikon - Acres Harvested |
| | | Rhubarb | Acres | Canada | Rhubarb - Acres |
| | | | | USA | Rhubarb - Acres Harvested |
| | | Rutabagas and turnips | Acres | Canada | Rutabagas (turnips) - Acres |
| | | | | | Rutabagas and turnips |
| | | | | | Rutabagas and turnips - Acres |
| | | | | USA | Turnips - Acres Harvested |
| | | Spinach | Acres | Canada | Spinach |
| Spinach - Acres | | | | | |
| USA | Spinach - Acres Harvested | | | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|-------------------------------|------------------------------|---|---------------------------------------|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Squash, pumpkins and zucchini | Acres | Canada | Pumpkins |
| | | | | | Pumpkins - Acres |
| | | | | | Squash and zucchini |
| | | | | | Squash And Zucchini - Acres |
| | | | | | Squash, pumpkins and zucchini |
| | | | | | Squash, Pumpkins And Zucchini - Acres |
| | | USA | Pumpkins - Acres Harvested | | |
| | | | Squash - Acres Harvested | | |
| | | Sweet corn | Acres | Canada | Sweet Corn - Acres |
| | | | | | Sweet corn |
| | USA | | | | Sweet Corn - Acres Harvested |
| | Tomatoes | Acres | Canada | Tomatoes - Acres | |
| | | | | Tomatoes | |
| | | | USA | Tomatoes, In The Open - Acres Harvested | |
| | Other vegetables | Acres | Canada | Kale - Acres | |
| Other Vegetables - Acres | | | | | |
| USA | | | Artichokes - Acres Harvested | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|---------------------------|-------|--------|--------------------------------------|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Other vegetables (cont'd) | Acres | USA | Chicory - Acres Harvested |
| | | | | | Eggplant - Acres Harvested |
| | | | | | Escarole & Endive - Acres Harvested |
| | | | | | Ginger Root - Acres Harvested |
| | | | | | Gourds - Acres Harvested |
| | | | | | Greens, Collard - Acres Harvested |
| | | | | | Greens, Kale - Acres Harvested |
| | | | | | Greens, Mustard - Acres Harvested |
| | | | | | Greens, Turnip - Acres Harvested |
| | | | | | Herbs, Fresh Cut - Acres Harvested |
| | | | | | Horseradish - Acres Harvested |
| | | | | | Melons, Cantaloup - Acres Harvested |
| | | | | | Melons, Honeydew - Acres Harvested |
| | | | | | Melons, Watermelon - Acres Harvested |
| | | | | | Okra - Acres Harvested |
| | | | | | Parsley - Acres Harvested |
| Parsnips - Acres Harvested | | | | | |

| Group | Subgroup | Commodity | Unit | Census | Data_item |
|---|---------------------|---------------------------|-------|--------|-------------------------------------|
| Vegetables, melons, potatoes, and sweet potatoes (cont'd) | Vegetables (cont'd) | Other vegetables (cont'd) | Acres | USA | Sweet Potatoes - Acres Harvested |
| | | | | | Vegetables, Mixed - Acres Harvested |
| | | | | | Vegetables, Other - Acres Harvested |
| | | | | | Watercress - Acres Harvested |

C.1.4 Statistics Canada

C.1.4.1 Table: Farm cash receipts, quarterly (x 1,000)

Quarterly data on farm cash receipts was downloaded from Statistics Canada (<https://doi.org/10.25318/3210004601-eng>) for the provinces of Ontario and Quebec. Monetary values were converted from Canadian dollars to U.S. dollars by multiplying them by 0.7685, the average exchange rate for 2022 according to the Bank of Canada (<https://www.bankofcanada.ca/rates/exchange/annual-average-exchange-rates/>).

C.1.4.2 Table: Land use, Census of Agriculture, 2021

To get summary data for total amounts of agricultural land in Ontario and Quebec, we downloaded data from Statistics Canada Table 32-10-0249-01 (<https://doi.org/10.25318/3210024901-eng>) at the province and census division scales.

C 1.5 Limitations

The Great Lakes states have better than average response rates for the US Census of Agriculture (Figure A1). However, response rates are still less than 100% and have gradually declined over time. To compensate for nonresponses, the USDA NASS and Statistics Canada employ robust statistical methodologies to estimate the missing information. This helps produce reliable overall data, but results in estimates rather than direct reports.

Census Data Collection

Response Rate by State, 2022

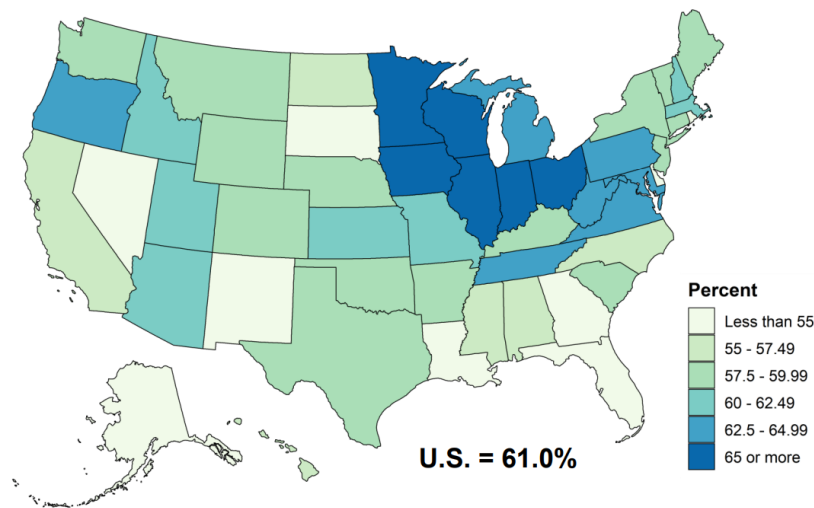


Figure A1: Response rates by state for the US Census of Agriculture in 2022. USDA National Agricultural Statistics Service, 2022 Census of Agriculture. Complete data available at www.nass.usda.gov/AgCensus.

As mentioned earlier, data is redacted or suppressed in areas where the number of farms reporting a specific item is low enough that an individual farm’s data could be reverse-

engineered or identified. While this is necessary to protect the confidentiality of respondents, it limits the granularity of data available at the county or census division level.

C.2 Data sources for jurisdiction-specific narratives

The jurisdiction tab summarizes the already described federal census data for each state/province as well as observed and expected climate impacts on agriculture. Where available, the 2019 Great Lakes State Climate Change Summaries for Agriculture were used as the primary source for information on climate impacts (Giesting et al. 2022). The reports were downloaded from <https://www.climatehubs.usda.gov/hubs/midwest/topic/assessing-impacts-climate-change-midwest-agriculture>. For the jurisdictions that do not have one of these summaries, similar information on the agricultural impact of climate changes was sought with a preference for federal, state and provincial data sources, such as the Ontario Provincial Climate Change Impact Assessment Technical Report. Representatives of each state and province were invited to review the draft content in the dashboard for their jurisdiction and provide feedback and additional information that would be useful to include.

C.3 Satellite-Derived GIS Watershed Products

C.3.1 Area of Interest

The first piece of the mapping process involved mapping out all the different types of crops that are grown within the Great Lake States of Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York as well as the Canadian provinces of Ontario and Quebec by the watershed they are in. The area of interest was divided into geographic units of watersheds within the Great Lake Basin. The watershed boundaries for the US side of the area of study consisted of United States Geological Survey's HUC-8 watershed boundaries and Natural Resource Canada's National Hydrological Network Work Unit boundaries for Canada. The second piece of the mapping process involved mapping irrigated lands within the Great Lakes Basin. The area of interest for this part of the process was also the watershed boundaries within the Great Lakes Basin. The same geographic unit of watershed boundaries was used for this part as the first part of this mapping process.

C.3.2 Crop areas

Data Acquisition

To map the areas of crops being grown in each watershed, two different datasets had to be acquired for the US and Canada, as there was no uniform dataset that covered both

countries. The satellite-derived data used for the United States side was acquired from the United States Department of Agriculture's (USDA) Crop Sequence Boundaries (CSB) dataset, developed in conjunction with the USDA's Economic Research Service (Hunt et al. 2024). The Crop Sequence Boundaries product includes estimates of field boundaries, crop acreage, and crop rotations across the contiguous United States. It "uses satellite imagery with other public data and is open source, allowing users to conduct area and statistical analysis of planted U.S. commodities and providing insight into farmer cropping decisions" (USDA National Agricultural Statistics Service [NASS], 2025). Vector format Crop Sequence Boundaries data for 2015-2022 was downloaded from https://www.nass.usda.gov/Research_and_Science/Crop-Sequence-Boundaries/index.php. The data for 2021 was extracted and utilized for the watershed tab data visualizations to coincide with the census data used elsewhere in the dashboard.

For the US watershed boundaries, GIS data was acquired from the United States Geological Survey (USGS) Watershed Boundary Dataset. The Watershed Boundary Dataset is a nationwide digital map that shows U.S. drainage areas, called Hydrologic Units. The system is organized from large to small areas (HUC 2, 4, 6, 8, 10, and 12), with unique codes that identify regions, basins, and individual watersheds (U.S. Geological Survey, 2025). For this section, HUC-8 watershed data was downloaded.

The satellite data used for the Canadian side of the analysis was acquired from the Canadian Annual Crop Inventory produced by the Earth Observation Team of the Science and Technology Branch (STB) at Agriculture and Agri-Food Canada (AAFC). The Annual Crop Inventory (ACI) is a series of high-resolution digital maps created using satellite imagery to identify and classify crop types across the country each year (Agriculture and Agri-Food Canada, 2023). Data from the ACI for the year 2021 was downloaded for the area of interest in Canada.

For the Canadian watershed boundaries, GIS data was acquired from Natural Resource Canada's National Hydrological Network dataset (NHN). The NHN "provides geospatial digital data compliant with the NHN Standard such as lakes, reservoirs, watercourses (rivers and streams), canals, islands, drainage linear network, toponyms or geographical names, constructions and obstacles related to surface water" (Natural Resources Canada, 2024). The base watershed data, Working Units, was downloaded for the area of interest in Canada.

For the US irrigation vs water-fed agriculture data, raster data from NASA's EARTHDATA Landsat derived global rainfed and irrigated cropland product was acquired and used for the second GIS process. The Landsat-Derived Global Rainfed and Irrigated-Cropland Product (LGRIP) is a 30-meter resolution global map derived from Landsat satellite imagery

that identifies whether croplands are rainfed or irrigated (Teluguntla et al., 2023). One raster dataset was downloaded for complete coverage over the area of interest of the Great Lakes basin for the year 2015.

GIS Processing and Methods

To begin the GIS analysis, all the datasets were imported into ArcGIS Pro. Before analysis could proceed, the spatial extent of all datasets needed to be defined. To accomplish this, the Great Lakes Basin GIS watershed boundary was used to select all U.S. Geological Survey (USGS) HUC-8 watershed data and National Hydrological Network (NHN) Working Unit data located within the basin. The selected watershed data were then used as the geographic units to which the satellite-derived data were joined. To create the first satellite-derived GIS product—area of crop type by watershed—the crop datasets were joined to the watershed boundaries and summarized by crop area within each watershed. For the U.S. data, the Tabulate Area tool in ArcGIS Pro was used to summarize the Crop Sequence Boundaries data by HUC-8 watershed. This process produced a table in which each record represents a HUC-8 watershed and each field represents the total area, in square meters, of a specific crop type. The same procedure was applied to the Canadian data, with the Annual Crop Inventory raster data joined to the National Hydrological Network Working Unit boundaries and summarized to calculate the total area of each crop within each watershed.

After this step, the U.S. and Canadian summary tables were merged into a single, standardized dataset. To enable the merge, both tables were first aligned to an identical schema by adding any missing fields and ensuring consistent data types across datasets. Once the schemas matched exactly, the Add Join tool in ArcGIS Pro was used to join the tables using the ObjectID field as the join key. The resulting table contains total crop area values, in square meters, for all crop commodities across watersheds in the Great Lakes Basin.

To create the second satellite-derived GIS product—irrigated and rainfed acreage by watershed—the Landsat-derived global rainfed and irrigated cropland raster was integrated with the Great Lakes Basin watershed dataset. This raster classifies land as irrigated agriculture, rainfed agriculture, or non-agricultural land. The Tabulate Area tool in ArcGIS Pro was used to summarize the total area of each agricultural irrigation type within each watershed. The resulting table was composed of records of individual watersheds with three fields, the total area of irrigated AG land per watershed and the total area of water-fed AG land per watershed.

C.4 Great Lakes Regional Water Use Database

Data from the Great Lakes Regional Water Use Database (GLWUD) were downloaded from waterusedata.glc.org using the Create a Query tool. At the time of download, data were available through 2023. Please see the 2023 annual report (<https://cms.waterusedata.glc.org/media/2023-Water-Use-Report-FINAL.pdf>) for details on these data and how they are collected. While data has been collected since 1987, due to changes in data collection protocols over time, the dataset is consistent from 2011-present.

C.5 USDA Potential Climate Change Pressure Maps

The maps and graphs of growing degree days, plant hardiness zones and drought severity shown on the climate tab of the dashboard use data from the climate change pressures dataset developed by Matthews et al. (2018, 2019). The data were downloaded in raster format from <https://www.fs.usda.gov/rds/archive/catalog/RDS-2019-0001> and averages were calculated for counties and census divisions using Zonal Statistics in ArcGIS Pro.

D. References

Agriculture and Agri-Food Canada. (2023). *Annual Crop Inventory* [Data set]. Government of Canada. <https://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9>.

Giesting, K., Ontl, T., Baule, W., Shannon, D., Andresen, J., Wilson, A., Nowatzke, L., Todey, D. (2022). Dataset description and methods for historical and projected climate data for ag state summaries. Great Lakes Integrated Sciences and Assessments (GLISA); Northern Forests Climate Hub; Northern Institute of Applied Climate Science; USDA Natural Resources Conservation Service. https://www.climatehubs.usda.gov/sites/default/files/Methods%20for%20Historical%20and%20Projected%20Climate%20Data%20for%20Ag%20State%20Summaries_20220809.pdf.

Hunt, K. A., Abernethy, J., Beeson, P. C., Bowman, M., Wallander, S., & Williams, R. (2024). Crop sequence boundaries using USDA National Agricultural Statistics Service historic cropland data layers. *Statistical Journal of the IAOS*, 40(2), 237-246.

Matthews, Stephen N., Iverson, Louis R., Peters, Matthew P., & Prasad A. (2018). Assessing potential climate change pressures across the conterminous United States: mapping plant hardiness zones, heat zones, growing degree days, and cumulative drought severity throughout this century. Res. Map NRS-9. Newtown Square, PA: U.S. Department of

Agriculture, Forest Service, Northern Research Station. 31 p. <https://doi.org/10.2737/NRS-RMAP-9>.

Matthews, Stephen N., Iverson, Louis R., Peters, Matthew P., & Prasad, Anantha M. (2019). Climate change pressures for the conterminous United States: plant hardiness zones, heat zones, growing degree days, and cumulative drought severity. Fort Collins, CO: Forest Service Research Data Archive. <https://doi.org/10.2737/RDS-2019-0001>.

Natural Resources Canada. (2024). *National Hydro Network (NHN) – GeoBase Series* [GIS dataset]. Government of Canada. <https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977>.

Statistics Canada, (1996). "Census of Agriculture, 1996 [Canada] [Excel]", <https://doi.org/10.5683/SP3/CQOAME>, Borealis, V2 [accessed September 2025].

Statistics Canada (2001): "Census of Agriculture, 2001 [Canada] [Excel]", <https://doi.org/10.5683/SP3/E6MIKX>, Borealis, V2 [accessed September 2025].

Statistics Canada (2006). "Census of Agriculture, 2006 [Canada]: Farm Data and Farm Operator Data, Initial Release [Excel]", <https://doi.org/10.5683/SP3/9D6LKC>, Borealis, V2 [accessed September 2025].

Statistics Canada (2011). "Census of Agriculture, 2011 [Canada]: Farm Data and Farm Operator Data, Initial Release [Excel]", <https://doi.org/10.5683/SP3/QV4BPS>, Borealis, V2 [accessed September 2025].

Statistics Canada (2021). Census of Agriculture: data linked to geographic boundaries [online]. Available from <https://open.canada.ca/data/en/dataset/b944bd53-49e5-4a80-83e5-1048d3abf38d> [accessed September 2025].

Teluguntla, P., Thenkabail, P., Oliphant, A., Gumma, M., Aneece, I., Foley, D., & McCormick, R. (2023). *Landsat-Derived Global Rainfed and Irrigated-Cropland Product 30 m V001* [Data set]. NASA Land Processes Distributed Active Archive Center. <https://doi.org/10.5067/COMMUNITY/LGRIP/LGRIP30.001>.

United States Department of Agriculture (USDA) National Agricultural Statistics Service. (2025). *2024 Crop Sequence Boundaries* [Vector GIS data]. USDA NASS. https://www.nass.usda.gov/Research_and_Science/Crop-Sequence-Boundaries/.

U.S. Geological Survey. (2025). *Watershed Boundary Dataset (WBD)* [GIS dataset]. U.S. Geological Survey. <https://www.usgs.gov/national-hydrography/watershed-boundary-dataset>.