Managing Water Quality in Rapidly Changing Times: Insights from In-Lake Modeling

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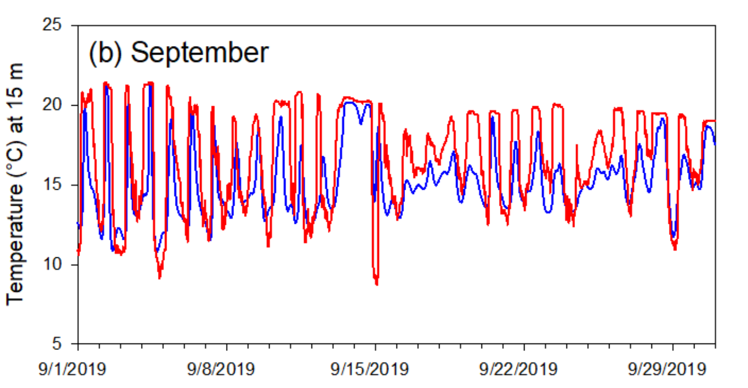
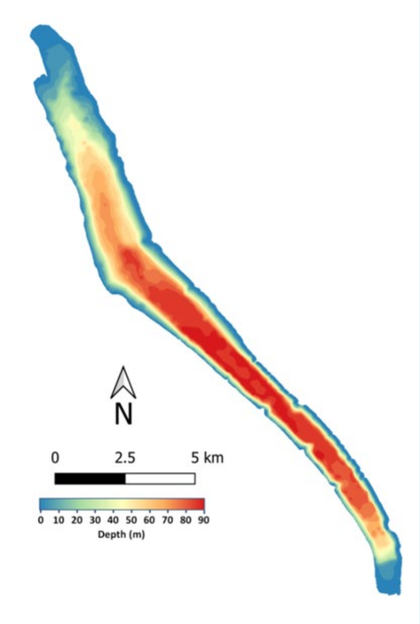
Preview

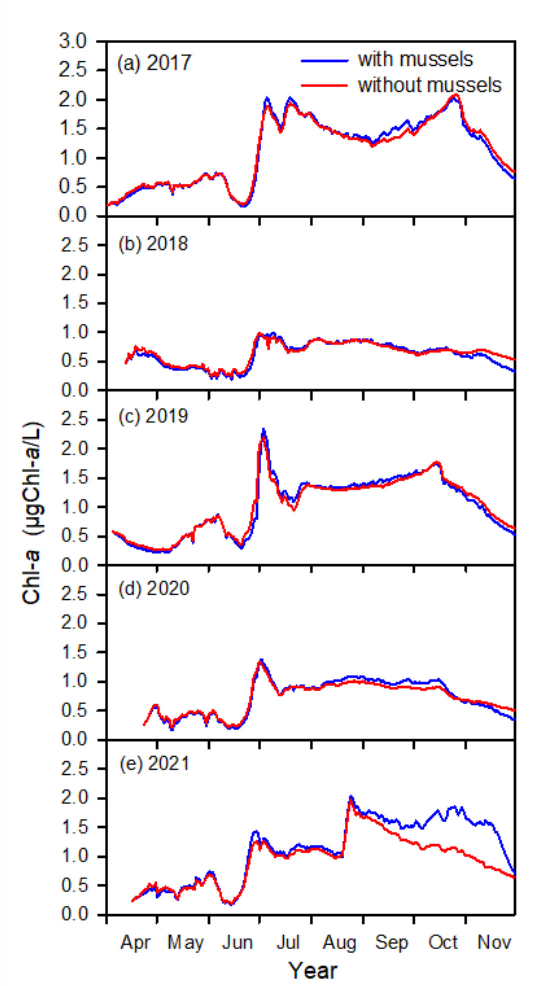
- Modeling and Nine Element Plans
- The model (CE-QUAL-W2)
  - Structure
  - Data requirements
- Model calibration and testing
- Insights from modeling
  - Extreme storm events
  - Phytoplankton community composition
  - Transport of cyanobacteria
  - Climate change
  - Water quality impacts of dreissenid mussels
- Summary





Why Develop Lake and Watershed Models?

1. **Provide a quantitative basis to evaluate future conditions and management strategies**
   - How will the lake respond to changes in nutrient loading?
   - How will climate change affect water quality conditions?
   - What are the impacts of dreissenid mussels?
2. **Support 9 Element Watershed Management Plans (9EPs)**
   - Objective, quantitative tools
   - Connect watershed actions to in-lake water quality
3. **9EPs enable funding opportunities**
   - Water Quality Improvement Projects (WQIP)

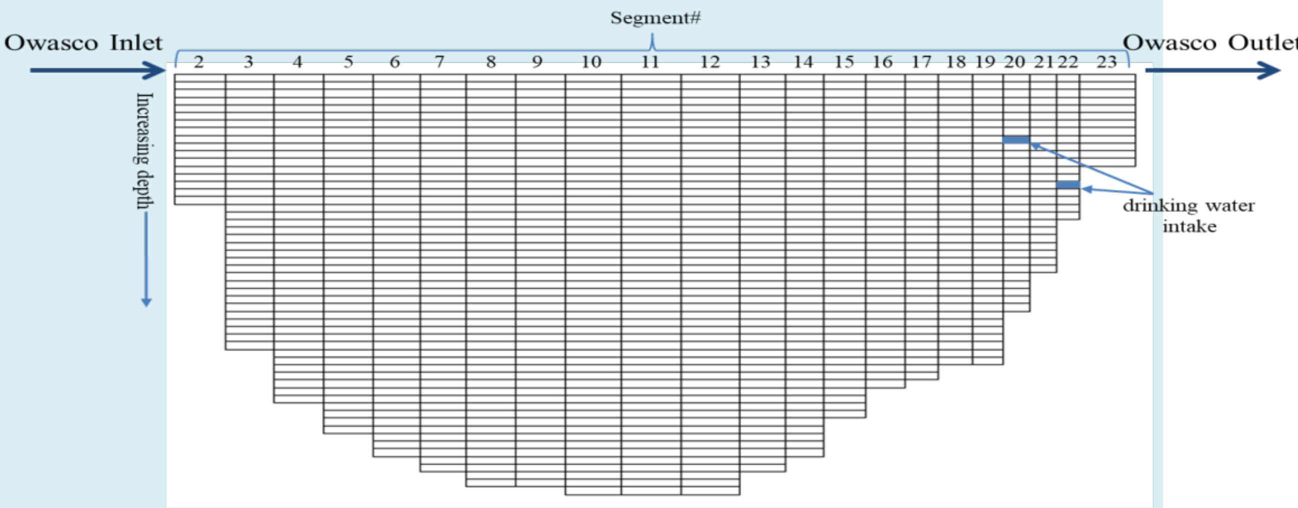


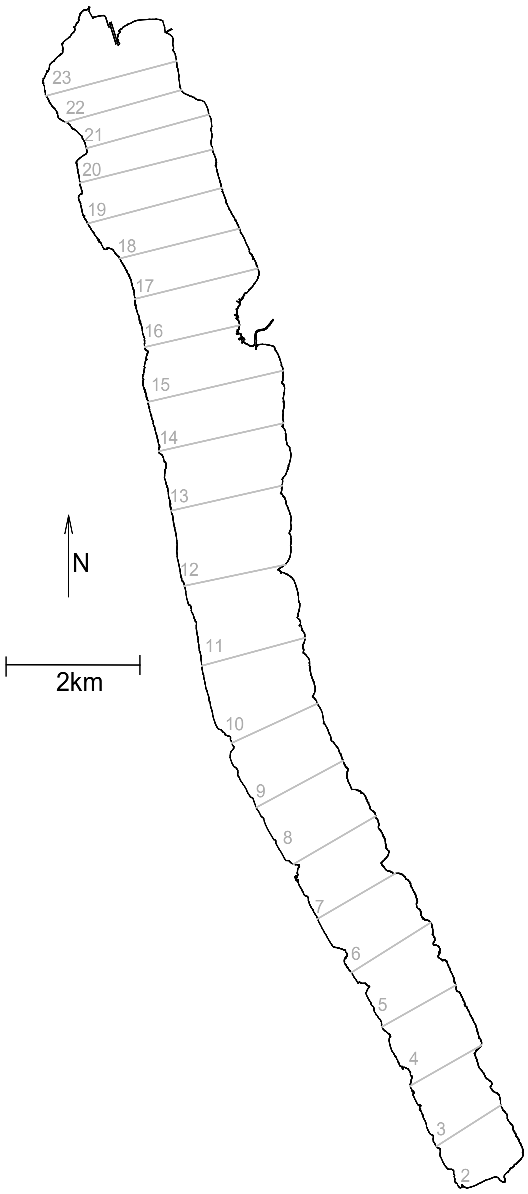
The In-Lake Model – CE-QUAL-W2

- Mechanistic, 2-dimensional (longitudinal/vertical) hydrodynamic and water quality model
- Developed by US Army Corps of Engineers and currently maintained by Portland State University
- Publically available and has been applied to hundreds of rivers, lakes and reservoirs
  - Cayuga, Owasco, Skaneateles, Oneida, Otsego on deck
- Why selected?
  - Well-suited for long, narrow lakes
  - Prior experience (e.g., NYC reservoirs)
  - Public access and acceptable to NYSDEC
  - Dreissenid mussel sub-model developed by UFI

Physical Structure of the Model

- 2-dimensional, laterally averaged
- 24 longitudinal segments - Owasco Lake
- 1-meter vertical layers





CE-QUAL-W2 State Variables

Symbol	Description	Units
T	temperature	°C
DO	dissolved oxygen	mg O_2/L
Phytoplankton as algal biomass (user defined groups)		
Alg1	diatoms	µg DW/L
Alg2	greens	µg DW/L
Alg3	cyanobacteria	µg DW/L
Organic Matter		
lDOM	labile dissolved organic matter	mg DW/L
rDOM	refractory dissolved organic matter	mg DW/L
lPOM	labile particulate organic matter	mg DW/L
rPOM	refractory particulate organic matter	mg DW/L
Nitrogen		
tNH_3	total ammonia	µg N/L
NO_X	nitrate + nitrite	µg N/L
lDON	labile dissolve organic nitrogen	µg N/L
rDON	refractory dissolve organic nitrogen	µg N/L
lPON	labile particulate organic nitrogen	µg N/L
rPON	refractory particulate organic nitrogen	µg N/L
Phosphorus		
SRP	soluble reactive phosphorus	µg P/L
lDOP	labile dissolve organic phosphorus	µg P/L
rDOP	refractory dissolve organic phosphorus	µg P/L
lPOP	labile particulate organic phosphorus	µg P/L
rPOP	refractory particulate organic phosphorus	µg P/L
Silica		
DRSi	dissolved reactive silica	mg Si/L
Psi	particulate biogenic silica	mg Si/L
Zooplankton as zooplankton biomass (user defined groups)		
Zoo1	herbivores	µg DW/L

State variables = modeled parameters

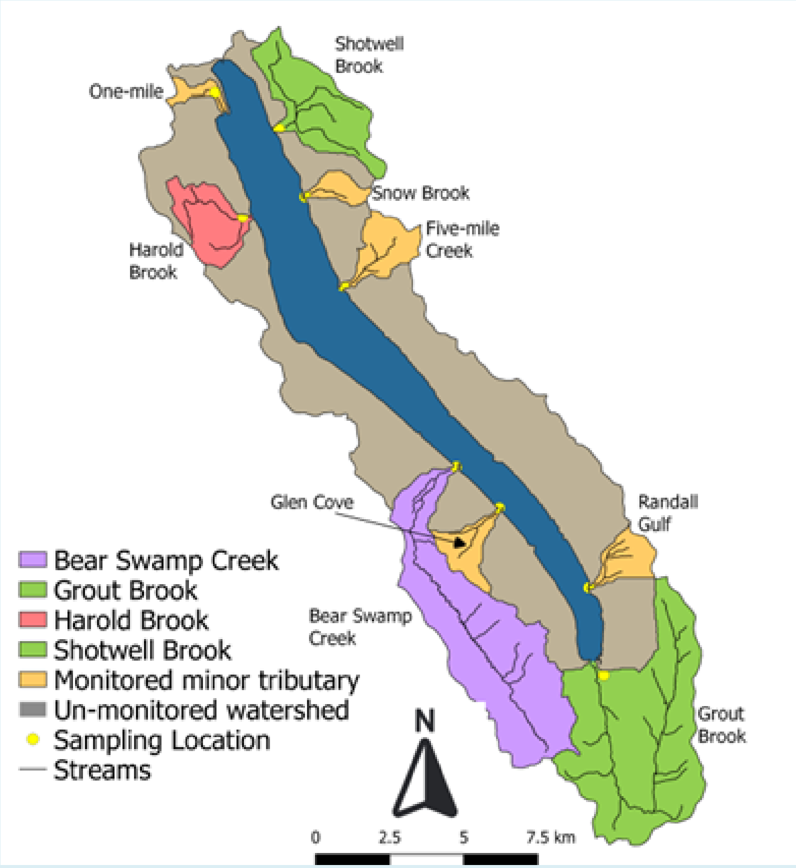
Sum to chlorophyll-*a* (Alg1–Alg3)

Sum to Total Nitrogen (tNH_3–rPON)

Sum to Total Phosphorus (SRP–rPOP)

measured, calculated, or literature values

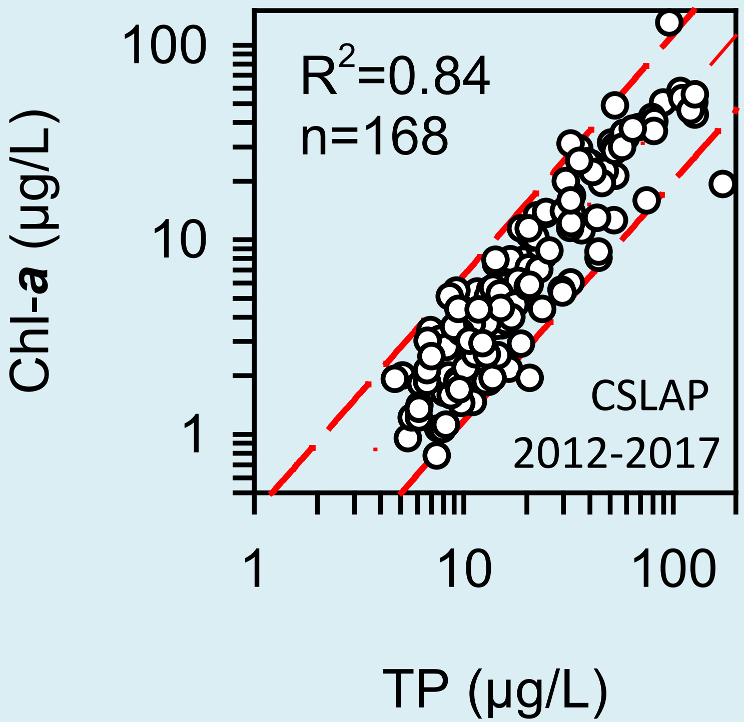
Data Requirements



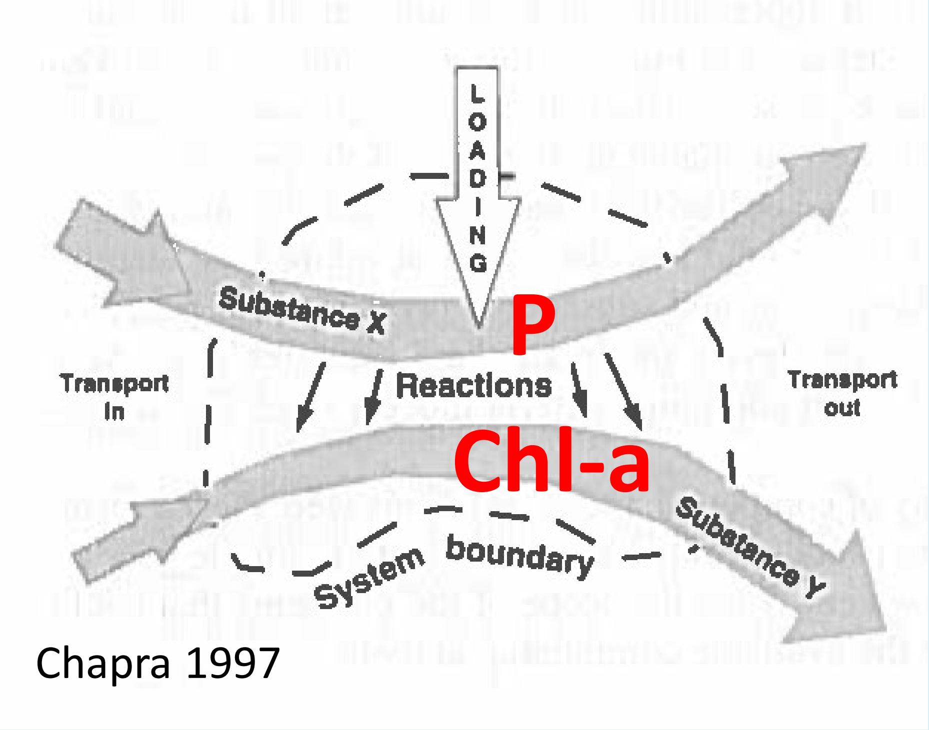
- Detailed bathymetry
- Water surface elevation
- Sub-watershed areas
- Measured inflows, outflows, loads
- Meteorology - air temperature, wind speed and direction, dew point, cloud cover, solar radiation, precipitation
- Initial concentrations for all state variables

Comparing Empirical/Statistical and Mechanistic Models

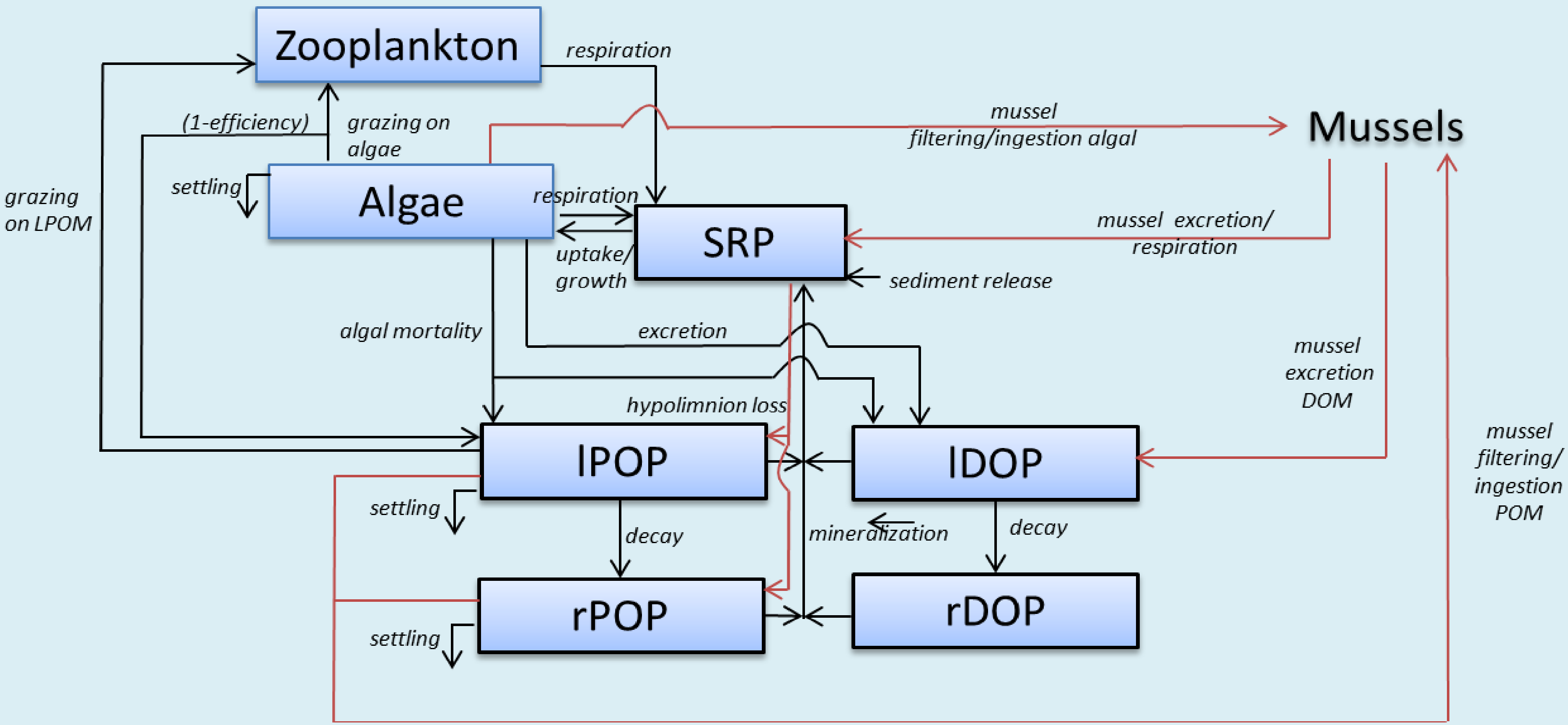
Chl-*a* = *a*(TP) + *b*



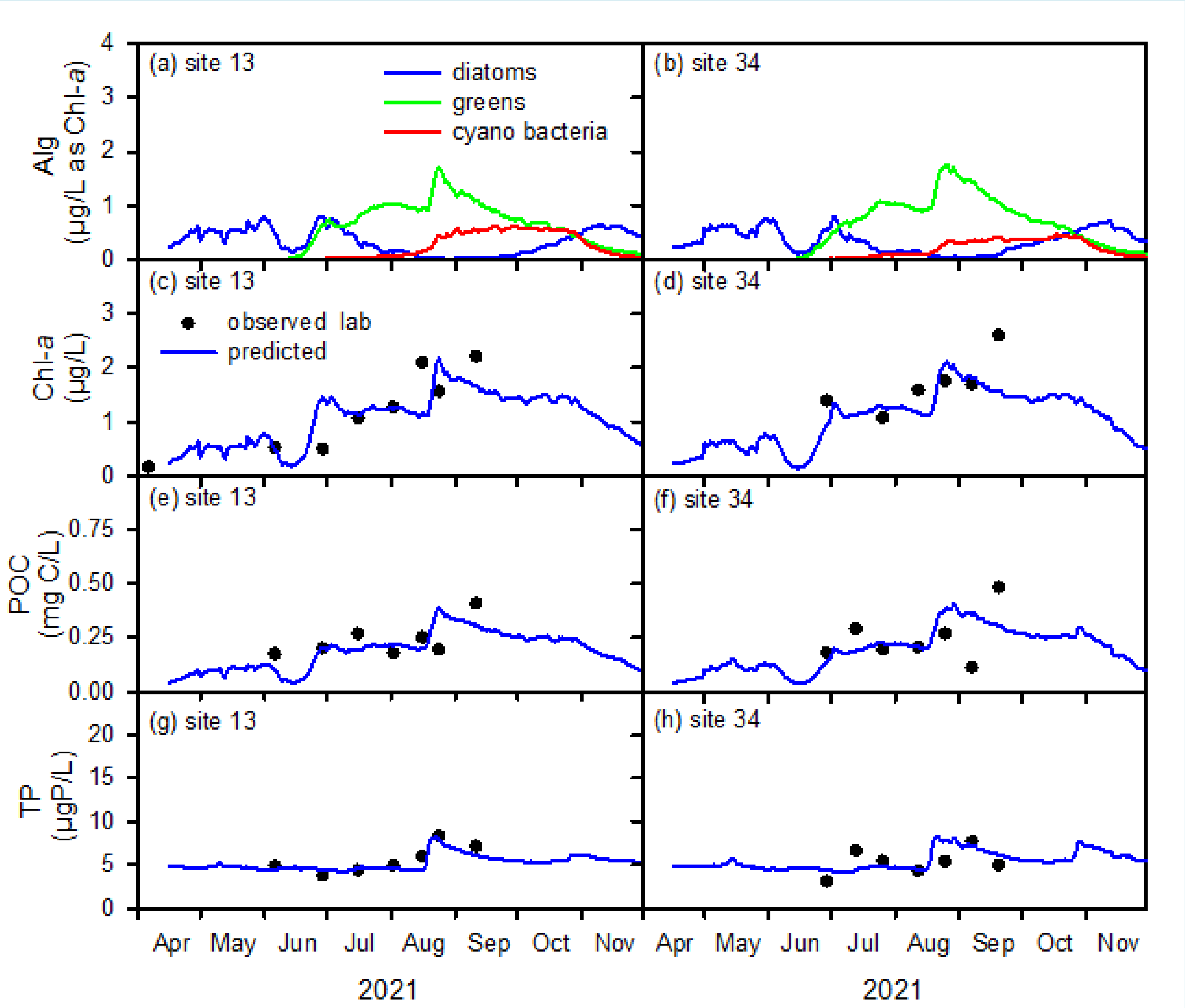
Chl-*a* = *f*(W_{TP}; physics, chemistry, biology)



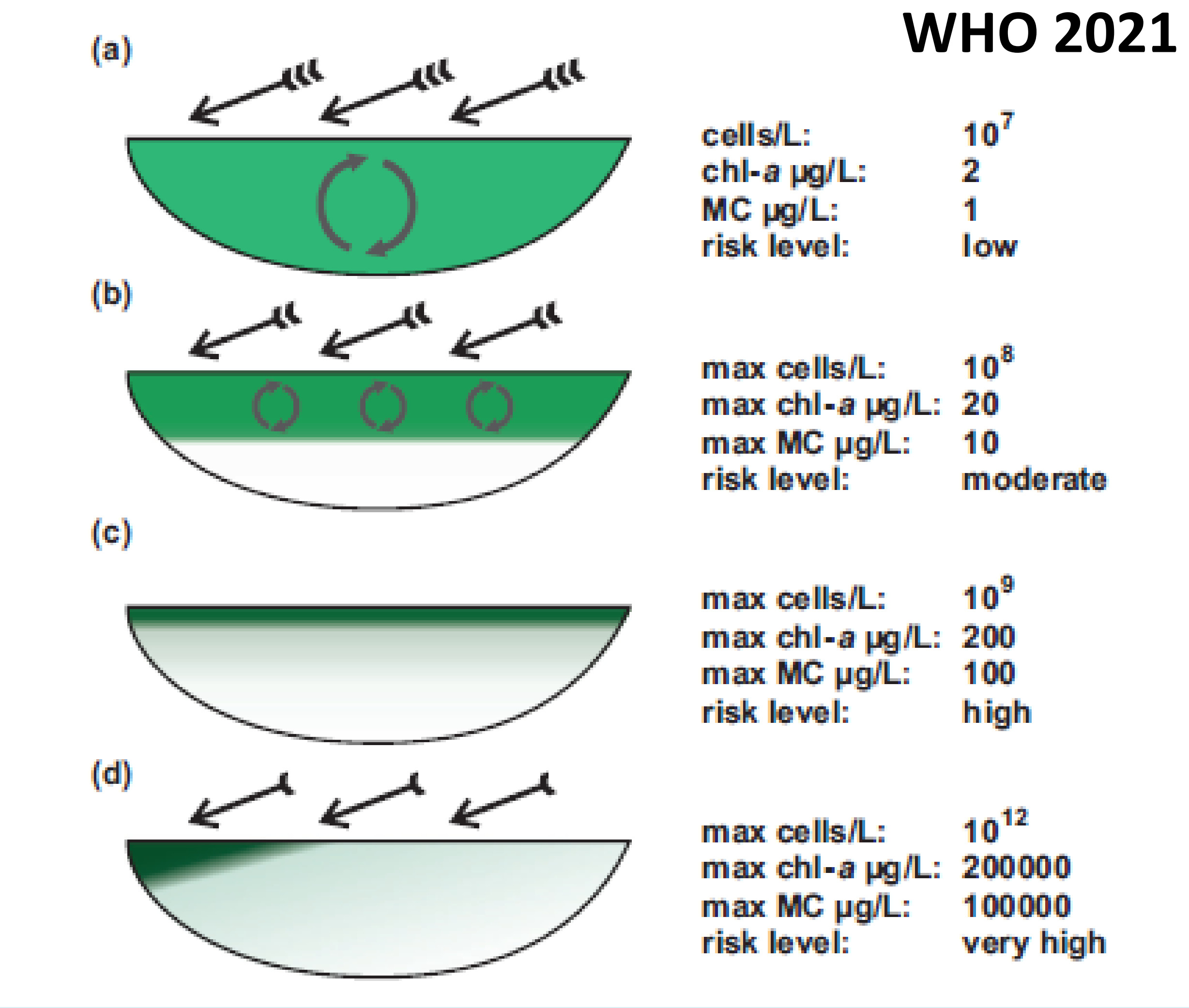
Conceptual Diagram for Phosphorus



Calibration of the Water Quality Model



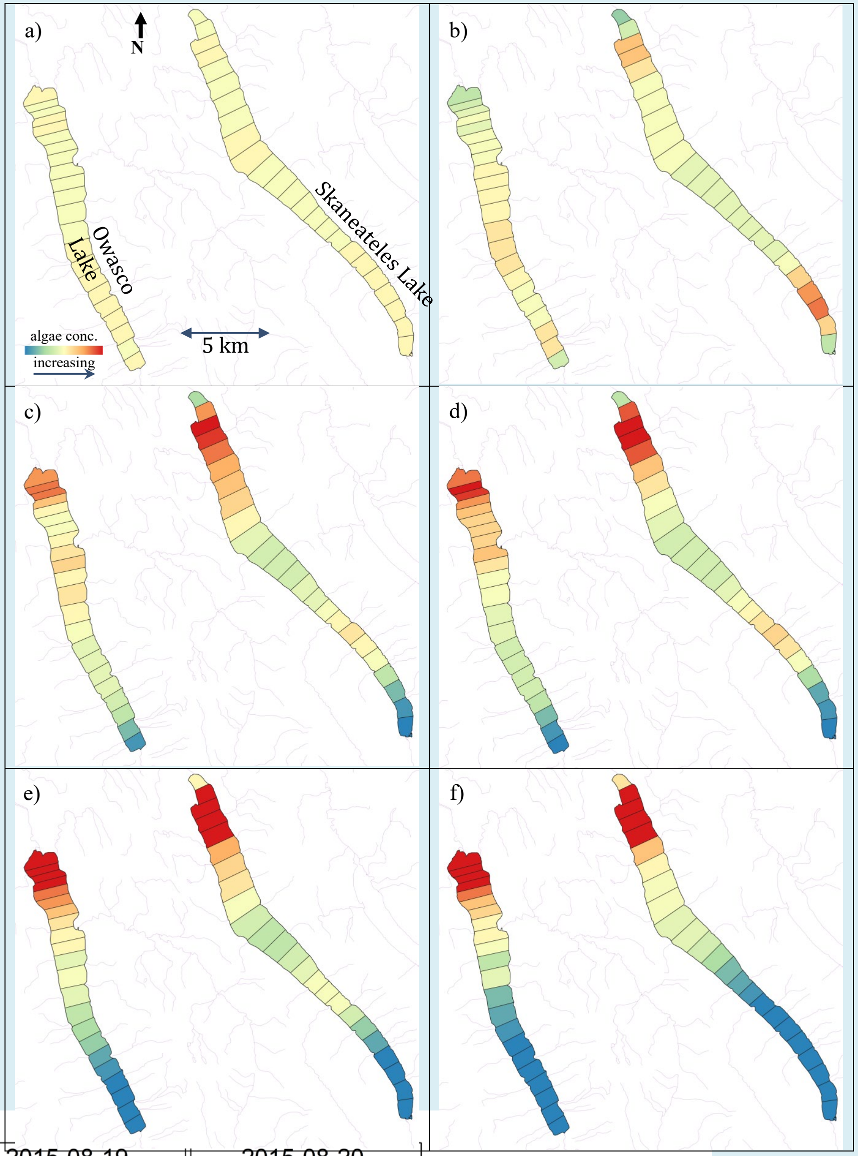
Theories of Bloom Formation

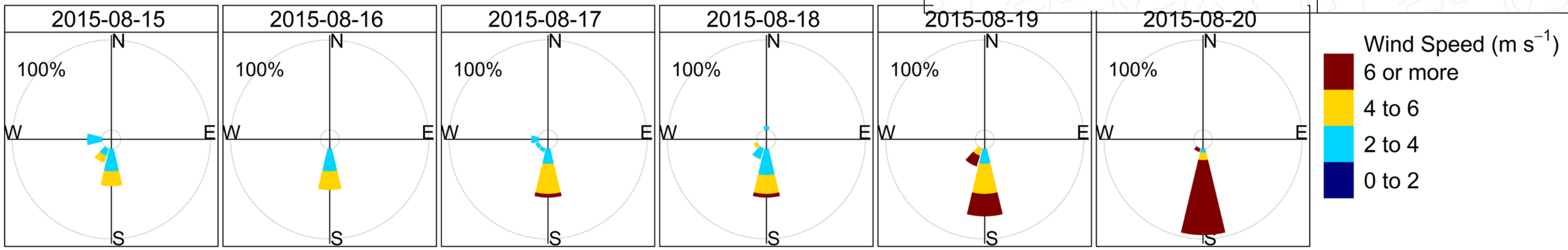


The shape and orientation of the Finger Lakes makes them especially susceptible to this mechanism of bloom formation

Wind-driven Transport of Cyanobacteria

- Simulations of a <u>floating</u> conservative tracer to represent cyanobacteria
- Southerly wind over six consecutive days
- Simulated bloom conditions in Owasco and Skaneateles Lakes





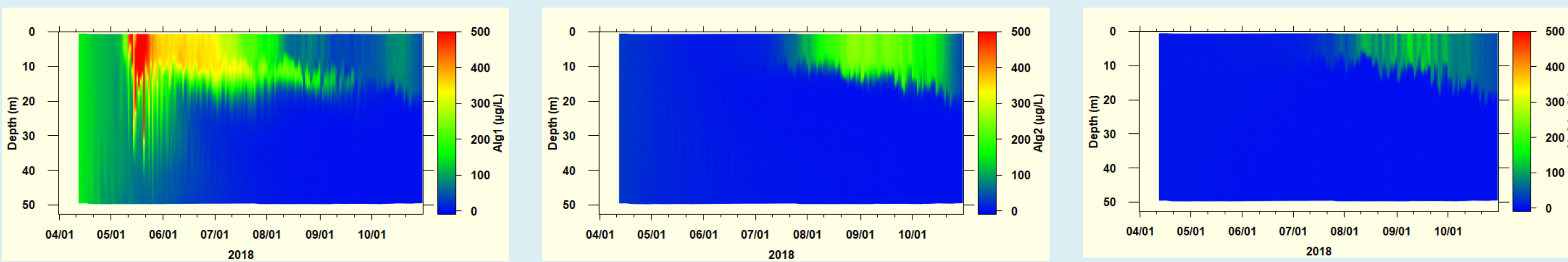
Impacts of Dreissenid Mussels on Phytoplankton Community Composition

- Little change in algal biomass – selective feeding caused an important shift in assemblage

With mussels

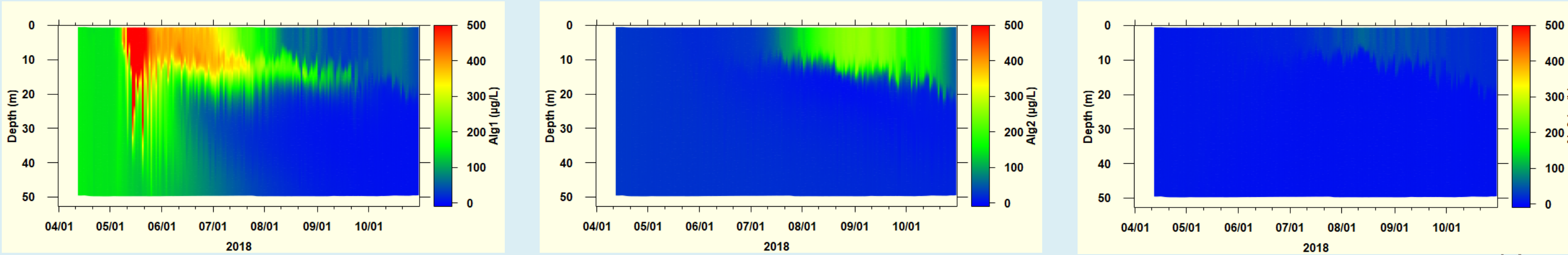
diatoms | greens | cyanobacteria

Depth

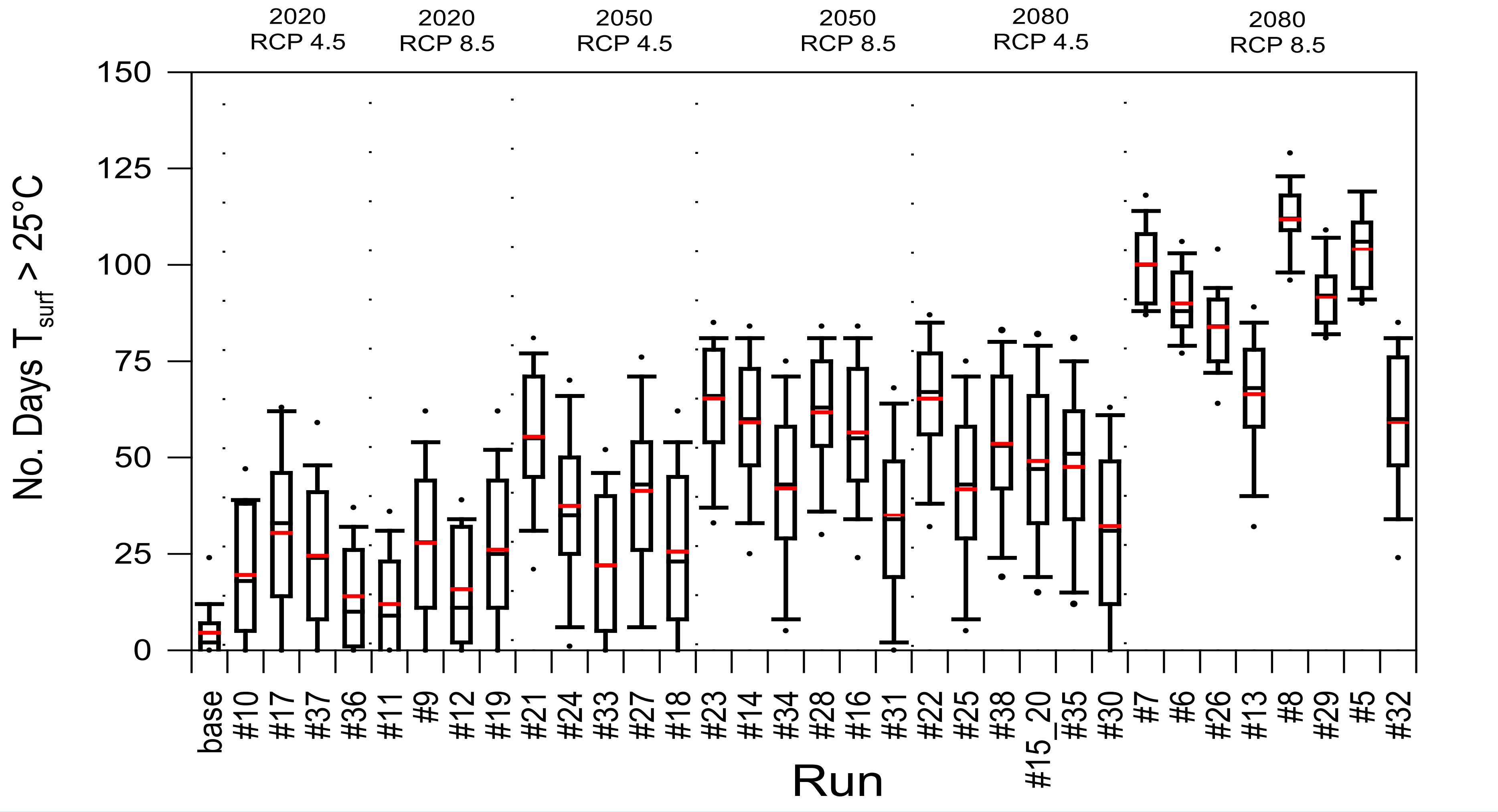


time

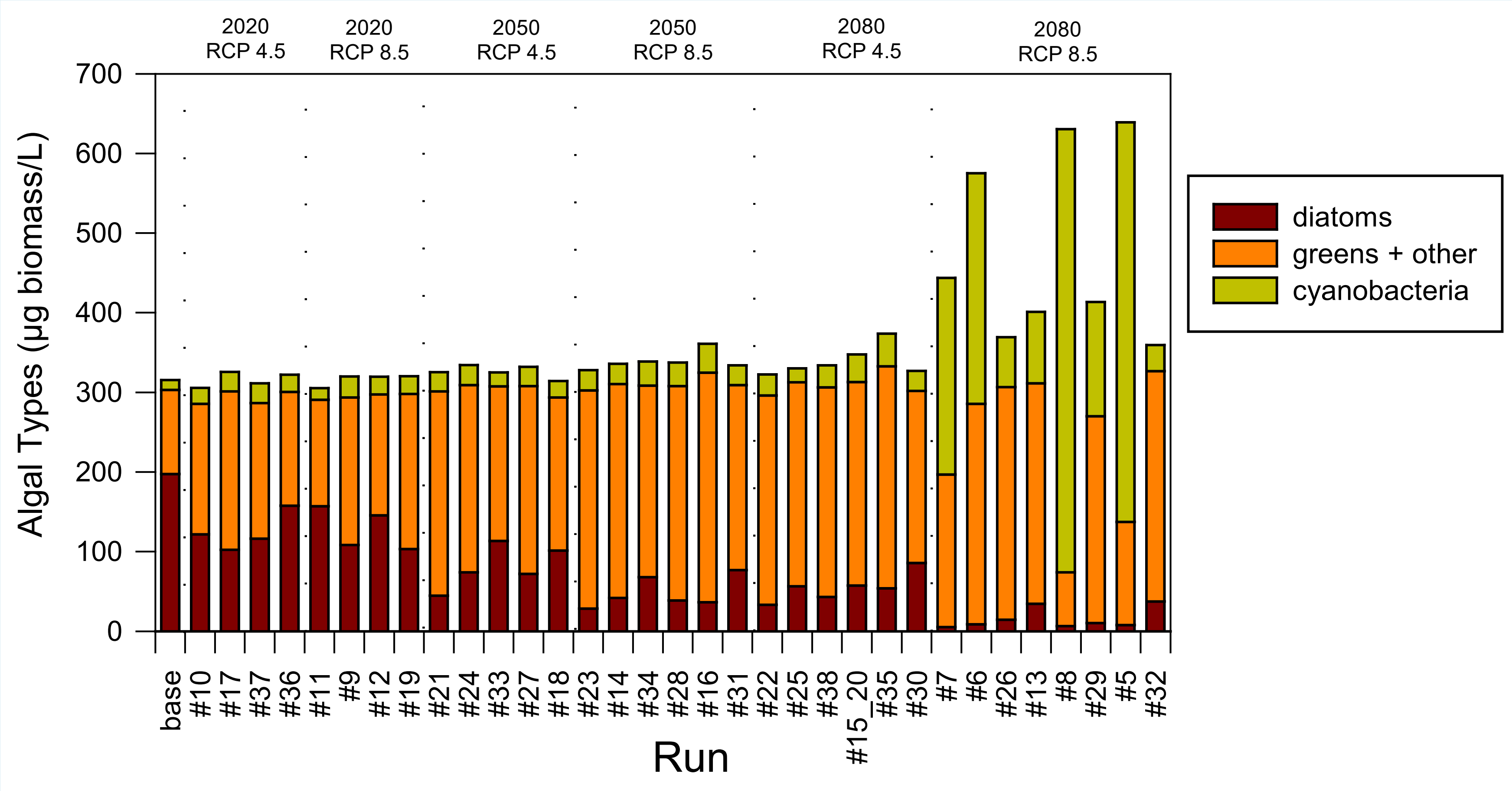
Without mussels



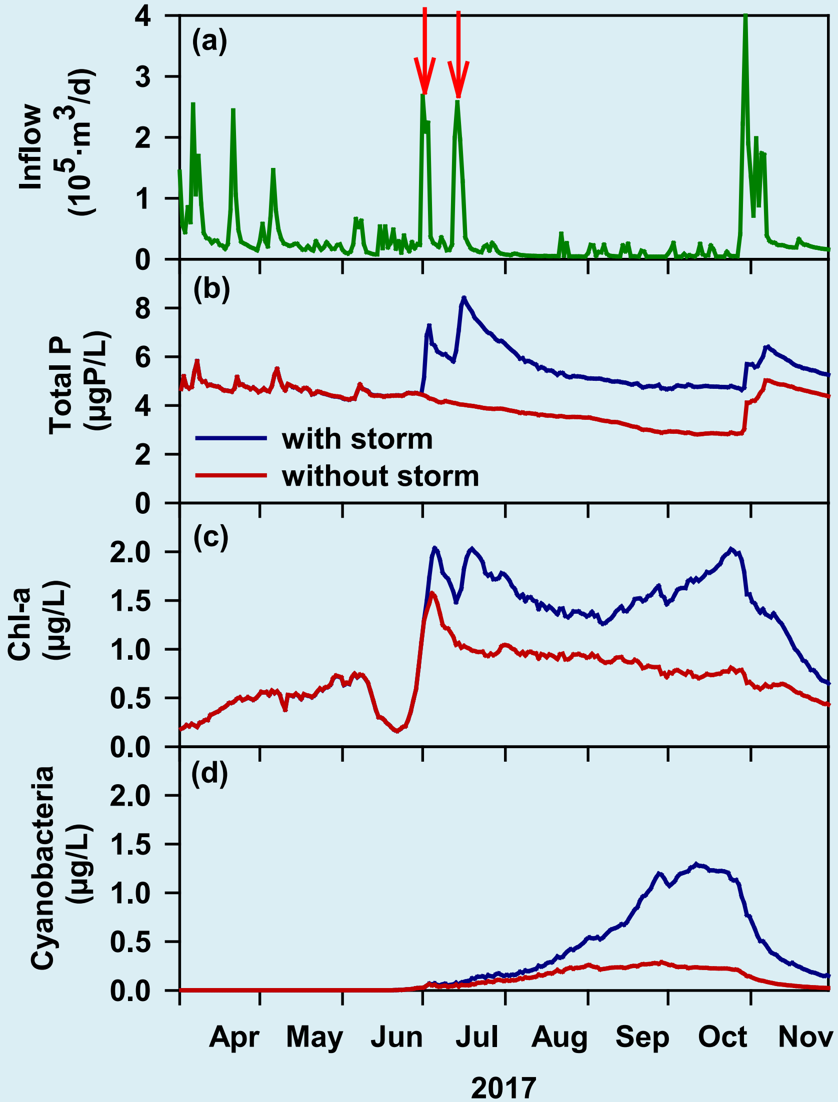
Impact of Climate Change on Surface Water Temperatures



Impact of Climate Change on Phytoplankon Community Composition



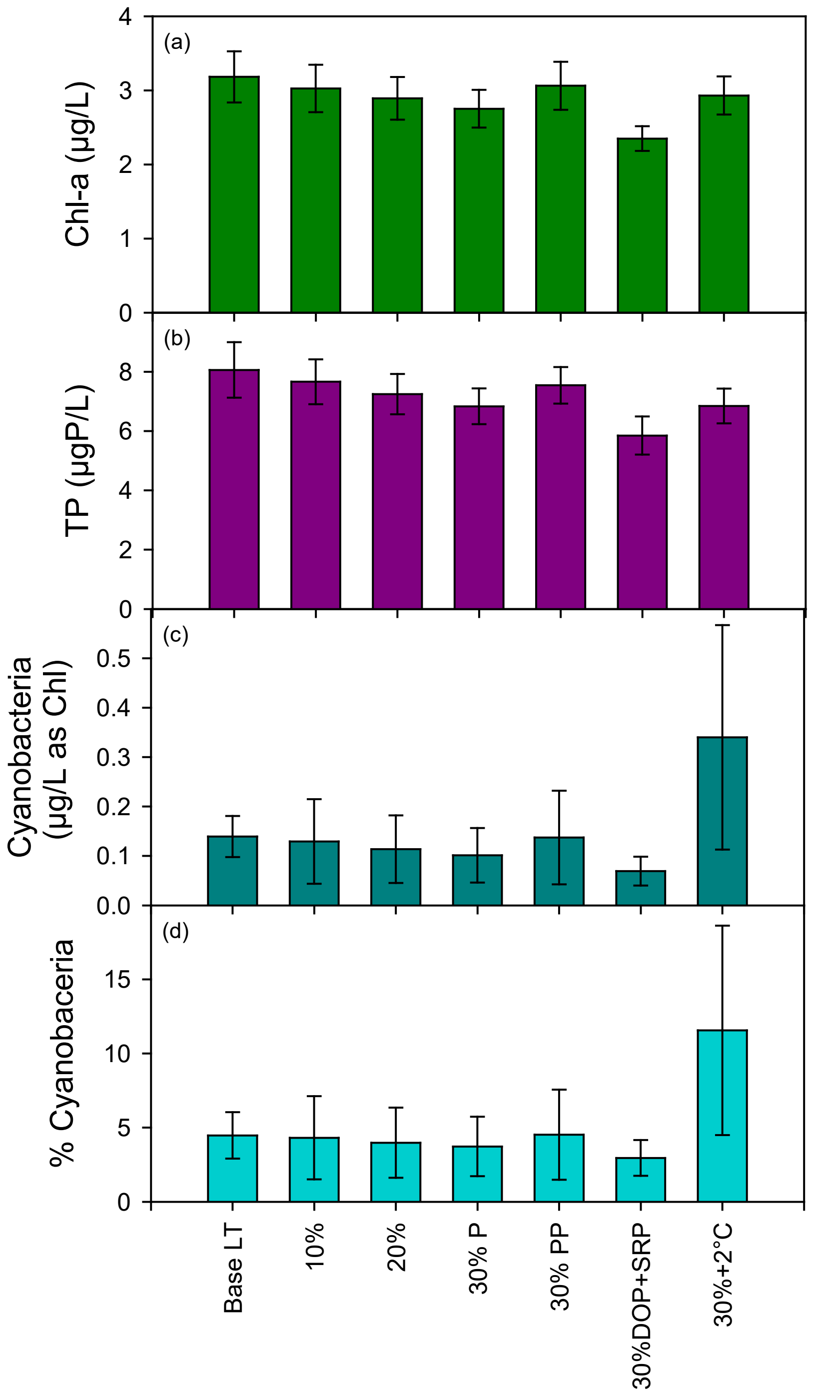
Impact of Extreme Storms on Phytoplankton Growth



- Skaneateles Lake
  - big lake
  - small watershed
- water residence time of about 12 years

Management Scenarios – Owasco Lake

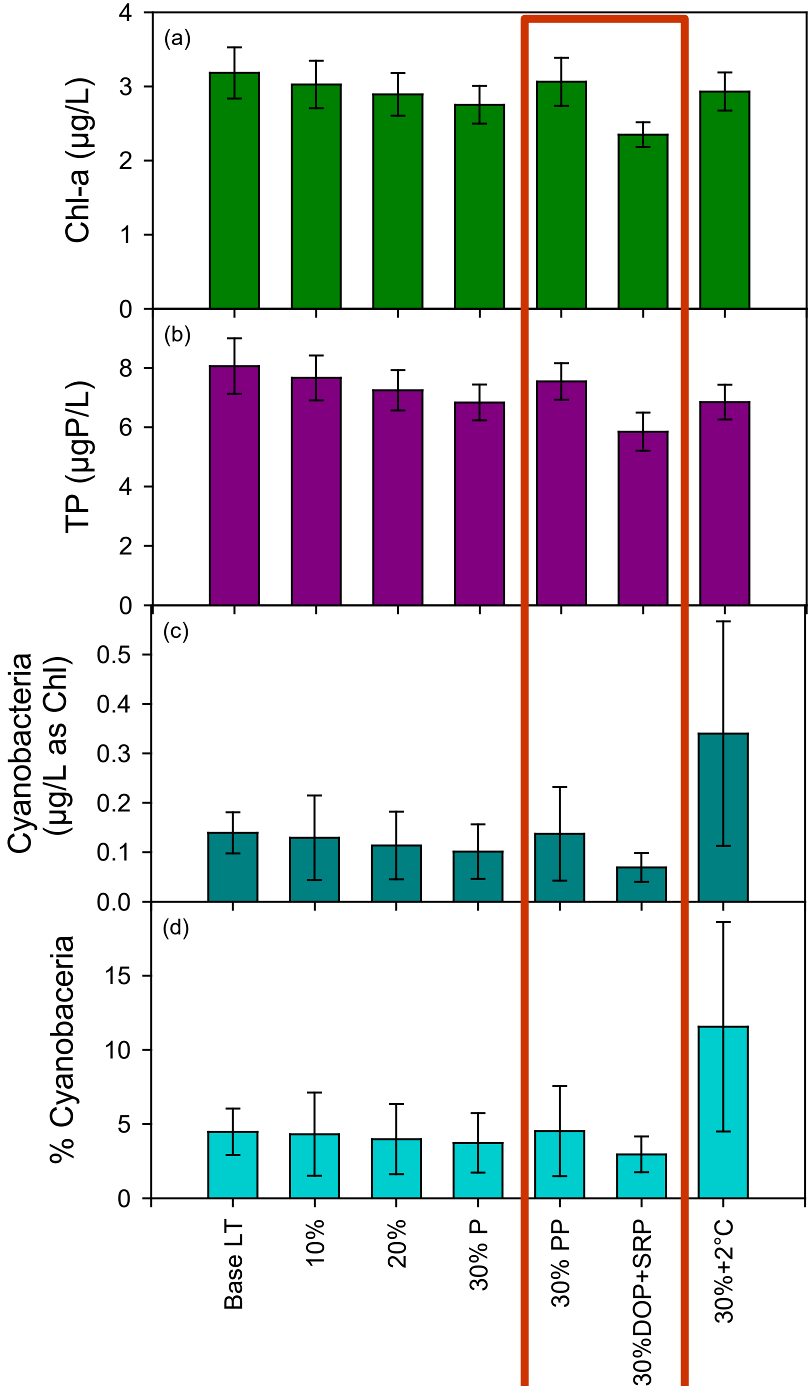
- Base Case – 2000-2018 (19 years)
- tributary TP loading reduced by 10% (SRP, DOP, PP)
- tributary TP loading reduced by 20% (SRP, DOP, PP)
- tributary TP loading reduced by 30% (SRP, DOP, PP)
- tributary TP loading reduced by 30% (PP)
- tributary TP loading reduced by 30% (SRP, DOP)
- tributary TP loading reduced by 30% (SRP, DOP, PP) and 2°C temperature increase



Management Scenario Results

- The forms of TP targeted matter
  - 30% TP loading reduction via PP results in a 3% decrease in Chl-*a*
  - 30% TP loading reduction via SRP and DOP results in a 26% decrease in Chl-*a*
- A 2°C increase in air temperature would more than negate cyanobacteria decrease from reduced TP loading

Management Scenario Results



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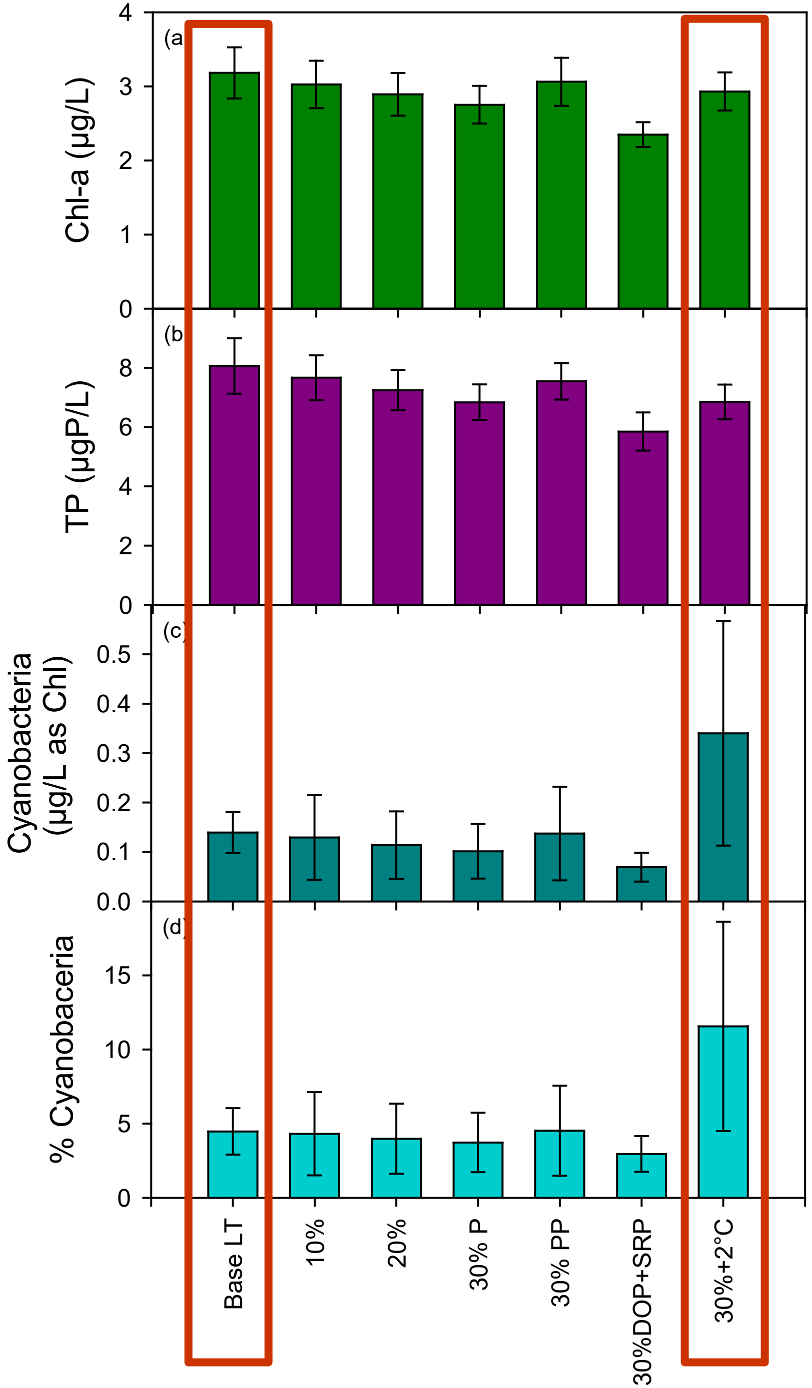

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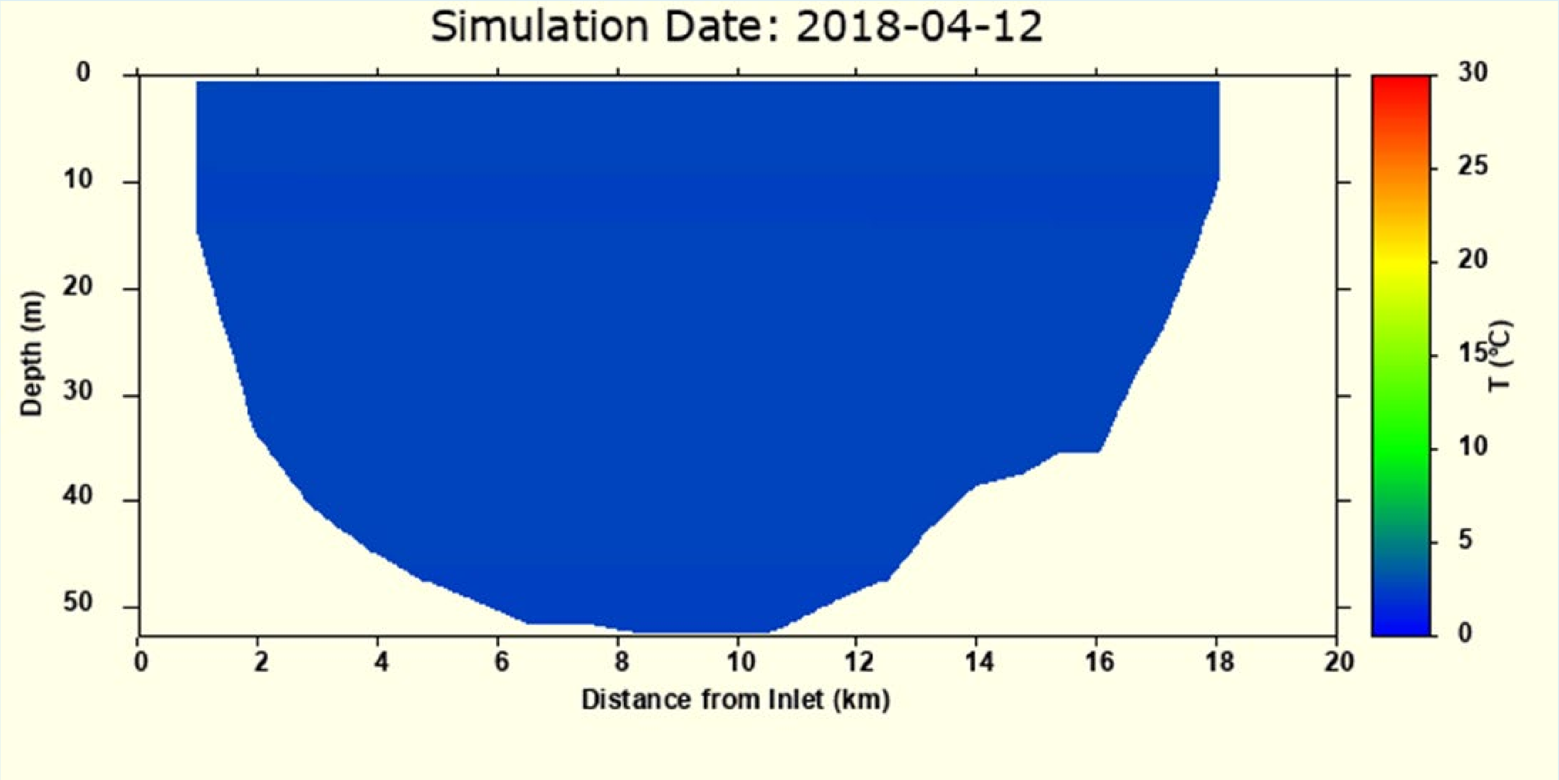
Summary of Findings

- **Water quality models of Owasco and Skaneateles Lakes successfully calibrated, tested, and applied**
- **Predominant southerly winds during summer contribute to the formation of HABs along northern shorelines**
- **Selective feeding by dreissenid mussels favors cyanobacteria over other phytoplankton taxa**
- **Future climate change will favor cyanobacteria and potentially negate the benefits of phosphorus loading reductions**
- **BMPs intended to address phytoplankton growth and HABs should focus on extreme storm events and dissolved forms of P**

Questions?

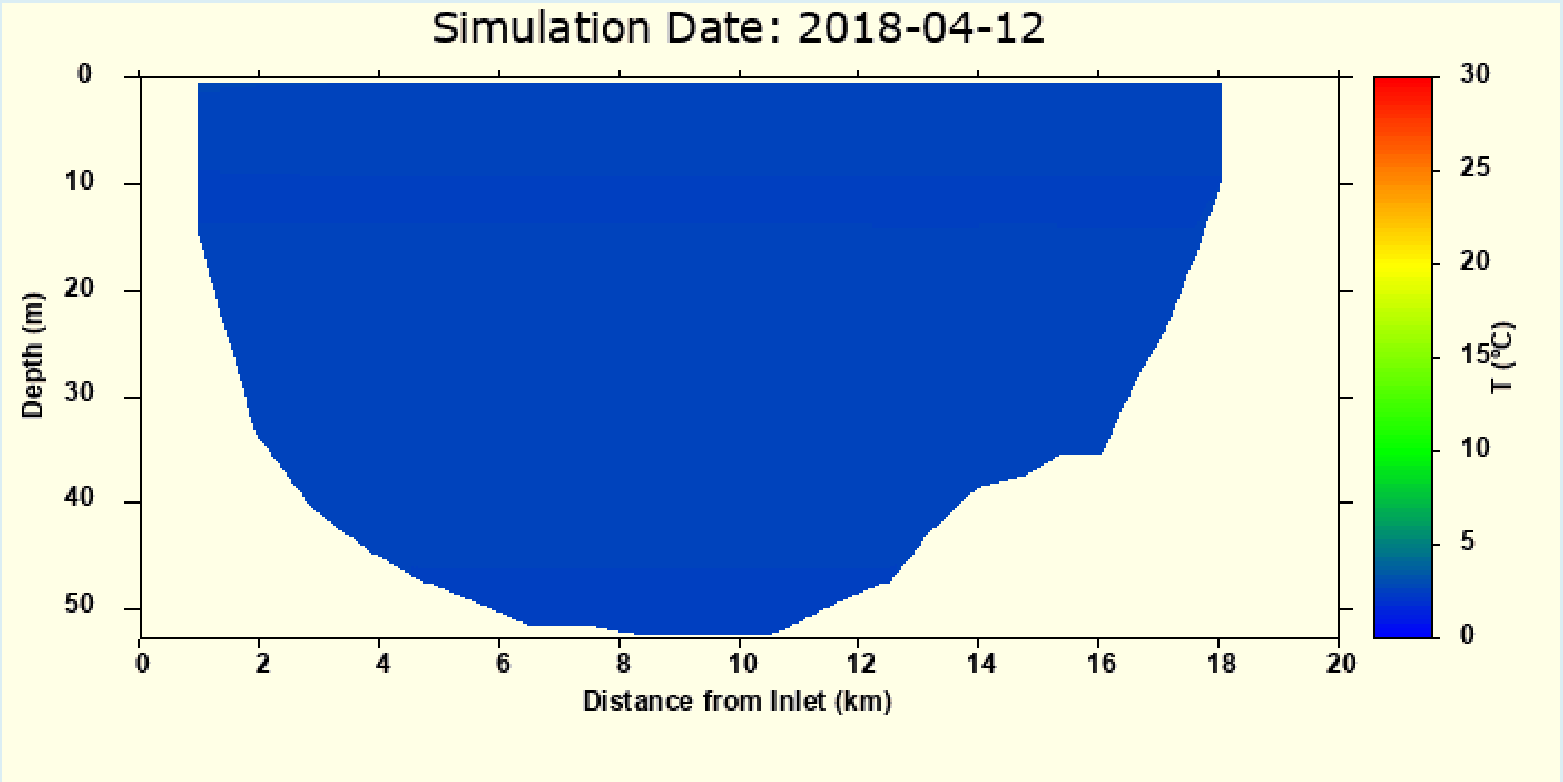
Simulation of Water Temperature and the Stratification Regime, 2018



Depth

South → North

Simulation of the Temperature Stratification Regime, 2018



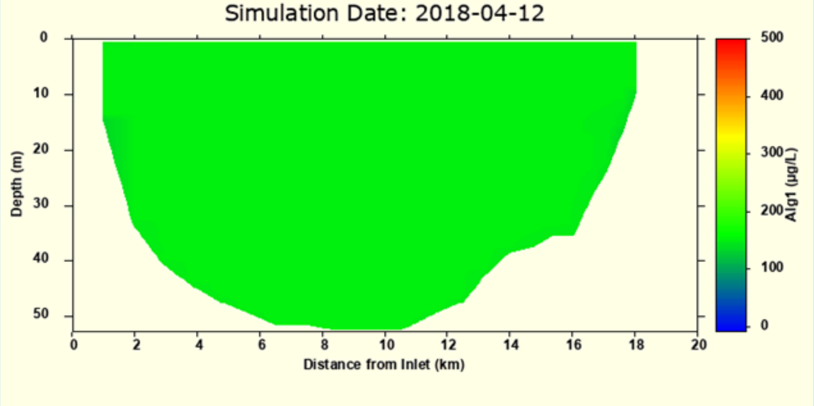
Depth

South → North

Phytoplankton Succession

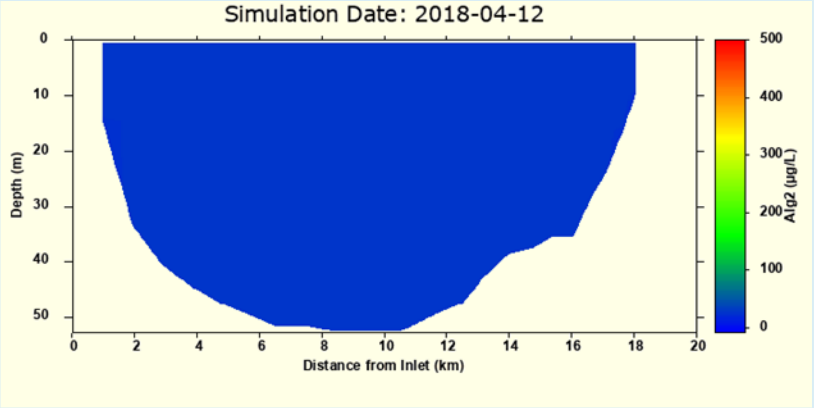
Depth

Diatoms

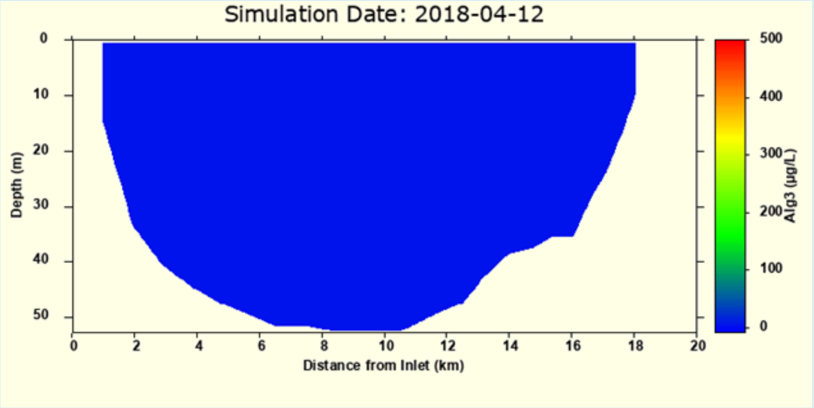


South North

Greens



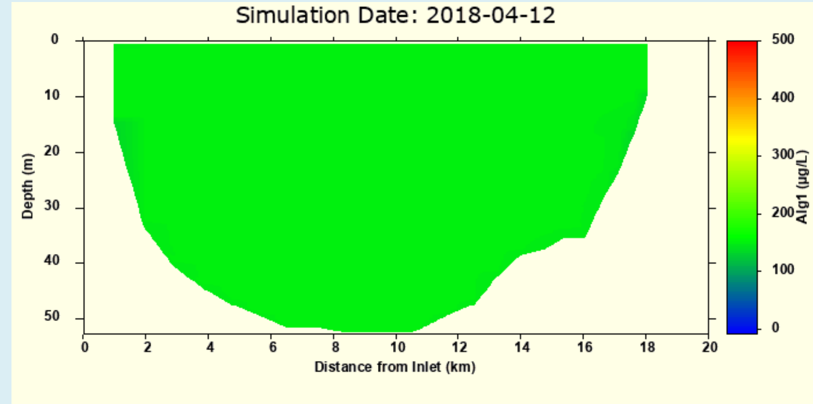
Cyanobacteria



Phytoplankton Succession

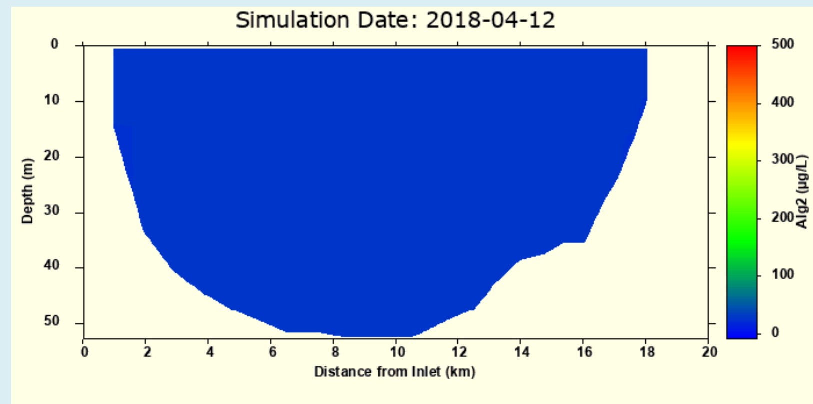
Depth

Diatoms

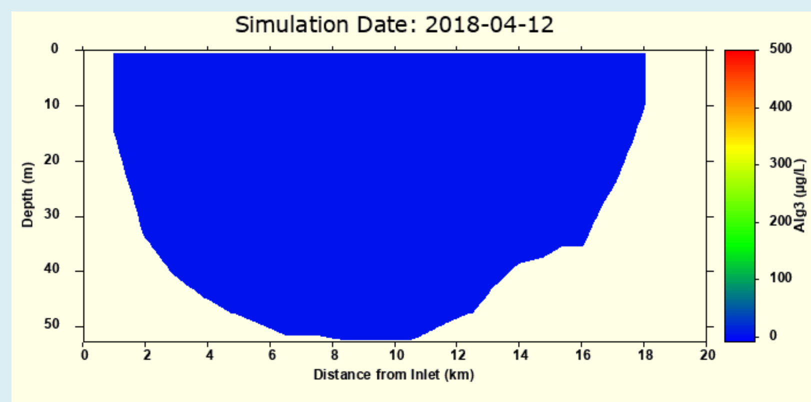


South North

Greens



Cyanobacteria



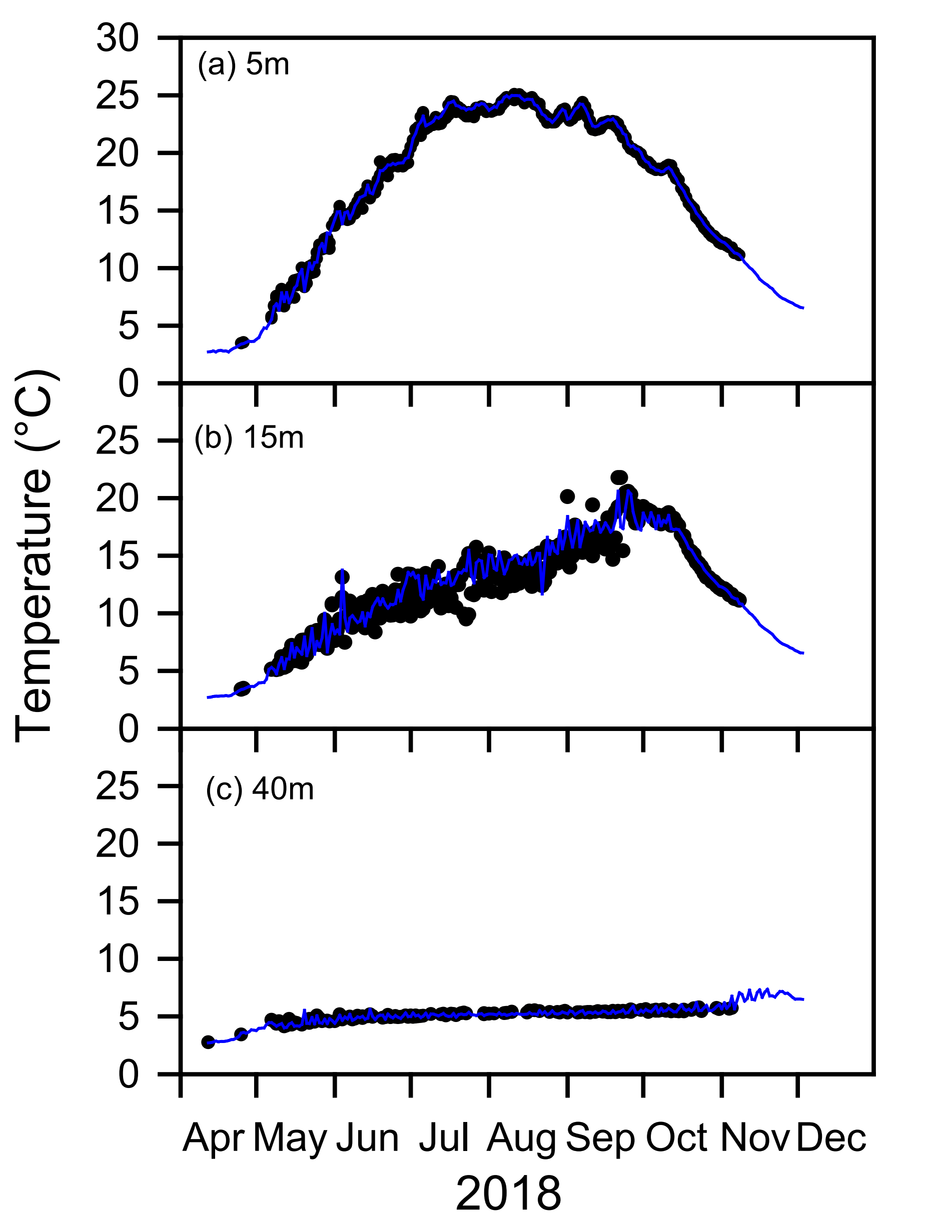
Purpose and Related Efforts

- Develop in-lake models to support development of NYS-funded Nine Element Watershed Management Plans (9EPs)
  - Owasco Lake, Skaneateles Lake, Oneida Lake, Cayuga Lake (TMDL)
  - Otsego Lake, on deck
- Linked in-lake and watershed models are quantitative science-based tools
- Scenario evaluation to guide management

Calibration and Confirmation

- **Comparison of model simulations to observations**
- **Calibration is an iterative process where coefficients are adjusted, within ranges established by the literature, to fit observations**
- **The model is considered to be confirmed if it can adequately simulate another set of observations without adjusting coefficients**
- **Ideally, calibration and confirmation data sets represent a wide range of driving conditions (e.g., weather)**

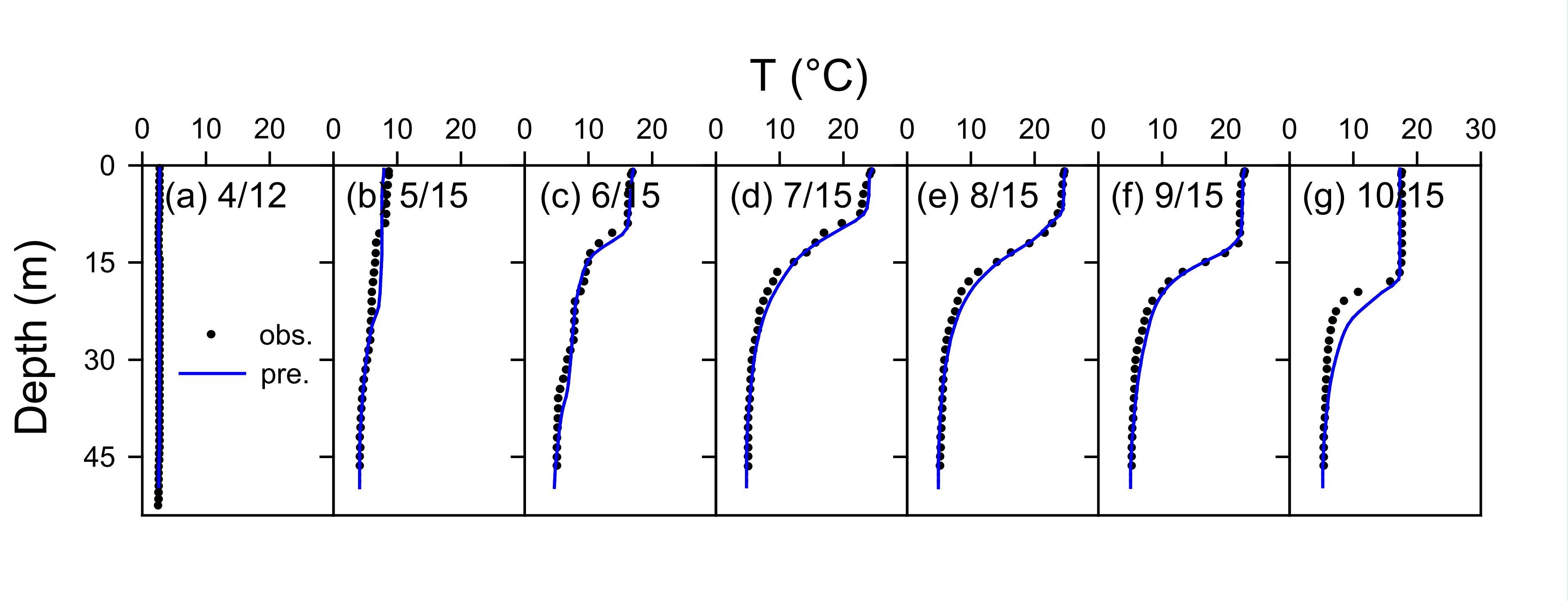
Hydrothermal Calibration



Owasco Lake

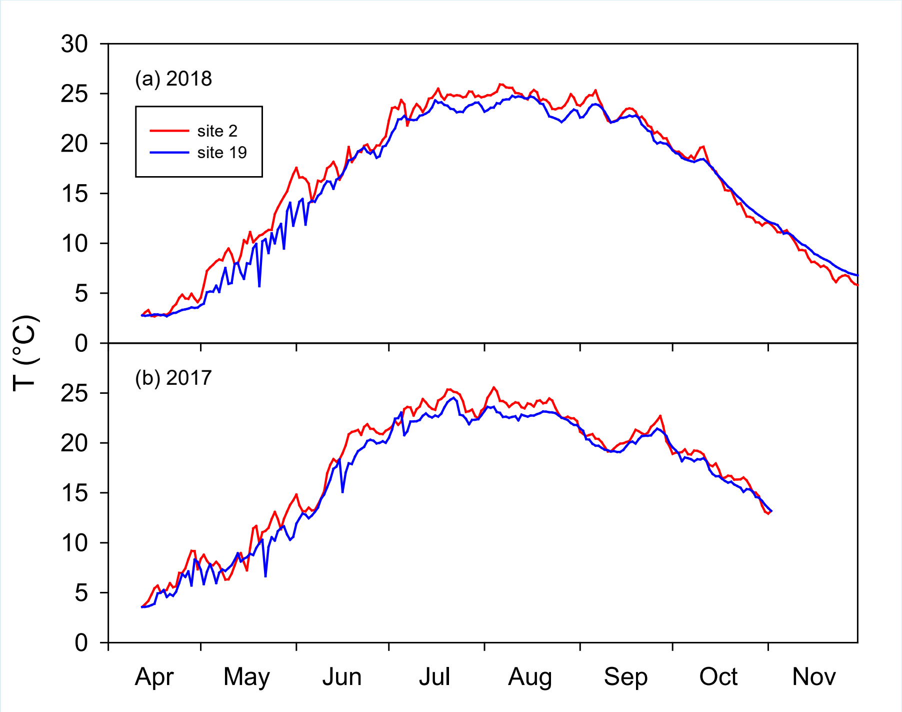
- **Excellent performance in the epilimnion and hypolimnion**
- **Wide short-term temperature fluctuations at the thermocline caused by internal waves (seiches)**
- **On-site wind direction was critical**
  - **Finger Lakes Institute buoy**

Hydrothermal Calibration

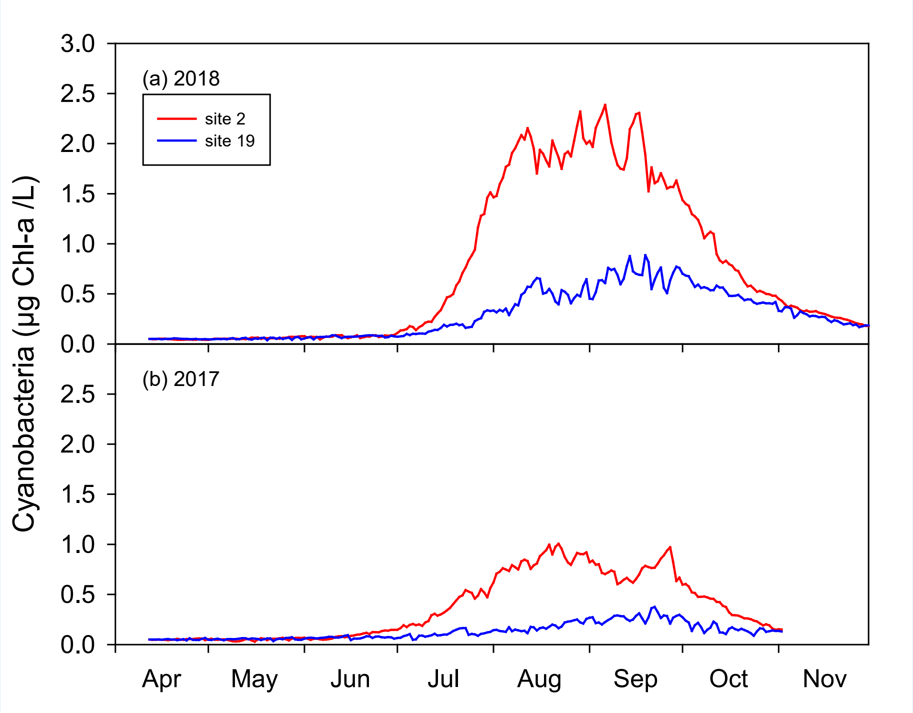


Longitudinal Patterns in Temperature and Cyanobacteria

Surface water temperature higher at the northern end of the lake

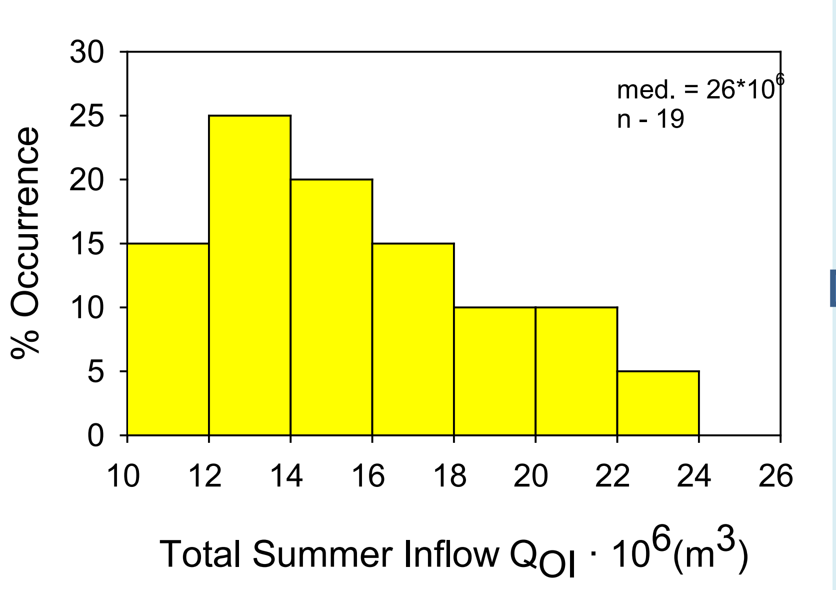


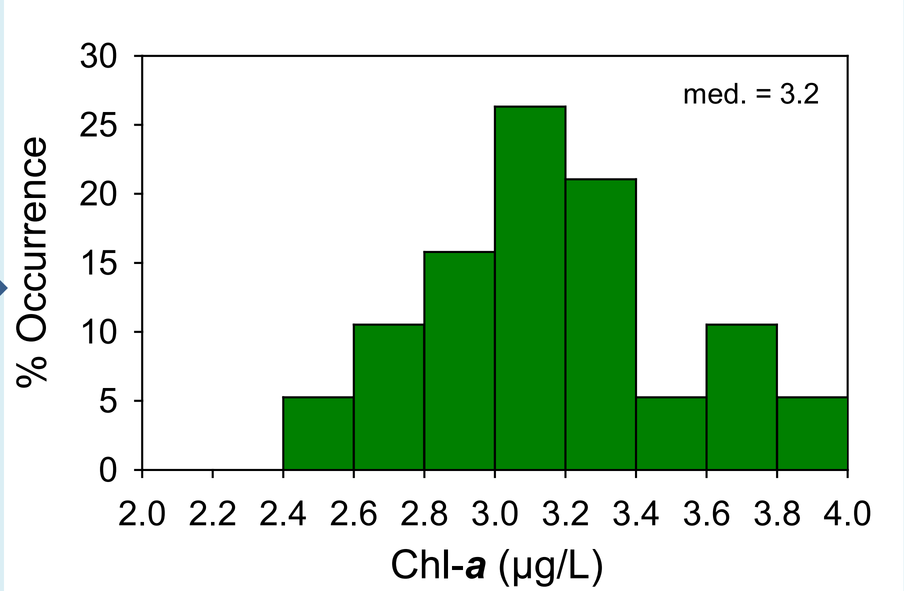
Cyanobacteria more abundant at the northern end of the lake

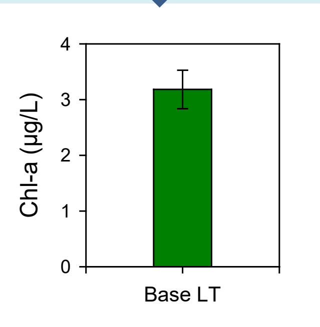


Probabilistic Approach to Management Runs

- Run model for 19 years (2000-2018) of weather conditions to represent natural variability
- Predictions take the form of distributions that reflect uncertainty







Upstate Freshwater Institute

Background

- established in 1981
- not-for-profit [501(c)(3)]
- independent, but close professional ties to Syracuse University and SUNY-ESF

- overseen by a board of directors
- conducts fundamental and applied interdisciplinary research

Upstate Freshwater Institute

Mission

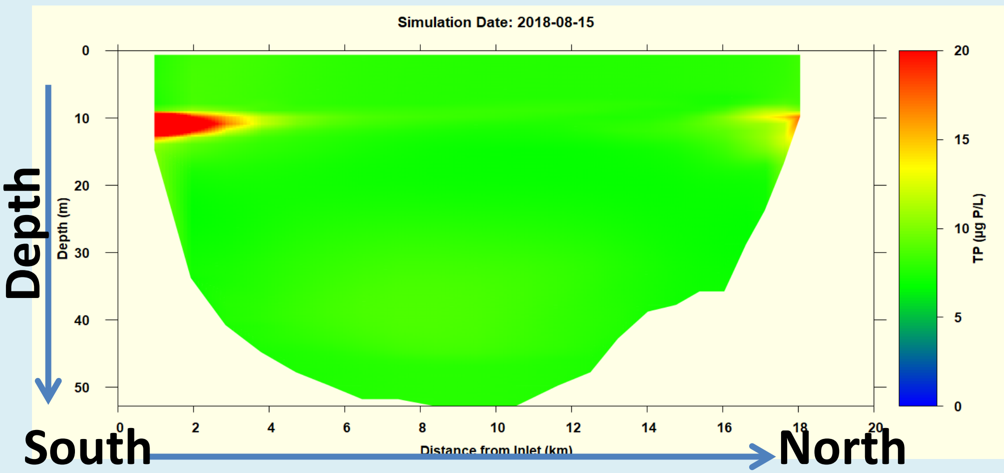
- provide the scientific basis for protection of the freshwater resources of New York State
- advance freshwater research and education

Comparing Mechanistic Models and Empirical/Statistical Models

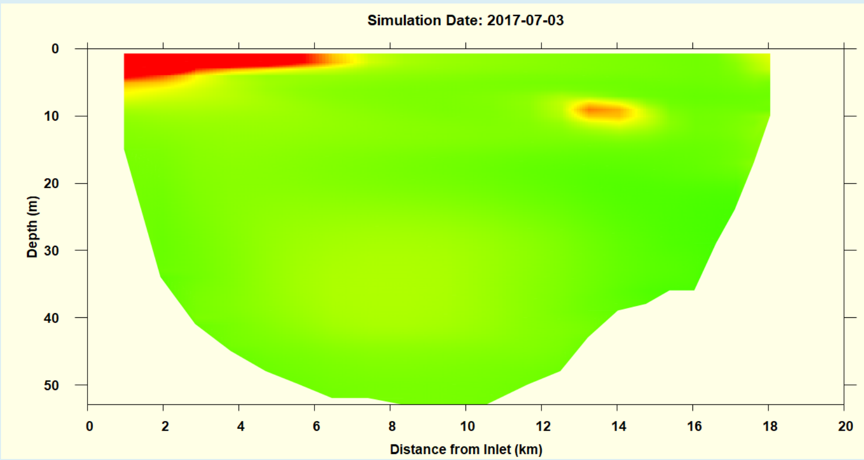
	Mechanistic Models	Statistical Models
Principle	Theoretical, mass balance	Data-based
Equations	Complex	Simple
Data	Many parameters, few observations	Many observations, few parameters
Implementation	High effort	Low effort
Interpolation	Yes	Yes
Extrapolation	Yes	No
Increase understanding of processes	**Yes**	**Limited**

Vertical Distribution of Total Phosphorus Affected by Tributary Entry Depth

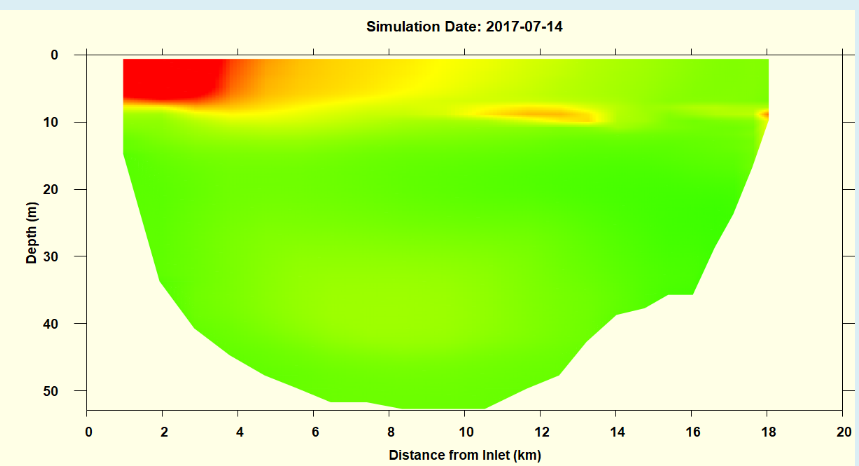
interflows



overflow and interflow



overflow and interflow following a storm



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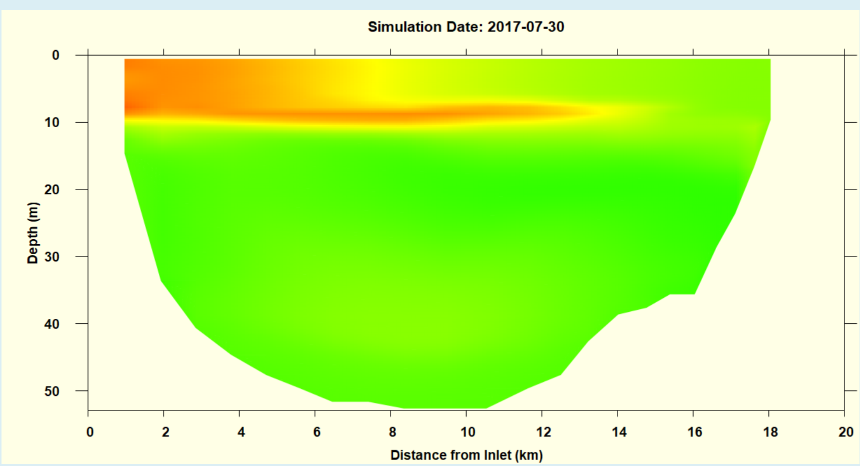
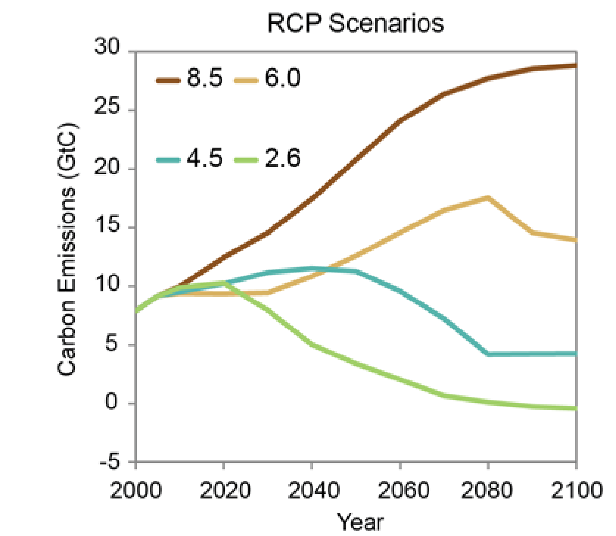
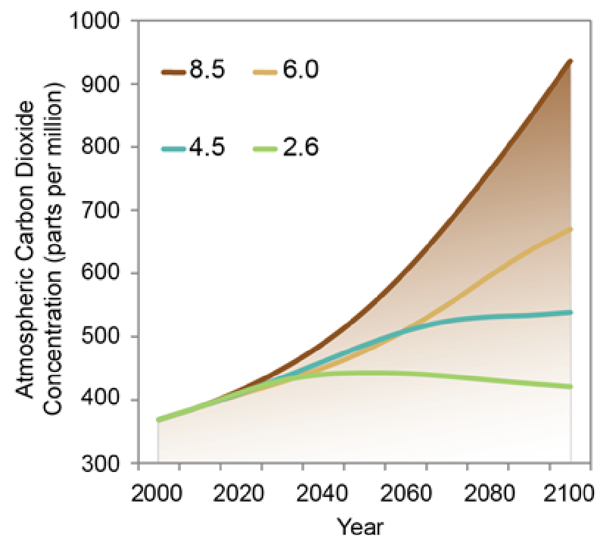


Climate Change Vulnerability of Eutrophication and Algal Blooms in New York

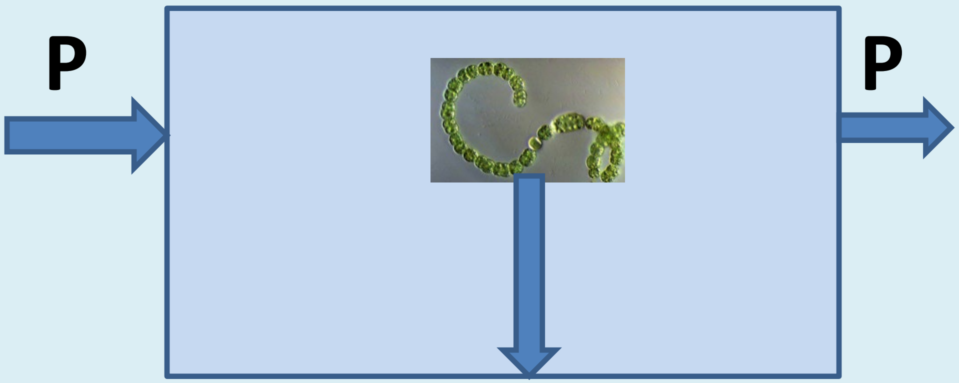




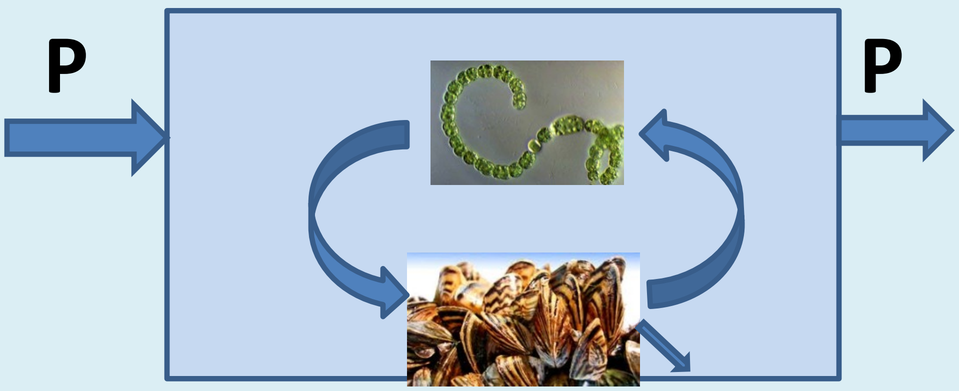
- A NYSERDA project conducted by Hazen and Sawyer and UFI
- Considered climate change impacts on Owasco, Cayuga and Skaneateles Lakes
- Two Representative Concentration Pathways – RCP 4.5 and RCP 8.5
- Three time slices – 2020, 2050, 2080

Regulation of Phosphorus Cycling by Dreissenid Mussels

Without mussels, oxic hypolimnion

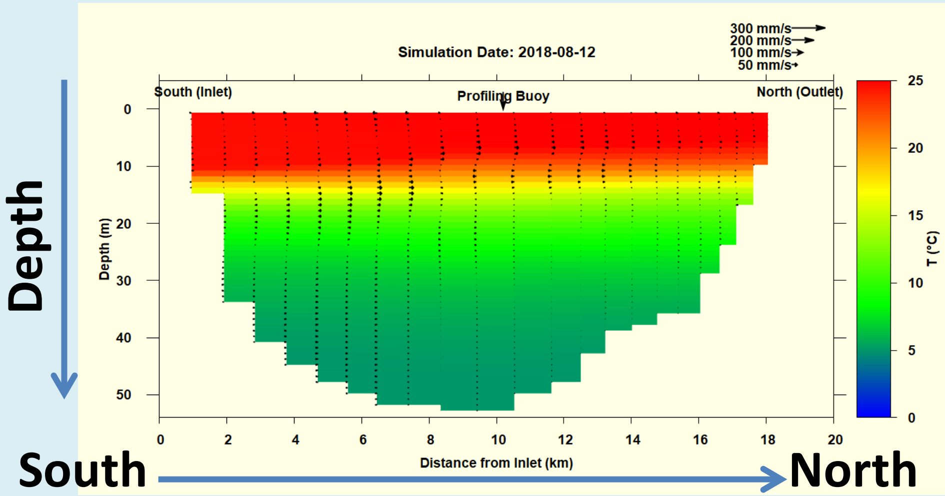


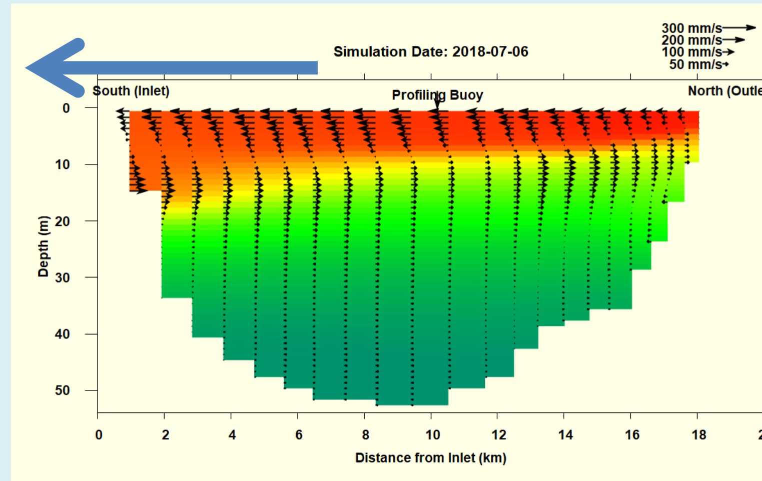
With mussels, oxic hypolimnion

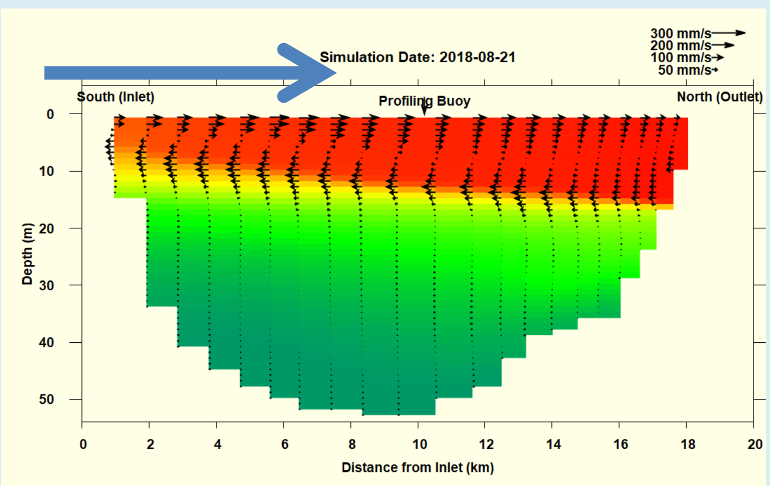


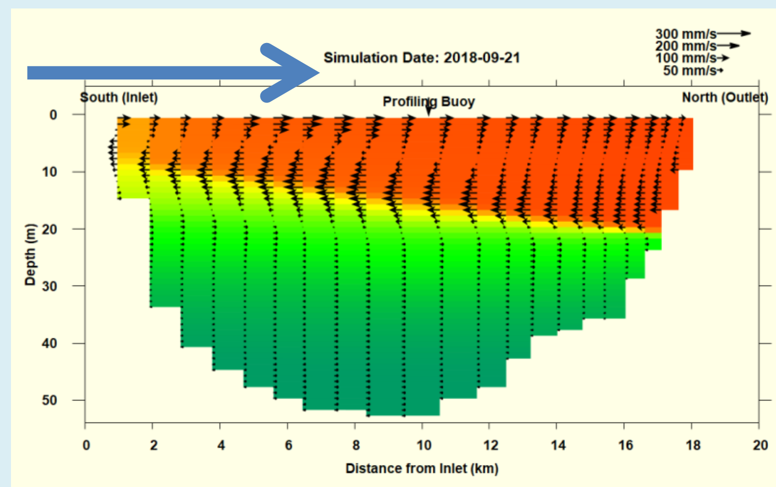
- Modeling indicates that internal recycle of P in Owasco Lake due to mussels ≈ external P loading
- "Benthic invaders control the P cycle in the world's largest freshwater ecosystem" Li et al. 2021
  - "P availability is now regulated by the dynamics of mussel populations while the role of external inputs of P is suppressed"

Impact of Wind on Water Motion



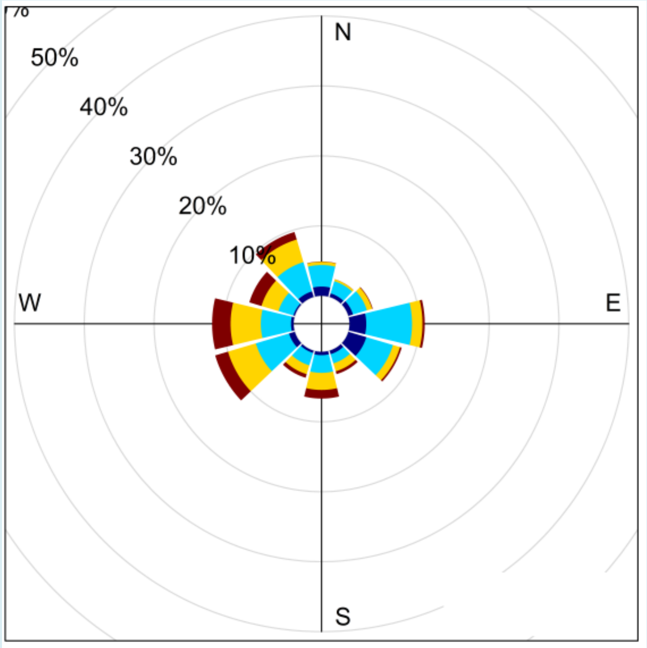




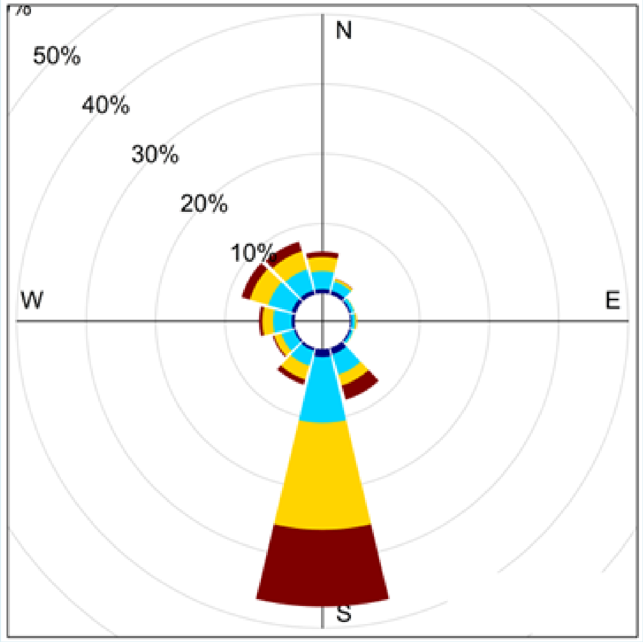


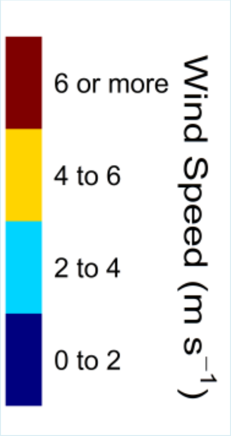
On-site Wind Data

Syracuse Airport



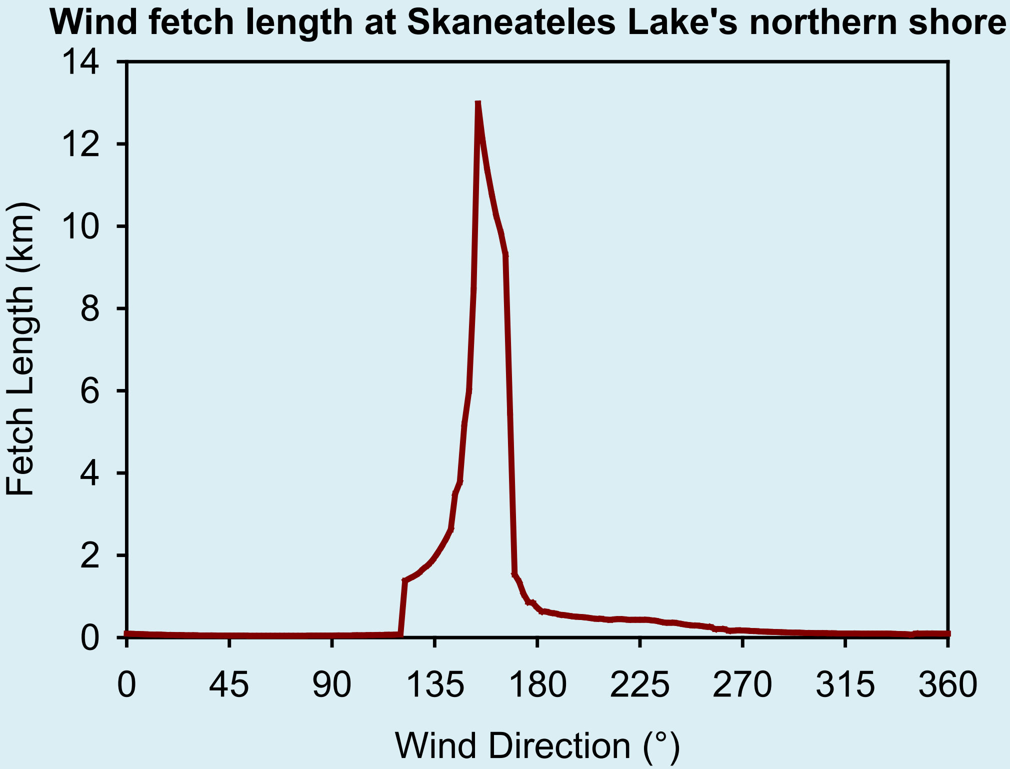
FLI Buoy – Owasco Lake





Go Fetch!!


Image © 2024 Airbus


Wind fetch length at Skaneateles Lake's northern shore
Fetch Length (km)
0
2
4
6
8
10
12
14
0
45
90
135
180
225
270
315
360
Wind Direction (°)

Confirmation of the Water Quality Model