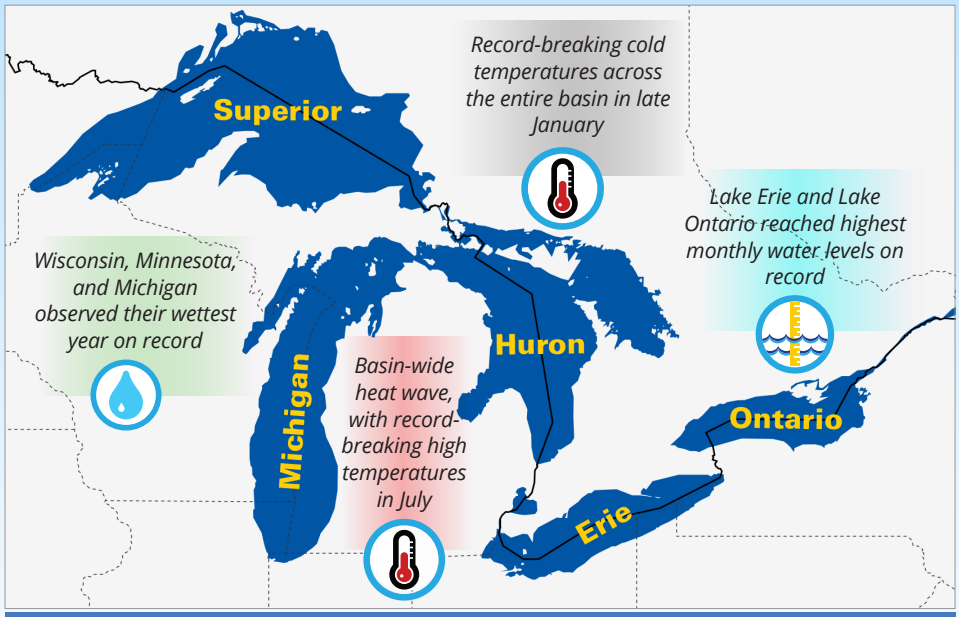
2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

During the 2019 reporting period, several notable events and trends were observed across the Great Lakes basin, including extreme cold from a polar vortex event and a period of extreme summer heat, which both set temperature records. The basin had a wet spring with impacts on water levels and agriculture. Water levels in the five Great Lakes continued to be very high, with Lake Erie and Lake Ontario reaching their highest monthly mean water level on record. Locations around the basin experienced coastal flooding and erosion due to high water levels through summer and fall. At 80.9% areal coverage, Great Lakes maximum ice cover for the year was 25% above the long-term average.



*Arrows indicate how 2019 average values compare to long-term average:

Above Below Variable

Air Temperature	Basin Precipitation	Water Temperature	Ice Cover	Water Levels
↓	↑	↓	↑	↑

2019 Highlights

High Preciptitation

Much of the basin experienced above average precipitation in the spring and several states set new annual precipitation records. Relatively cool temperatures delayed snowmelt, also contributing to overall wet spring conditions. This caused delays in crop planting, led to an above average rise in water levels on all of the Great Lakes, and contributed to flooding across the basin.

Record Water Levels

Water levels on all five Great Lakes were well above average in 2019. Heavy spring precipitation across the basin caused all of the Great Lakes to approach or exceed monthly records through the spring and summer. In June, Lakes Erie and Ontario reached their highest monthly mean levels on record. These conditions contributed to shoreline flooding around the basin that lasted through the fall. Many areas experienced accelerated coastal erosion due to strong storms that brought high winds and waves.

Extreme Temperatures

Both extreme cold and extreme heat were observed basin-wide in winter and summer, respectively. Late January saw a record cold spell from a disturbance in the polar vortex that caused Arctic air to shift southward into the Great Lakes and Midwest for several days. A heat wave in mid-July brought record high temperatures to the basin.

Photo: Lake Erie shoreline flooding, Berlin Township, MI, with Fermi II nuclear plant in background, May 5, 2019 (Credit: Monroe News / Tom Hawley)

Photo: Erosion on Lake Michigan shoreline, Manistee, MI, October 10, 2019 (Credit: Interlochen Public Radio / Gary Langley)

Environment and Climate Change Canada
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2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Climate Overview: December 2018 - November 2019

The December 2018 – November 2019 reporting period* was characterized by high variability in temperature and precipitation. Despite above average global temperatures in 2019, mean annual temperatures across the Great Lakes region were near average to slightly below average by -0.5 to -1.5 °C (Figure 1a). Annual precipitation totals were above average (10 to 25%), particularly in southwestern areas of the basin (Figure 1b). Wet and cold conditions characterized the first half of 2019 for parts of the basin, giving way to much warmer and drier conditions in the latter half of the year. Most of the Great Lakes region experienced record-breaking cold in January, as well as a heat wave and August drought.

Annual water temperatures for all of the Great Lakes were below their long-term averages. Basin-wide precipitation, runoff, and evaporation totals were greater than normal in 2019, consistent with long-term trends. Over the period from 1981-2010 across the region, air temperature (+0.26 °C/decade), precipitation (+23.4mm/decade), evaporation (+19.9mm/decade), and water temperatures (+0.53 °C/decade) have all increased. Highlights and links to additional data are given in the sections below.

**This report utilizes climatological seasons, which includes December from the previous year as part of the winter season.*

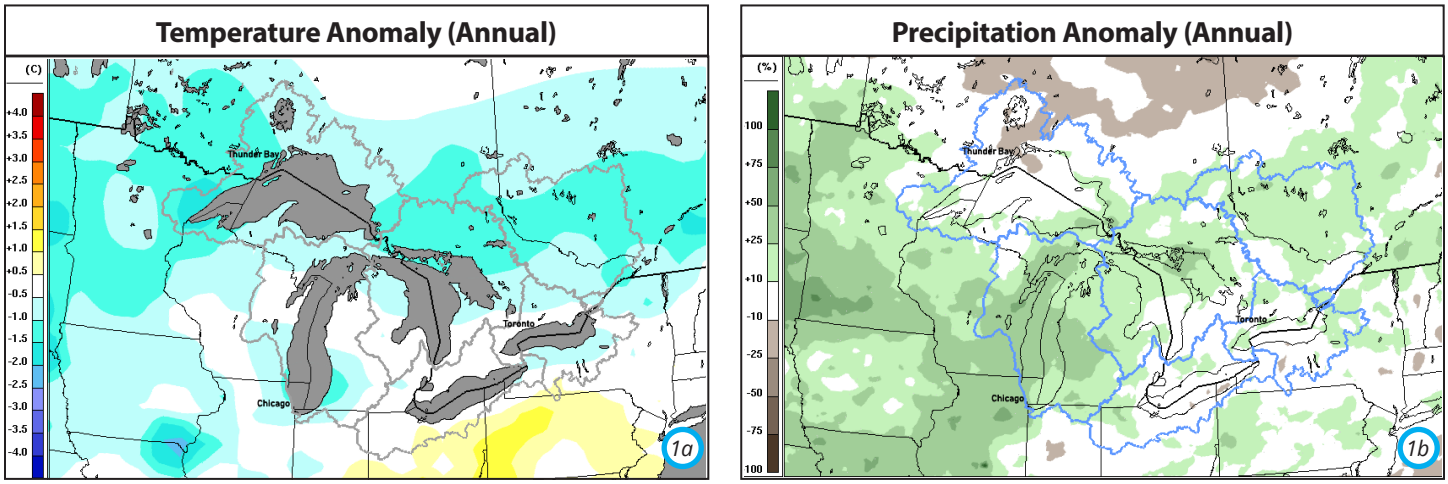

Figure 1. Maps displaying annual anomalies for temperature (1a) and total precipitation accumulation (1b) in the Great Lakes region. Anomalies for temperature are departures from the 1981-2010 mean. Anomalies for precipitation are % departure from the 2002-2018 mean. Gray/blue outlines depict the individual lake basins. Data for temperature are from ECCC and NOAA surface observations and precipitation is a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. Figures created by ECCC.

***LTA: Long-Term Average*

		Superior		Michigan		Huron		Erie		Ontario	
		2019	LTA	2019	LTA	2019	LTA	2019	LTA	2019	LTA
Water Temps (°C)	Max	16.60	17.65	21.75	22.52	20.41	21.32	24.86	24.94	23.18	23.43
	Min	0.20	0.62	0.86	1.24	0.20	0.59	0.20	0.33	1.12	1.25
	Avg	6.08	6.57	9.12	9.70	8.24	8.88	11.24	11.35	9.83	10.28
Ice Cover (%)	Max	94.9	61.6	55.8	40.1	95.7	64.6	94.3	82.4	39.8	30.0

		Superior		Michigan-Huron		Erie		Ontario	
		2019	LTA	2019	LTA	2019	LTA	2019	LTA
Water Levels (meters)	Max	183.88	183.57	177.37	176.59	175.14	174.38	75.91	75.09
	Min	183.57	183.23	176.81	176.23	174.60	173.89	74.71	74.42
	Avg	183.74	183.41	177.11	176.42	174.83	174.15	75.24	74.76
Precipitation (millimeters)	Ann Sum	891.6	711.6	852.8	794.4	1030.7	842.4	1045.4	859.2
Evaporation (millimeters)	Ann Sum	579.0	556.8	554.4	504.0	918.2	896.4	657.0	650.4

*Table 1: Summary of hydro-climate variables by lake. Long-Term Average (LTA) changes depending on variable: **Water Temps (°C) --** 2019: Dec 2018 - Nov 2019, LTA: Dec 1992 - Nov 2018; **Ice Cover (%)** -- 2019: Dec 2018 - May 2019, LTA: 1973-2018; **Water Levels (meters)** -- 2019: Dec 2018 - Nov 2019, LTA: Period of Record (Dec 1918 - Nov 2018); **Precipitation (mm) --** 2019: Dec 2018 - Nov 2019, LTA: Dec 1981 - Nov 2010; **Evaporation (mm) --** 2019: Dec 2018 - Nov 2019, LTA: Dec 1981 - Nov 2010. Estimated from NOAA Great Lakes Surface Environmental Analysis (water temps), NOAA GLERL CoastWatch (ice cover), US Army Corps of Engineers (lake levels), NOAA GLERL Great Lakes Hydrologic Data (precipitation and evaporation).*

****Lakes Michigan and Huron are treated as one unit for water levels, precipitation, and evaporation since there is no physical separation between the lake bodies.*

2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Historical Trends

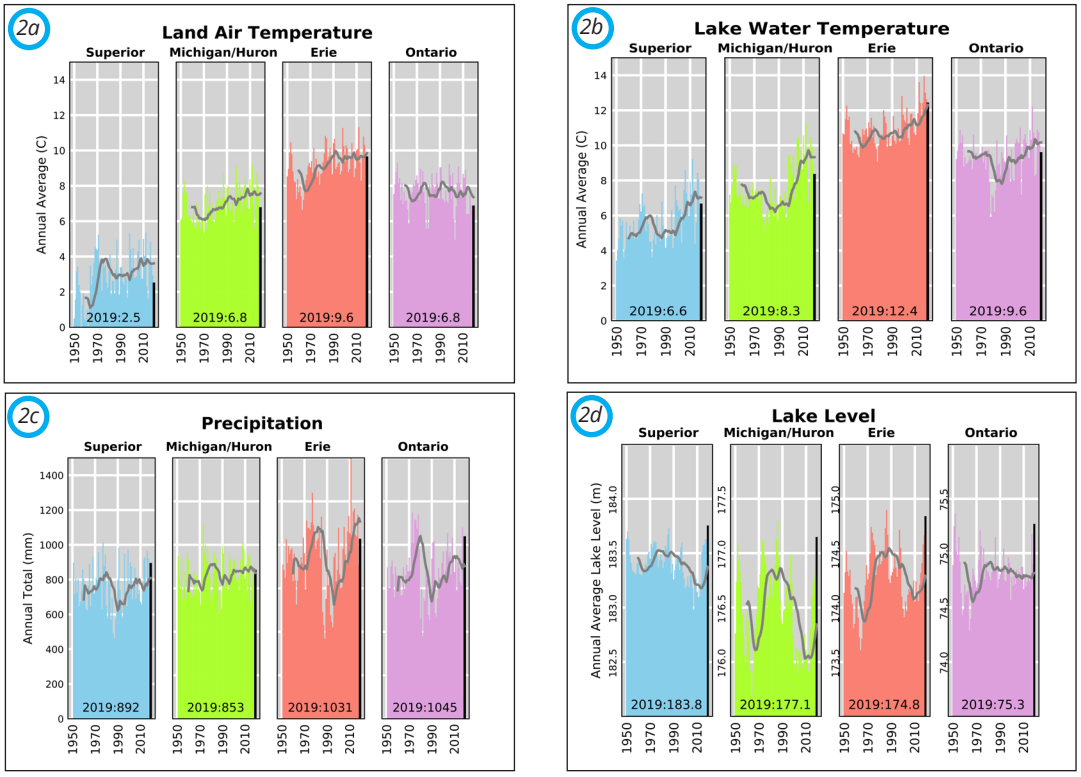

Figure 2. Time series of air temperatures (2a), water temperatures (2b), precipitation (2c), and water levels (2d) by lake basin from 1950-2019. The grey line is a 10-year moving average and the black line is the 2019 average. Estimated from GLERL Great Lakes Monthly Hydrologic Data, and Coordinating Committee on Great Lakes Basin Hydraulic and Hydrologic Data.

Air (Figure 2a) and water temperatures (Figure 2b) were near or below the 10-year average for each lake basin in 2019. There has been an upward trend in both air and water temperatures in recent years that is particularly notable in the upper Great Lakes and their basins. Annual precipitation accumulation (Figure 2c) in 2019 was above the 10-year average for the Superior and Ontario basins and near the 10-year average for the Michigan/Huron and Erie basins. This follows a general upward trend observed in recent years, though substantial interannual variability is common. Water levels remained above the 10-year average on all of the Great Lakes in 2019, with several exceeding record highs (Figure 2d). Lake levels have risen since 2013 after a period of low lake levels lasting from the 1990s to the mid-2000s.

Temperature Highlights: Extreme Winter Cold, Summer Heat Wave

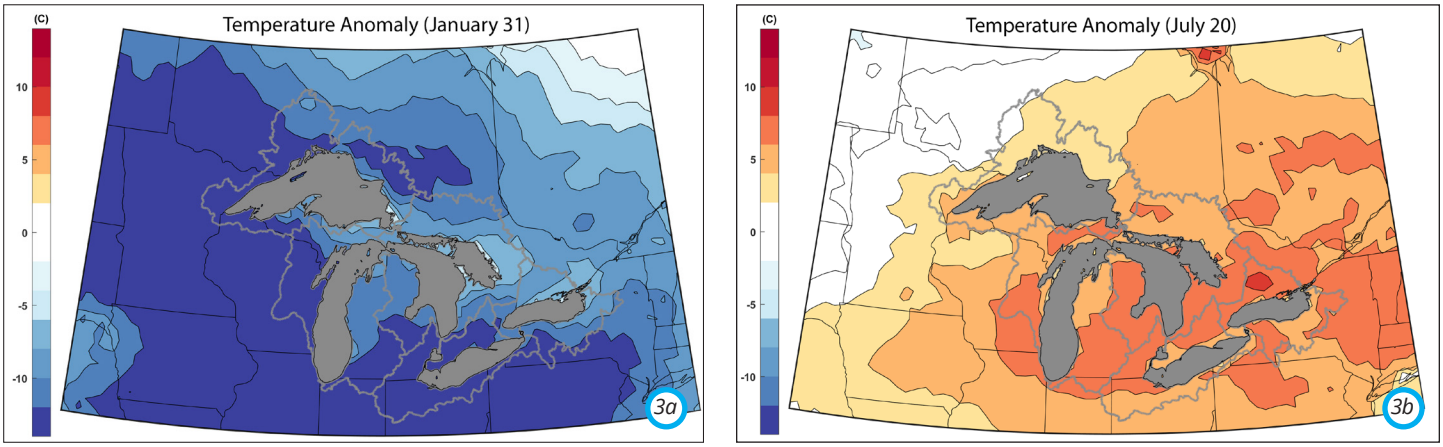

Figure 3. Temperature anomalies (vs. 1981-2010 mean) for Jan 31 (3a) and July 20 (3b). Gray outlines depict the individual lake basins. Estimated from the North American Regional Reanalysis (NARR) combined model and assimilated dataset.

Periods of extreme cold and extreme heat both occurred in 2019. During late January, an Arctic air mass shifted south and caused a prolonged cold period over the entire basin from January 29 to February 1, with many areas experiencing all-time record lows (Figure 3a). Locations like Chicago, IL (-23 °C), and Cotton, MN (-32 °C), set all-time low records for maximum daily temperature. Some locations in Minnesota saw temperatures reach as low as -45 °C. Several of the lakes experienced rapid ice formation during this time, with Lake Erie's ice cover growing from 20% to 90% in one week. Some locations in the western basin observed a rise of over 21 °C in the days following this event.

The basin experienced a heat wave from July 16-21 that set temperature records around the region (Figure 3b). Chicago set a record high minimum temperature of 27 °C and Alpena, MI, set a maximum temperature record of 35 °C. Humidex values (apparent temperature with humidity) were also extremely high, reaching 46 °C in Windsor, ON. This heat wave created dangerous outdoor conditions and was tied to two deaths in the Chicago area.

2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

High Lake Levels

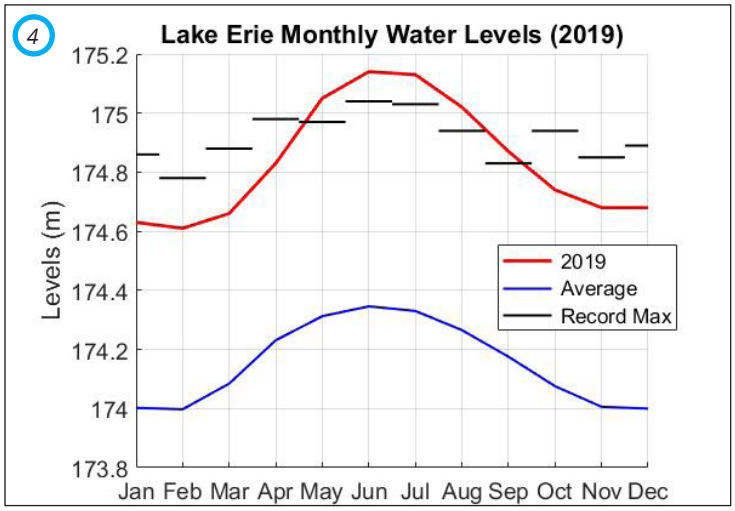

Figure 4. 2019, historical average, and record lake levels for Lake Erie. Average levels based on 1918-2018 mean. Estimated from US Army Corps on Engineers data.

In 2019, water levels on all five of the Great Lakes were well above their long-term average. New monthly mean water levels records were set on Lake Superior and Lake Erie for the months of May through September, and on Lake Ontario for the months of June and July. The June monthly mean levels on Lake Erie and Lake Ontario were the highest on record. At the start of 2019, all five lakes began with conditions similar to the start of 2018, but they rose more than average in the spring and summer months to reach these records, mainly due to higher than average spring precipitation. This led to flooding events and prolonged shoreline erosion around the basin, including Detroit, MI; Buffalo, NY; Traverse City, MI; and Chicago, IL.

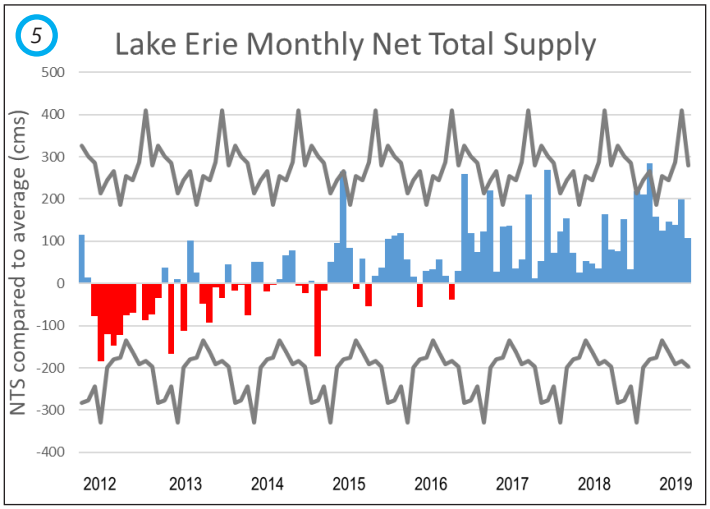

Figure 5. Lake Erie monthly net total supply (NTS = precipitation + runoff + inflow – evaporation). Red bars depict months with below average NTS, blue bars depict above average NTS. Gray lines depict the long-term monthly minimum and maximum NTS. Estimated from the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

High water levels in 2019 followed an increasing trend in the lakes' net total water supply (i.e. the sum of precipitation, runoff, and upstream inflow into the lake minus evaporation from the lake). Lake Erie's net total supply has not had a month below average since 2016, and had only a small number of below average months since 2014 (Figure 5). These conditions represent a shift from the previous decade, where net total supplies saw significantly more months below average, contributing to the lower lake levels during this time.

Precipitation Patterns

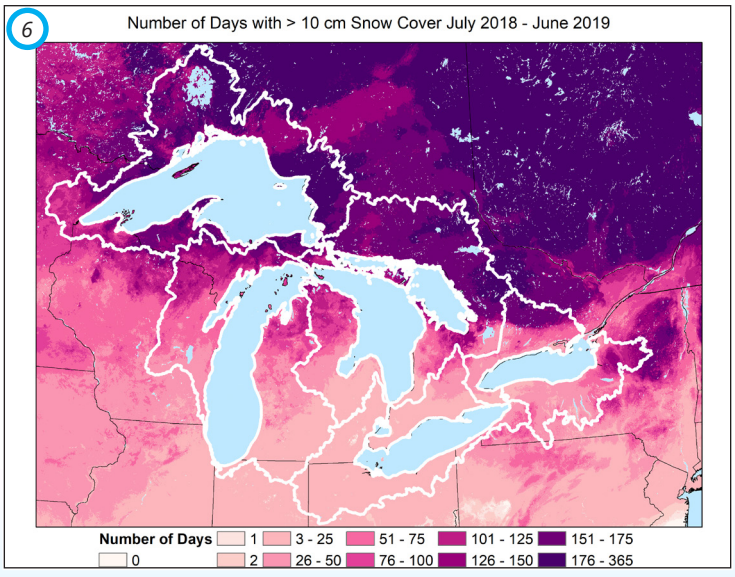

Figure 6. Days with > 10 cm snow cover July 2018-June 2019. White outlines depict the individual lake basins. Estimated from the NOAA National Operational Hydrologic Remote Sensing Center (NOAA NOHRSC) model output.

A multi-year stretch of above average net total supply for the Great Lakes has been mainly driven by precipitation trends, with the previous 12 seasons (3 years) seeing above average precipitation in most of the basin. Particularly wet conditions in the spring of 2019 contributed to the above average increase in water levels in 2019. Minnesota, Wisonsin, and Michigan all observed their wettest year on record.

Snowfall in the northern part of the basin also contributed to spring shoreline flooding, when the delayed runoff from snowpack melt contributed to an above average rise in water levels. Days with substantial snow cover (> 10 cm) across the region ranged from 3-25 days in the southern portions of the basin to more than 176 days in the northern reaches of the basin (Figure 6). Much of the region saw fewer days with snow cover during the period from July 2018-June 2019 when compared to July 2017- June 2018, especially the areas around Lake Superior and Lake Huron. Exceptions to this occurred in Southeastern Ontario, the north-east lower peninsula of Michigan, and southern Wisconsin, which experienced more days with substantial snow cover over the same period.

2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Major Climatic Events

Winter 2018-2019

- Record-breaking cold impacted the entire basin in late January into early February, with all-time record low temperatures set at several stations.
- January monthly snowfall for Toronto, ON, was more than double the average for the month.
- Several locations in the northern region of the U.S. basin had record or near record snowfall in February, including Duluth, MN, and the upper peninsula of Michigan.
- Snow load and structural risk was an issue in Ontario between February to mid-March due to the combination of thick snowpack and several thaw or short rain events.
- Cold conditions and high winds led to ice being pushed onshore along Lake Huron and Lake Erie in late February.

Photo: Ice from Lake Erie pushed onshore in Buffalo, NY, February 25, 2019 (Credit: Buffalo News / Derek Gee)

Spring 2019

- Great Lakes ice cover reached its peak this year on March 8 at 80.9%, which was greater than the long-term average ice coverage of 55.7%.
- Across much of the basin, precipitation was extremely persistent for the month of May, with many locations setting records for the most days in May with measurable precipitation.
- May monthly mean water levels on Lakes Superior, St. Clair, and Erie surpassed their May record high water levels.
- Above normal precipitation throughout the spring led to several major flooding events, delayed planting, and near record or record-breaking high lake levels across the basin.

Photo: Saturated soybean field, Jasper, MI, May 2019 (Credit: Detroit Free Press / Eric Seals).

Summer 2019

- Eight Great Lakes monthly mean high water level records were broken and two records were nearly matched for the months of June through August.
- Continuous wet conditions through June and early July led to delayed crop planting, or in some cases, no planting at all.
- A heat wave occurred from July 16-21, setting many record maximum and record high minimum temperatures across the basin.
- A new 24-hour rainfall record of 328 mm for the state of Michigan was set on July 20 in Branch Township (Mason County).

Autumn 2019

- The ongoing wet conditions across the basin continued into the fall, impacting the ability to harvest crops and carry out fall field work.
- For much of the basin, October was warmer and wetter than normal until a Halloween storm swept through the region, leading into a November that was colder and drier than average.
- Water levels remained near record high through the fall, which contributed to shoreline flooding and coastal erosion, especially during high wave events when strong wind conditions occurred.

2019 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

New Research, Applications, and Activities

This section highlights research findings from across the region from the previous year. Findings from these efforts have implications for a wide range of sectors across the region, improve the understanding of regional climate, and show promise for informing planning efforts and policy implementation in the Great Lakes.

Regional Modeling & Natural Resources

- By the 2080s, 100-year floods will increase in most Midwestern rivers and peak flows will start earlier in the year, as demonstrated by Variable Infiltration Capacity (VIC) modeling of watersheds (Byun et al. 2019).
- A new assessment shows climate change impacts on groundwater resources (e.g., levels, recharge, soil moisture) of the Grand River Watershed, that are heavily modulated by local features (Erler et al. 2019).
- An overall increase in the Great Lakes net basin supply from 1953 to 2100 is projected by 28 climate change simulations from five NA-CORDEX regional climate models (Mailhot et al. 2019).
- "Hyperscale" modeling demonstrates the temperature record of thousands of midwestern lakes (1979-2019) and explains these changes in terms of lake ecosystems (Read 2019).
- Fine resolution models show the roles of lake bathymetry and climate factors in Great Lakes surface temperature from 1982-2012, including amplified warming in Lake Superior, central-northern Lake Michigan, and central Lake Huron (Zhong et al. 2019).
- A framework and tools are provided for identifying distribution of optional and vulnerable habitats with climate change, using a case study on the Great Lakes Basin (U.S. side) (McKenna 2019).
- Recent lake level fluctuations induced by weather extremes and climate variability, including the Lake Ontario flood of 2017 and the preceding extended period of low water levels, cannot be reasonably attributed to water management (Gronewold and Rood 2019).
- Future warming may lead to less nutrient runoff in Lake Erie, as evidenced by running the Soil and Water Assessment Tool for Maumee River watershed (flowing into Lake Erie) using climate projections for 2046-2065 as inputs (Kalcic et al. 2019).
- Variable amounts and character of nutrients and dissolved organic matter (DOM) are delivered to Lake Superior by tributaries, which has expected implications related to climate change (Marcarelli et al. 2019).

Adaptation & Resilience

- Regional experts published a synthesis report for policy makers and the public that evaluates Great Lakes climate impacts, including shorelines, regional land use, biodiversity, and urban cities (Wuebbles et al. 2019).
- Municipalities can make an effective case for local climate action, based on a report co-produced with 13 different communities (Lawson 2019).
- A new guide identifies priority areas for coordinated action in the Chequamegon Bay Area, as developed from a community survey with up-to-date estimated climate change impacts to the region (Kemkes and Salmon-Tumas 2019).
- The Great Lakes Indian Fish and Wildlife Commission published general guidance for working with Indigenous communities, using a framework for culturally appropriate climate adaptation planning for tribes and non-tribal partners (Tribal Adaptation Menu Team 2019).
- McMaster University is partnering with the community of Port Hope and the City of Hamilton (public works) in support of climate change planning and action (Northumberland News).
- The Ontario Climate Consortium performed an assessment of the strengths, limitations, and knowledge gaps in Great Lakes climate modeling (Delaney and Milner 2019).
- A report on the conditions leading to the 2017 Lake Ontario high water levels synthesizes climate change research on future water levels, and recommends a new 100-year flood level for Toronto Island (Baird et al. 2019).
- The Northern Institute of Applied Climate Science developed and led 21 climate and adaptation workshops for regional organization and Hub partners, providing direct training to more than 400 natural resource professionals (Northern Institute of Applied Climate Science).
- The Red Rock Indian Band collaborated with Lakehead University and the Grand Portage Band of Lake Superior Chippewa to identify valued ecosystem components, assess vulnerabilities and plan for adaptation from an Anishinaabe perspective.

About This Document

Coordinated by a partnership between climate services organizations in the U.S. and Canada, this product provides a synthesis report summarizing the previous years' climate trends, events, new research, assessments, and related activities in the Great Lakes Region. This product is a contribution to the U.S.-Canada Great Lakes Water Quality Agreement, through Annex 9 on Climate Change Impacts, and to the national climate assessment processes in the U.S. and Canada. It should be cited as: Environment and Climate Change Canada and the U.S. National Oceanic and Atmospheric Administration. 2019 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2020. Available at https://binational.net.

Contributing Partners

Environment and Climate Change Canada
canada.ca/en/environment-climate-change

Great Lakes Environmental Research Laboratory
glerl.noaa.gov

Great Lakes Integrated Sciences and Assessments
glisa.umich.edu

Great Lakes Water Quality Agreement
binational.net

Illinois-Indiana Sea Grant
iiseagrant.org

Midwestern Regional Climate Center
mrcc.isws.illinois.edu

National Oceanic and Atmospheric Administration
noaa.gov

Northeast Regional Climate Center
nrcc.cornell.edu

Contact Information

NOAA: glisa-info@umich.edu | ECCC: ec.enviroinfo.ec@canada.ca

For additional figures, information, and sources visit:
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