Phosphorus Dynamics in the Saginaw Bay Ecosystem

Presentation to
Phosphorus Committee of the
Saginaw Bay Coastal Initiative
April 11, 2008

Joseph V. DePinto, Edward Verhamme,
Victor J. Bierman, Jr.
LimnoTech, Inc., Ann Arbor, MI
jdepinto@Limno.com

Carlo DeMarchi, Craig Stow, Julie Dyble
NOAA-GLERL

Chansheng He
Western Michigan University

Saginaw Bay Multiple Stressors

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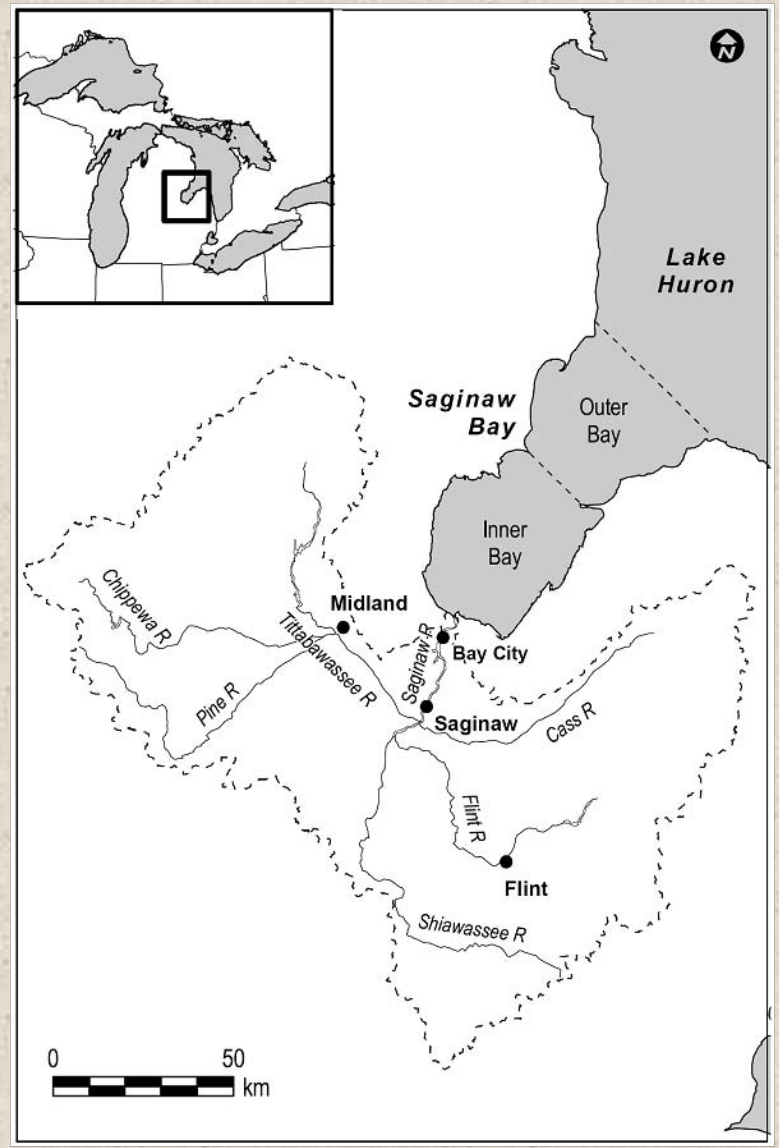
Water | Environment | Scientists | Engineers

Outline

- 1970's and 80's: Meeting target phosphorus loads established by GLWQA
- 1990's and 2000's: Apparent reversion to historical problems
  - Dreissenid invasion of Saginaw Bay beginning in 1991
  - Reoccurrence of *Microcystis* cyanophyte blooms
  - Reoccurrence of nearshore attached nuisance algae (*Cladophora*)
  - Reoccurrence of "muck" washing up on shoreline
- Evaluation of cause-effect relationships for recent observations



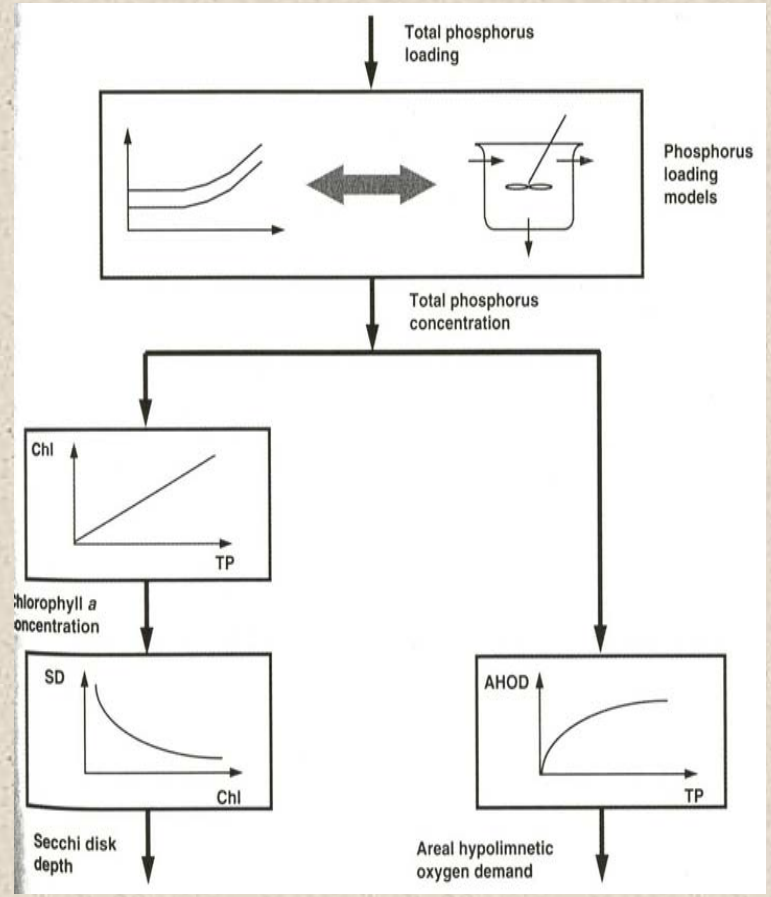
1970's and 1980's: Successful achievement of TP target load and associated water quality improvements

1972 Great Lakes Water Quality Agreement and Annex 3 Focused on Eutrophication

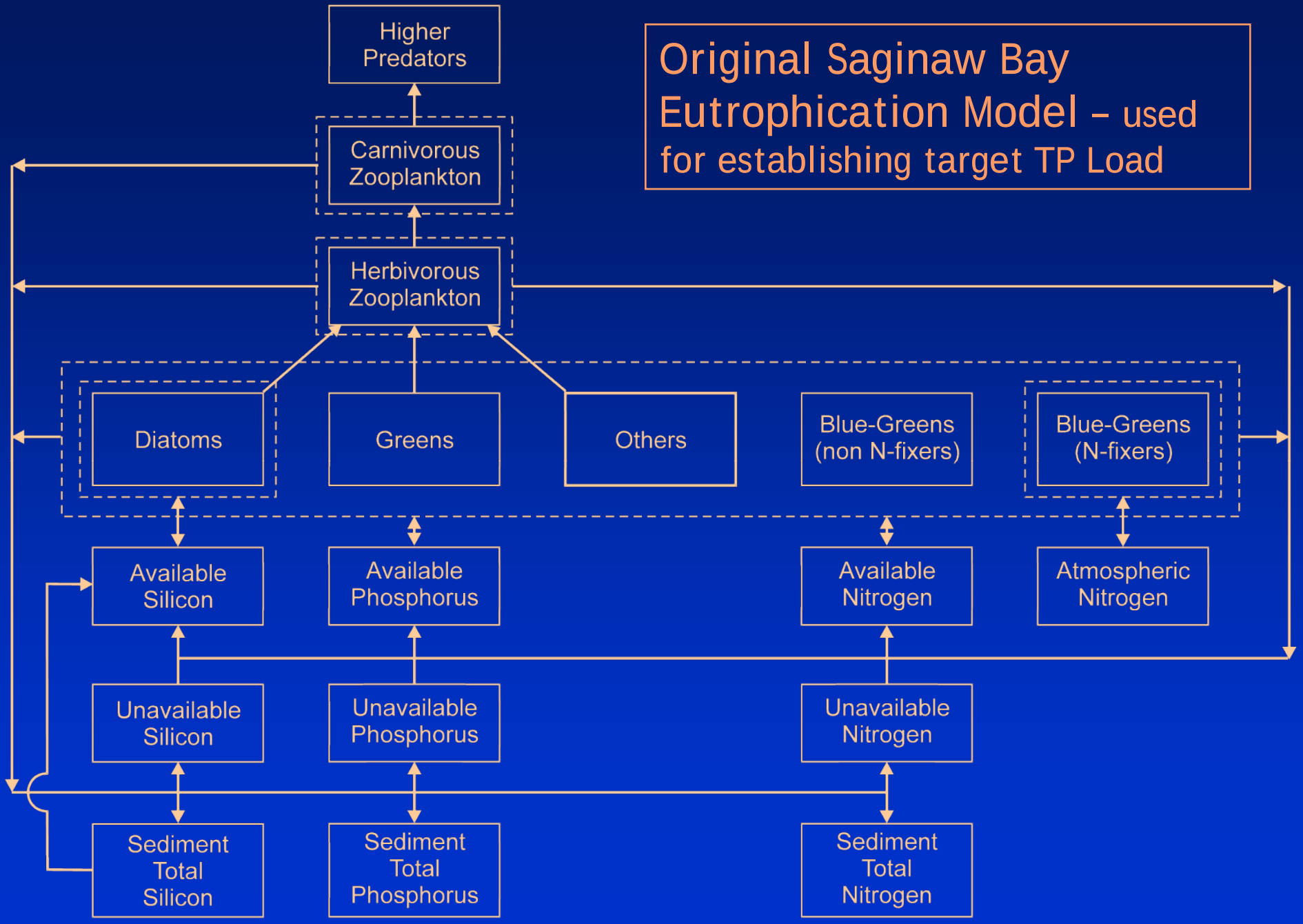
- Public concern leads to political action
- 1972 signing of Binational Great Lakes Water Quality Agreement (GLWQA)
  - "restore and maintain the chemical, physical, and biological integrity of the Great Lakes Basin Ecosystem."
- Annex 3 (1978)
  - Implicated phosphorus as primary cause of nuisance algal growth
  - phosphorus concentrations "...should be limited to the extent necessary to prevent nuisance growths of algae, weeds and slimes that are or may become injurious to any beneficial water use."
  - "year-round aerobic conditions in bottom waters of the central basin of Lake Erie"
  - Initiated efforts to reduce phosphorus loads
  - Established targets phosphorus loads to control eutrophic conditions

Task Group III models used to establish Annex 3 target P loads

- **Vollenweider (all basins)**
  - Empirical
  - Steady-state
- **Chapra (all basins)**
  - Semi-empirical
  - Dynamic TP mass balance
  - Chlorophyll *a* and DO empirically correlated with TP
- **Thomann Lake I model (Lake Ontario and Lake Huron)**
  - Process model
  - Dynamic MB of P, N, chlorophyll, zooplankton
- **DiToro Lake Erie model**
  - Process model
  - Dynamic MB of P, N, Si, DO, diatom and non-diatom chlorophyll, zooplankton
- **Bierman Saginaw Bay model**
  - Process model
  - Dynamic MB of P, N, Si, five phytoplankton groups, zooplankton



Original Saginaw Bay Eutrophication Model – used for establishing target TP Load

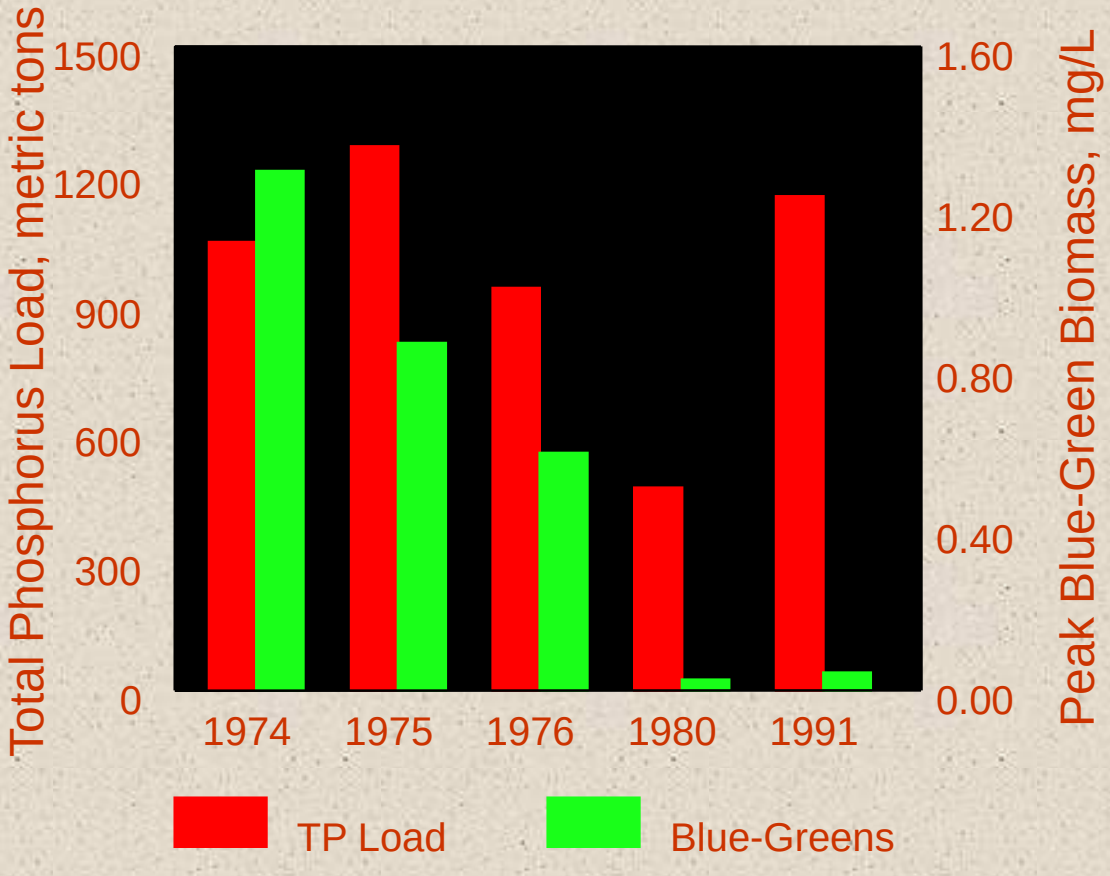


Target Phosphorus Loads (metric tonnes/yr)

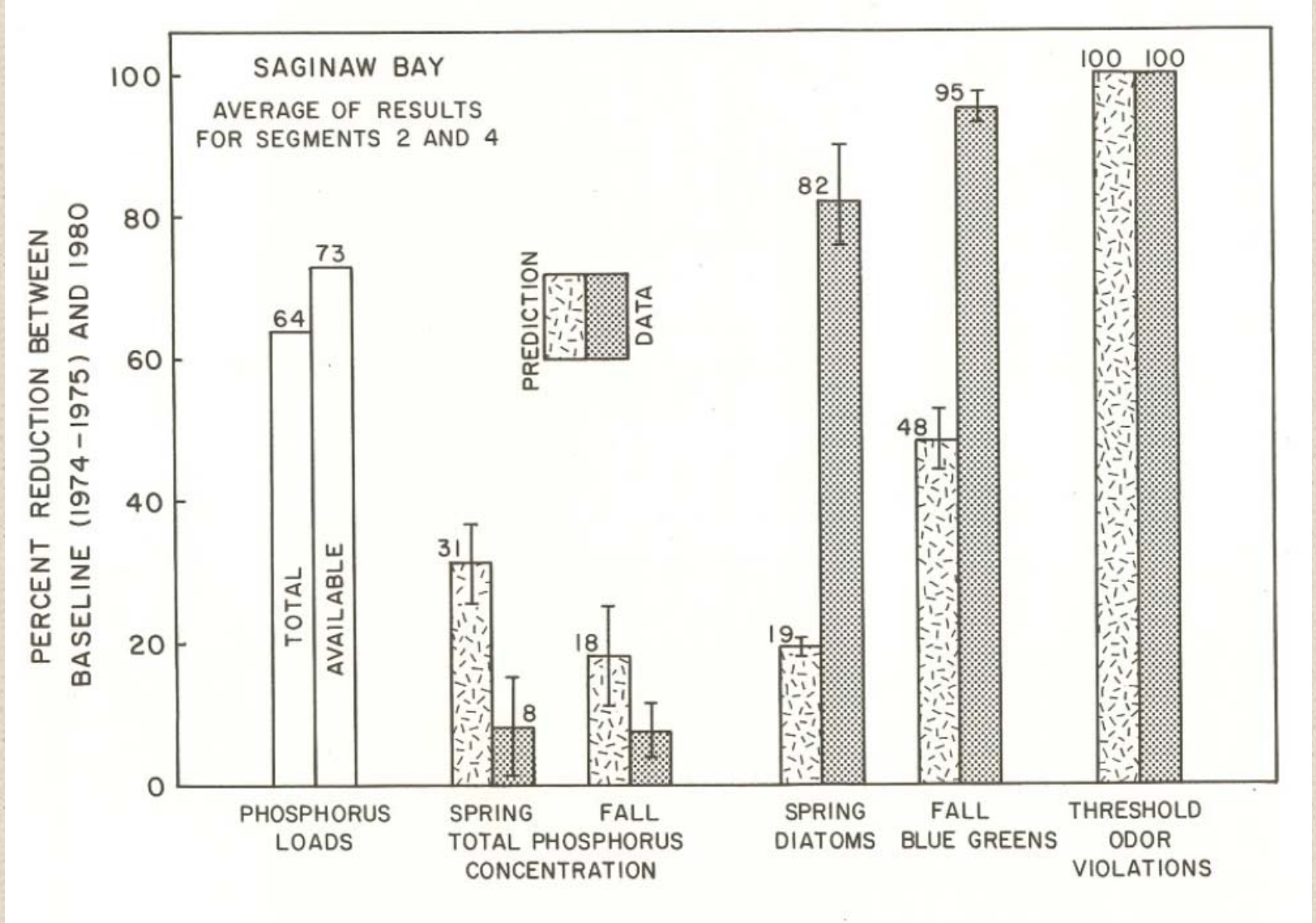
Basin	1976 TP Load (mta)	Target TP Load (mta)
Lake Superior	3600	3400
Lake Michigan	6700	5600
Main Lake Huron	3000	2800
Georgian Bay (LH)	630	600
North Channel (LH)	550	520
Saginaw Bay (LH)	870	440
Lake Erie	20000	11000*
Lake Ontario	11000	7000*

* Require 1 mg/L PS effluent + 50% diffuse source reduction or
0.5 mg/L PS effluent + 30% diffuse source reduction

TP Load and Blue-Greens



Saginaw Bay Phytoplankton Model Post-audit
(from Bierman and Dolan 1986)

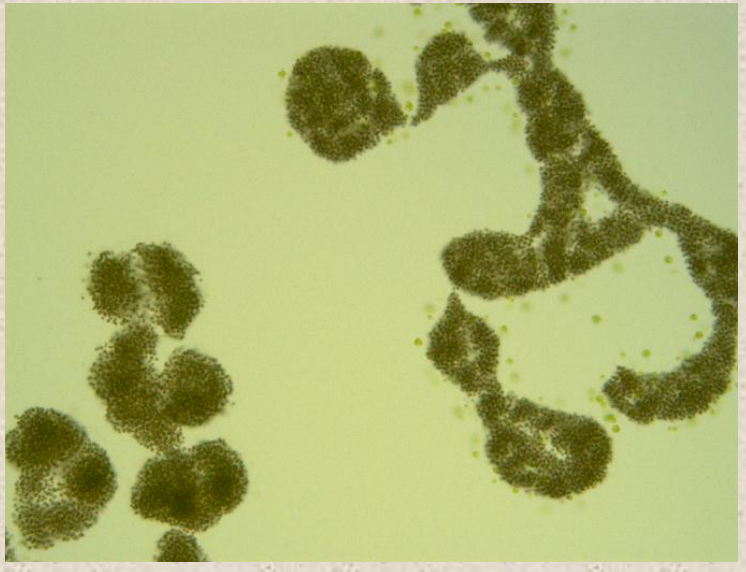


1990's – present:

Reoccurrence of water quality problems

Return of *Microcystis* Blooms to Great Lakes embayments, including Saginaw Bay

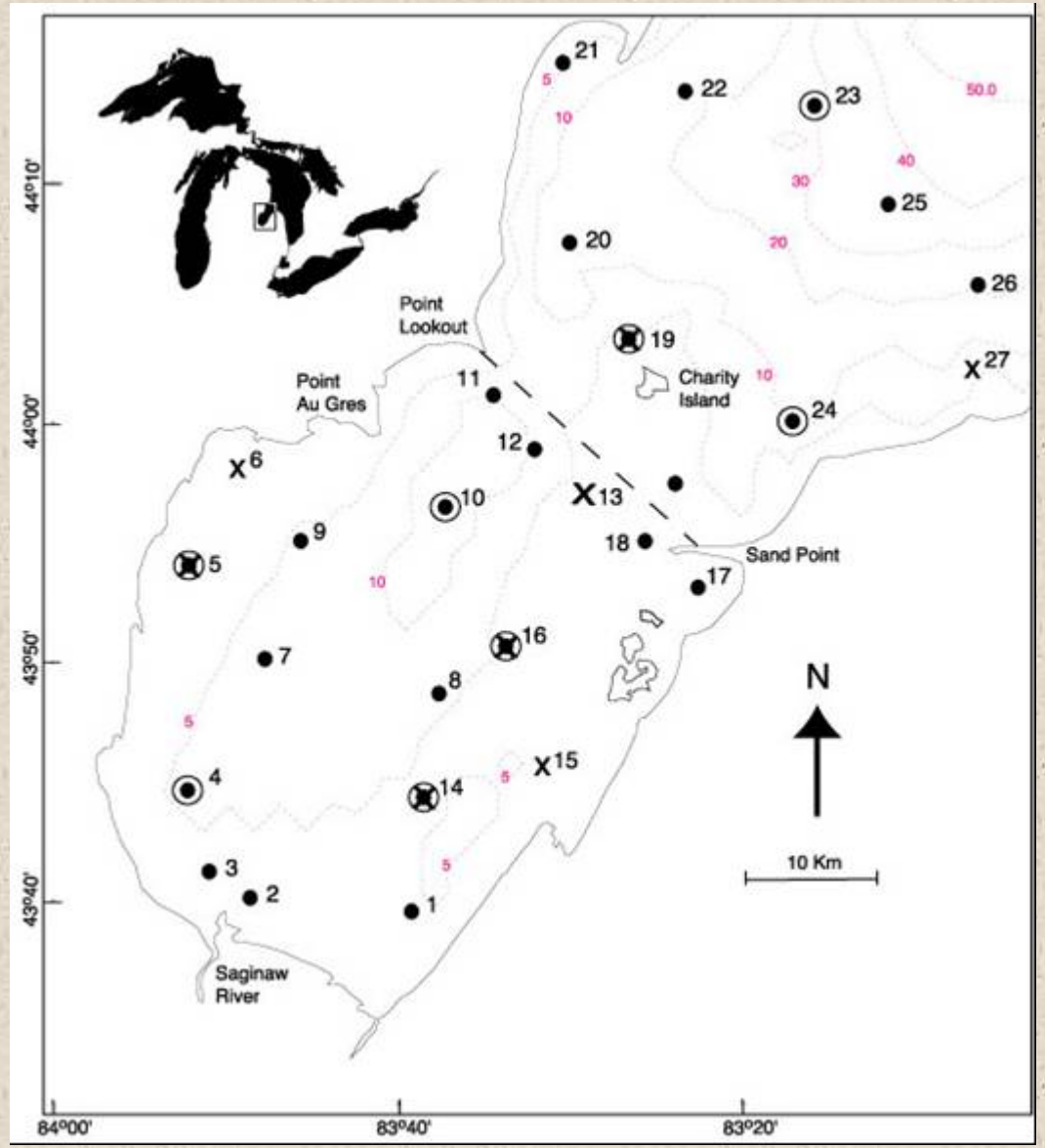
- Colonial harmful algal bloom species (HAB)
- Forms blooms and scums
  - Taste/odor issues
  - Loss of recreational and fishing value to affected waters
  - Hypoxia/anoxia, may lead to mortality in benthic invertebrate community and fish kills
  - Potential production of hepatotoxin - microcystin

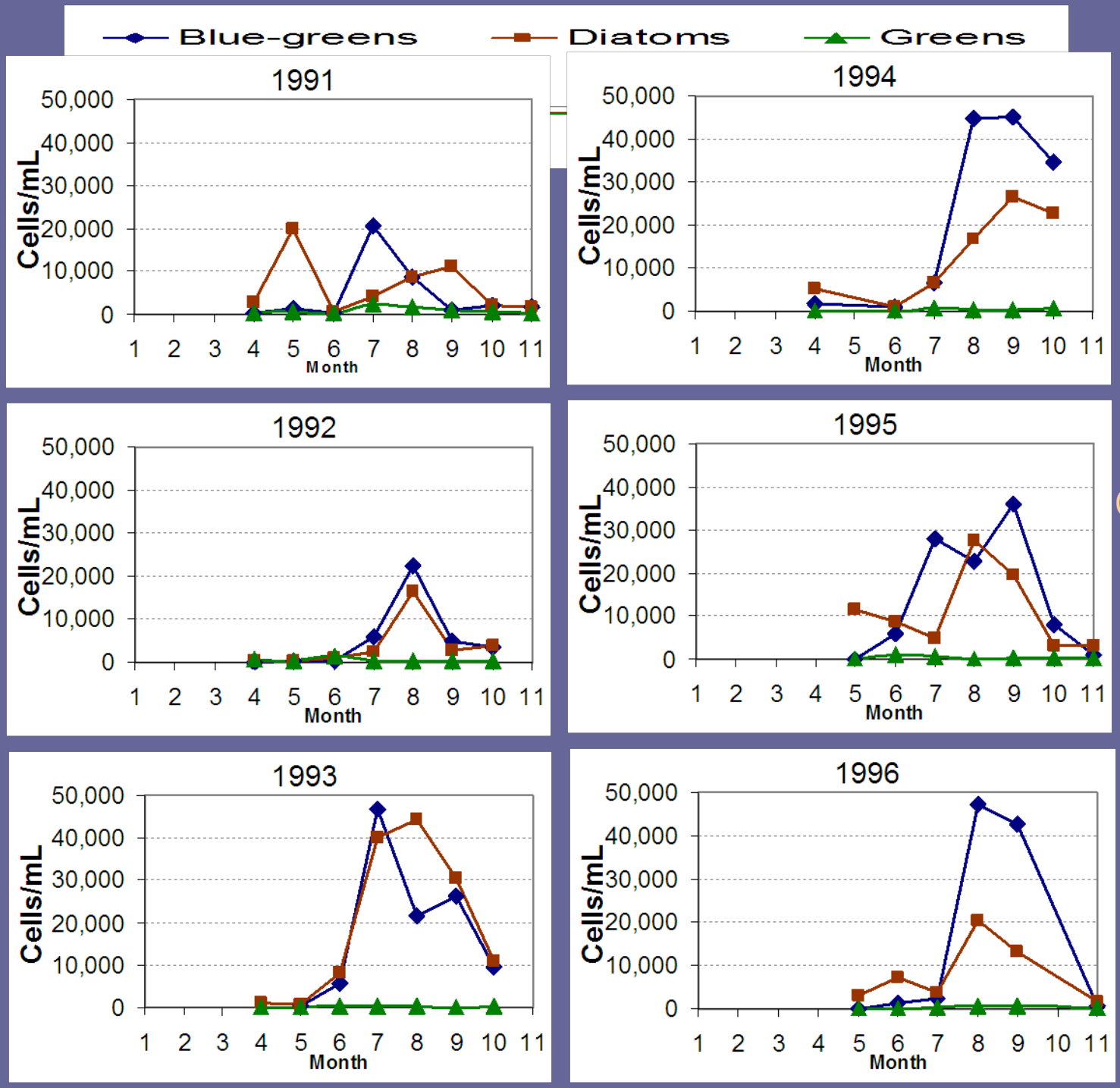


Microcystis

Put-In-Bay, August 2004

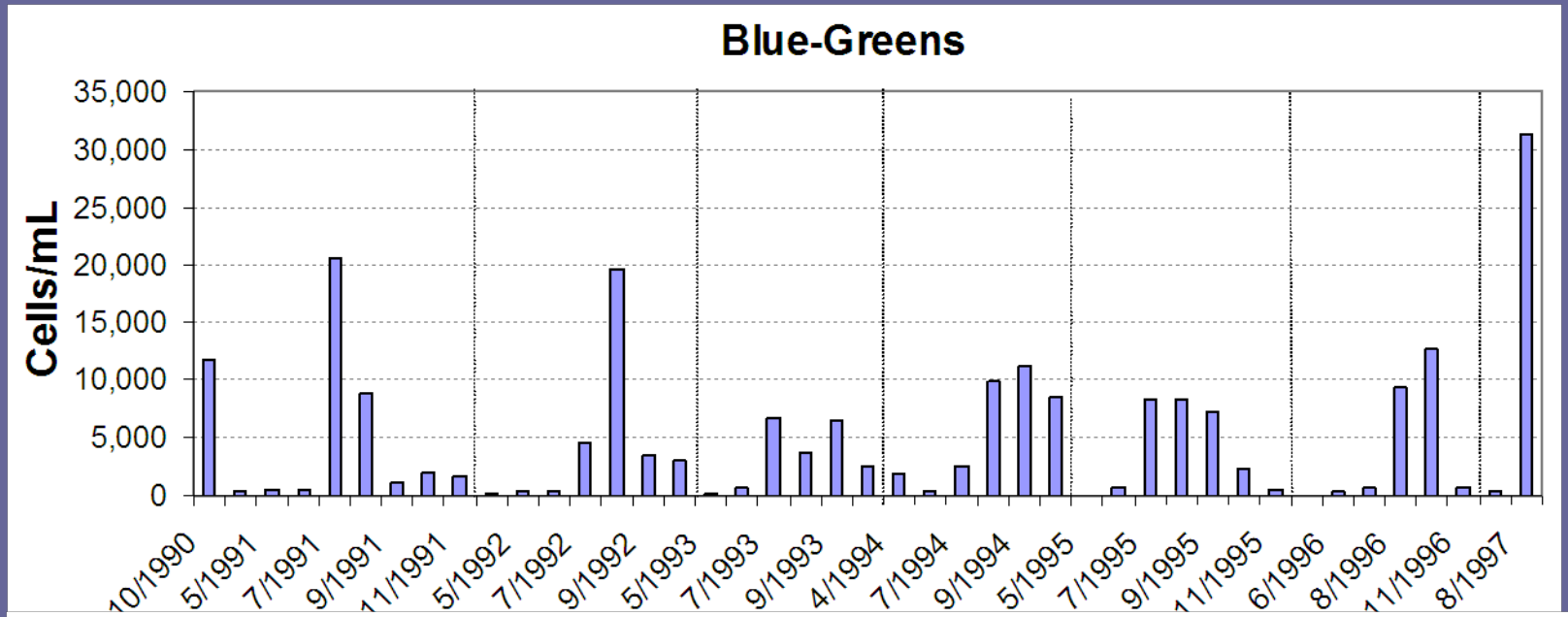
NOAA-GLERL Conducted Bay Sampling from 1991 - 1996

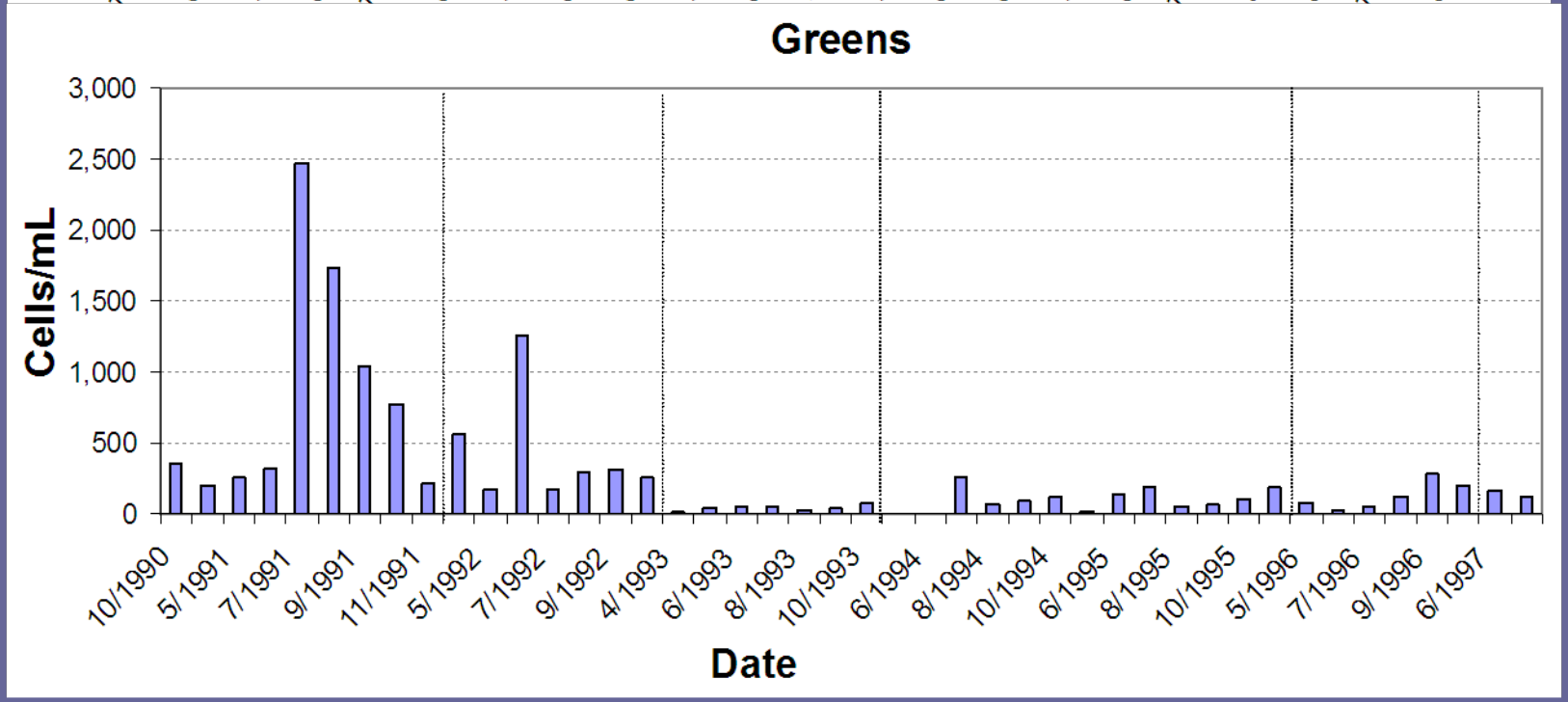




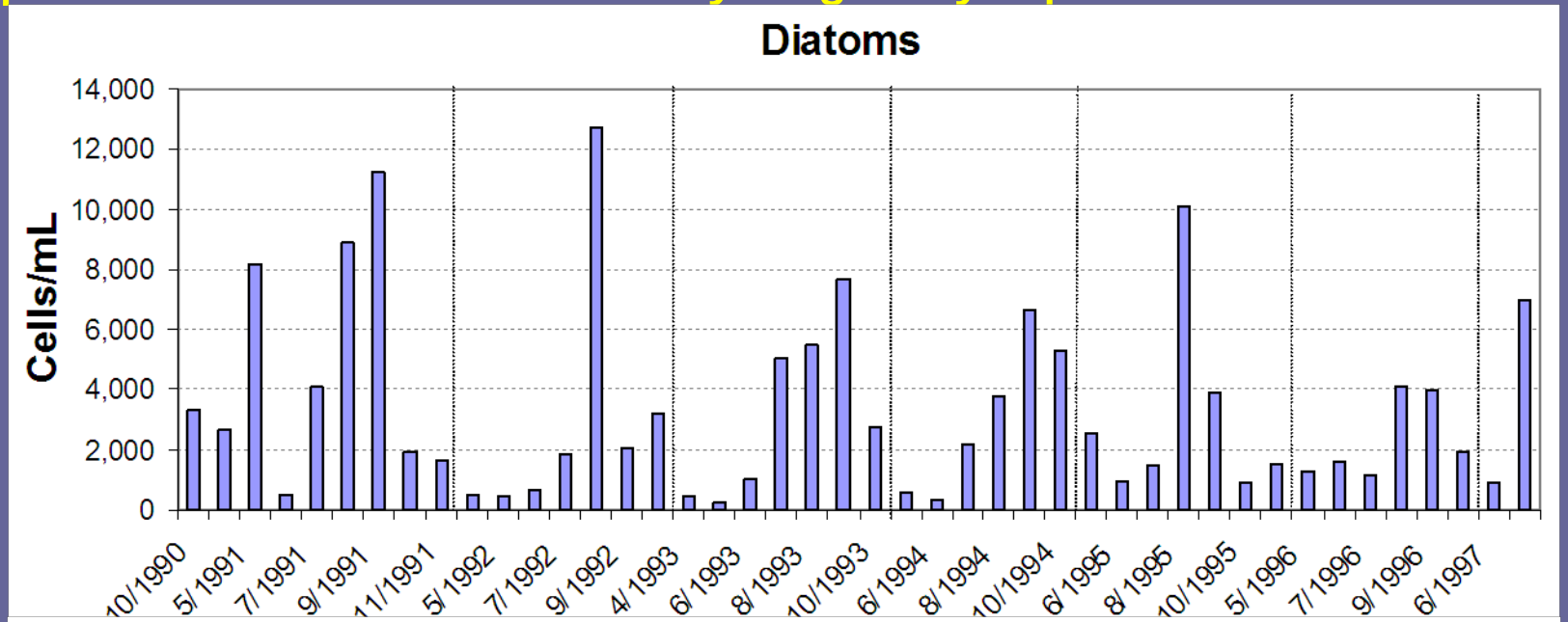
Species Composition

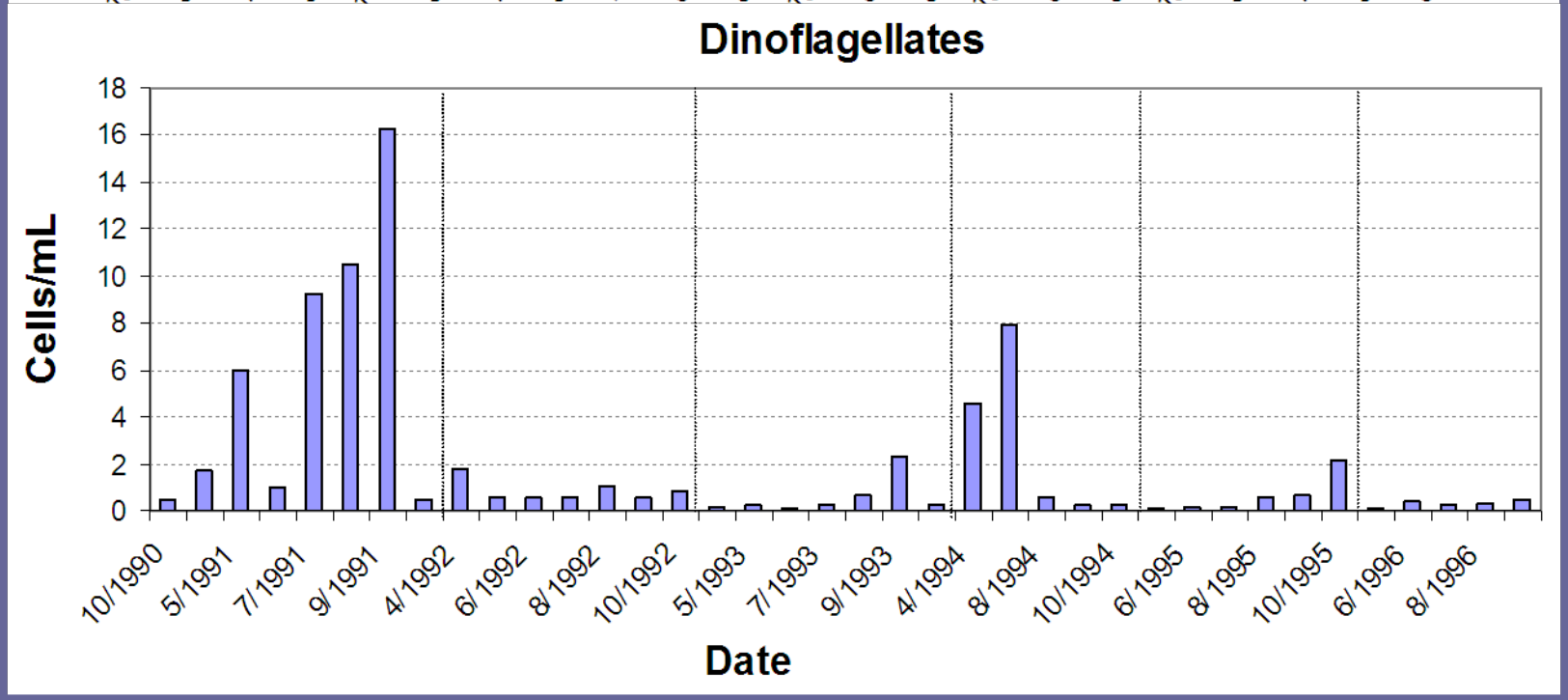
Temporal Variations in Monthly Avg. Phytoplankton Cell Densities





Temporal Variations in Monthly Avg. Phytoplankton Cell Densities

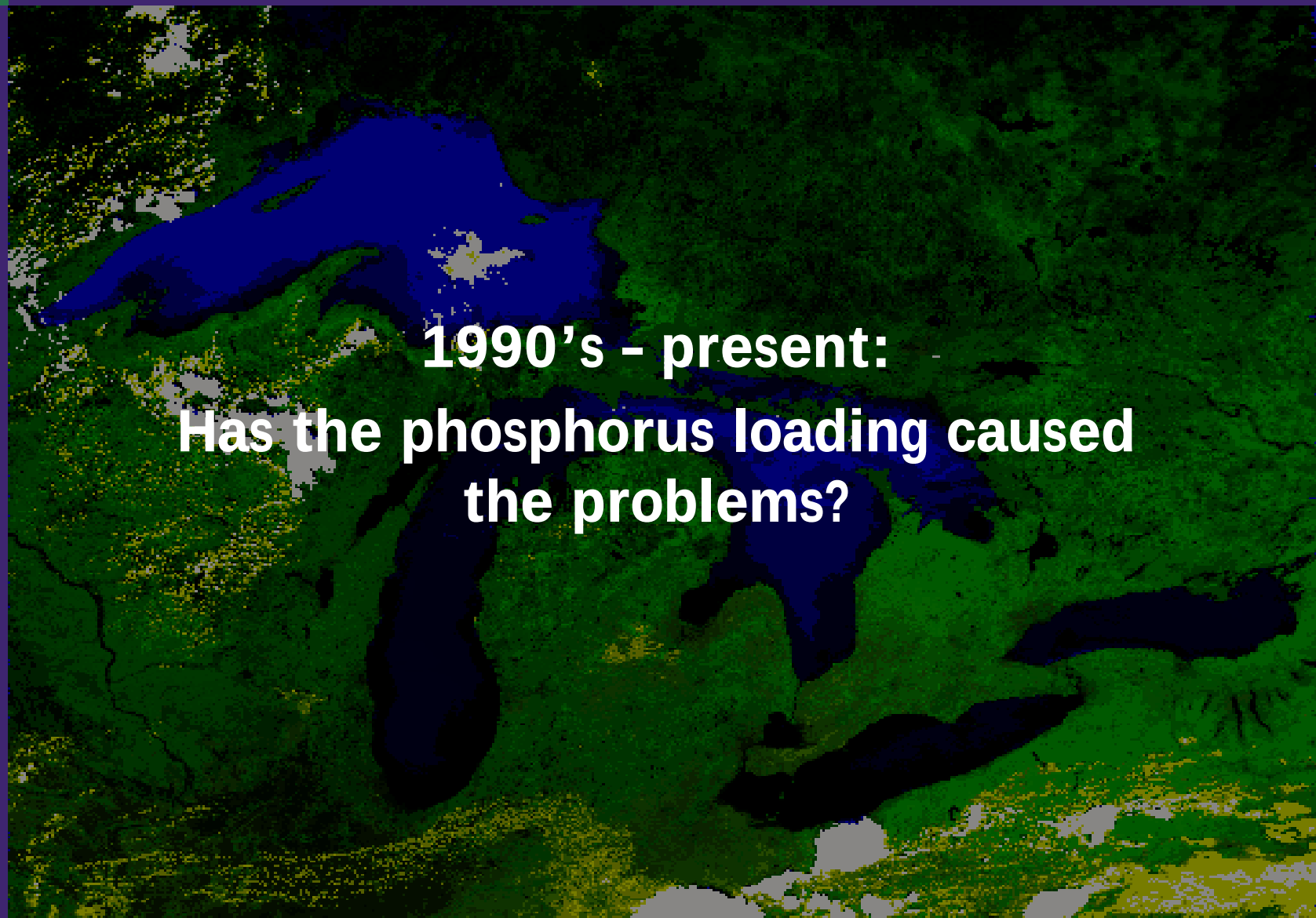




Return of “Muck” to the Bay Shoreline

“Muck” along shoreline at Bay City State Park

Return of Benthic Algae Blamed for “Muck”



1990's – present:

Has the phosphorus loading caused the problems?

Historic Study Sites (1991-1996)

○ 1991-1992

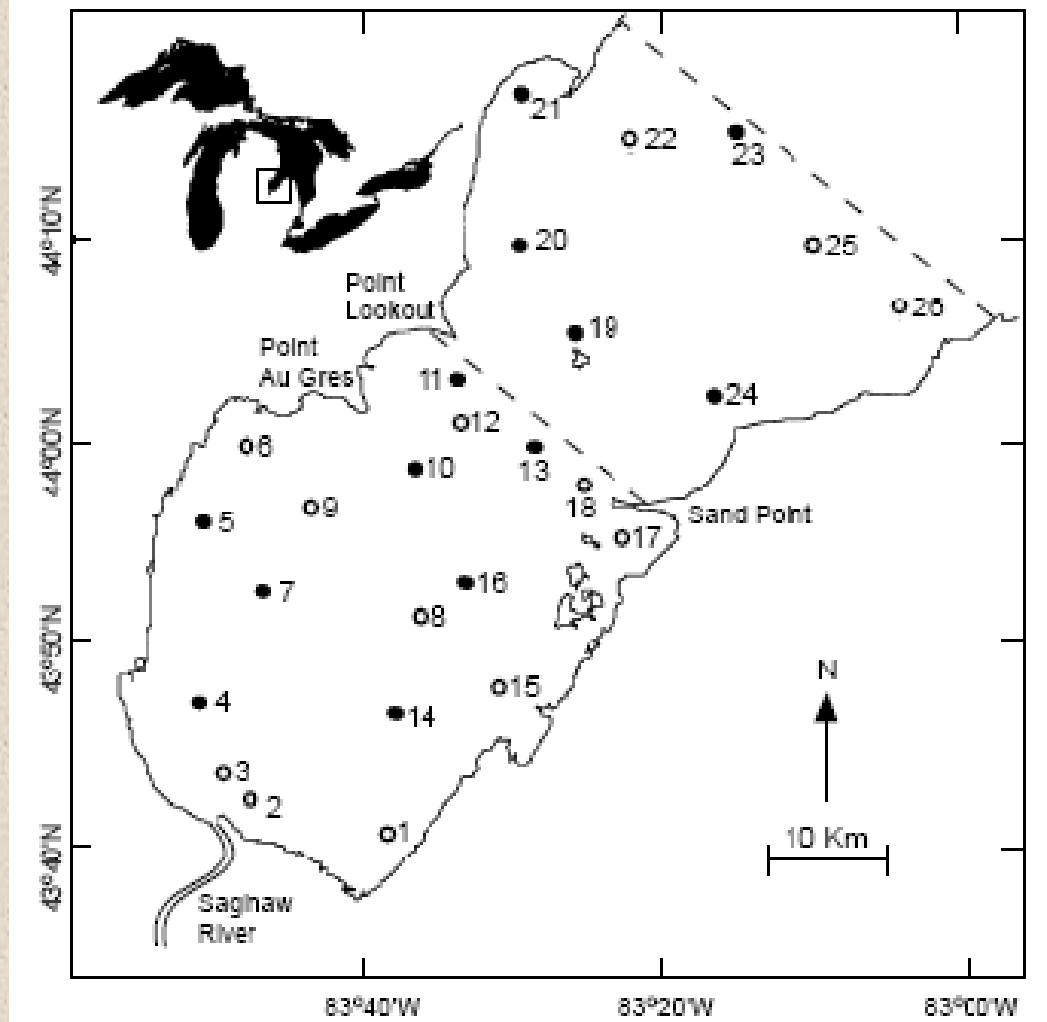
26 sites (18 inner, 8 outer)

● 1991-1996

13 sites (8 inner, 5 outer)

○ 1974 - 1980

sampled by EPA & others
(Smith et al. 1977)
(Bierman et al. 1984)



TP concentrations in Saginaw Bay

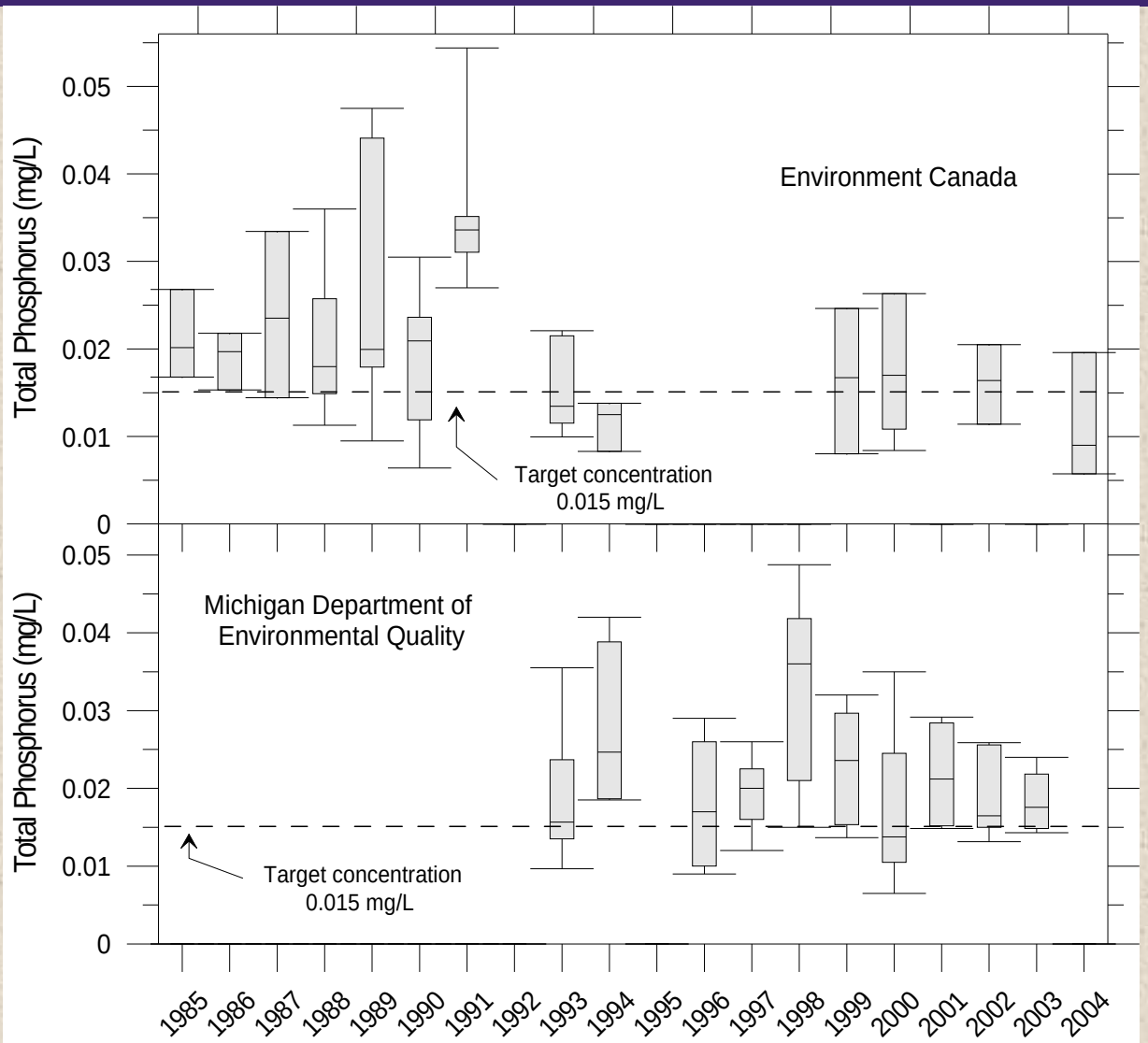


Figure 3. Box and Whisker Plot of Total Phosphorus Data by Year.
Boxes show upper and lower data quartiles; the central solid line represents the median.
Whiskers represent 1.5 times the interquartile range, up to the maximum and minimum data values.

MDEQ (2005)

Saginaw River

Water Quality Stations

N

Legend

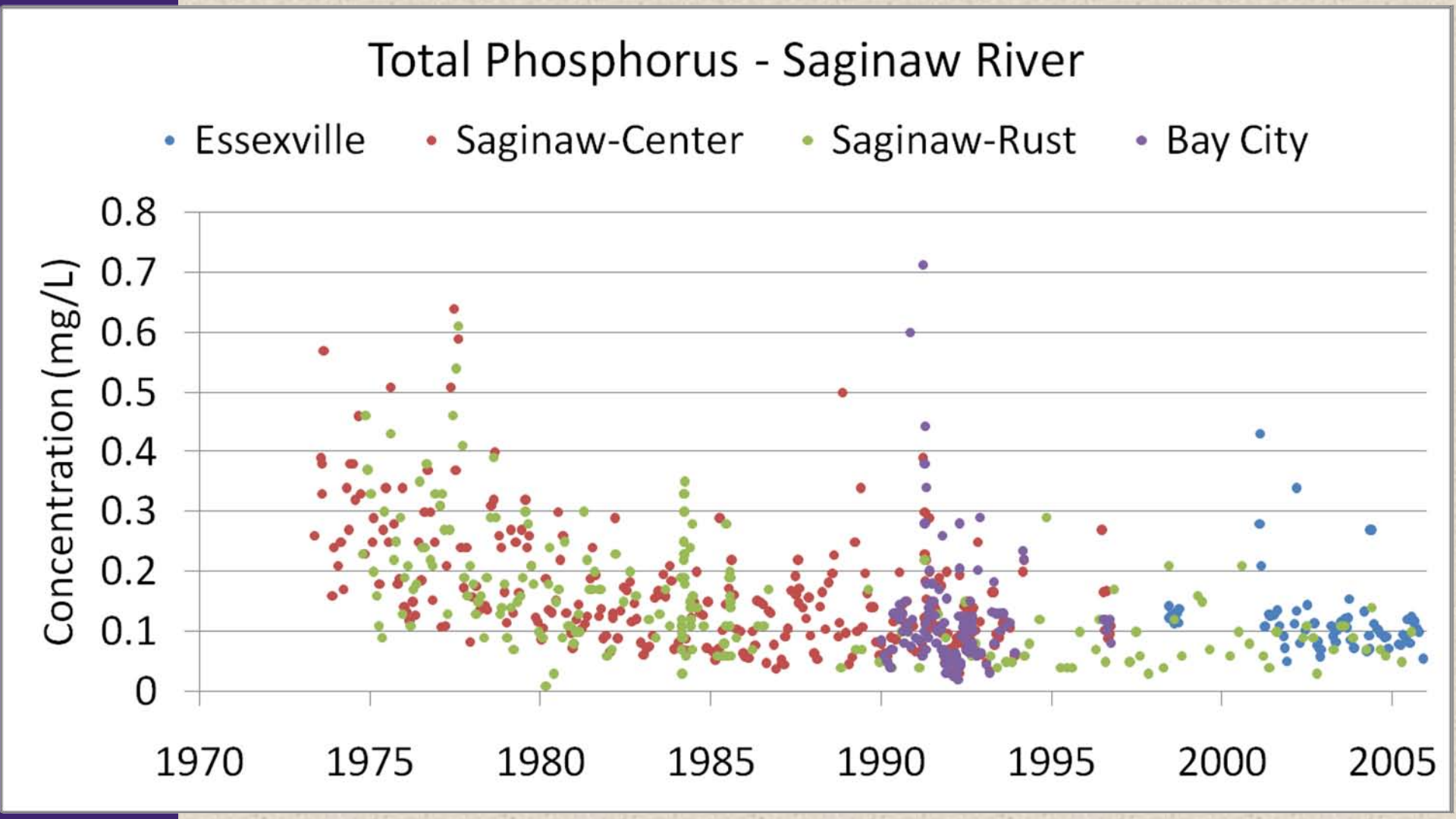
- Stations
- County
- Municipal

0 1 2 3 4 mi

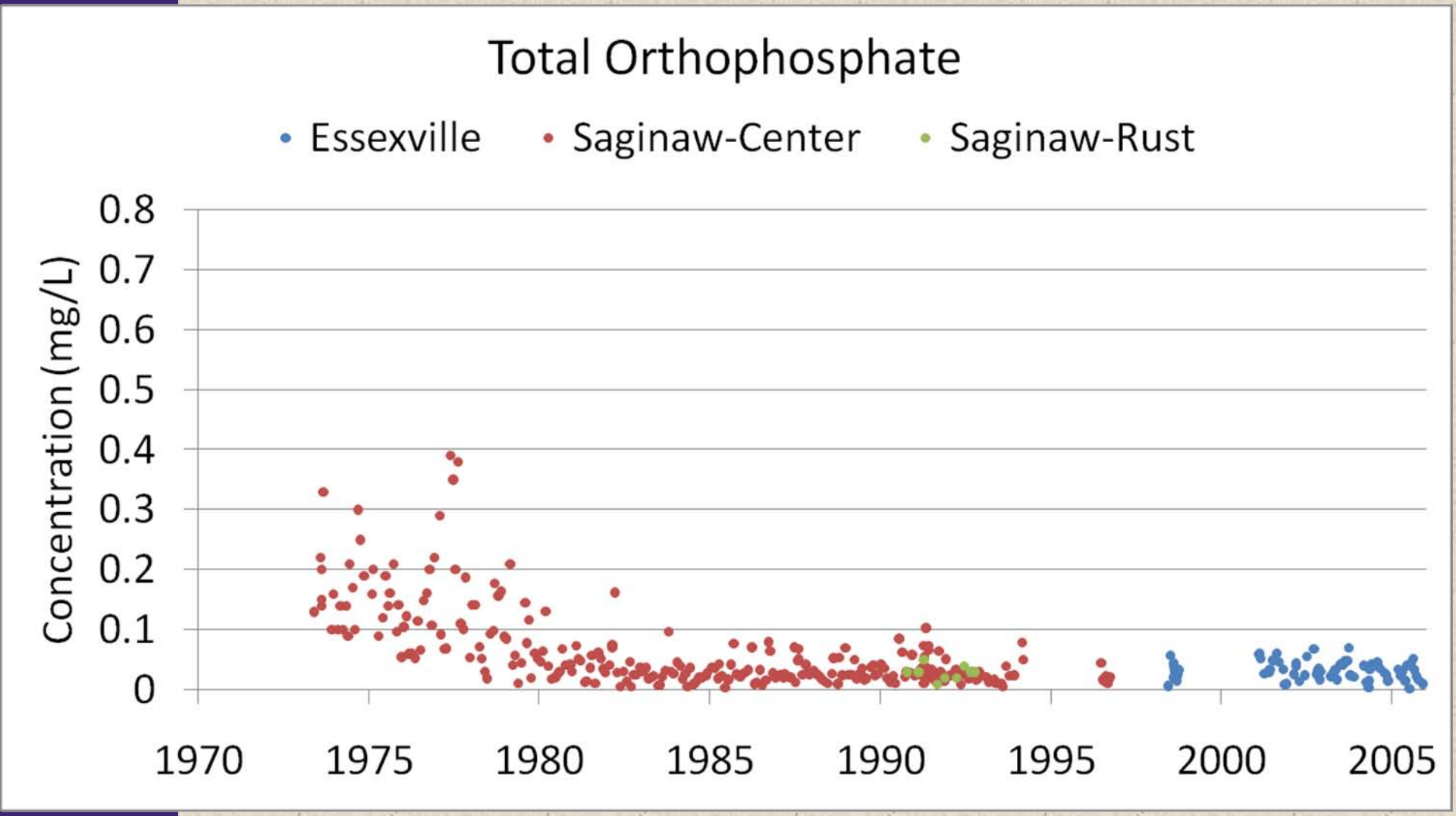
0 1 2 3 4 5 6 7 km

LimnoTech

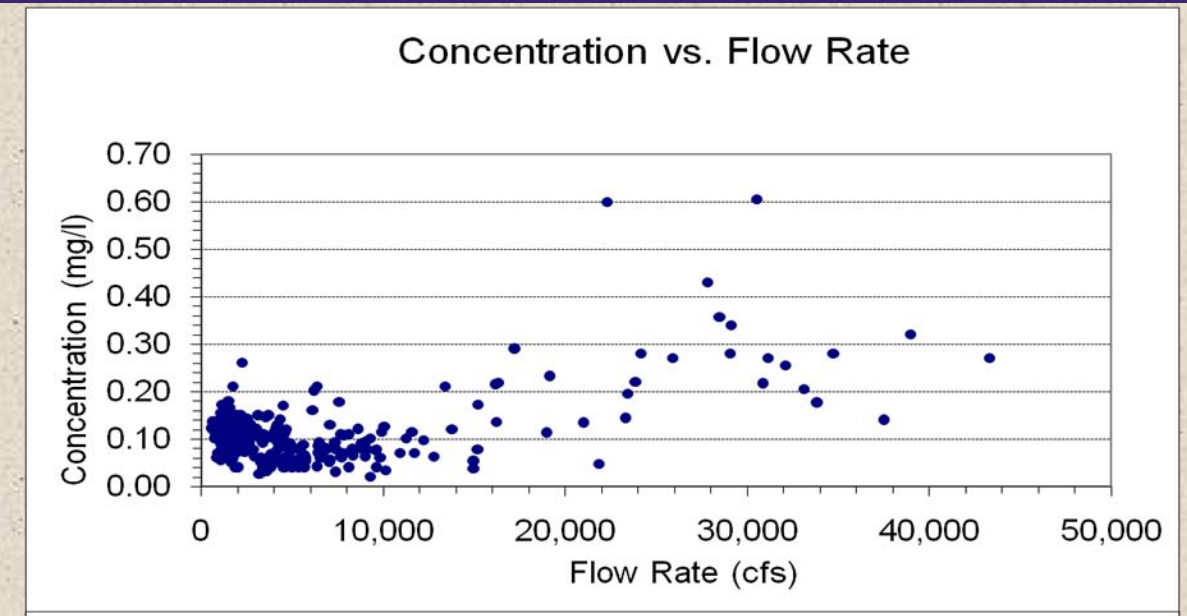
Long Term Data Set for Saginaw River Total Phosphorus

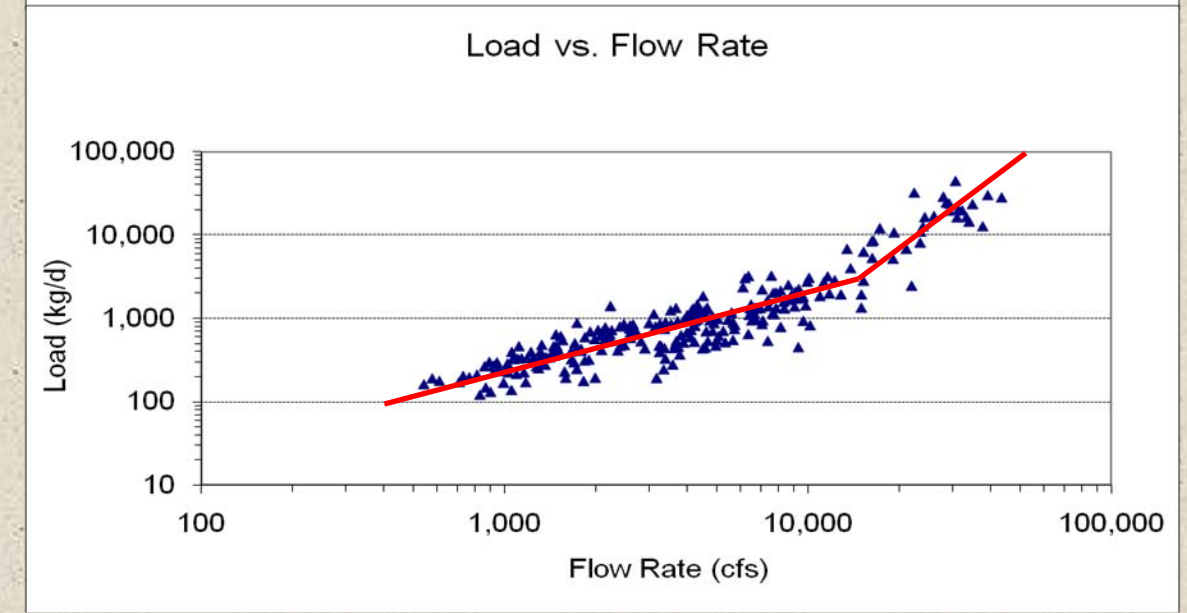


Long Term Data Set for Saginaw River Orthophosphate

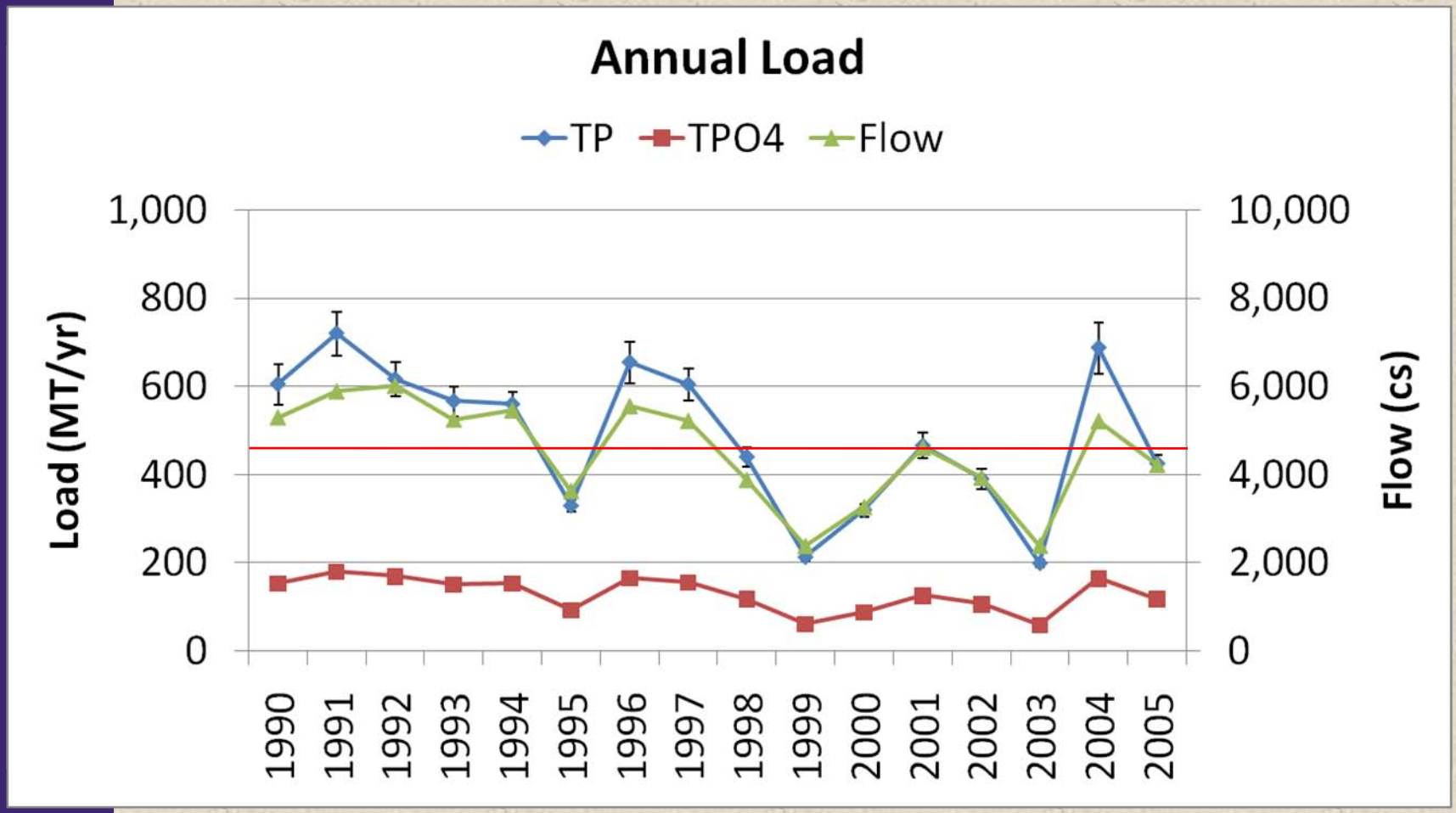


TP Concentration and Load Relationship to Flow
(All data from 1990 to 2005)





USGS MVUE Estimate of Saginaw River Annual Phosphorus Load

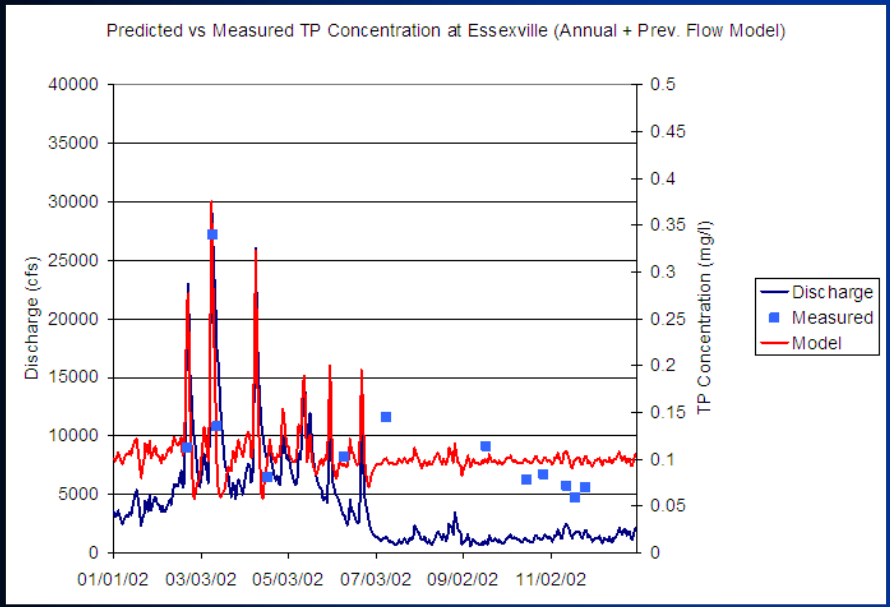


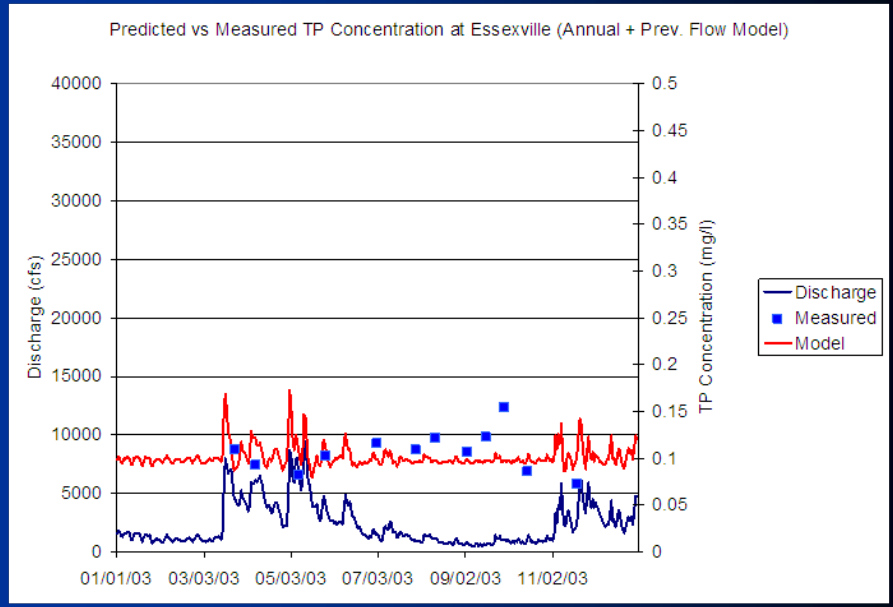
Saginaw River Load Estimates

- MDEQ: Stratified Beale Ratio, using single year data

$$L_{Beale} = \overline{Q}\frac{\overline{L}}{\overline{Q}_L}\left[\frac{1+\frac{S_{LQ}}{N\overline{L}\overline{Q}_L}}{1+\frac{S_{QQ}}{N\overline{Q}^2}}\right]$$

- Regression approach using all 1998-2005 data:
  - Concentration as linear function of Q and season
  - Concentration as linear function of Q and antecedent 5-day average flow


Predicted vs Measured TP Concentration at Essexville (Annual + Prev. Flow Model)
Discharge (cfs)
TP Concentration (mg/l)
40000
35000
30000
25000
20000
15000
10000
5000
0
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
01/01/02
03/03/02
05/03/02
07/03/02
09/02/02
11/02/02
Discharge
Measured
Model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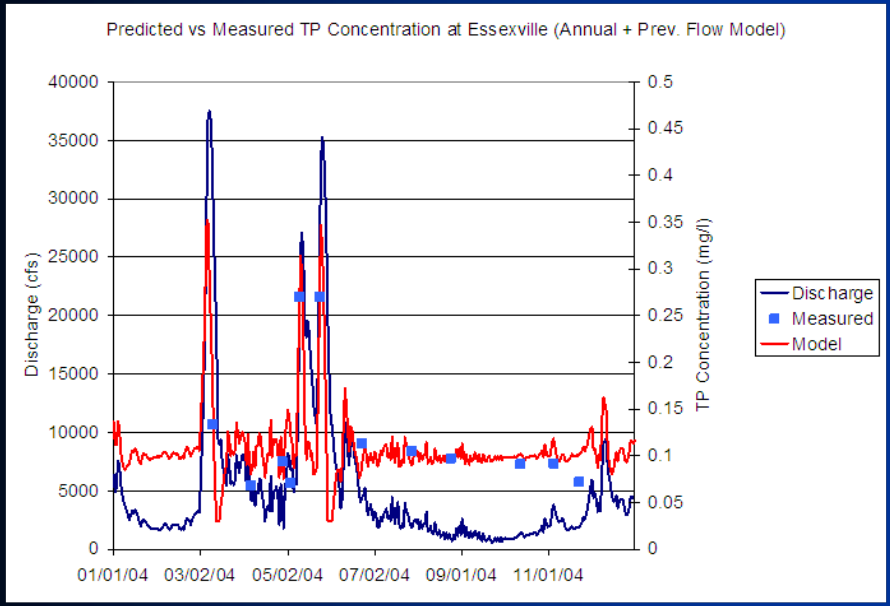
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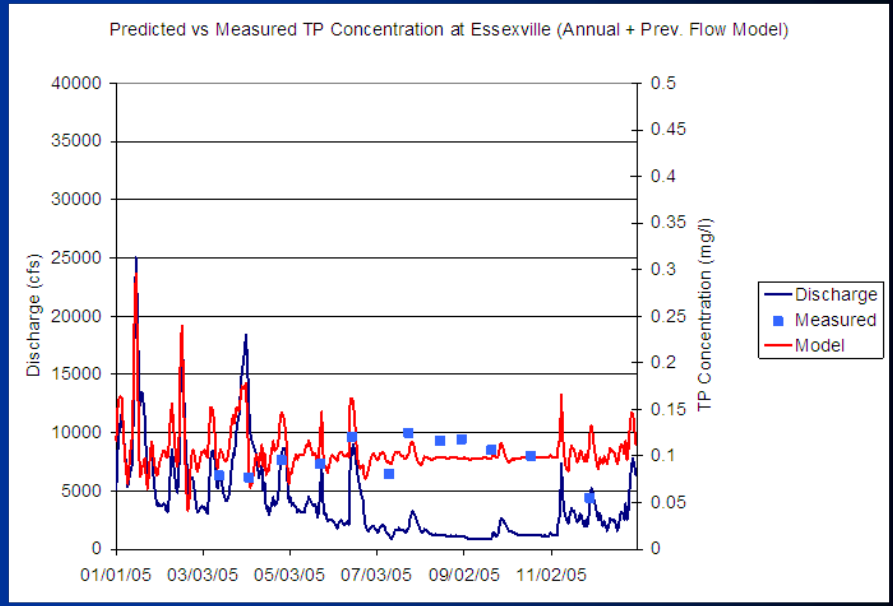
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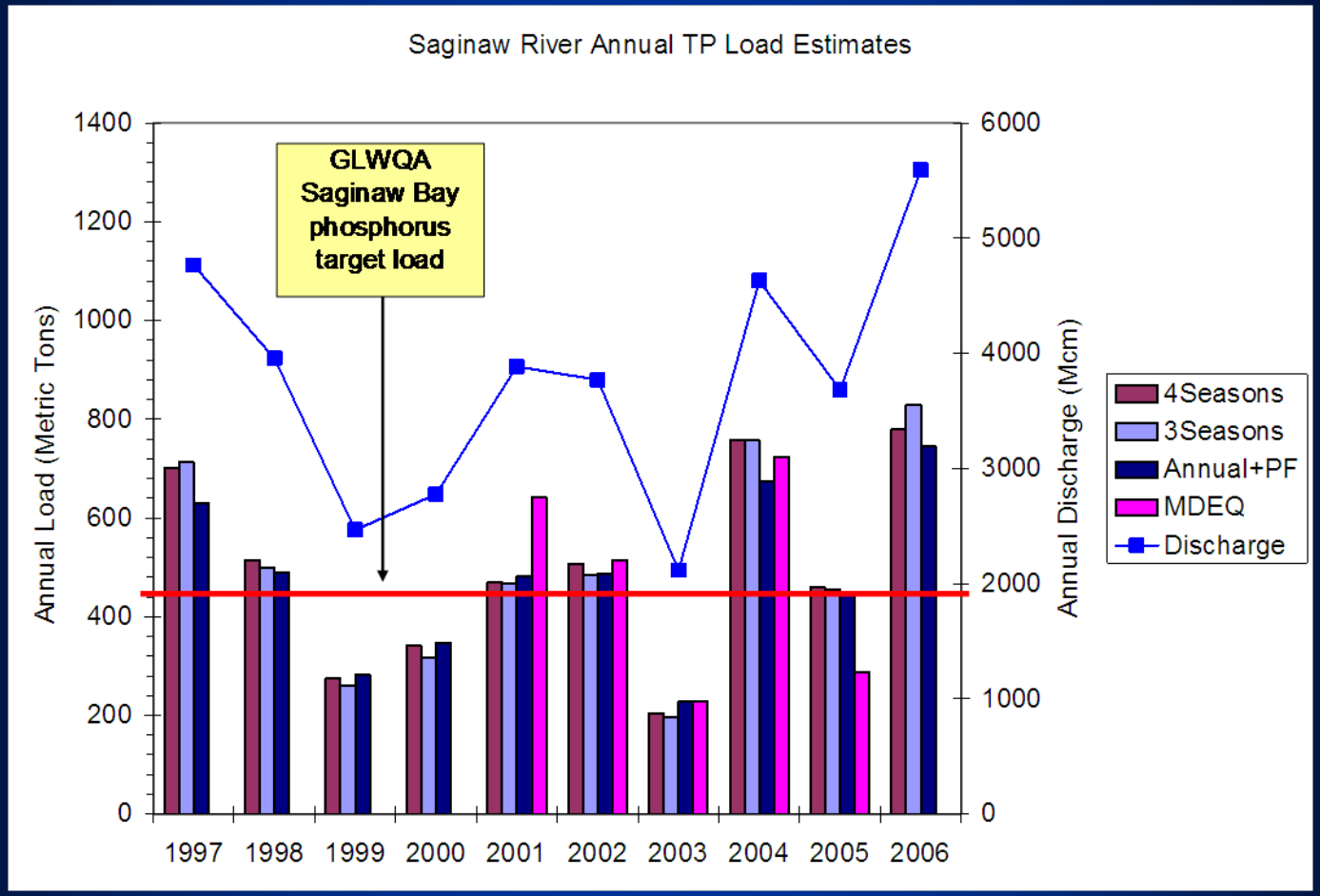
0.05
0
01/01/05
03/03/05
05/03/05
07/03/05
09/02/05
11/02/05
Discharge
Measured
Model

1997-2006 Saginaw River Load

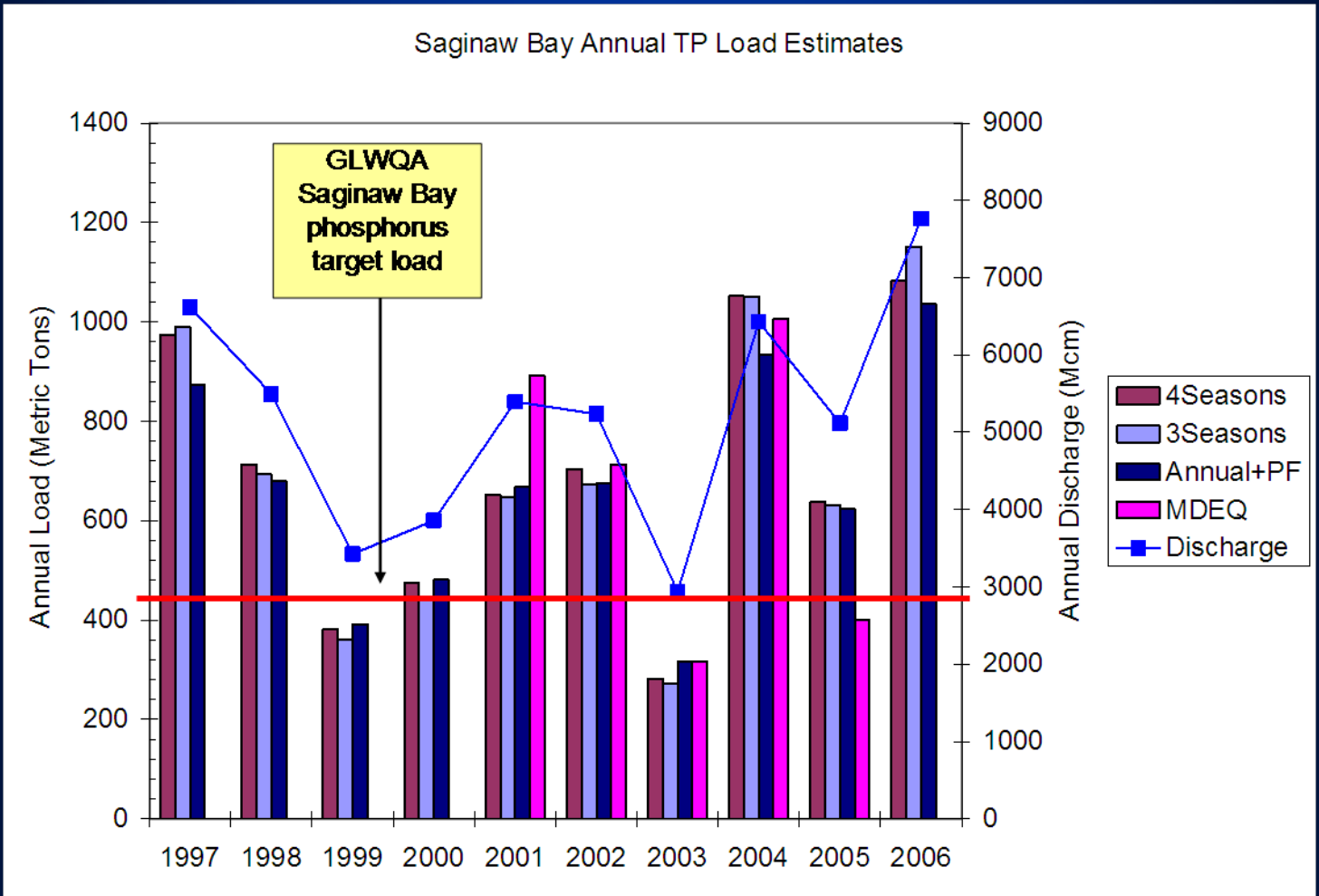


Saginaw Bay TP Annual Load (2004-06)?

Basin	Area (km^2)	Area (%)	2004-2006 WWTP Effluent (Met. Ton.)	2004-2006 WWTP Effluent (%.)	2004 Load (Met. Ton)	2005 Load (Met. Ton)	2006 Load (Met. Ton)
Saginaw	16,680	71.6	110-127	15.3 – 38.2	673-758	288-459	746-829
AuGres/ Rifle	2,777	11.9	3.7-4.6	2.6-3.5	112-126	47-76	124-138
KawKawlin/ Pine	1,409	6.0	5.1-6.4	3.7-4.3	57-64	24-38	63-70
Pigeon/ Wiscoggin	2,425	10.5	9.8-10.8	6.7-8.0	97-110	42-67	108-121
Total	23,291		130-147		939-1058	402-640	1041-1157

Saginaw Bay Watershed Annual TP Load

Assuming rest of watershed behaves as Saginaw River (same areal load)



CSO and WWTP Fraction of Saginaw River TP Annual Load

	CSO/SSO Est. (Met. Ton)	WWTP Effluent (Met. Ton.)	Total Load MDEQ (Met. Ton)	Total Load Regr. (Met. Ton)	CSO's Fraction of load (%)	WWTP Fraction of load (%)
2000	1.78	--	--	316-346	0.50 / 0.56	-- / --
2001	2.43	--	642	467-480	0.38 / 0.52	-- / --
2002	3.02	--	513	485-507	0.59 / 0.62	-- / --
2003	0.59	--	228	196-228	0.17 / 0.30	-- / --
2004	2.98	116	724	673-758	0.40 / 0.44	15.3 / 17.2
2005	--	110	288	449-459	-- / --	24.0/38.2
2006	--	128	--	746-829	-- / --	15.4/17.2

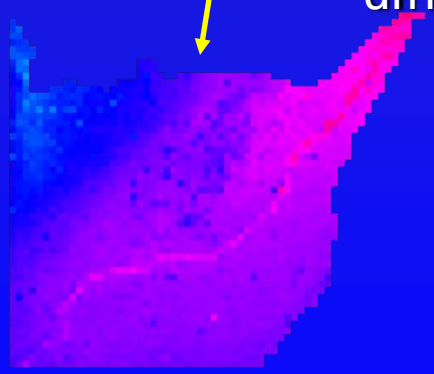
Modeling Approach to Saginaw Bay Watershed (DLBRM)

Watershed divided into four sub-basins

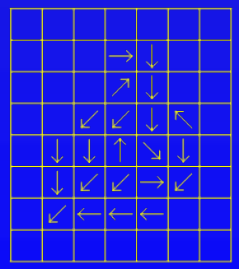
- Saginaw River
- AuGres/Rifle
- Kawkawlin/Pine
- Pigeon/Wiscoggin

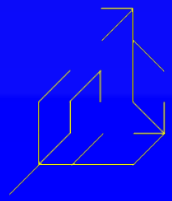
Subwatersheds are subdivided into a grid of square pixels (1 km x 1 km)

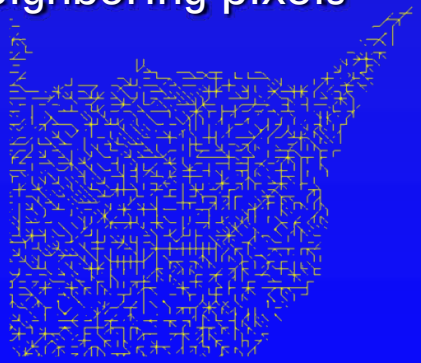
Water and pollutants move horizontally according to the difference in elevation between neighboring pixels



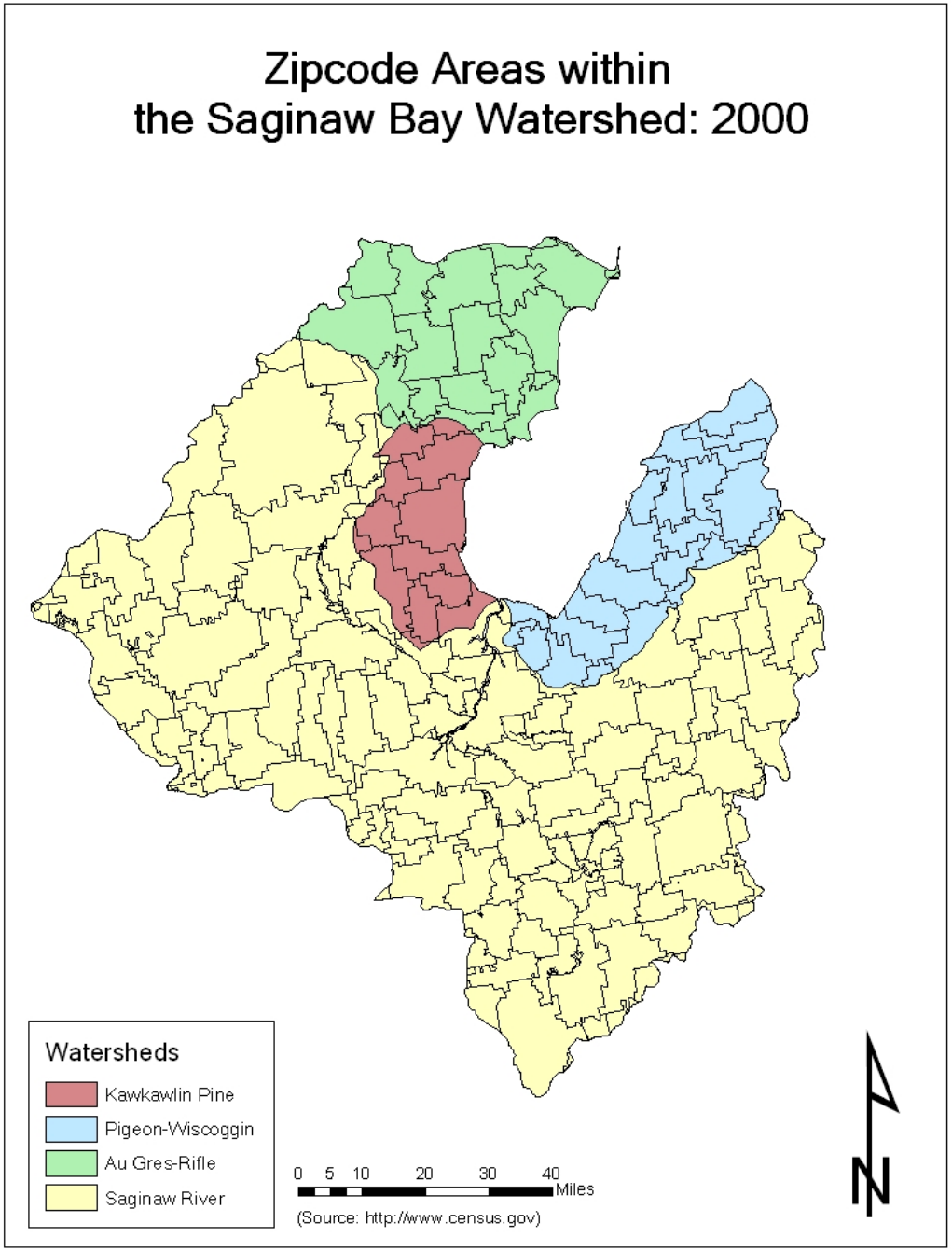
Elevation





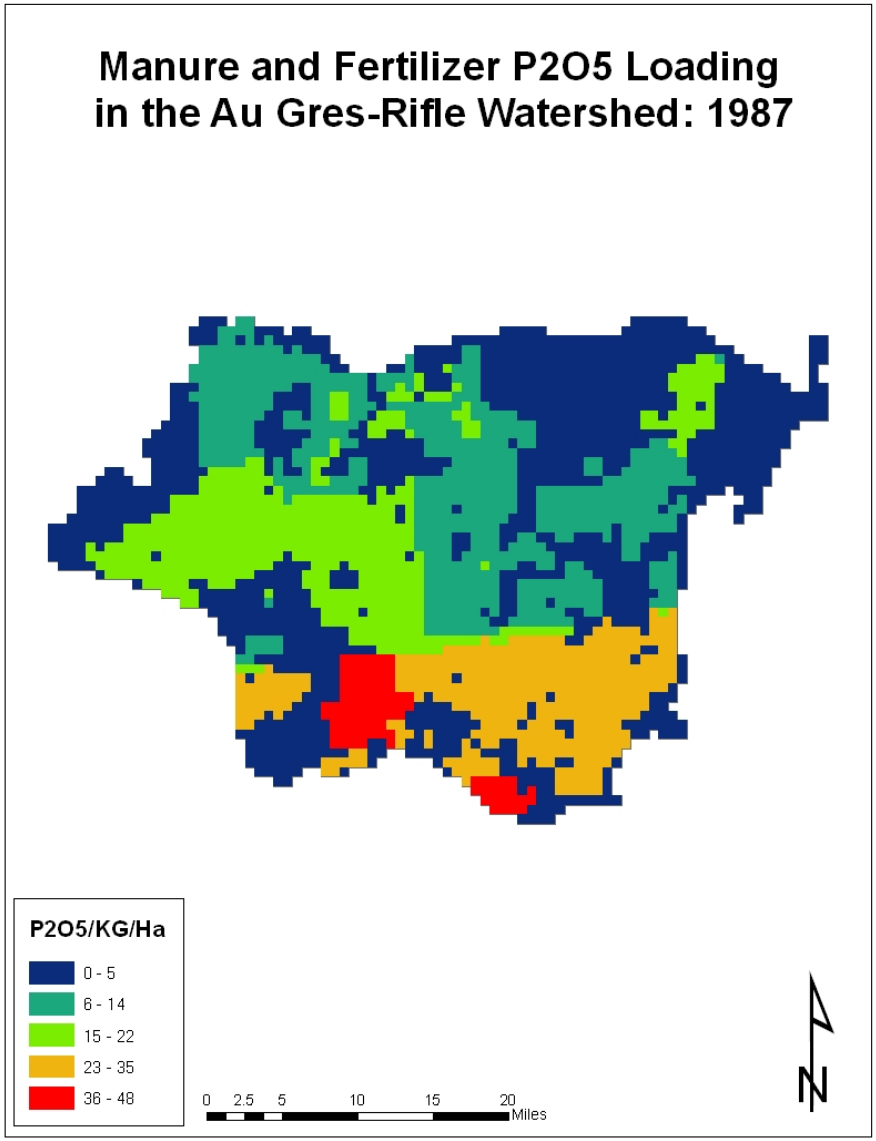


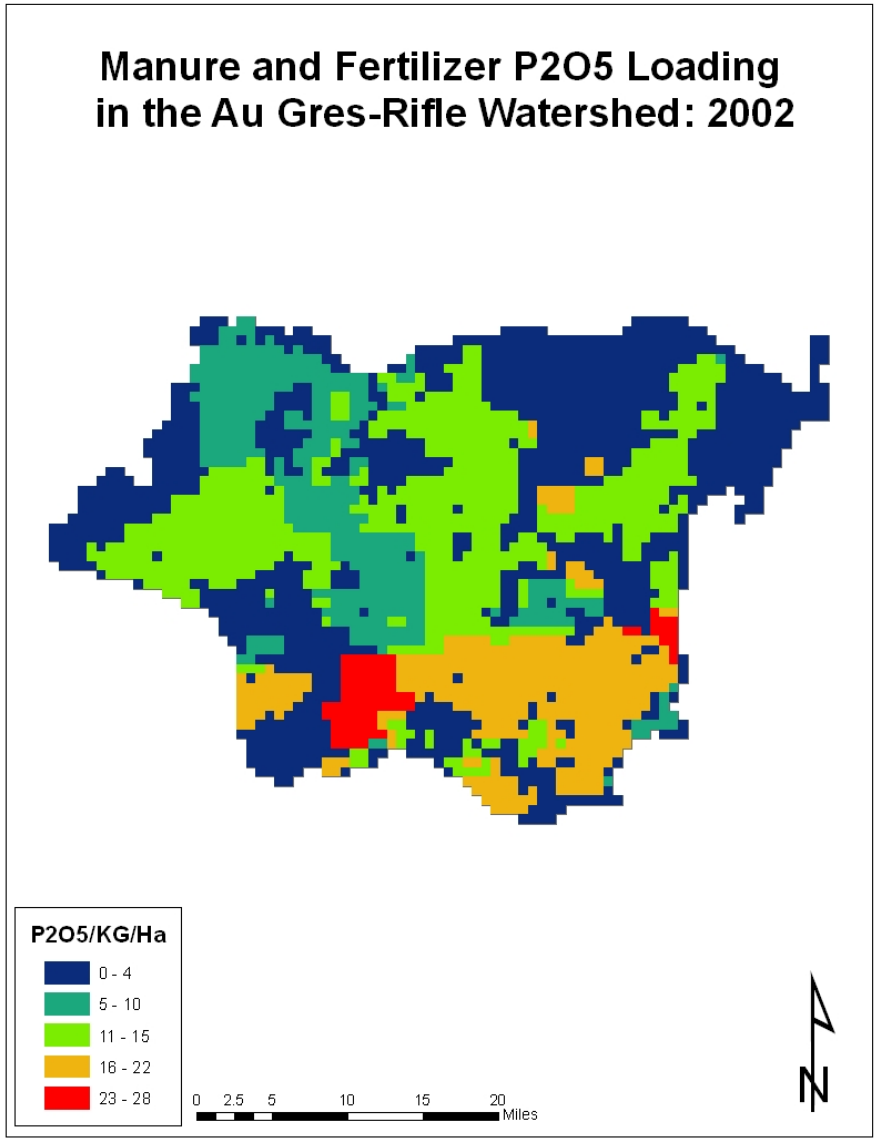
Flow network



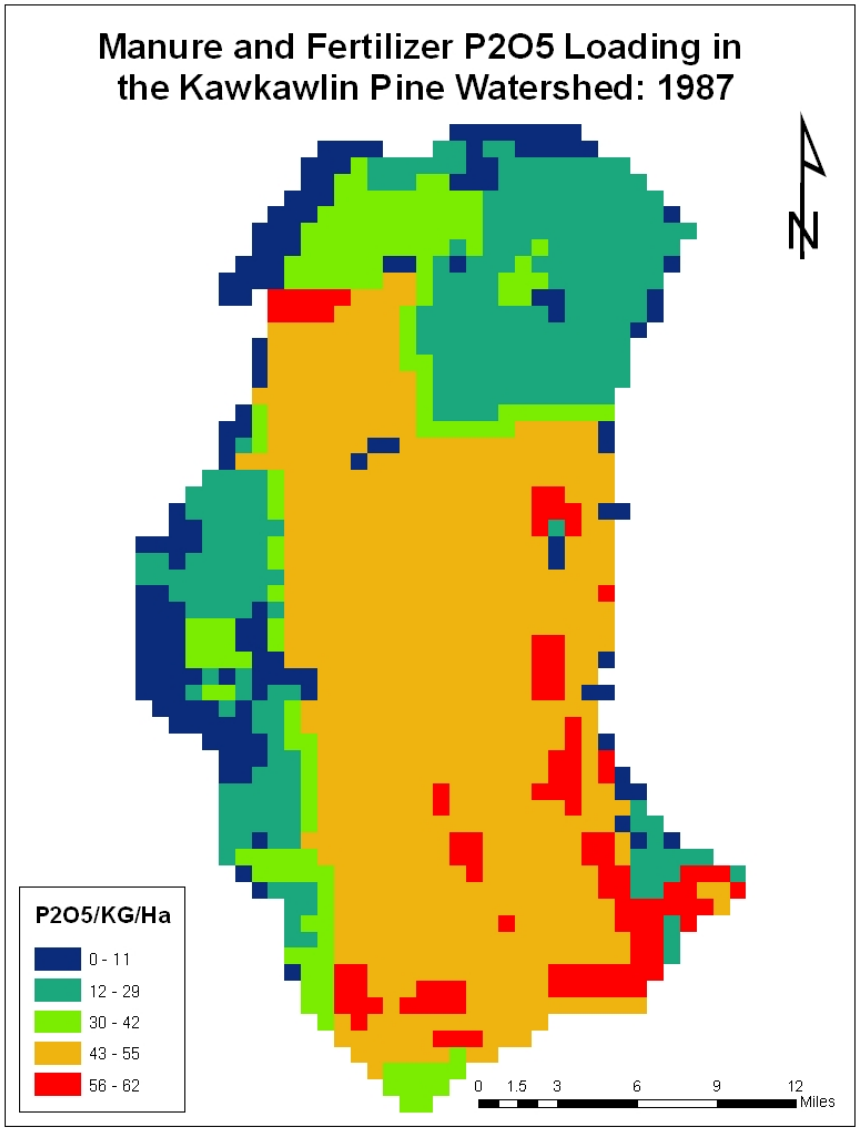
Manure and fertilizer application data compiled by Chansheng He, Western Michigan University

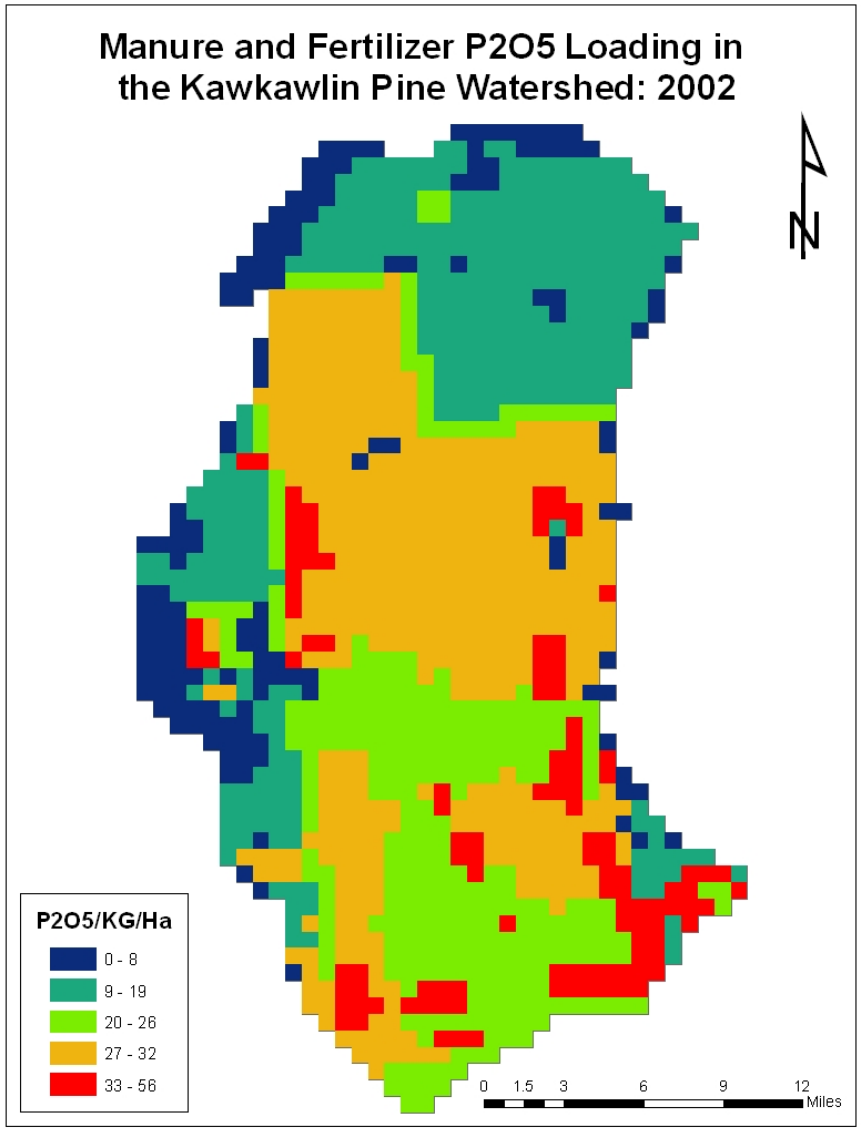
Au Gres – Rifle Watershed



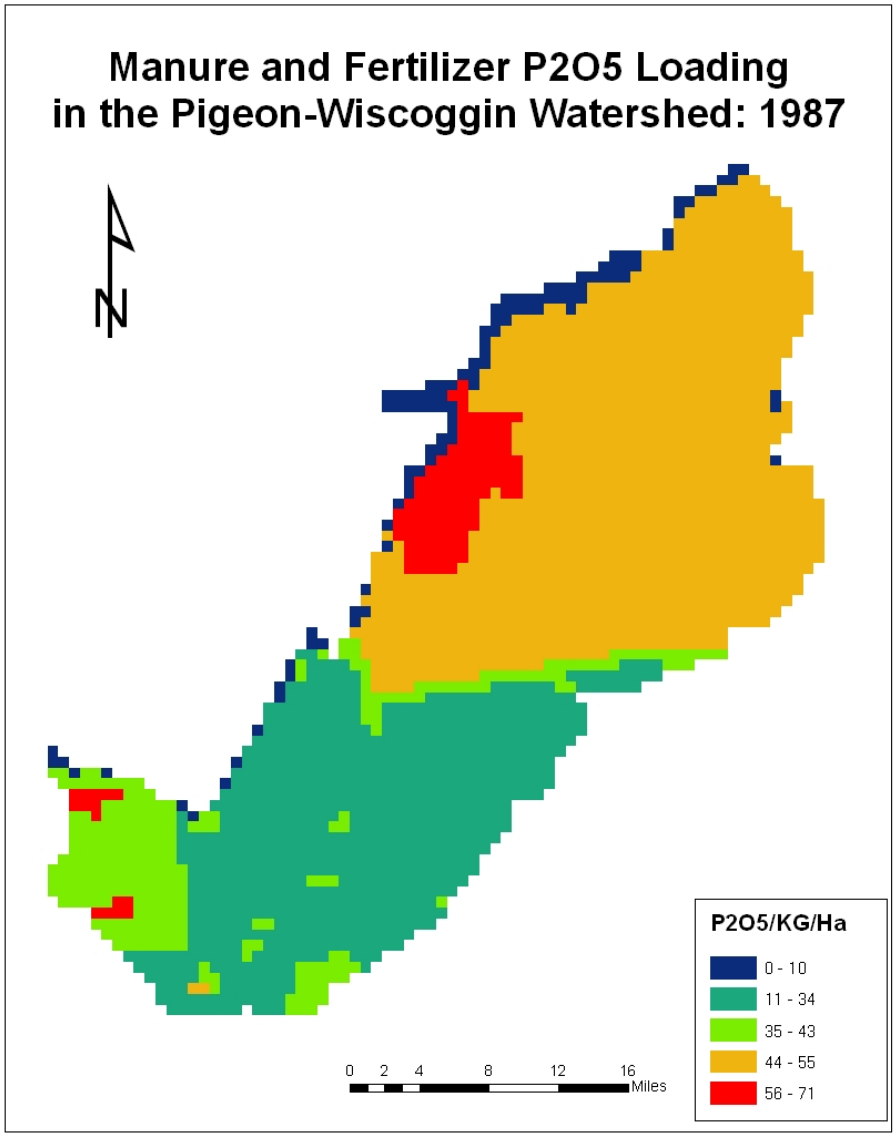


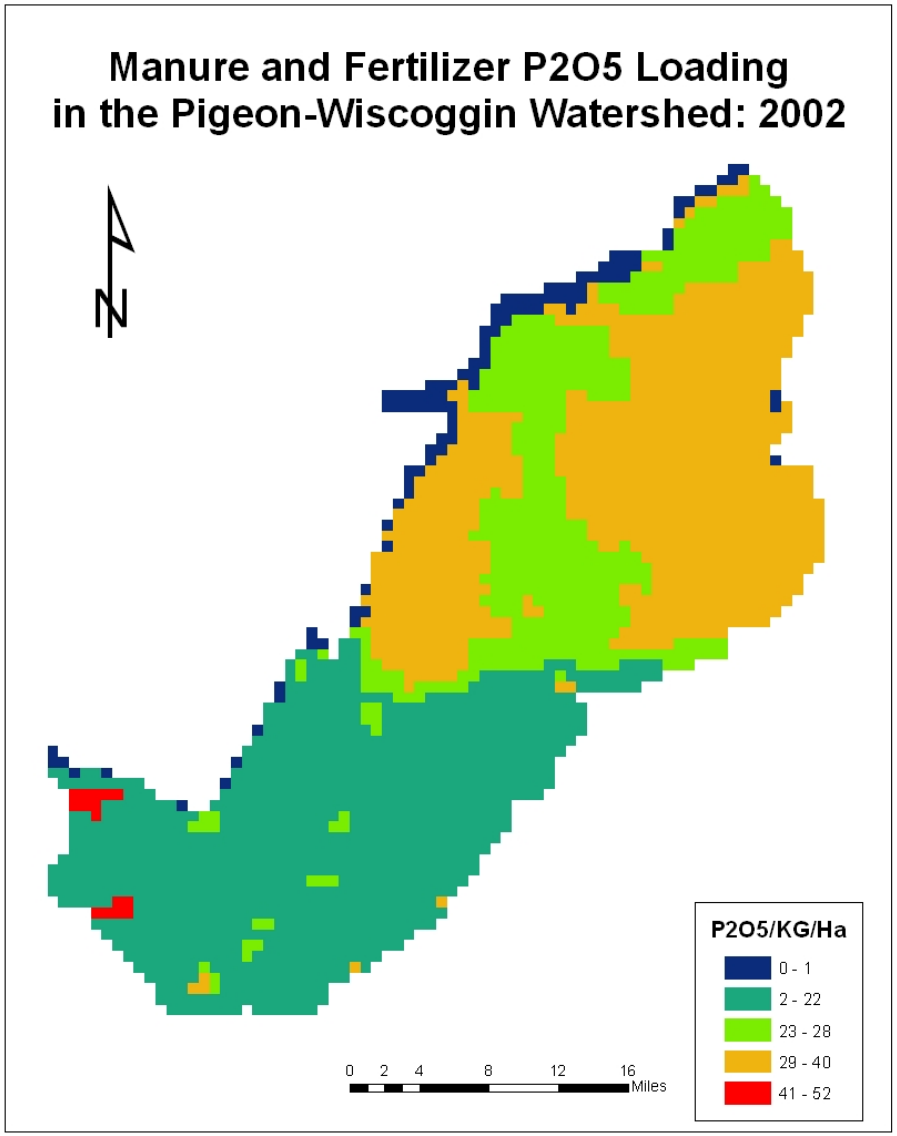
Kawkawlin – Pine Watershed



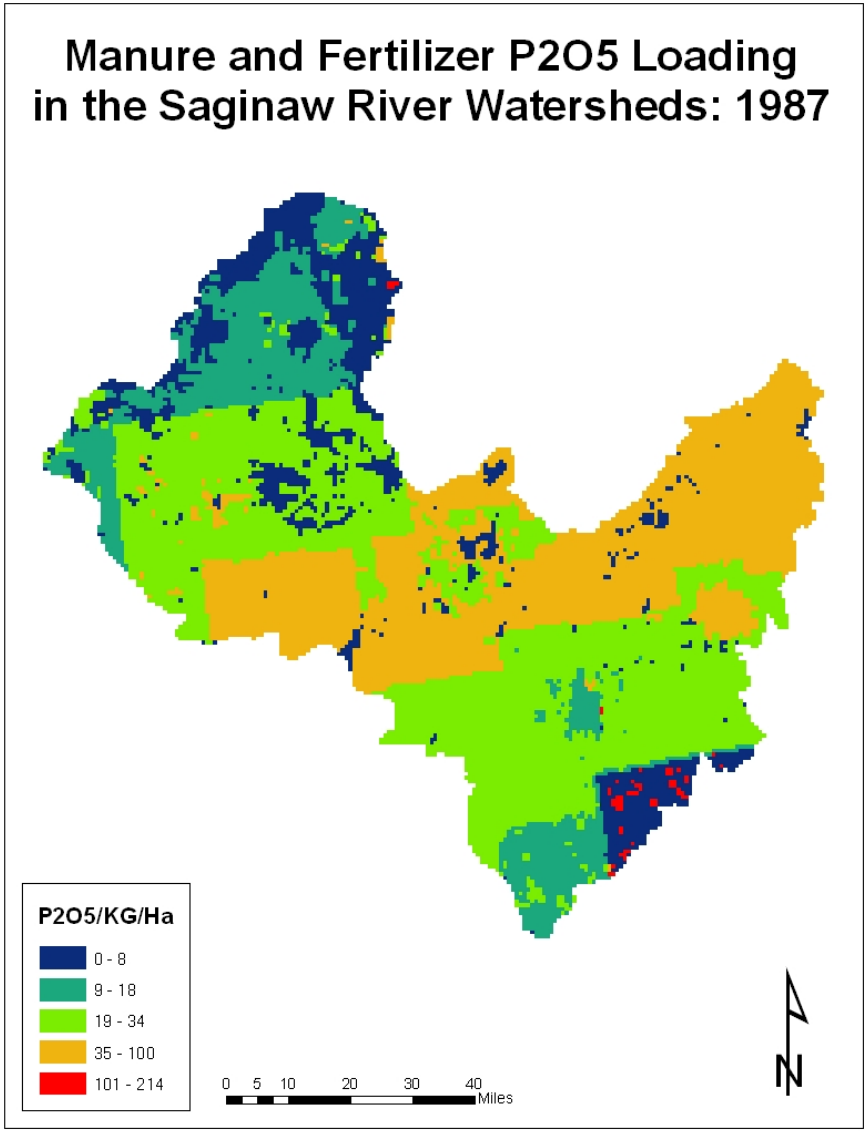


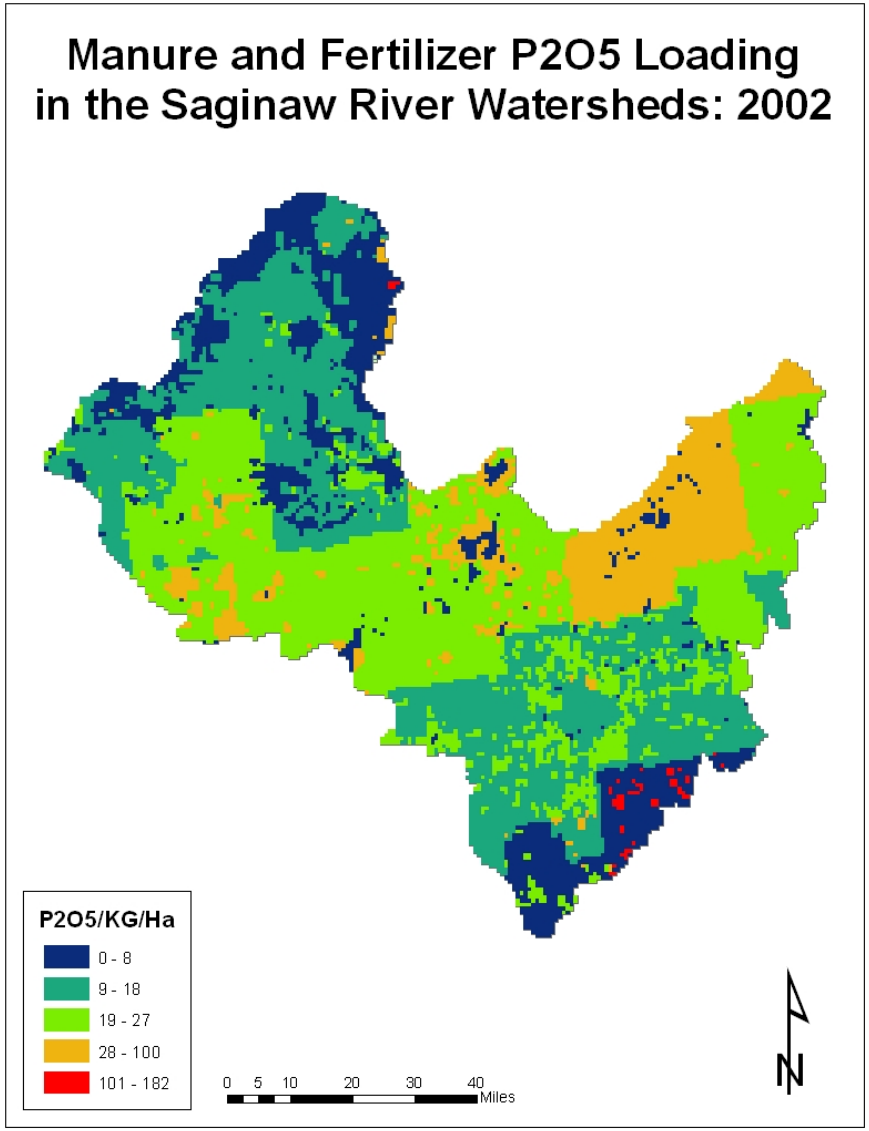
Pigeon – Wiscoggin Watershed





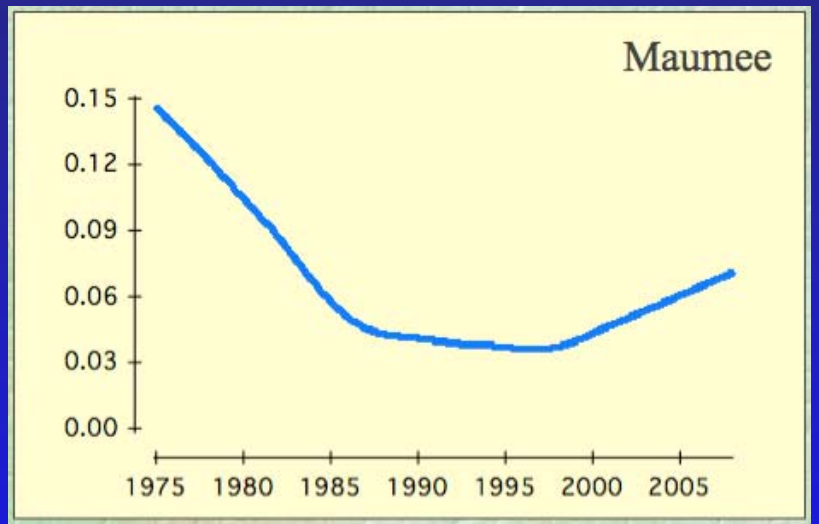
Saginaw River Watershed

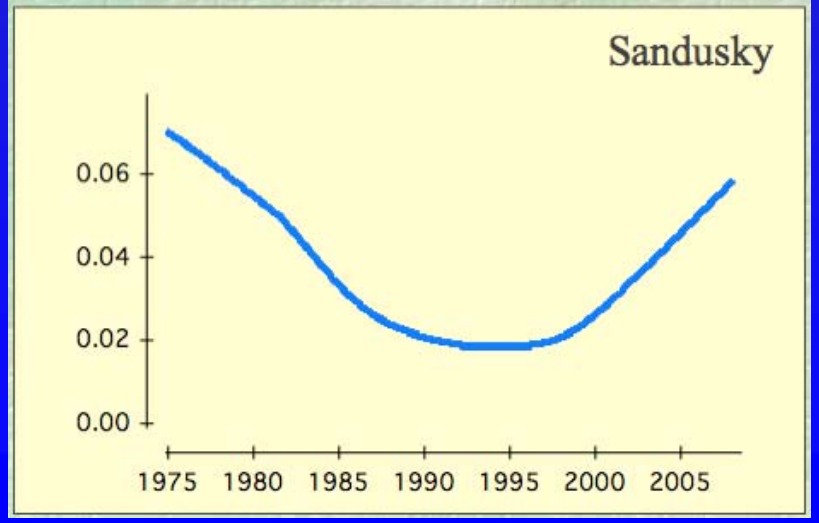




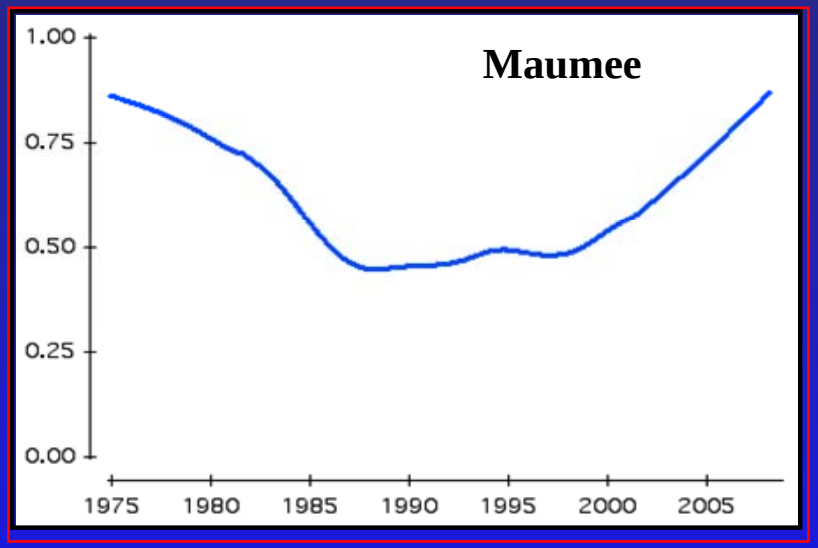
Heidelberg WQL Data for SRP, 1975-2007

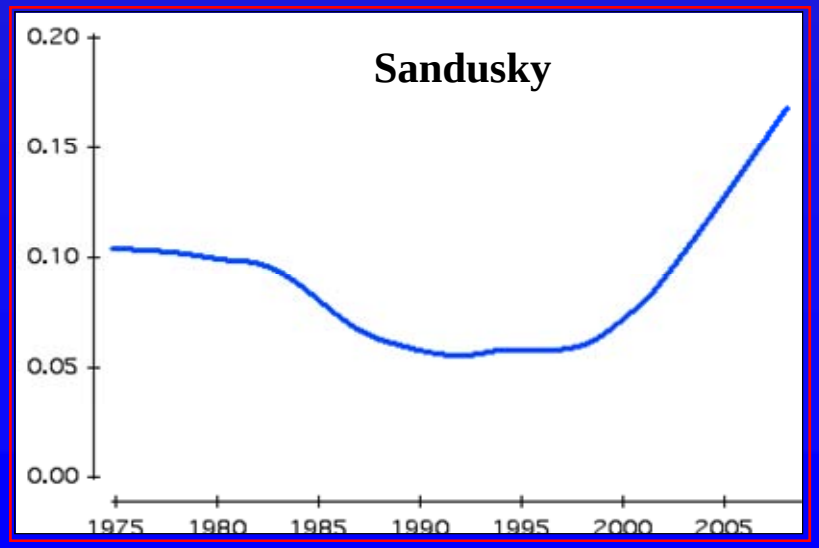
Ave. Daily Conc., mg/L

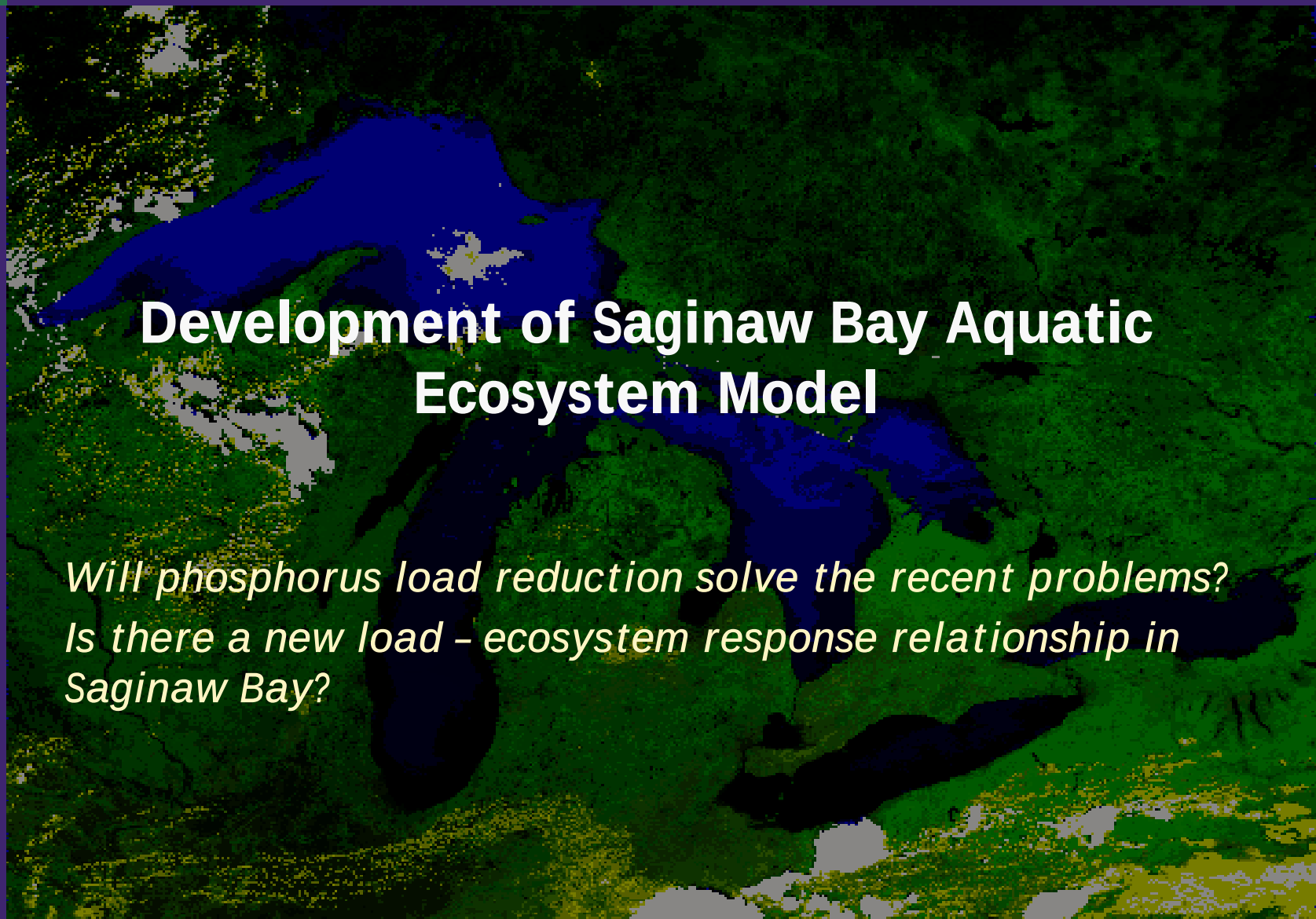




Ave. Daily Load, metric tons/day





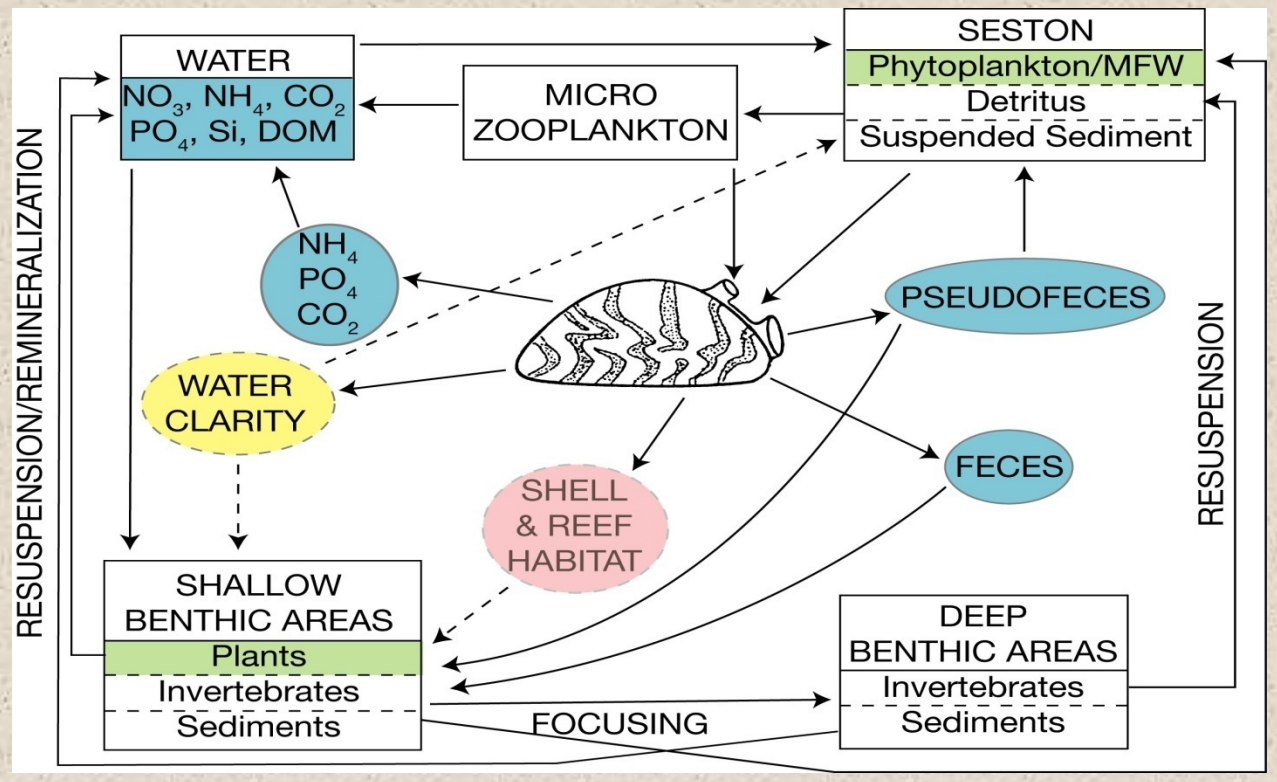


Development of Saginaw Bay Aquatic Ecosystem Model

Will phosphorus load reduction solve the recent problems?

Is there a new load – ecosystem response relationship in Saginaw Bay?

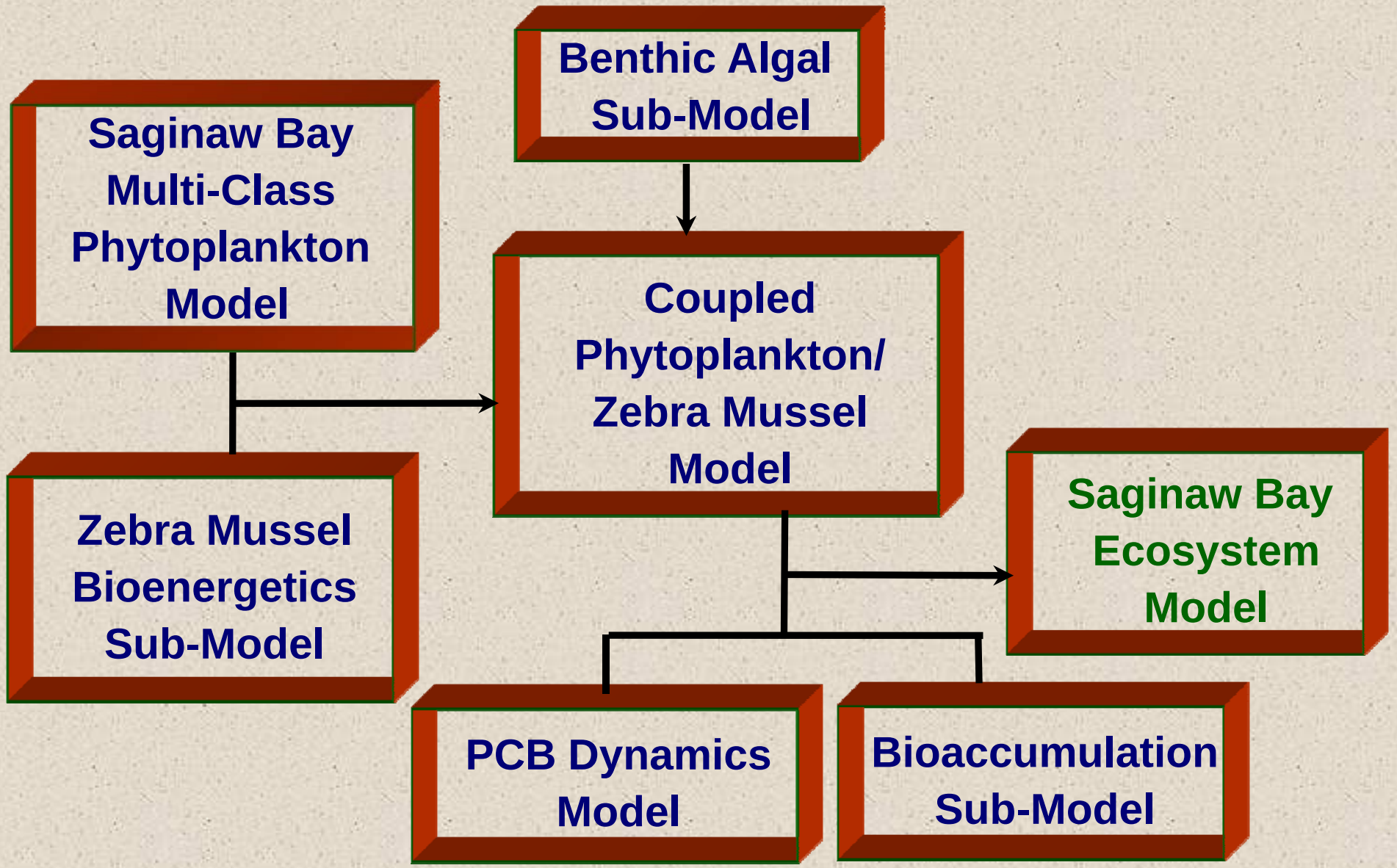
Dreissenids are Effective Ecosystem Engineers



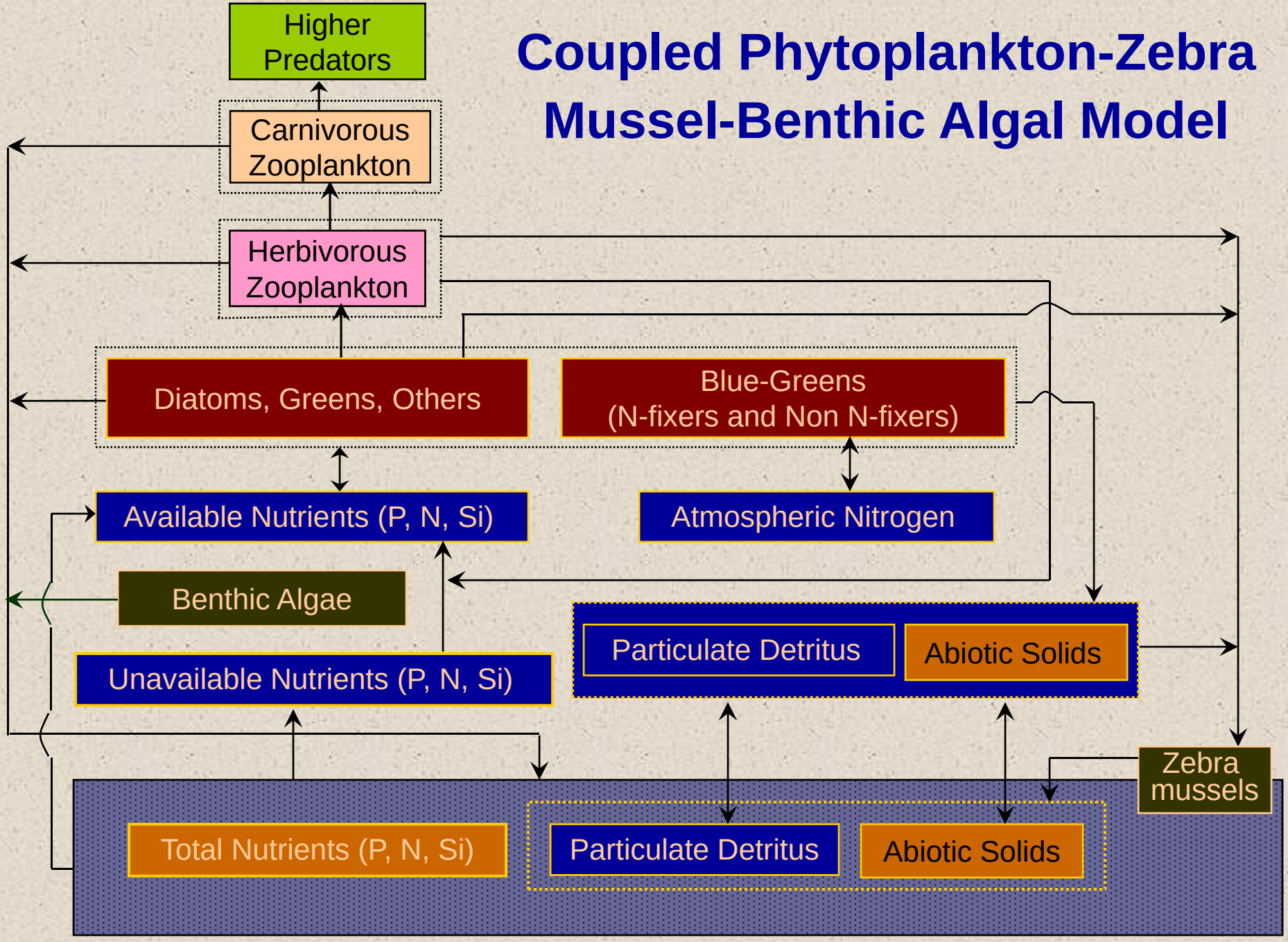
Vanderploeg, et. al., (2007)

Interactions of dreissenid mussels with other ecosystem components in shallow systems via mussel feeding, nutrient excretion (blue), and physical ecosystem engineering (habitat modification: yellow & red). Solid lines indicate material flow (C, nutrients, sediment), and broken lines indicate physical engineering effects.

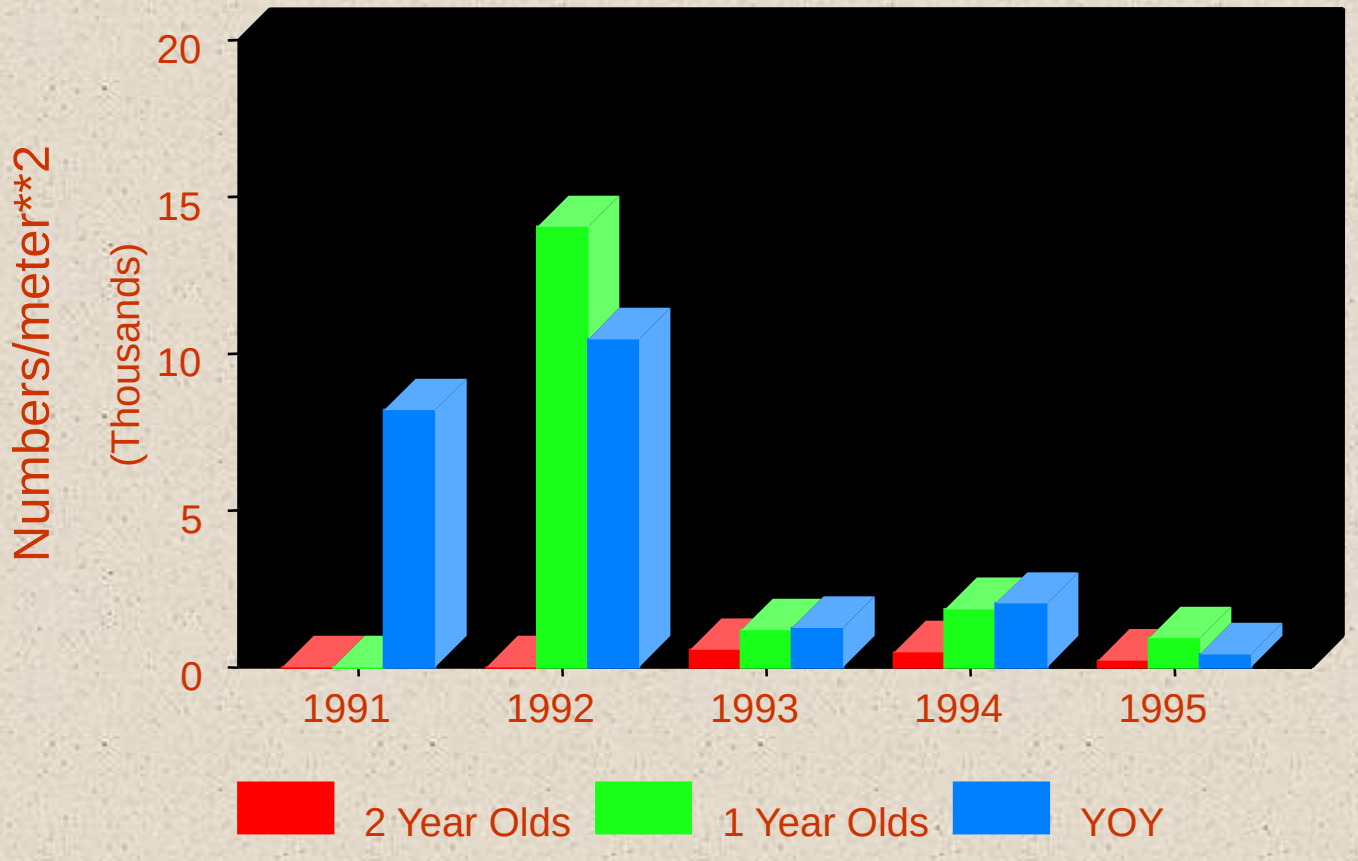
Model Development Concept



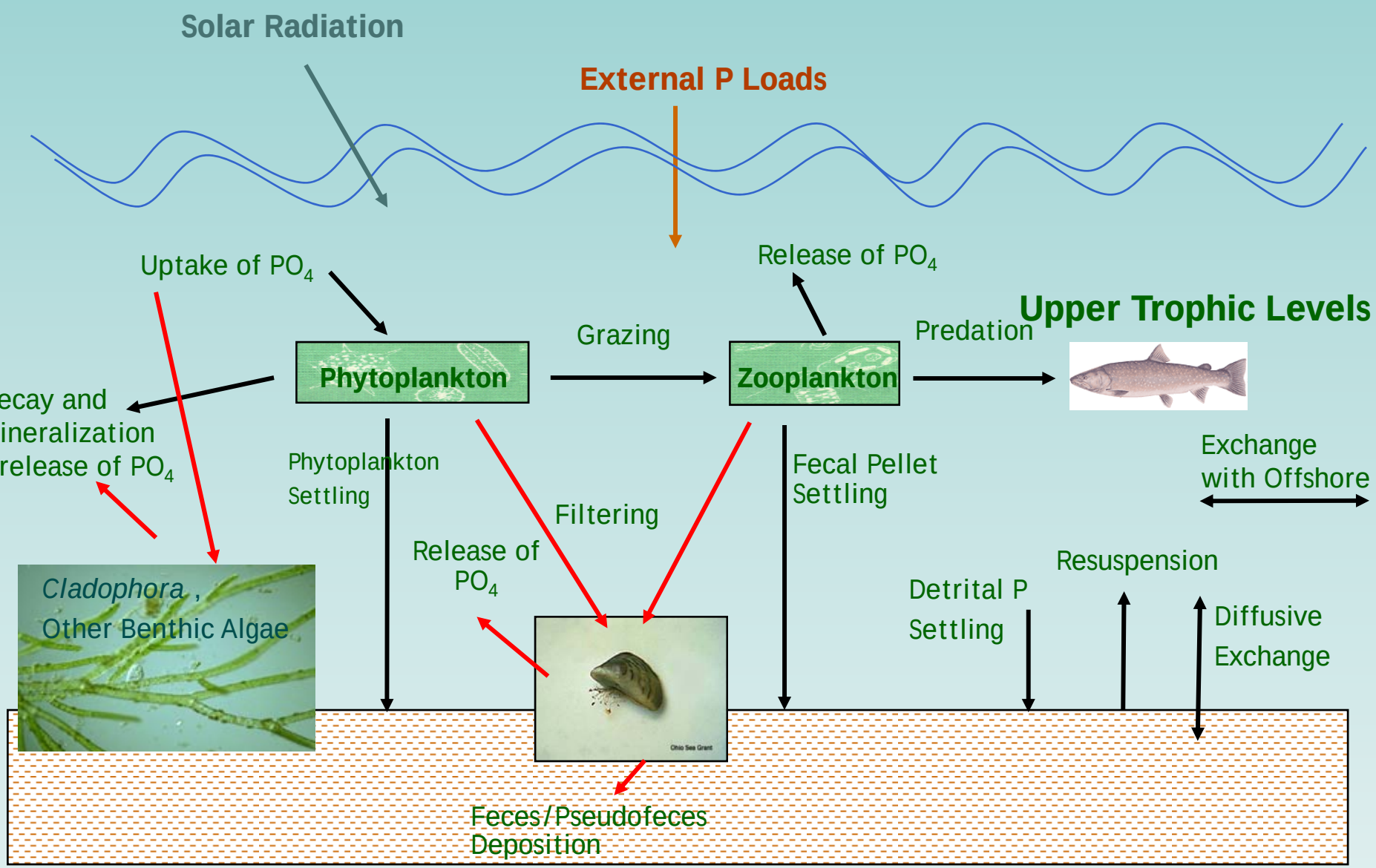
Coupled Phytoplankton-Zebra Mussel-Benthic Algal Model



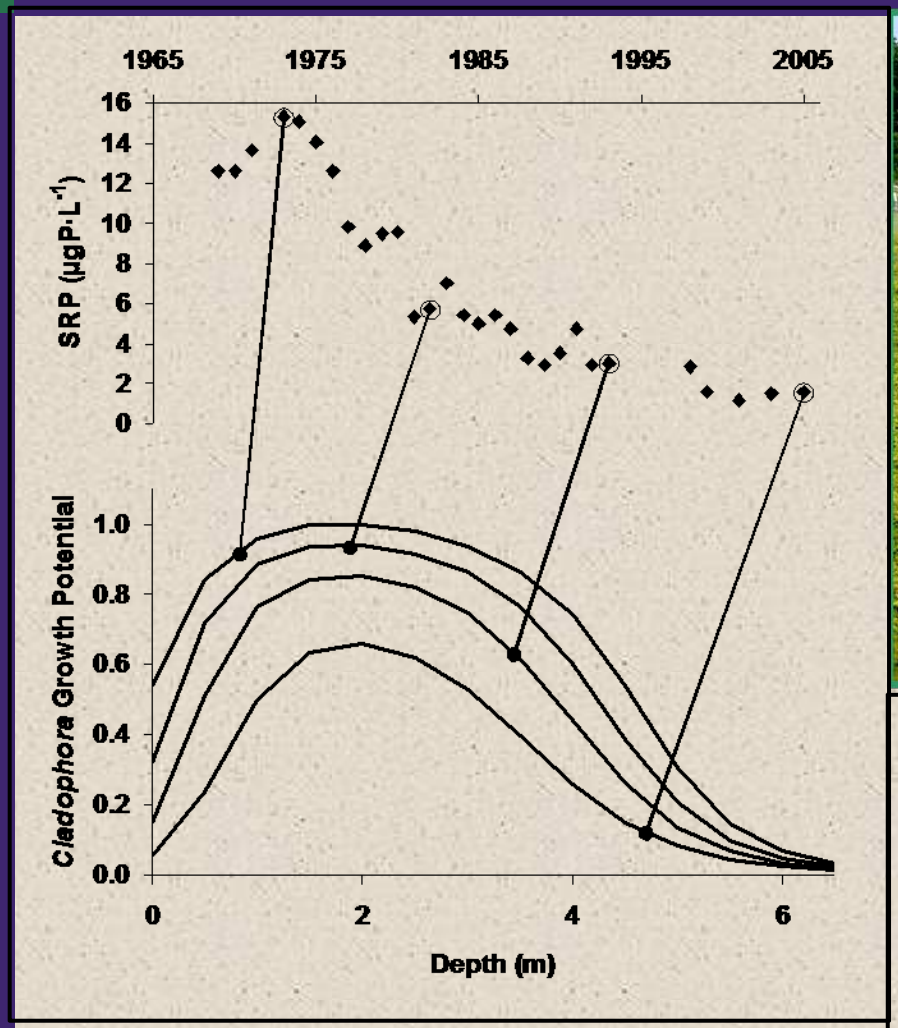
Zebra Mussel Input Conditions
(data from NOAA-GLERL)

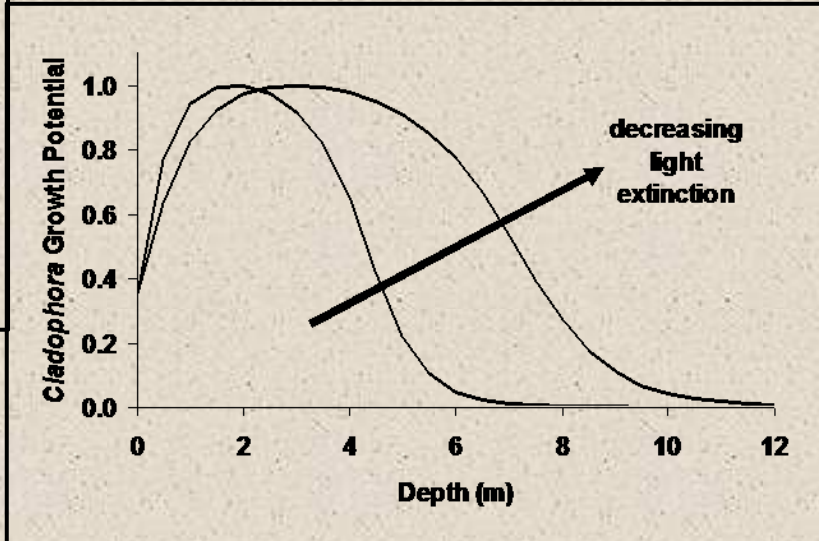


Phosphorus Cycling in New Saginaw Bay Ecosystem



Chladophora Respond to Nearshore SRP and Light Availability (Auer, Higgins, et al.)



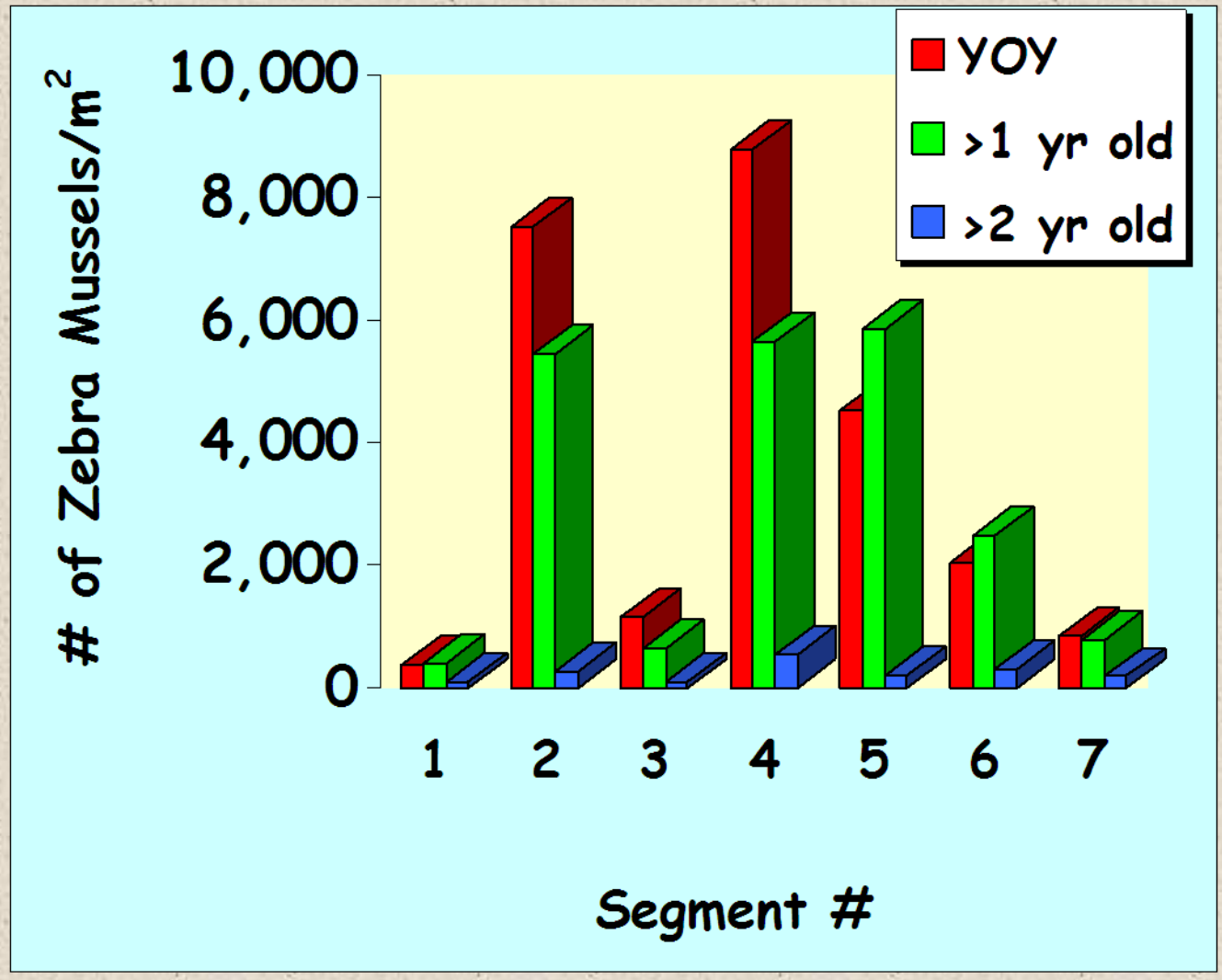


Use of SAGEM to Understand Nutrient - Trophic Changes

Modeling Protocol

- Start with phytoplankton-zebra mussel model confirmed with 1991 field data
- Incorporate zebra mussel and benthic algae sub-models
- Run diagnostic comparisons with, in general:
  - No zebra mussels
  - Zebra mussels at 1991-1995 average densities
  - Adjustments by:
    - inclusion/exclusion of P cycling processes
    - Allowing mussels to filter blue-greens

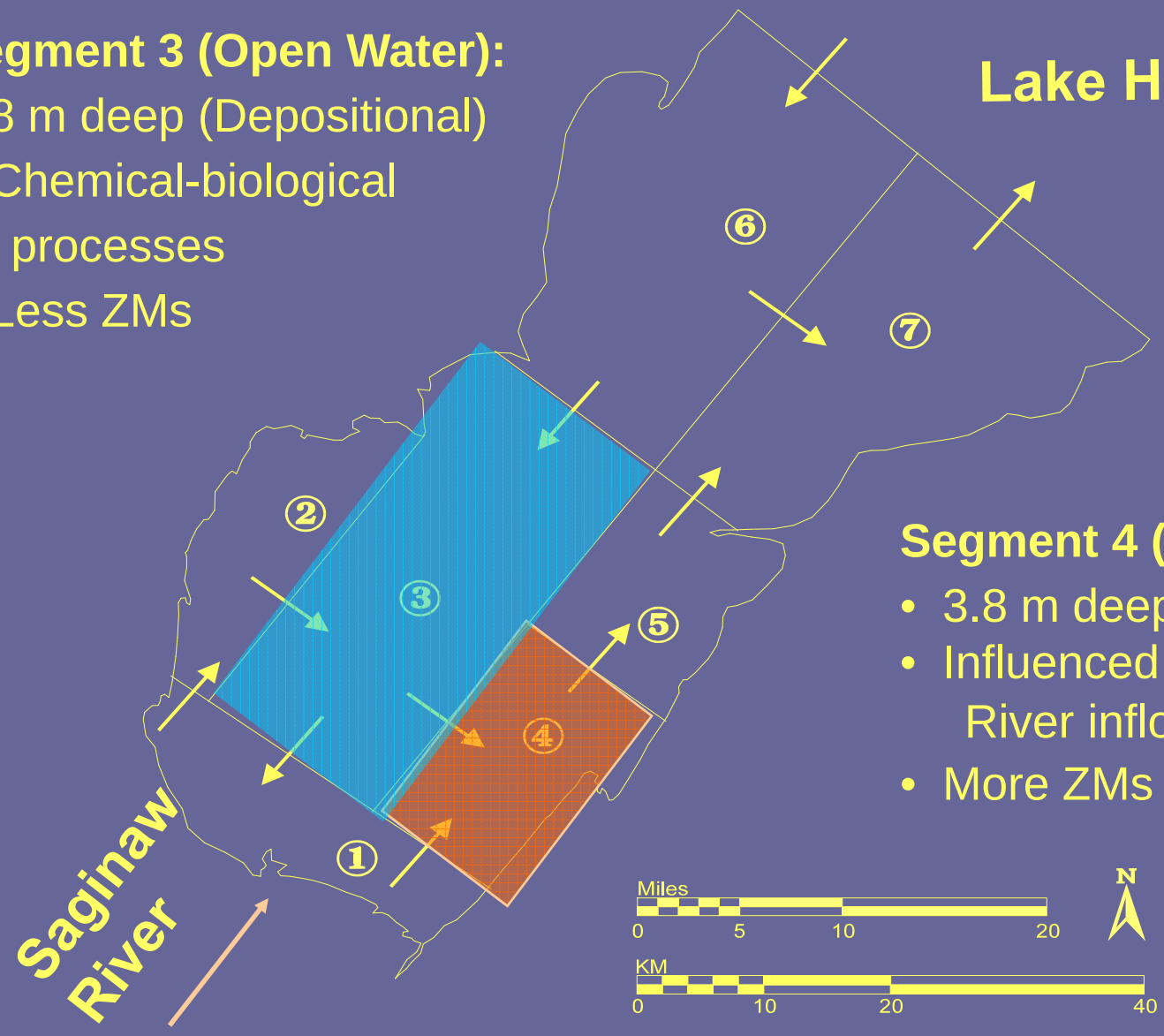
Zebra Mussel Densities
(Avg. 1991-1995)



Open Water and Near Shore Regions

Segment 3 (Open Water):

- 8 m deep (Depositional)
- Chemical-biological processes
- Less ZMs

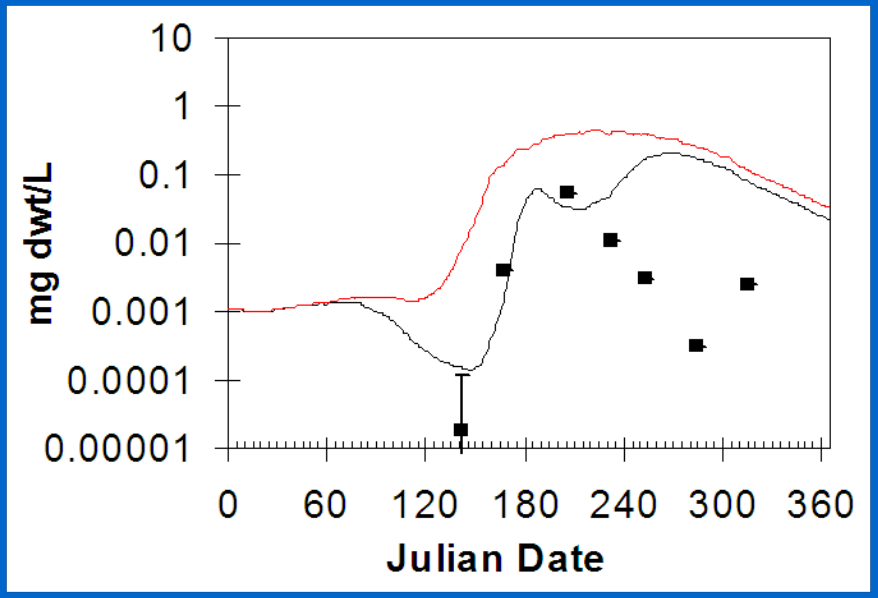


Segment 4 (Near Shore):

- 3.8 m deep
- Influenced by Saginaw River inflow
- More ZMs

Time Series for Total Blue-Greens

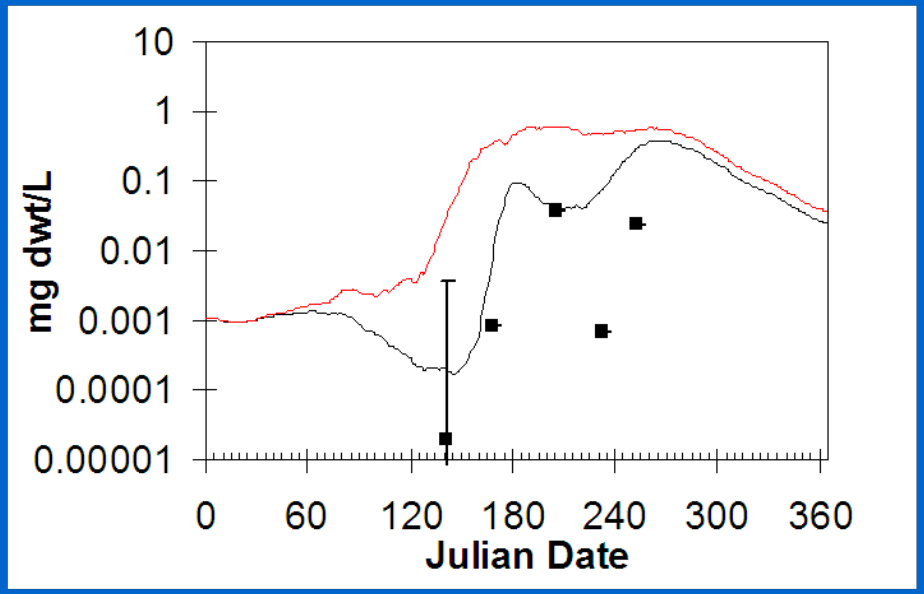
(Adding zebra mussels to base run)



Open Water

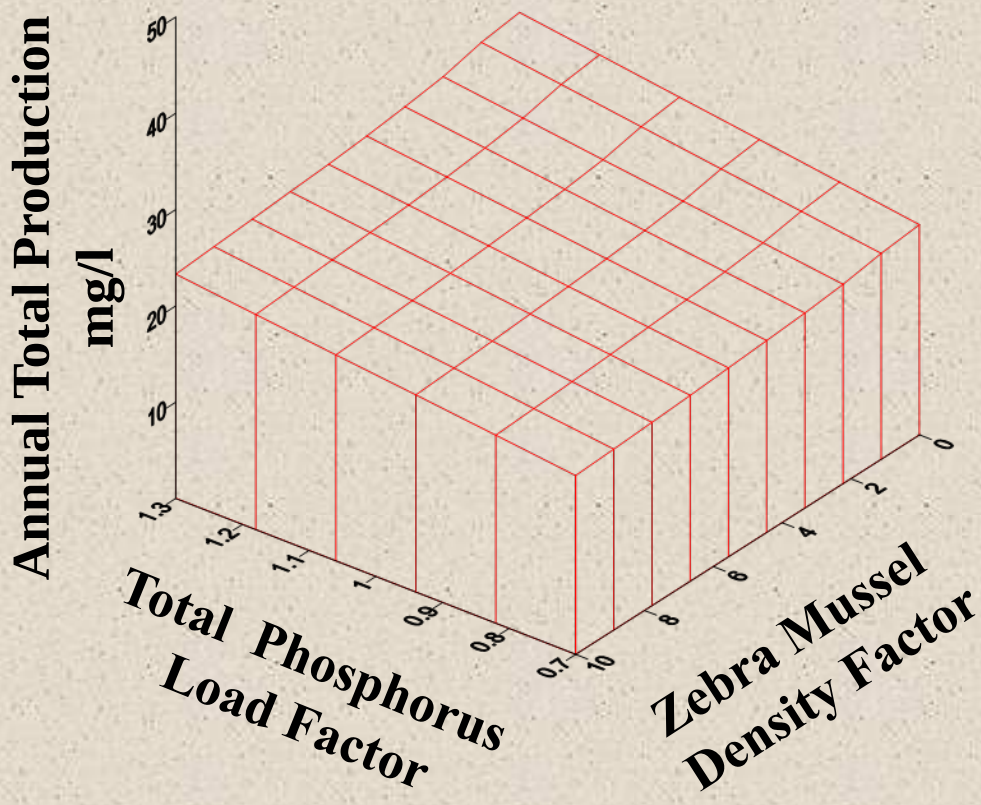
- Base Run
- With zebra mussels
- Data 1991

Near Shore

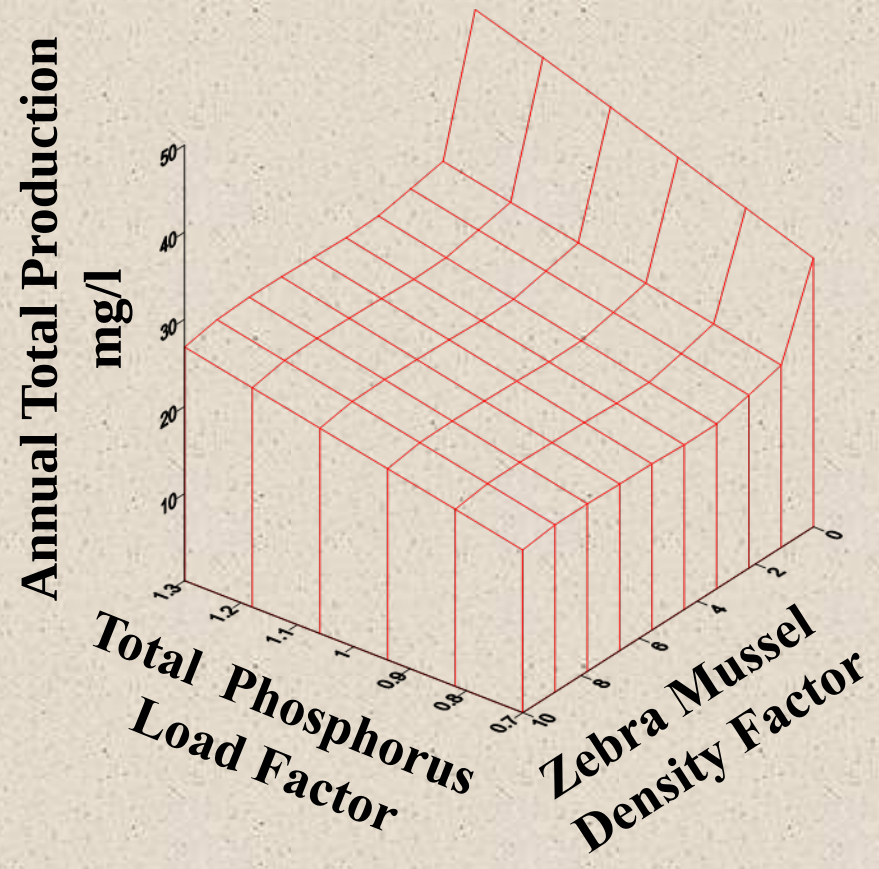


Model Diagnostic Results

Open Water Responses

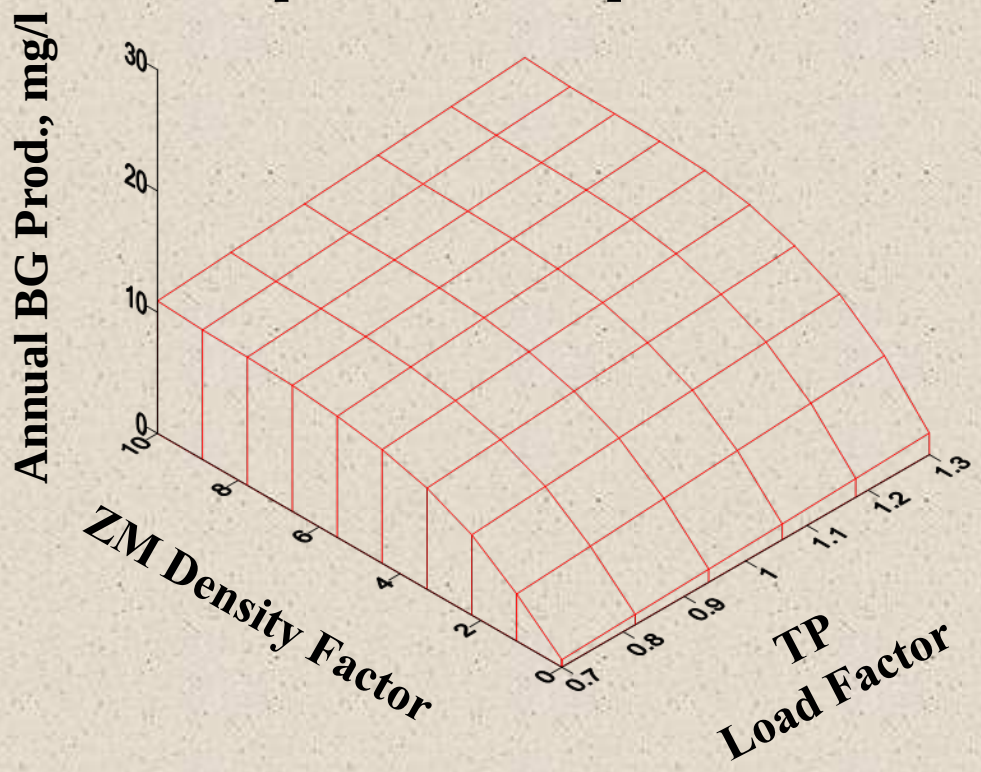


Near Shore Responses

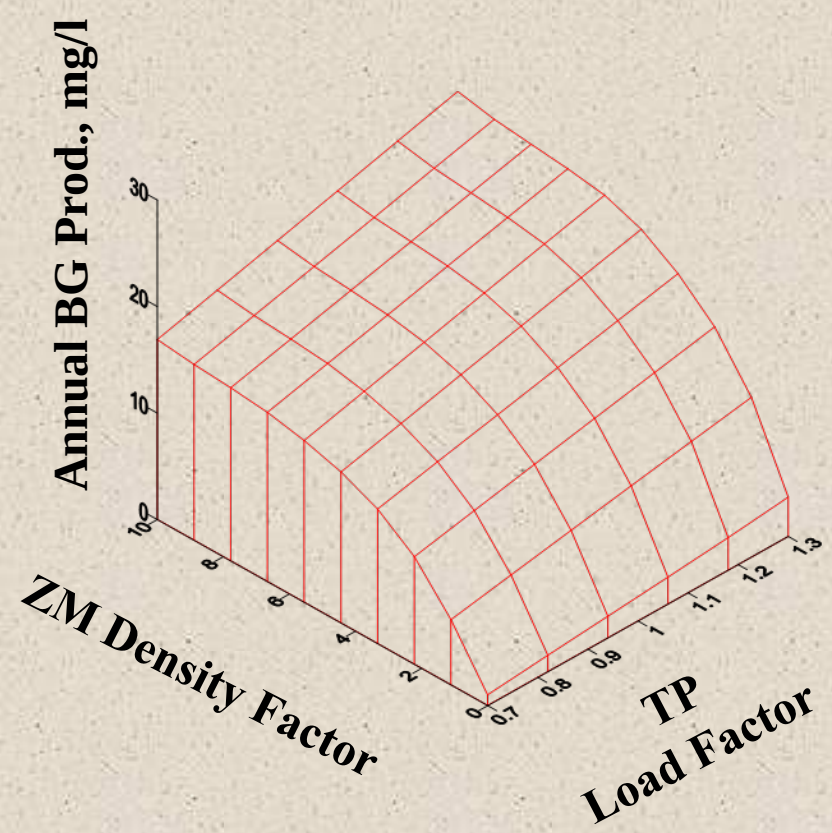


Model Diagnostic Results

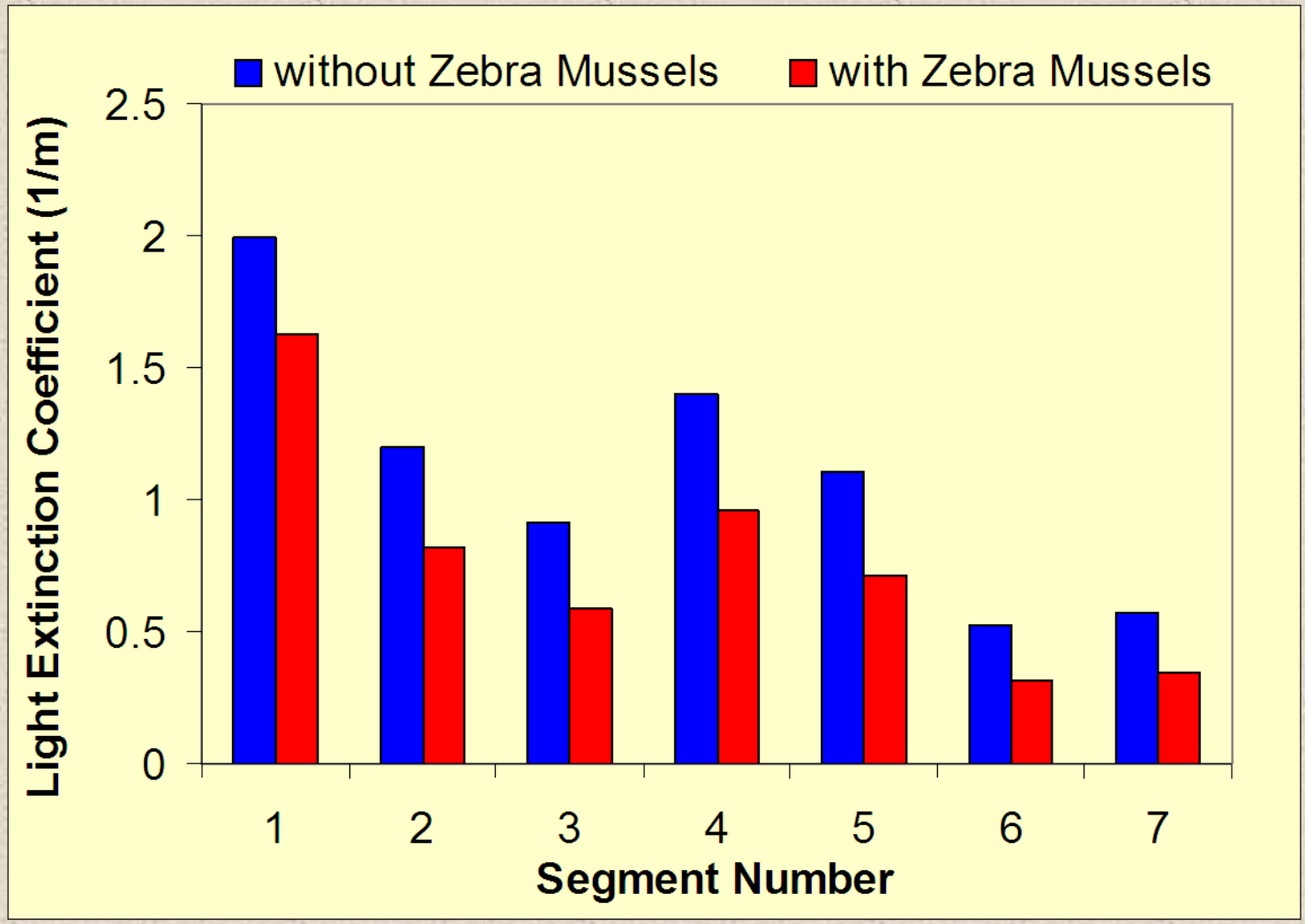
Open Water Responses



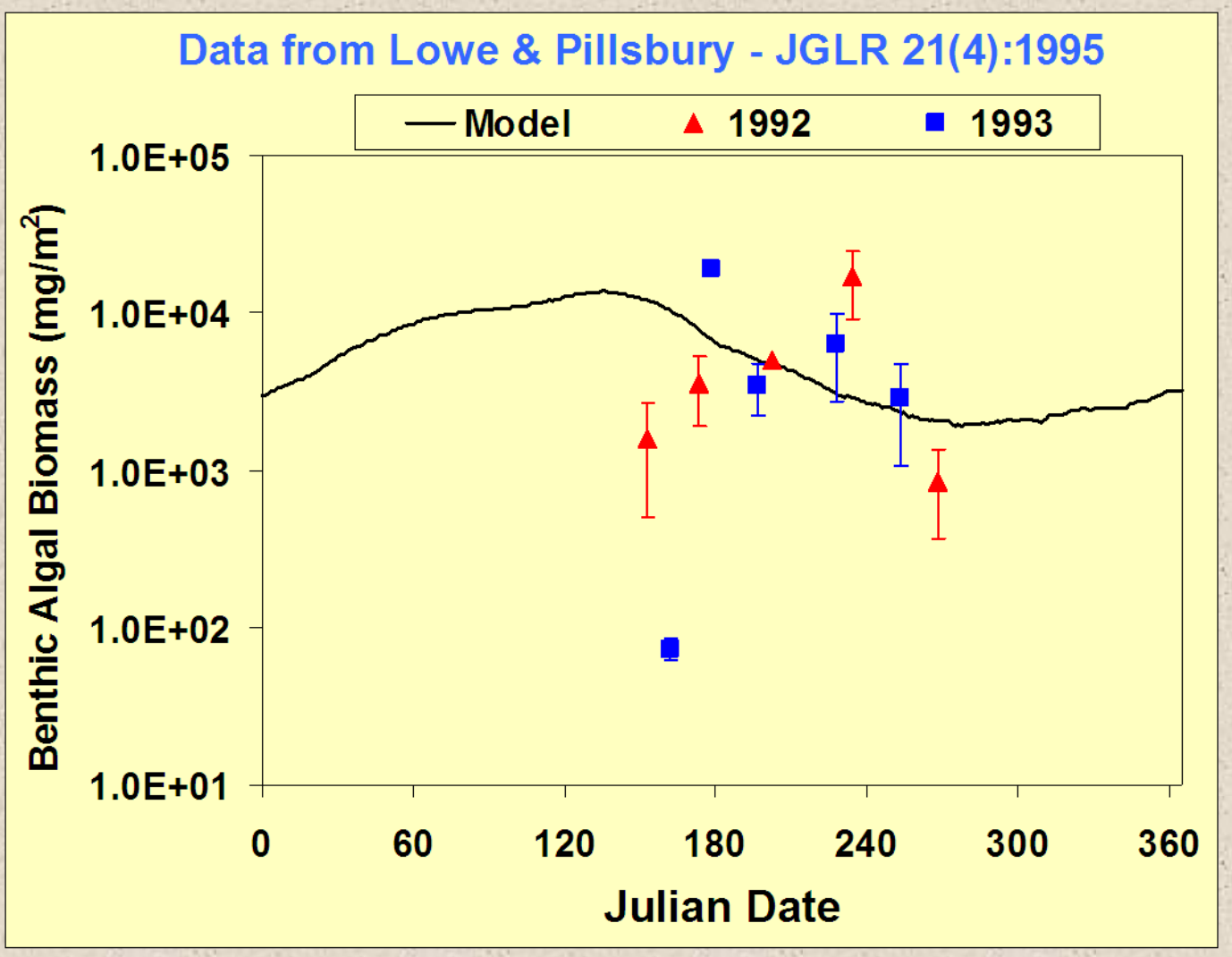
Near Shore Responses



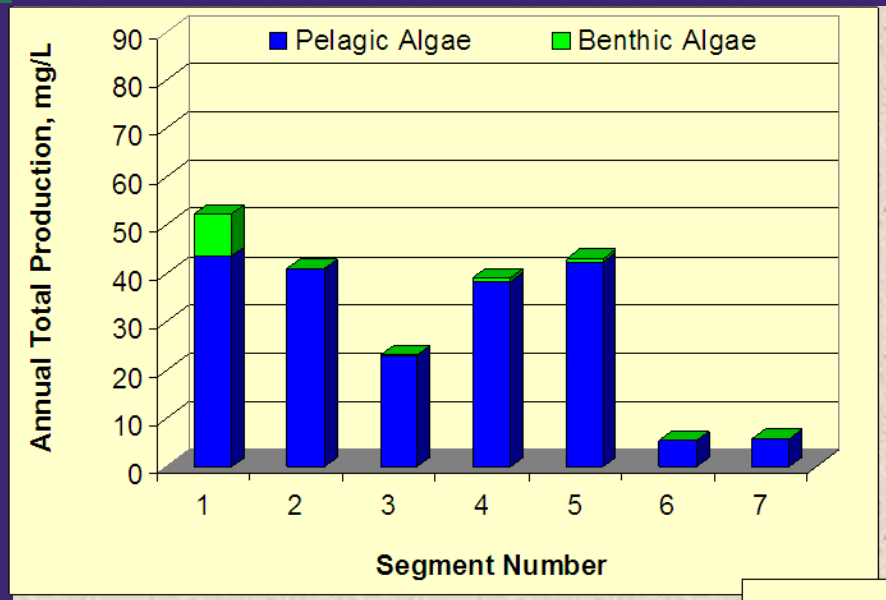
Effect of Mussels on Light Penetration



Model Data Comparison

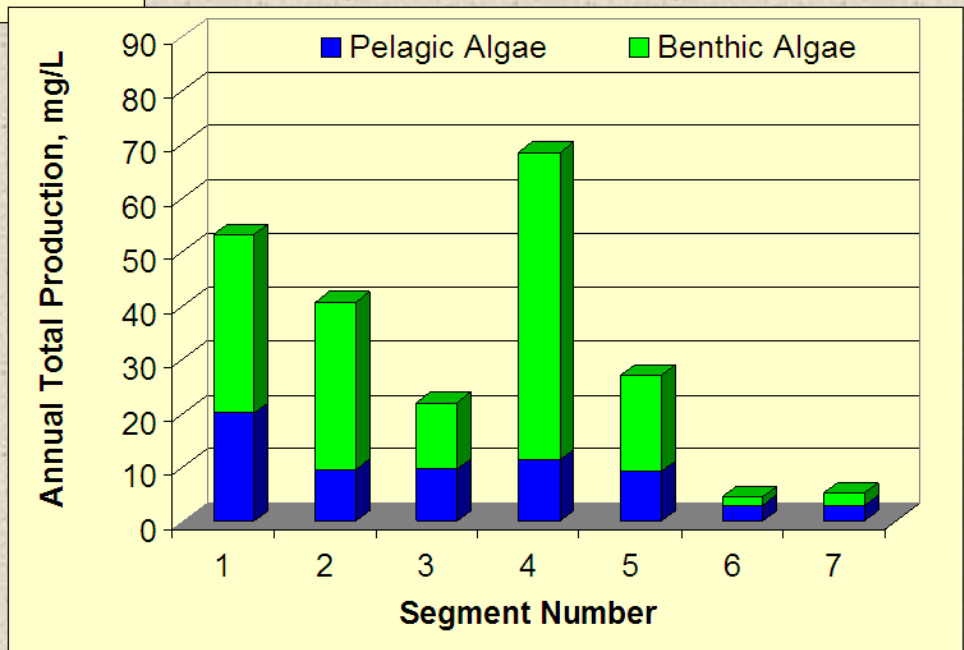


Increased Water Clarity Promotes Benthic Primary Production

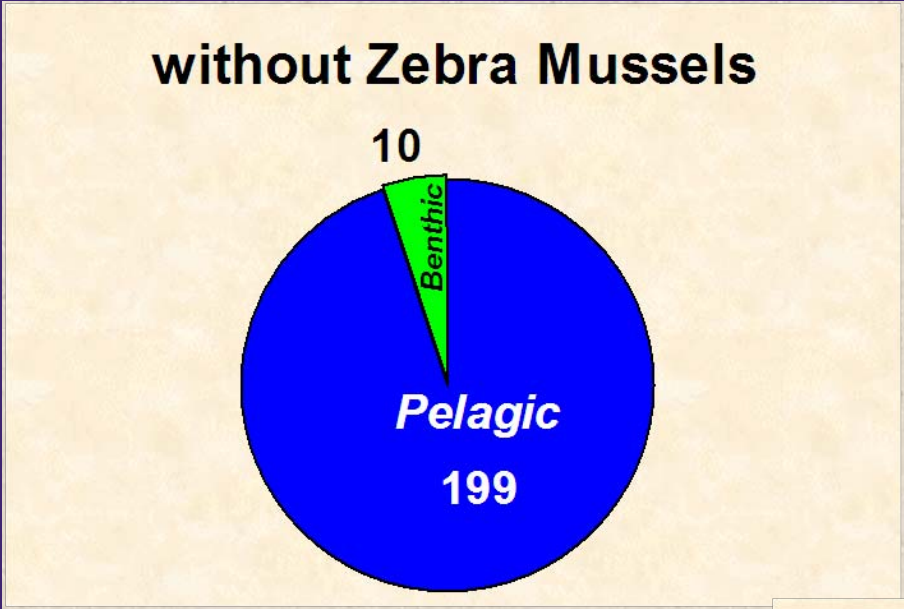


Scenario 1 – No Zebra Mussels

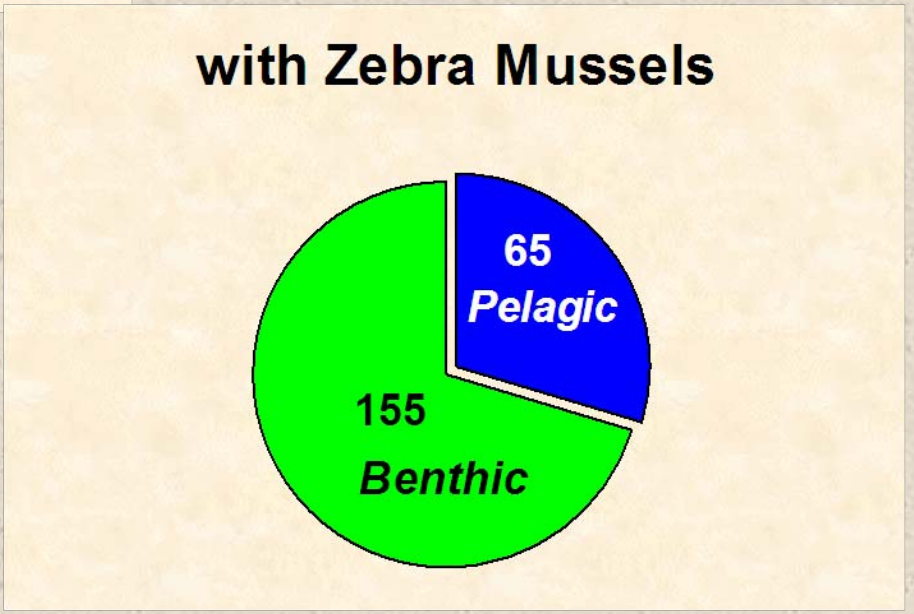
Scenario 2 – Zebra Mussels



Bay-wide Primary Production



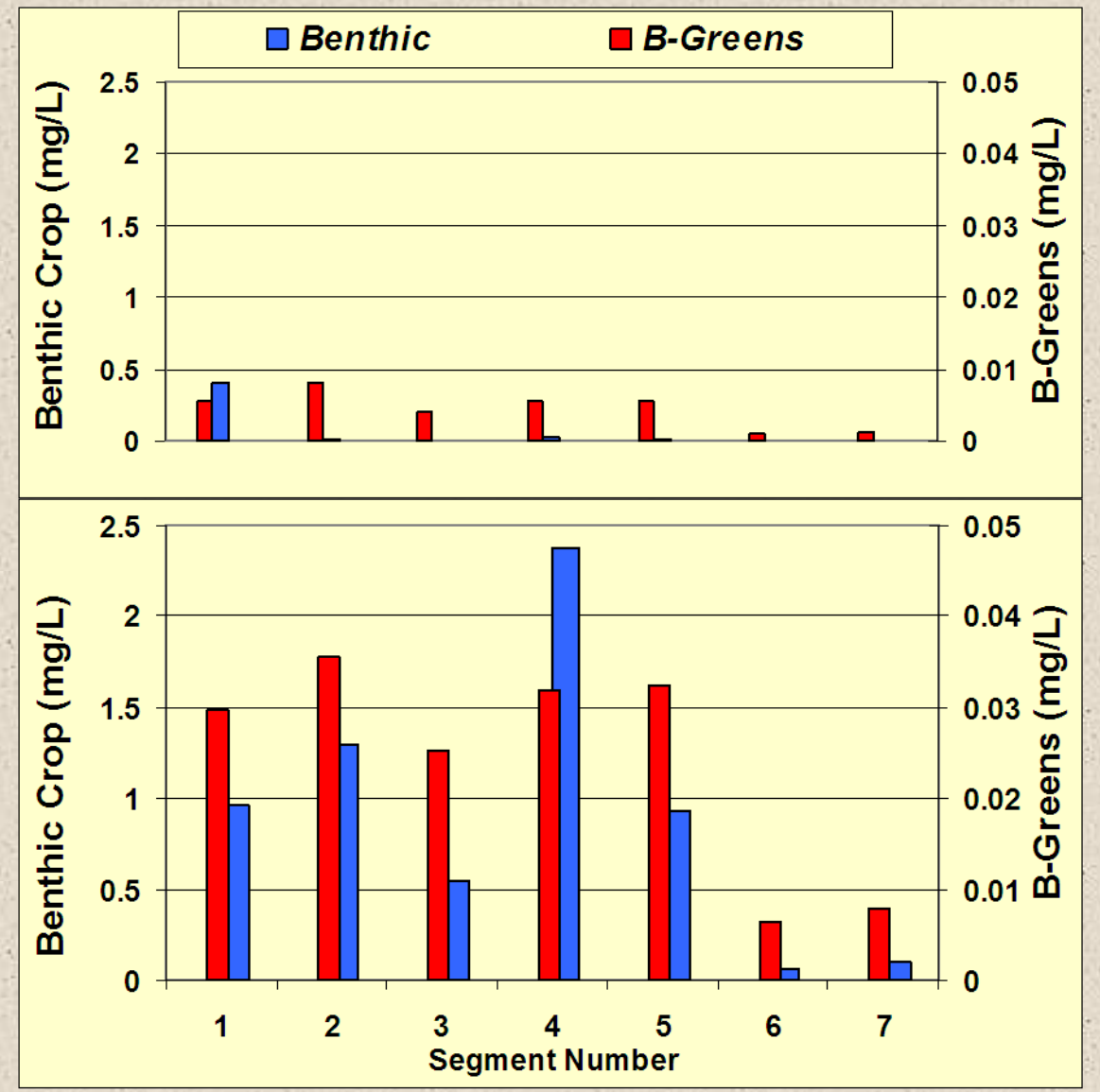
Gross Production Remained Same



Blue-Greens and Benthic Algae Response

Without Zebra Mussels

With Zebra Mussels



Summary of Trophic Impacts

- Total phytoplankton production is directly proportional to external phosphorus load and inversely proportional to zebra mussel density.
- Blue-green production is directly proportional to external phosphorus load and zebra mussel density.
- Selective rejection of blue-greens by zebra mussels appears to be a necessary factor in enhancement of blue-green production in the presence of zebra mussels, but late summer P recycle is also necessary.
- Zebra mussel invasion of Saginaw Bay did not appear to significantly alter total system primary production, but shifted a substantial portion of system primary production from the pelagic to the benthic compartment due to increase in water clarity

Summary of Trophic Impacts

- Phosphorus is the limiting nutrient in Saginaw Bay, and P recycle is important to maintaining late-summer phytoplankton production even in the absence of zebra mussels.
- The presence of zebra mussels alters P recycle by introducing a benthic recycle pathway (zebra mussel P recycle) that accounts for approximately half of the internal P recycle in the system.

- Summary of Impacts
  - Alteration of phosphorus cycling – new recycle process
  - Alteration of phytoplankton speciation – enhanced blue-green production
  - Alteration of primary production - benthification

Next Steps – Saginaw Bay Multi-stressor Project

- Upgrades of Saginaw Bay Ecosystem Model (SAGEM)
  - Link SAGEM to fine-scale hydrodynamic model
  - Add *Cladophora* sub-model to SAGEM
  - Add upper food web (fish) to SAGEM
- Run revised SAGEM for entire 1991-97 to confirm model and evaluate full impact of zebra mussels on nutrient-trophic relationships
- Apply model to help design and interpret Project field monitoring/experimental program
- Apply watershed and bay models to evaluate alternative management scenarios for Saginaw Bay

Questions/Discussion

KEEP 'EM GREAT

Joseph V. DePinto
LimnoTech
jdepinto@limno.com

LimnoTech
Water | Environment | Scientists | Engineers

Saginaw Bay
Multiple Stressors