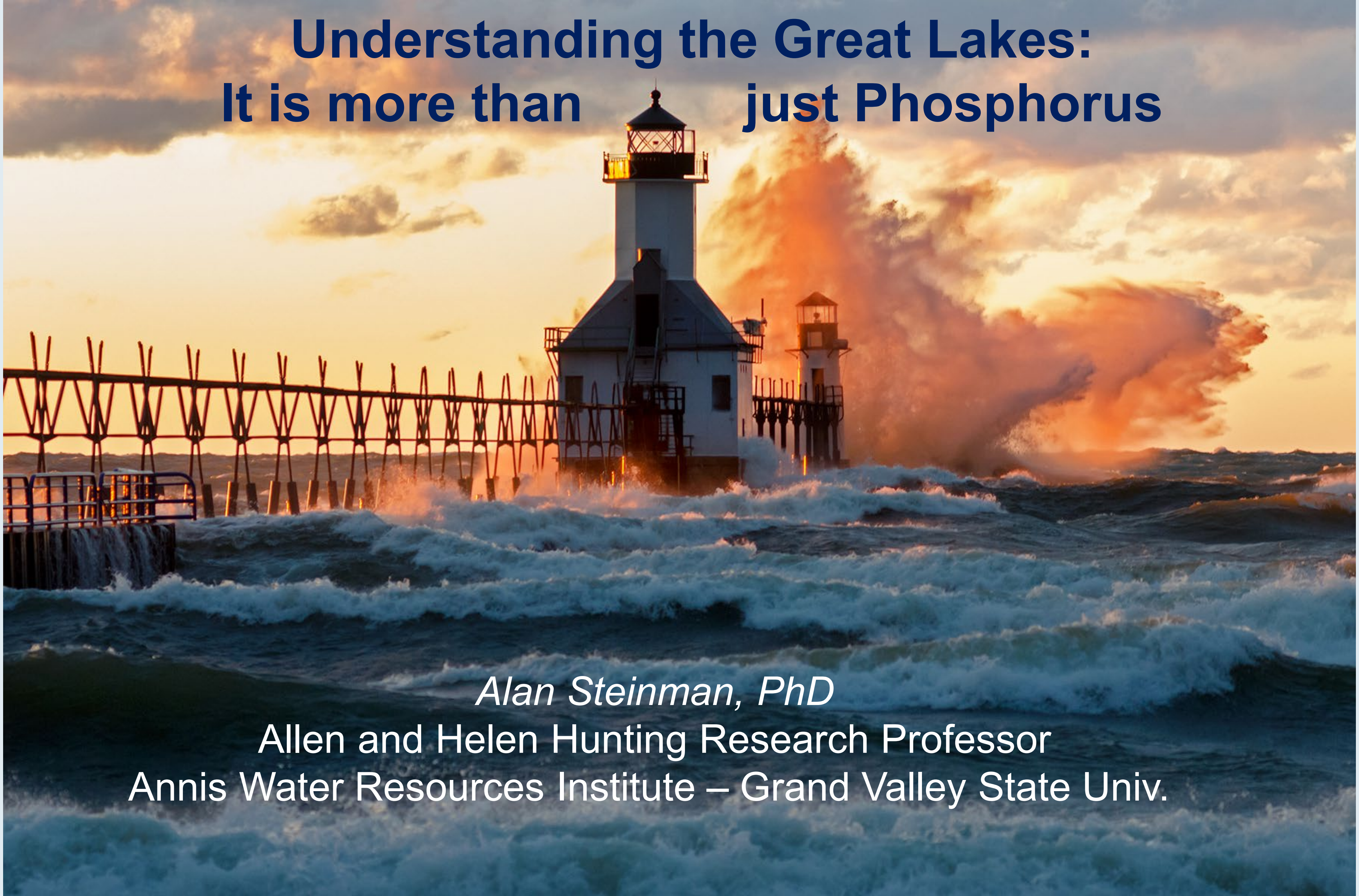
Understanding the Great Lakes: It is more than just Phosphorus



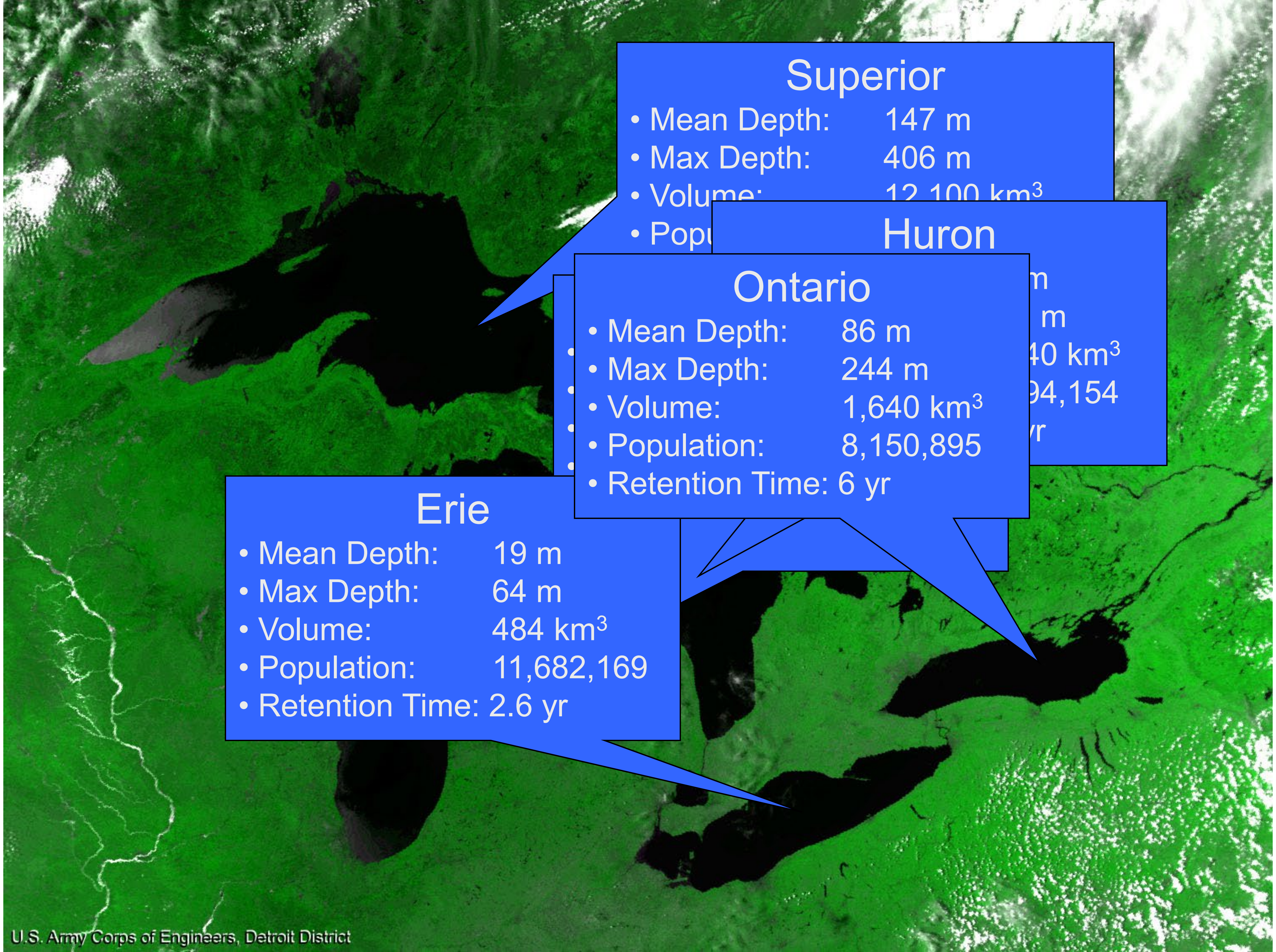
Alan Steinman, PhD

Allen and Helen Hunting Research Professor

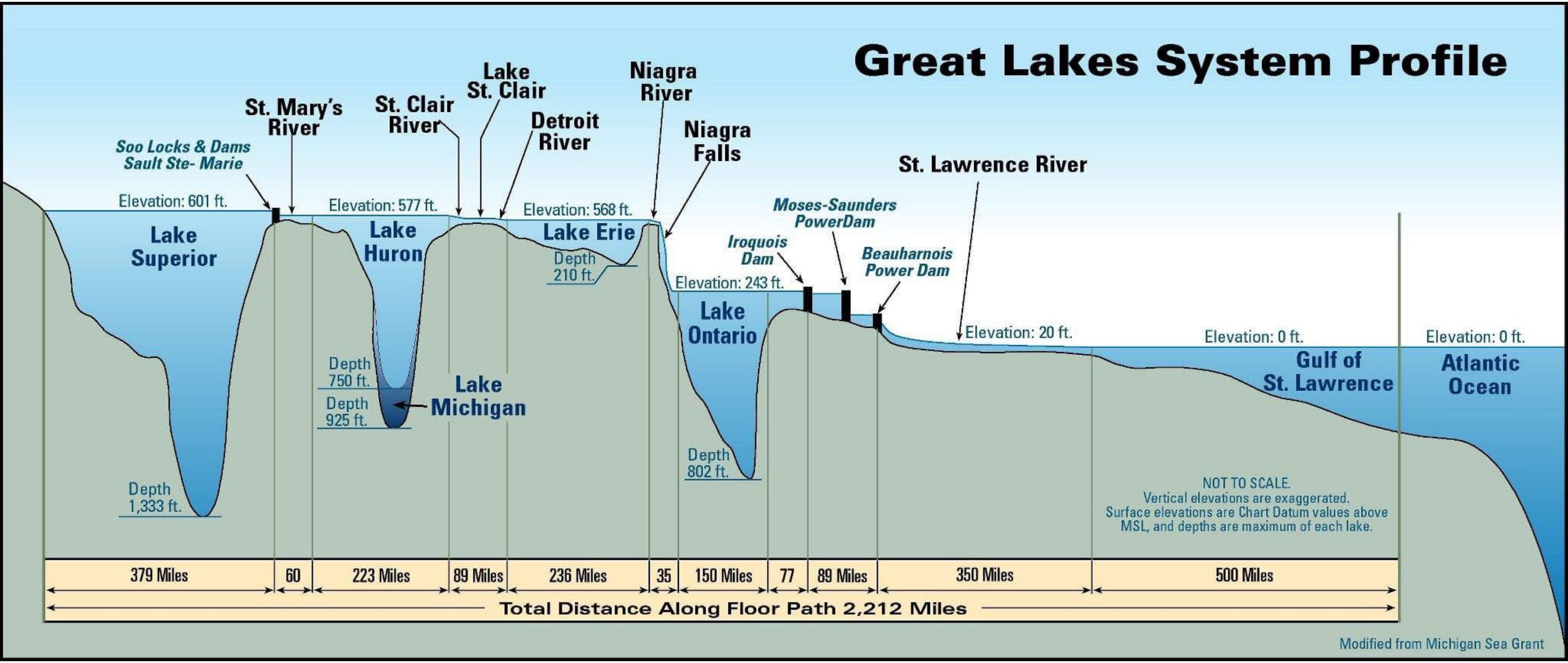
Annis Water Resources Institute – Grand Valley State Univ.

Outline

- Overview of Great Lakes
- Drowned River Mouth Lakes/Coastal Wetlands
- Great Lakes Sinkholes
- Salinization?
- Summary



Superior
• Mean Depth: 147 m
• Max Depth: 406 m
• Volume: 12,100 km³
Huron
Ontario
• Mean Depth: 86 m
• Max Depth: 244 m
• Volume: 1,640 km³
• Population: 8,150,895
• Retention Time: 6 yr
Erie
• Mean Depth: 19 m
• Max Depth: 64 m
• Volume: 484 km³
• Population: 11,682,169
• Retention Time: 2.6 yr
U.S. Army Corps of Engineers, Detroit District

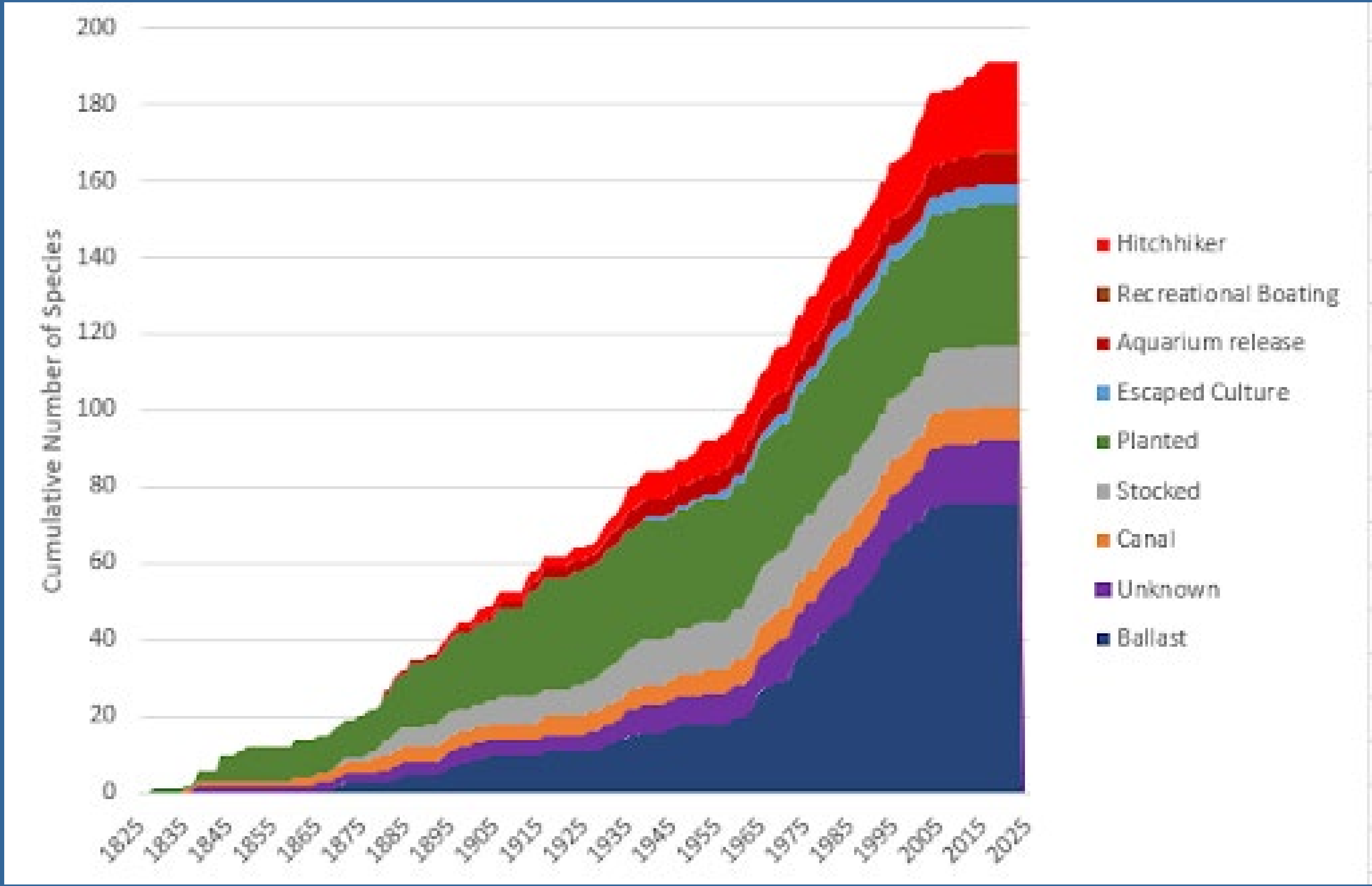

Great Lakes System Profile
Soo Locks & Dams
Sault Ste- Marie
St. Mary's River
St. Clair River
Lake St. Clair
Detroit River
Niagra River
Niagra Falls
St. Lawrence River
Elevation: 601 ft.
Lake Superior
Depth 1,333 ft.
Elevation: 577 ft.
Lake Huron
Depth 750 ft.
Depth 925 ft.
Lake Michigan
Elevation: 568 ft.
Lake Erie
Depth 210 ft.
Moses-Saunders PowerDam
Iroquois Dam
Beauharnois Power Dam
Elevation: 243 ft.
Lake Ontario
Depth 802 ft.
Elevation: 20 ft.
Elevation: 0 ft.
Gulf of St. Lawrence
Elevation: 0 ft.
Atlantic Ocean
NOT TO SCALE.
Vertical elevations are exaggerated.
Surface elevations are Chart Datum values above MSL, and depths are maximum of each lake.
379 Miles
60
223 Miles
89 Miles
236 Miles
35
150 Miles
77
89 Miles
350 Miles
500 Miles
Total Distance Along Floor Path 2,212 Miles
Modified from Michigan Sea Grant

Project GLEAM: Mapping Individual Stressors Across the Great Lakes

Fred A. and Barbara M.
Erb Family Foundation

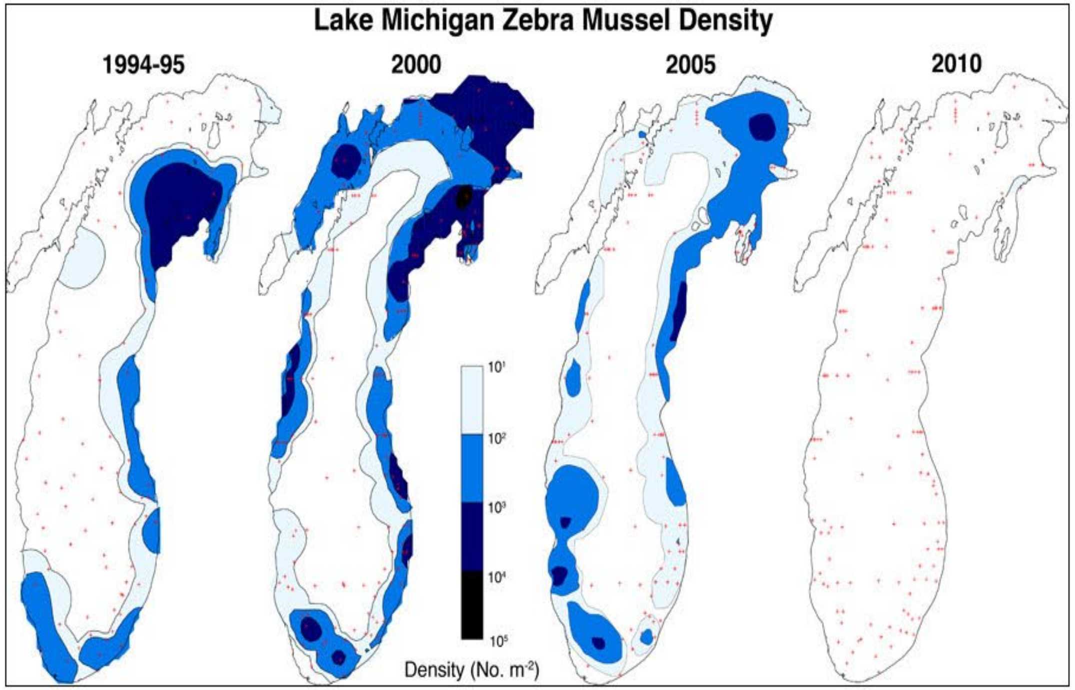
Modified from Dave Allan, UM

Cumulative established aquatic invasives in the Great Lakes, by vector of introduction.



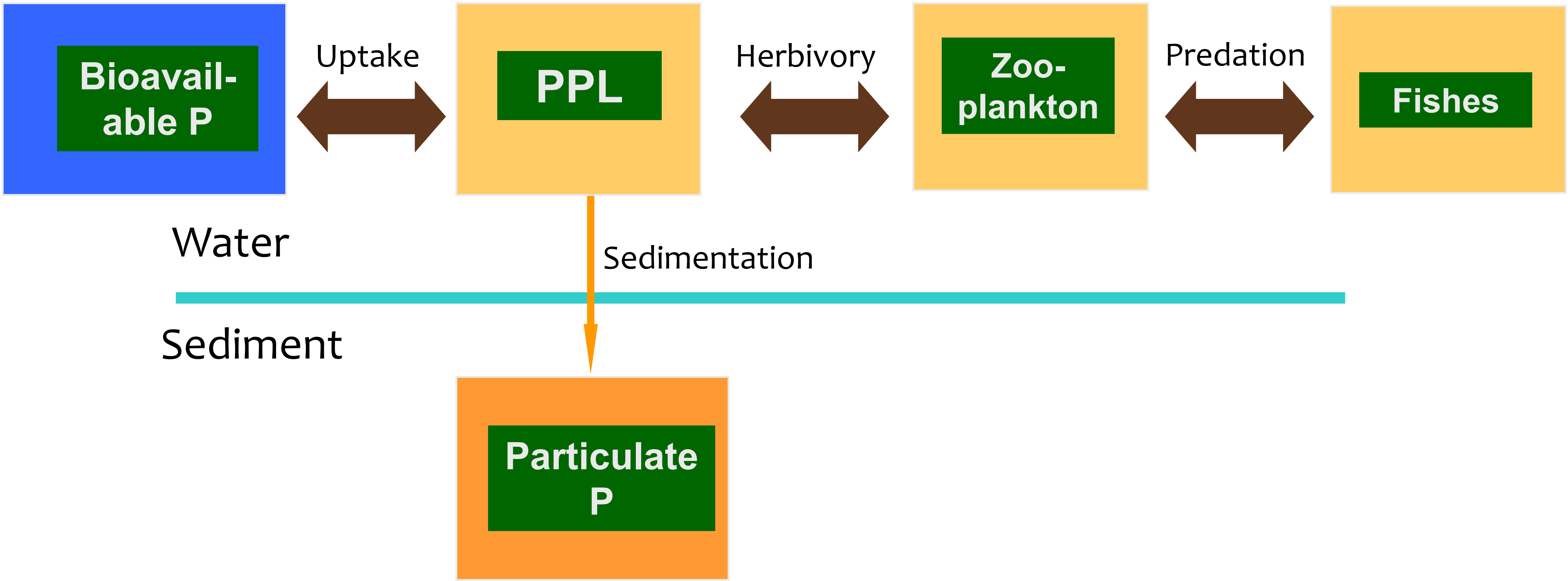
No new introductions have been attributed to ballast water since 2006.

Zebra Mussel



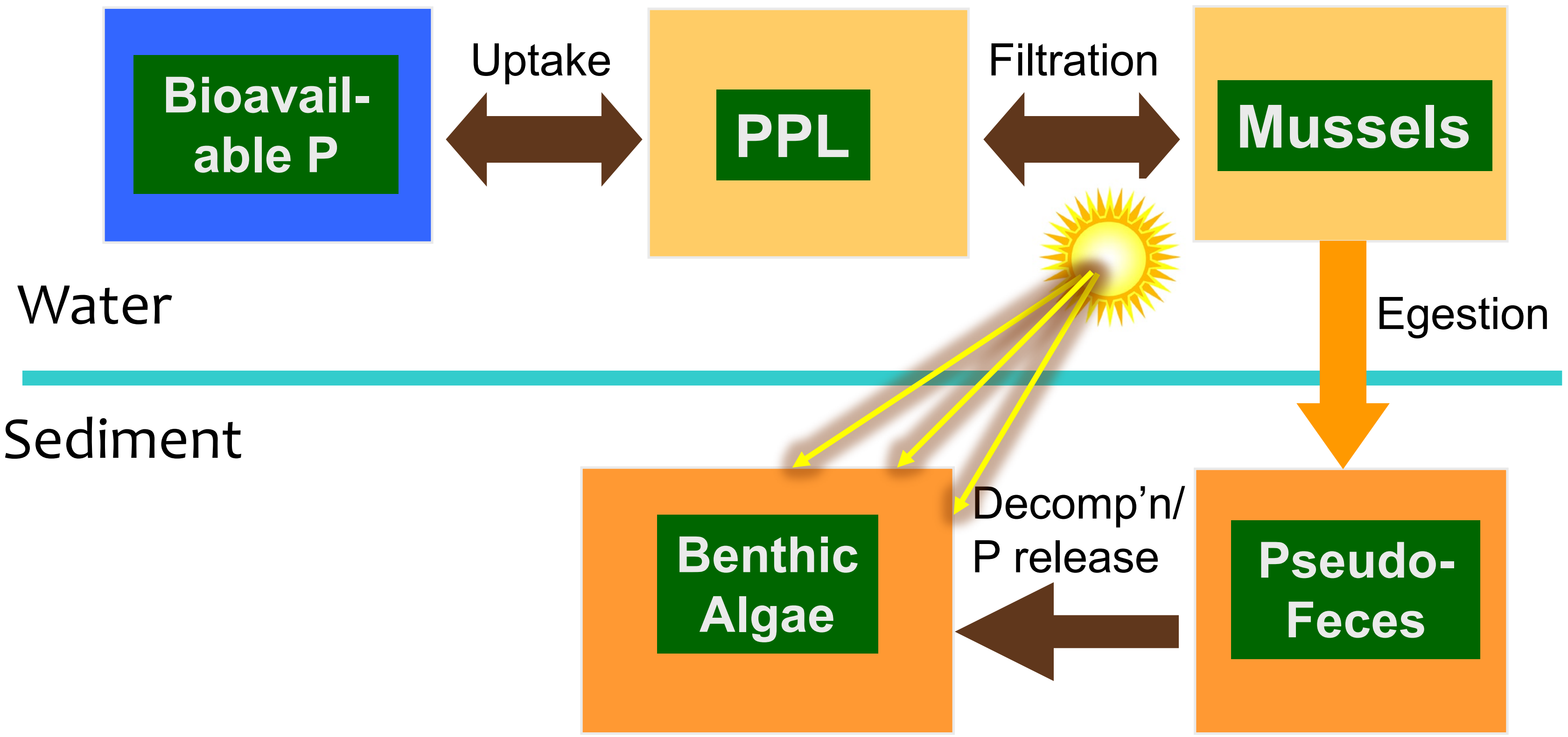
Data: Tom Nalepa, NOAA

Benthification of Great Lakes: <u>pre</u>-dreissenid mussels



Adapted from Hecky et al. (2004) CJFAS

Benthification of Lake Michigan: <u>post</u>-dreissenid mussels

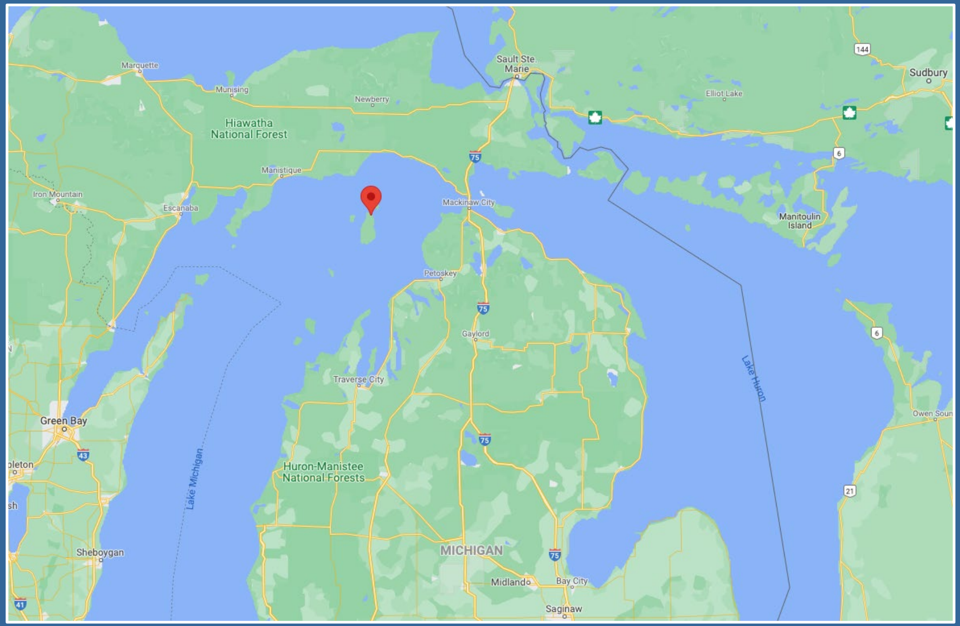


Adapted from Hecky et al. (2004) CJFAS

Photo courtesy of S. Higgins – U. of Waterloo

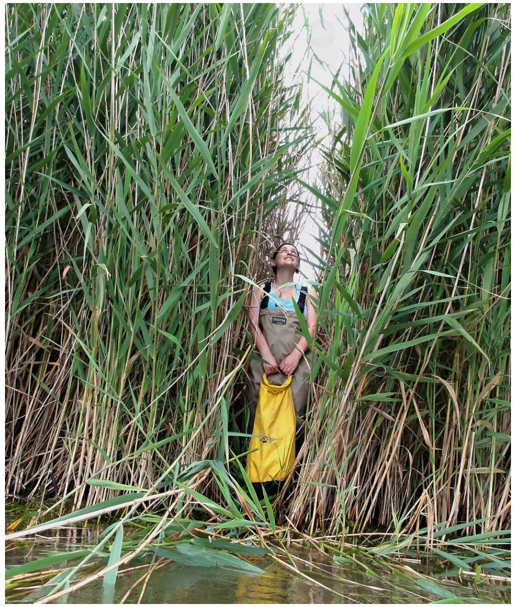
Loss of Coastal Habitat

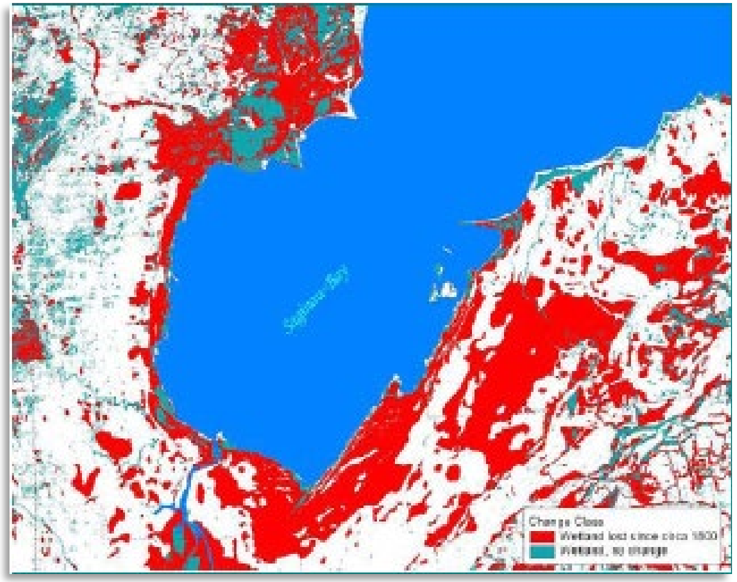
~50% of coastal wetlands lost

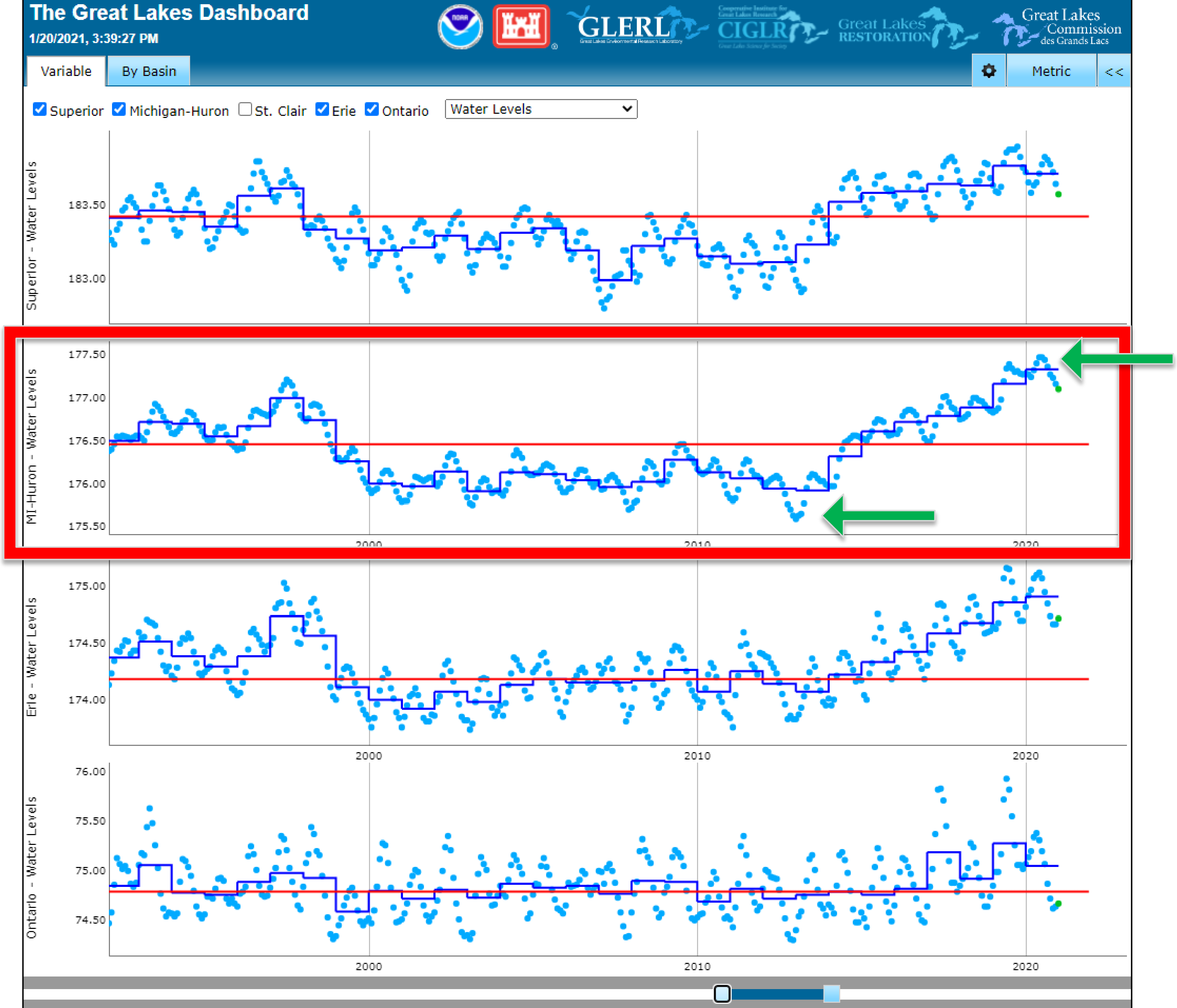


Great Lakes Coastal Wetlands: Impacts

- Development
- Nutrient loading
- Invasive species
- Fragmentation
- *Hydrology*

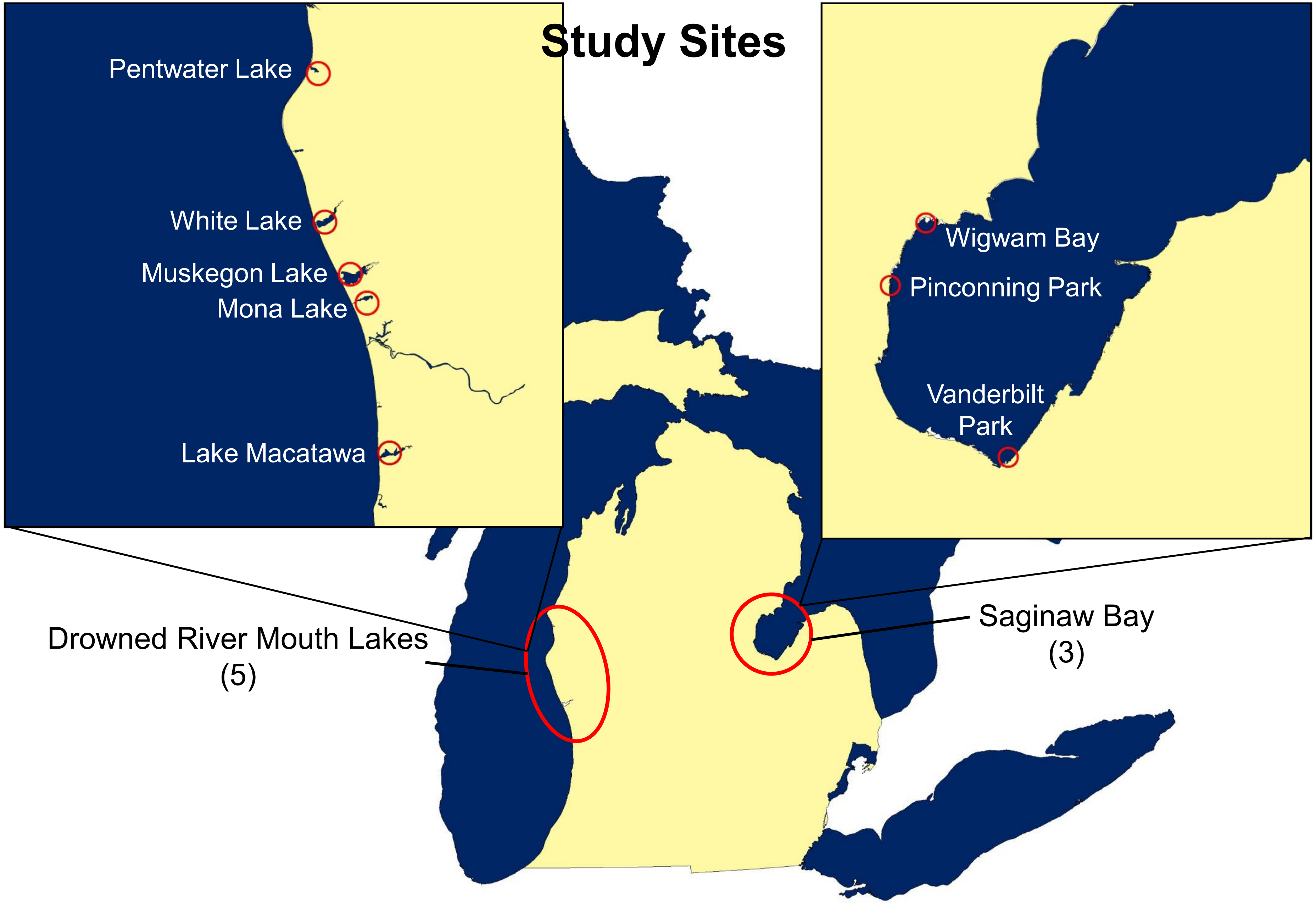






The Great Lakes Dashboard
1/20/2021, 3:39:27 PM
Variable
By Basin
Metric
Superior
Michigan-Huron
St. Clair
Erie
Ontario
Water Levels
Superior - Water Levels
183.50
183.00
MI-Huron - Water Levels
177.50
177.00
176.50
176.00
175.50
Erie - Water Levels
175.00
174.50
174.00
Ontario - Water Levels
76.00
75.50
75.00
74.50
2000
2010
2020

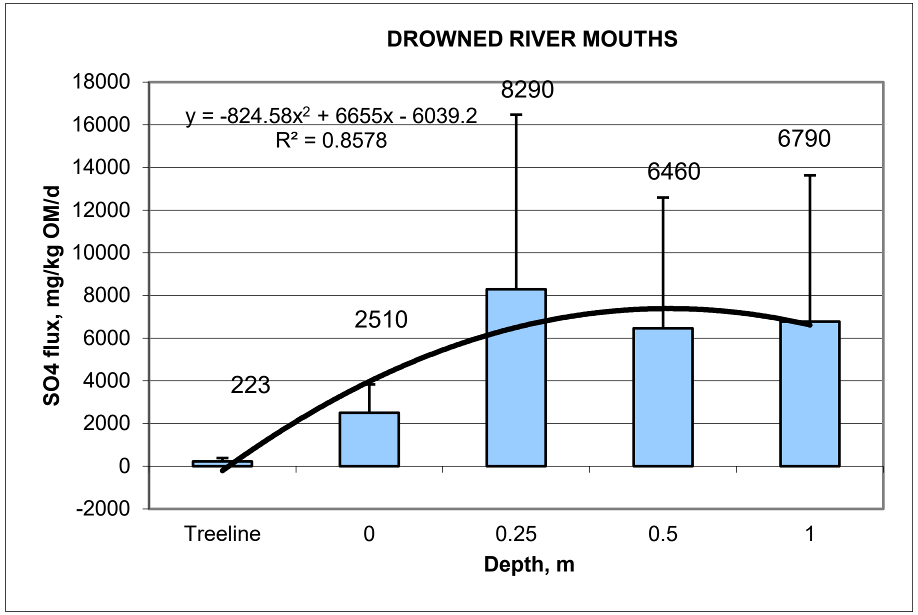
Study Sites

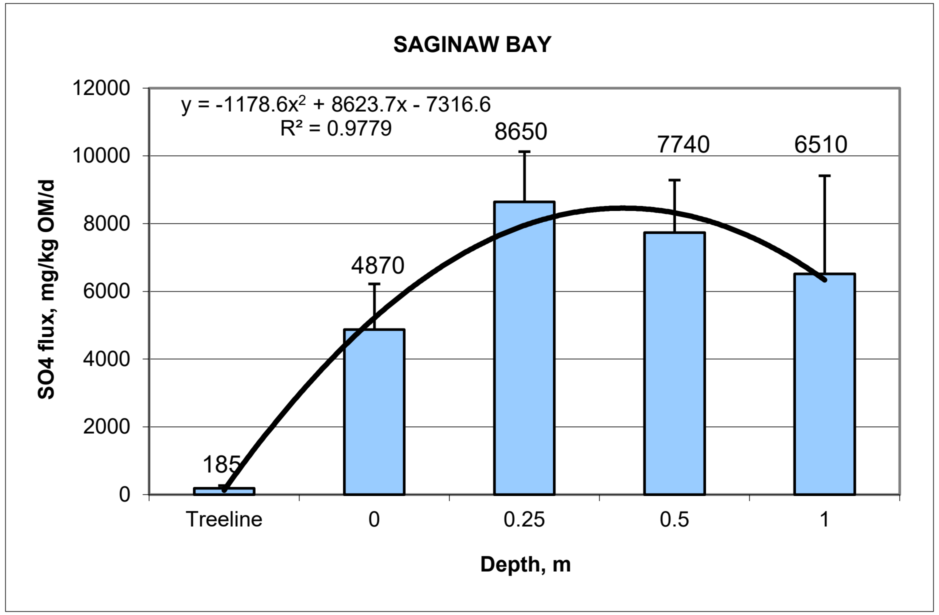


Pentwater Lake
White Lake
Muskegon Lake
Mona Lake
Lake Macatawa
Wigwam Bay
Pinconning Park
Vanderbilt Park
Drowned River Mouth Lakes (5)
Saginaw Bay (3)


5-W-C
2

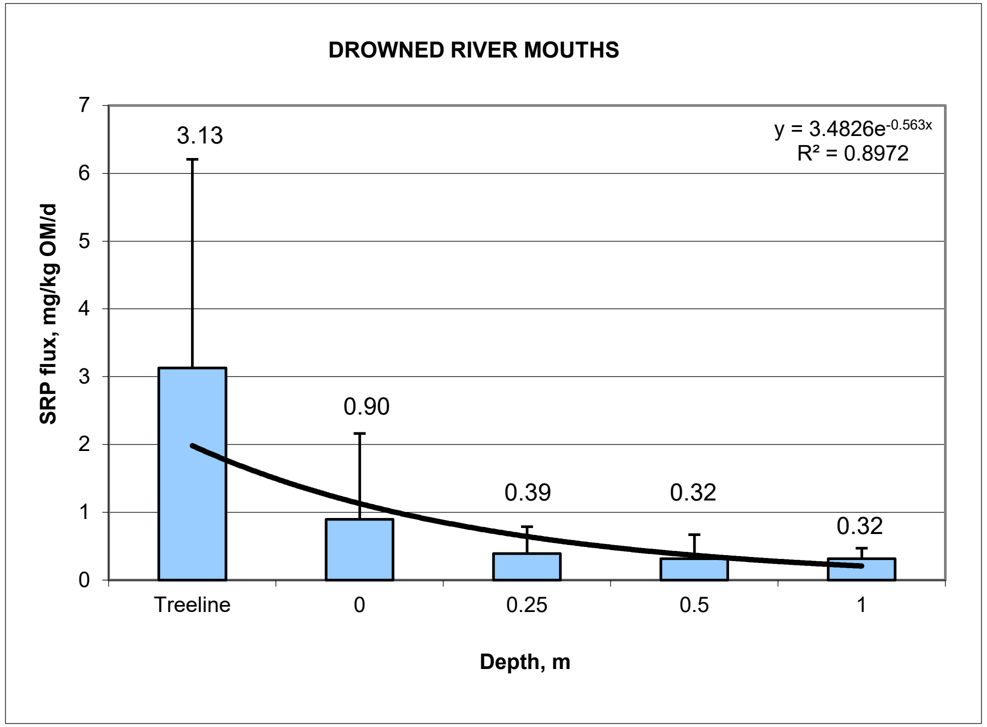
Sulfate (mg/kg/d)

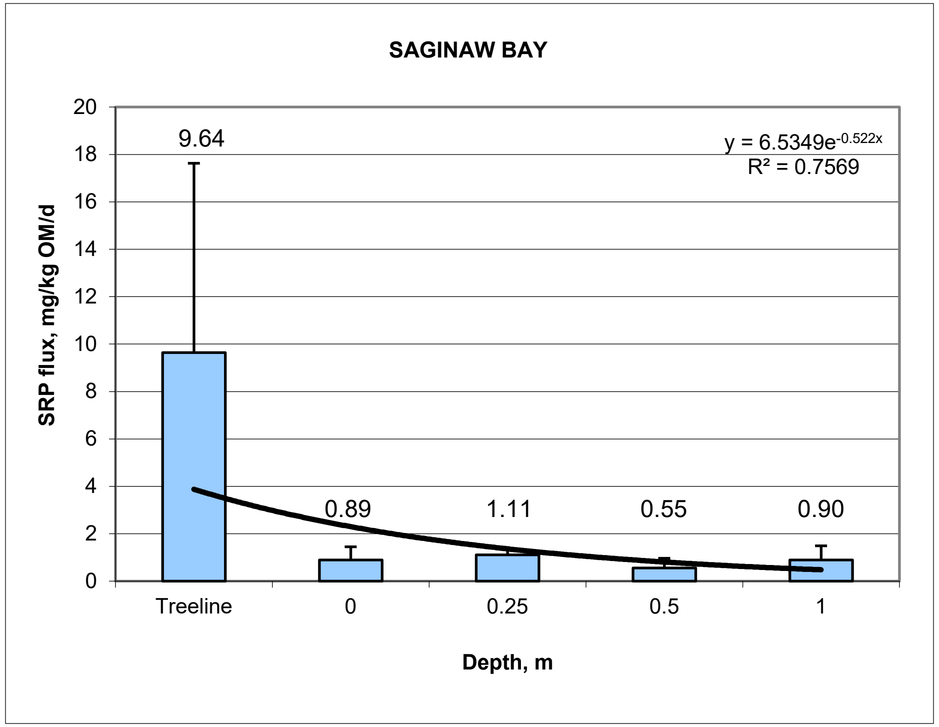




- Very low release rates at treeline
- Higher release rates at depths >0.25m

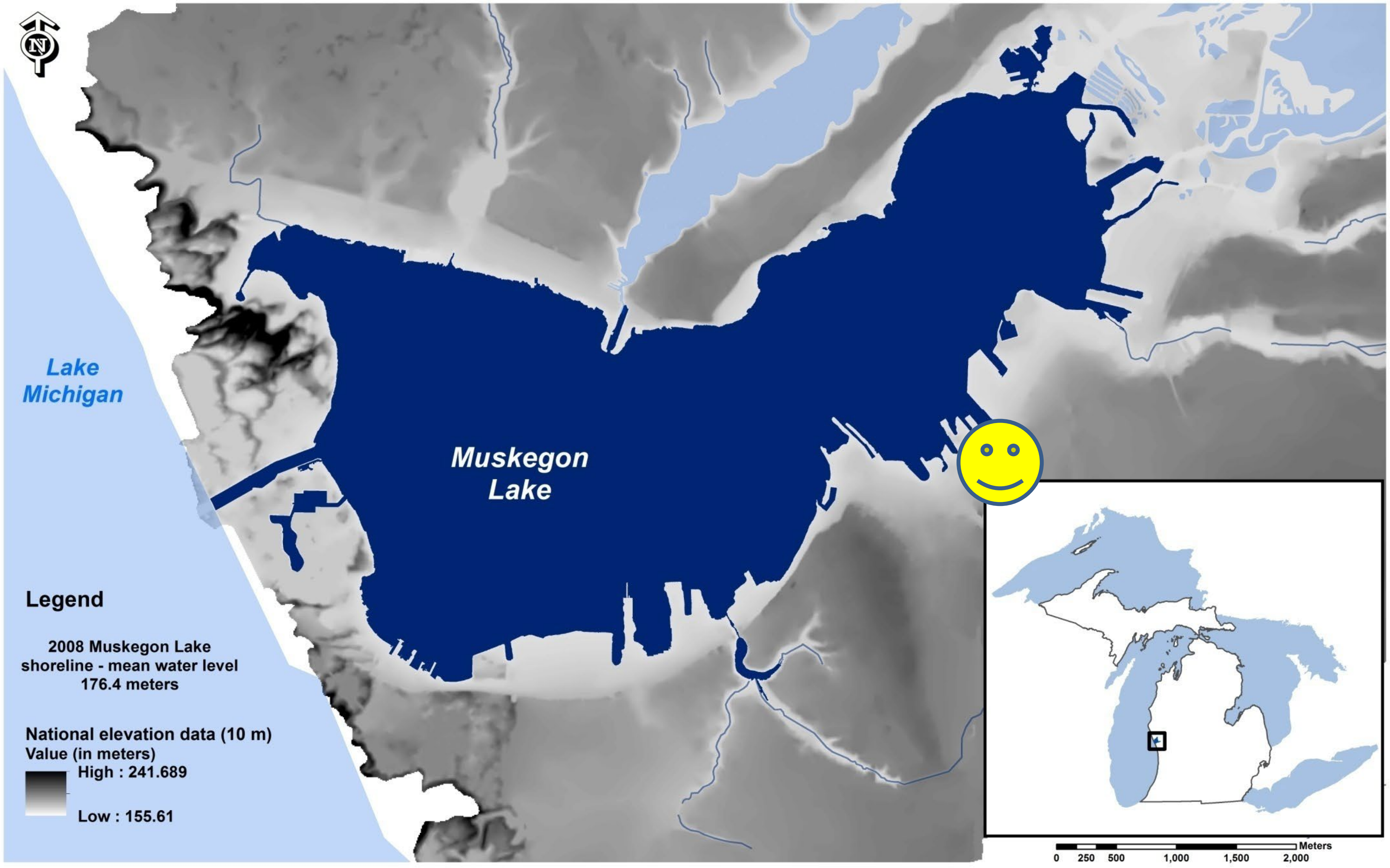
Phosphate (mg/kg/d)





- Declining release rate with water depth

Base Water Level



Water Level Scenarios: PO_4

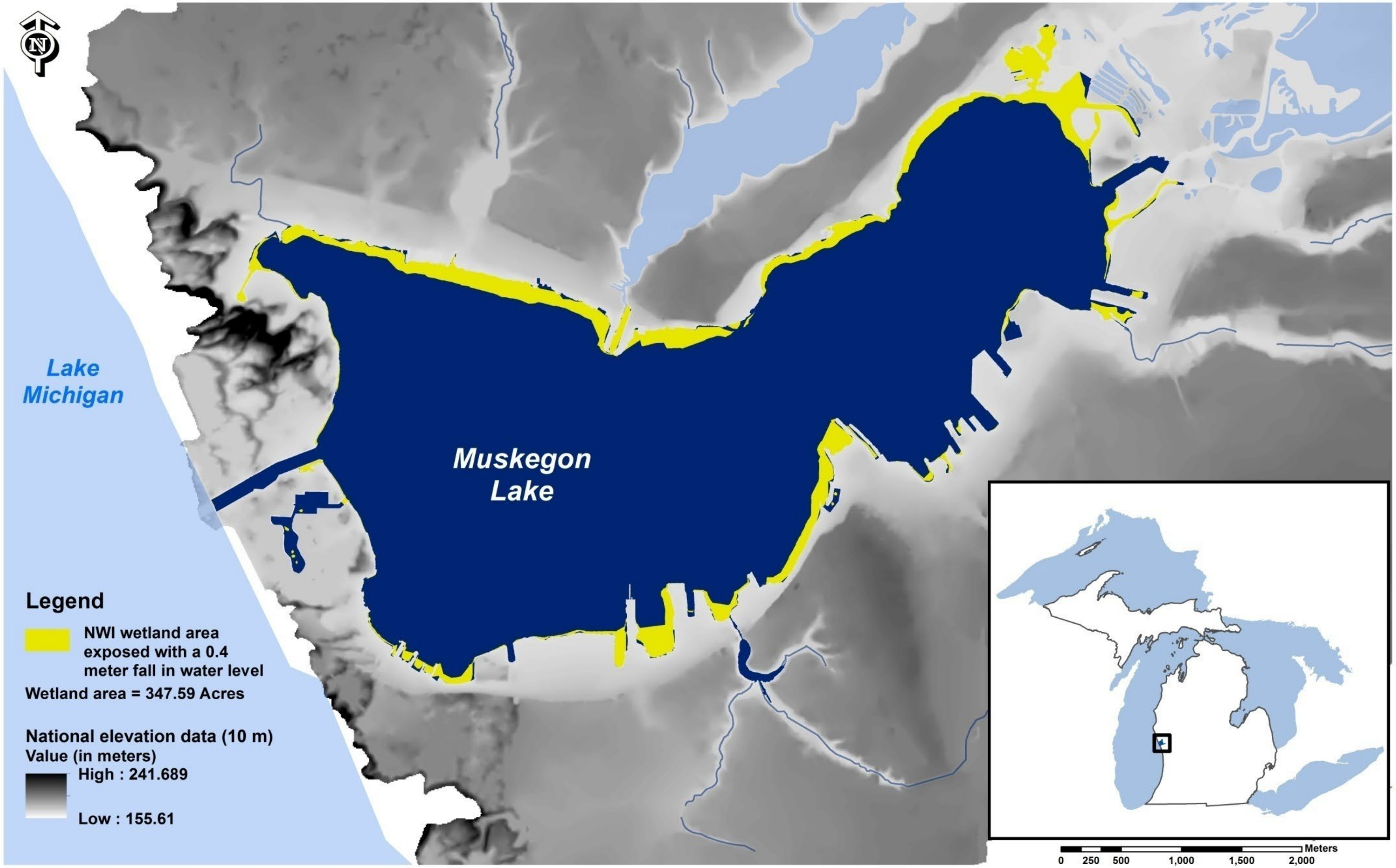
<u>Decline:</u>

- 0.4 m; then inundation
- 0.8 m; then inundation
- 1.5 m; then inundation

<u>Increase:</u>

- 0.4 m

-0.4 m decline: 141 ha*

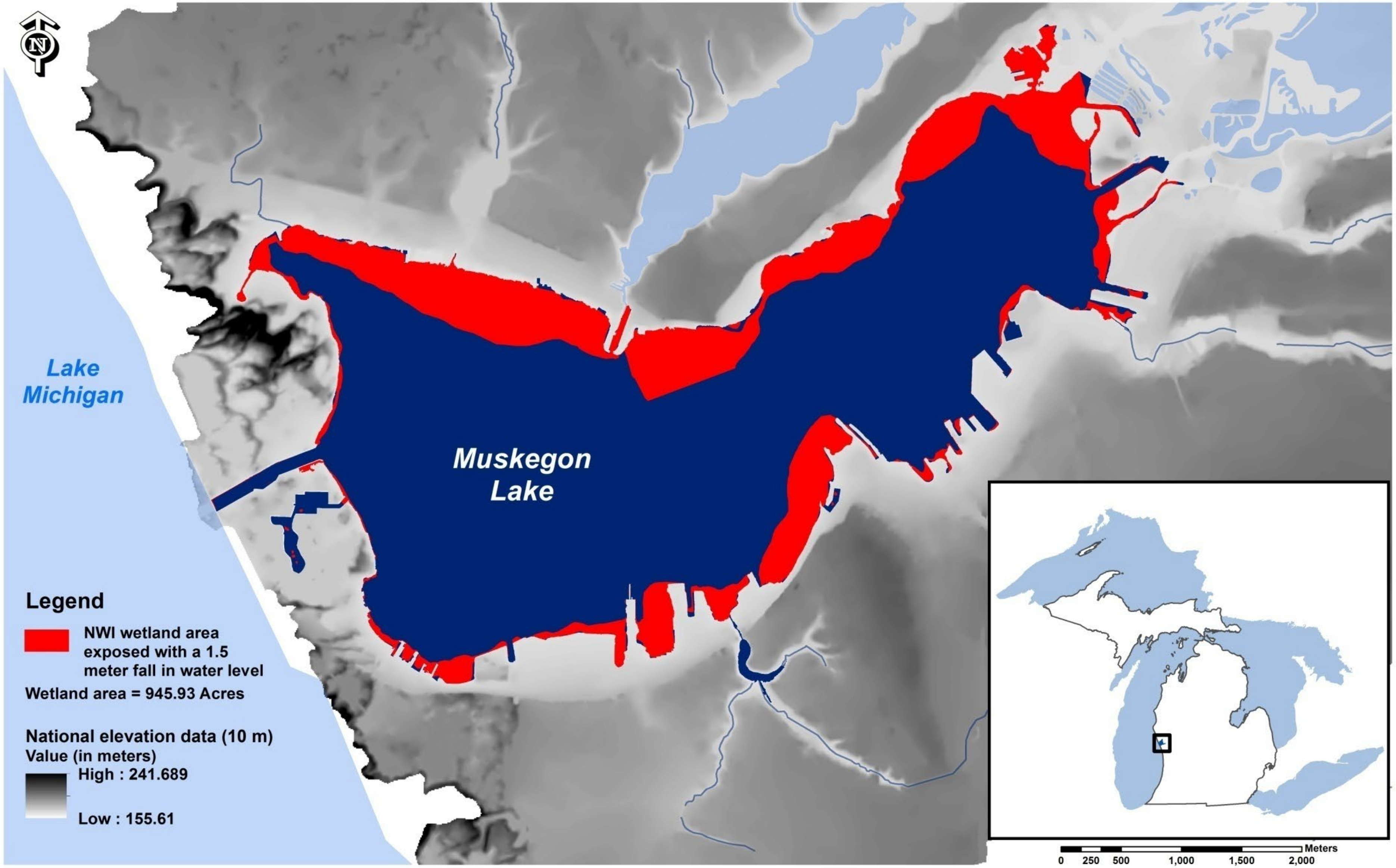


*includes only wetlands (NWI)

-0.8 m decline: 229 ha*

*includes only wetlands (NWI)

-1.5 m decline: 383 ha*



*includes only wetlands (NWI)

+0.4 m increase: 25 ha*

*includes only wetlands (NWI)

Phosphate: Muskegon Lake

Water Level Change (m)	Area Exposed / Flooded (ha)
- 0.4	140.7 (exposed)
-0.8	229.1 (exposed)
-1.5	382.8 (exposed)
+0.4	25.4 (flooded)

Steinman et al. (2012) JGLR

Water Level Summary

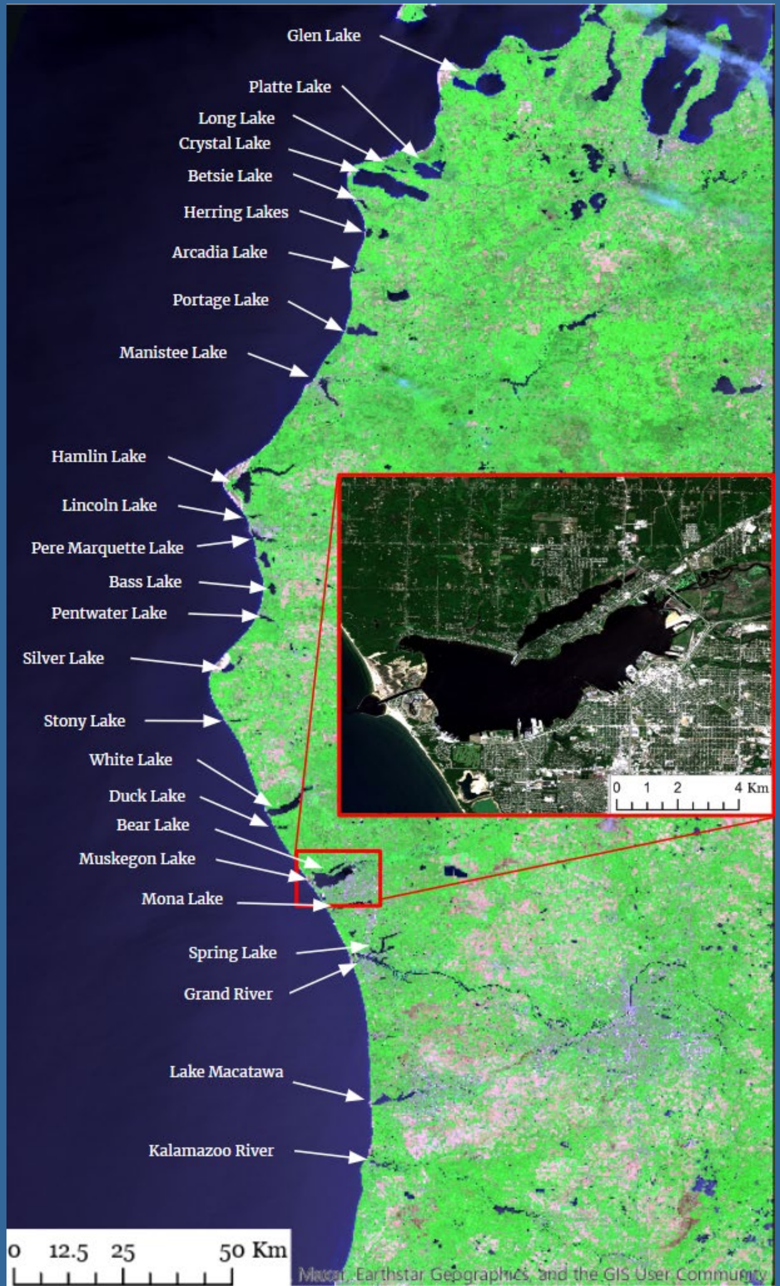
- Large potential nutrient release from coastal wetland sediments

- Release dynamics vary with nutrient

- Spatial variability both within wetlands (veg class) and among wetlands

- Fate of nutrients needs to be determined

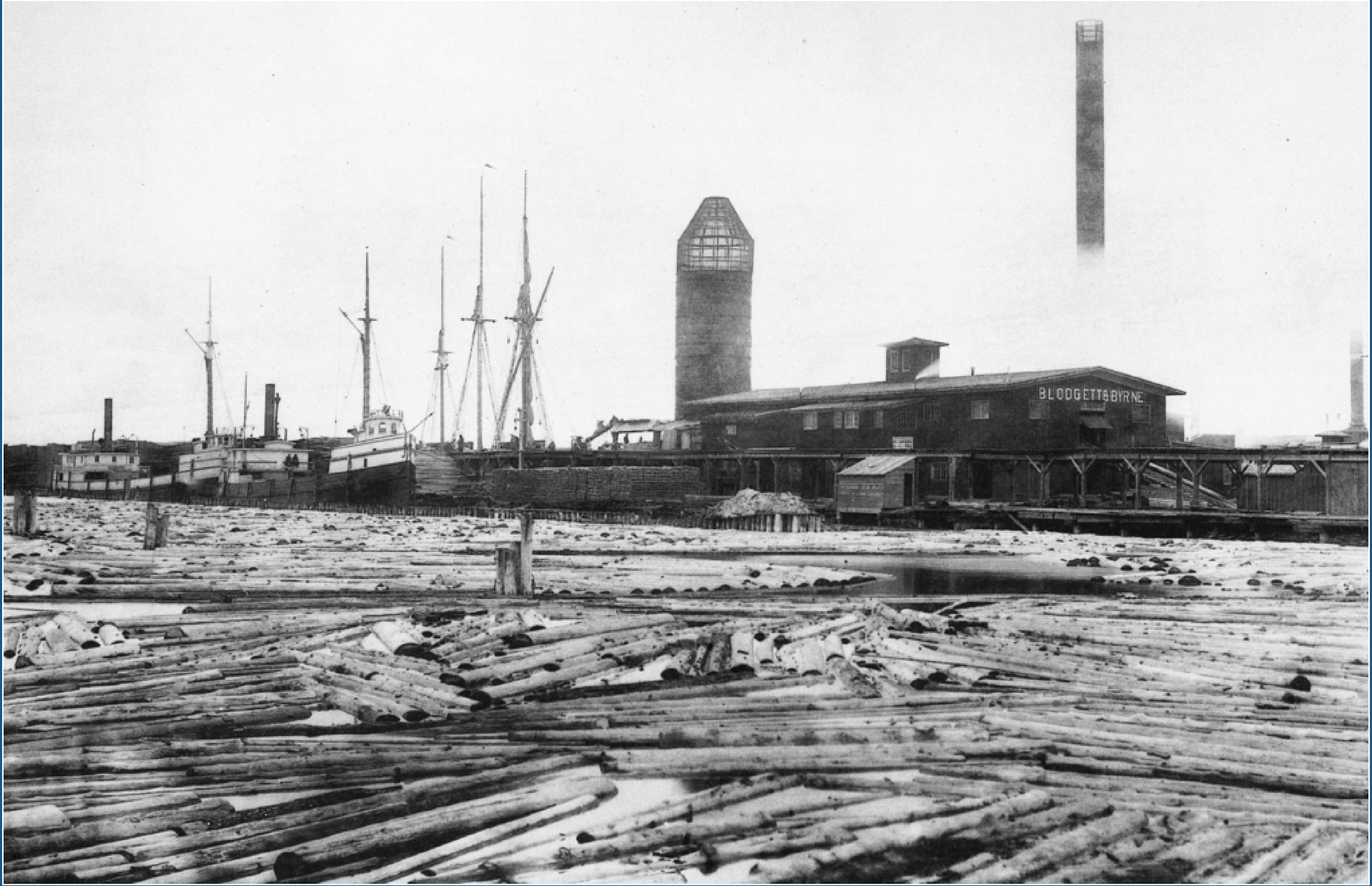
Drowned River Mouth Systems



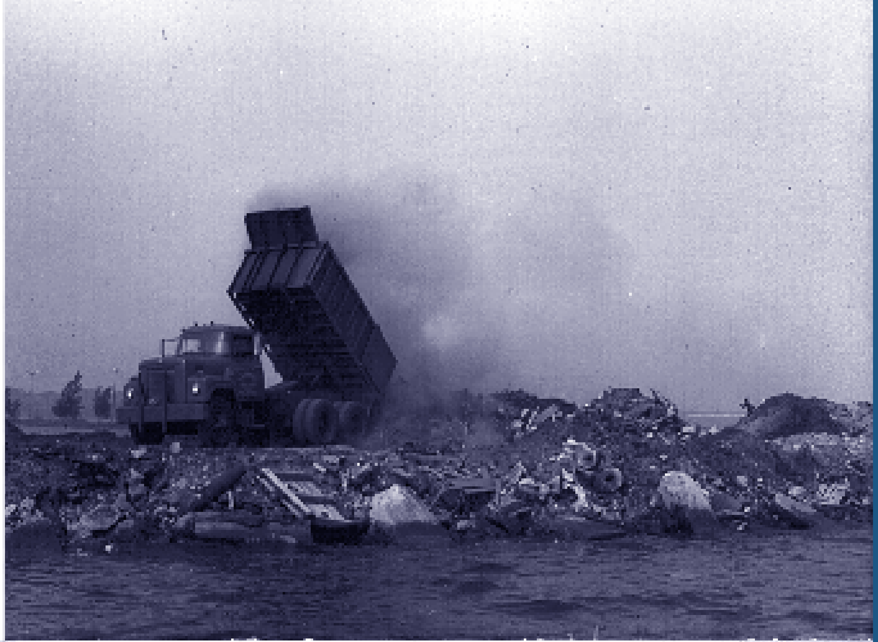
Muskegon Lake

Parameter	Muskegon
Surface Area (km^2)	16.8
Mean Depth (m)	7.1
Max. Depth (m)	24
HRT (d)	21
Mean TP (µg/L)	~28
Mean Chl *a* (µg/L)	~9
Trophic status	Meso/Eutrophic

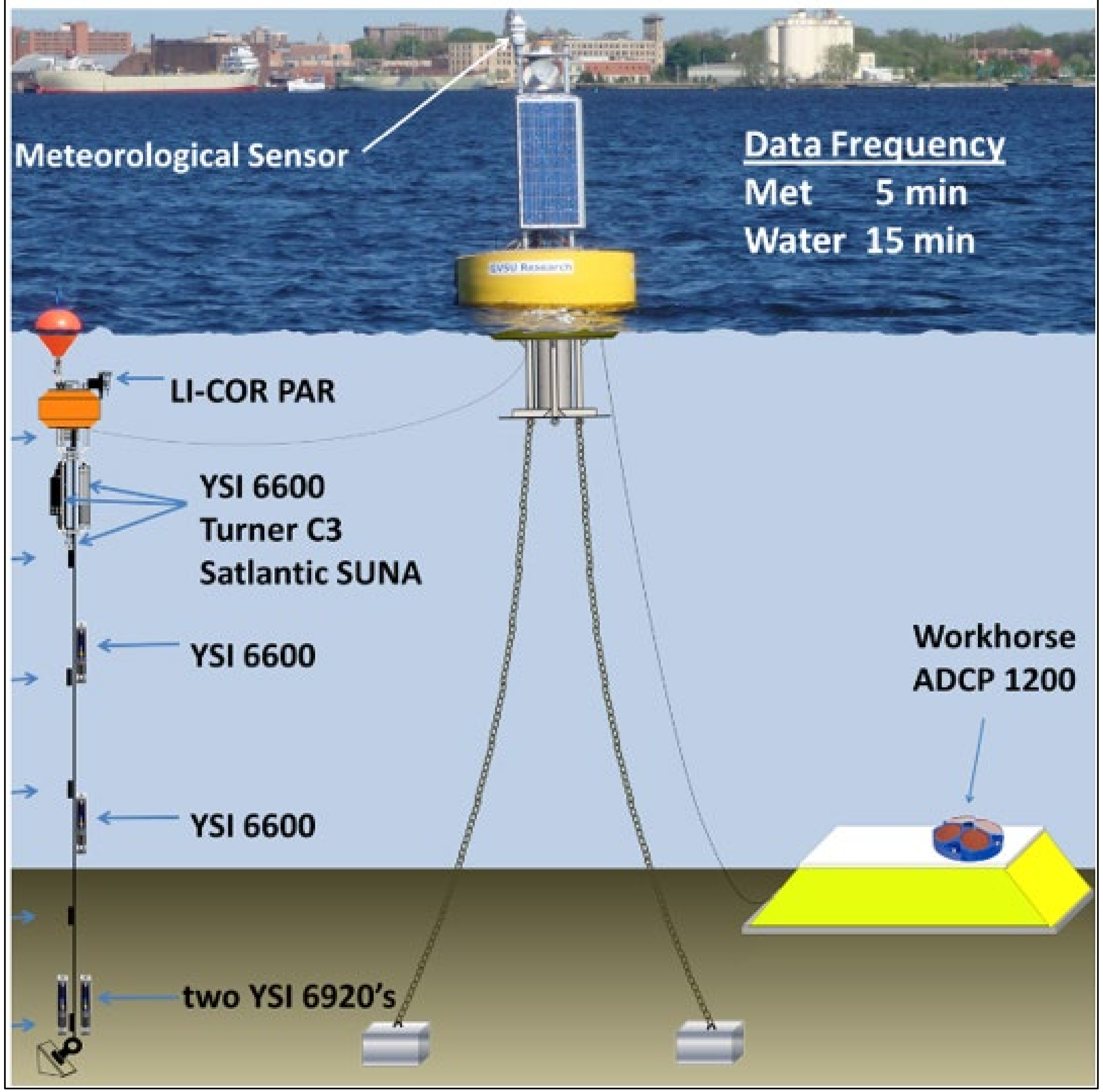
Sawmills



Muskegon Lake, MI: 1900-1960

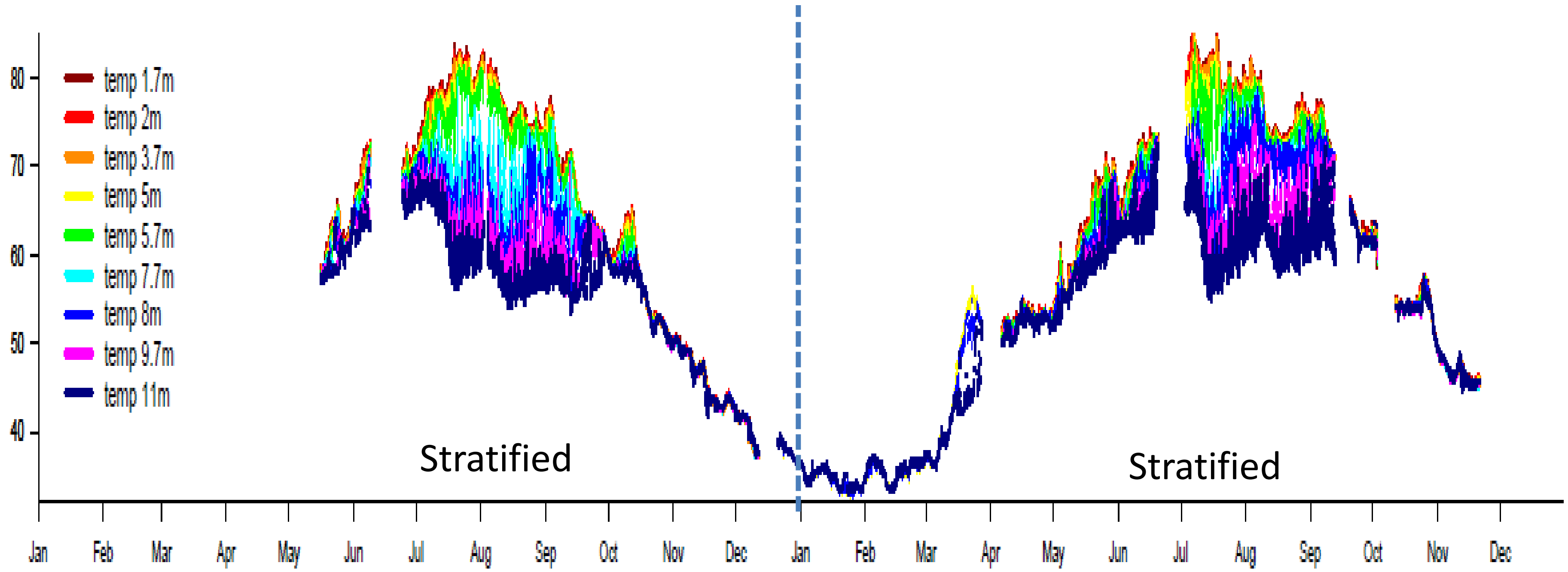



GVSU Research



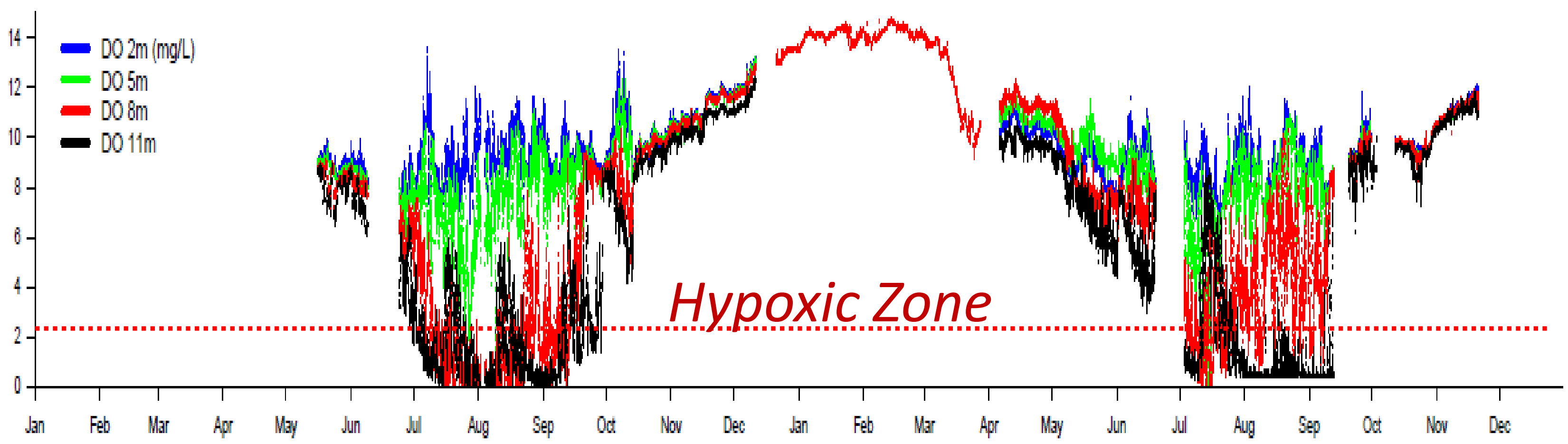
Open access current and archived data: www.gvsu.edu/buoy

TEMP



80
70
60
50
40
temp 1.7m
temp 2m
temp 3.7m
temp 5m
temp 5.7m
temp 7.7m
temp 8m
temp 9.7m
temp 11m
Stratified
Stratified
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

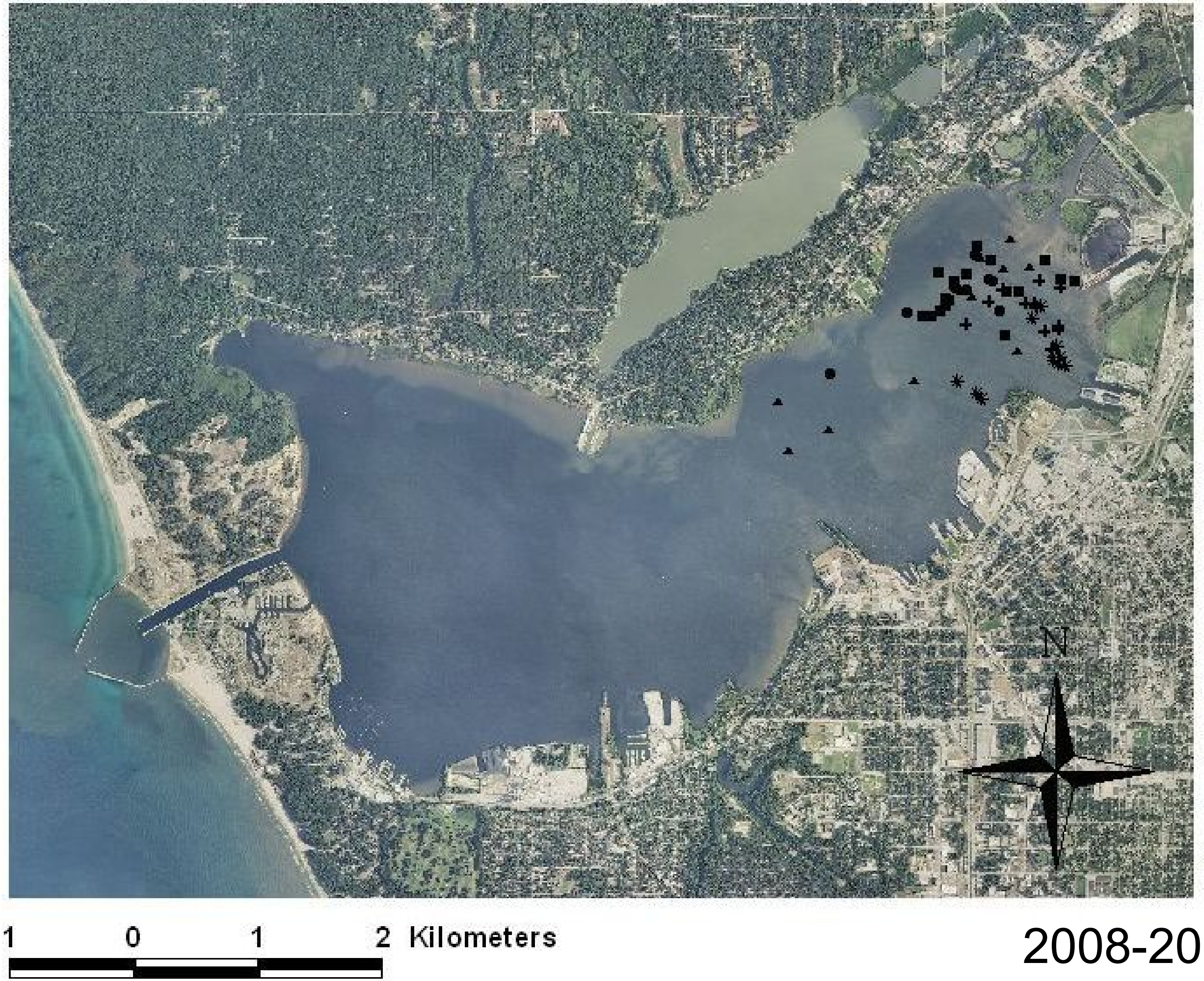
DO



14
12
10
8
6
4
2
0
DO 2m (mg/L)
DO 5m
DO 8m
DO 11m
Hypoxic Zone
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

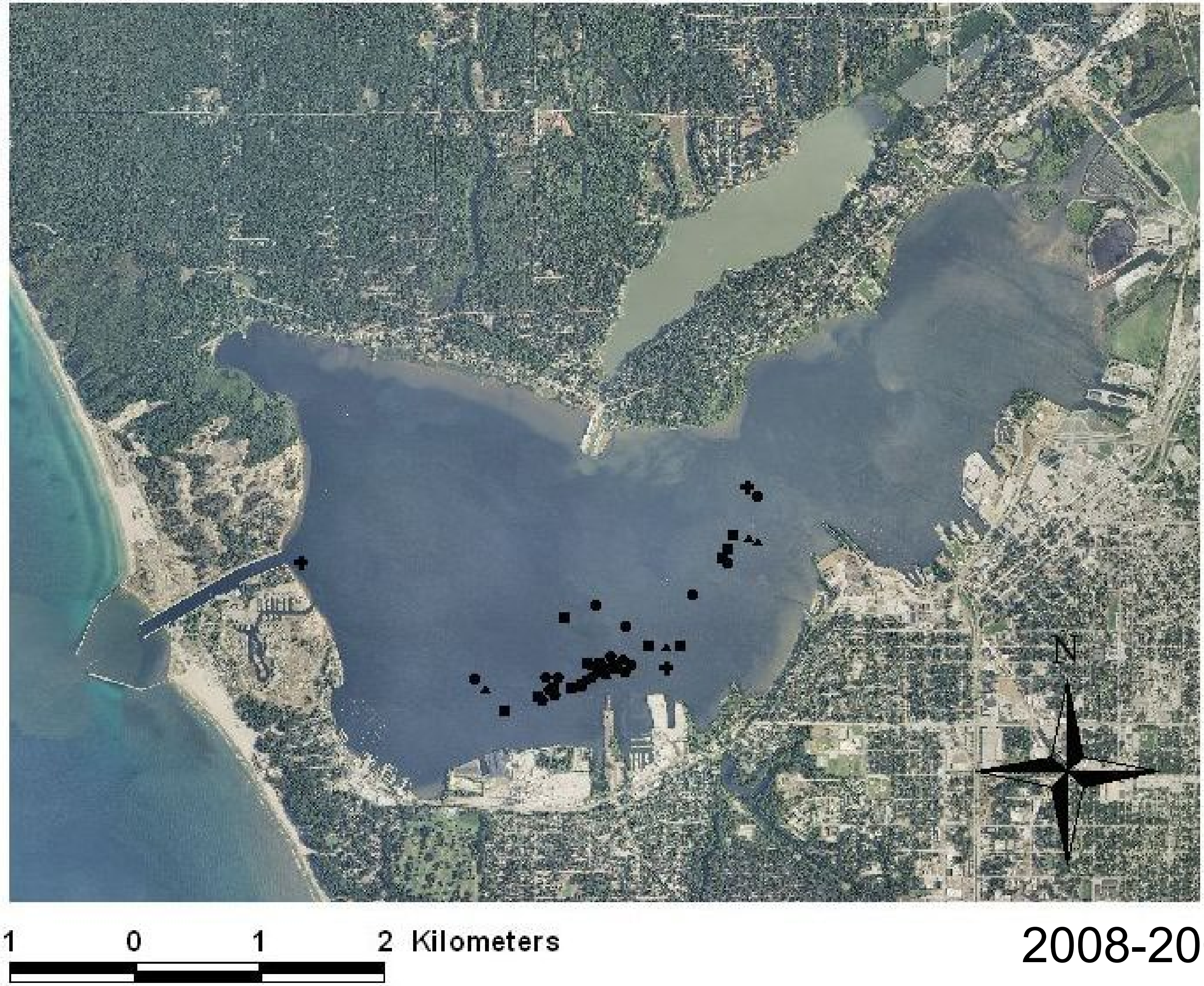
- Implanting ultrasonic emitters
- Hydrophone and passive receivers detect unique frequencies

Before Turnover



2008-2009

After Turnover



2008-2009

Bear Lake TP Concentration: 45-60 μg/L

TMDL: 30 μg/L

Objectives

Primary: Restore additional habitat in the Muskegon Lake Area of Concern

Secondary: Don’t contribute to excess phosphorus to downstream Bear Lake

Hydrography and TP Concentrations

Sediment Phosphorus

- Porewater
- Isotherms
- Sediment core incubations
- Sediment fractionation

Peeper SRP (mean ± SD)

Depth	West Field (undredged)	East Field (dredged)

Steinman & Ogdahl (2016) *ESPR*

P Release Experiment

- Simulate reconnection of Bear Creek water (30 ppb) to muck field sediments

Smit & Steinman (2015) *Wetlands*

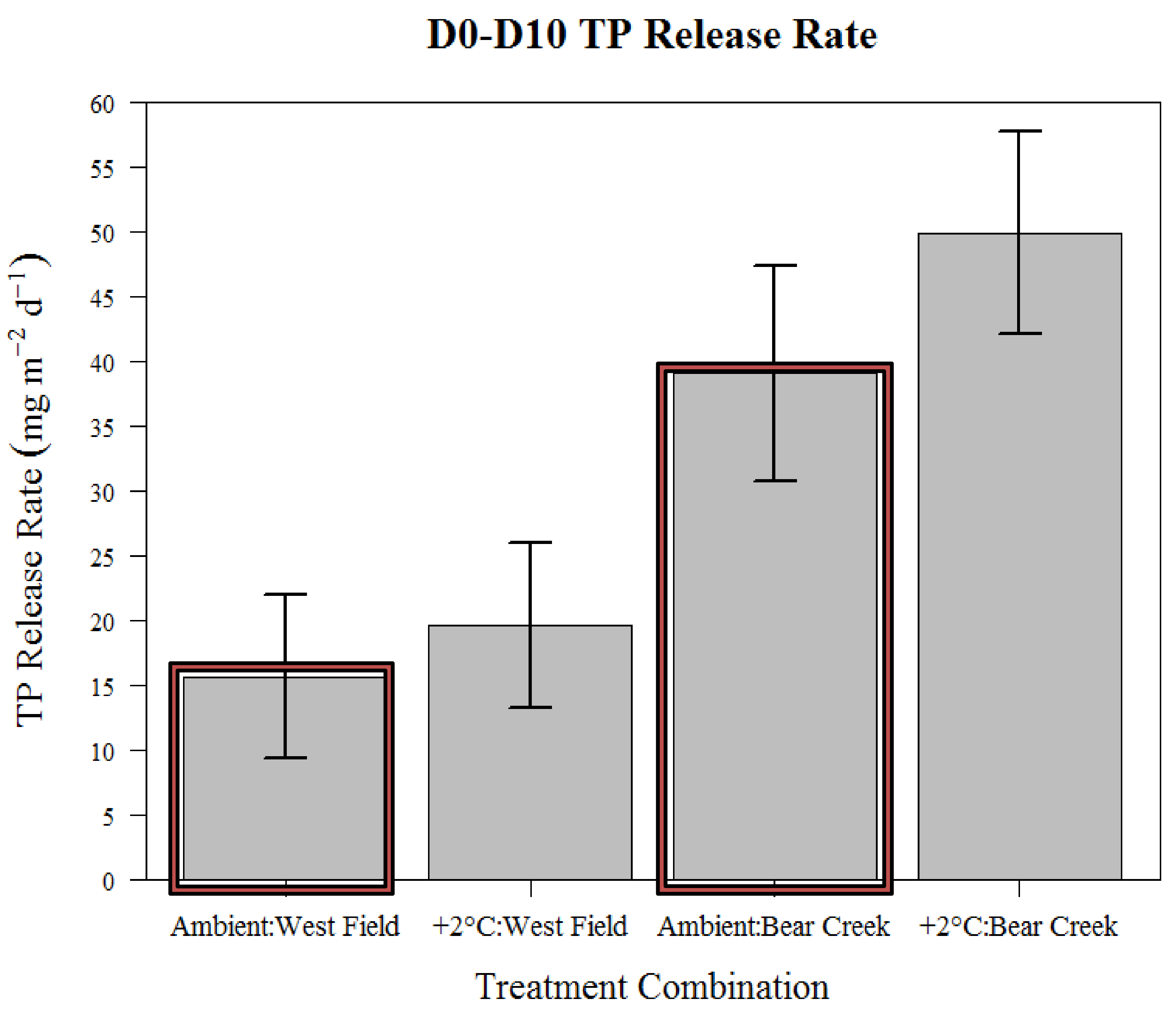
D

Ambient

West Field

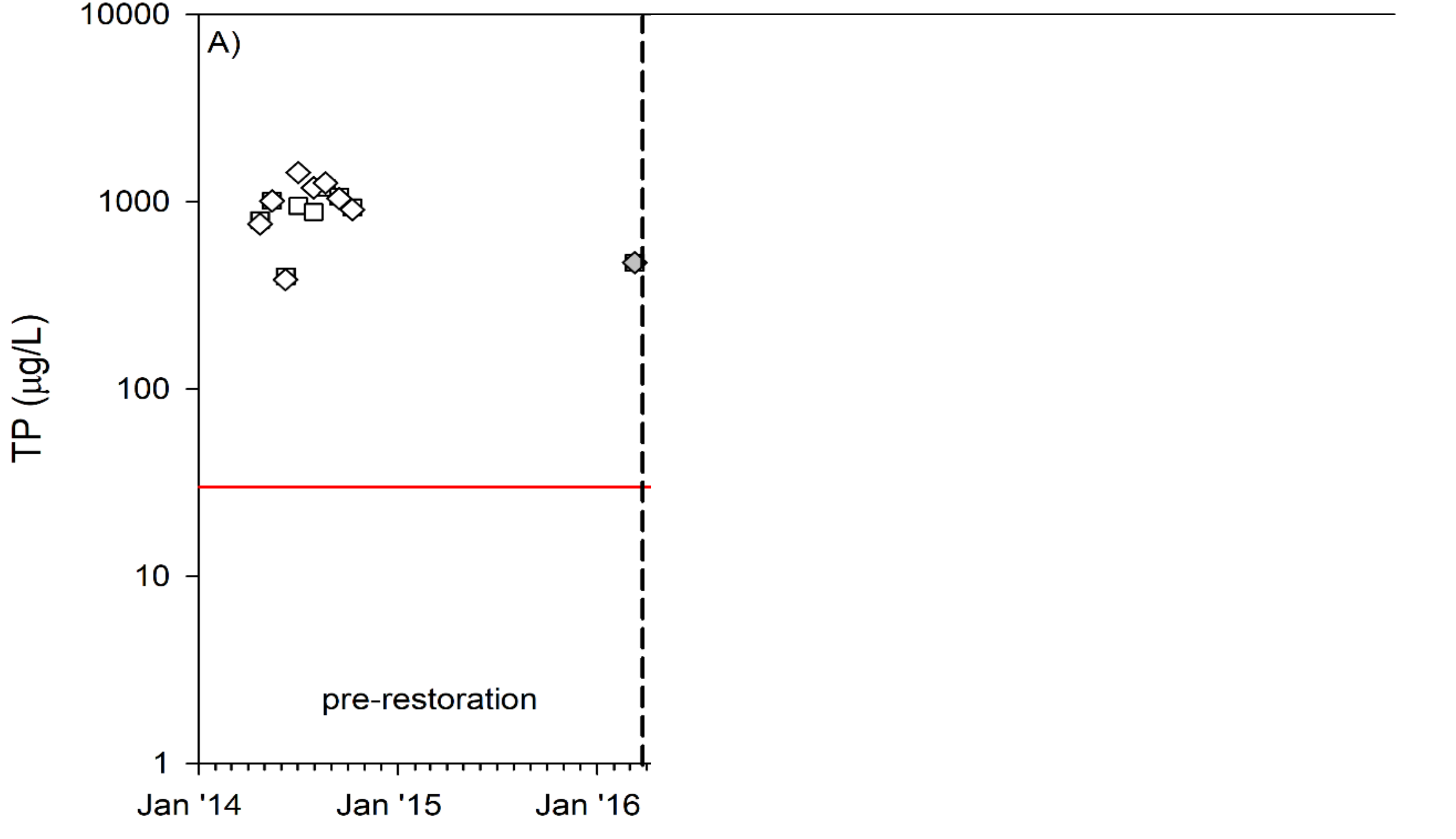
West Field

6x


D0-D10 TP Release Rate
TP Release Rate (mg m⁻² d⁻¹)
60
55
50
45
40
35
30
25
20
15
10
5
0
Ambient:West Field
+2°C:West Field
Ambient:Bear Creek
+2°C:Bear Creek
Treatment Combination

July 2015

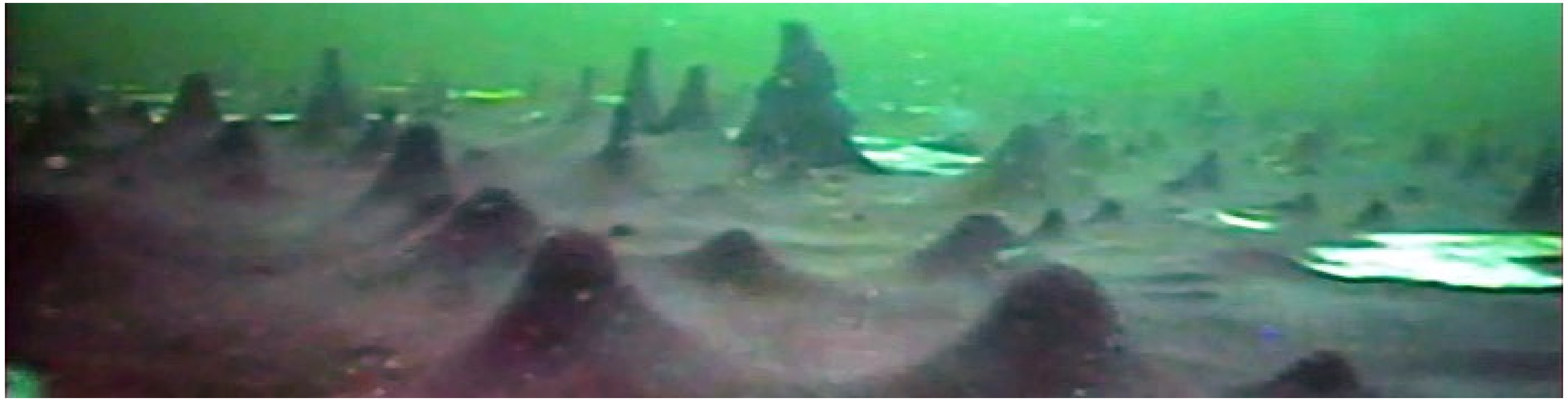
Total Phosphorus: West Pond



Hassett and Steinman (2022) *Land*

Submerged Karst Sinkholes in the Great Lakes

Bopi Biddanda



GRAND VALLEY STATE UNIVERSITY
ANNIS WATER RESOURCES INSTITUTE

National Science Foundation
WHERE DISCOVERIES BEGIN

STOUT
UNIVERSITY OF WISCONSIN

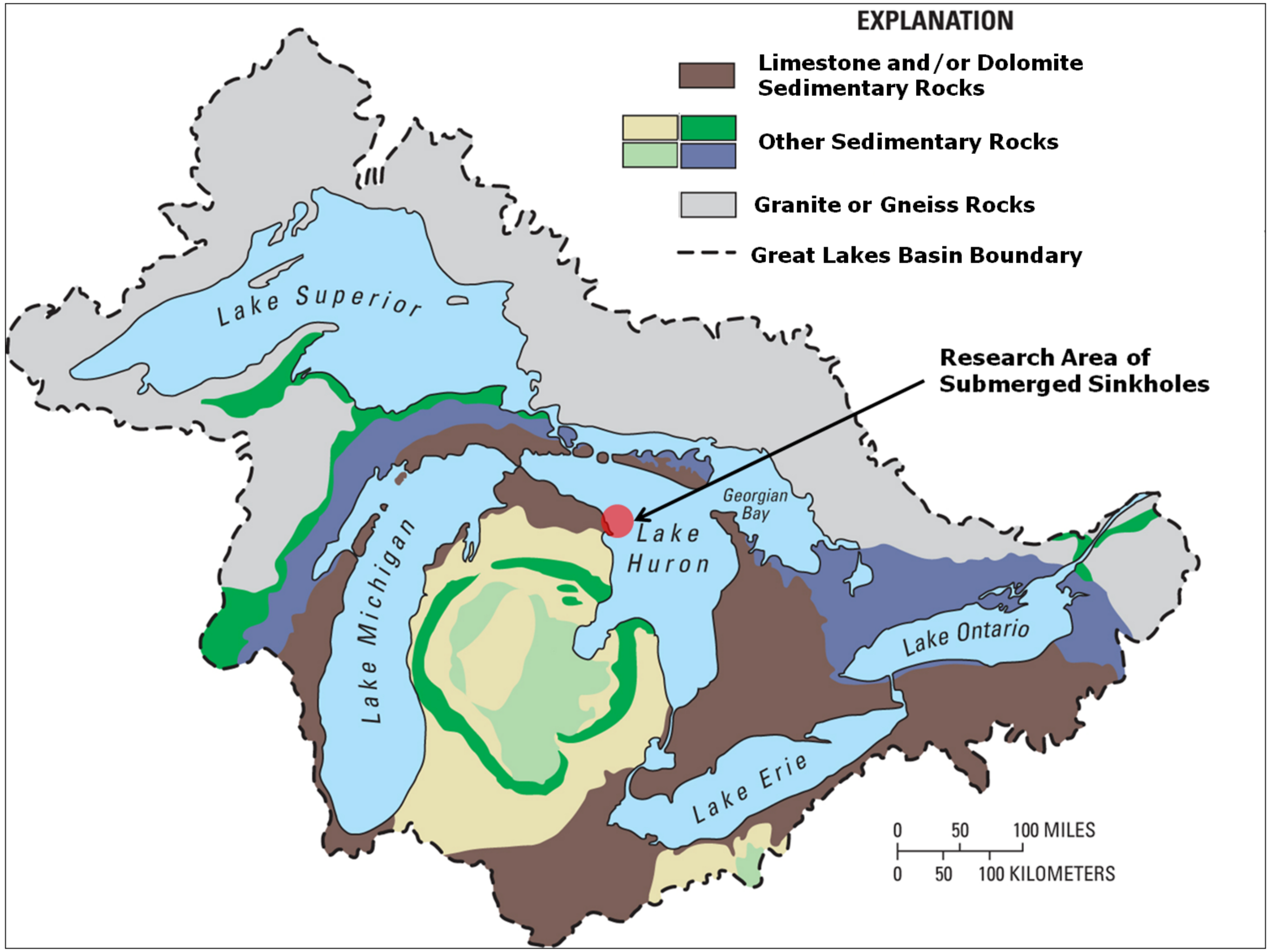
NOAA

MICHIGAN

Thunder Bay National Marine Sanctuary

NATIONAL MARINE SANCTUARIES

Bedrock Aquifers in the Great Lakes Basin



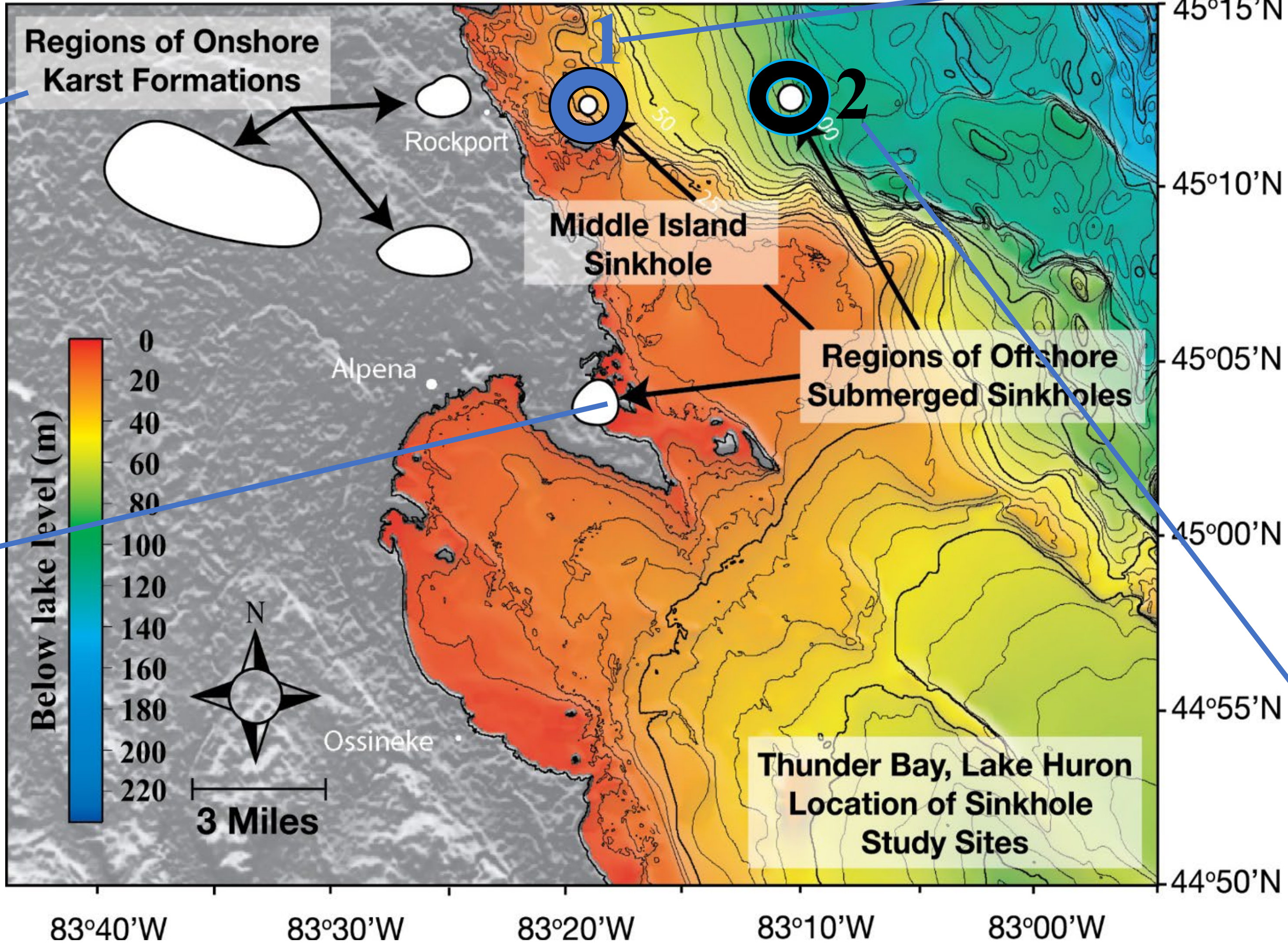
http://water.usgs.gov/ogw/pubs/WRI004008/WRIR_00-4008.pdf

- Lakes MI and Huron lined by Paleozoic Carbonate Aquifers

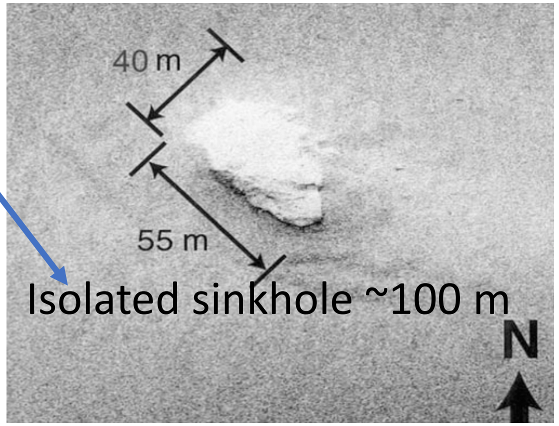
On-land Sinkholes and Submerged sinkholes in NW Lake Huron

On-land Sinkholes
NW of Rockport

Shallow Sinkholes
El Cajon Bay



Middle Island Sinkhole (median depth 23 m)



Eos, 2009

Primary Production Process

Oxygenated Water Column

<u>In Light</u>

Photosynthesis

Purple Cyanobacteria:

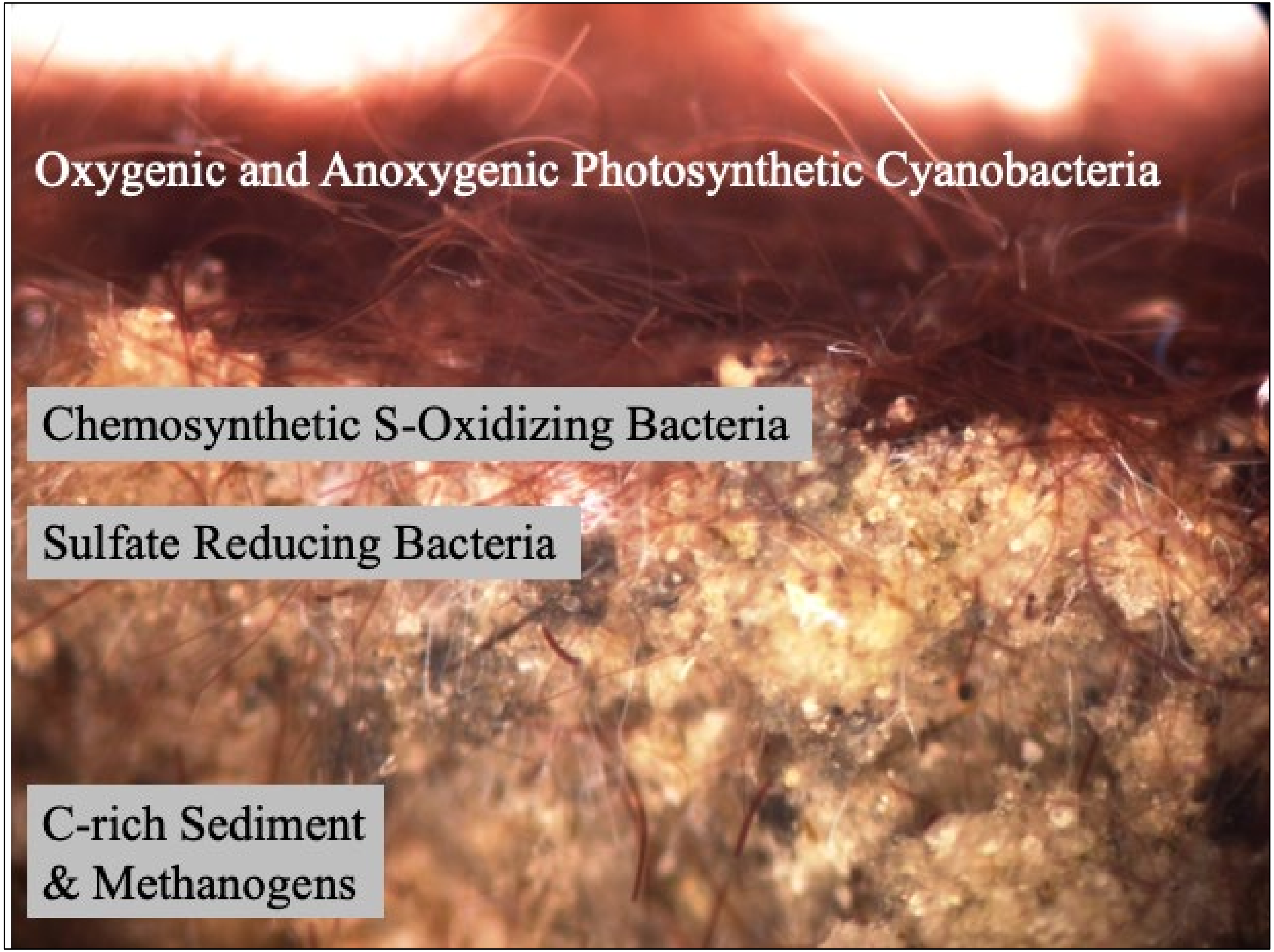
Oxic and Anoxic

<u>In Light or Darkness</u>

Chemosynthesis

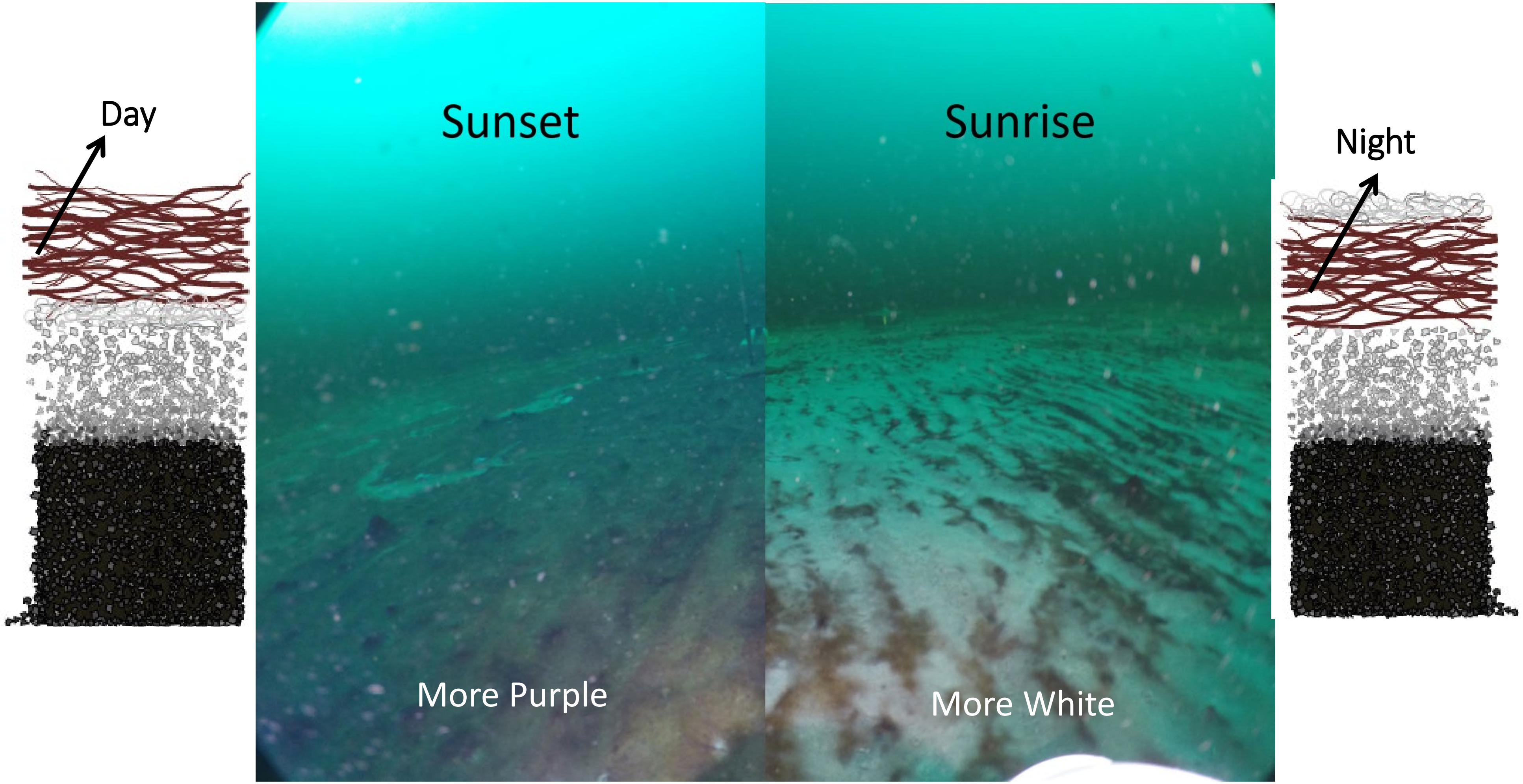
(White Sulfur Oxidizing Bacteria and Archaea)

Geobiology 2012
mSystems 2021
Ecol. Evol. 2024



Geobiology 2012
mSystems 2021
Ecol. Evol. 2024

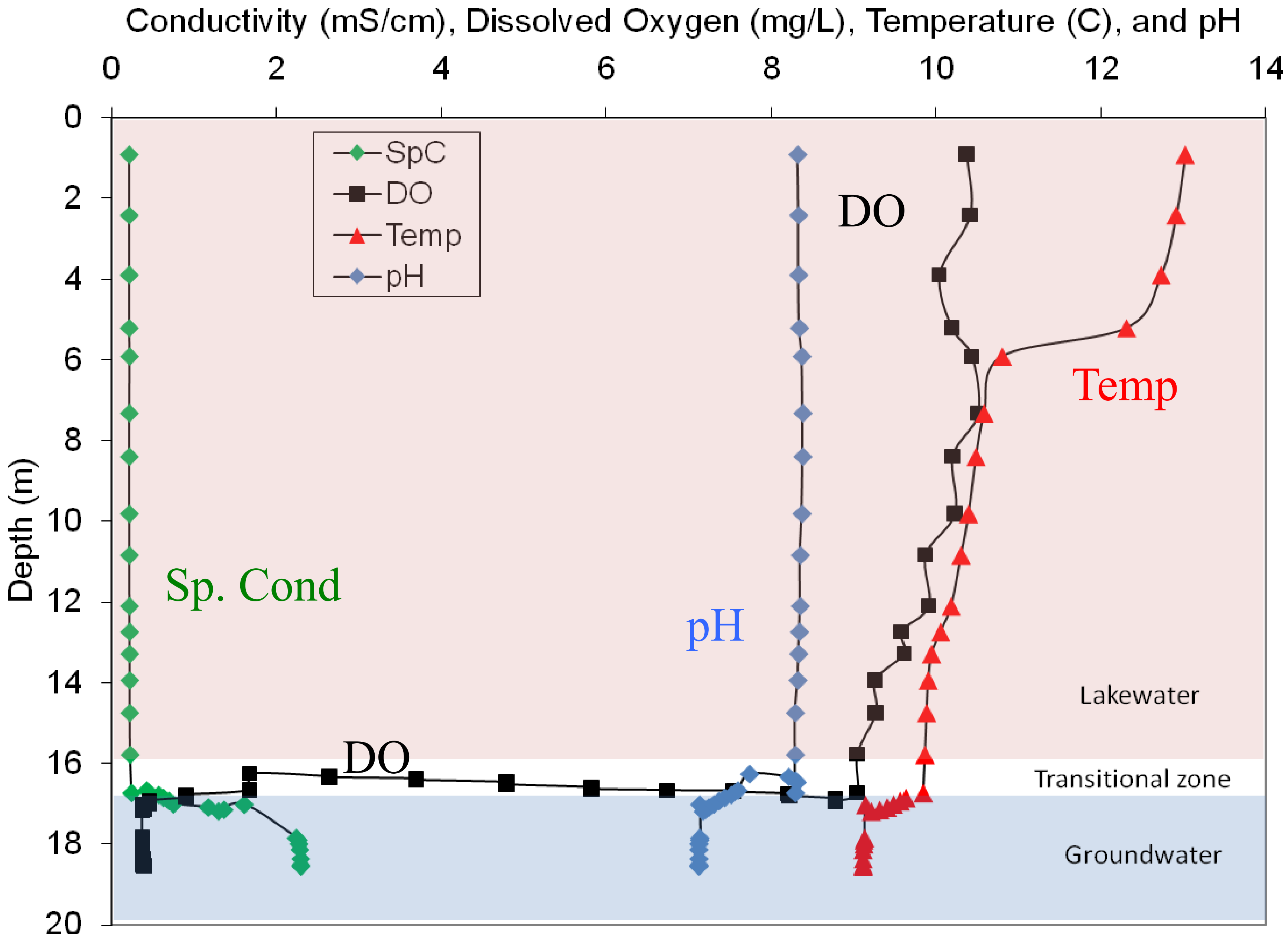
Diurnal Changes



- In daylight, purple photosynthetic filaments move up towards sunlight
- At night, chemosynthetic white filaments move up to scavenge remaining O_2 while using H_2S below

J. Great Lakes Res. 2023

Typical Water-Column Features over a Lake Huron Sinkhole



Nature Education Knowledge 2012

Where else "On Earth" are such microbial mat communities found?

Freshwater Salinization

Road salt application:

1975: 8 million metric tons

2015: 32 million metric tons

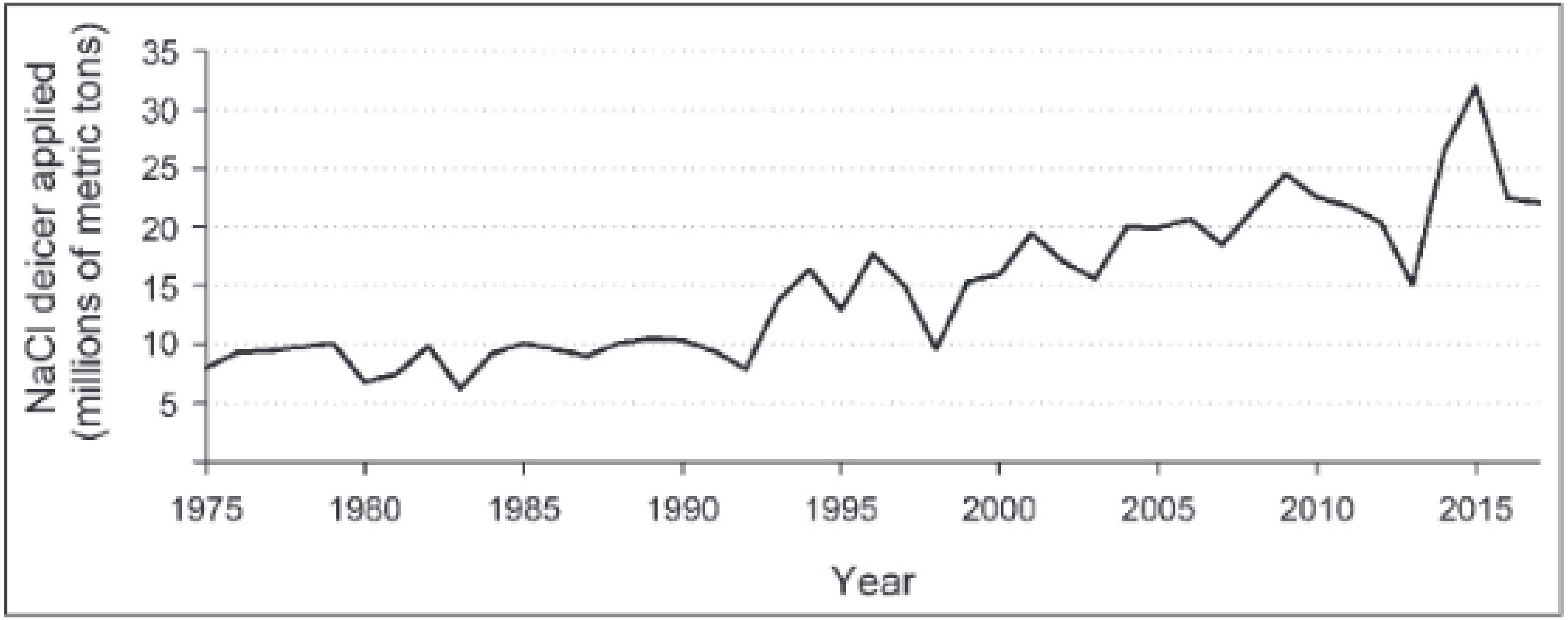
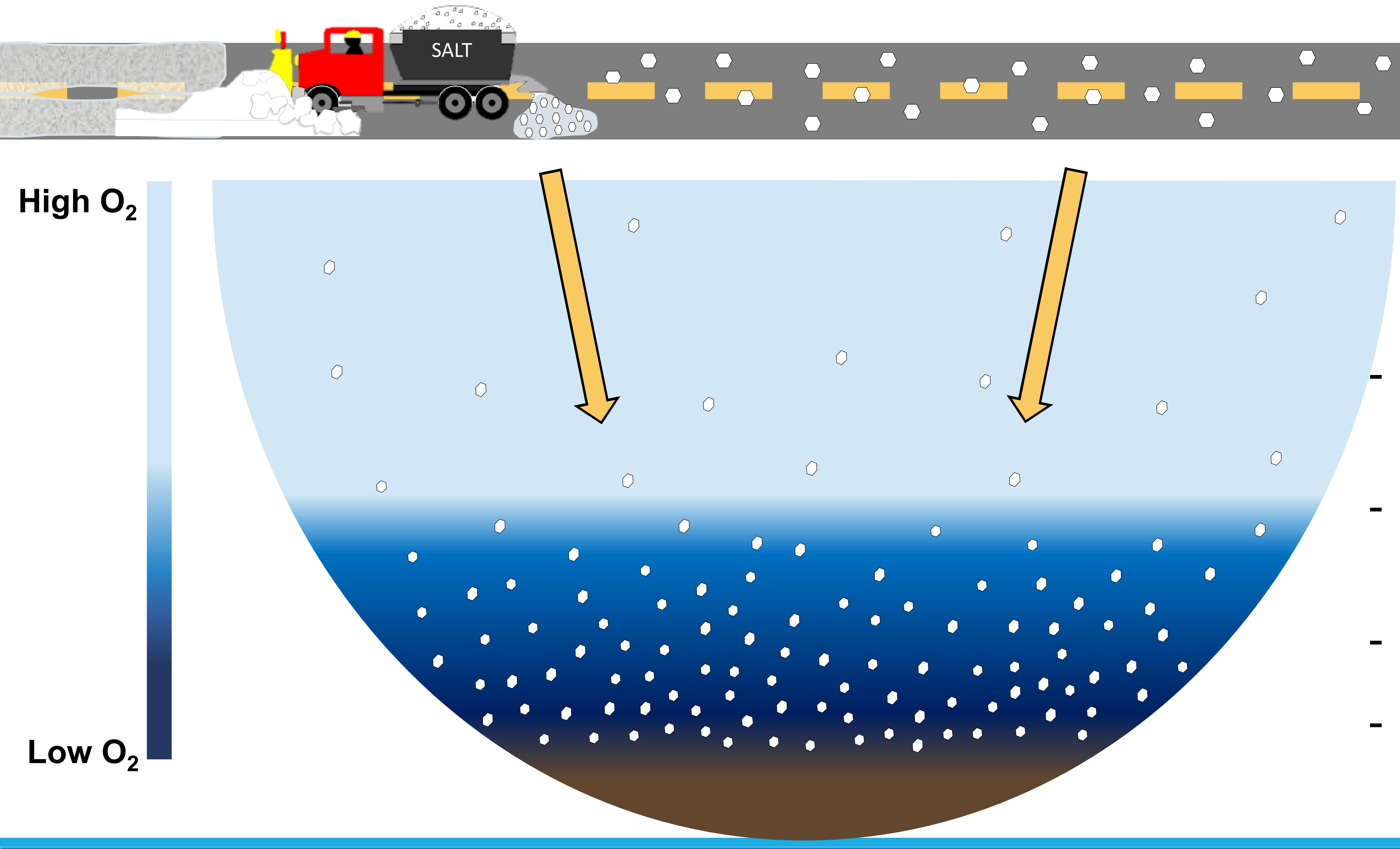


Figure 1. Metric tons of sodium chloride (NaCl) used for deicing purposes in the US from 1975–2017. Graph redrawn from Kelly *et al.* (2019); data from Kelly and Matos (2014).

Road Salt (Chloride) Impacts in Freshwater Ecosystems

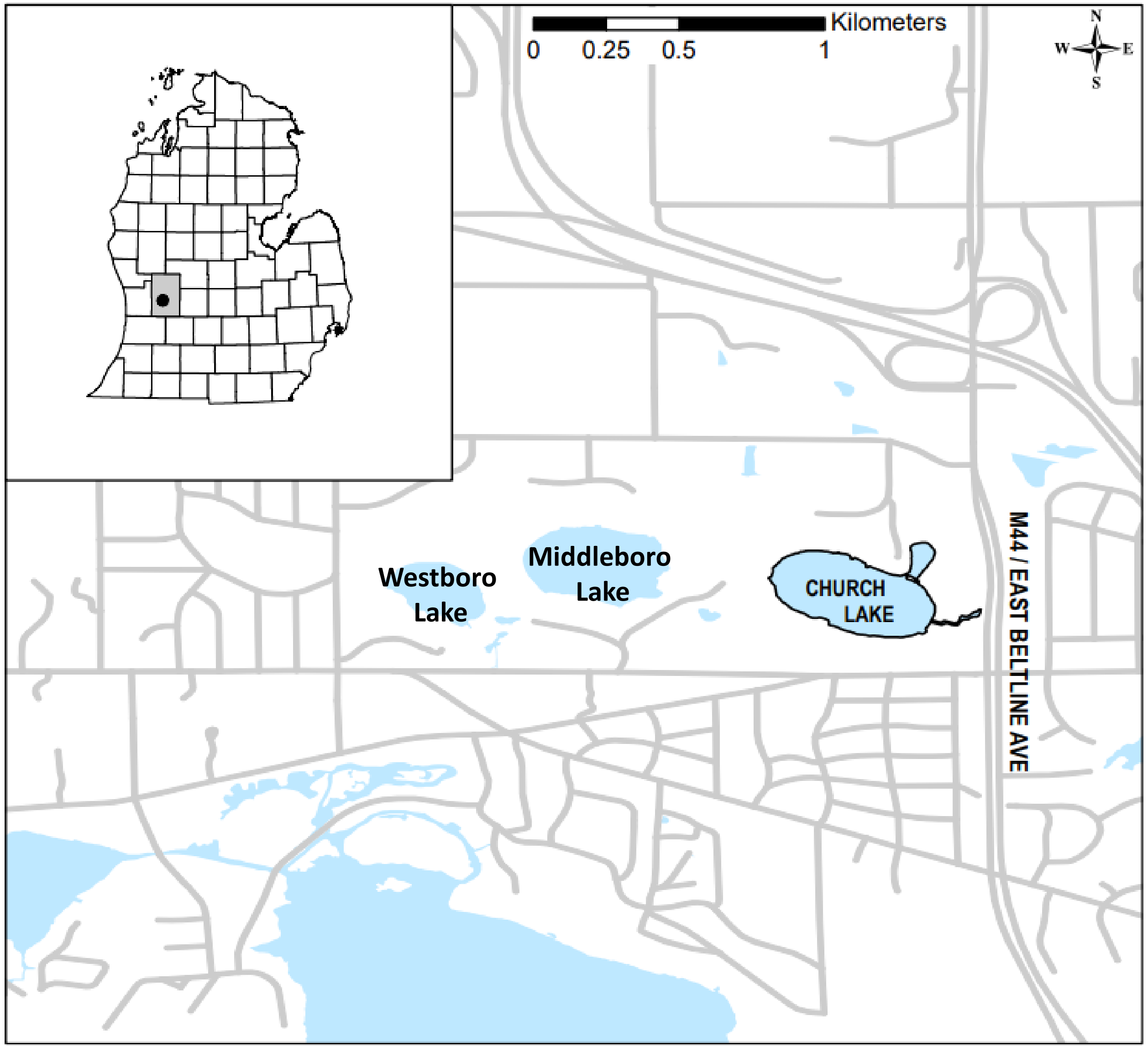
- Chloride is corrosive (pavement, concrete, cars, pipes, appliances, etc.)
- Detrimental impacts at all trophic levels
  - Decreased reproduction
  - Increased mortality
  - Decline in biodiversity
- Effects seen below chronic threshold of 230 mg/L (EPA) and 150 mg/L (Michigan)



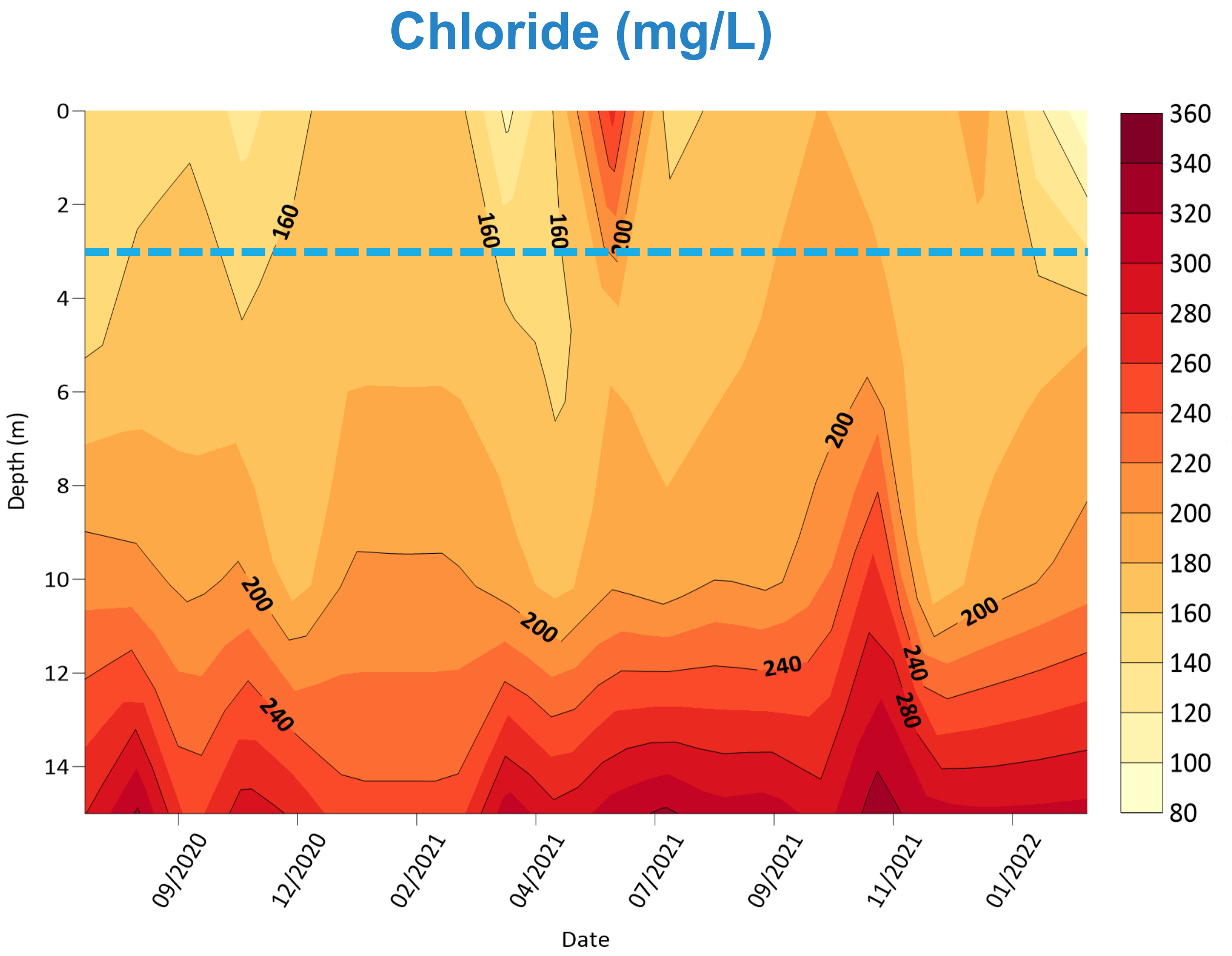
Excess Road Salt

- Dense saline layer at bottom
- Prevents seasonal mixing
- Low oxygen
- Accumulation of reduced analytes

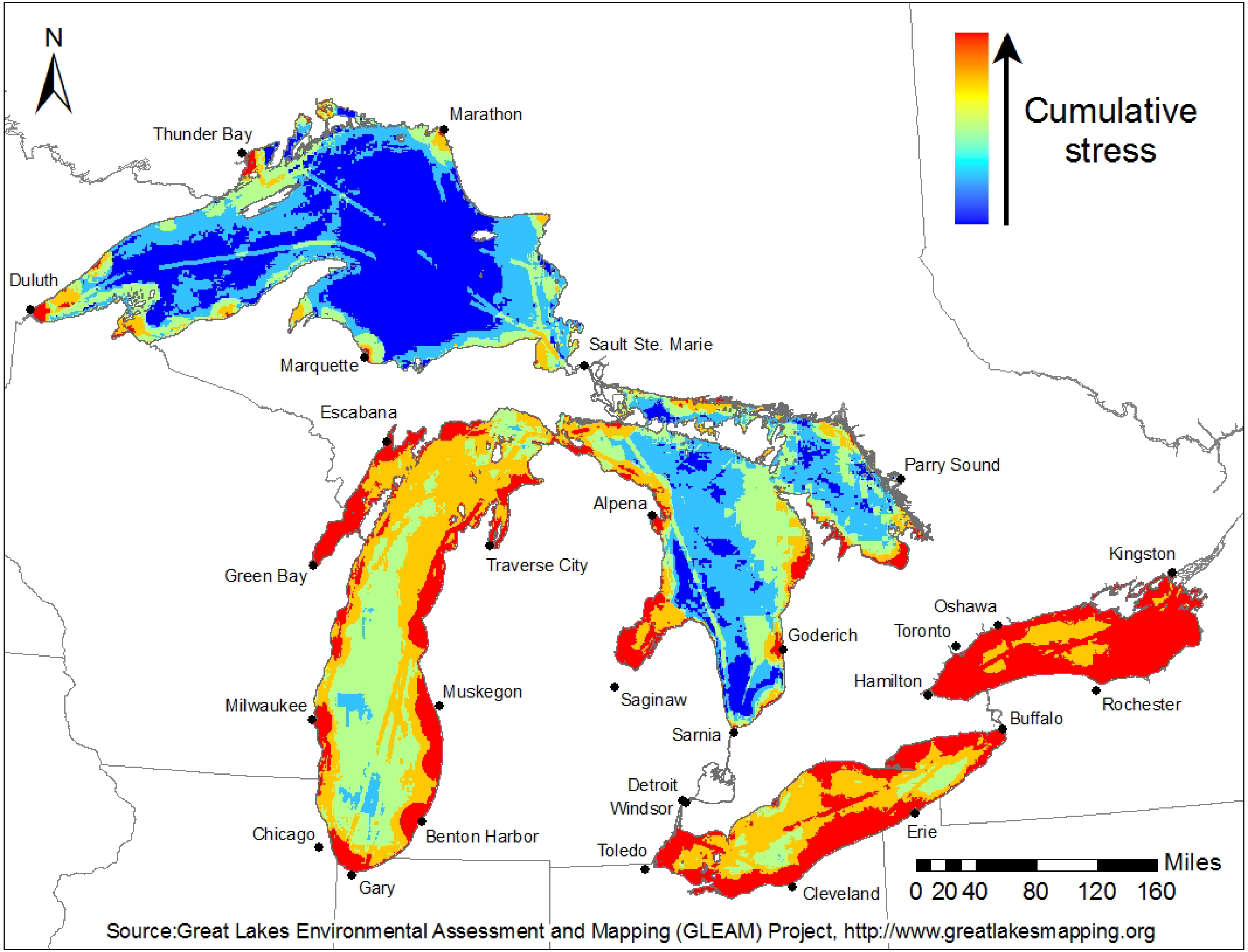
Study Location: Tri-Lake Region



Church Lake: Cl^- and TP



Foley and Steinman (2023) *Sci. Total Environ*.



Allan et al. (2013) *PNAS*

Threats to the Great Lakes

- Diverse
  - Nonpoint runoff, toxics, invasives, development
- Changing in importance over time
  - May be diminishing, stable, or increasing
- Differ by location
  - E.g., upper vs. lower lakes and within a lake
- **Multiple stressors influencing basin biogeochemistry; requires unique diagnostic studies as the biology, geology, and chemistry varies from place to place**

Thank you

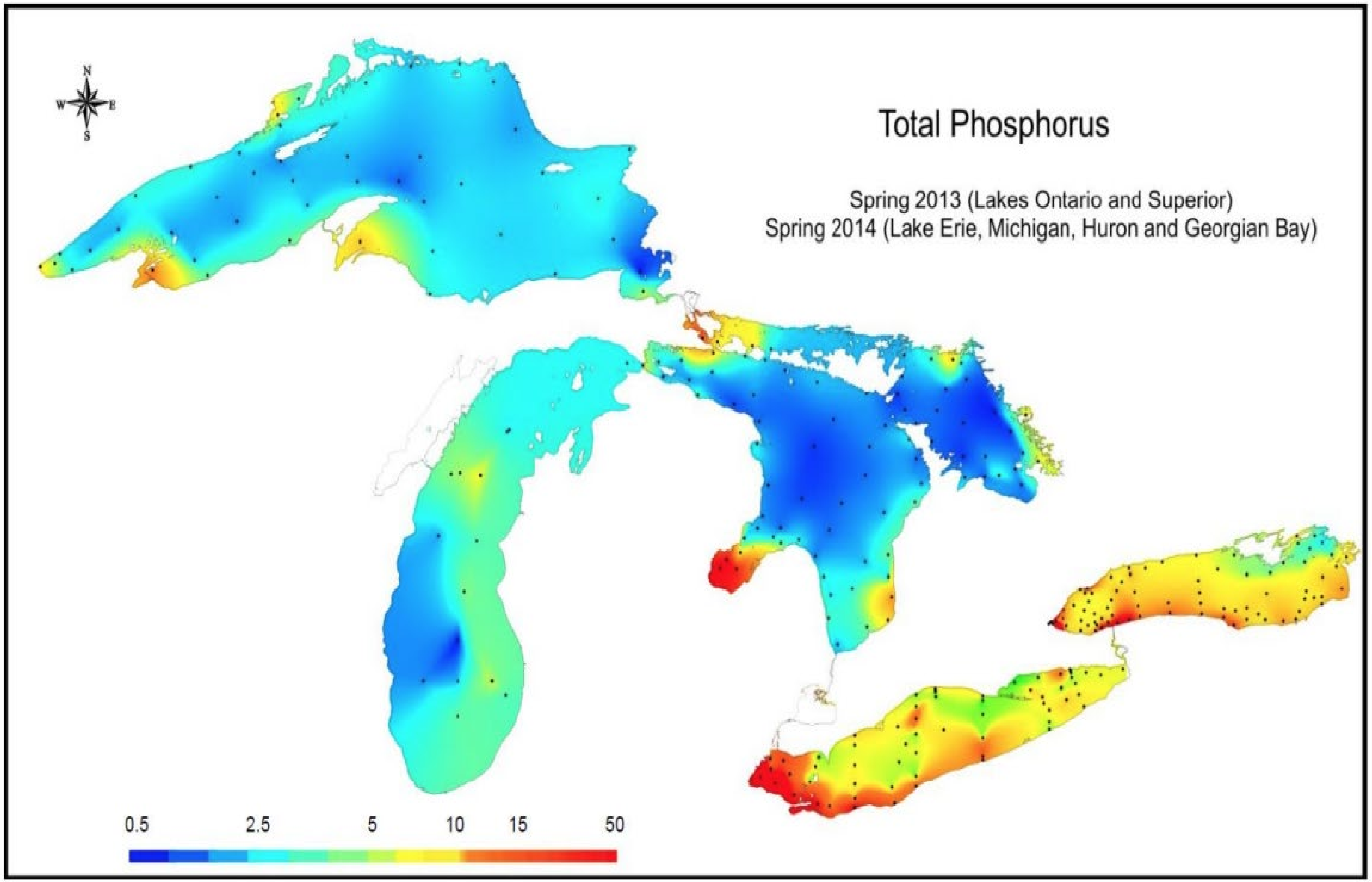
steinmaa@gvsu.edu

Grand Valley State University
Robert B. Annis Water Resources Institute

Category	Stressor	Pooled Weight (%)	Category	Stressor	Pooled Weight (%)
Aquatic Habitat	Hypoxia	2.83	Fisheries	*Diporeia* decline	-
Aquatic Habitat	Industrial ports and harbors	2.91	Invasive Species	Ballast risk	3.81
Aquatic Habitat	Light pollution	1.82	Invasive Species	Invasive fish	3.54
Aquatic Habitat	Marinas/boating	2.43	Invasive Species	Invasive mussels	4.02
Aquatic Habitat	Shipping lanes	2.08	Invasive Species	Invasive wetland plants	3.04
Aquatic Habitat	Shoreline extensions	2.48	Invasive Species	Sea lampreys	3.65
Aquatic Habitat	Shoreline hardening	2.89	Invasive Species	Emerging fish diseases	-
Aquatic Habitat	Dams (altered flow, nutrient, and sediment regimes)	3.21	Invasive Species	Harmful algal blooms	-
Aquatic Habitat	Channel dredging	-	Invasive Species	Invasive littoral plants	-
Aquatic Habitat	Dams (barriers to fish passage)	-	Invasive Species	Invasive plankton	-
Aquatic Habitat	Submerged cables and pipelines	-	Invasive Species	Nuisance benthic algal blooms	-
Climate Change	Changing water level	3.68	Nonpoint pollution	CSOs	2.54
Climate Change	Decreasing ice cover	3.38	Nonpoint pollution	N loading	3.02
Climate Change	Warming water temperature	3.89	Nonpoint pollution	P loading	3.42
Coastal Development	Coastal development	3.21	Nonpoint pollution	Sediment loading	3.03
Coastal Development	Coastal mines	2.64	Toxic Chemicals	AOCs	3.27
Coastal Development	Coastal power plants	2.68	Toxic Chemicals	Metals – biomagnifying	2.45
Coastal Development	Coastal recreational use	1.84	Toxic Chemicals	Metals – non-biomagnifying	2.78
Coastal Development	Coastal road density	2.69	Toxic Chemicals	Organics – biomagnifying	3.40
Fisheries	Aquaculture	2.00	Toxic Chemicals	Emerging toxic chemicals	-
Fisheries	Commercial fishing	2.81	Toxic Chemicals	Organics – non-biomagnifying	-
Fisheries	Native fish stocking	2.37	Toxic Chemicals	Pharmaceutical loading	-
Fisheries	Non-native fish stocking	2.98	Toxic Chemicals	Toxic pesticides	-
Fisheries	Recreational fishing – charter	2.20	Water Withdrawals	Inland and groundwater withdrawals	-
Fisheries	Recreational fishing (non-charter)	-	Water Withdrawals	Great Lakes withdrawals	-

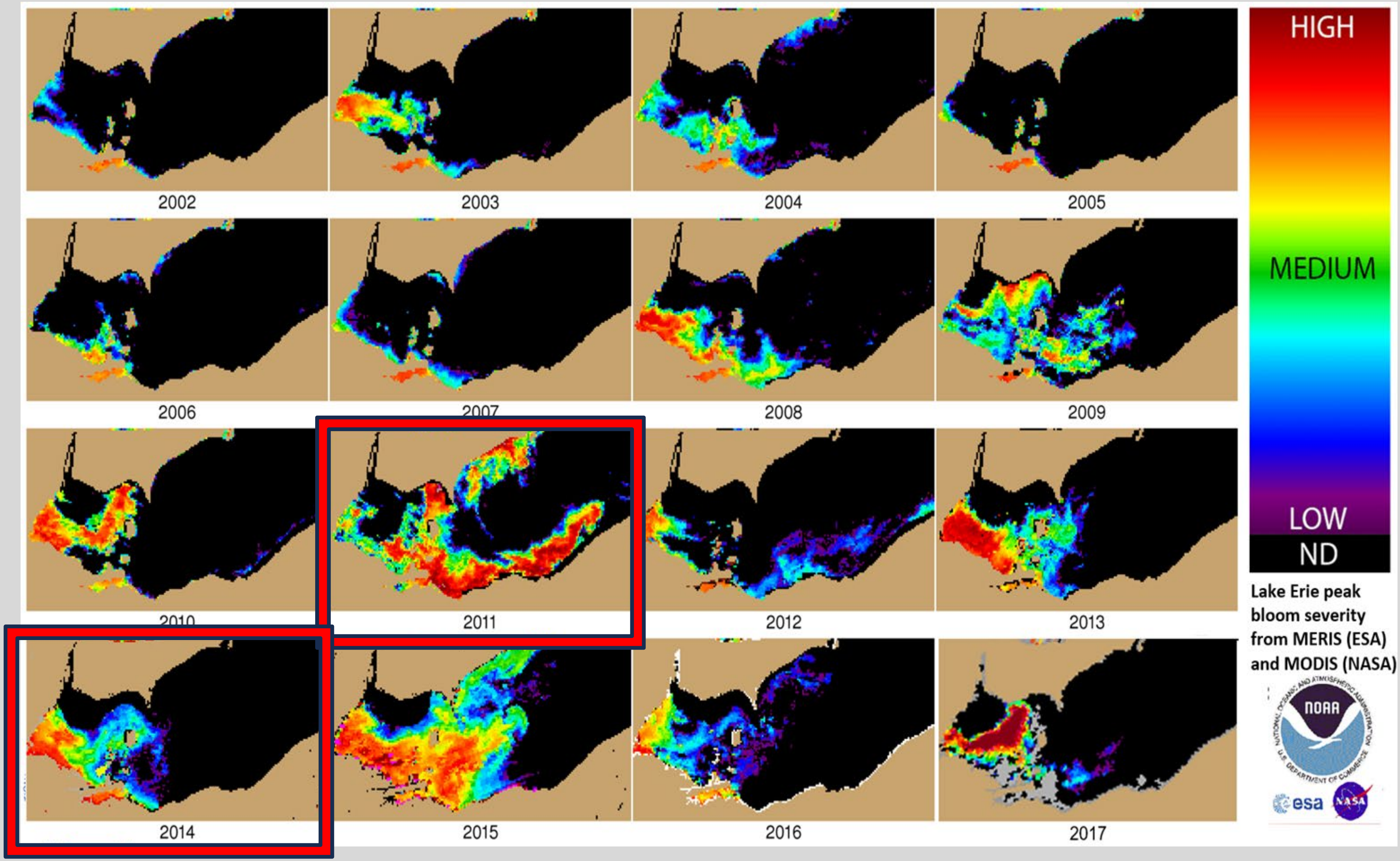
HABs

Blooms occur in the GL spatially with elevated TP



Total Phosphorus Concentrations (μg/L) based on lake-wide cruises conducted by Environment and Climate Change Canada and the United States Environmental Protection Agency.

Interannual variability in Lake Erie bloom size



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A first assessment of cyanobacterial blooms in oligotrophic Lake Superior

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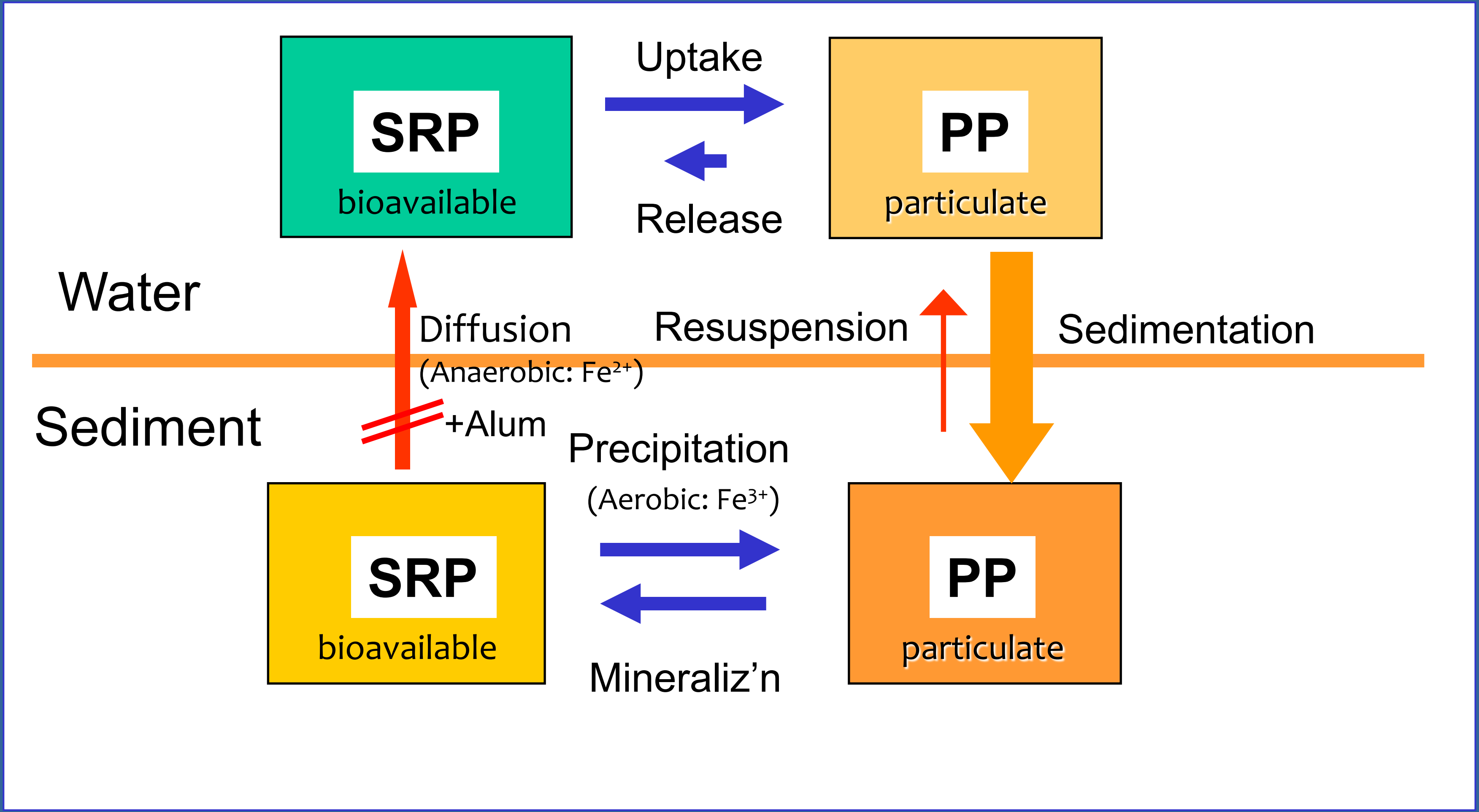
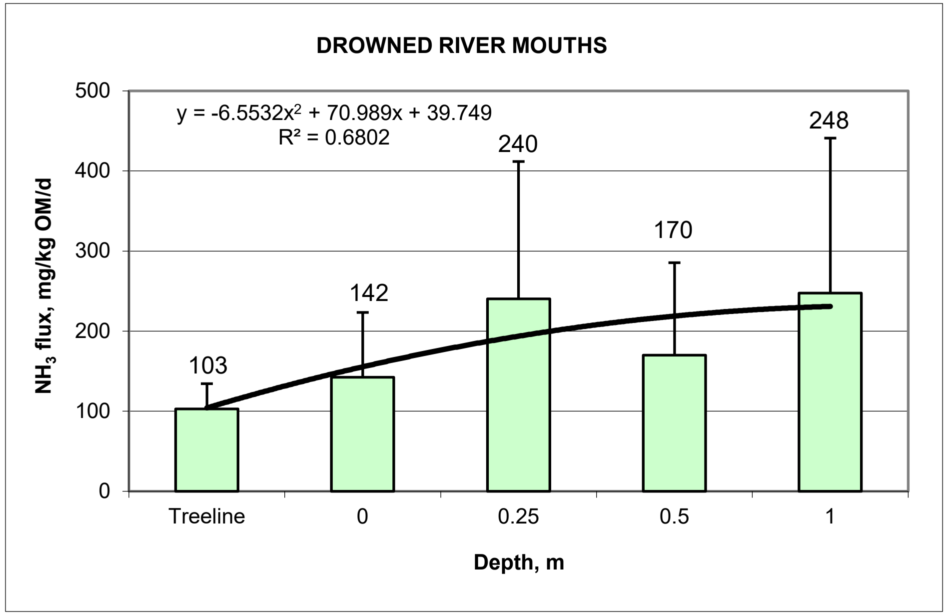
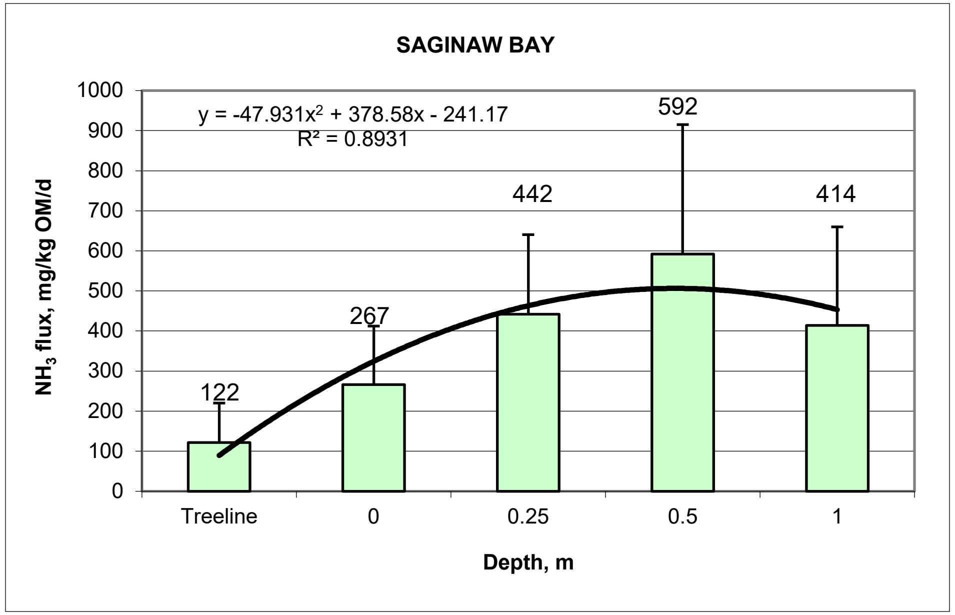
HABs and Internal P Loading



Ammonia (mg/kg/d)





- Slight asymptote with DRM sites
- Curvilinear function at Saginaw sites