LAKE ERIE DISSOLVED OXYGEN MONITORING PROGRAM

TECHNICAL REPORT

Dissolved Oxygen and Temperature Profiles for the Open Waters of the Central Basin of Lake Erie during Summer/Fall of 2020

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Great Lakes RESTORATION

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Cover photo: *Sunrise over Lake Erie, Edgewater Park, Cleveland, Ohio.* Photo by Michael Wheeler. Used with permission.

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1 EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) Great Lakes National Program Office (GLNPO) Lake Erie Dissolved Oxygen Monitoring Program annually monitors the oxygen and temperature profiles at 10 fixed stations in the central basin of Lake Erie during the stratified season to assess water quality trends and measure progress made in achieving water quality improvements.

In 2020, disruption of field sampling due to the COVID-19 pandemic resulted in reduced temporal and spatial sampling for this program. Specifically, during the course of the 2020 sampling season (August 11 – September 24):

- Only four of the six scheduled surveys were completed during the 2020 field season (all conducted aboard the USGS R/V *Muskie*).
- Only the five stations within U.S. waters could be sampled during 2020 due to the Canada - United States border restrictions.
- Surface water temperatures reached their highest level, 23.8°C, during the second survey (August 25, 2020) before decreasing, while hypolimnion temperatures increased from 11.78°C to 13.8°C over the four surveys.
- Low-oxygen conditions (< 6 mg O_2/L) were recorded during the first survey on August 11, 2020.
- By September 9, 2020, all stations where a hypolimnion was present experienced anoxic conditions (< 1 mg O_2/L).
- The annual corrected oxygen depletion rate for 2020 was not calculated due to the reduced amount of spatial and temporal data collected.

While the reduced sampling during the 2020 stratified season precluded a full comparative analysis and trends assessment, the data collected with assistance from USGS provided important information on Lake Erie central basin hypolimnion conditions.

2 INTRODUCTION

Lake Erie has been severely impacted by excessive anthropogenic loadings of phosphorous resulting in abundant algal growth and is a factor that contributes to dissolved oxygen (DO) depletion in the bottom waters of the central basin. Total phosphorus loads to Lake Erie reached their peak in the late 1960s and early 1970s with annual loads in excess of 20,000 metric tonnes per annum (MTA) (Maccoux et al., 2016). In 1978, Canada and the United States signed an amendment to the 1972 Great Lakes Water Quality Agreement (GLWQA) that sought to reduce total phosphorus loads to Lake Erie to 11,000 MTA. In order to determine if the areal extent or duration of the oxygen-depleted area was improving or further deteriorating, annual monitoring of the water column for thermal structure and DO concentration was needed throughout the stratified season. The U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office (GLNPO) established the Lake Erie Dissolved Oxygen Monitoring Program in 1983. This program was designed to collect necessary DO concentration data to calculate an annual normalized rate of DO depletion in the central basin of Lake Erie. Additionally, these data could be used by federal and state water quality agencies to assess the effectiveness of phosphorus load reduction programs.

Numerous phosphorus reduction programs were implemented in support of the GLWQA, and by the early 1980s, the annual phosphorus load to Lake Erie had been reduced to near targeted amounts (Dolan, 1993). Correspondingly, the load reduction resulted in the decrease of the total area affected by low oxygenated waters (Makarewicz and Bertram, 1991). By the mid-1990s, the total extent of the hypoxic area (DO levels < 2 mg/L) had decreased in size compared to observations from previous decades. However, by the 2000s the annual extent of area affected by hypoxia had increased, returning to the larger areal extent seen in the late 1980s (Zhou et al., 2013). The annual average hypoxic area in the central basin since the early 2000s is approximately 4,500 km^2 (1,737 mi^2) (U.S.EPA, 2018a), while the largest hypoxic extent recorded in the past decade – 8,800 km^2 (3,398 mi^2) – occurred in 2012, following the record-setting algal bloom in 2011 (U.S. EPA, 2018a).

Hypoxia in Lake Erie reduces habitat and food supply for fish and complicates drinking water treatment (Rowe et al., 2019).

In 2012, the GLWQA was updated to enhance water quality programs that ensure the “chemical, physical and biological integrity” of the Great Lakes (Canada and United States, 2012). As part of Annex 4 (Nutrients Annex) of this agreement, the governments of the United States and Canada adopted the following Lake Ecosystem Objectives:

- minimize the extent of hypoxic zones in the waters of the Great Lakes associated with excessive phosphorus loading, with particular emphasis on Lake Erie;
- maintain the levels of algal biomass below the level constituting a nuisance condition;
- maintain algal species consistent with healthy aquatic ecosystems in the nearshore Waters of the Great Lakes;
- maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the Waters of the Great Lakes;
- maintain an oligotrophic state, relative algal biomass, and algal species consistent with healthy aquatic ecosystems, in the open waters of Lakes Superior, Michigan, Huron and Ontario; and
- maintain mesotrophic conditions in the open waters of the western and central basins of Lake Erie, and oligotrophic conditions in the eastern basin of Lake Erie.

GLNPO continues to monitor the thermal structure and DO concentrations in the central basin of Lake Erie throughout the stratified season each year. The ongoing monitoring ensures that data are available to assess the objectives put forth in the GLWQA, and also allow for the evaluation of status and trends over time. This report summarizes the results of the 2020 Lake Erie Dissolved Oxygen Monitoring Program survey and places those results within the context of historical data, where possible.

3 METHODS

Typically, 10 fixed stations (Figure 1) in the offshore waters of the central basin are sampled at approximately 3-week intervals, during the stratified season (June-October). Sampling usually begins in early June, when the water column begins to stratify, or separate, into a warmer upper layer (epilimnion) and a cooler bottom layer (hypolimnion) and typically concludes in late September to mid-October just before the water column seasonally destratifies, or “turns over,” and assumes a uniform temperature profile. The EPA R/V *Lake Guardian* is used as the sampling platform whenever scheduling and other operating constraints permit. In the event that the R/V *Lake Guardian* is not available for one or more scheduled sampling times, or additional surveys are scheduled, alternate vessel support is used to conduct the sampling.

Due to health and safety concerns associated with the novel COVID-19, all R/V *Lake Guardian* sampling activities, including all scheduled DO surveys, were suspended for the 2020 field season. The USGS R/V *Muskie* was used to conduct all surveys during 2020. Additionally, because of attempts to limit the spread of COVID-19, the United States and Canada temporarily restricted all non-essential travel across its borders beginning on March 21, 2020. As a result, the R/V *Muskie* could not enter Canadian waters, and therefore only five stations within the U.S. waters of Lake Erie could be sampled during 2020.

At each station visit, the thermal structure of the water column is recorded by an electronic profiling CTD (Conductivity, Temperature, Depth (pressure) sensor) while DO concentrations are measured and recorded by an additional oxygen sensor integrated into the CTD instrument package. For 2020, a SeaBird Scientific SBE 19plus V2 SeaCAT Profiler CTD was used for collecting water temperature data, and a SBE43 Dissolved Oxygen Sensor integrated into each of the SBE CTDs was used for collecting DO data.

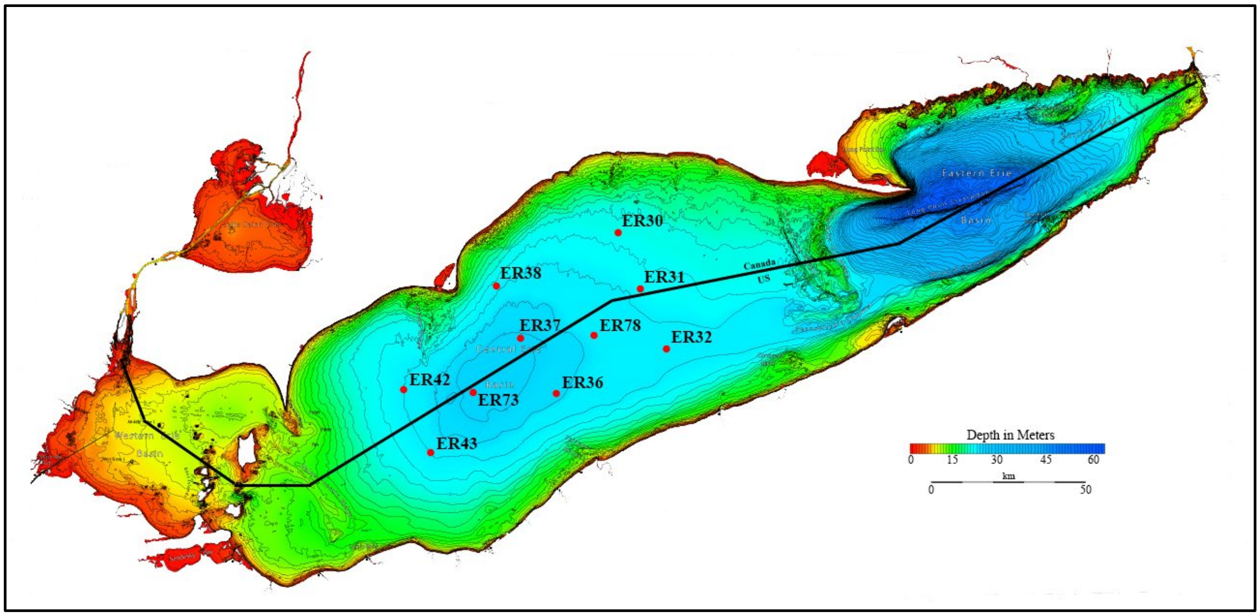

Figure 1. Map of GLNPO dissolved oxygen (DO) monitoring stations in the central basin of Lake Erie. Solid black line demarcates the US-Canada border. Stations sampled during 2020 include: ER43, ER73, ER36, ER78 and ER32.

The resulting temperature and DO depth profiles, which provide a visual display of the thermal structure and DO content of the water (Figure 2), are normally used to calculate the annual DO depletion rate (U.S. EPA, 2018b). However, as the first half of the stratified season was not sampled, generating an annual DO depletion rate would not have been an accurate representation of what occurred during this season. As such, no depletion rate was calculated for the 2020 field season.

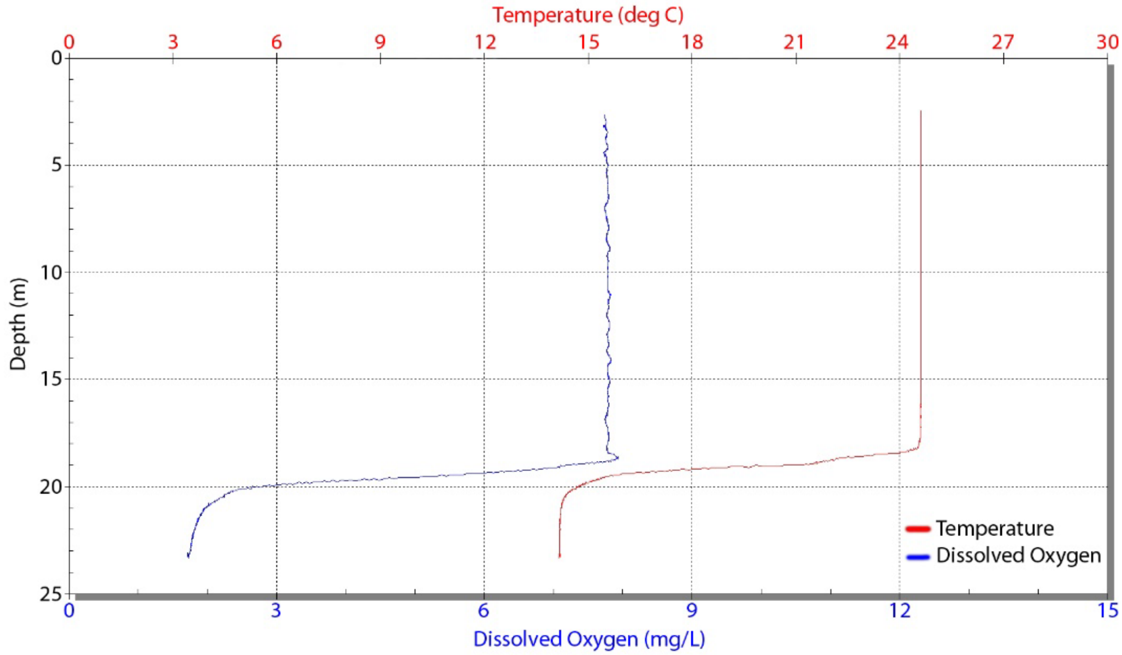

Figure 2. Example of a temperature and DO depth profile from Lake Erie central basin in late summer.

Quality Assurance samples were collected at two of the stations during each survey and used to confirm the accuracy of the sensor measurements. DO measurements from the sensor are compared to those determined by the Winkler micro-titration method (U.S. EPA, 2018b) for water samples collected at 2 meters below the surface and at 1 meter above the lake bottom. Temperature measurements from the sensor are compared to surface water thermometer readings obtained from the hull mounted transducer on the research vessel.

After each survey, water temperature and DO concentration data from the CTDs are averaged for the epilimnion and hypolimnion. A grand mean of hypolimnion DO concentration is calculated for each station to generate a map of bottom DO concentrations for the central basin of Lake Erie at the time of sampling.

To reduce the amount of inter-annual variability in DO data from Lake Erie, an annual corrected oxygen depletion rate is calculated using a Microsoft Access program (LakeErieDOv05.mdb). This software statistically adjusts the data for vertical mixing and seasonable variability and normalizes it to a constant temperature and hypolimnion thickness according to the procedures used by Rosa and Burns (1987). The resultant or "corrected" annual rate of DO depletion (mg O_2/L/month) is artificial for any given year but permits the identification of time trends with more precision.

4 QUALITY ASSURANCE AND QUALITY CONTROL

GLNPO's DO monitoring surveys operate under an approved Quality Management Plan, a Quality Assurance Project Plan (QAPP), and standard operating procedures (U.S. EPA, 2020). In 2020, QAPP Revision 11, dated May 2018, was used (U.S. EPA, 2018b). The overall data quality objective for this project is to acquire measurements of DO and temperature at the central basin stations in Lake Erie that are representative of the actual conditions present at the time of sampling.

Acceptance criteria for DO and temperature (Table 1) are based on the Relative Percent Difference (RPD) between two independently derived measurements. By definition, RPD is the difference between two measurements divided by the average of both and is expressed as a percent value.

The accuracy criterion for acceptable DO measurements is an RPD of 10% between sensor and averaged Winkler values or an absolute difference between measurement methods of 0.5 mg/L when DO concentrations are less than 5 mg/L. A maximum RPD of 2% is the acceptable accuracy for water temperature. Acceptable levels of precision are defined as a maximum difference of 0.2 mg/L between Winkler replicates and agreement within 5% between sensor measurements for DO. Acceptable precision for water temperature was defined as agreement within 2% between sensor measurements.

Table 1. Acceptance criteria for DO and temperature data

Parameter	Accuracy criteria	Precision criteria
Temperature	2% RPD	• 2% between sensor measurements
Dissolved oxygen (≥ 5 mg/L)	10% RPD	• 0.2 mg/L between Winkler replicates • 5% between sensor measurements
Dissolved oxygen (< 5 mg/L)	0.5 mg/L absolute difference	

For this project, completeness is the measure of the number of samples obtained compared to the amount that was expected to be obtained under normal conditions. The completeness goal is to obtain DO and temperature profiles within accuracy and precision limits at 90% of all designated stations during each survey.

5 RESULTS AND DISCUSSION

During the first survey, August 11, 2020, epilimnion temperatures (23.61°C) were already near their highest recorded value for 2020 (23.88°C), which occurred during the subsequent survey, August 25, 2020.

Hypolimnion temperatures increased over all four surveys from 11.78°C on August 11, 2020 to 13.80°C on September 24, 2020 (Table 2). Low-oxygen conditions (< 6 mg O_2/L) were recorded at four of the five stations during the first survey on August 11, 2020. By September 9, 2020, all stations where a hypolimnion was sampled, were experiencing anoxic conditions (< 1 mg O_2/L) (Figure 3). The average hypolimnion DO concentration declined across all four surveys, from 4.46 mg O_2/L during the first survey, to 0.11 mg O_2/L during the last survey on September 24, 2020.

Hypolimnion thickness decreased during the first three surveys, from 4.70 m to 1.66 m before increasing again to 2.23 m during the last survey (September 24, 2020). A hypolimnion was not present at three stations sampled during the September 9, 2020 survey and at two stations sampled during the September 24, 2020 survey. Winkler precision checks exceeded the acceptance criteria for approximately 36% of the samples collected (Appendix A). However, all Winkler-CTD accuracy checks for values above 5.0 mg/L were within acceptance criteria.

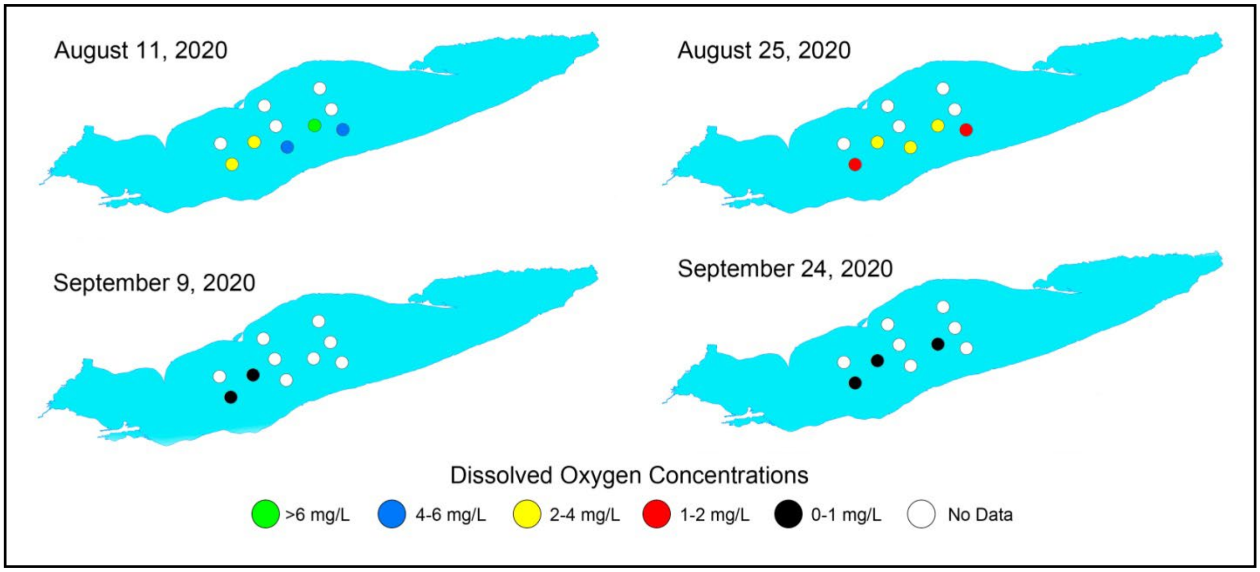

Figure 3. 2020 station means for hypolimnion DO concentrations in the central basin of Lake Erie.

Table 2. Mean water temperature (± SD) and DO for each survey in 2020*

2020 Survey dates	CTD Used	Stations (#)	Epilimnion		Hypolimnion		
			Temperature(°C)	DO (mg/L)	Temperature (°C)	DO (mg/L)	Thickness (m)
August 11	SBE 19+	5	23.61 ± 0.75	8.02 ± 0.15	11.78 ± 1.03	4.46 ± 1.56	4.70 ± 2.20
August 25	SBE 19+	5	23.88 ± 0.18	8.14 ± 0.19	12.14 ± 1.04	2.33 ± 0.72	3.34 ± 0.99
September 9	SBE 19+	2	22.25 ± 0.32	7.54 ± 0.06	13.22 ± 0.77	0.41 ± 0.25	1.66 ± 0.08
September 24	SBE 19+	3	19.17 ± 0.59	8.63 ± 0.17	13.80 ± 0.47	0.11 ± 0.01	2.23 ± 1.09

* *N indicates the number of stations used to calculate survey averages.*

6 COMPARISON TO HISTORICAL RESULTS

Due to the sampling limitations imposed on the 2020 season, comparison of the 2020 data to historical data poses some challenges. Reduction in spatial and temporal sampling hinders both within-season and long-term trend comparisons.

Over the course of the summer, DO levels in the bottom waters of Lake Erie's central basin steadily decline (Burns et al., 2005). Variability in the rate of DO depletion and the severity and duration of hypoxia are related to year-to-year differences in the thickness and temperature of the bottom water layer, and winter ice coverage. Year-to-year differences in the hypolimnion characteristics are determined by the weather over Lake Erie in the spring (i.e., average air temperature and wind velocity). Rapidly climbing air temperature with calm winds will result in a thinner, warmer epilimnion and a thicker, cooler hypolimnion that retains more DO longer into the season. A cooler, windy spring will permit the entire water column to warm before the lake stratifies, resulting in a deeper thermocline depth and a warm, thin hypolimnion that is more prone to oxygen depletion earlier in the season (Conroy et al., 2011). Furthermore, reduced ice coverage over the winter will result in earlier springtime mixing and a longer stratification period, thus increasing the risk of oxygen depletion in the hypolimnion (Perello et al., 2017).

For comparisons between years, results over a 10-year period are compared statistically using a general linear model (GLM) approach to test whether there is a significant difference in the relationship between time and either hypolimnion temperature, thickness or DO concentration (performed using the GLM procedure in SAS Version 9.4 (SAS Institute, Cary, NC). However, since the first two months of the stratified season were not sampled in 2020, such an analysis would not provide a meaningful comparison over the full 2020 season. Similarly, as a substantial amount of both temporal and spatial data was not collected in 2020 as compared to previous years, a corrected annual oxygen depletion rate was not calculated for 2020. For 1970-2019 oxygen depletion rates see *Lake Erie Dissolved Oxygen Monitoring Program Technical Report: Dissolved Oxygen and Temperature Profiles for the Open Waters of the Central Basin of Lake Erie during Summer/Fall of 2017-2019*.

Most of the hypolimnion temperature, DO and thickness data from 2020 fall near the mean values for each parameter across a 10-year period from 2011-2020 (Figures 4-6). One exception is the hypolimnion thickness during the September 9, 2020 survey. The 1.66 m thickness was the smallest value recorded over the 10-year period. However, this value is an average from only two stations, so it may not be representative of conditions throughout the entire central basin or comparable to other years where the values for survey mean hypolimnion thickness were assessed over all 10 program monitoring stations. Overall, the data collected suggest that 2020 was a relatively typical year with respect to these three parameters.

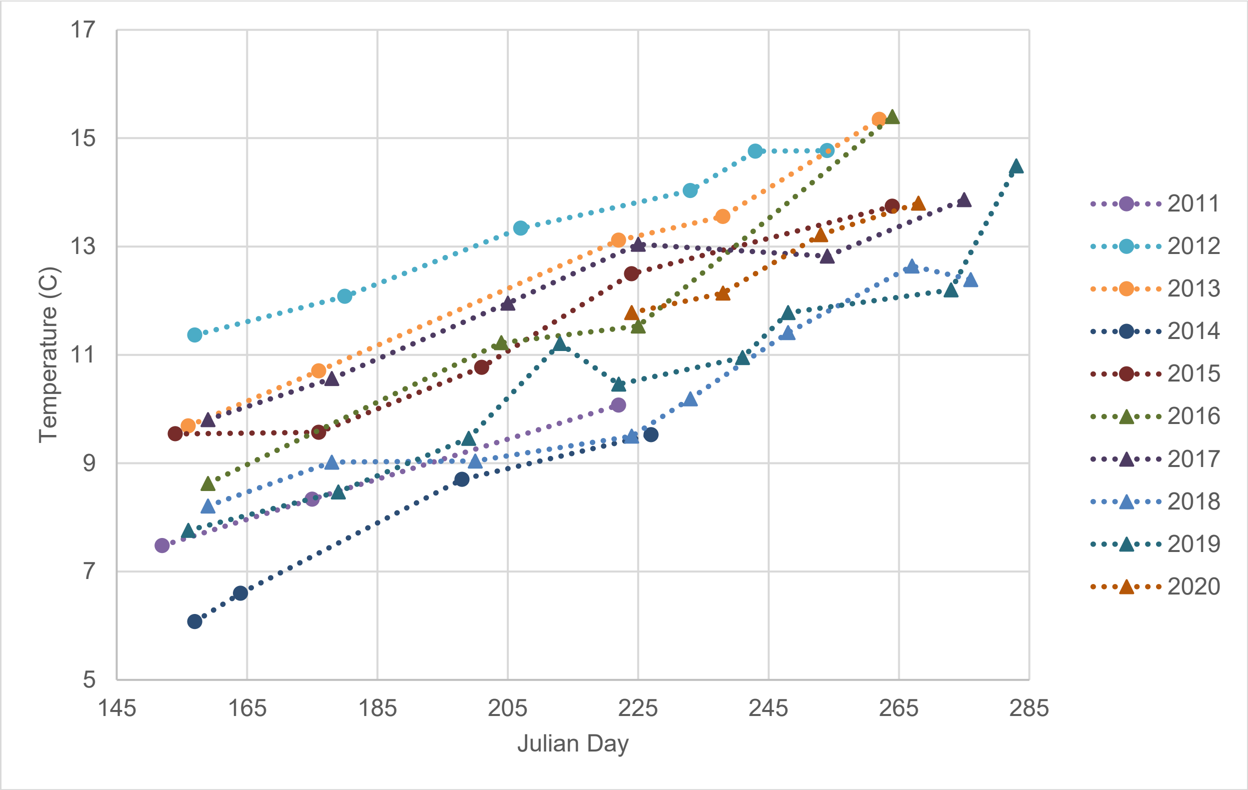

Figure 4. Survey mean hypolimnion temperatures in the central basin of Lake Erie from 2011-2020.

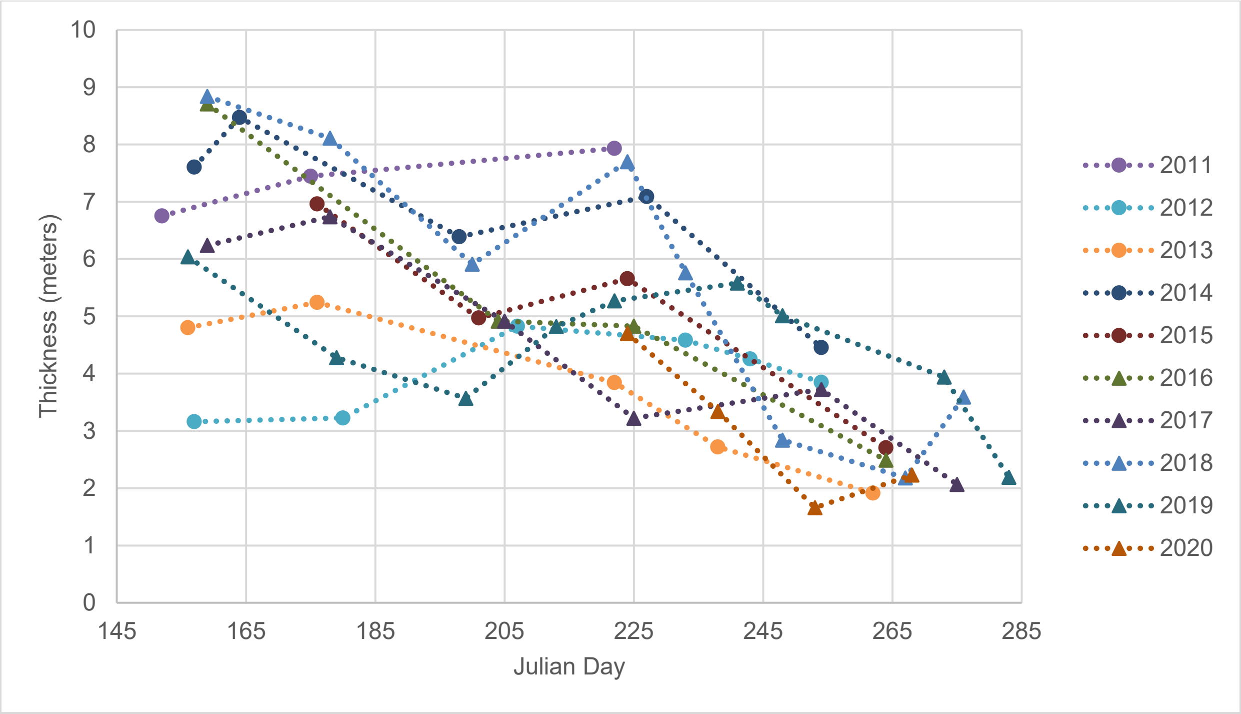

Figure 5. Survey mean hypolimnion thicknesses in the central basin of Lake Erie from 2011-2020.

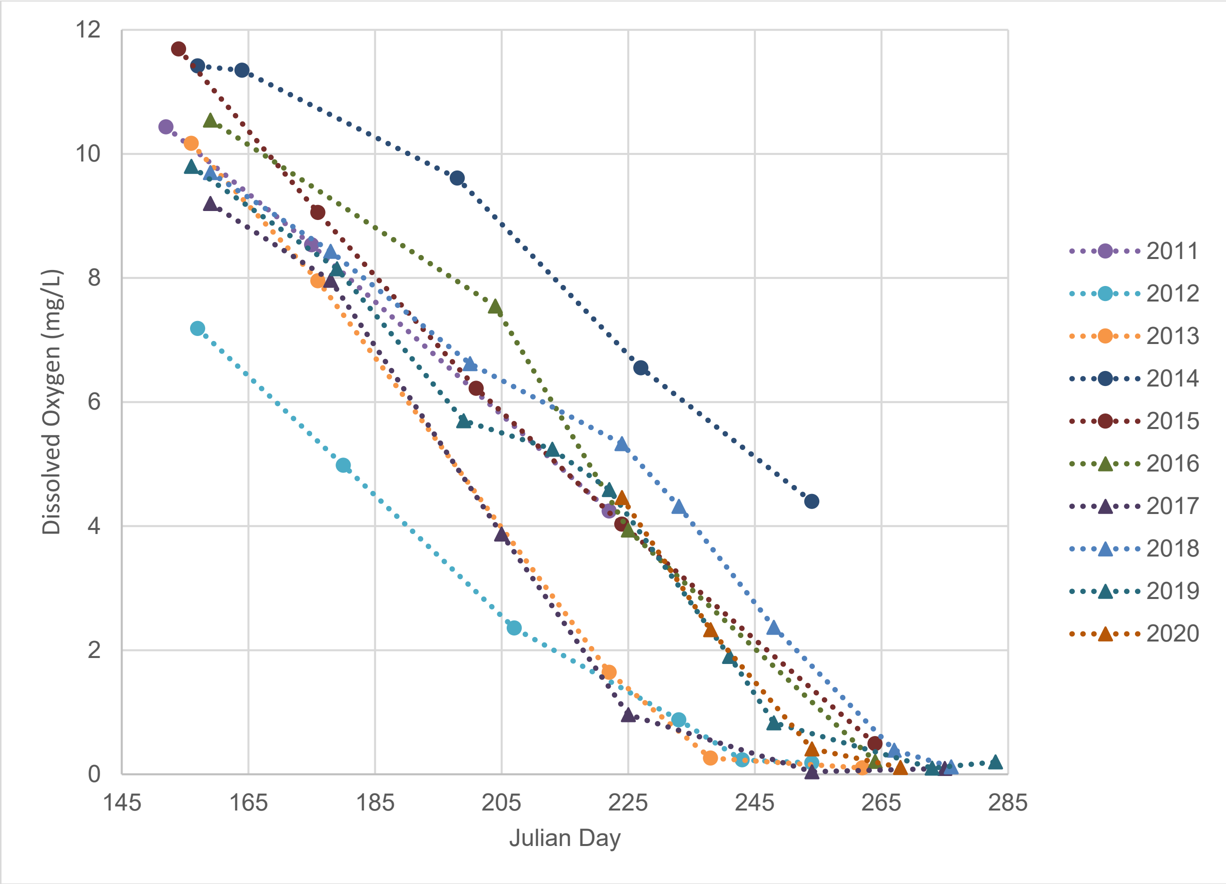

Figure 6. Survey mean hypolimnion dissolved oxygen concentrations in the central basin of Lake Erie from 2011-2020.

7 CONCLUSIONS

The U.S. EPA GLNPO Lake Erie Dissolved Oxygen Monitoring Program monitored the oxygen and temperature profiles at five fixed stations in the central basin of Lake Erie from August – September 2020 to assess water quality trends and measure progress made in achieving water quality improvements. Only a subset of the program's annual spatial and temporal data was collected and presented in this technical report, as a reduction in sampling for 2020 occurred as a result of field schedule disruptions and the Canada - United States border closure associated with the COVID-19 pandemic. While the 2020 data provide some insight into hypolimnion conditions during that year, the reduced spatial and temporal coverage during the 2020 sampling season hinders the full assessment of inter and intra-annual trends for the parameters measured. The importance of the cooperative partnerships established to support this program cannot be overstated, as no data for this program would have been collected during the 2020 field season without assistance from our USGS partners.

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APPENDIX A - QUALITY CONTROL RESULTS

A summary of 2020 results not meeting acceptance criteria is provided in the table below.

Table A-1. Quality control (QC) scorecard of 2020 CTD-collected temperature and dissolved oxygen (DO) data not meeting acceptance criteria.

Survey	Issue	Cause	Decision	Corrective Actions
August 11	Winkler precision check exceeded the QC criterion (2 of 4 samples)	Analyst error	QC sample exceedance does not affect quality of CTD data. CTD DO values are considered valid.	Additional training and/or observational period will be required for inexperienced analysts. Run additional replicate Winkler analyses until consistency is achieved.
	For samples with DO < 5 mg/L, the absolute difference between the difference between the SeaBird values and Winkler values exceeded the QC criterion (1 of 2 samples)	Due to a thin hypolimnion, thermocline or epilimnion water may have been present in the Winkler sample.	All samples where DO >5.00 mg/L were within QC criteria (3 of 3 samples). CTD DO values are considered valid.	Not Applicable
	Temperature accuracy check exceeded QC criterion (2 of 2 samples)	Temperature of the hull may be affecting the measurements from the hull-mounted transducer.	Suspected issue with QC sample methodology and does not affect quality of CTD data. CTD temperature values are considered valid.	Independent temperature sensor will be used for 2021 surveys.

Survey	Issue	Cause	Decision	Corrective Actions
August 25	Winkler precision check exceeded the QC criterion (3 of 4 samples)	Analyst error	QC sample exceedance does not affect quality of CTD data. CTD DO values are valid.	Additional training and/or observational period will be required for inexperienced analysts. Run additional replicate Winkler analyses until consistency is achieved.
	Temperature accuracy check exceeded QC criterion (2 of 2 samples)	Temperature of the hull may be affecting the measurements from the hull-mounted transducer.	Suspected issue with QC sample methodology and does not affect quality of CTD data. CTD temperature values are considered valid.	Independent temperature sensor will be used for 2021 surveys.
September 9	For samples with DO < 5 mg/L, the absolute difference between the SeaBird values and Winkler values exceeded the QC criterion (1 of 2)	Due to a thin hypolimnion, thermocline or epilimnion, water may have been present in the Winkler sample.	All samples where DO >5.00 mg/L were within QC criteria (2 of 2 samples). CTD DO values are considered valid.	Not Applicable
	Temperature accuracy check exceeded QC criterion (2 of 2 samples)	Temperature of the hull may be affecting the measurements from the hull-mounted transducer.	Suspected issue with QC sample methodology and does not affect quality of CTD data. CTD temperature values are considered valid.	Independent temperature sensor will be used for 2021 surveys.
September 24	Temperature accuracy check exceeded QC criterion (2 of 2 samples)	Temperature of the hull may be affecting the measurements from the hull-mounted transducer.	Suspected issue with QC sample methodology and does not affect quality of CTD data. CTD temperature values are considered valid.	Independent temperature sensor will be used for 2021 surveys.