Great Lakes HABs models

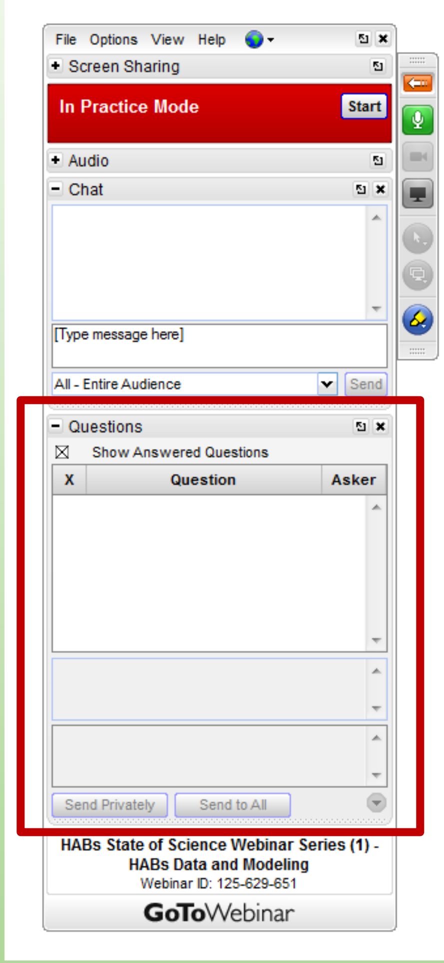
Speakers:

Ed Verhamme, LimnoTech

Serghei Bocaniov, University of Michigan

GoToWebinar Housekeeping Items

- Submit your text questions and comments using the Questions Panel
- Note: This webinar is being recorded and will be posted on the HABs Collaboratory website



Why a modeling webinar?

- Interest in a more in-depth webinar focused on modeling from summer “State of the Science” webinar series.
- Cross-system comparisons within the Great Lakes.
- Better understand what models are available to model HABs.
- Conversation between modelers and scientists.
  - Comparison between computational model and conceptual model.

Summary of Survey

- 20 survey participants.
- 2 question survey
  - What is the largest scientific knowledge gap related to HABs?
  - What questions can models help answer that your data can't alone?

What is the largest scientific knowledge gap related to HABs?

- Environmental triggers for growth and toxicity of HABs.
- Ability to measure the effect of incremental changes in nutrient loading on bloom frequency.
- Role of nitrogen in HAB formation.
- Impact of HABs on ecosystem.

What questions can models help answer that your data can't alone?

- Predicting the timing, location, and toxicity of HABs.
- How much of a nutrient reduction is needed to reduce/eliminate HABs?
- Potential climate change effects.
- Project future status of the lake.
- Synthesize the effects of multiple parameters on HABs.
  - Temperature, nutrient loading, etc.

Presenters

- Ed Verhamme, LimnoTech
- Serghei Bocaniov, University of Michigan

Western Lake Erie Ecosystem Model – An operational model for the management community

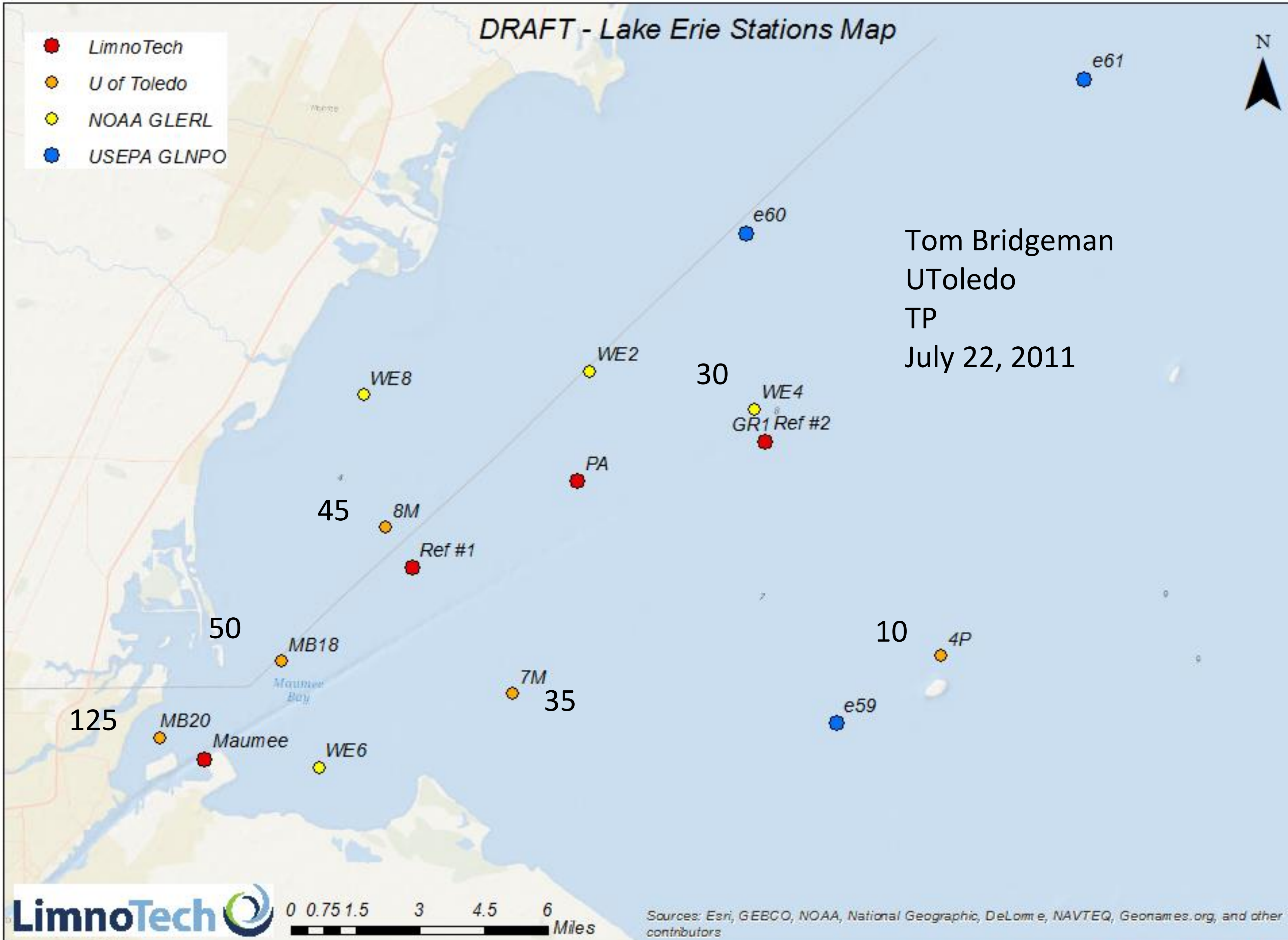
Ed Verhamme, John Bratton, Joseph V. DePinto, Todd Redder, and Derek Schlea

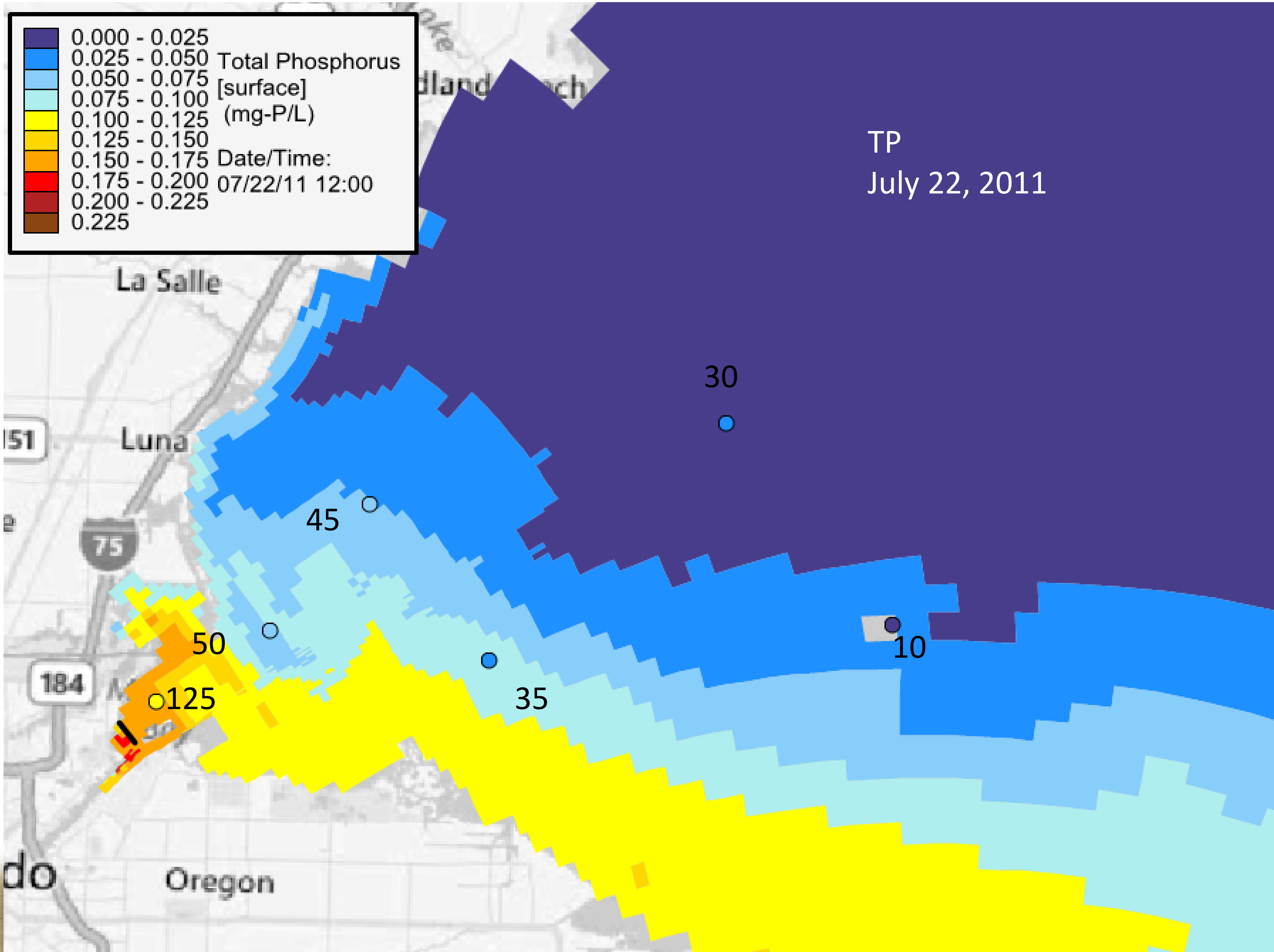
LimnoTech

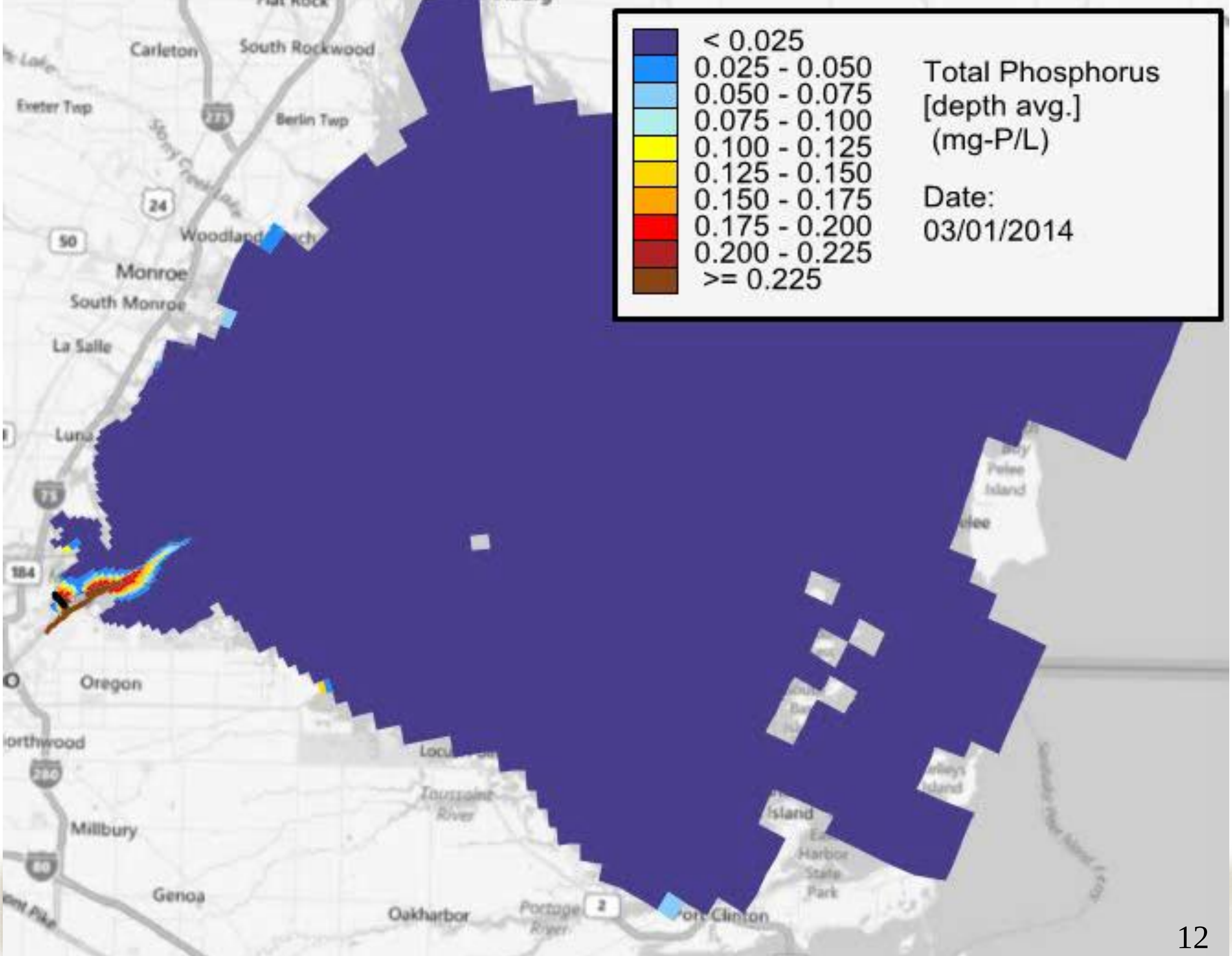
Water Environment | Scientists Engineers

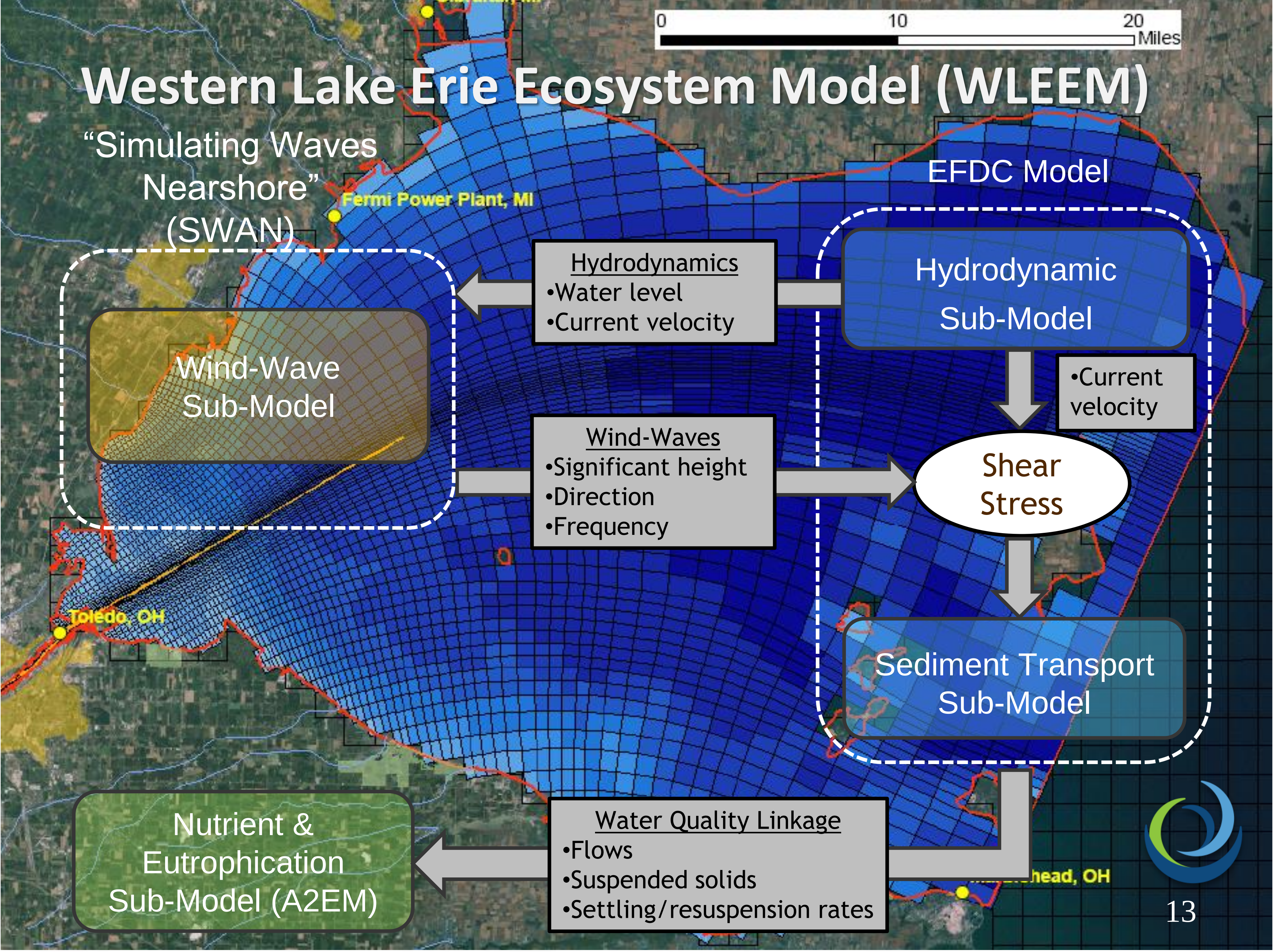
Why Model Lake Erie?

- Dynamic system
  - Field sampling captures brief snapshots of current conditions
  - Interactions among sources & within system are difficult to separate
- Large spatial gradients
  - Difficult to capture full snapshot with station data
  - Satellites help, but are limited by clouds and time
- Overwhelming amount of physical, chemical, biological data
- Many hypothesis/questions to answer

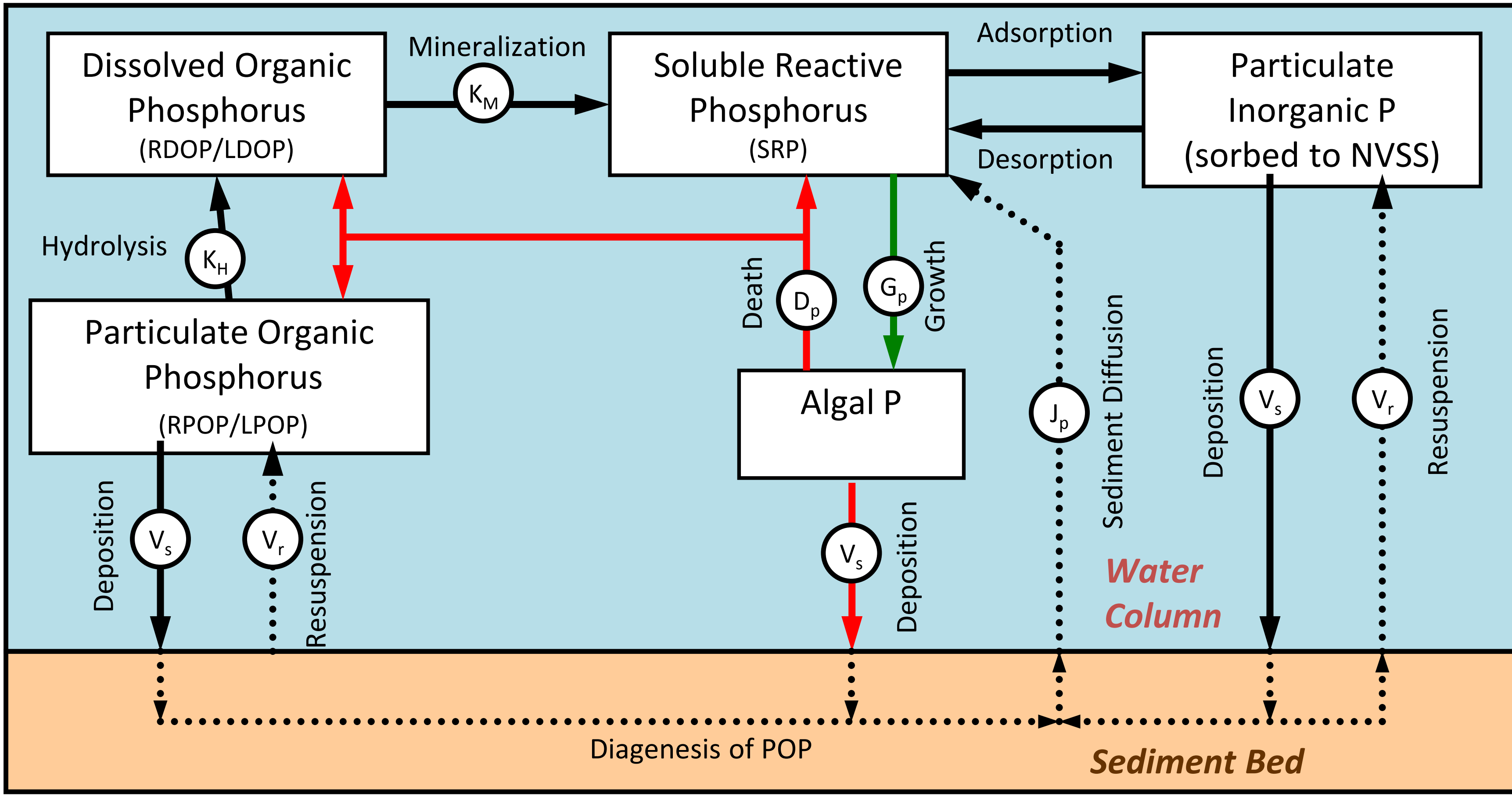

DRAFT - Lake Erie Stations Map
LimnoTech
U of Toledo
NOAA GLERL
USEPA GLNPO
N
e61
e60
Tom Bridgeman
UToledo
TP
July 22, 2011
WE2
30
WE8
WE4
GR1 Ref #2
PA
45
8M
Ref #1
50
MB18
Maumee Bay
10
4P
7M
35
e59
125
MB20
Maumee
WE6
LimnoTech
0 0.75 1.5 3 4.5 6
Miles
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors


0.000 - 0.025
0.025 - 0.050
0.050 - 0.075
0.075 - 0.100
0.100 - 0.125
0.125 - 0.150
0.150 - 0.175
0.175 - 0.200
0.200 - 0.225
0.225
Total Phosphorus [surface] (mg-P/L)
Date/Time: 07/22/11 12:00
TP
July 22, 2011
La Salle
Luna
75
184
Oregon
30
45
50
125
35
10


< 0.025
0.025 - 0.050
0.050 - 0.075
0.075 - 0.100
0.100 - 0.125
0.125 - 0.150
0.150 - 0.175
0.175 - 0.200
0.200 - 0.225
>= 0.225
Total Phosphorus
[depth avg.]
(mg-P/L)
Date:
03/01/2014
Carleton
South Rockwood
Exeter Twp
Berlin Twp
Monroe
South Monroe
La Salle
Oregon
Millbury
Genoa
Oakharbor
Port Clinton

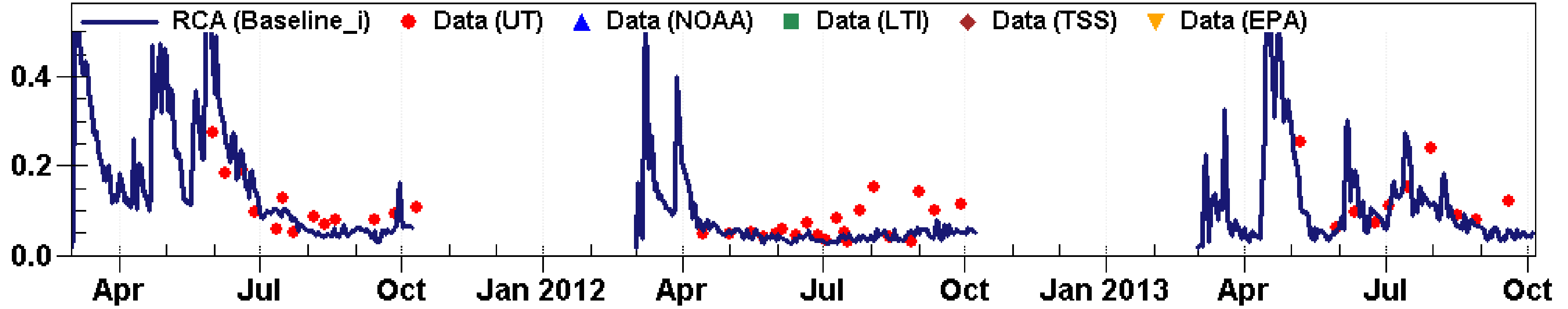

Western Lake Erie Ecosystem Model (WLEEM)
"Simulating Waves Nearshore" (SWAN)
0 10 20 Miles
Fermi Power Plant, MI
Toledo, OH
EFDC Model
Wind-Wave Sub-Model
Hydrodynamics
•Water level
•Current velocity
Hydrodynamic Sub-Model
•Current velocity
Wind-Waves
•Significant height
•Direction
•Frequency
Shear Stress
Sediment Transport Sub-Model
Nutrient & Eutrophication Sub-Model (A2EM)
Water Quality Linkage
•Flows
•Suspended solids
•Settling/resuspension rates

Phosphorus Cycling in WLEEM

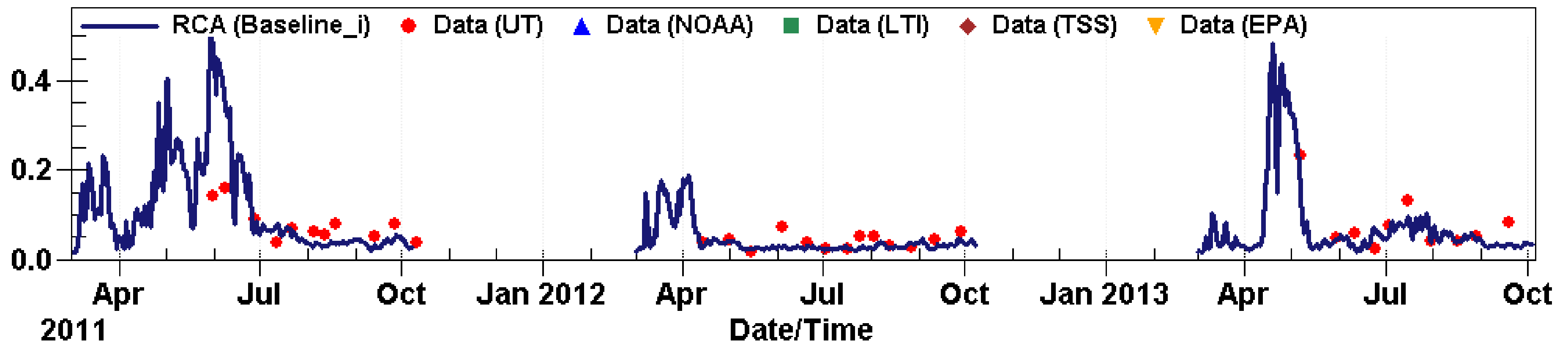


Total Phosphorus (mg/L)

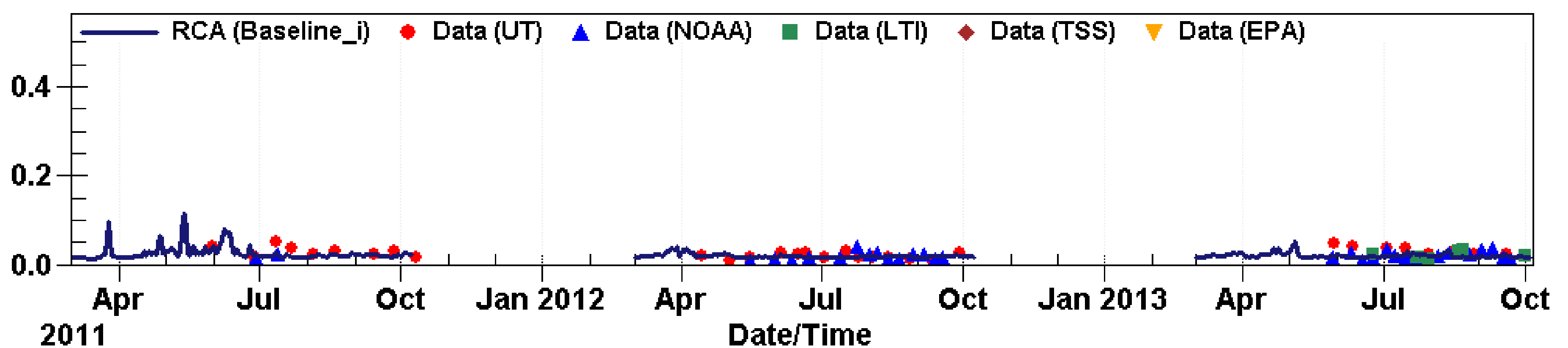
Station: 2.00, Pool 1 (I=245, J=54, K= 1) Stations: MB18, MB18

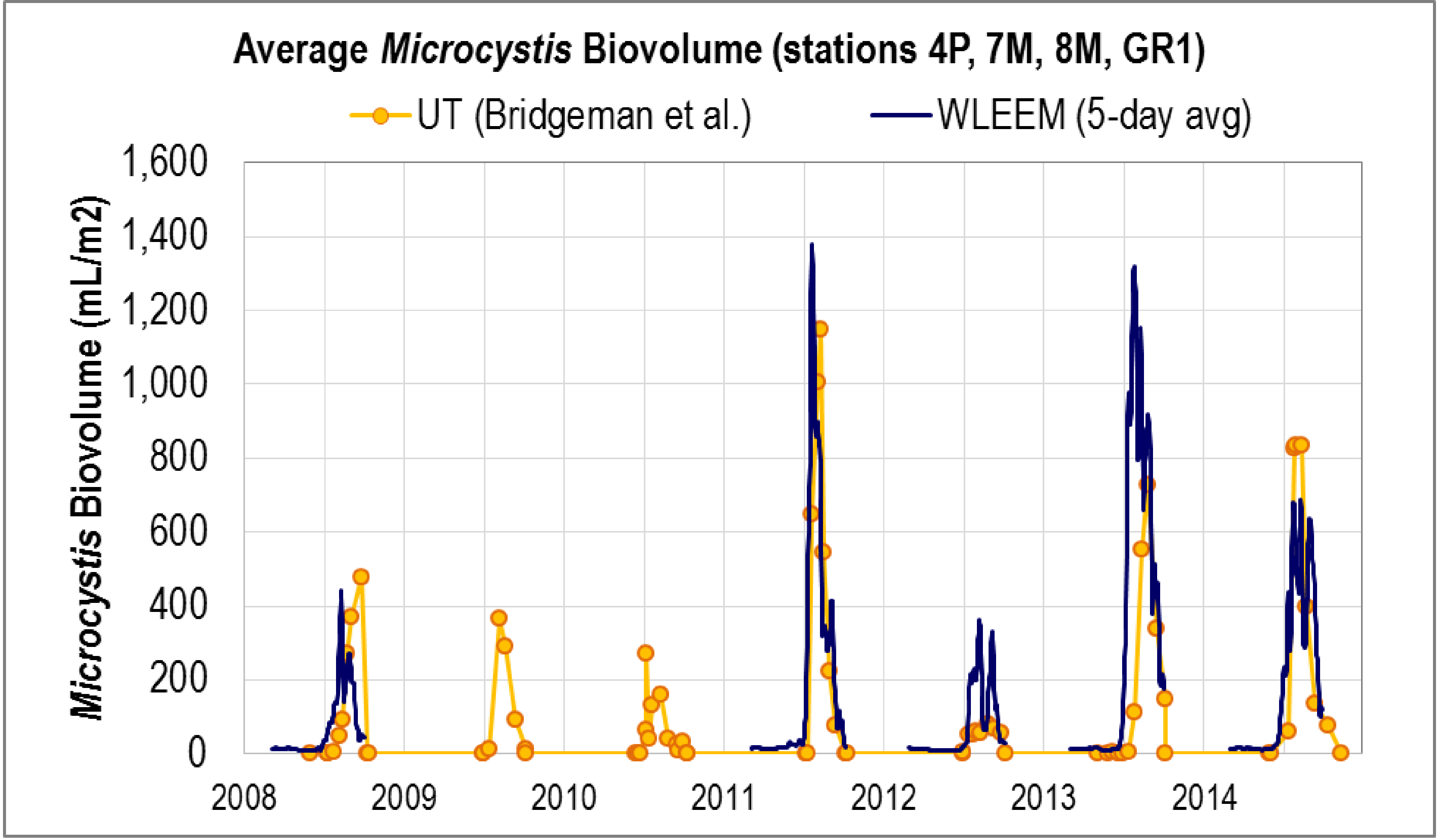


Station: 4.00, Pool 1 (I=262, J=57, K= 1) Stations: 8M, 8M



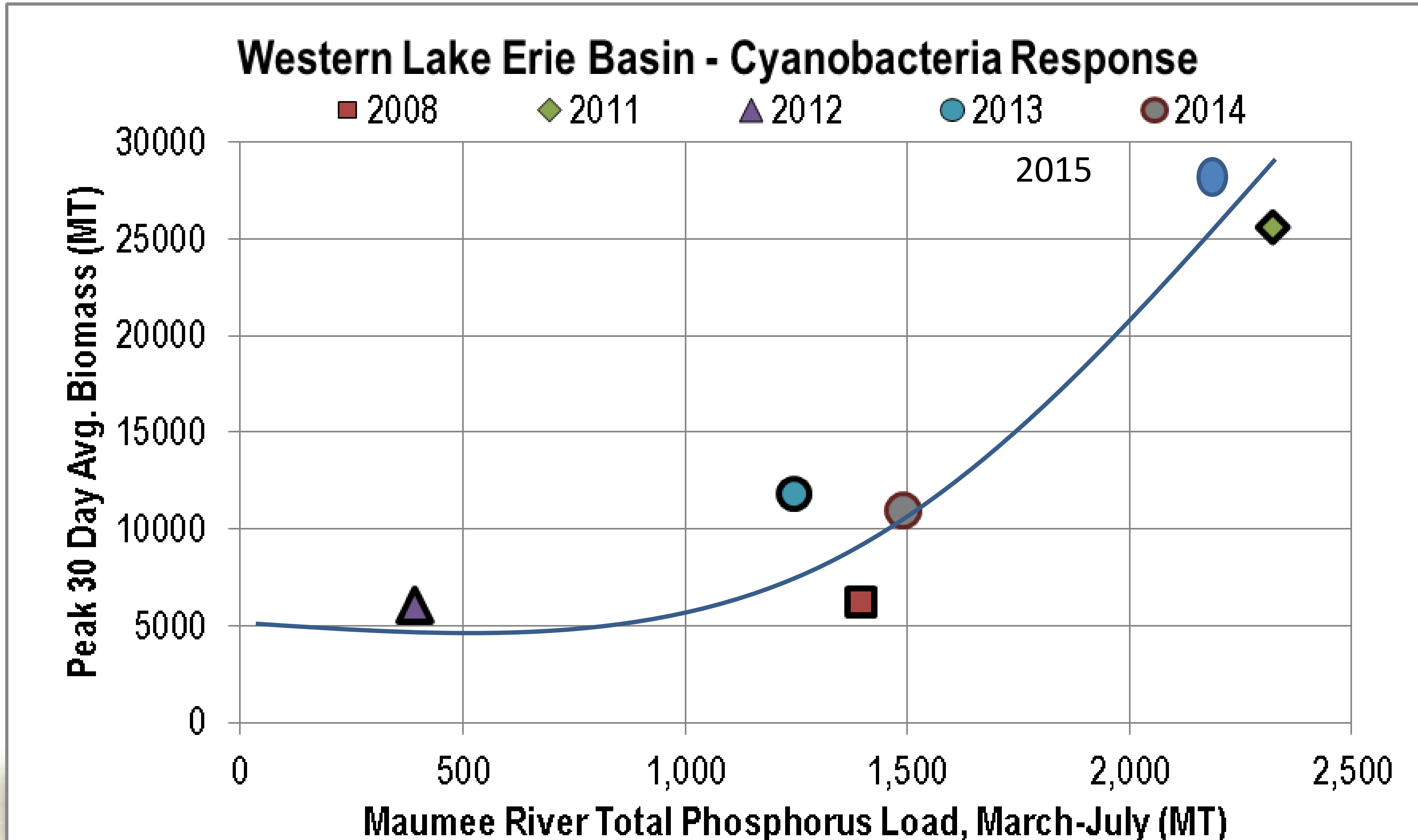
Station: 6.00, Pool 1 (I=281, J=38, K= 1) Stations: GR1, GR1, LTI27, WE4



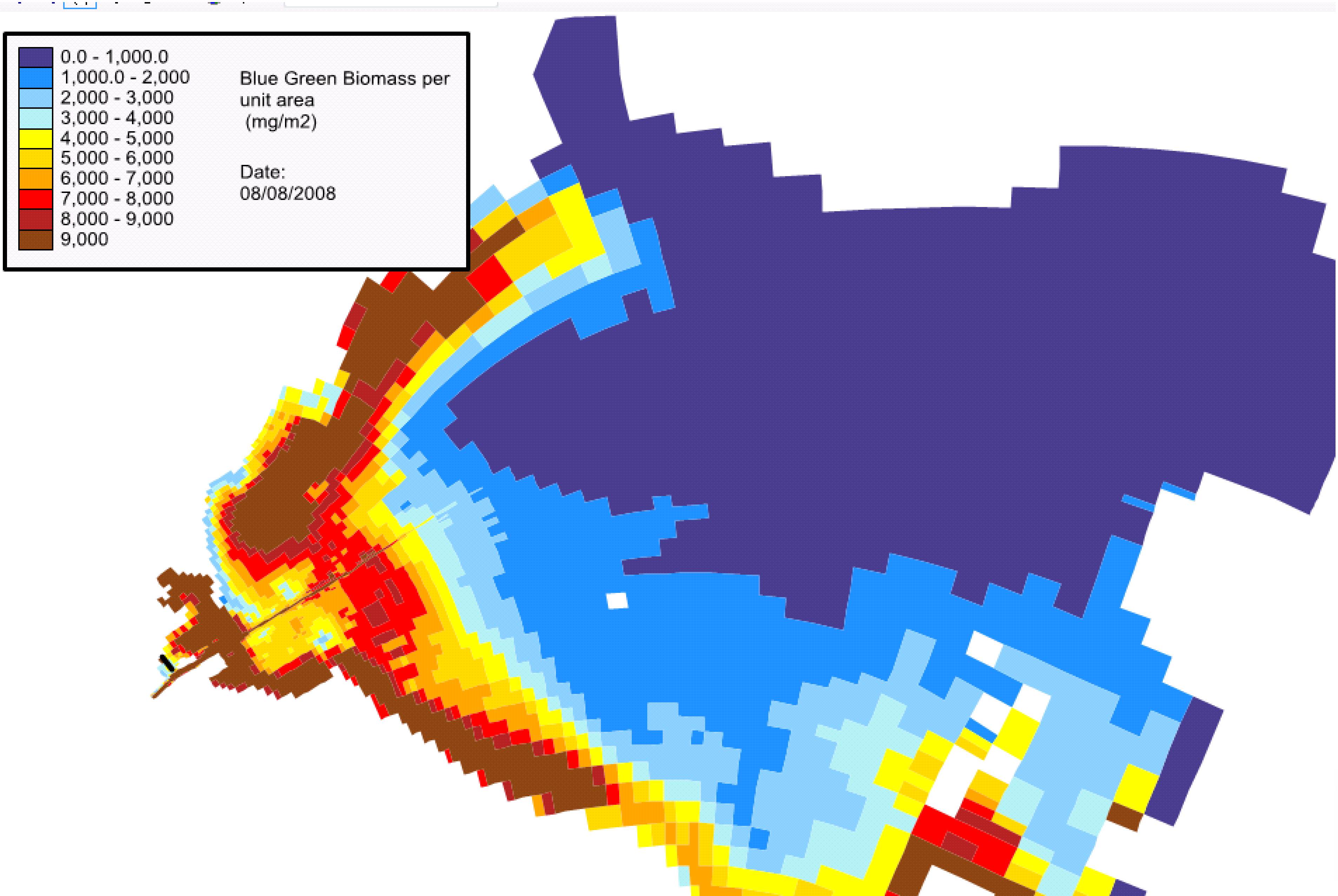


Data Credit: T. Bridgeman, University of Toledo

Baseline Load-Response Points

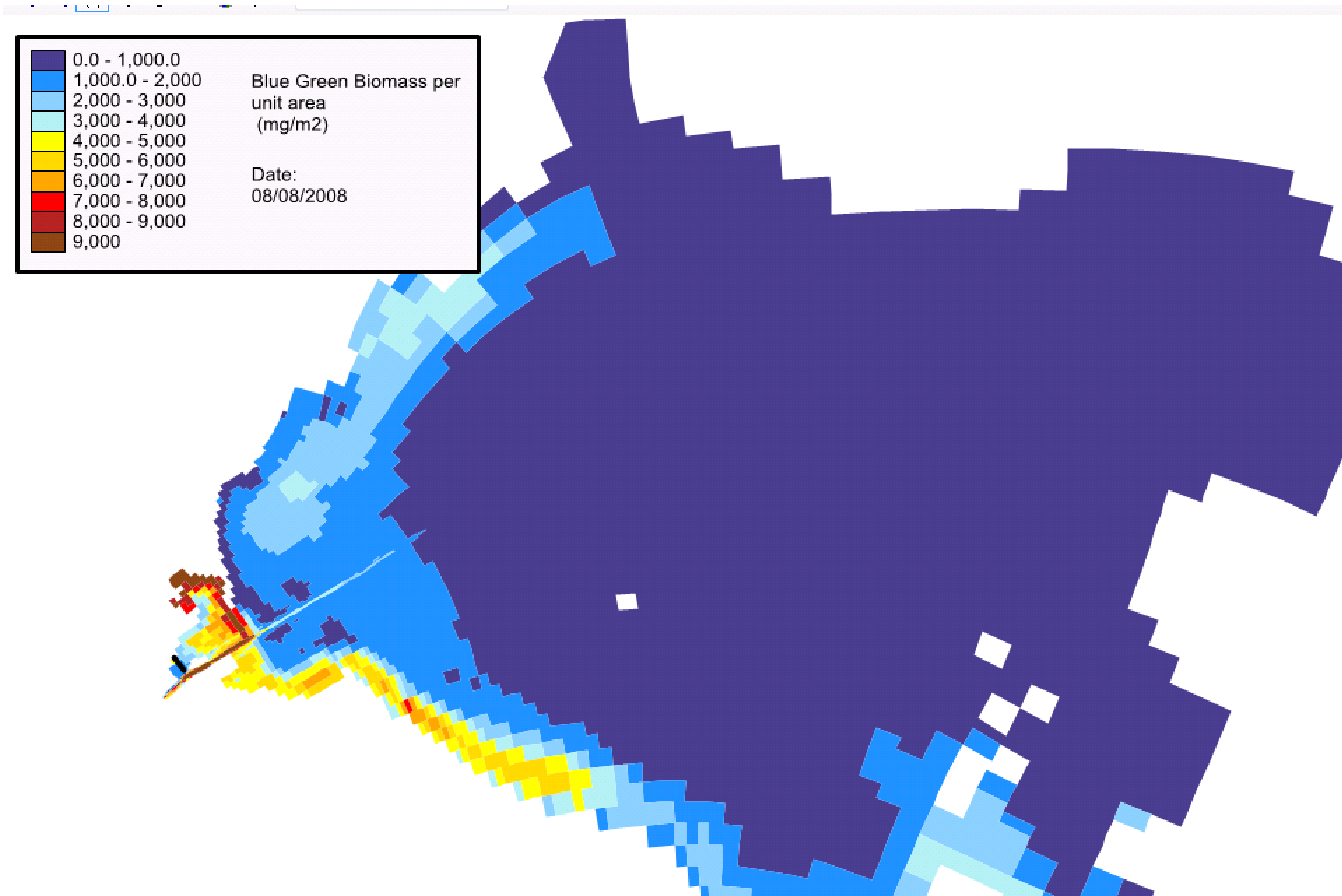


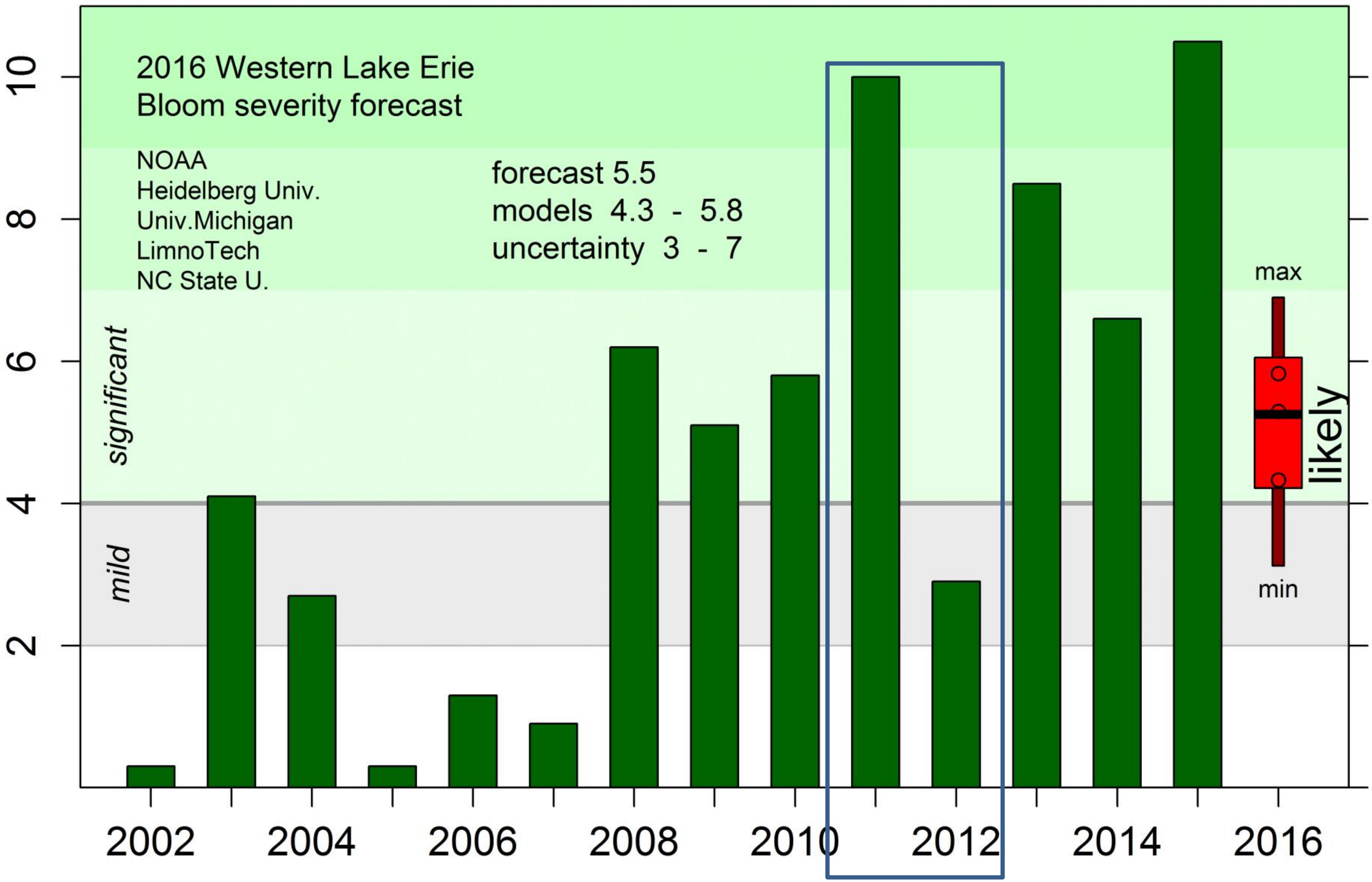
Baseline



0.0 - 1,000.0
1,000.0 - 2,000
2,000 - 3,000
3,000 - 4,000
4,000 - 5,000
5,000 - 6,000
6,000 - 7,000
7,000 - 8,000
8,000 - 9,000
9,000
Blue Green Biomass per unit area (mg/m2)
Date: 08/08/2008

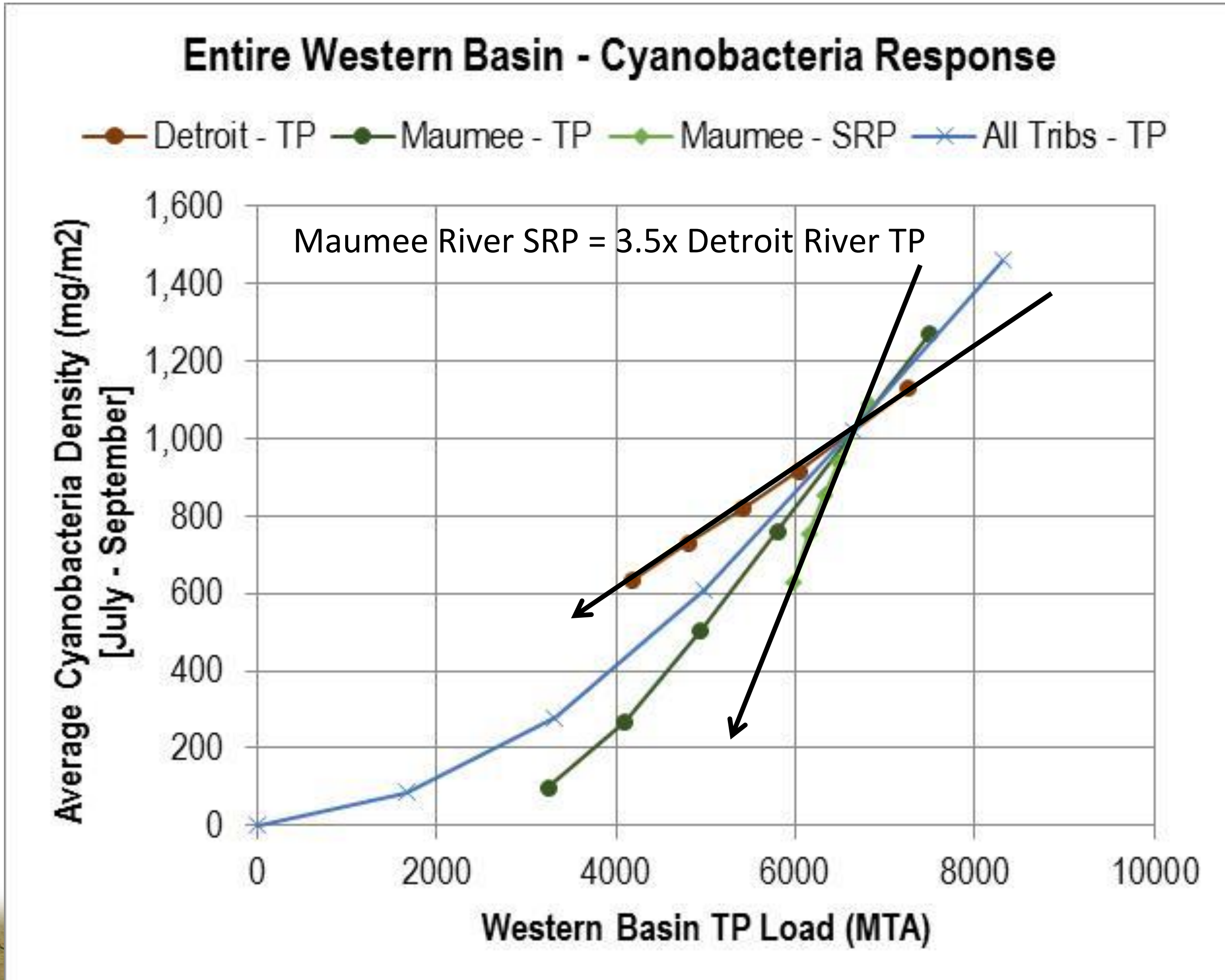
All Tribs 50% Reduction



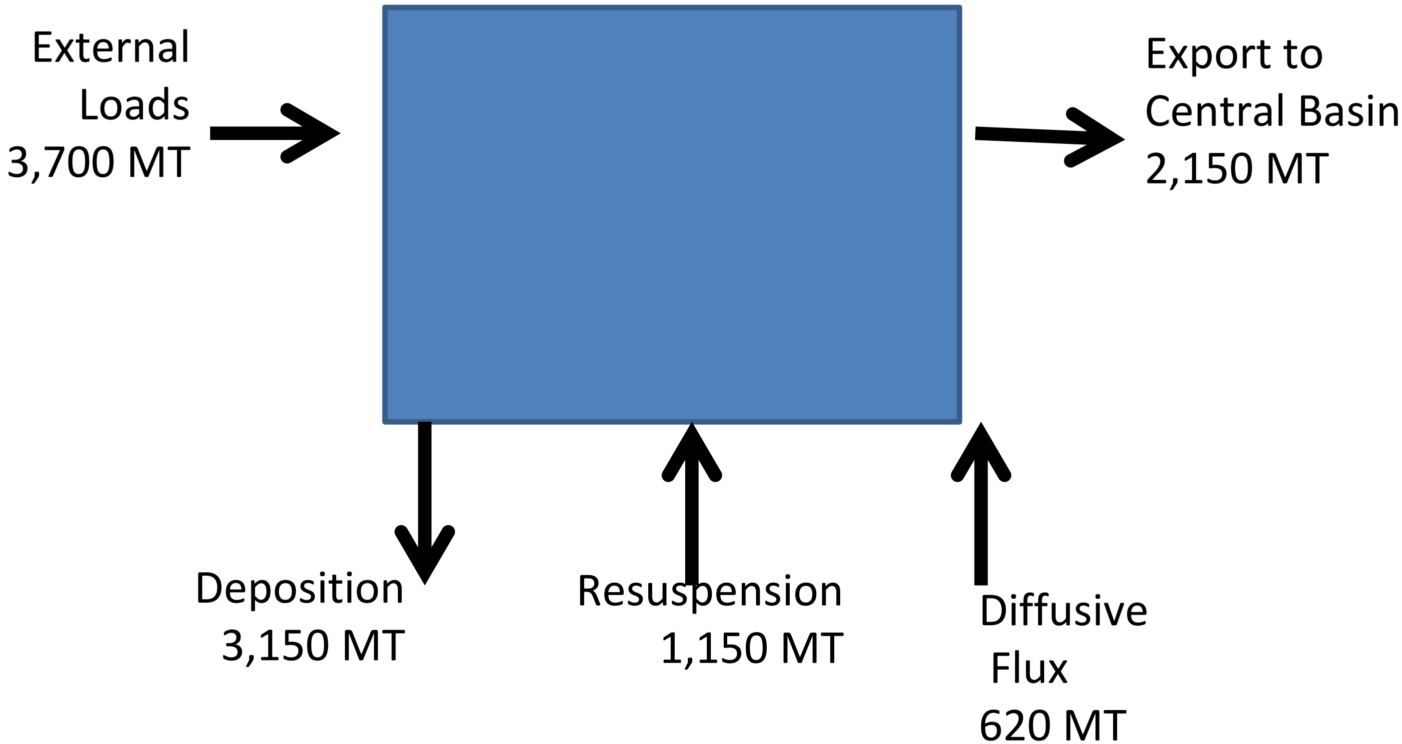


2016 Western Lake Erie
Bloom severity forecast
NOAA
Heidelberg Univ.
Univ.Michigan
LimnoTech
NC State U.
forecast 5.5
models 4.3 - 5.8
uncertainty 3 - 7
significant
mild
max
min
likely
2
4
6
8
10
2002
2004
2006
2008
2010
2012
2014
2016

Load Source Diagnostics

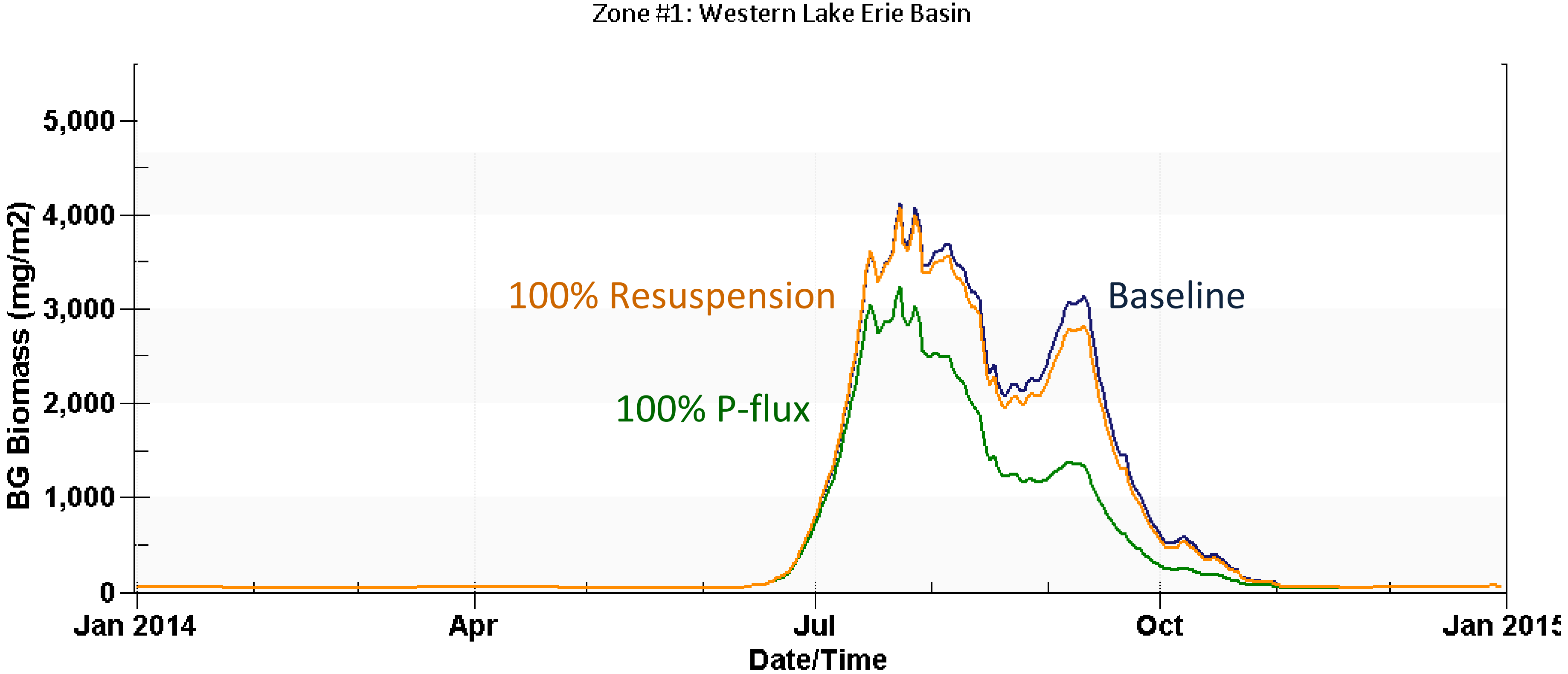


Phosphorus Mass Balance
Mar-Sept 2014



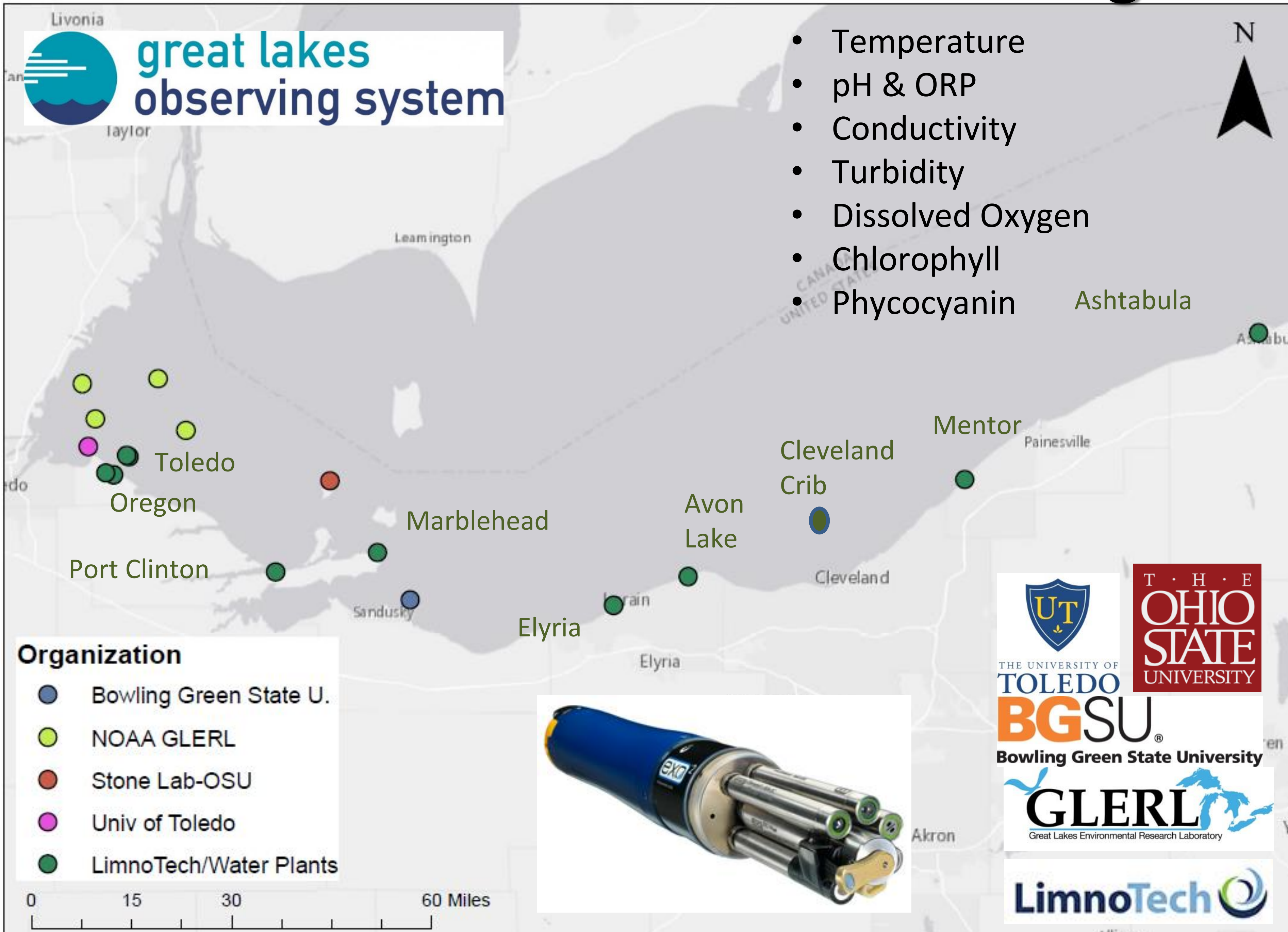
Model Diagnostic Scenarios

TP Load Reduction Scenarios: Internal Loads

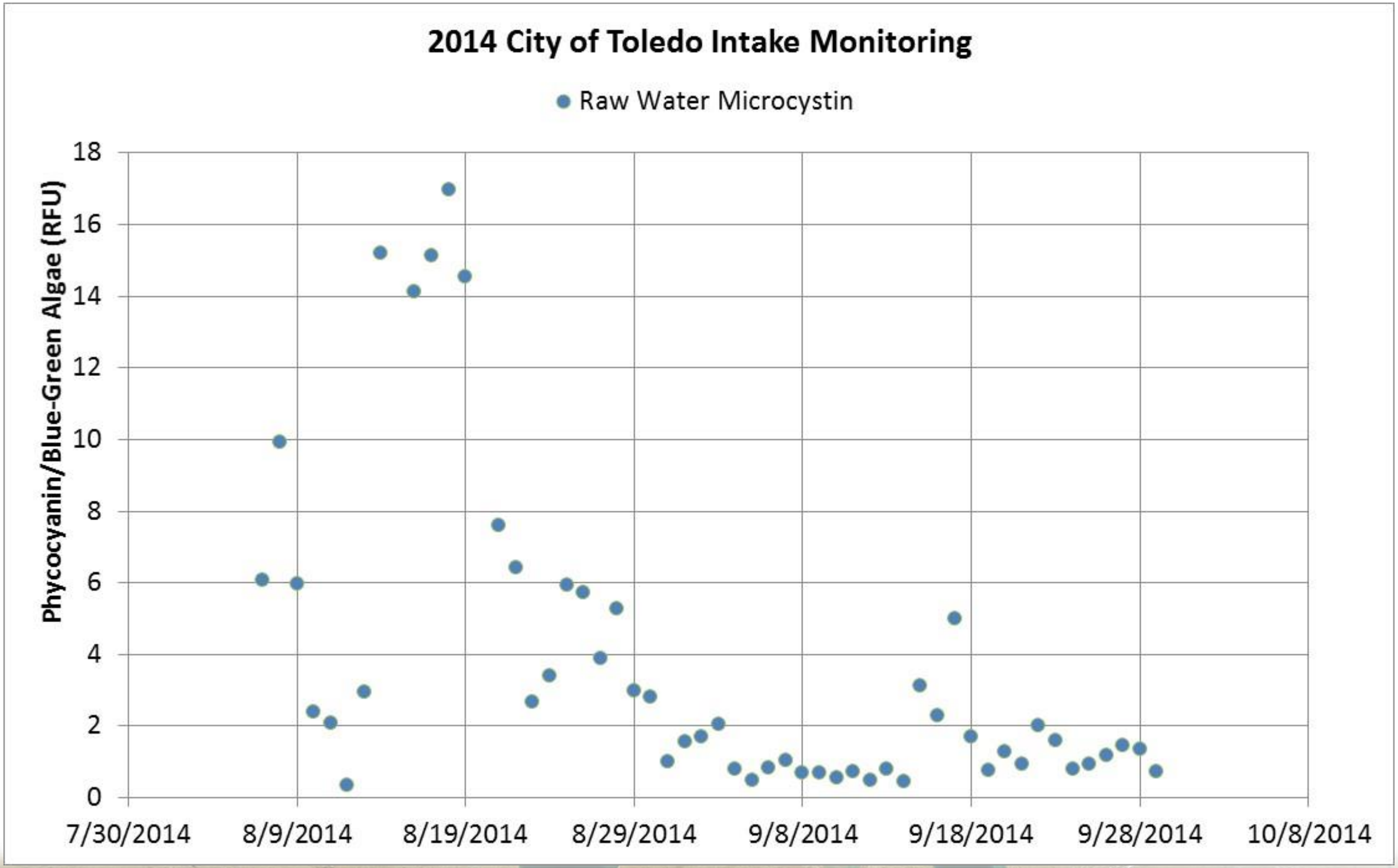


2016 HABs Real-Time Monitoring

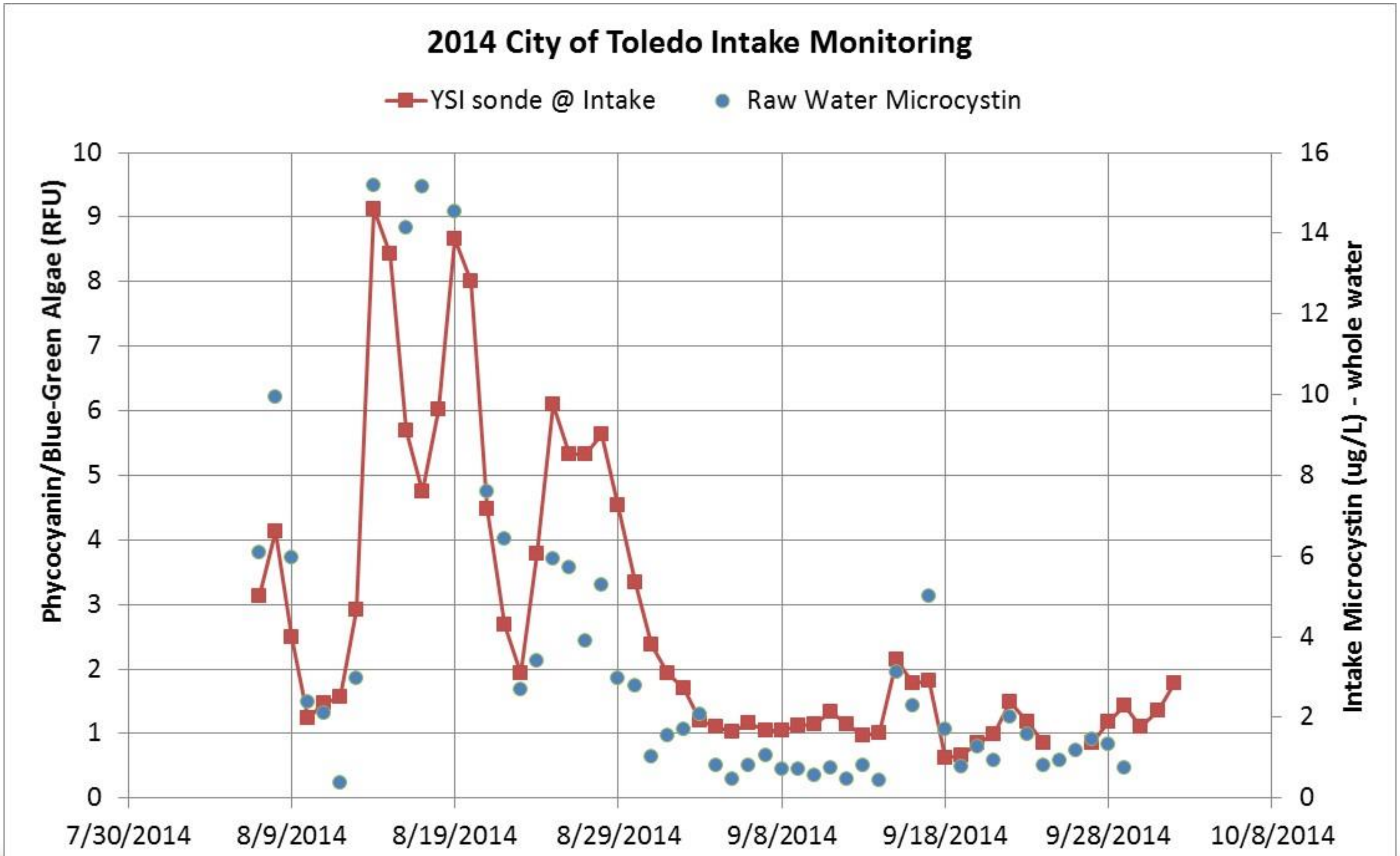
- Temperature
- pH & ORP
- Conductivity
- Turbidity
- Dissolved Oxygen
- Chlorophyll
- Phycocyanin



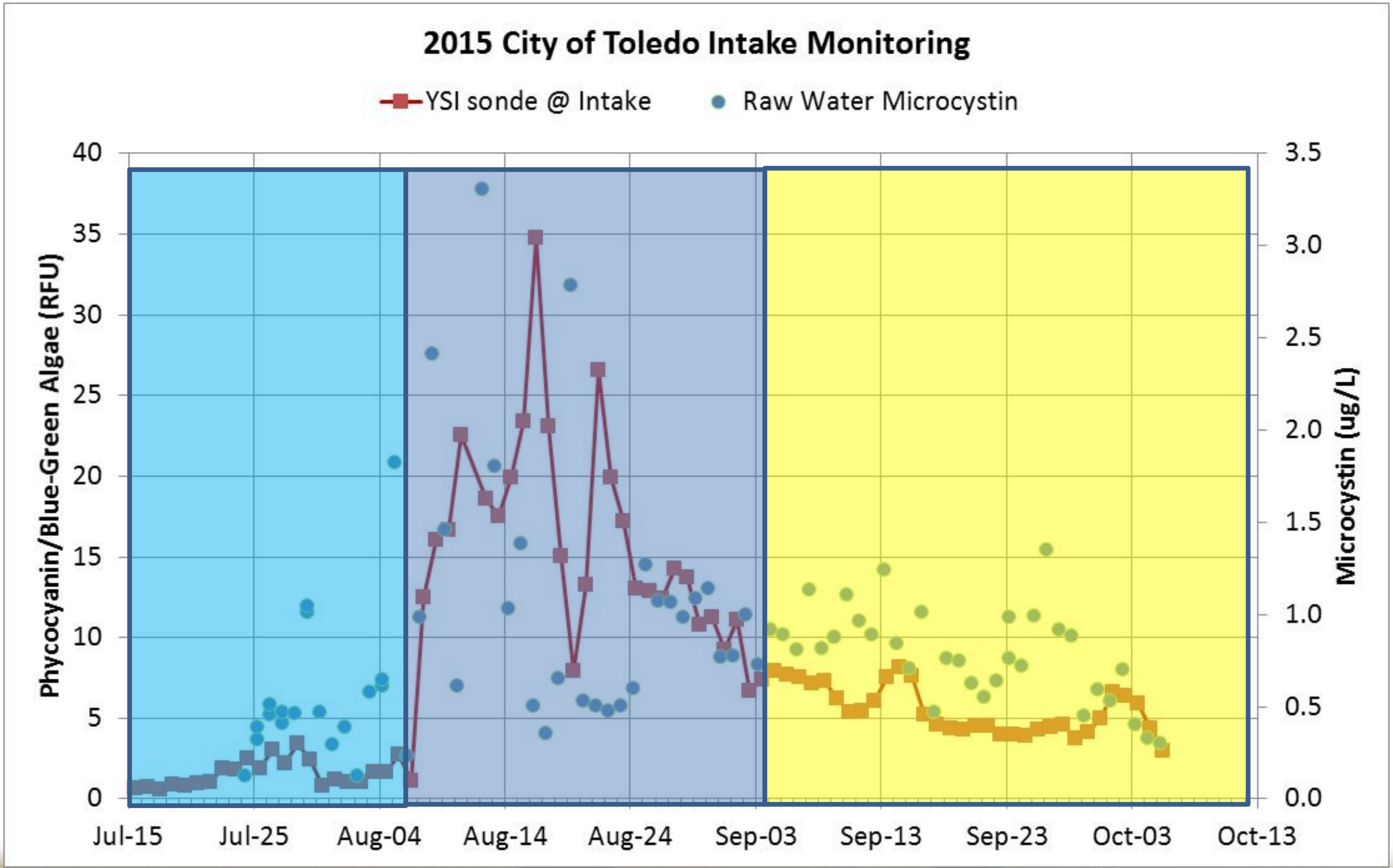
2014 City of Toledo Lake Monitoring



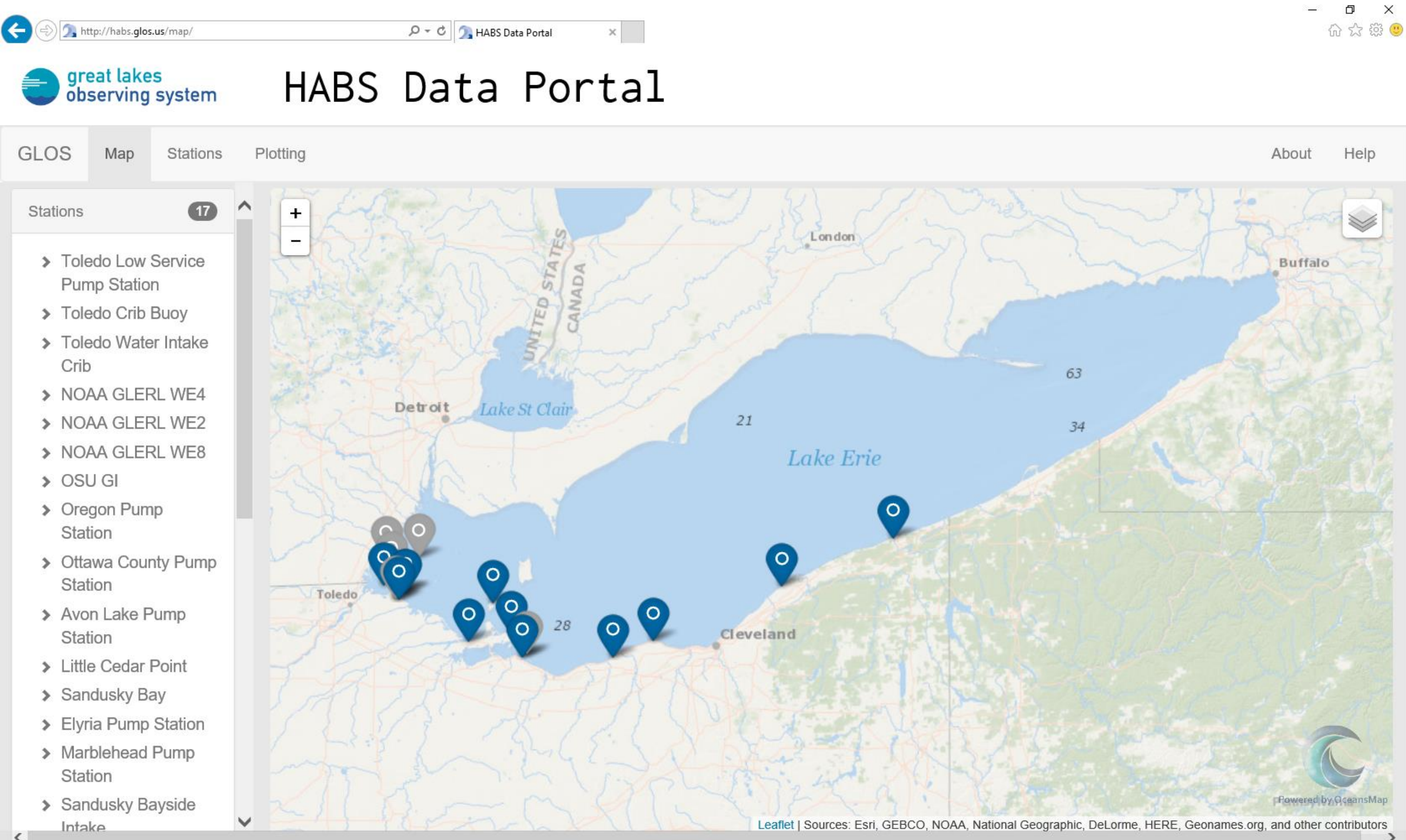
2014 City of Toledo Lake Monitoring



2015 City of Toledo Lake Monitoring



GLOS HABs Data Viewer



http://habs.glos.us

(Operational) Ecosystem Model

- **2010: USACE -** Wind driven resuspension is responsible for a significant portion of deposition in Toledo Harbor channel
- **2012: USACE -** Phosphorus from Maumee is a significant contribution to HABs in Western Lake Erie
- **2013: NSF** – Increased spring runoff will increase HABs
- **2014: USACE** - Open-lake placement does not contribute to HABs
- **2015: USEPA** – Annex 4, P reductions WILL reduce HABs severity (~40% needed)
- **2016: USEPA** - Internal loading, while not insignificant, has minimal affect on size and severity of HAB
- 2017 - ???

Questions

Ed Verhamme

LimnoTech

everhamme@limno.com

LimnoTech

Water | Scientists
Environment | Engineers

Three-dimensional modelling of the impact of invasive Dreissenid mussels in Lake Erie

S. Bocaniov[1,2], R. Smith[2], C. Spillman[3],
M. Hipsey[4], D. Scavia[1], L. Leon[2,5]

1. Graham Sustainability Institute, University of Michigan
2. University of Waterloo
3. Australian Bureau of Meteorology
4. University of Western Australia
5. Environment and Climate Change Canada

March 7, 2017

Presentation outline

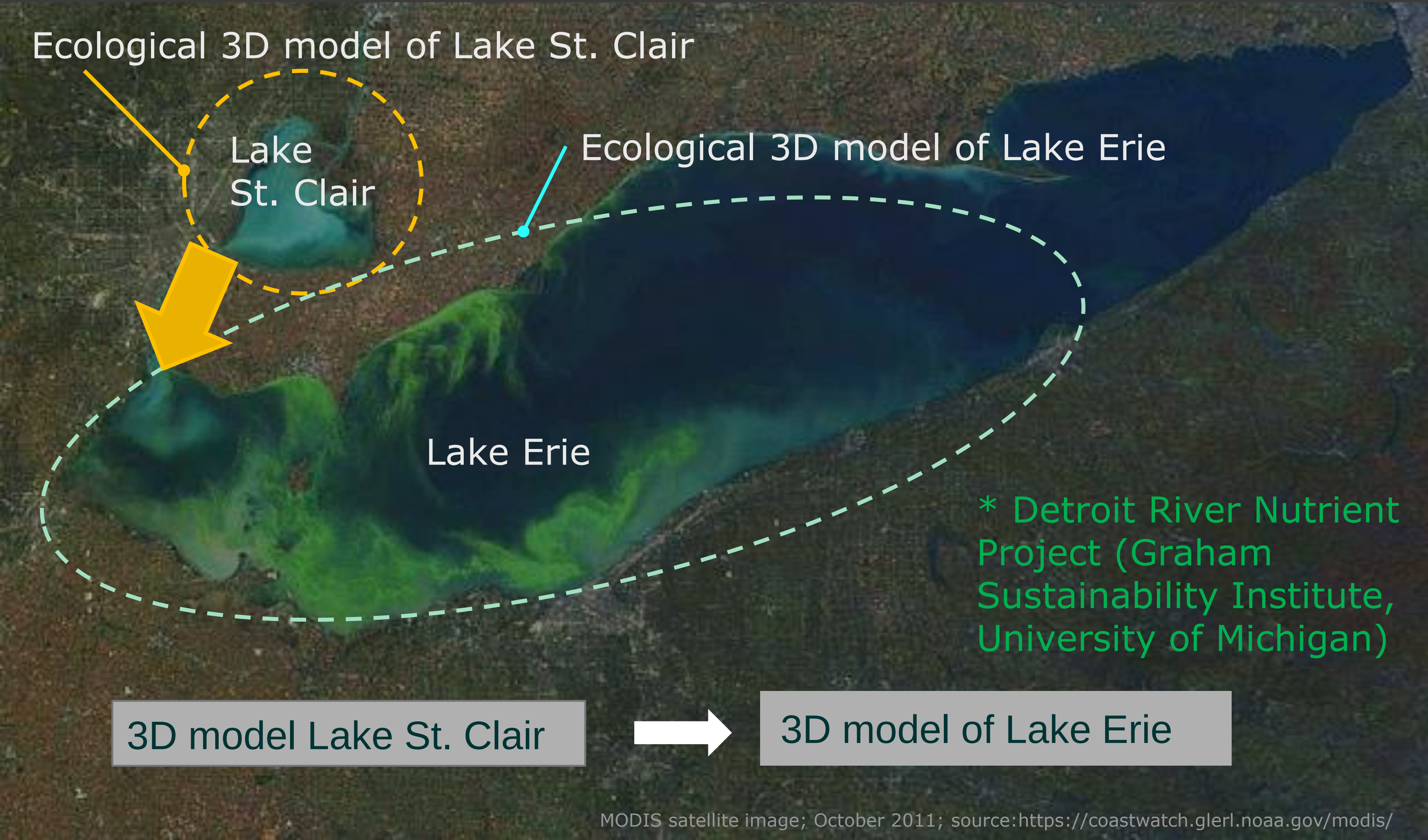
- main objective
- feedback on modeling webinar survey & answers
- 3D model of Lake Erie
- previous model applications to Lake Erie
- modeling mussels in Lake Erie

Main objective:

To present the process-based 3-dimensional coupled hydrodynamic and ecological model of Lake Erie that includes mussels as a state variable (*Bocaniov et al., 2014; Hydrobiologia 731, 151-172*)

The model is potentially very useful for modeling and understanding of HABs in western basin of Lake Erie (e.g. includes mussels, and/or could be coupled to a 3D ecological model of Lake St. Clair)

The 3D Lake Erie model can be coupled to a newly developed 3D ecological model of Lake St. Clair* to improve our understanding of the role of Lake St. Clair in the development of HABs in Lake Erie



Presentation outline

- main objective

- **feedback on modeling webinar survey & answers**

- 3D model of Lake Erie

- previous model applications to Lake Erie

- modeling mussels in Lake Erie

Feedback on modelling webinar survey & responses:

- Q1: What is the largest scientific knowledge gap related to HABs?
  - **- Environmental triggers for growth and toxicity of HABs;**
  - **- Ability to measure the effect of incremental changes in nutrient loading on bloom frequency;**
  - **- Role of nitrogen in HAB formation.**

- Q2: What questions can models help answer that your data alone cannot?
  - **- Predicting the timing, location and toxicity of HABs;**
  - **- How much of nutrient reduction is needed to control HABs;**
  - **- Potential climate change effects & future status of the lake.**

Presentation outline

- main objective
- feedback on modeling webinar survey & answers
- **3D model of Lake Erie**
- previous model applications to Lake Erie
- modeling mussels in Lake Erie

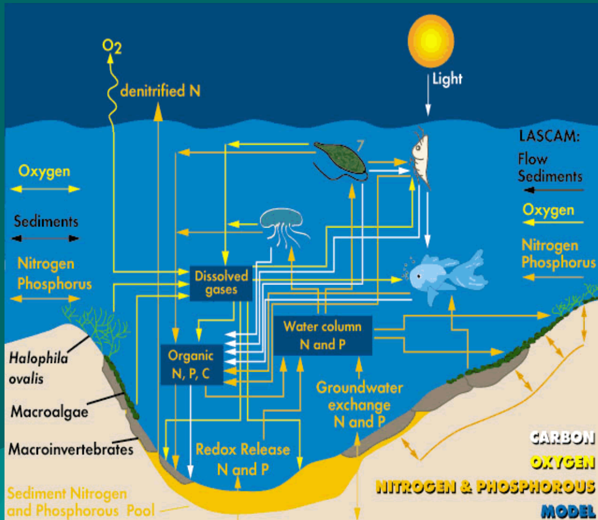
3D hydrodynamic & ecological model of Lake Erie (ELCOM-CAEDYM or ELCD)

Estuary & Lake COmputer Model (ELCOM)

- 3D hydrodynamic model
- baroclinic & barotropic responses
- tidal forcing, wind stresses
- surface thermal forcing, inflows & outflows

Computational Aquatic Ecosystem Dynamics Model (CAEDYM)

- ecological & water quality model
- nutrient, C, O_2 & metal cycling
- water column & sediment dynamics
- phytoplankton (7 groups)
- zooplankton (5 groups)
- fish (3), fish eggs and fish larvea (3)



Phytoplankton configuration in Lake Erie model: 5 groups*, **

Taxa	Description	Associated with
Cyanobacteria	larger and potentially N-fixing taxa	warm and stable waters
Early Diatoms	early blooming diatom taxa	high Si requirements and sinking rates
Late Diatoms	diatom taxa occurring later in the season	lower Si requirements and sinking rates
Flagellates	cryptophytes and other flagellates; some nonmotile forms	cooler waters and/or deeper strata; low sinking rates
Other Phytoplankton	flagellates and nonmotile forms	warmer and brighter conditions

*Leon *et al*., 2011; JGLR 37:41-53 ** Bocaniov *et al*., 2016; JGLR 42:1228-1240

CAEDYM allows modeling algal toxin & metabolite production*

each algal group can be configured to produce metabolites:

$$\frac{\partial X_a}{\partial t} = f_{A_a}^{BME} - f_{X_a}^{MIN}$$

cell lysis & excretion *microbial decay*

X_a - concentration of the toxin/metabolite (*mg L*$^{-1}$)

$f_{A_a}^{BME}$ - metabolite contribution from mortality and excretion by A_a

$f_{X_a}^{MIN}$ - bacterially mediated decay of metabolites

*Hipsey & Hamilton, 2008

Presentation outline

- main objective
- feedback on modeling webinar survey & answers
- 3D model of Lake Erie
- **previous model applications to Lake Erie**
- modeling mussels in Lake Erie

Previous applications of ELCD to Lake Erie

- Modeling phytoplankton and nutrient dynamics

  (e.g. *Leon et al., 2011; JGLR 37: 41–53*)

- Modeling Lake Erie’s thermal structure

  (**e.g**. *Liu et al., 2014; JGLR 40: 827−840*)

- Modeling winter conditions and the effects of ice cover

  (e.g. *Oveisy et al., 2014; JGLR 40: 19–28*)

- Modeling Lake Erie hypoxia

  (e.g. *Bocaniov & Scavia, 2016; Water Resour. Res., 52: 4247 −4263*
  Bocaniov et al., 2016; JGLR 42: 1228−1240)

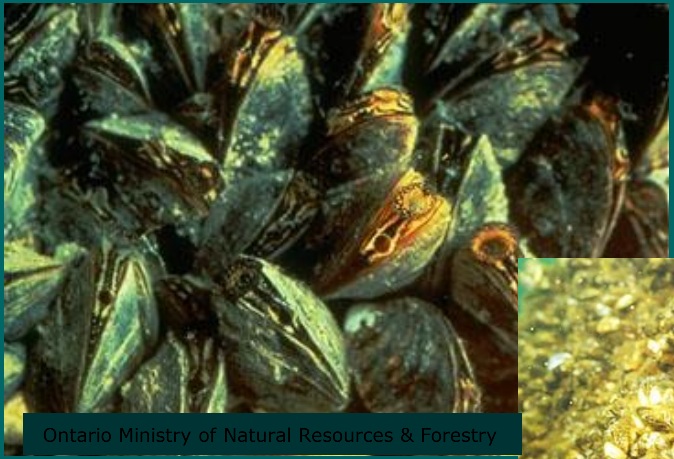
- Modeling mussels in Lake Erie (today’s presentation)

  (e.g. *Bocaniov et al., 2014; Hydrobiologia 731: 151-172*)

Presentation outline

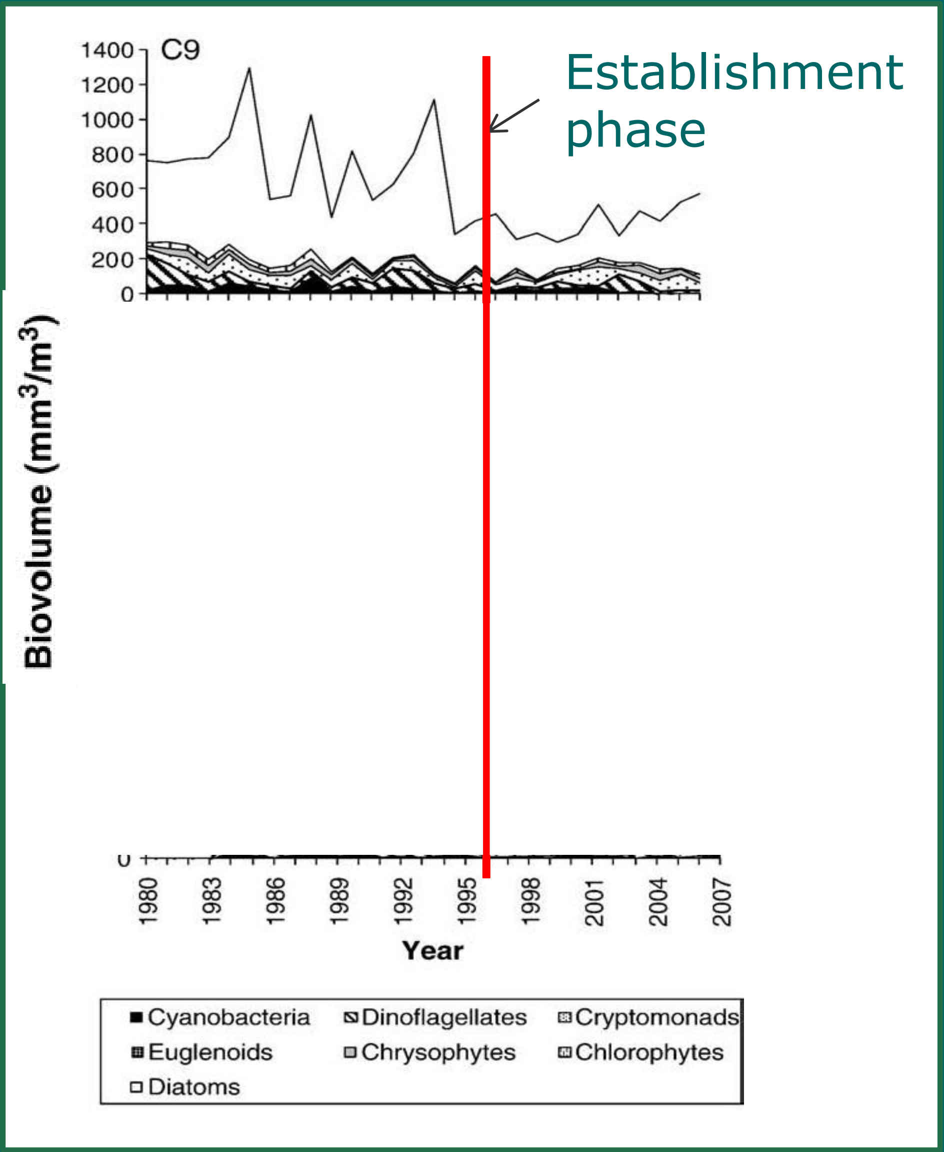
- main objective
- feedback on modeling webinar survey & answers
- 3D hydrodynamic & WQ model of Lake Erie
- previous model applications to Lake Erie
- **modeling mussels in Lake Erie**

Mussels as Ecosystem Engineers[1,2]



- remove particles
- ↑ water clarity
- ↓ small zooplankton
- nutrient (N) cycling: part. N -> dissolved N
- stabilize sediments & create new habitat
- ↓ phytoplankton

[1] Jones et al. 1994; [2] Karatayev et al. 2002



Examples of apparent mussel impacts on phytoplankton in lakes certainly abound

But credible predictive models of the role of mussels in lake ecology are still developing

e.g. Lake Simcoe (bar indicates establishment phase; Winter *et al*., 2010)

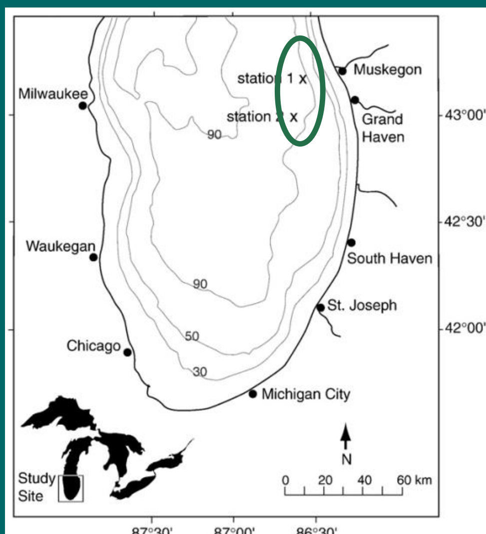
The nearshore shunt hypothesis[1]

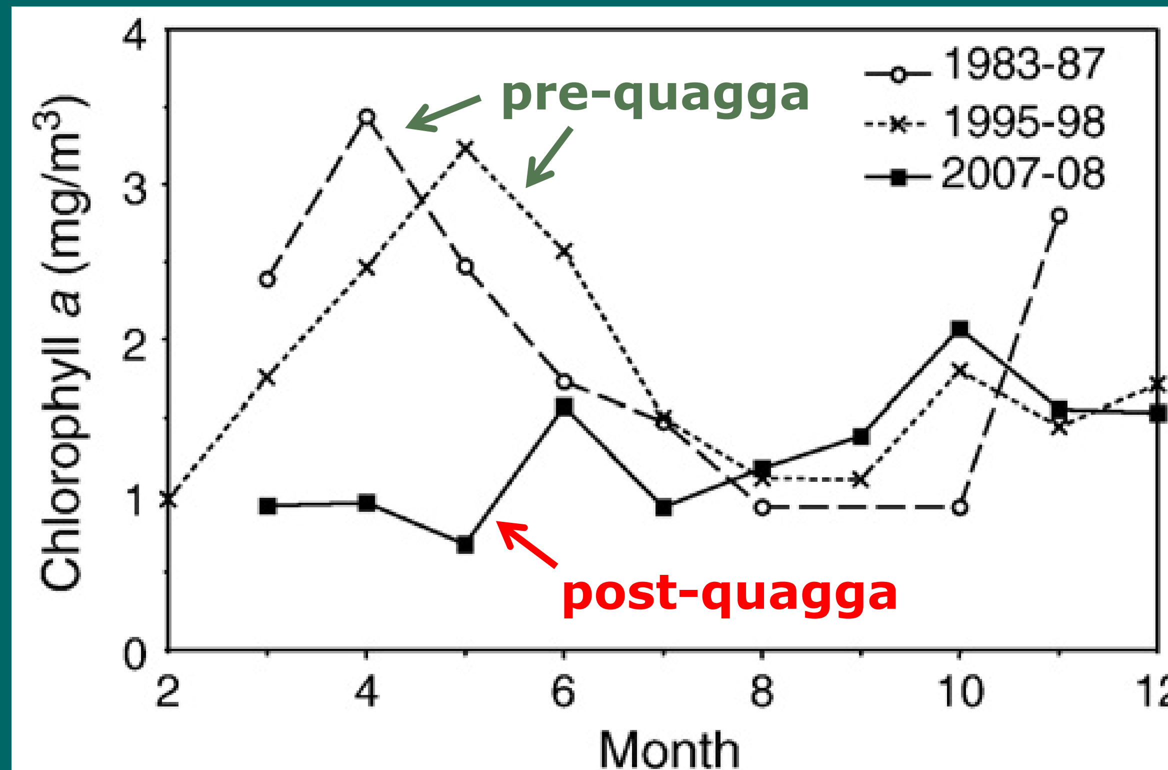
- Mussels re-direct nutrients and energy to benthos
- Re-direction is most effective in nearshore (shallow, well-mixed)
- Preferential decrease of nearshore plankton (plankton oligitrophication)
- Lesser effects offshore, but …….

[1] Hecky *et al*., 2004; CJFAS 61: 1285-1293

The Lake Michigan experience

Fahnenstiel et al., 2010; JGLR 36: 20-29





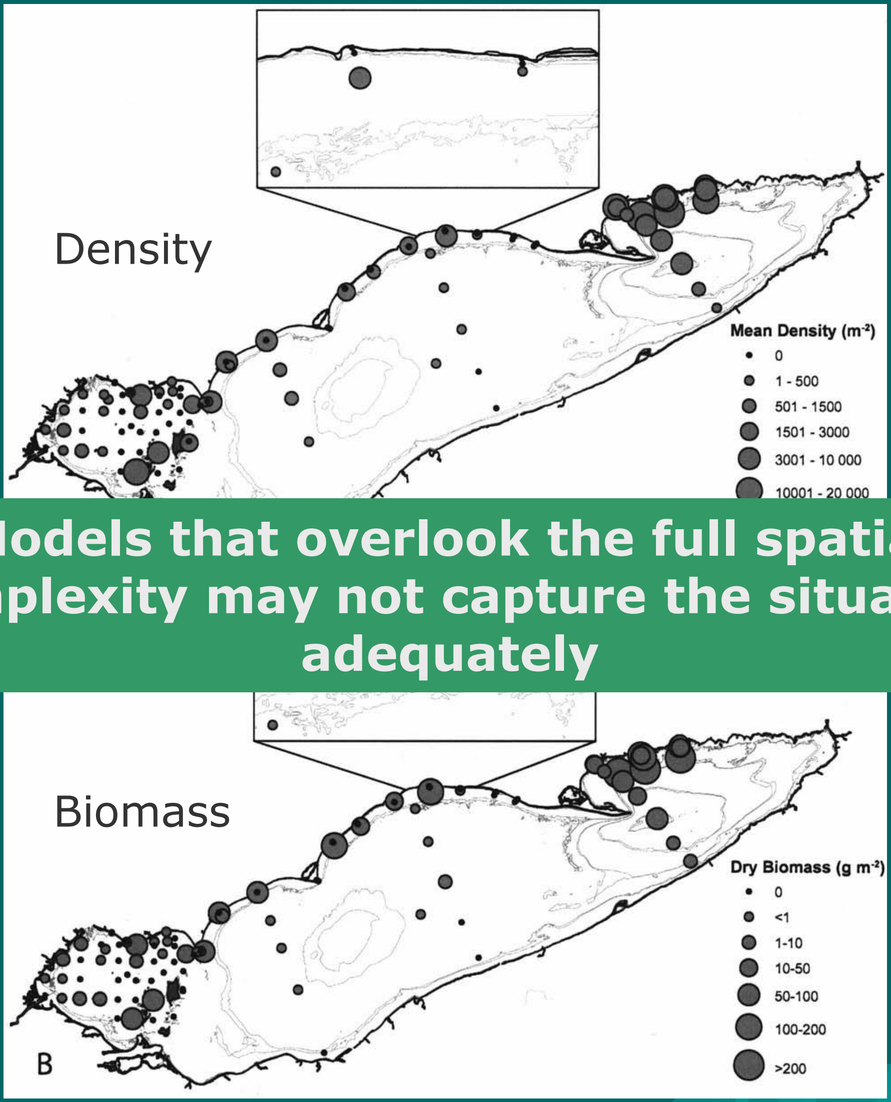
Large loss of phytoplankton and primary production at deep offshore stations associated with quagga establishment

Mussels are confined to bottom and feeding success is partly under hydrodynamic control

e.g. Edwards *et al*. 2005; CJFAS 62: 205-214.

Modeling of the role of mussels must recognize this reality

Mussels also have patchy and discontinuous distributions, e.g. Lake Erie 2002



Patterson et al., 2005; JGLR 31 (2): 223-237

Models that overlook the full spatial complexity may not capture the situation adequately

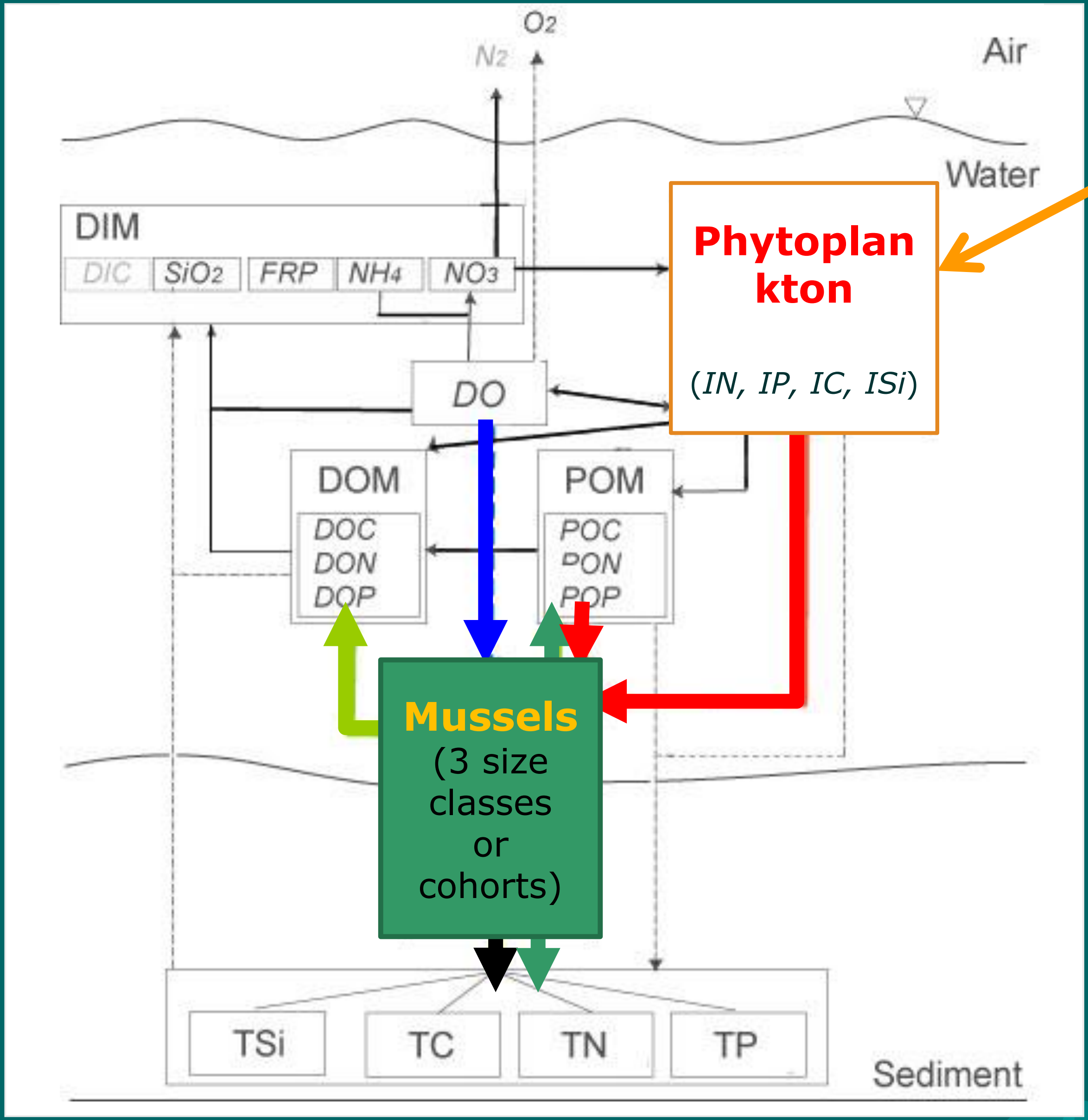
Objectives: use a calibrated model with realistic hydrodynamics & mussel distributions to:

1. Determine if nearshore shunt predictions are supported

2. Ask if we can expect major mussel impacts even in deep, cold waters

3. Determine if there is an evidence of stimulation of phytoplankton growth

Mussel-system interactions

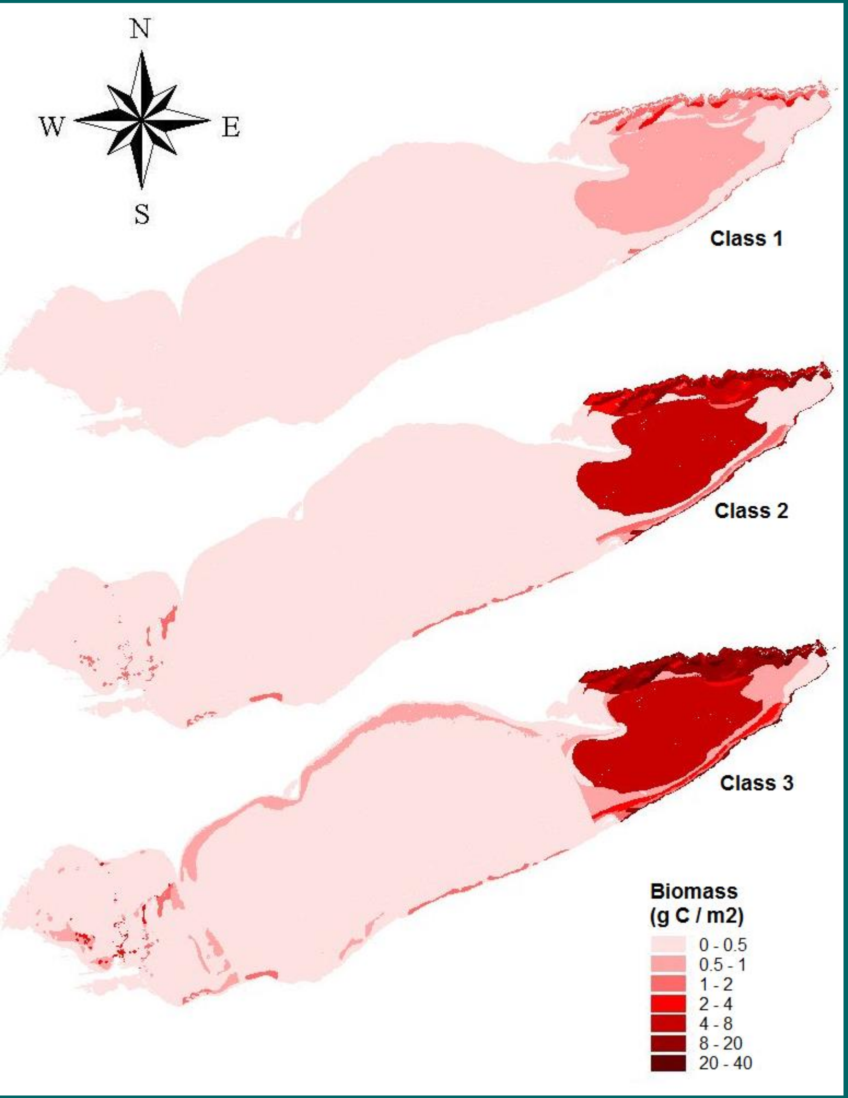


Current model uses 5 phytoplankton groups

Grazing
Excretion
Egestion
Respiration
Mortality

Bocaniov et al., 2014; Hydrobiologia, 731, 151-172

Distribution and size class specifications modelled by basin, substrate and depth distributions for Lake Erie* in 2002 (Patterson *et al*. 2005)



Model used 2 km horizontal grid and 40 vertical layers

Mussel classes 1, 2 and 3 have mean shell lengths of 5, 15 and 25 mm

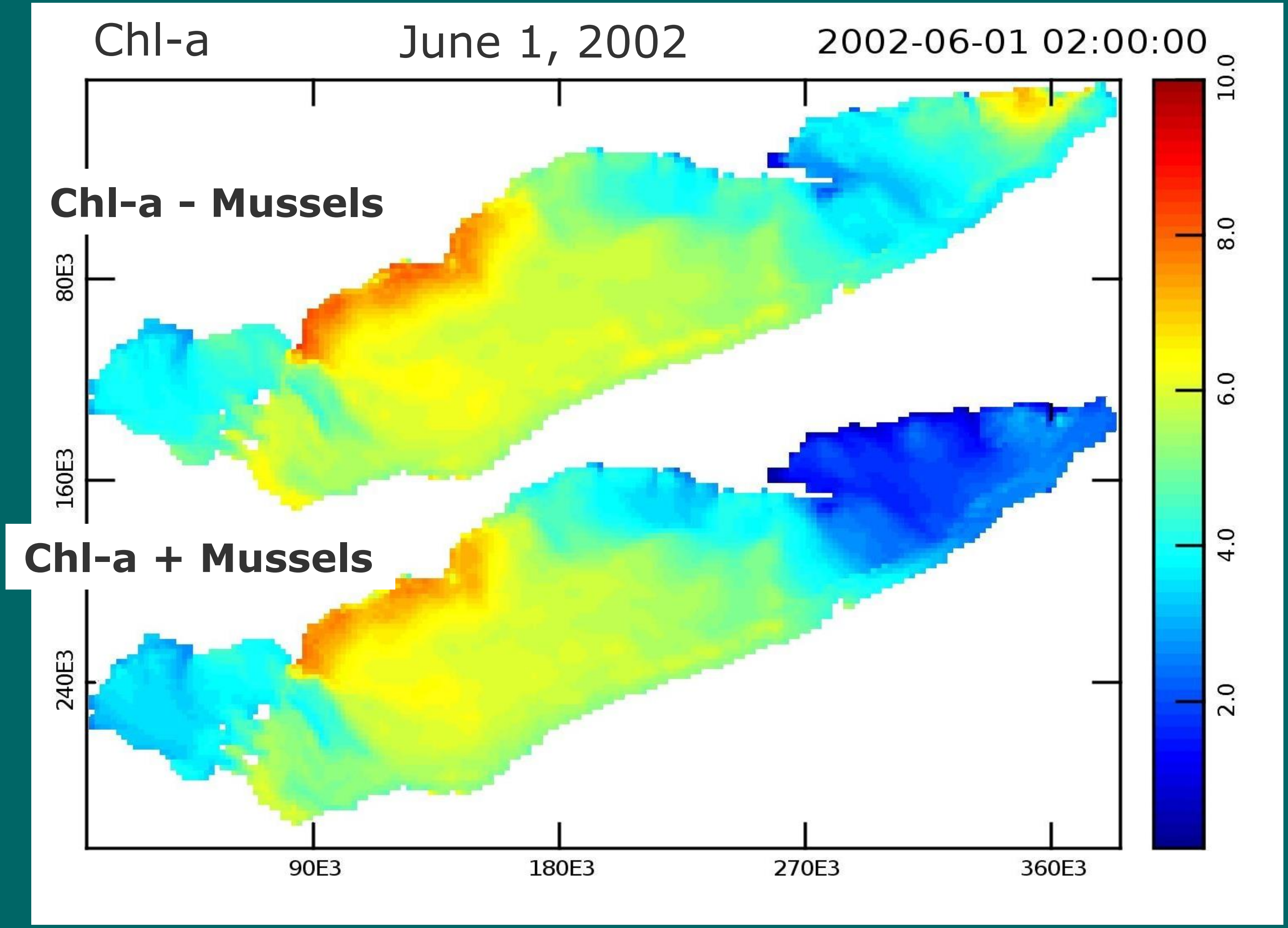
Average biomass (gC/m^2):

- 11.6 (East basin),
- 0.19 (Central basin)
- 0.32 (West basin)

** Bocaniov et al., 2014; Hydrobiologia, 731, 151-172*

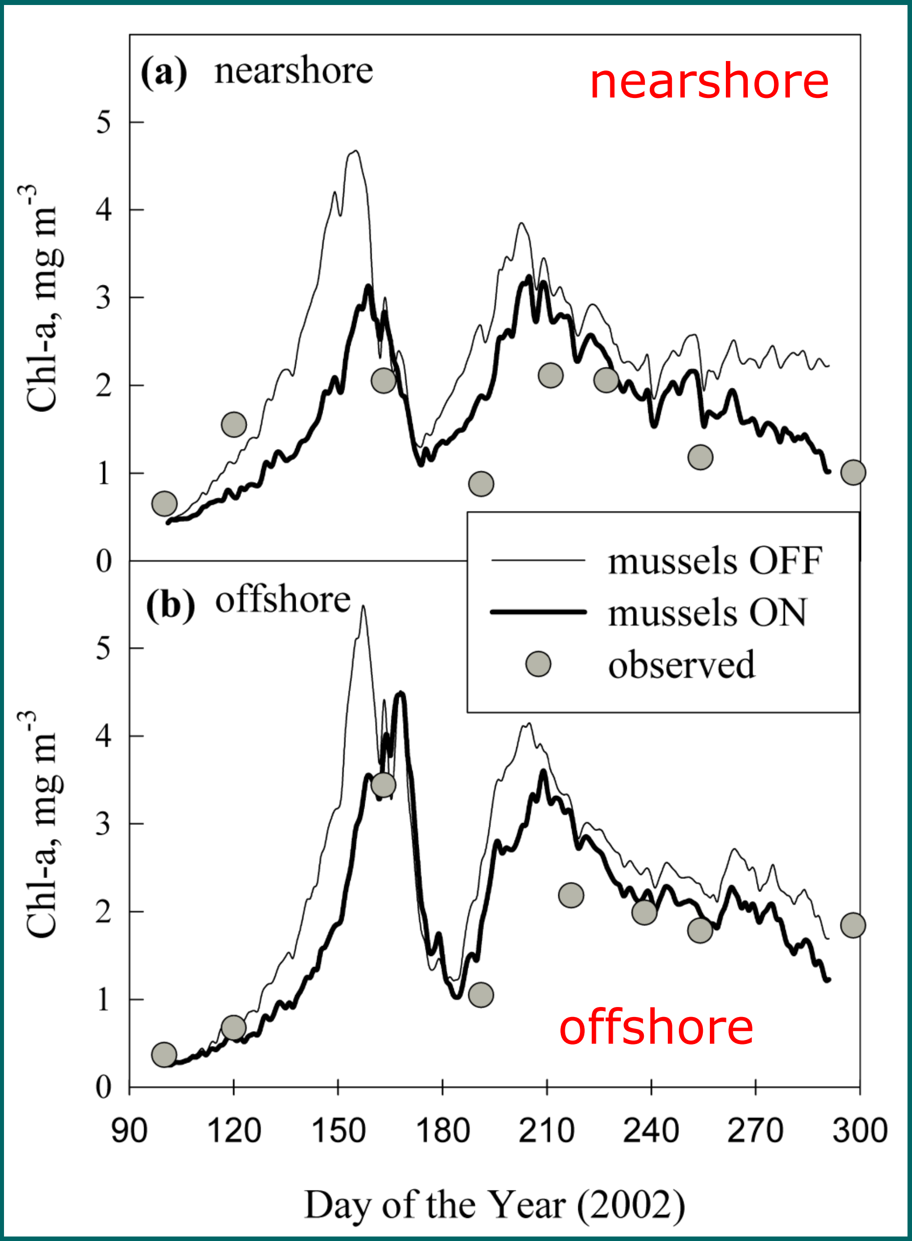
Results: spatial patterns of impact

(modified from ***Bocaniov*** *et al., 2014; Hydrobiologia 731: 151-172*)



Evidence for a strong spatial variability in predicted mussel impact? YES

Results: Nearshore vs. offshore dynamics within East basin*



Mussels decrease Chl-a substantially in nearshore

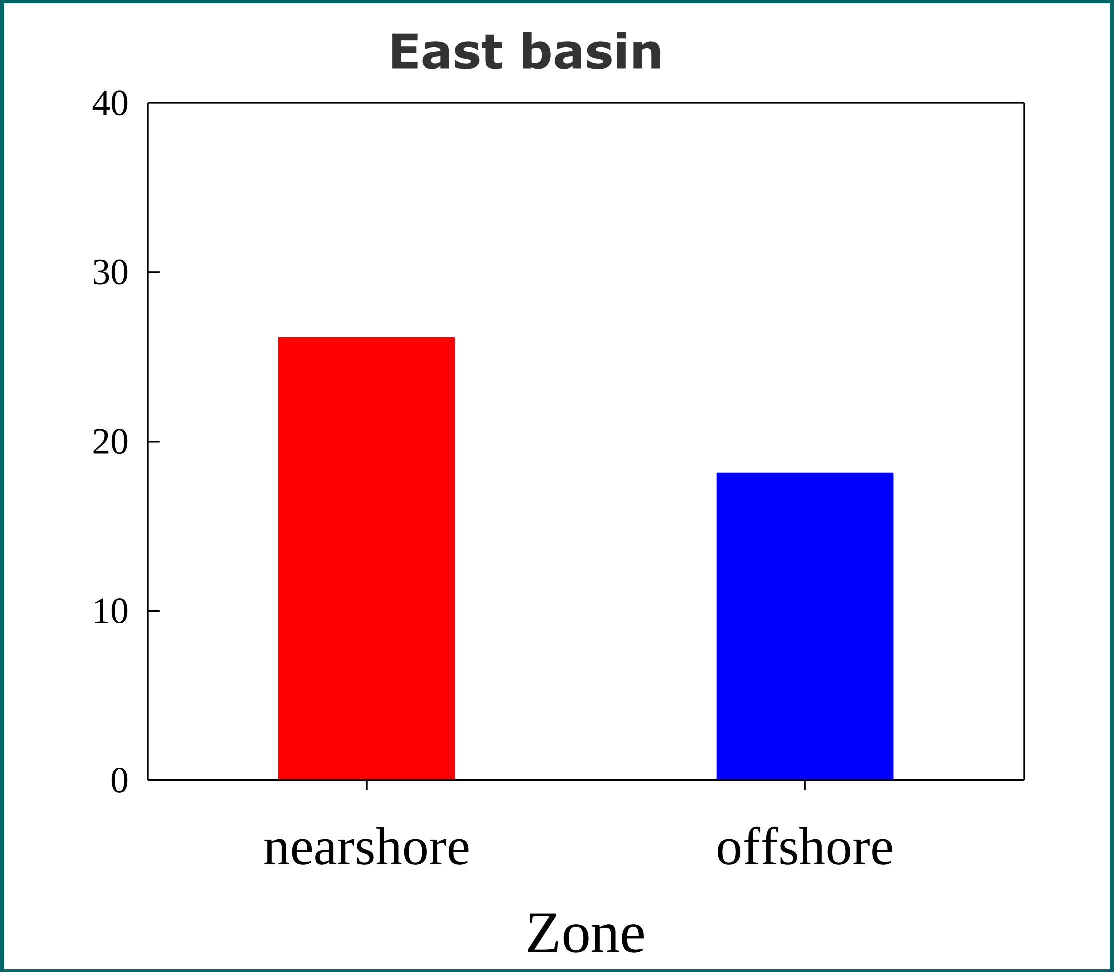
BUT also in offshore

The "spring bloom" is attenuated and delayed in both zones

Evidence for offshore, spring-time effects? YES

* *Bocaniov et al., 2014; Hydrobiologia, 731, 151-172*

Percent decrease of predicted phytoplankton biomass (April-October average) with addition of mussels

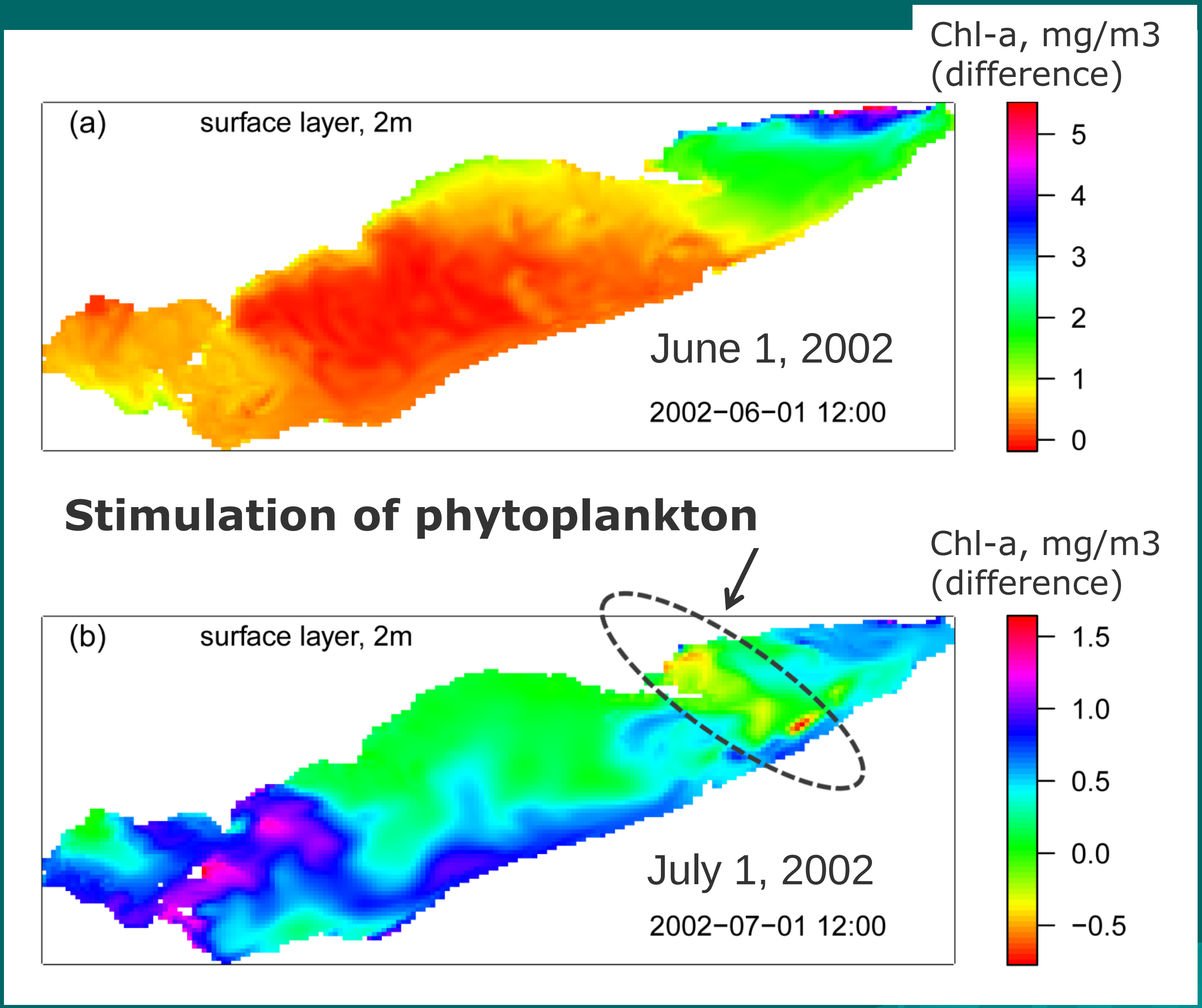


Evidence for the nearshore shunt? YES

Stimulation of phytoplankton growth by grazing*

Differences in Chl-a concentrations:

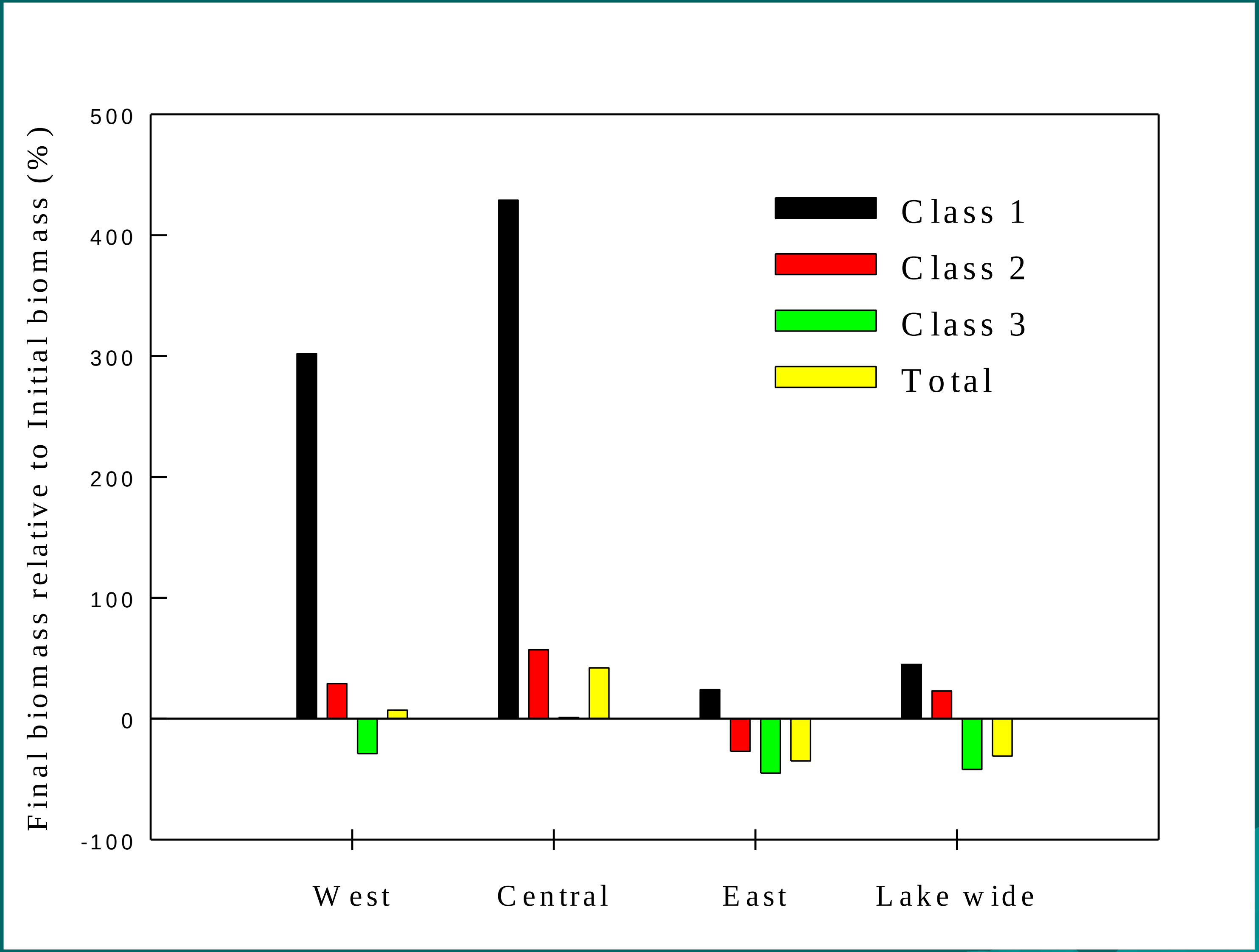
Chl-a (mussels OFF) – Chl-a (mussels ON)



Modified from Bocaniov et al., 2014; Hydrobiologia, 731, 151-172

Change in final mussel biomass[1]

(Final biomass as % of Initial biomass)



[1] Simulation time: 191 days (April 10 to October 17, 2002)

Conclusions

- 3-D modelling predicts very dynamic picture of seasonal mussel biomass development
- Different basin-wide impact:

  East B > West B > Central B

- Shunt and offshore effects supported
- Mussel grazing can stimulate the growth of phytoplankton
- Model can be used for modeling HABs

Conclusions (*possible next steps*)

- Knowledge of mussel behaviour and energetics has improved (e.g. *Vanderploeg et al., 2017**) and the model could accommodate the new information about temperature responses, feeding rates, and excretion

- Model has seston stoichiometry and can captute the stoicheometry-dependent behaviour demonstrated by Vanderploeg *et al*. (2017)*

- Zooplankton can be included too

* *Vanderploeg et al., 2017; Freshwater Biol. 62: 664-680*

QUESTIONS?

Serghei Bocaniov
Graham Sustainability Institute
University of Michigan
Phone: (734) 647 8393
Email: bocaniov@umich.edu serghei.bocaniov@gmail.com