Final Report

Title: An Ensemble Modeling Approach to Assess Response to Changes in Nutrient Loads

Project Period: August 2024 - February 2026

Project PI: Donald Scavia, University of Michigan

Budget: The project budget has been spent and the report is attached.

Project Goals

Over a decade ago, phosphorus loading targets were established to combat Harmful Algal Blooms (HABs) and low oxygen levels (hypoxia) in Lake Erie. Because governments have not yet met these targets (Annex 4 2025), this study uses updated data and models to review the effectiveness of existing targets.

By combining multiple models in an ensemble, we understand how nutrient levels dictate the severity of HABs and hypoxia across models. Herein, we provide critical information to evaluate existing targets, while also factoring in climate change and potential impacts on fish and fisheries.

Core Objectives

- **Review Indicators:** Review existing and update, if necessary, the Environmental Response Indicators (ERIs).
- **Improve Modeling:** Combine individual HAB and hypoxia models into an ensemble.
- **Assess Loads:** Use these models to determine what nutrient loads meet ERIs and compare them to past efforts.
- **Evaluate External Impacts:** Determine how climate change and fish dynamics affect loads and the targets.
- **Share Findings:** Provide data to agencies, NGOs, and stakeholders, and publish in peer-reviewed journals to ensure credibility.

Key Takeaways

- **HABs Targets Are Sufficient:** Phosphorus reductions called for in the ensemble are slightly more than what was previously planned for HABs, but they are close enough that the original load reduction is likely sufficient under current climate conditions.
- **Hypoxia Targets Are Sufficient:** The phosphorus target for preventing serious hypoxia is likely sufficient under current climate conditions.
- **Climate Change Will Demand More:** As the lake warms, stricter phosphorus reductions will be needed to control both HABs and hypoxia.

- **Fish Populations Will Not be Affected:** Current and target HABs do not appear to negatively impact fish and hypoxia does not impact Yellow Perch. However, Walleye commercial catches have declined with increasing hypoxia and reducing phosphorus loads below the target for hypoxia may harm fish populations and catches.

Core Findings

1) Updated Ecosystem Indicators (ERIs)

- **HABs:** The target Cyanobacteria Index (CI) has been updated to 2.9 (up from 1.7), reflecting recent changes in National Oceanic and Atmospheric Administration's (NOAA) methodology.
- **Hypoxia:** The target remains unchanged: summer dissolved oxygen above 2 mg/l.

2) Spring loads for HABs: To meet a HAB goal of CI = 2.9, spring phosphorus loads (March–July) must be reduced to:

- 227 MT of Total Bioavailable Phosphorus (TBP)
- 807 MT of Total Phosphorus (TP)
- 132 MT of Dissolved Reactive Phosphorus (DRP)
- The original target is 253 MT TBP and the ensemble predicts CI = 3.6. This, and the associated load, is close to the original target.

3) Annual loads for Hypoxia: The current TP annual load of roughly 6,000 MTA is still effective. At this level, the model predicts a dissolved oxygen of 3.2 mg/l and a hypoxic area of 3,100 km². These values are close to past recommendations.

4) Impacts on Fish & Fisheries

Biomass: The central basin biomass model predicts that the hypoxia target might be close to harming Walleye. Lake Whitefish does not appear harmed by hypoxia. Yellow Perch appears to benefit from higher phosphorus loads despite increased hypoxia.

Commercial catch rates: Commercial catch rates of Walleye and Yellow Perch in the western basin were not affected by HABs. Walleye and Lake Whitefish catches appeared to not be limited at the hypoxia target and associated phosphorus loads. However, increased hypoxia would be expected to limit Walleye catches. Yellow Perch catches were not limited by hypoxia; in fact, Yellow Perch appear to benefit from higher phosphorus loads.

5) Climate Change Implications The models indicate that a warmer lake will make it harder to achieve the goals. To maintain the same ERIs, models show that future loads need to be lowered from the current targets.

Detailed Findings

Environmental Response Indicator (ERI) Analysis

Western Basin HABs ERI: NOAA's previous target had an average CI = 1.7 (the 25th percentile). NOAA has since updated its methods, resulting in generally higher CI estimates. Adjusted for this new method, the 25th percentile baseline results in a new ERI threshold of 2.9. Also, previous studies aimed to keep blooms "mild" 90% of the time based on the 2008 river discharge rate. But the river flow patterns have changed. High spring flows in 2011, 2015, 2017, and 2019 mean that the 90^{th}-percentile flow is better represented by the average of 2011 and 2019. This will change the year basis to achieve the ERI most of the time.

Central Basin Hypoxia ERI: The Annex 4 Task Team opted for a minimum DO threshold of > 2.0 mg/L (expecting an average between 2.2 and 3.5 mg/L). At the time, models predicted this threshold would result in a hypoxic area between 2,500 and 4,500 km^2 (Area = -1464*DO + 7719). Based on the updated ensemble model, the current ERI is set for DO of at least 3.2 mg/L and a hypoxic area of 3,100 km^2.

Model Calibration, Validation, and Testing

Detailed descriptions of the models used here, including calibrations and the resulting response curves (RCs), will be detailed and published in peer-reviewed journals. Below is a summary of the individual models.

3D Ecosystem Models

Redder et al. (Lake Erie Ecosystem Model - LEEM): A 3D model (2012–2023) focusing on nutrient load reductions and variable weather. It modeled western basin HABs as biomass (later converted to the Cyanobacteria Index, or CI). This model was also crucial for providing environmental data to the fish models. *(Funded by the Erb Family Foundation)*

Bocaniov et al. (Estuary and Lake Computer Model – Computational Aquatic Ecosystem DYnamics Model - ELCOM-CAEDYM): A 3D lake model tracking DO and HABs for 2008, 2014, and 2019. Researchers tested how wind, air temperature, and warmer climate scenarios impact both HABs and central basin hypoxia. It successfully captured seasonal peaks in cyanobacteria. *(Funded by the Erb Family Foundation)*

Valipour et al. (Aquatic Ecosystem Model 3D - AEM3D): An updated 3D modeling framework calibrated for 2013, 2016, 2017, and 2019. It incorporated revised Canadian (Environment and Climate Change Canada - ECCC) phosphorus loading estimates and zooplankton observations to evaluate the existing targets on hypoxia. *(Funded by Environment and Climate Change Canada)*

Statistical HAB and Hypoxia Models

Scavia et al. (University of Michigan/North Carolina State University - UM/NCSU Central Basin Hypoxia Model): A statistical model estimating late-summer (August–September) hypoxic areas from 1959 to 2024 based on TP loads and air temperature. It generated response curves for both current and future climates. *(Funded by the Erb Family Foundation)*

Scavia et al. (UM/NCSU HABs Model): A recalibrated model tracking HABs through 2024. It was updated to include temperature data alongside TBP loads to better predict blooms. *(Funded by the Erb Family Foundation)*

Benmore, Gottardo, Michalak, et al. (Stanford/Carnegie HAB Model): Extended through 2024 to predict HAB extent based on Maumee River DRP loads and climate. It specifically tested whether yearly bloom changes are driven more by land management or by weather (precipitation and temperature). *(Funded by the Erb Family Foundation)*

Stumpf (NOAA HAB Model): Recalibrated the existing NOAA HAB forecasting model through 2024 and coordinated comparisons across the different modeling methods used in the broader study. *(Funded by NOAA)*

Satellite Data and Tracking

Stumpf et al. (NOAA Satellite Time Series): Reprocessed long-term satellite data (from 2000 onward) to provide consistent observations of cyanobacteria (CI). Crucially, this separated the data between the western and central basins to ensure accurate inputs for the other models. *(Funded by NOAA)*

Fish and Fisheries Models

Zhang et al. (Ecopath with Ecosim - EwE): A food web model evaluating fish biomass. It used outputs from the LEEM model (temperature, phosphorus, hypoxic area/volume) and historical data (1996–2023) to generate response curves showing how fish react to different hypoxic conditions. *(Funded by the Great Lakes Fishery Commission (GLFC) and the Erb Family Foundation)*

Mallick, Ludsin, et al. (Commercial Fisheries Catch Model): Analyzed historical commercial fishing data (1969–2024) to examine whether catches of Lake Whitefish, Walleye, and Yellow Perch are influenced by HAB and hypoxia in the western and central basins, respectively. These models also considered the impact of changes in climate. *(Funded by the Erb Family Foundation and Great Lakes Fishery Commission*

The Ensemble Model

Creating the Ensemble Response Curve (RC) - Once the individual models were calibrated and validated, they were used to create individual RCs, and these were used to create the ensembles. The details of our approach to develop the ensemble RCs can be found in Borah et al. (in review).

The HAB Ensemble RC - To achieve the new CI target of 2.9, TBP would be reduced to 227 MT. That is a 60.0% reduction compared to the new 90th percentile loading years (the average of the extremely high flows in 2011 and 2019) and a 26.7% reduction compared to our current, modern baseline (the 2020–2024 average). The original Annex 4 load aimed for a TBP load of 253.4 MT (roughly 40% reduction from 2008 levels). The ensemble model shows that achieving this load results in a CI of 3.6. This is fairly close to the new CI target of 2.9.

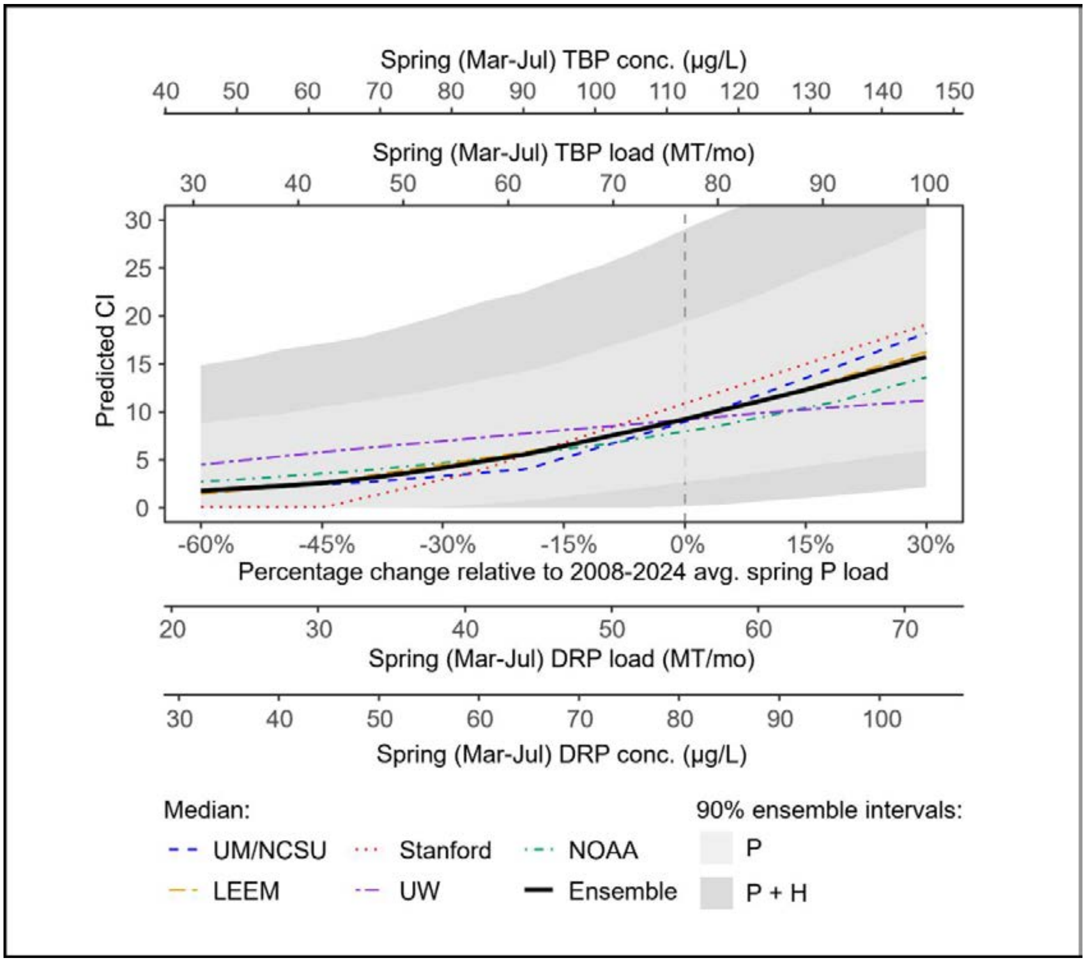

Figure 1. Ensemble RC showing predicted CI levels as a function of percentage change in spring P loads relative to 2008-2024 average (bottom x-axis). The corresponding spring DRP and TBP load and flow-weighted concentrations are shown on the secondary x-axes. RC lines represent the medians of the predictive distributions for the overall ensemble (black, bold) and individual models (various colors and line types). The shaded bands represent 90% ensemble intervals, accounting for prediction (P) and hydrologic (H) uncertainties. The vertical dashed line indicates the baseline load conditions.

Table 1. Target spring (March-July) P loads to the western basin of Lake Erie from Annex 4 and from the ensemble HAB response curve, along with the corresponding cyanobacteria index (CI) values predicted by the ensemble HAB response curve. Spring P loads for 2008, 2011&2019 average, 2020-2024 average, and 2008-2024 average are shown together with the percentage load reductions required to achieve each target load.

	Spring P	Target loads (MT)	CI	Baseline load (MT) and % reduction needed to attain target loads							
				2008		2011&2019 avg.		2008-2024 avg.		2020-2024 avg.	
				load	%	load	%	load	%	load	%
Annex 4	TBP	253.4	3.6	413.4	38.7	566.9	55.3	384.1	34.0	309.7	18.2
	DRP	186.0		302.2	38.5	387.7	52.0	275.0	32.4	206.9	10.1
	TP	860.0		1414.1	39.2	2180.0	60.5	1366.1	37.0	1235.2	30.4
Ensemble	TBP	226.8	2.9	413.4	45.1	566.9	60.0	384.1	41.0	309.7	26.8
	DRP	162.4		302.2	46.3	387.7	58.1	275.0	41.0	206.9	21.5
	TP	806.5		1414.1	43.0	2180.0	63.0	1366.1	41.0	1235.2	34.7

The Hypoxia Ensemble RC - This curve shows how central basin hypoxia is expected to change as annual TP loading rates fluctuate compared to the 2008–2024 average. The ensemble model validates the original goal. It shows that maintaining a 6,000 MTA load will produce a DO concentration of 3.1 mg/L and a hypoxic area of 3,100 km². (DO of 2.2 mg/L correspond to a TP load of 8,729 MTA; 3.5 mg/L correspond to a TP load of 4,904 MTA). The Annex 4 Task Team set an annual target load of 6,000 MTA, it predicted a DO concentration above 2 mg/L or between 2.2 mg/L and 3.5 mg/L.

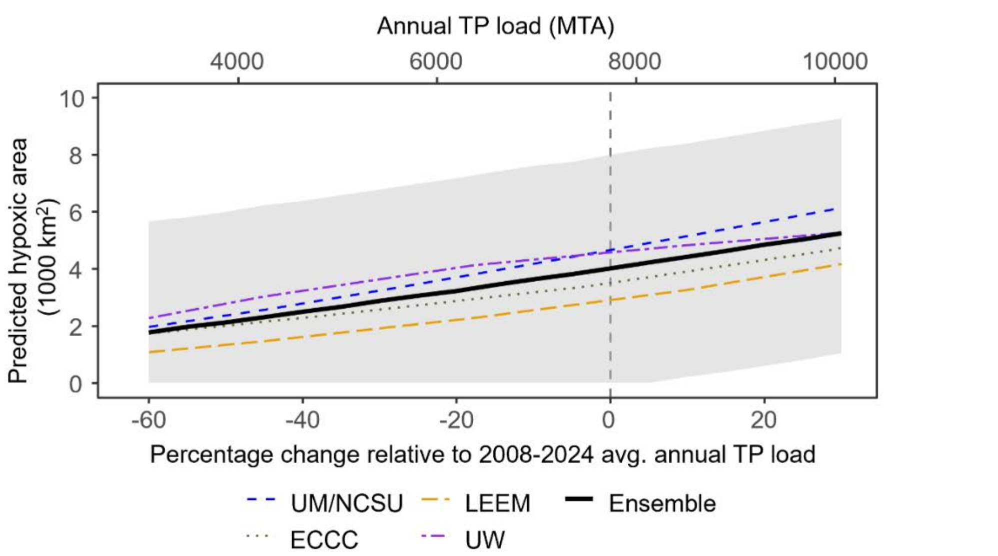

Figure 2. Ensemble RC showing predicted hypoxia area as a function of percentage change in TP loads relative to 2008-2024 average (bottom x-axis). The corresponding annual TP load is shown on the secondary x-axis. Solid lines denote median predictions from individual models and the ensemble. The shaded bands represent 90% ensemble intervals for prediction uncertainty. The vertical dashed line indicates the baseline (0%) load conditions.

Table 2. Hypolimnetic mean DO concentrations and hypoxic areas associated with target TP loads from the Annex 4 study and from the ensemble HAB response curve. Conversion between hypoxic area and mean DO is based on Annex 4 modeling outcomes (hypoxic area, $km^2 = -1464DO$, $mg/L + 7719$; $R^2 = 0.89$). Percent TP loading reductions required to attain each target are also reported relative to four reference conditions: 2008, 2011&2019 average, 2020-2024 average, and 2008-2024 average. Note that TP loads for these reference conditions are 9559, 10768, 7499, and 7745 MT/y, respectively.

	Target TP load (MT/y)	Mean DO (mg/L)	Hypoxic area (1000 km^2)	% reduction needed to attain target load			
				2008	2011&2019 avg.	2020-2024 avg.	2008-2024 avg
Annex 4	6000	3.1	3.1	37.2	44.3	22.5	20.0
Ensemble*	3308	4.0	1.9	65.4	69.3	57.3	55.9
	4904	3.5	2.6	48.7	54.5	36.7	34.6
	8729	2.2	4.5	8.7	18.9	-12.7	-16.4
	9274	2.0	4.8	3.0	13.9	-19.7	-23.7
	5944	3.2	3.1	37.8	44.8	23.3	20.7

* The Ensemble target loads represent TP loads corresponding to typical DO thresholds for hypoxia (2 and 4 mg/L), together with the DO range anticipated (2.2-3.5 mg/L) by Annex 4 when its target loads are achieved.

Fish and Fisheries Impacts

To understand how changing lake conditions may affect fish, researchers used two models: a Fish Biomass Model of the central basin and a Commercial Fishery Catch Regression Models in the western and central basins.

Fish Biomass Model uses an *Ecopath with Ecosim* (EwE) framework to test how fish populations react to different levels of hypoxia and phosphorus, provided from the Redder et al. model, and compared them to the current (6,700 km²) and target hypoxic areas (3,100 km²).

Yellow Perch: Not affected by hypoxia. In fact, its biomass increases when phosphorus loads are higher.

Lake Whitefish: Its total biomass in the central basin is low to begin with (less than a tenth of the Walleye biomass). This species does not appear to be substantially impacted by current or target hypoxia levels.

Walleye: Walleye populations appear more sensitive to hypoxia levels and loads close to the target area. The model indicates that reaching the target hypoxia level could potentially negatively impact their biomass via “bottom-up” effects (i.e., food limitation).

The "Goldilocks" Problem: While reducing hypoxia and phosphorus is good for overall water quality, reducing load too much (below the target levels) may lead to broad declines in fish biomass across the food web.

The Commercial Fishery Catch Models

Walleye Regression Model analyzed historical commercial catch data in relation to observed HABs (west basin catches only), hypoxia (central basin catches only), and a variety of climate indices, including spring warming rate, summer temperature, and ice cover during the same year. Walleye catches in the western basin were unrelated to HABs during 2002-present. During 1976-2023, Walleye catches in the central basin increased with decreasing hypoxia and ice cover. Using the most recent ice cover (2020-2024), the regression predicts 382,000 fish/yr at the current hypoxia (6,700 km^2) and 1,256,000 fish/yr at the target hypoxia (3,100 km^2). Catches at the target hypoxia level are not unlike the higher catches. Walleye catches are expected to increase at reduced (target) hypoxia levels. Below that threshold, lower phosphorus loads might negatively impact Walleye.

Lake Whitefish Regression Model: No strong relationship between HABs, hypoxia, or climate was revealed in our modeling. Even so, the model suggests a weak negative effect of hypoxia on Lake Whitefish. There may be a threshold effect, but the regression predicts 6391 kg/yr at the current hypoxia (6,700 km^2) and 114,862 kg/yr at the target hypoxia (3,100 km^2). Catches at the target hypoxia level are similar to the higher rates.

Note that commercial catches of Lake Whitefish have been consistently low during hypoxic months (July-September) in the central basin, with most harvest occurring before or after the hypoxia period. Thus, hypoxia could be negatively affecting Lake Whitefish in a way that is not detectable by our statistical model.

A threshold model may be more significant. The rough threshold at the lower 95% harvest rate is 4300 km^2. Below the current predicted hypoxic area requires lower phosphorus loads that might negatively impact other fish species as well.

Yellow Perch: Consistent with previous studies, hypoxia does not appear to severely limit them. In fact, reducing phosphorus loads to reduce hypoxia may negatively affect Yellow Perch through bottom-up effects.

Comparison to Previous Studies: Scavia et al. (2024) provided hypoxia thresholds using 1959-2022 lake-wide catch data that were not transformed, did not account for other factors like climate variation, and used model-derived hypoxia estimates, so they are not directly comparable. However, the comparison is useful. In that study, the hypoxia thresholds for Walleye and Lake Whitefish catch rates were 4,700 km^2 and 3,900 km^2, respectively. Both are above the target hypoxia area. So, the new models suggest that both Walleye and Lake Whitefish are unlikely to be negatively affected at target hypoxia levels and associated phosphorus loading. In fact, reducing hypoxia is expected to benefit these species.

Lake Climate Effects

Models were used to predict how a warming climate will alter the phosphorus load needed to meet existing hypoxia ERIs. These models only calculate how the lake itself reacts to warming; they do not factor in how climate change might increase runoff from the surrounding land.

Process Models: Compared a "typical" year (2019) to a warm and windy year (2017).

Statistical Models: Used three global climate scenarios predicting temperature increases ranging from 1.4°C to 2.6°C by mid-century, and up to 4.9°C by late-century.

For Hypoxia: The process models suggest 52% to 65% reduction is needed beyond what is needed today. The statistical model suggests the required extra reduction depends on human behavior. Under a "Sustainability" scenario, 20–27% more reductions are needed. Under a "Fossil-Fueled" scenario, 34–71% more reduction is needed.

For HABs: The statistical model suggests 9% to 14% additional reduction is needed beyond the current target by mid-century, but the process models did not show a change.

Stricter Reductions Will be Needed - As the lake warms, it becomes more susceptible to HABs and hypoxia. To maintain the ERIs, we will have to reduce phosphorus loads significantly more than we do today.

Future Work

While this report represents a major step forward from previous modeling efforts, there are still opportunities to refine the data and models. Future priorities include:

Improving Physical & Chemical Modeling: Better representing how light penetrates the water, how sediments interact with the water column (diagenesis), and how water layers and moves (stratification and transport).

Better Data Inputs: Securing more consistent nutrient loading data and improving spatial resolution to make process-based models more accurate.

Modernizing Targets: Developing new, ecosystem-wide eutrophication targets with detailed time-and-space tracking to enhance future nutrient management decision.

Coordination with Others

To ensure the various models and datasets aligned perfectly, the research team maintained a rigorous meeting schedule internally and with external partners.

Internal Project Meetings

- **Meeting 1 (In-person | Jan 22–23, 2025):** Shared early model calibration results, updated observational data, reviewed preliminary response curves for the current climate, and determined the methodology for calculating future climate curves.
- **Meeting 2 (In-person | April 28–29, 2025):** Shared modeling results for "typical" and future climate years, outlined the strategy for developing the unified ensemble response curve, and established the specific data the fish modeling teams needed from the other modelers.
- **Ongoing Virtual Meetings (Bi-monthly through Feb 2026):** Held every other month to coordinate the ensemble model, finalize which years to use for climate scenarios, and facilitate data exchanges between statistical and process modeling groups.

Annex 4 Modeling Group Collaboration The team actively participated in Annex 4 modeling group meetings every two months to ensure our work aligned with broader, binational efforts.

- Presented our models and shared information.
- Participated in a comprehensive survey of all active Lake Erie models.
- Reviewed the EPA and ECCC (Environment and Climate Change Canada) load estimation efforts.
- Ensured our current study effectively bridged past modeling work with future initiatives.

Community Engagement

Communicating with policy-oriented stakeholders was a priority throughout the project.

- **Pre-Project:** Met with key stakeholders to gather feedback before finalizing the proposal.
- **Ongoing:** Launched and maintained a dedicated project website (Graham Sustainability Institute).
- **Dec 2, 2024 & Nov 14, 2025:** Sent out comprehensive email updates regarding the project's status and ongoing conditions.
- **Jan 14, 2026:** Consulted with Gail Hesse (former Annex 4 coordinator) to ensure the team fully understood the historical context of past target decisions.

- **March 12, 2026:** Met with Mike Shiberg (Water Center Director) to gauge current stakeholder perspectives.
- **April 22, 2026:** Hosted a final briefing for project stakeholders, the Annex 4 modeling group, and the Annex 4 Adaptive Management Task Team.

Barriers & Risks

At this stage, the primary risk is potential resistance or misunderstandings from water quality managers implementing these targets. We are actively mitigating this by working closely with stakeholder and modeling groups to ensure our recommendations are clearly understood.

Evaluation & Learning

Our primary takeaway was that relying on individual models produces too wide a range of responses. However, combining them into a unified "ensemble"—and carefully factoring in their respective uncertainties—yields a much more cohesive, reliable, and actionable result.

This project's progress is recorded on the Graham Sustainability Institute's website: https://graham.umich.edu/project/erie-ensemble-modeling

The team will share what they have learned with the scientific community by publishing the following manuscripts in academic journals:

- Benmore, S., P. Gottardo, A.M. Michalak. (in review). Understanding major drivers controlling hypolimnetic hypoxia in Lake Erie: Effects of climate change.
- Bocaniov et al. (in review). Understanding major drivers controlling hypolimnetic hypoxia in Lake Erie: Effects of climate change.
- Bocaniov, S., K.G. Lamb, Y.R. Rao, P. Van Cappellen. (in review). On the combined and separate effects of air temperature and wind speed on summer stratification and hypolimnetic hypoxia in a large temperate lake.
- Borah, S.S., D.R. Obenour, Y-C. Wang, D. Scavia et al. (in review). Ensemble Response Curves.
- Mallick et al. (in review). Harmful Algal Bloom and Hypoxia Effect of Lake Erie Walleye and Yellow Perch.
- NOAA/NCCOS. (in prep). Recalibrated NOAA HAB model through 2024.
- Redder, T., D. Schlea, D. Rucinski. (in review). Application of a Mechanistic Whole-Lake Ecosystem Model to Support an Ensemble Modeling Approach to Assessing Nutrient Loading Targets for Lake Erie HABs and Hypoxia.
- Scavia, D., Y-C. Wang, and D.R. Obenour. (in review). Harmful algal bloom and hypoxia nutrient load and temperature models for current and future climates in Lake Erie.

- Stumpf et al. (in review). Changes in Lake Erie Cyanobacterial Bloom Timing and Phenology.
- Valipour, R. et al. (in review). Development of a three-dimensional ecological model to support water quality management in Lake Erie.
- Zhang et al. (in review). Impacts of Phosphorus-Loading Reductions on the Central Basin Food Web of Lake Erie: An Ecopath with Ecosim Modeling Study Integrated with Hydrodynamic Outputs.

Continued Financial Support

There are currently no plans or funding for this specific team to continue this effort. We are transitioning the momentum and data to the Annex 4 modeling group to carry the work forward

---

Financial Report: *(See attached document).*

References

Annex 4 Adaptive Management Task Team. (2023). *Binational Adaptive Management Evaluation for Lake Erie (2017-2021)*. Available at binational.net.

Benmore, S., P. Gottardo, A.M. Michalak. (in review). *Understanding major drivers controlling hypolimnetic hypoxia in Lake Erie: Effects of climate change.*

Bocaniov, S.A., K.G. Lamb, Y.R. Rao, P. Van Cappellen. *(in review). On the combined and separate effects of air temperature and wind speed on summer stratification and hypolimnetic hypoxia in a large cold-temperate lake (Lake Erie, Canada and United States)*. Ecological Indicators

Bocaniov, S.A., Y.R. Rao, P. Van Cappellen (in review). *Oxygen declines in the era of Global Climate Change: Projecting hypoxia responses in a large cold-temperate lake (Lake Erie, Canada-USA).* Ecological Informatics

Borah, S.S., D.R. Obenour, Y-C. Wang, D. Scavia (in review). *Ensemble Response Curves.*

GLWQA 2015 Task Force. (2015). *Recommended phosphorus loading targets for Lake Erie.* Annex 4 Objectives and Targets Task Team Final Report to the Nutrients Annex Subcommittee. US EPA Great Lakes National Program Office, Chicago. 70 pp.

Hounshell, A.G., L.T. Johnson, and R.P. Stumpf. (2023). *Nutrient and environmental factors regulating western Lake Erie cyanobacterial blooms.* Aquatic Ecosystem Health & Management, 26(4): 63-75.

Mallick et al. (in review). *Harmful Algal Bloom and Hypoxia Effect of Lake Erie Walleye and Yellow Perch.*

NOAA/NCCOS. (in prep). *Recalibrated NOAA HAB model through 2024.*

Redder, T., D. Schlea, D. Rucinski. (in review). *Application of a Mechanistic Whole-Lake Ecosystem Model to Support an Ensemble Modeling Approach to Assessing Nutrient Loading Targets for Lake Erie HABs and Hypoxia.*

Scavia, D., J.V. DePinto, I. Bertani. (2016). *A Multi-model approach to evaluating target phosphorus loads for Lake Erie.* J. Great Lakes Res. 42: 1139-115.

Scavia, D., S.A. Ludsin, M. Han, L.T. Johnson, A.M. Michalak, D.R. Obenour, Y-C. Wang, G. Zhao, Y. Zhou. (2024). *Water quality-fisheries tradeoffs in a changing climate underscore the need for adaptive ecosystem-based management.* Supporting Information Proc. Nat. Acad. Sci. 10.1073/pnas.2322595121.

Scavia, D., Y-C. Wang, and D.R. Obenour. (in review). *Harmful algal bloom and hypoxia nutrient load and temperature models for current and future climates in Lake Erie.*

Stumpf et al. (in review). *Changes in Lake Erie Cyanobacterial Bloom Timing and Phenology.*

Stumpf, R. P., L.T. Johnson, T.T. Wynne, & D.B. Baker. (2016). *Forecasting annual cyanobacterial bloom biomass to inform management decisions in Lake Erie.* Journal of Great Lakes Research, 42(6), 1174-1183.

Valipour, R. et al. (in review). *Development of a three-dimensional ecological model to support water quality management in Lake Erie.*

Zhang et al. (in review). *Impacts of Phosphorus-Loading Reductions on the Central Basin Food Web of Lake Erie: An Ecopath with Ecosim Modeling Study Integrated with Hydrodynamic Outputs.*

Zhou, Y., D.R. Obenour, D. Scavia, T.H. Johengen, A.M. Michalak. (2013). *Spatial and Temporal Trends in Lake Erie Hypoxia, 1987-2007.* Environ. Sci. Technol. 47 (2), pp 899-905.