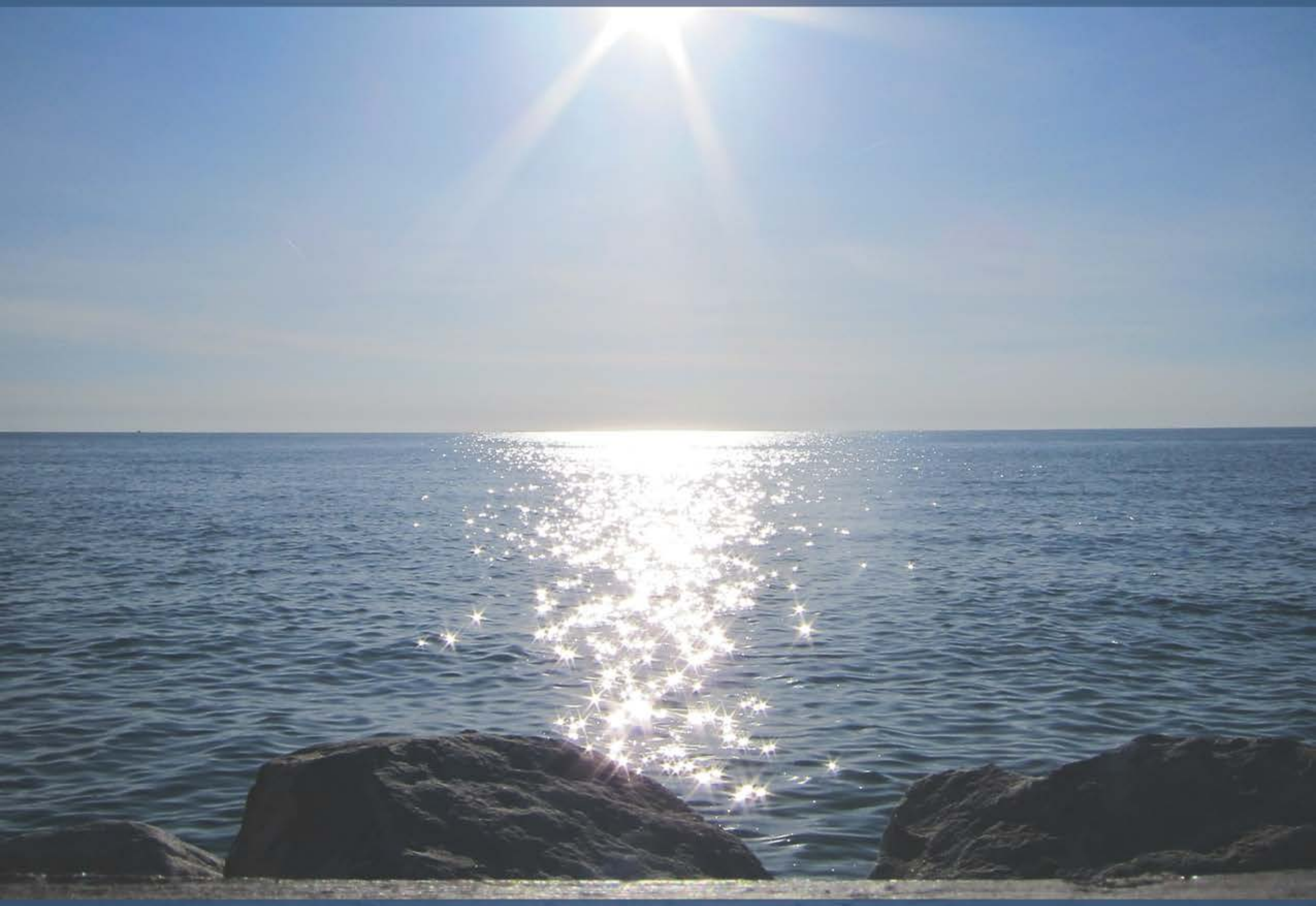
LAKE ERIE DISSOLVED OXYGEN MONITORING PROGRAM

TECHNICAL REPORT

Dissolved Oxygen and Temperature Profiles for the Open Waters of the Central Basin of Lake Erie during Summer/Fall of 2016



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Prepared By:
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Great Lakes National Program Office

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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 monitors the oxygen and temperature profiles at 10 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.

During the course of the 2016 sampling season (June 6 – September 21):

- Six surveys were conducted during the 2016 sampling season using the EPA R/V *Lake Guardian* and USGS R/V *Muskie*.
- Surface water temperatures increased from 15.1°C to 24.3°C, while hypolimnion temperatures increased from 8.6°C to 16.2°C.
- Hypolimnion dissolved oxygen (DO) concentrations during the sampling season decreased from approximately 10.5 mg O_2/L to 0.2 mg O_2/L.
- Low DO conditions (< 6 mg O_2/L) were first recorded at two stations on July 21-22, 2016.
- Hypoxic conditions (< 2 mg O_2/L) were first recorded at one station on August 11-12, 2016. Low DO (< 6 mg O_2/L) was observed at all other stations during this sampling event.
- Nine of the 10 stations were anoxic (< 1 mg O_2/L) on September 20-21, 2016.
- The annual corrected DO depletion rate was 3.38 mg O_2/L/month.

When compared to the previous 10-year record, the hypolimnion at the beginning of the 2016 sampling season was similar in temperature, but thicker and contained more DO. While surface water values are centrally located within the observed range for the last 10 years, the hypolimnion temperature became one of the warmest in recent years near the end of the season. The corrected annual oxygen depletion rate referenced above was slightly above the median for the 2007-2016 time period and was similar to the 46-year long term average from 1970-2016.

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 U.S. signed the Great Lakes Water Quality Agreement (GLWQA) which sought to reduce future phosphorus loadings 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 below 2 mg/L) had decreased such that the total impacted area was smaller (in km^2) than had been observed in previous decades. However, by the 2000s the annual area affected by hypoxia had increased, returning to the larger areal extent seen in the late 1980s (Zhou, et al., 2013). The average hypoxic area in the central basin since the early 2000s is approximately 4,500 km^2 (1,737 mi^2) (U.S.EPA, 2018), 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, 2018).

In 2012, the GLWQA was updated to enhance water quality programs to 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 U.S. and Canada are required to adapt 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. This ensures that data are available to assess the objectives put forth in the GLWQA, but also allow for the evaluation of status and trends over time. This report summarizes the results of the 2016 Lake Erie Dissolved Oxygen Monitoring Program surveys and places those results within the context of historical data.

3 METHODS

Annually, 10 sites (Figure 1) in the relatively homogenous area of the central basin offshore waters (Lesht, et al., 2018) 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, alternate vessel support is used to conduct the sampling. For 2016, the USGS R/V *Muskie* was used to conduct two surveys. 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 2016, a SeaBird Scientific SBE 911plus CTD, SBE 19plus V2 SeaCAT Profiler CTD and SBE 25plus Sealogger CTD were used for collecting water temperature data, while a SBE43 Dissolved Oxygen Sensor, which was integrated into each of the SBE CTDs, was used for collecting DO data. Comparison analyses using the standard QC criteria for the DO program are conducted to ensure comparable data are being collected between different instrumentation whenever more than one SBE CTD is used during a given season. Samples from each instrument are assessed. 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 used for calculating the annual DO depletion rate (U.S. EPA, 2016).

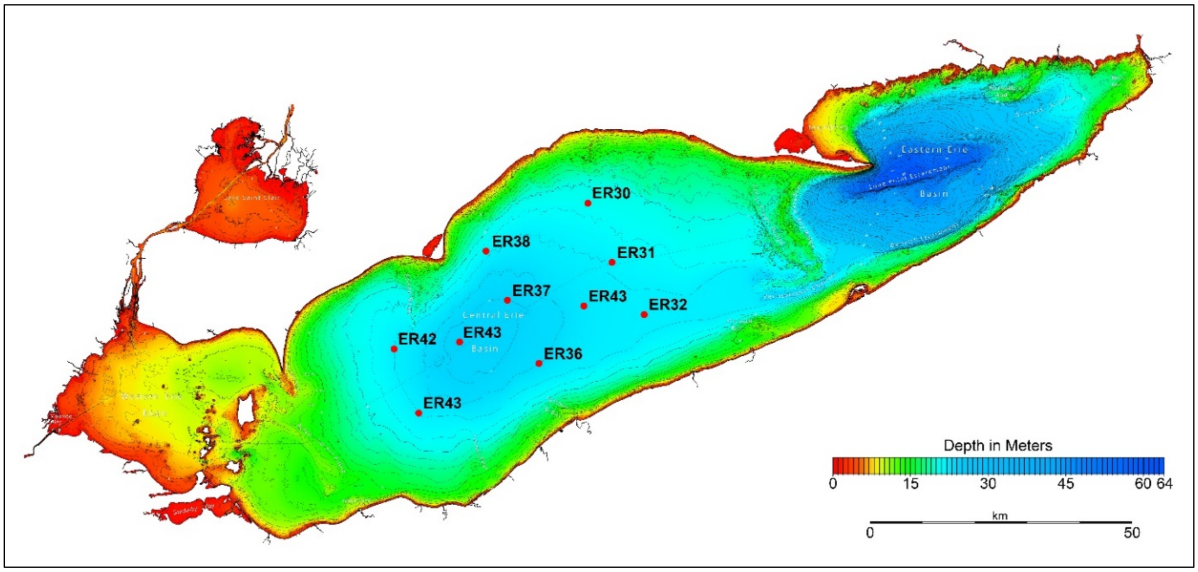

Figure 1. Map of GLNPO dissolved oxygen (DO) monitoring stations in the central basin of Lake Erie.

Quality Assurance samples are collected at two of the 10 stations during each survey and used to confirm the accuracy of the sensor measurements. Dissolved oxygen measurements from the sensor are compared to those determined by the Winkler micro-titration method (U.S. EPA, 2016) 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.

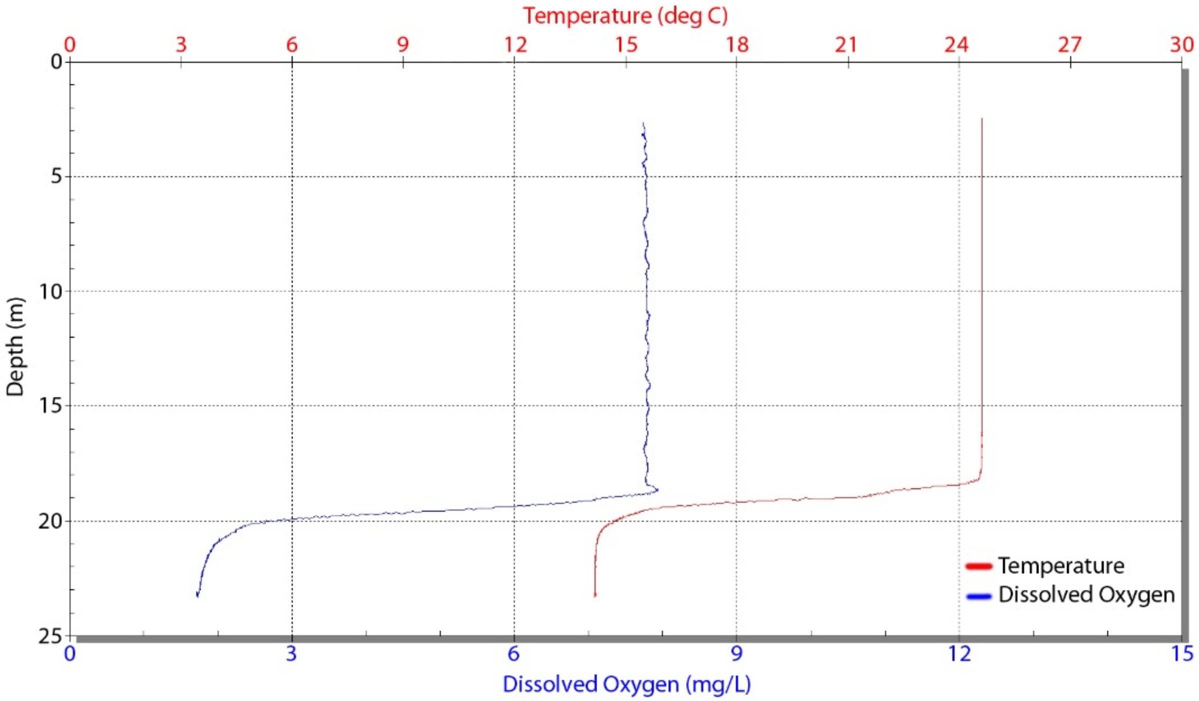

Figure 2. Example of a temperature and DO depth profile from Lake Erie central basin in late summer.

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.

For comparisons between years, results over a 10-year period (2007-2016) were compared statistically using a general linear model (GLM) approach to test whether there is a significant difference in the relationship between time (expressed as Julian day minus 150 to place the y-intercept near the beginning of the sampling period; referred to as SurveyDay in Table 3) and either hypolimnion temperature, thickness or DO concentration (Tables 3a, 3b and 3c). This approach assumes a constant rate of change per day in the unadjusted measurements (i.e., hypolimnion temperature, thickness and DO) over the full June to October sampling period within each year, which differs slightly from the Rosa and Burns (1987) method that only assumes a constant rate of change between sampling events, but not across the entire sampling period. The GLM model includes a separate factor for the sampling year, and a Julian day x year interaction term, which is used to test whether the rate of change in the hypolimnion temperature, thickness or DO varies significantly between years (i.e., whether the estimated slope varies between years). Statistical significance of the GLM model tests was set at alpha=0.05. Statistical analysis was performed using the GLM procedure in SAS Version 9.4 (SAS Institute, Cary, NC).

4 QUALITY ASSURANCE AND QUALITY CONTROL

GLNPO's DO monitoring surveys operate under an approved Quality Management Plan (QMP), a Quality Assurance Project Plan (QAPP), and standard operating procedures (SOP) (U.S. EPA, 2014). In 2016, QAPP Revision 09, dated March 2016, was used. The overall 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 expressed as a percent value.

The accuracy criteria 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 number that was expected to be obtained under normal conditions. The completeness goal is to obtain DO and water temperature profiles within accuracy and precision limits at 90% of all designated stations during each survey.

5 RESULTS AND DISCUSSION

During the first survey (June 6-7, 2016), all stations were stratified with an average temperature difference of nearly 6.5°C between the epilimnion and hypolimnion layers, and most stations remained stratified throughout the sampling period (Table 2). Over the sampling season, average temperatures increased in the epilimnion from 15.1°C to 24.3°C and in the hypolimnion from 8.6°C to 16.2°C. Average dissolved oxygen (DO) concentrations during the sampling season decreased from approximately 10.5 mg O_2/L during the first survey to 8.1 mg O_2/L in the epilimnion and to 0.2 mg O_2/L in the hypolimnion at the end of the sampling season.

Low DO concentrations (< 6 mg O_2/L) in the hypolimnion were first detected at the two western-most sampling stations (ER42 and ER43) during the July 21-22 cruise (Figure 3). By mid-August, all stations had DO concentrations below 6 mg O_2/L, and one station had become anoxic (ER43, < 1 mg O_2/L). By the September 20-21 survey, all stations, except one (ER30), were experiencing anoxic conditions (Figure 3). However, during this survey, the hypolimnion at four stations (ER30, ER32, ER36 and ER43) was very thin (≤ 1.0 m), making it difficult to position the CTD (Conductivity, Temperature, Depth (pressure) sensor) within this water layer. As such, ER30 may also have been anoxic, but due to a very deep thermocline present at this site, the hypolimnion (if one was present) was not able to be sampled, resulting in no data.

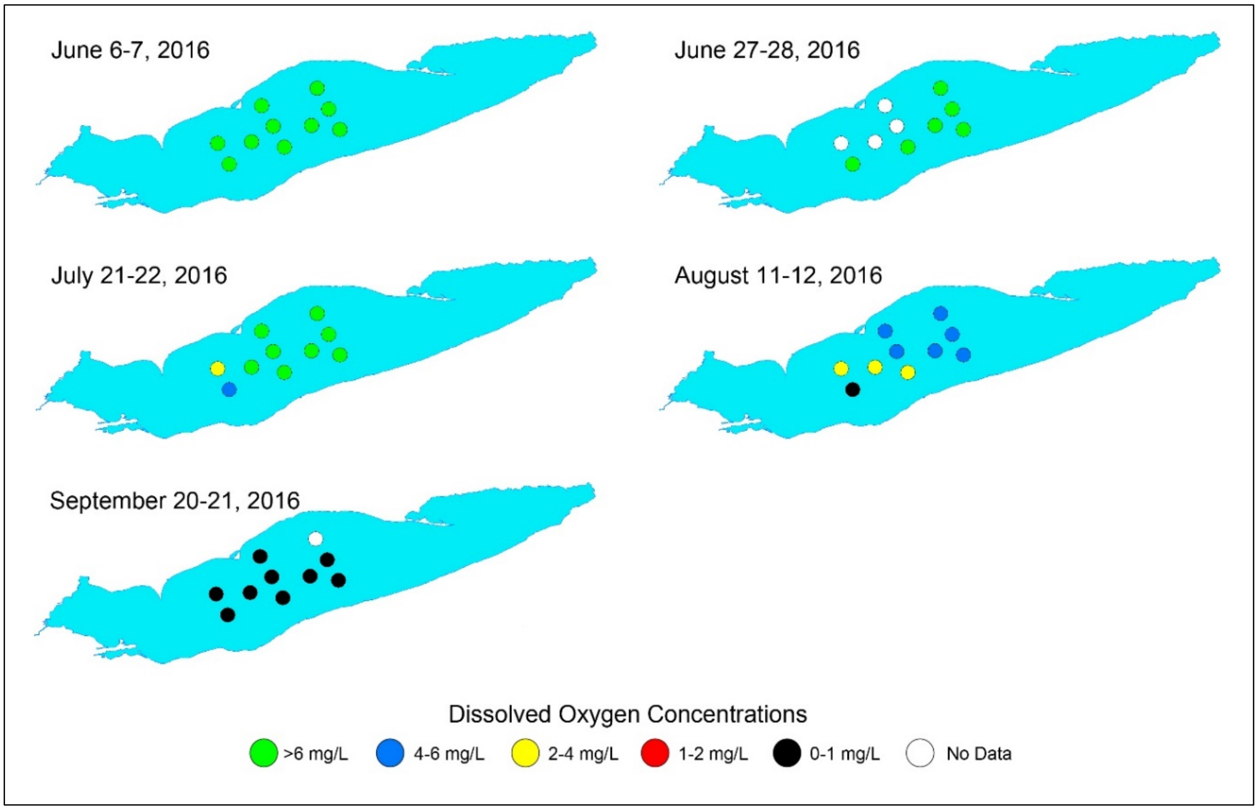

Figure 3. 2016 station means of hypolimnion DO concentrations in the central basin of Lake Erie.

Table 2. Mean water temperature (± SD) and DO for each survey in 2016.[*]

2016 Survey Dates	CTD Used	N (#)	Epilimnion		Hypolimnion		
			Temperature (°C)	DO (mg/L)	Temperature (°C)	DO (mg/L)	Thickness (m)
June 6-7	SBE 911+	10	15.05 ± 0.77	10.47 ± 0.25	8.63 ± 0.18	10.55 ± 0.63	8.71 ± 1.54
June 27-28	SBE 25	6	19.19 ± 0.43	8.02 ± 0.43	9.82 ± 0.37	8.52 ± 0.65	5.51 ± 1.20
July 21-22	SBE 911+	10	22.55 ± 0.91	8.61 ± 0.28	11.22 ± 0.74	7.55 ± 2.11	4.92 ± 2.82
August 11-12	SBE 911+	10	24.32 ± 1.18	8.36 ± 0.28	11.53 ± 0.82	3.94 ± 1.53	4.83 ± 1.18
September 6-7	SBE 19	0	ND	ND	ND	ND	ND
September 20-21	SBE 911+	9	23.02 ± 0.49	8.08 ± 0.25	14.47 ± 0.69	0.21 ± 0.23	2.49 1.95

[*] N indicates the number of stations used to calculate survey averages; ND indicates no data available.

COMPARISON TO HISTORICAL RESULTS

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, its severity, and its duration are related to year-to-year differences in the thickness and temperature of the bottom water layer, as well as 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, 2017).

In 2016, the hypolimnetic temperature remained near the previous 10-year average through most of the season; however, by the end of the season temperature had increased to one of the highest levels observed over this time period (Figure 4). The rate of change in hypolimnion temperature varied significantly between years (Table 3b), with the hypolimnion temperature increasing significantly faster in 2016 than in 2008, 2009, 2011, 2012 and 2014 (Table 3b, 3c).

At the start of the 2016 season, the hypolimnion was one of the thickest observed over the 10-year period. Not only does a thicker hypolimnion contain a greater quantity of DO, but it has also been shown to be associated with an overall slower depletion rate (Charlton, 1980; Bouffard, 2013). However, by the end of the season, the hypolimnion was one of the thinnest observed (Figure 5). The rate of change in hypolimnion thickness varied significantly between years (Table 3b), with the hypolimnion thickness decreasing faster in 2016 than for all years prior to 2013 other than 2010 (Table 3c).

The average hypolimnion oxygen concentration at the start of the 2016 season was one of the highest concentrations observed over the 10-year period (Figure 6). It remained relatively high throughout most of the season, dropping to 2 mg O_2/L at the third latest date over the 10-year period (approximately September 1st). The rate of change for unadjusted DO did not vary significantly between years (Table 3b).

The corrected annual oxygen depletion rate for 2016 was 3.38 mg O_2/L/month (Figure 7). This is fairly typical, approximately 0.08 mg O_2/L/month above the median for the 2007-2016 time period. The June 27-28 and September 6-7 survey data were not included in the 2016 oxygen depletion rate analysis.

In 2016, there were three surveys for which data were either not collected or failed QA checks (as described in Table A-1 of Appendix A), which limited their use in trend analysis. During the June 27-28 survey, no QC samples were collected. Therefore, the SeaBird data values could not be evaluated to ensure the instrumentation was functioning properly and within acceptance limits. No data were available for the September 6-7 survey due to the instrumentation not functioning properly. The new SeaBird used during this survey was not set up correctly; the minimum conductivity required to turn on the water pump was set to a value appropriate for seawater. As such, the water pump never turned on and no valid data were collected. Data from the ER30 (Figure 1), during the September 20-21 survey could not be included, as hypolimnion values were not sampled due to the absence of the hypolimnion at that station.

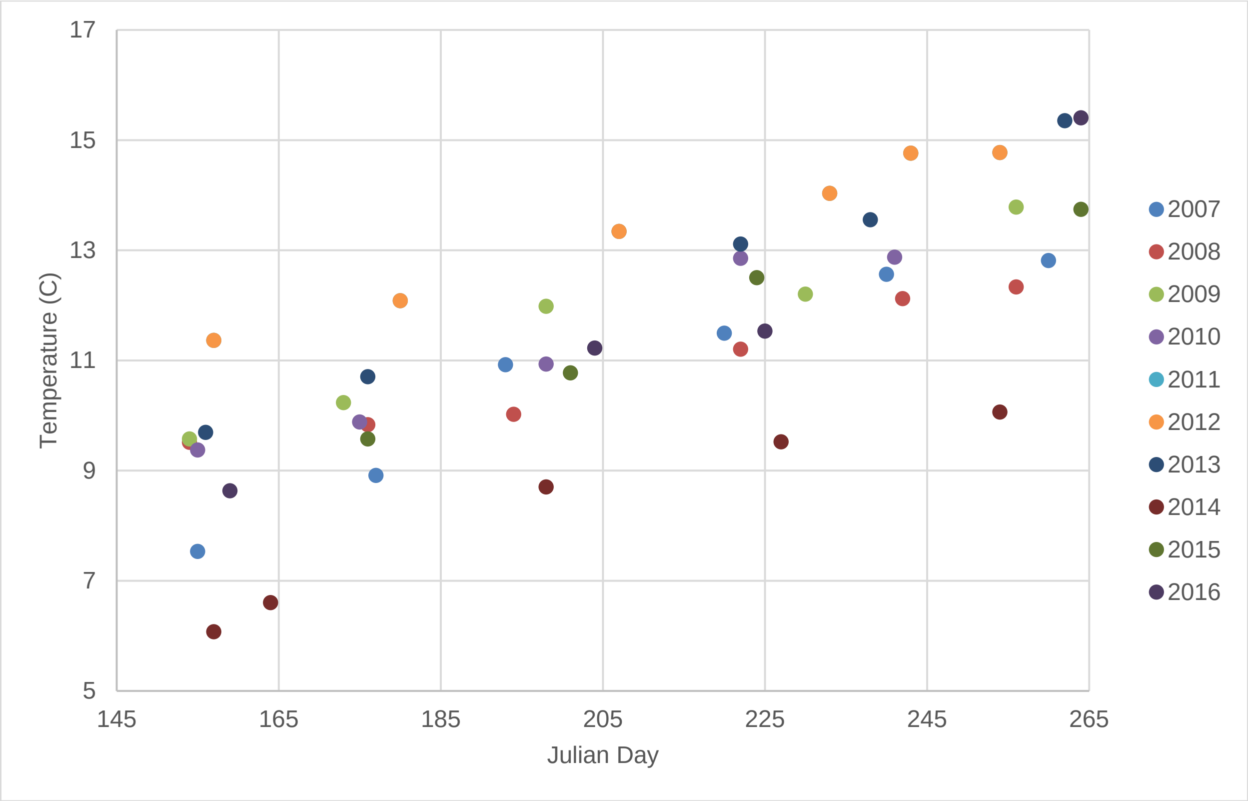

Figure 4. Hypolimnion temperatures in the central basin of Lake Erie from 2007-2016.

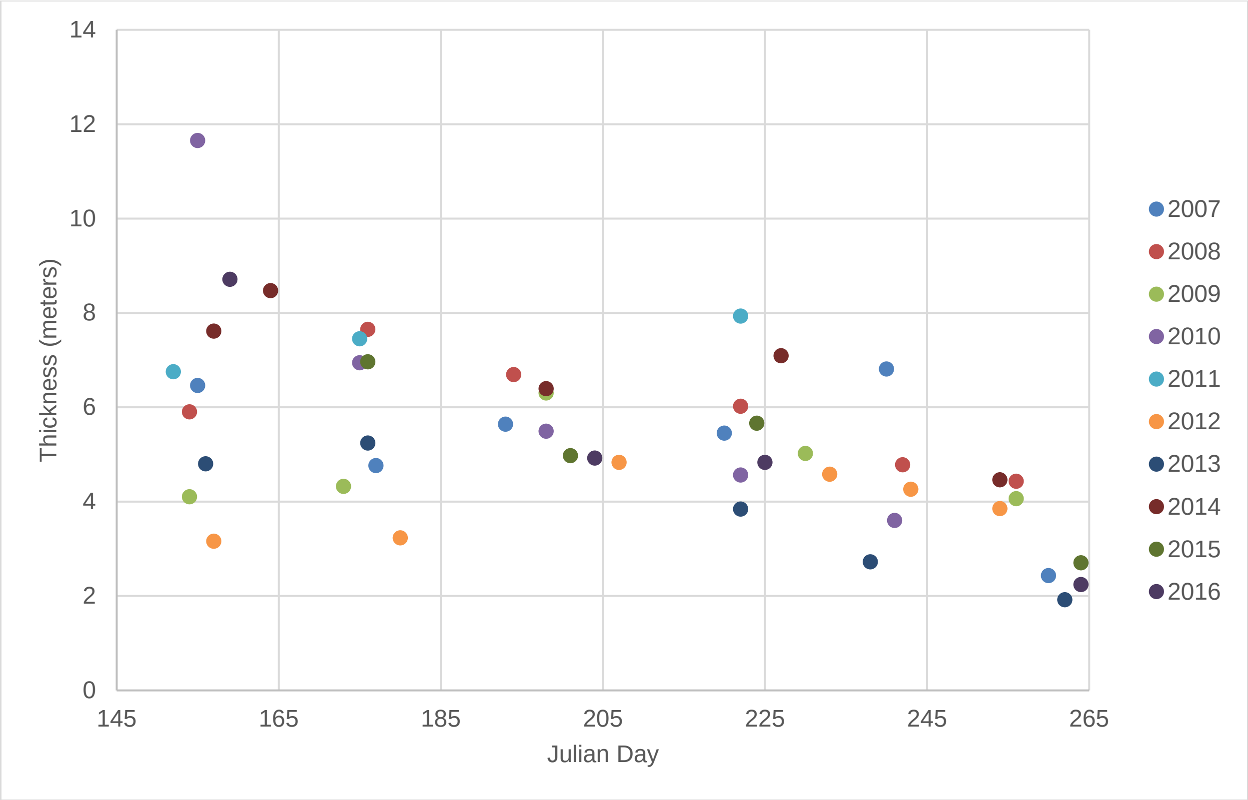

Figure 5. Hypolimnion thicknesses in the central basin of Lake Erie from 2007-2016.

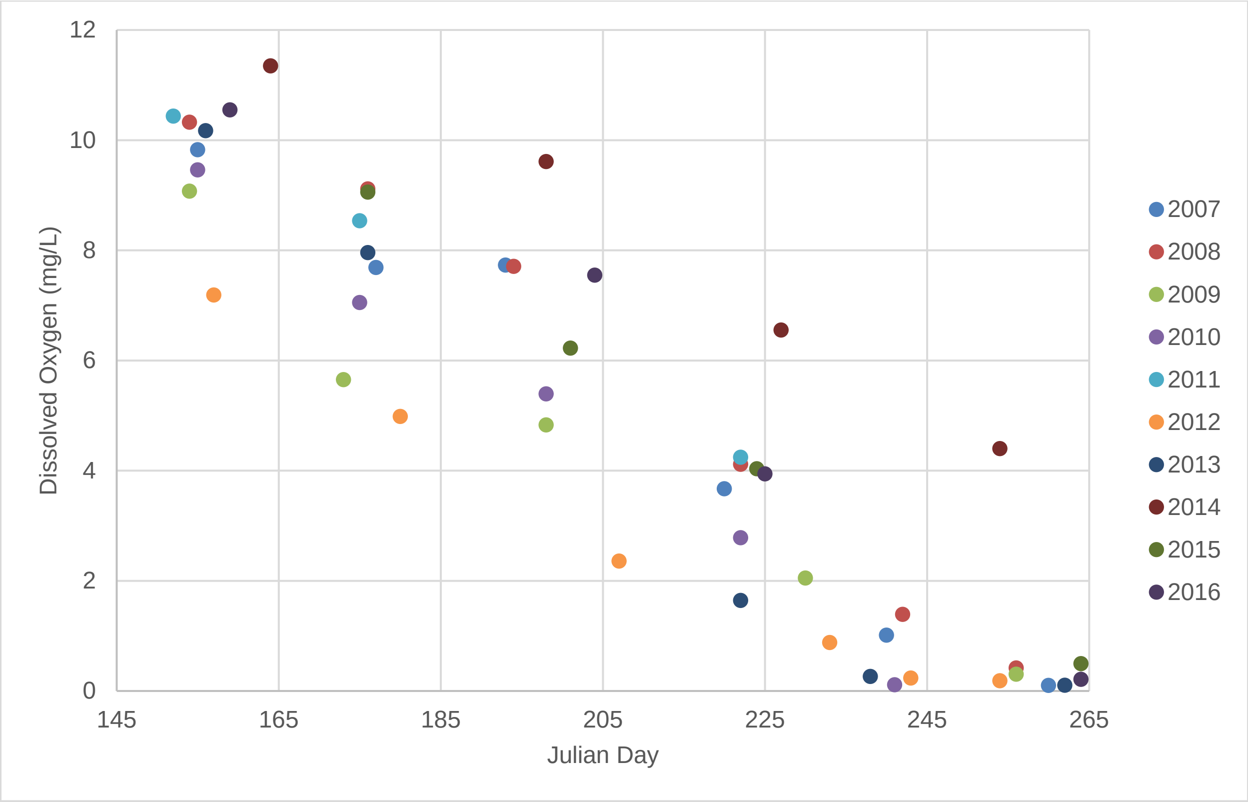

Figure 6. Hypolimnion DO concentrations in the central basin of Lake Erie from 2007-2016.

Table 3. Generalized linear model (GLM) results for the relationships between SurveyDay and hypolimnion temperature, thickness and DO concentration.

In the model, the SurveyDay term is defined as Julian day minus 150 to place the y-intercept near the beginning of the sampling period. The GLM model includes a separate factor for the sampling year, and a Julian day x year interaction term, which is used to test whether the rate of change in the hypolimnion temperature, thickness or DO varies significantly between years (i.e., whether the estimated slope varies between years). Statistical significance of the GLM model tests was set at alpha=0.05.

Table 3a. Overall GLM results.

Source	DF	Temperature					Thickness					DO concentration				
		Sum of Squares	Mean Square	F statistic*	p-value	R^2 †	Sum of Squares	Mean Square	F statistic	p-value	R^2	Sum of Squares	Mean Square	F statistic	p-value	R^2
Model	19	232.64	12.24	64	<.0001	0.9767	141.75	7.46	7.28	<.0001	0.8267	667.61	35.14	67.77	<.0001	0.9780
Error	29	5.55	0.19				29.72	1.02				15.04	0.52			

Table 3b. GLM fit statistics.

Source	DF	Temperature				Thickness				DO concentration			
		Type III SS‡	Mean Square	F statistic	p-value	Type III SS	Mean Square	F statistic	p-value	Type III SS	Mean Square	F statistic	p-value
SurveyDay§	1	107.93	107.93	564.15	<.0001	37.37	37.37	36.46	<.0001	469.39	469.39	905.27	<.0001
Year	9	26.26	2.92	15.25	<.0001	57.98	6.44	6.29	<.0001	32.02	3.56	6.86	<.0001
Interaction (i.e., SurveyDay x year)	9	4.92	0.55	2.86	0.0153	44.17	4.91	4.79	0.0006	9.35	1.04	2	0.0757

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* Ratio of the Mean Squares to its Error (i.e., overall model significance)

† Estimate of the overall variability explained by the model

‡ Sum of Squares that includes the variation that is unique to the effect listed in that row (e.g., Temperature and SurveyDay) after adjusting for all other effects that are included in the model

§ Julian day minus 150

Table 3c. GLM estimates of deviations in model intercept and slope used to calculate rate of change in water temperature, thickness and DO concentration of the hypolimnion for years 2007-2015 compared to 2016 reference year.

Parameter	Temperature (˚C)				Thickness (m)				DO concentration (mg/L)			
	Estimate	Standard Error	T statistic[#]	p-value	Estimate	Standard Error	T statistic	p-value	Estimate	Standard Error	T statistic	p-value
Intercept in 2016	7.7807	0.4243	18.34	<.0001	8.9320	0.9822	9.09	<.0001	11.9180	0.6986	17.06	<.0001
Slope in 2016	0.0621	0.0058	10.76	<.0001	-0.0596	0.0134	-4.46	0.0001	-0.1009	0.0095	-10.62	<.0001
Difference in intercept in 2007[††]	0.0063	0.5407	0.01	0.9908	-2.5838	1.2515	-2.06	0.048	-1.2254	0.8902	-1.38	0.1792
Difference in intercept in 2008	1.3196	0.5410	2.44	0.0211	-1.7398	1.2522	-1.39	0.1753	-0.4476	0.8907	-0.5	0.6191
Difference in intercept in 2009	1.7154	0.5425	3.16	0.0037	-4.2310	1.2557	-3.37	0.0021	-3.3592	0.8931	-3.76	0.0008
Difference in intercept in 2010	1.1866	0.5576	2.13	0.0419	1.5582	1.2905	1.21	0.237	-1.9196	0.9179	-2.09	0.0454
Difference in intercept in 2011	-0.3751	0.5707	-0.66	0.5161	-2.0792	1.3209	-1.57	0.1263	-1.2484	0.9395	-1.33	0.1943
Difference in intercept in 2012	3.3044	0.5609	5.89	<.0001	-5.6415	1.2983	-4.35	0.0002	-4.6477	0.9234	-5.03	<.0001
Difference in intercept in 2013	1.5574	0.5569	2.8	0.0091	-3.4113	1.2891	-2.65	0.013	-1.5496	0.9169	-1.69	0.1017
Difference in intercept in 2014	-1.6828	0.5373	-3.13	0.0039	-0.5629	1.2437	-0.45	0.6542	0.4576	0.8846	0.52	0.6089
Difference in intercept in 2015	0.6484	0.6544	0.99	0.3299	-0.9656	1.5145	-0.64	0.5288	-0.5763	1.0772	-0.53	0.5967
Difference in slope in 2007[‡‡]	-0.0114	0.0076	-1.5	0.1436	0.0407	0.0176	2.31	0.0279	0.0020	0.0125	0.16	0.8769
Difference in slope in 2008	-0.0319	0.0076	-4.19	0.0002	0.0373	0.0176	2.12	0.0428	-0.0031	0.0125	-0.24	0.8088
Difference in slope in 2009	-0.0227	0.0078	-2.91	0.0069	0.0608	0.0181	3.36	0.0022	0.0209	0.0129	1.62	0.1162
Difference in slope in 2010	-0.0162	0.0086	-1.9	0.0678	-0.0242	0.0198	-1.22	0.2308	-0.0037	0.0141	-0.26	0.7965
Difference in slope in 2011	-0.0251	0.0104	-2.41	0.0224	0.0755	0.0241	3.13	0.0039	0.0120	0.0171	0.7	0.4885
Difference in slope in 2012	-0.0252	0.0077	-3.25	0.0029	0.0708	0.0179	3.96	0.0005	0.0266	0.0127	2.09	0.0457
Difference in slope in 2013	-0.0105	0.0076	-1.37	0.1809	0.0298	0.0177	1.69	0.1026	-0.0034	0.0126	-0.27	0.7883
Difference in slope in 2014	-0.0203	0.0078	-2.59	0.0149	0.0283	0.0181	1.56	0.1293	0.0267	0.0129	2.07	0.0477
Difference in slope in 2015	-0.0136	0.0089	-1.53	0.137	0.0160	0.0206	0.78	0.4442	0.0044	0.0146	0.3	0.764

[#] Ratio of the Estimate to its Standard Error

[††] Factors are for the difference in the intercept from the reference (i.e., 2016) and the specific year. The tests (i.e., T statistic and p-value) determine if there is a significant difference between the intercept in the reference year (i.e., 2016) and the specific year. For example, in 2007, the estimated temperature intercept (i.e., estimated value on the 150th Julian day) is 7.7870 ˚C (7.7807 + 0.0063), and it is not significantly different from the estimated temperature intercept in 2016 (i.e., 7.7807 ˚C) because the p-value is greater than alpha = 0.05.

[‡‡] Factors are for the difference in the slope from the reference (i.e., 2016) and the specific year. The tests (i.e., T statistic and p-value) determine if there is a significant difference between the slope in the reference year (i.e., 2016) and the specific year. For example, in 2007, the estimated thickness slope is -0.0189 m/day (-0.0596 + 0.0407), and it is significantly different from the thickness slope in 2016 (i.e., -0.0596 m/day) because the p-value is less than alpha = 0.05.

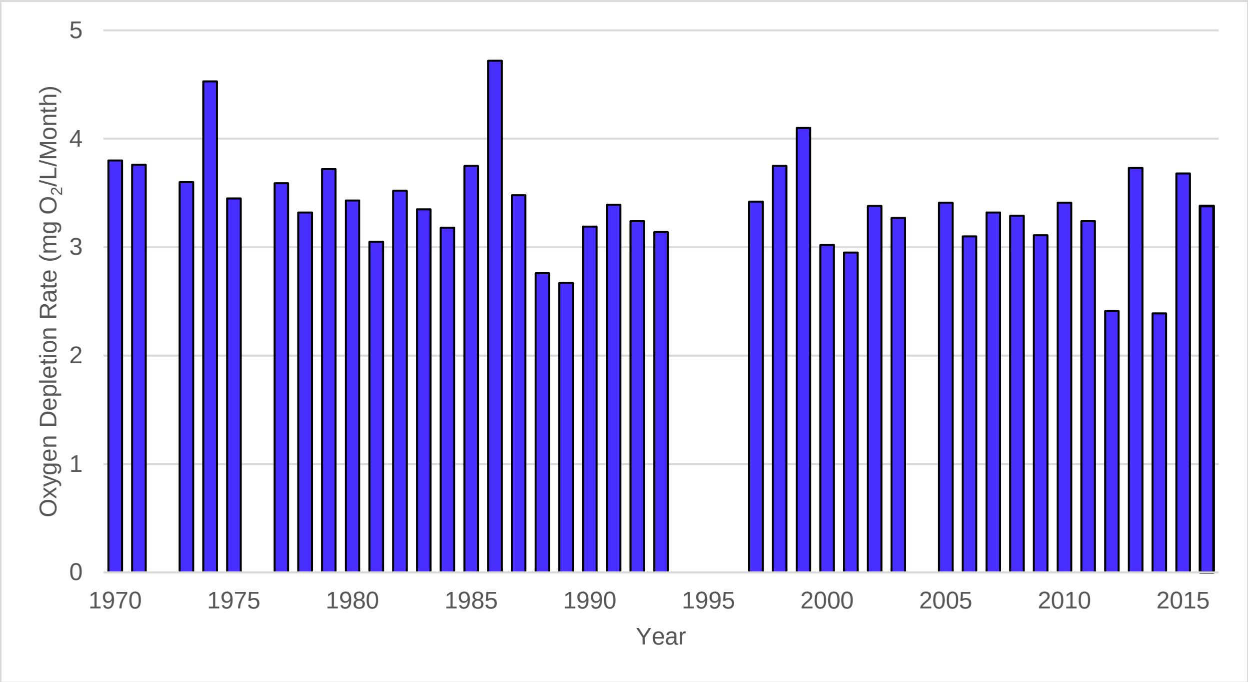

Figure 7. Dissolved oxygen depletion rate in the central basin of Lake Erie from 1970-2016. Data sources: Burns et al. (2005) and EPA GLNPO (unpublished).

6 CONCLUSIONS

The U.S. EPA GLNPO Lake Erie Dissolved Oxygen Monitoring Program monitors the oxygen and temperature profiles at 10 stations in the central basin of Lake Erie to assess water quality trends and measure progress made in achieving water quality improvements. Six surveys were conducted in 2016 from June 6 to September 21 (Table 2); however, data from two of these surveys did not meet the QAPP requirement for completeness due to instrumentation issues during those surveys (i.e., June 27-28 and September 6-7 surveys).

When compared to the previous 10-year record (2007-2015), the hypolimnion at the beginning of the 2016 sampling season was similar in temperature, but thicker and contained more dissolved oxygen (DO). Water temperatures increased from 15.1°C to 24.3°C in the epilimnion and from 8.6°C to 16.2°C in the hypolimnion during the sampling season. These temperature values are centrally located within the observed range for the last 10 years (see Figure 4); however, near the end of the season, the hypolimnion temperature became one of the warmest in recent years. The 2016 hypolimnion was the second thickest at the start of the sampling season, but by the end of the season it was one of the thinnest (see Figure 5). Consequently, oxygen concentrations decreased during the season from approximately 10.5 mg O_2/L to 8.1 mg O_2/L in the epilimnion and to 0.2 mg O_2/L in the hypolimnion. Low-oxygen conditions (< 6 mg O_2/L) were recorded in the hypolimnion at two western stations in July and at all stations in August. Hypoxic hypolimnion conditions (< 2 mg O_2/L) were recorded at one western station in August and at all stations meeting acceptance criteria in late September (n=9). Compared to the previous 10-year period (2007-2015), the average hypolimnion oxygen concentration for 2016 was the second highest at the beginning of the sampling season and remained at higher levels throughout the season, not dropping to 2 mg O_2/L until the third latest date for this time period (see Figure 6). The corrected annual oxygen depletion rate for 2016 was 3.38 mg O_2/L/month, which was slightly above the median for the 2007-2016 time period and was similar to the 46-year long term average from 1970-2016 (Figure 7).

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APPENDIX A - QUALITY CONTROL RESULTS

A summary of 2016 results not meeting acceptance criteria is provided in the table below.

Table A-1. Quality control (QC) scorecard of 2016 CTD-collected temperature and dissolved oxygen (DO) data not meeting acceptance criteria.

Survey	Issue	Cause	Decision	Corrective Actions
June 27-28	Accuracy of CTD DO data was not assessed	No water samples were collected.	Caution should be used with this dataset.	Adhere to QAPP and SOPs.
	Incomplete dataset	Data were not collected at 4 stations due to malfunctioning CTD.		This CTD was not used during the rest of the season.
Aug 11-12	DO accuracy check exceeded QC criterion	The hypolimnion was less than 2m thick at one of the stations sampled (ER32), so thermocline/epilimnion waters may have been in the water sample. The surface water sample at this station met the QC criterion.	All data are considered acceptable because failures were likely caused by water sampling and analytical error that would not have impacted CTD DO data.	Changes to sampling methodology are being considered to move water sampling container to the same height as CTD. Currently the Niskin bottle on the Rosette Sampler may be collecting water up to 1 m away from the CTD.
	Winkler precision check exceeded the QC criterion	An inexperienced technician ran Winkler analyses on one station which may have resulted in the greater variability in these two samples.		Exploring the possibility of incorporating an automatic titration system to reduce subjectivity differences between technicians.
Sept 6-7	Accuracy of CTD DO data was not assessed	No water samples were collected.	No DO data are acceptable because instrumentation did not function properly.	Adhere to QAPP and SOPs.
	Incomplete dataset	The DO pump on the CTD did not turn on during any of the casts.		Minimum conductivity frequency for pump turn on was changed to appropriate freshwater value.
Sept 20-21	DO accuracy check exceeded QC criterion	The hypolimnion thickness was only 0.7 m and 2.1 m at two of the sampled stations (ER32 and ER42, respectively), so thermocline/epilimnion waters may have been in the water sample.	All data are considered acceptable because failures were likely caused by water sampling error that would not have impacted CTD DO data.	Changes to sampling methodology are being considered to move water sampling container to the same height as CTD. Currently the Niskin bottle on the Rosette Sampler may be collecting water up to 1 m away from the CTD.