Lake Erie Phosphorus Task Force
October 1, 2008
Columbus, OH

How does Lake Erie process the phosphorus loading it receives, and has the Dreissenid invasion changed things?

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LimnoTech
Water | Environment | Scientists | Engineers

Outline of Presentation

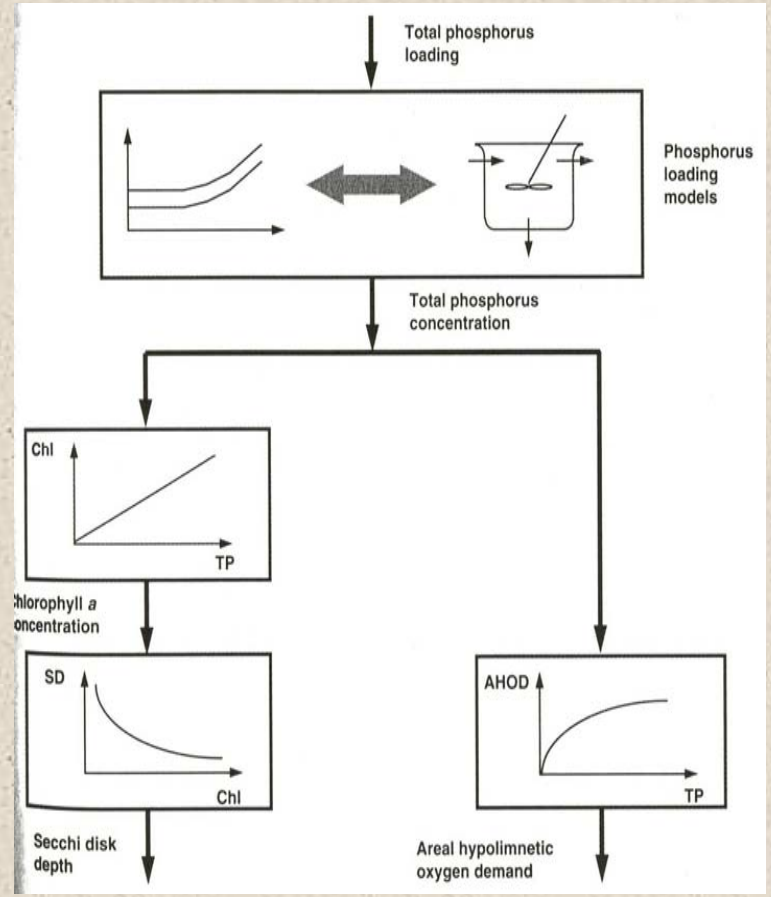
- What we learned during the pre-dreissenid era
  - Internal phosphorus cycling (DiToro and Connolly)
  - Bioavailability studies and impact on Lake Erie modeling
  - Sediment diagenesis modeling (Fitzpatrick)
  - Impact of hypoxia on P flux from sediments
- How has the dreissenid invasion changed things
  - Modeling ecological impacts of dreissenids
  - Hypothesis of new ecosystem functioning – the nearshore-offshore paradox
- Approaches to develop a new management paradigm
  - Ongoing programs
  - Proposed program GLEMM

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

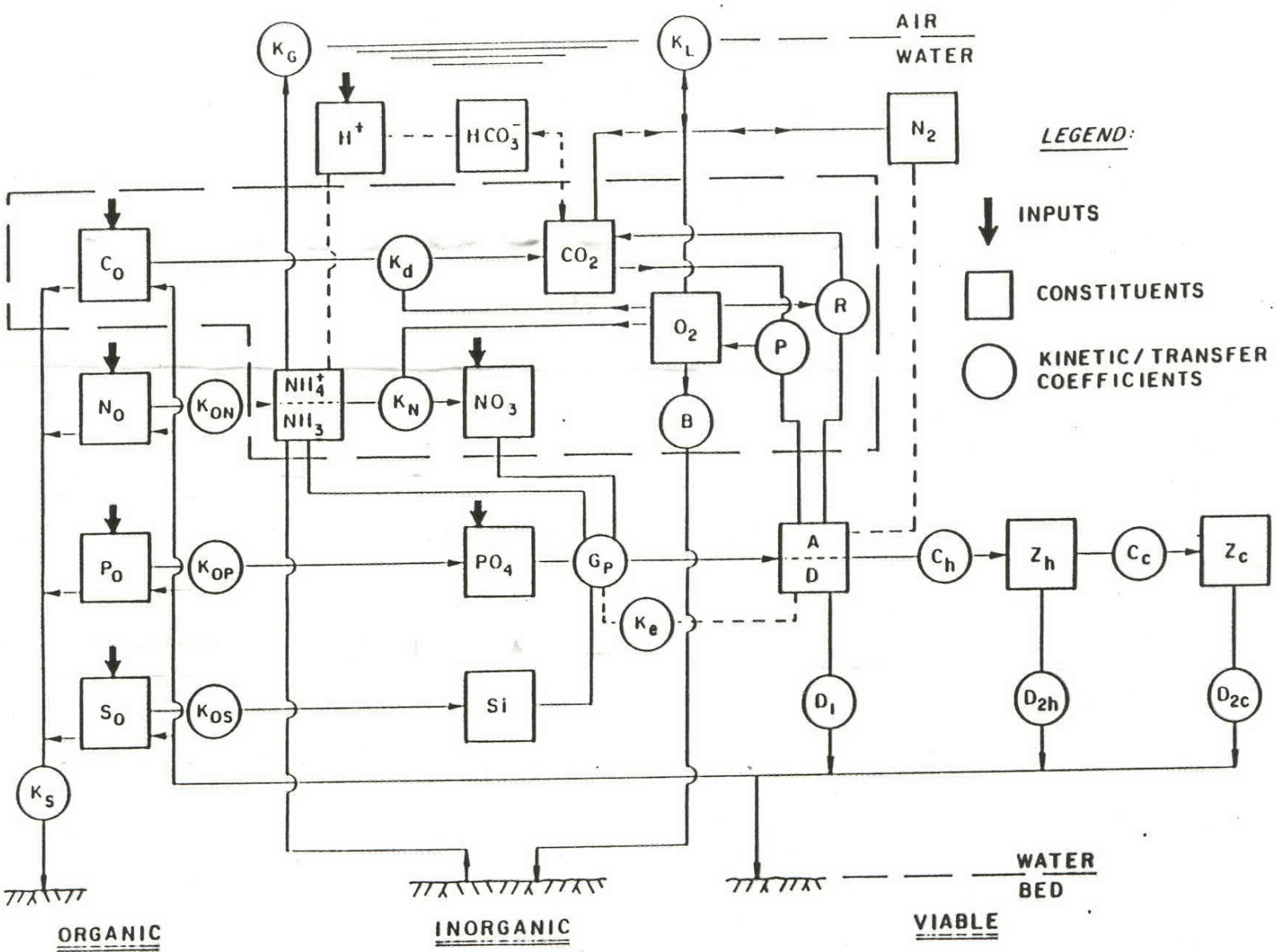
- Public concern leads to political action
- 1972 signing of Binational Great Lakes Water Quality Agreement (GLWQA)
  - "restore and maintain the chemical, physical, and biological integrity of the Great Lakes Basin Ecosystem."
- Annex 3 (1978)
  - Implicated phosphorus as primary cause of nuisance algal 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

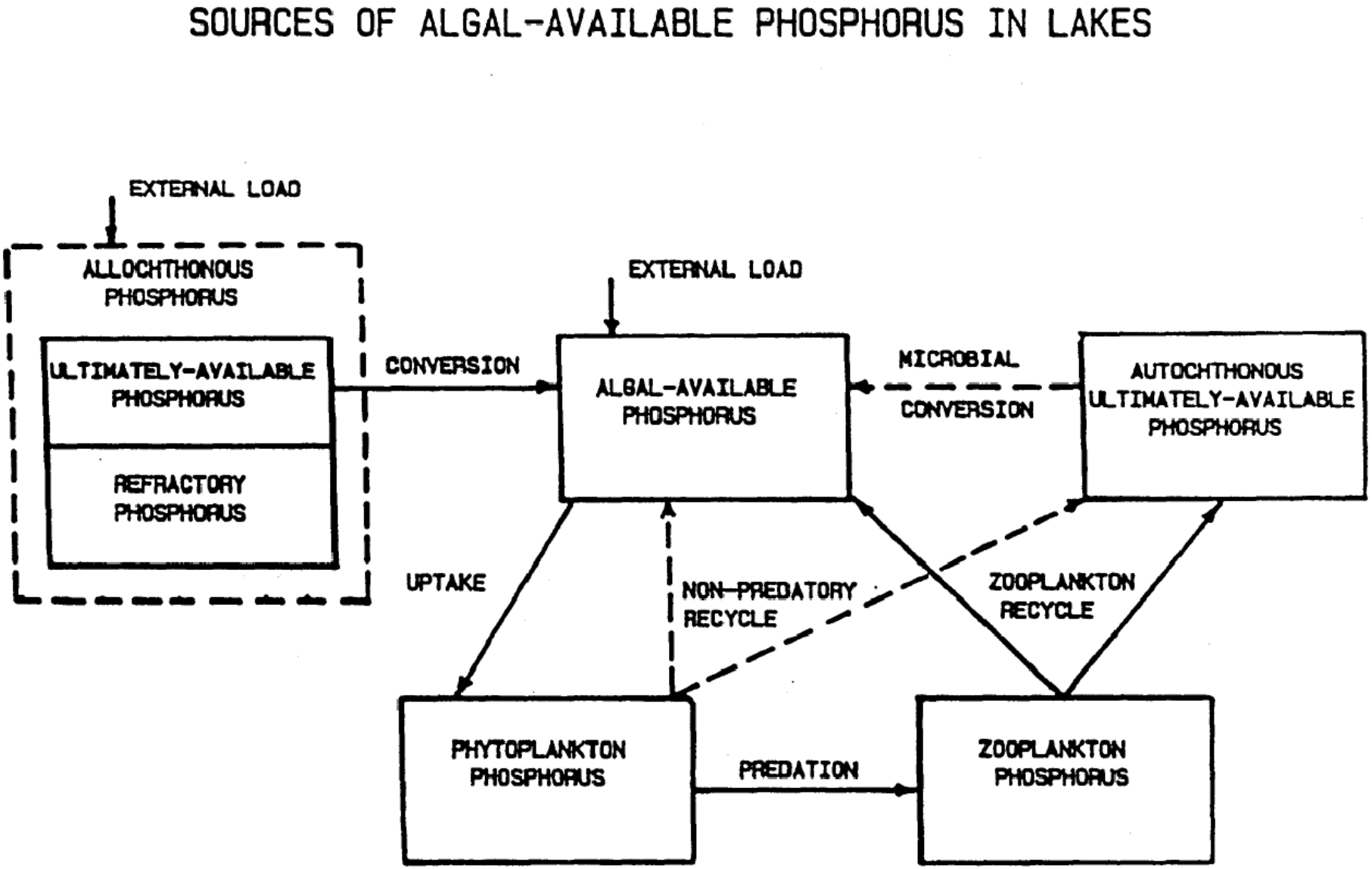
- **Vollenweider (all basins)**
  - Empirical
  - Steady-state
- **Chapra (all basins)**
  - Semi-empirical
  - Dynamic TP mass balance
  - Chlorophyll *a* and DO empirically correlated with TP
- **Thomann Lake I model (Lake Ontario and Lake Huron)**
  - Process model
  - Dynamic MB of P, N, chlorophyll, 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



DiToro, et al. (1976) Lake Erie Eutrophication Model



Water Column Cycling of Phosphorus



Phosphorus Recycle from Decomposing Algae in Water Column

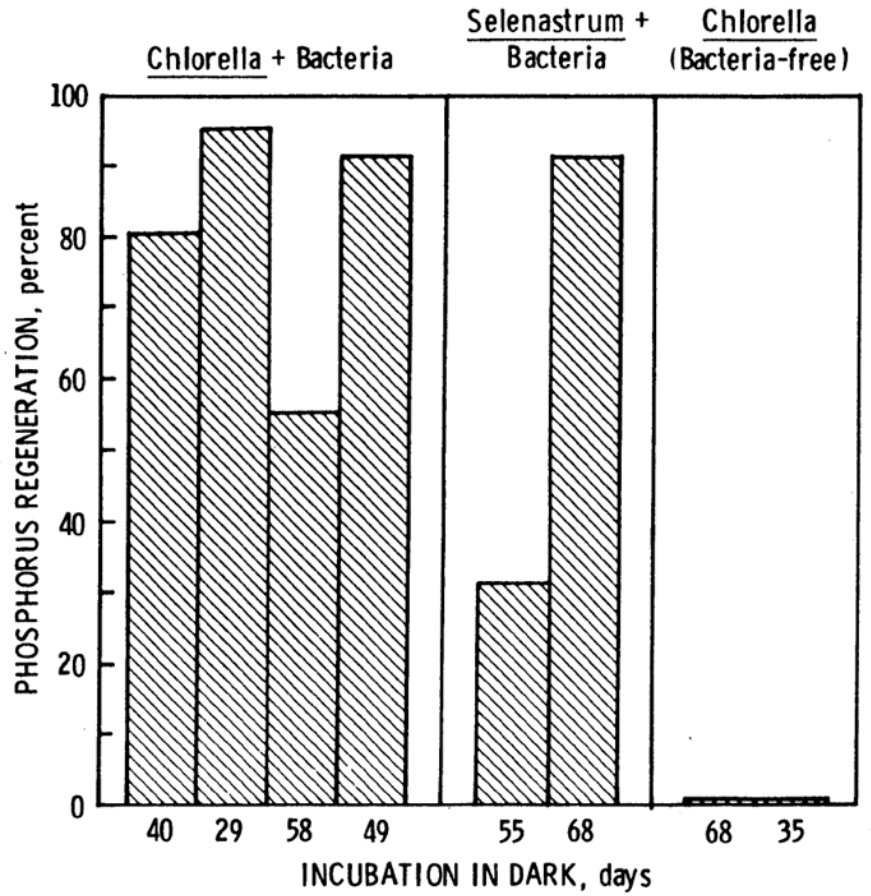


Figure 4. Extent of phosphorus regeneration in batch cultures of green algae incubated in the dark (from DePinto and Verhoff, 1977).

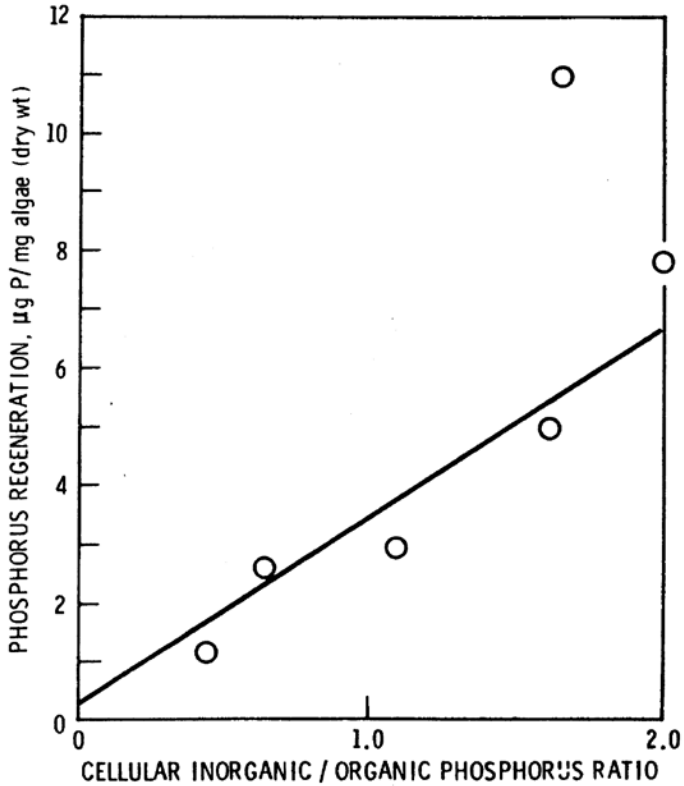


Figure 5. Extent of phosphorus regeneration in bacteria-inoculated batch green algae cultures as a function of cellular inorganic/organic phosphorus ratio (from DePinto and Verhoff, 1977).

Calibration (1970 data) and validation (1975 data) of Lake Erie Model

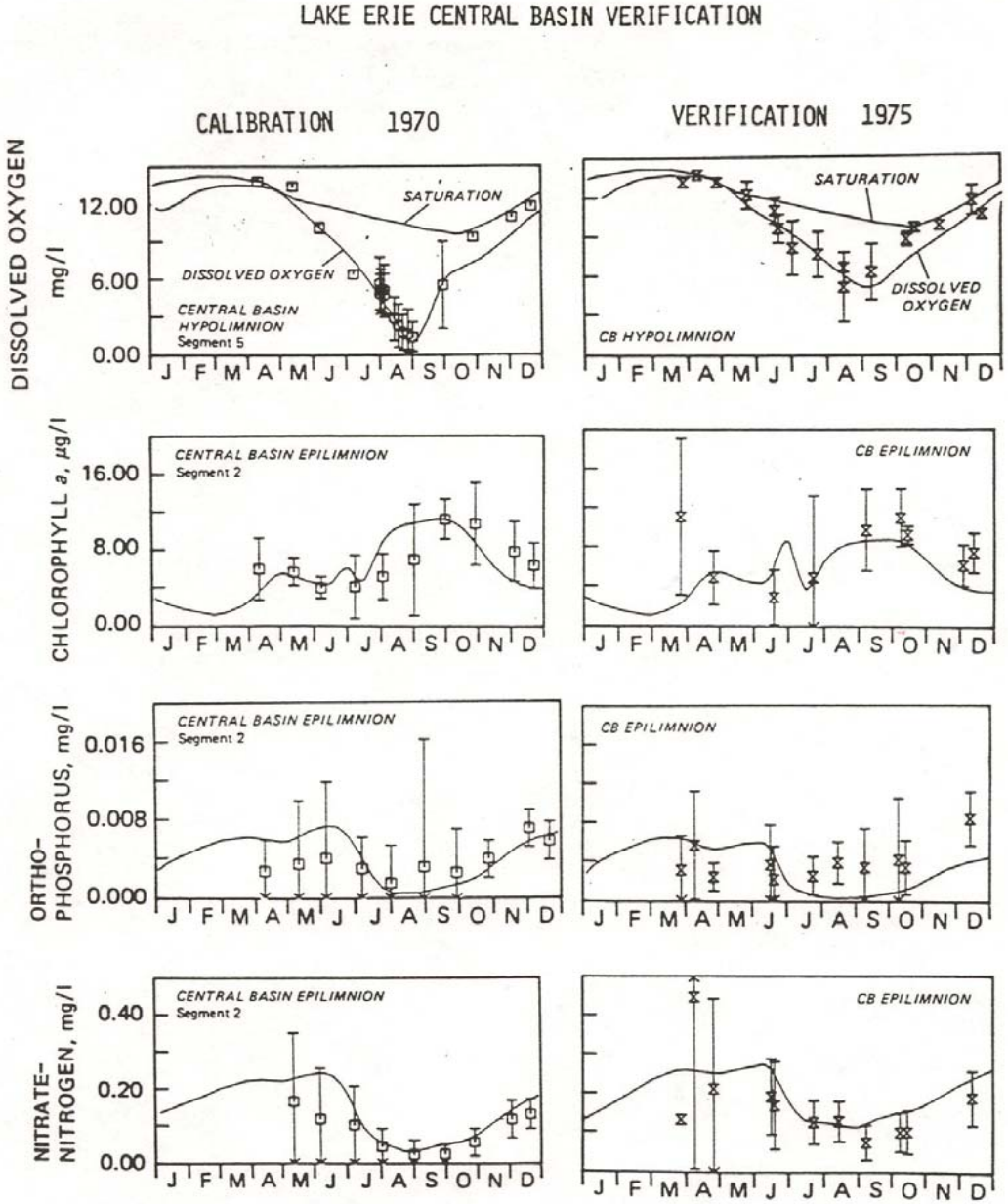


FIG. 5. Comparison of 1970 calibration (lefthand side) and 1975 verification (righthand side). Dissolved oxygen (top), chlorophyll a (upper middle), orthophosphorus (lower middle), nitrate nitrogen (bottom). Symbols mean ± standard deviation; lines are the computations.

P Load – Chlorophyll *a* Relationship in Central Basin

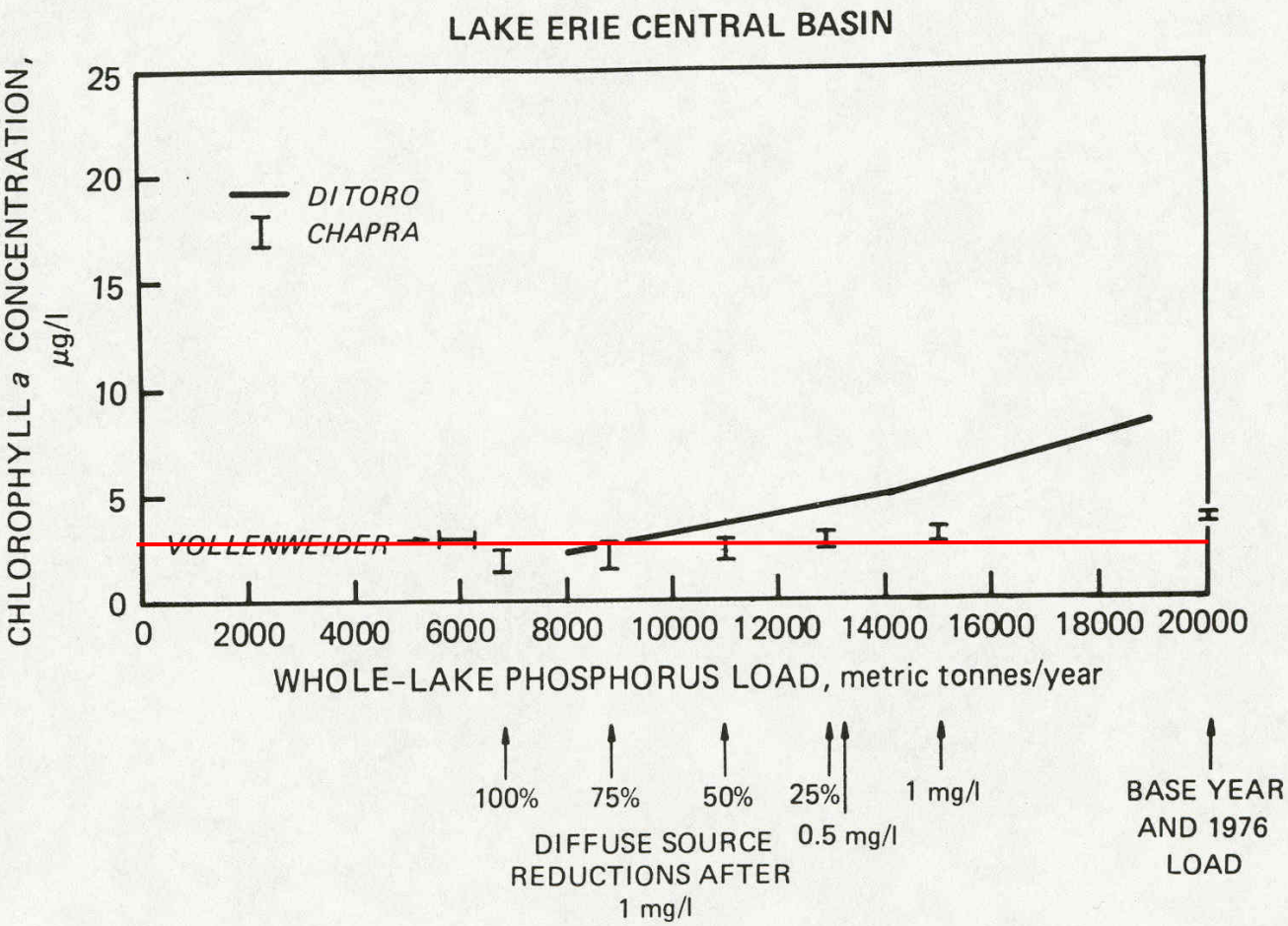


FIGURE 5

Relationship between chlorophyll a concentration and whole-lake phosphorus load in the Central Basin of Lake Erie for the Vollenweider, DiToro and Chapra models

P Load - Area of Anoxia Relationship in Central Basin

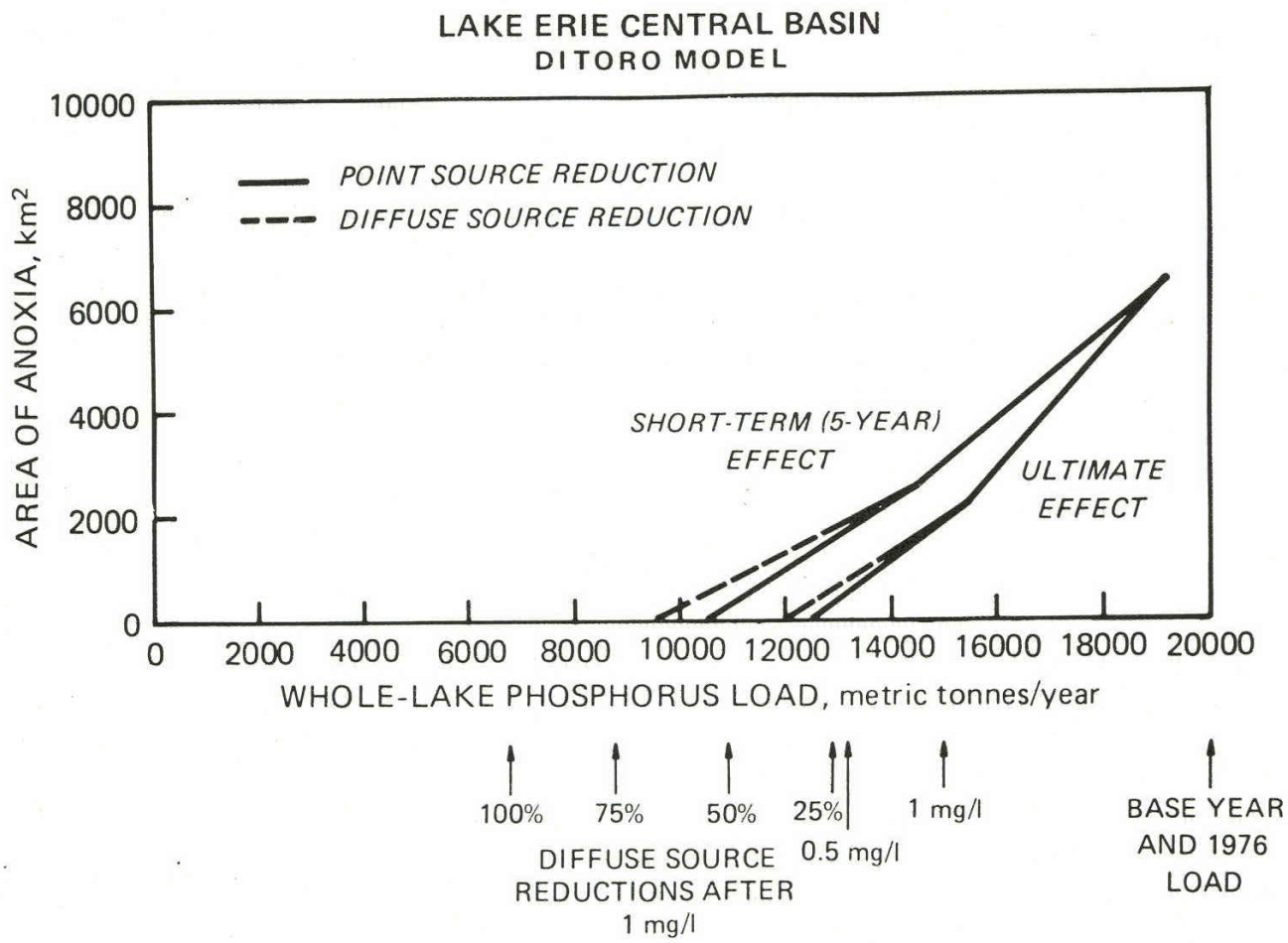


FIGURE 9

Relationship between area of anoxia and whole-lake phosphorus load in the Central Basin of Lake Erie for the DiToro model

P Load - Minimum DO Relationship in Central Basin

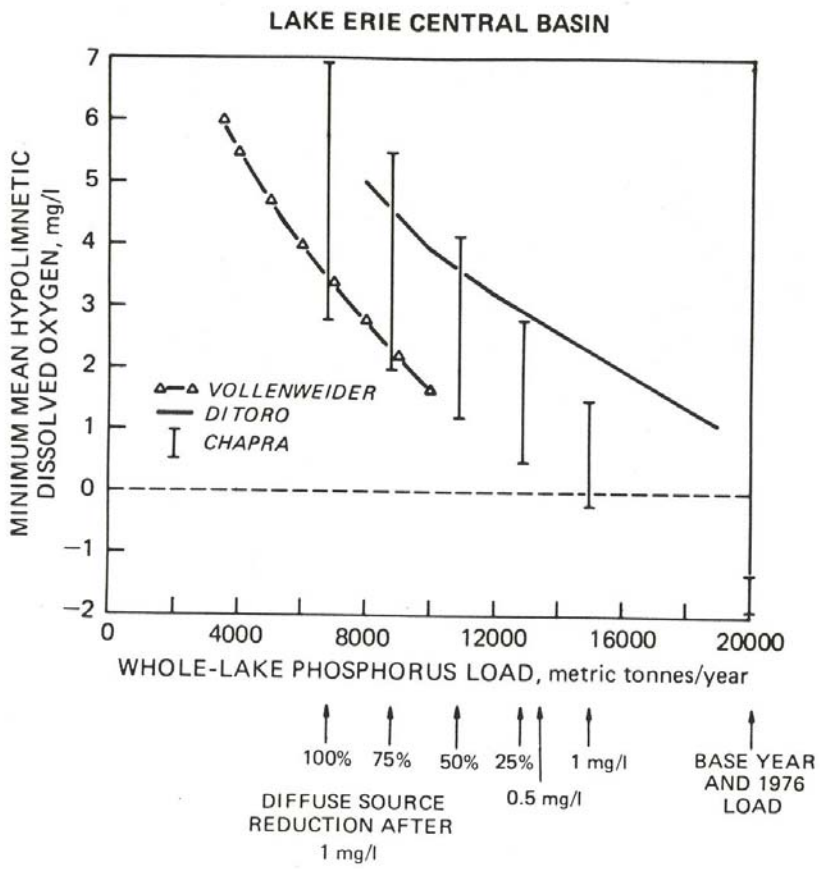
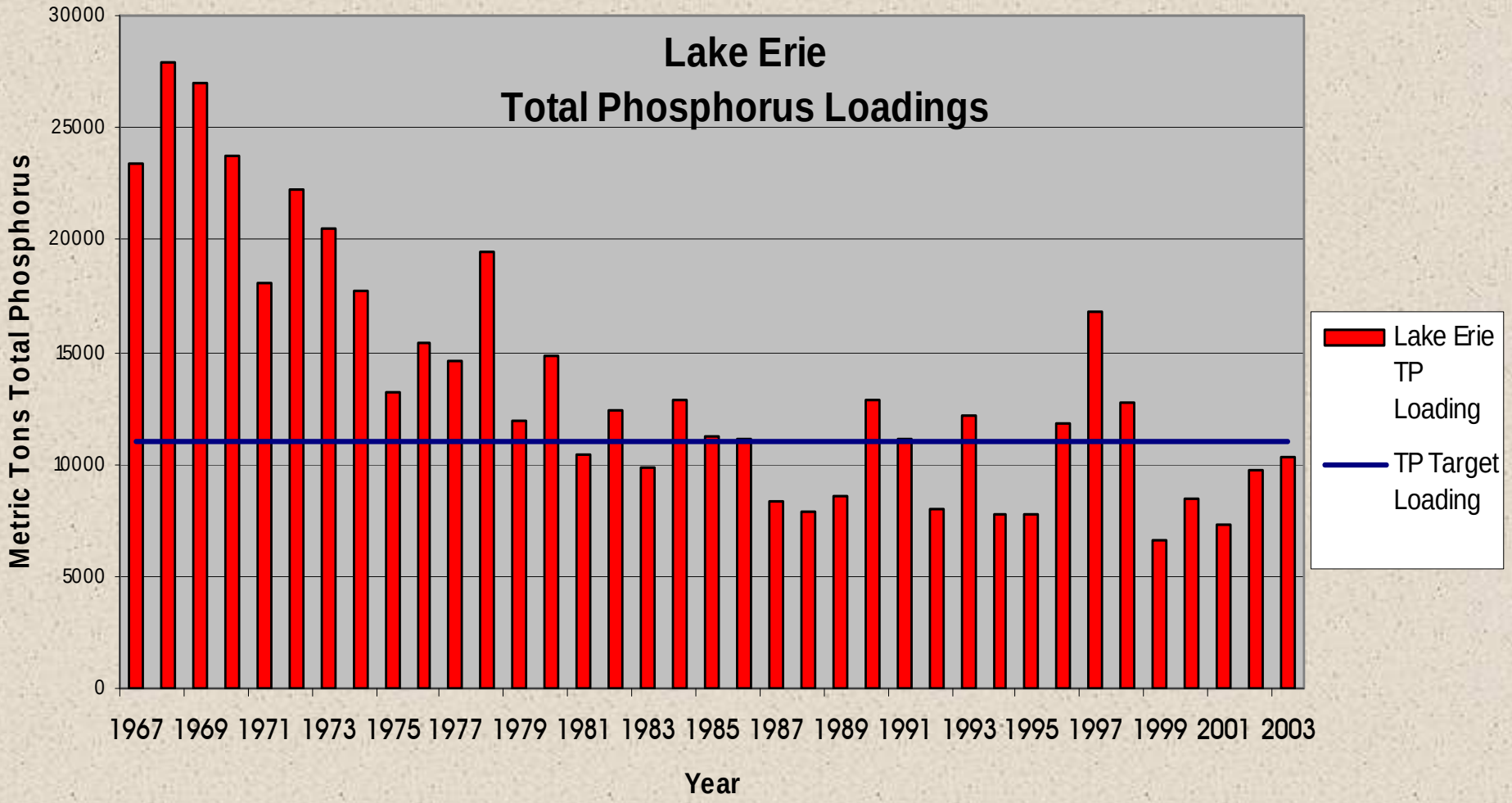


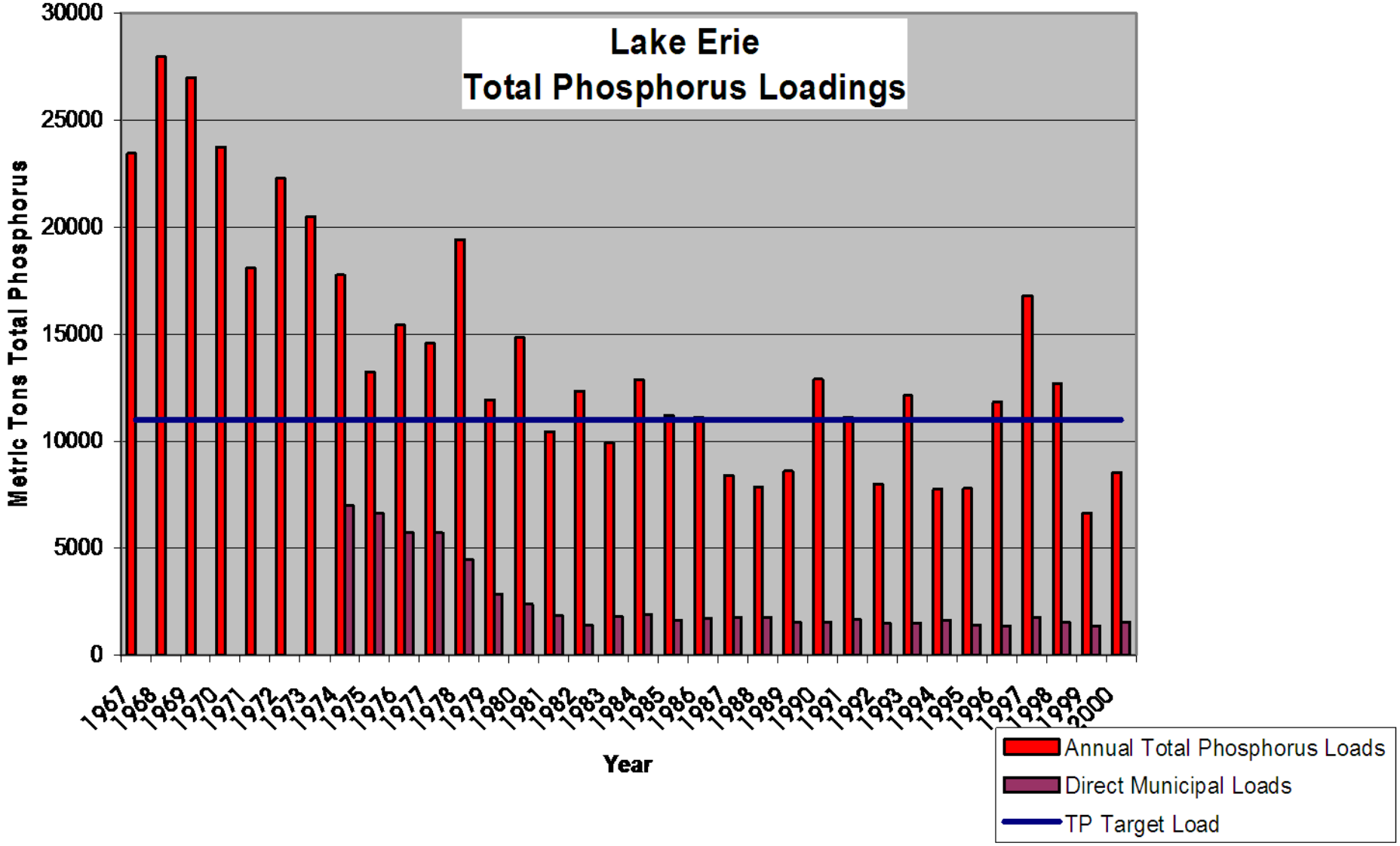
Figure 8

Relationship between minimum mean hypolimnetic dissolved oxygen concentration and whole-lake phosphorus load in the Central Basin of Lake Erie for the Vollenweider, DiToro and Chapra models

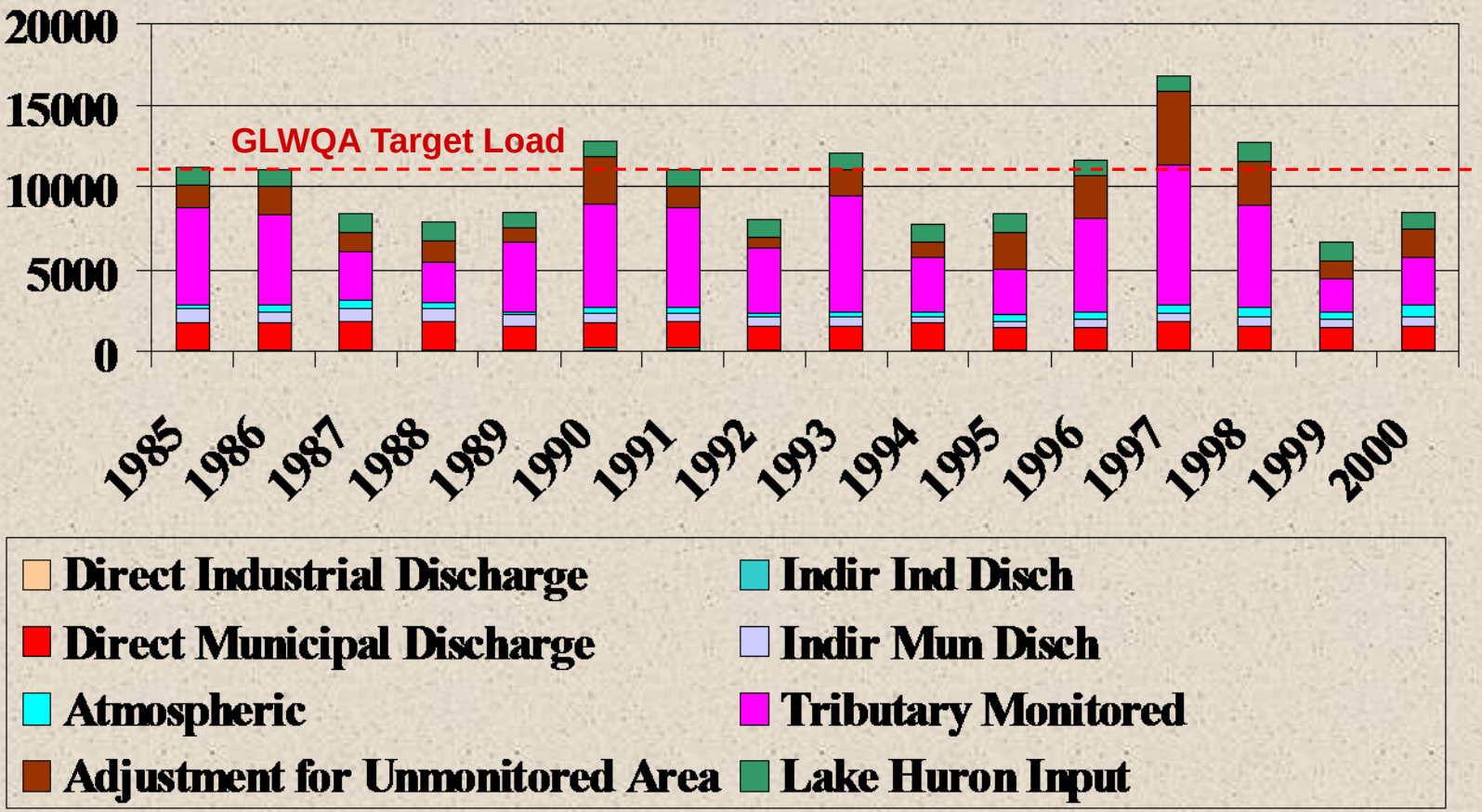
TP Loads to Lake Erie (1967 – 2003)



TP Loads to Lake Erie (1967 – 2001)



Total Phosphorus Loadings to Lake Erie by Source Category (1985-2000)



Lake Erie Model Post-audit (Chl *a*)

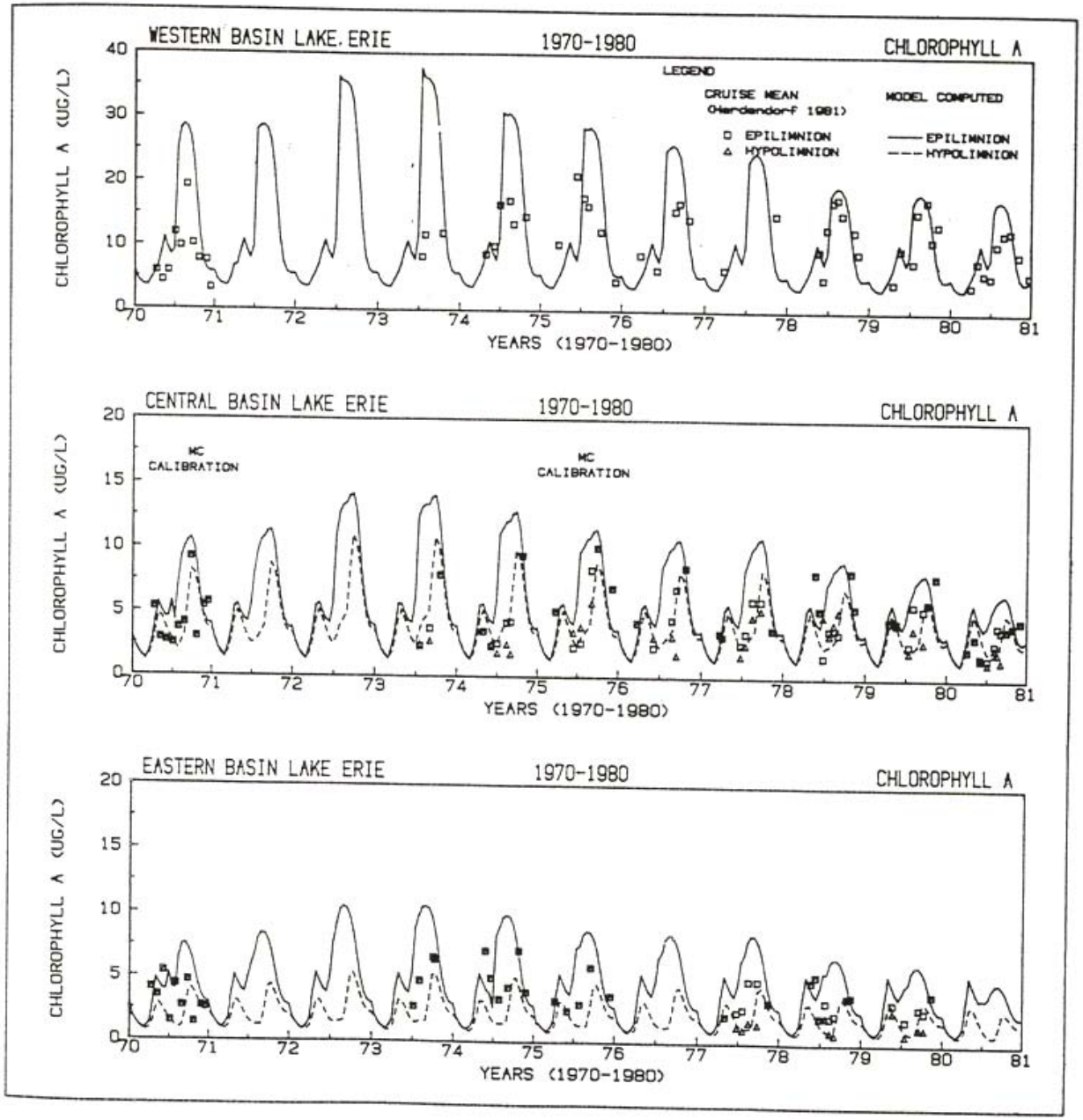
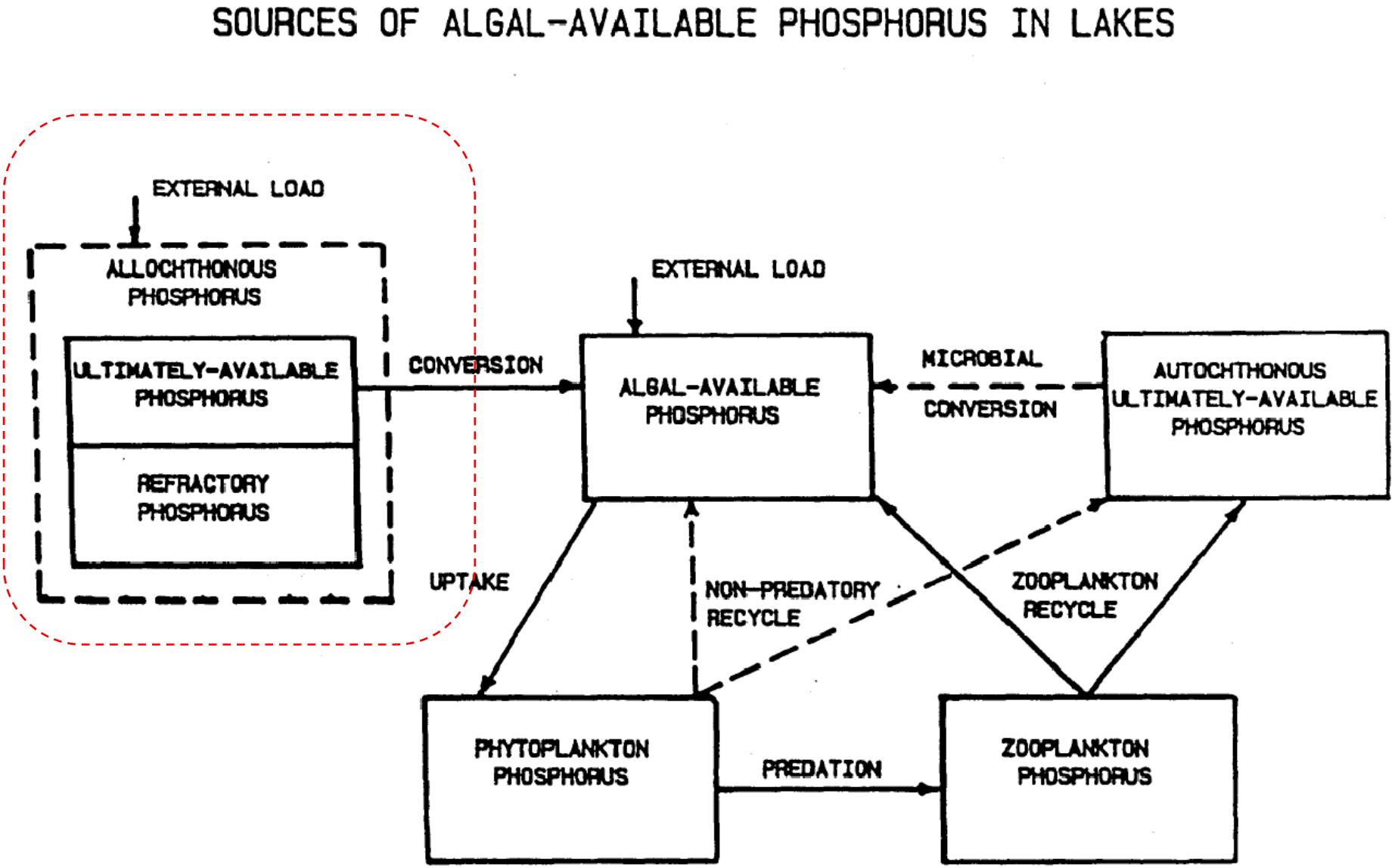


FIG. 10a. Comparison of model predicted and 1970 to 1980 observed cruise mean chlorophyll a *— western, central, and eastern basins of Lake Erie.*

1980's Brought Research on Algal Availability of Phosphorus



Assessing Phosphorus Availability in Great Lakes Tributaries

Technical Note

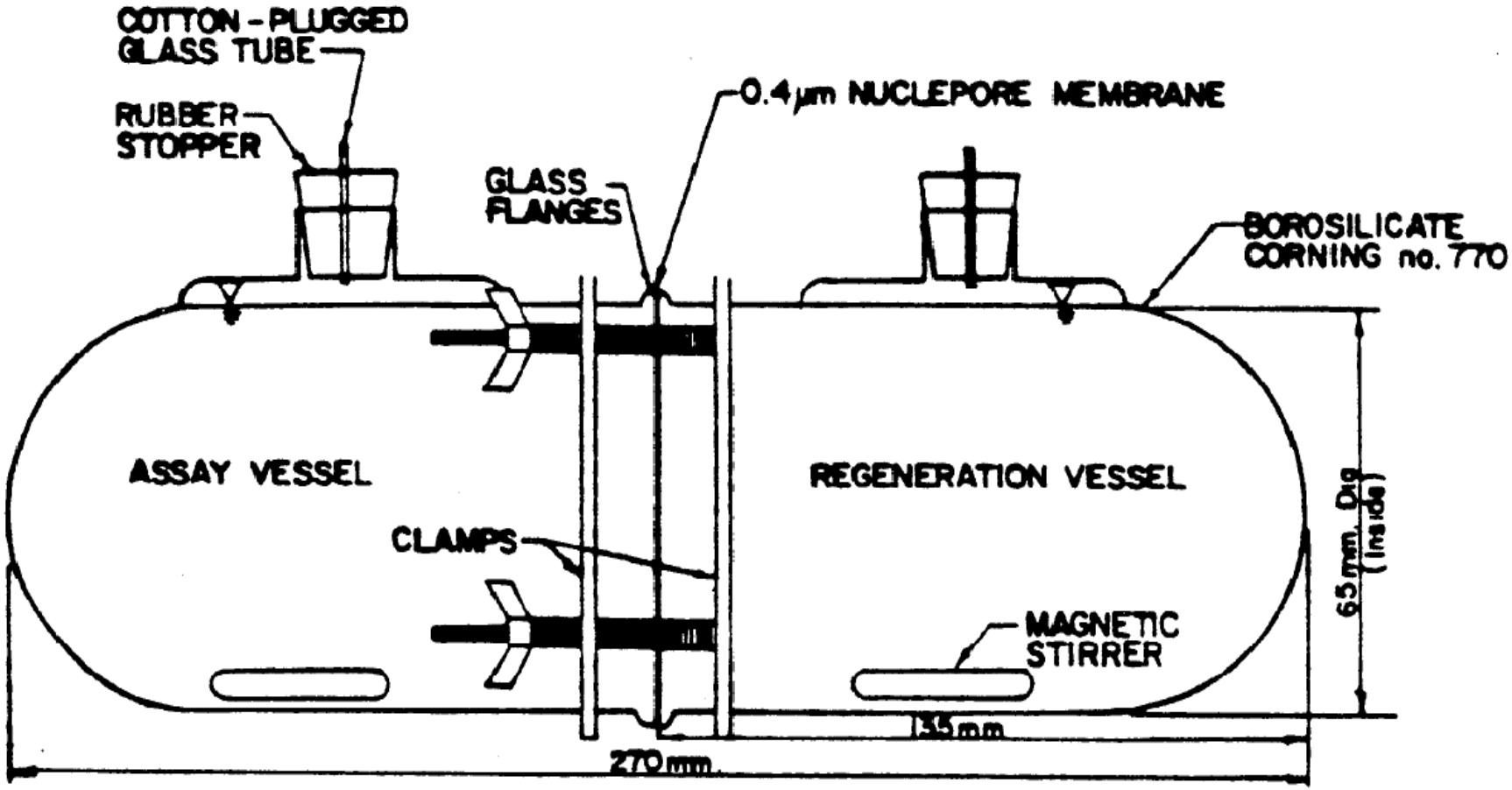


Fig. 1. Schematic of dual culture diffusion apparatus.

Algal Uptake in DCDA Correspond to Decrease in NaOH-extractable P

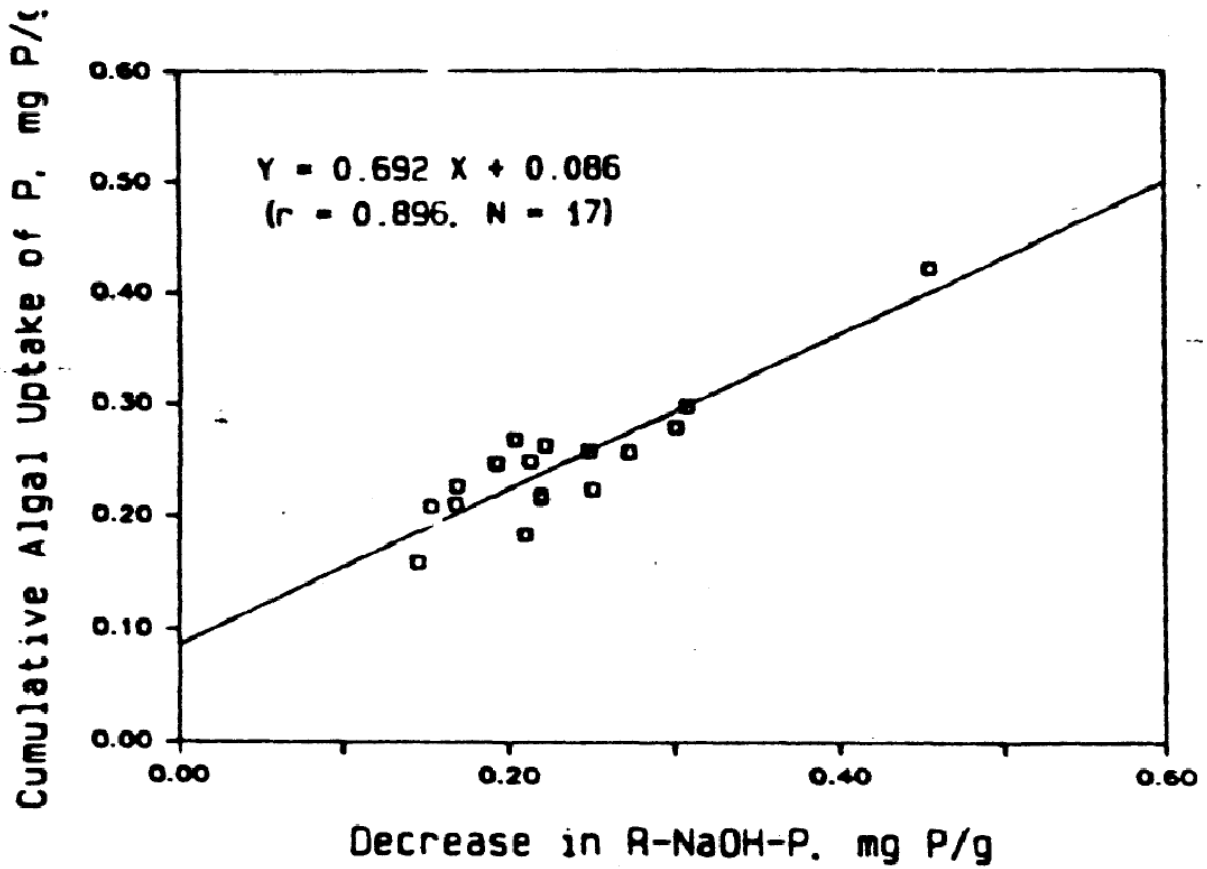


FIG. 1. Regression of cumulative uptake of P by algae on changes in R-NaOH-P content of sediments during available P bioassays. Sediments were collected from the Maumee, Sandusky, and Cuyahoga rivers and Honey Creek (Ohio) during 1981.

R-NaOH-P is good surrogate for ultimately available particulate phosphorus in tributaries

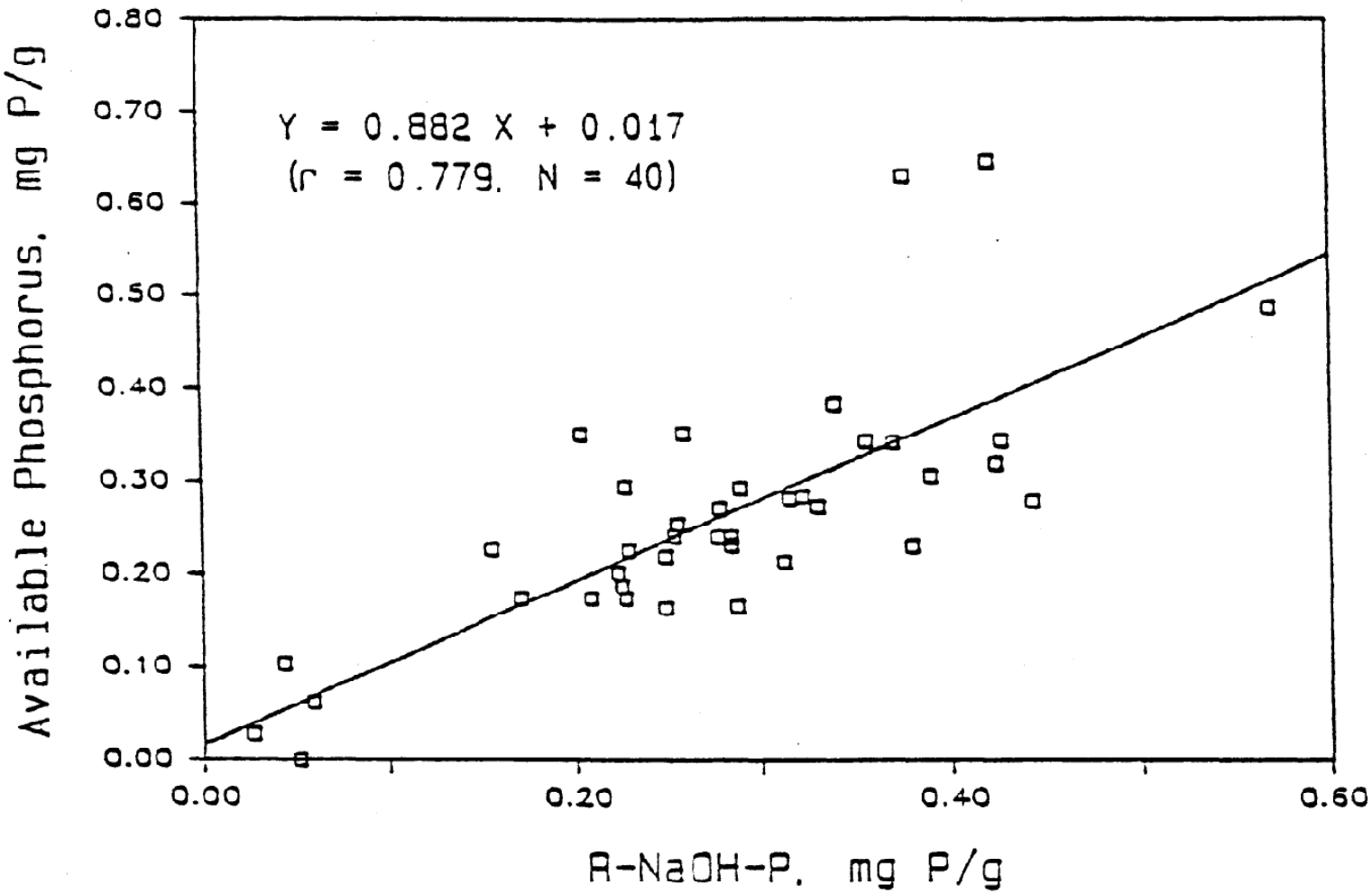


Fig. 1. Regression of algal available phosphorus on R · NaOH · P for 40 samples of suspended solids from Lower Great Lakes tributaries.

Research Led to Modification of DiToro Lake Erie Model

Must treat P release from tributary solids differently from P release from in-lake produced solids (i.e., algae)

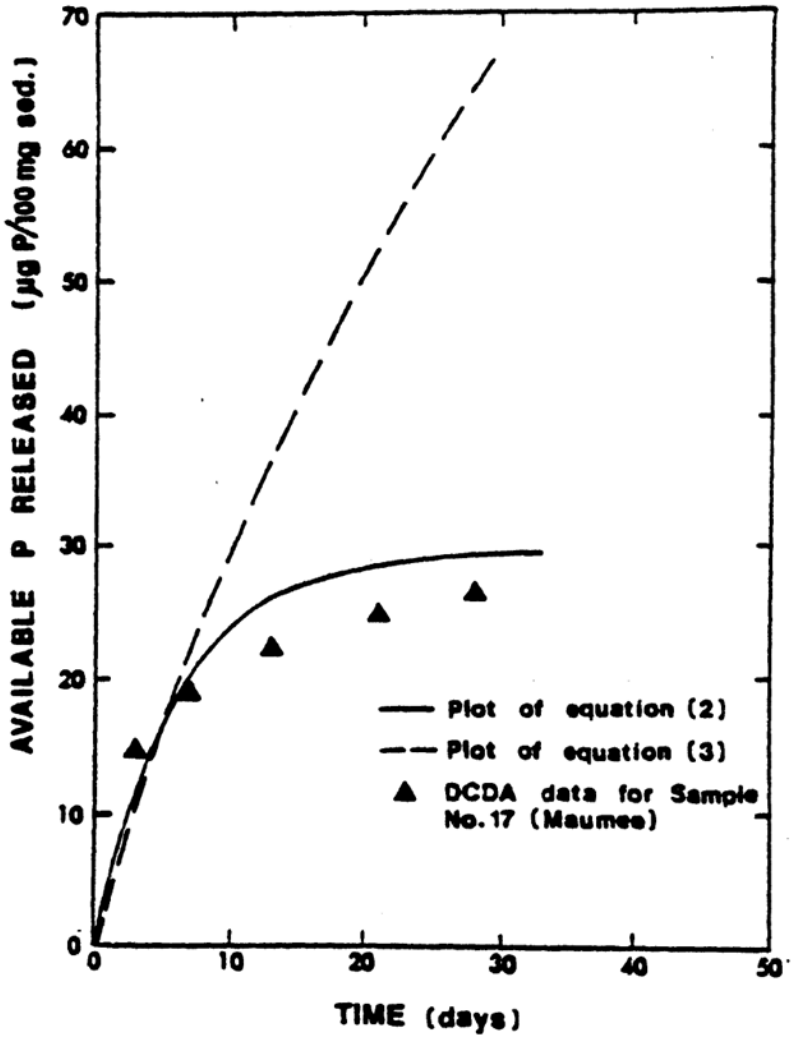


FIG. 5. Comparison of current Great Lakes model predictions of BAPP versus time (equation (3)) with actual data for sample no. 17 and first-order fit (equation (2)).

Tested Three Versions of Lake Erie Model

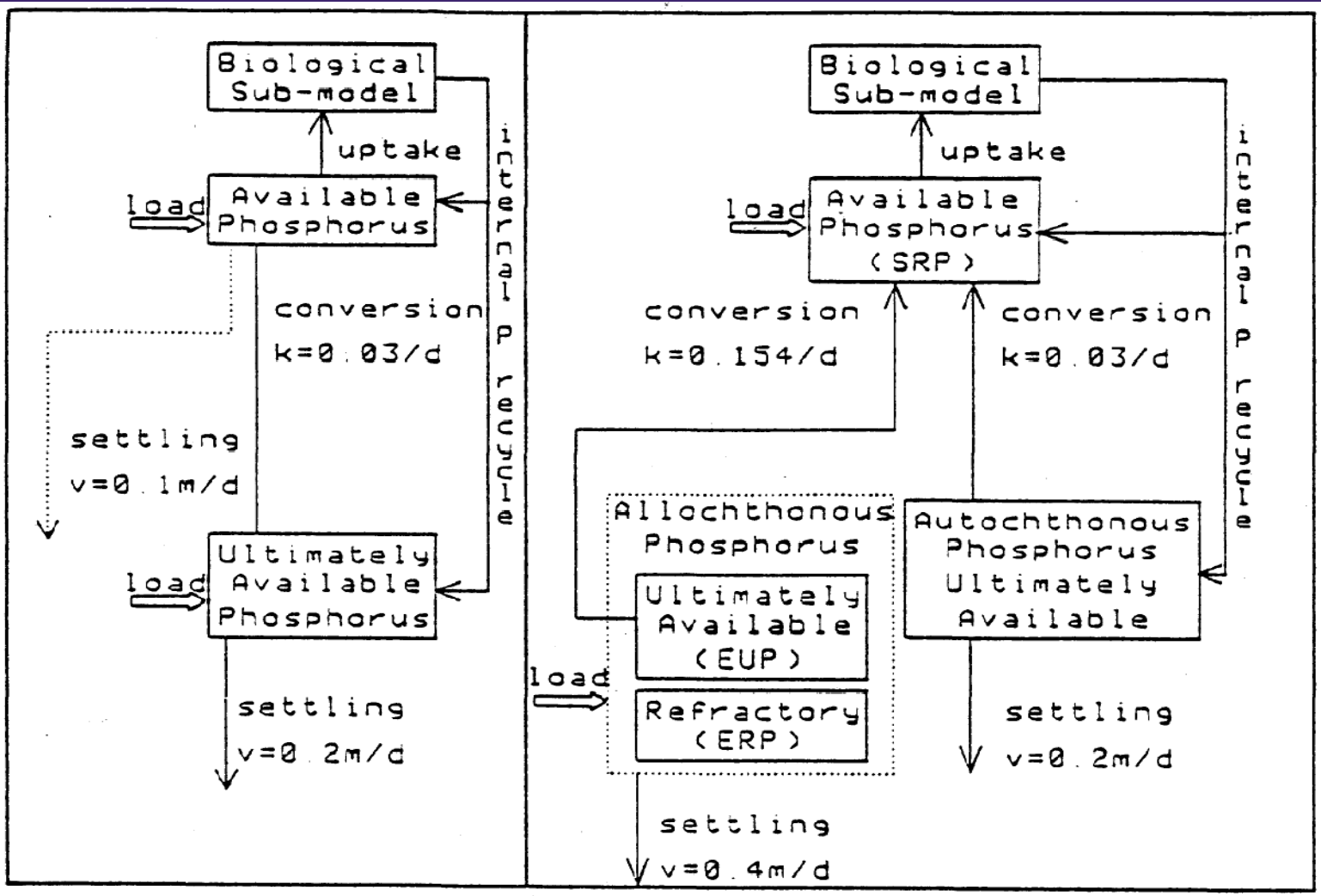


Fig. 4. Schematic diagram of P dynamics (kinetics, loading, and settling) in 3 modifications of Lake Erie phytoplankton model : LEM1 and LEM2 (left), and LEM3 (right).

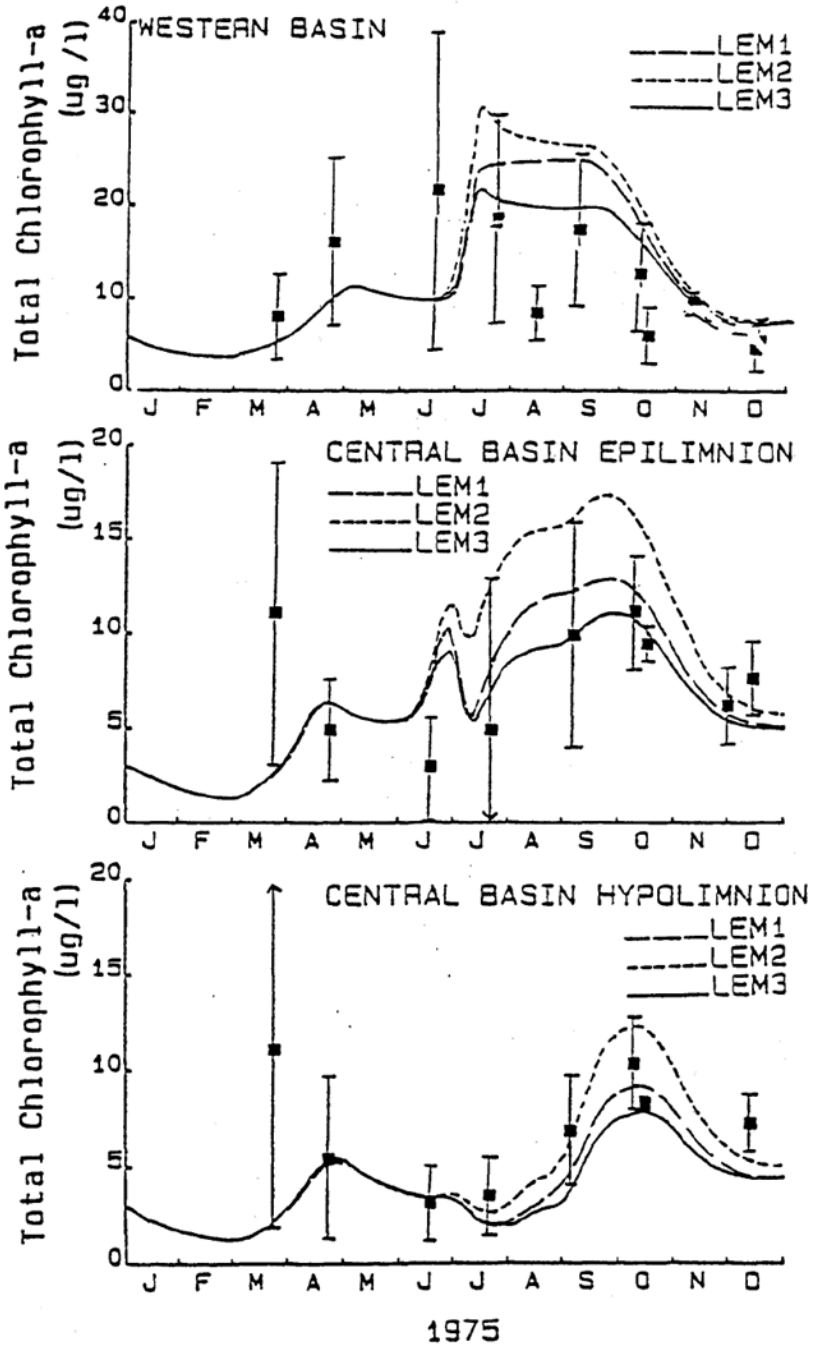


Fig. 5b. LEM1, LEM2, and LEM3 simulations for total chlorophyll-a in the Western Basin, Central Basin epilimnion, and Central Basin hypolimnion of Lake Erie, 1975.

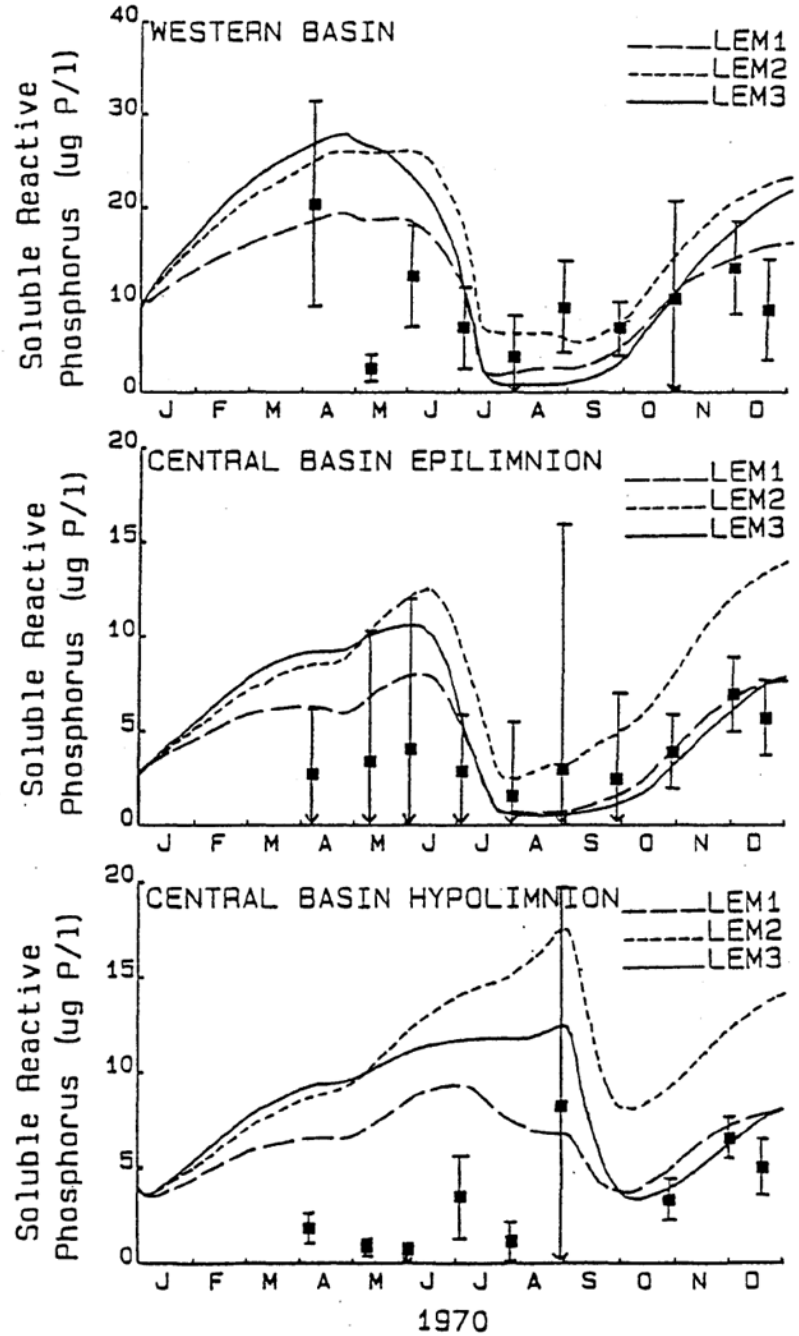


Fig. 6. LEM1, LEM2, and LEM3 simulations for soluble reactive phosphorus in the Western Basin, Central Basin epilimnion, and Central Basin hypolimnion of Lake Erie, 1970.

Importance of P Release from Particulates in the Water Column

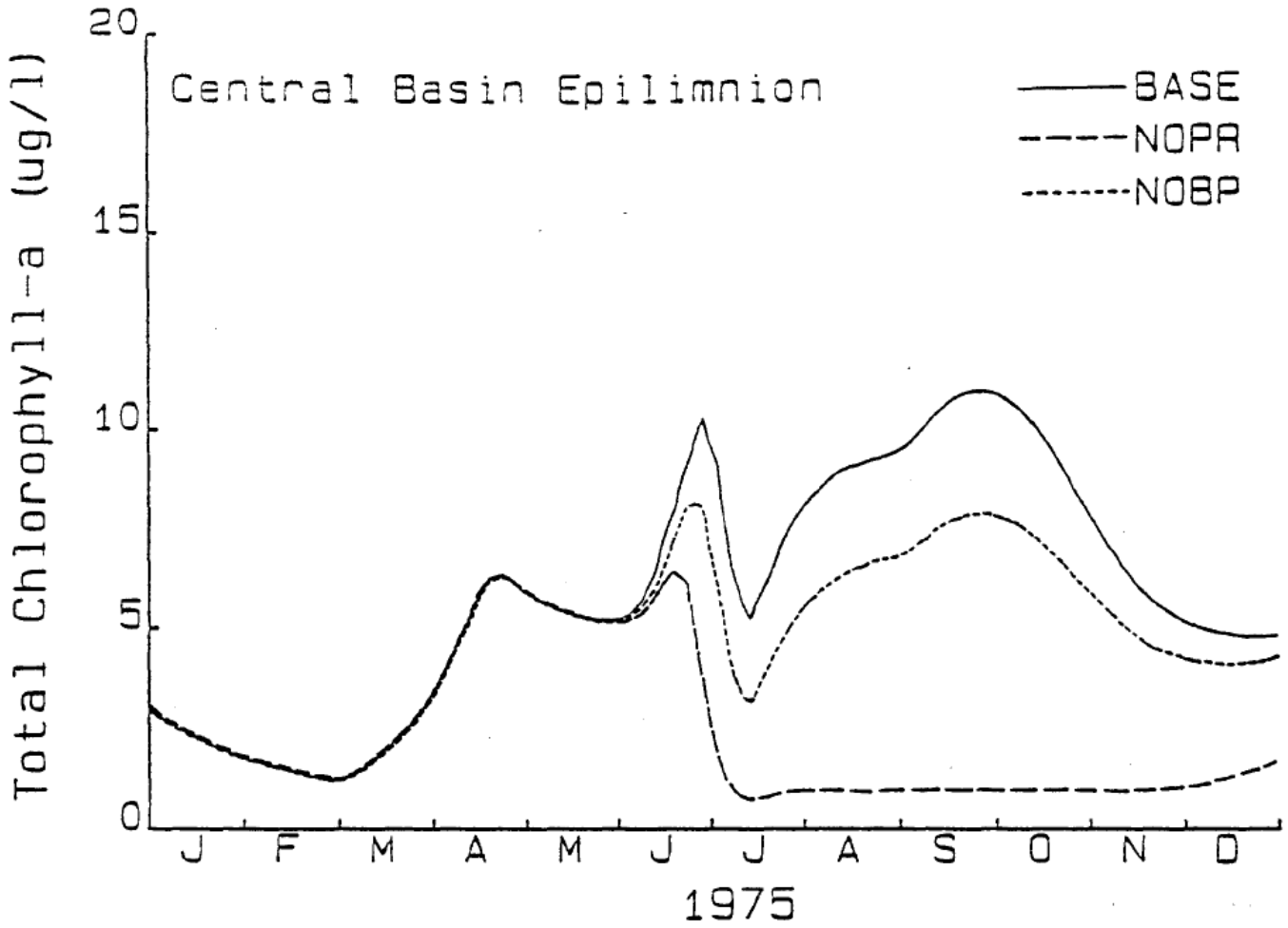


Fig. 8c. Sensitivity of Chlorophyll-*a* predictions by LEM3 using 1975 data for Central Basin epilimnion to exclusion of EUP conversion submodel (NOBP) and IUP recycle submodel (NOPR); BASE is LEM3 with both ultimately available P conversion submodels operating.

Halving SRP Load Gives Bigger Response than Halving EUP Load

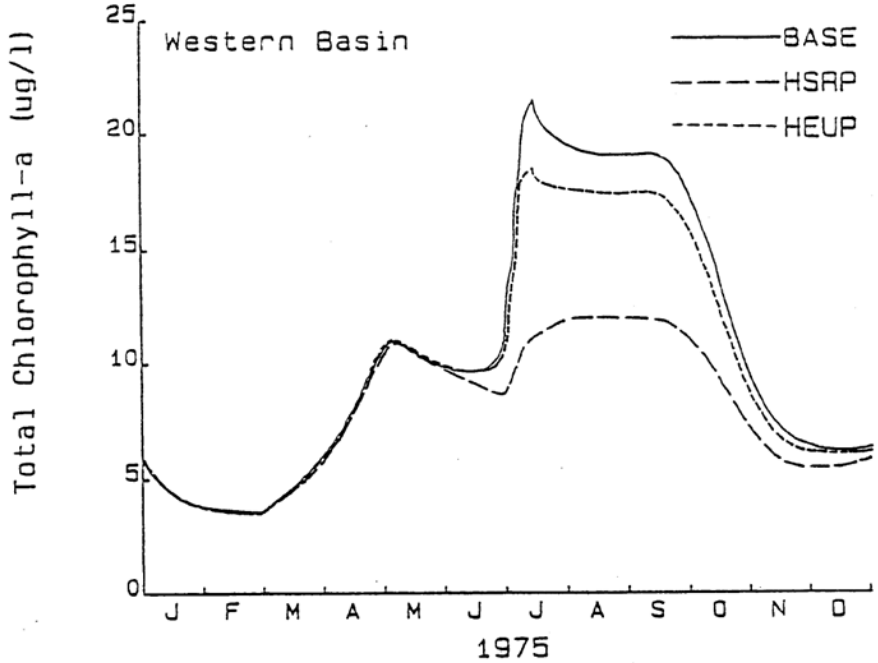


Fig. 9a. Effect on chlorophyll-a of halving SRP load (HSRP) or halving EUP load (HEUP) to Western Basin of Lake Erie, compared to existing loads for 1975 (BASE).

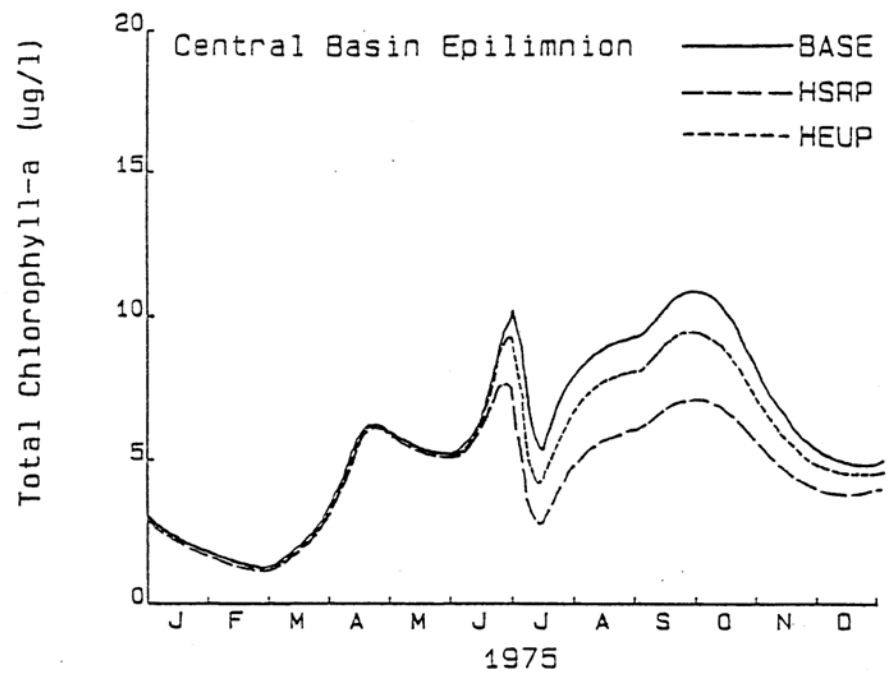
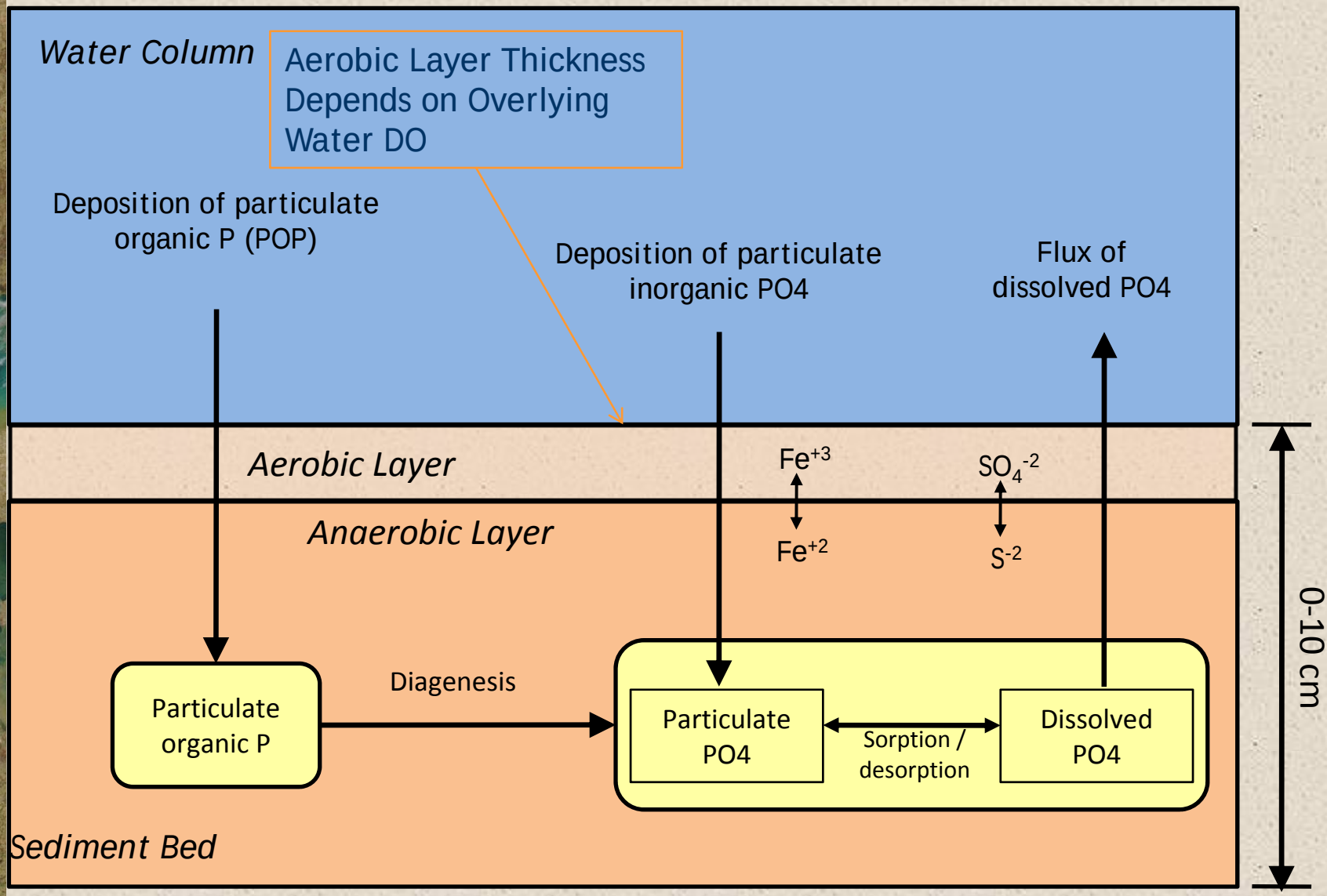


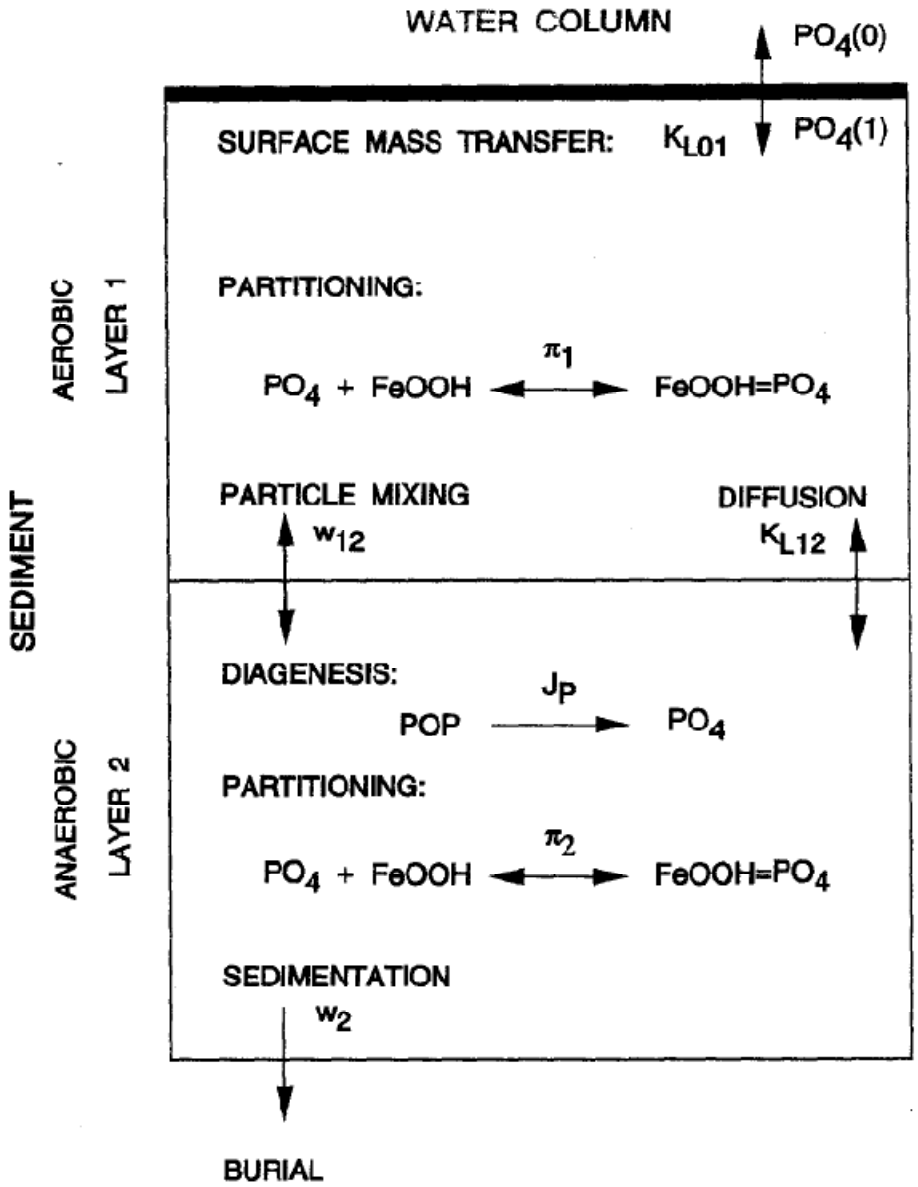
Fig. 9c. Effect on chlorophyll-a of halving SRP load (HSRP) or halving EUP load (HEUP) to Central Basin epilimnion, compared to existing loads for 1975 (BASE).

ADVANCES IN PHOSPHORUS SEDIMENT FLUX MODELING

Understanding of Sediment-Water Phosphorus Exchange Processes



Schematic of Phosphorus Diagenesis/Flux Sub-model in Revised DiToro Lake Erie Model (DiToro, 2001)



Overlying Water DO < 2 mg/L Causes Significant P Flux (DiToro, 2001)

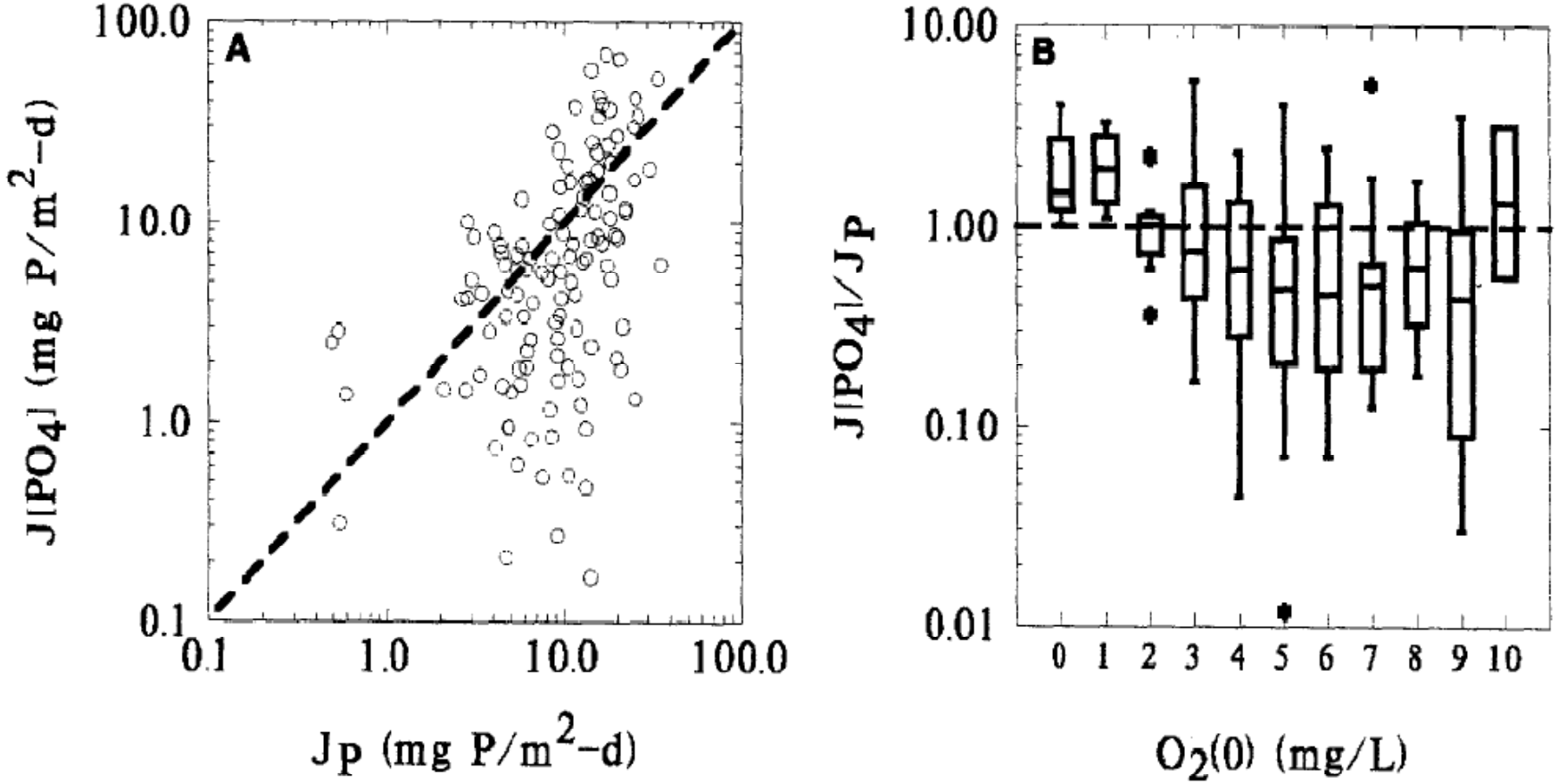
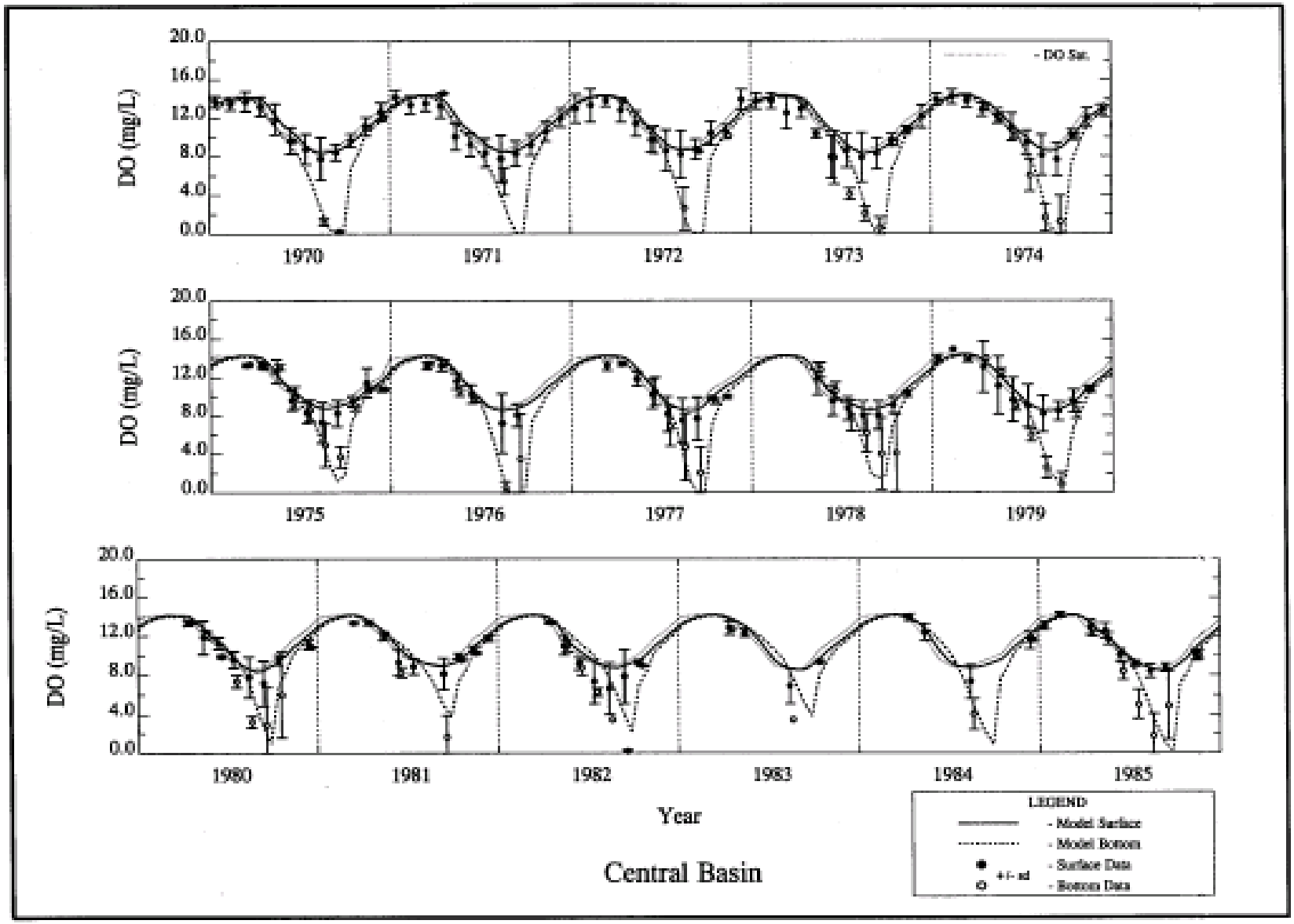


Fig. 6.6 (A) Phosphate flux $J[PO_4]$ versus phosphorus diagenesis J_P. (B) Ratio of phosphate flux to phosphorus diagenesis $J[PO_4]/J_P$ versus overlying water dissolved oxygen concentration $[O_2(0)]$.

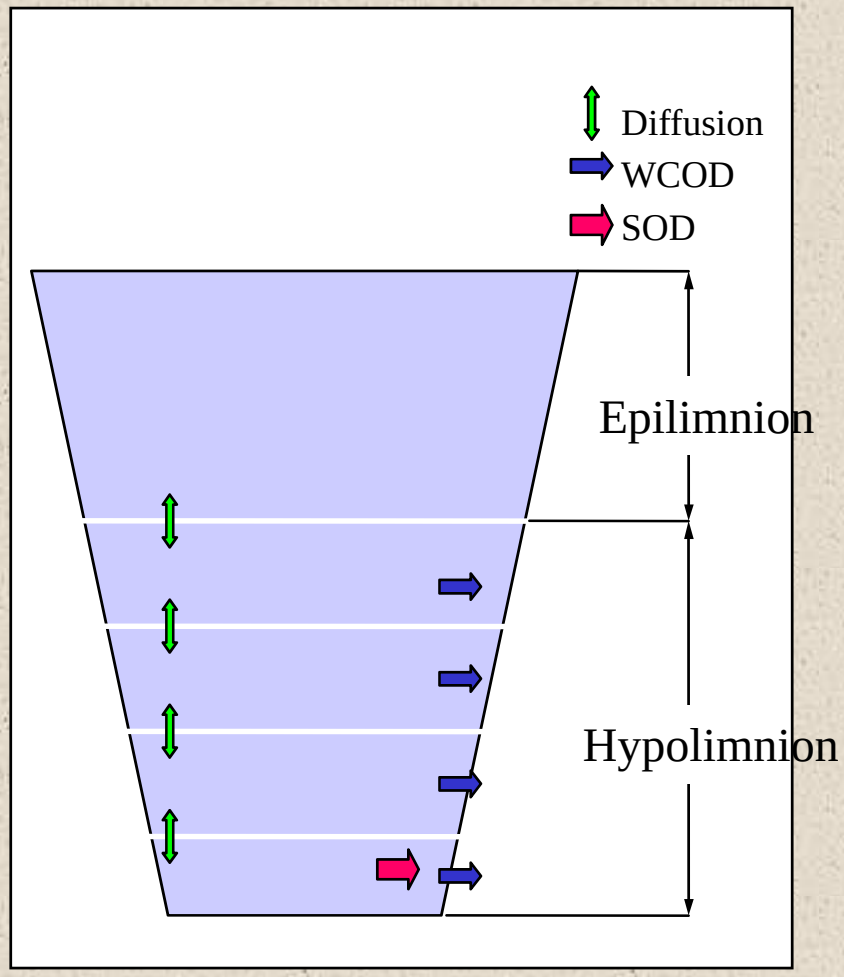
Lake Erie Model Post-audit with updated sediment diagenesis model (Fitzpatrick, 200



ECOFORE LEVEL 1 ANALYSIS OF SEDIMENT P FLUX

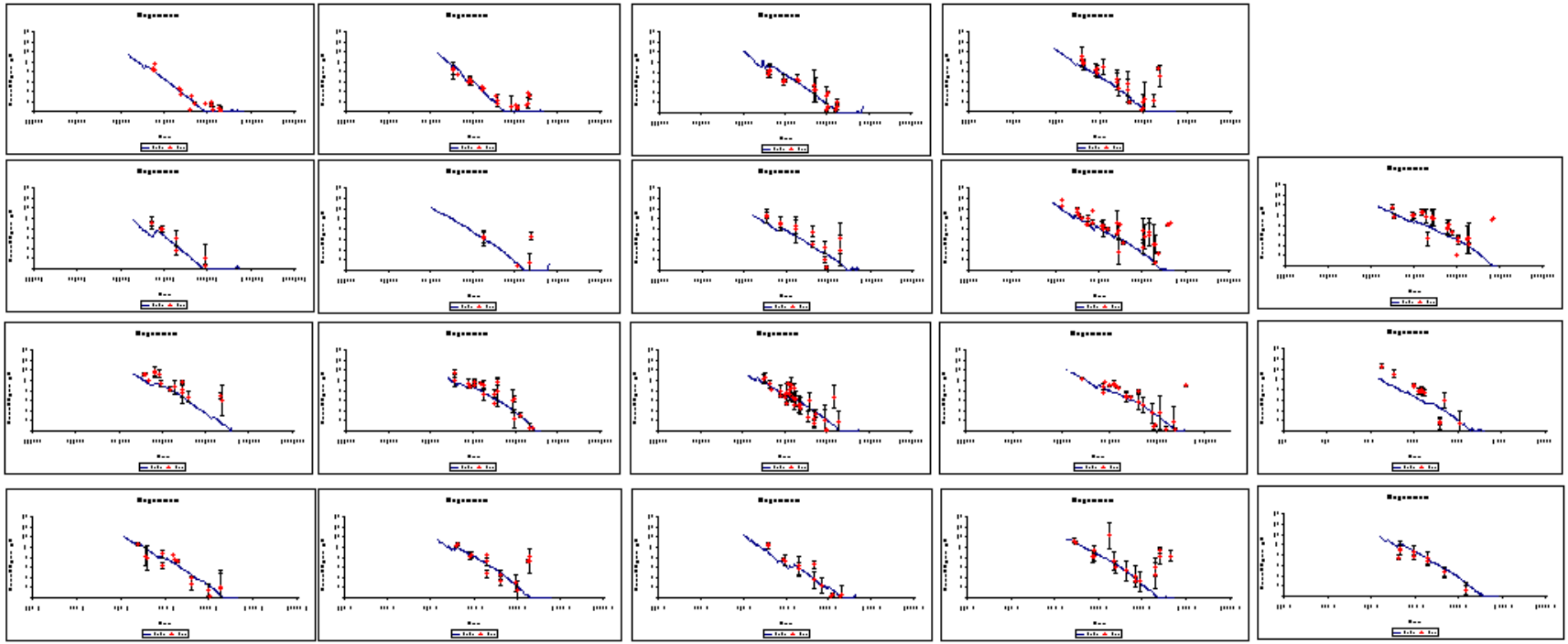
Simple 1D DO Model for Central Basin

- 1D Vertical Dynamic Model for Central Basin
- Hydrodynamic model is physically driven
  - Air temp, wind speed, solar radiation
- Static Surface Level, varying thermocline depth
- 48 Vertical Layers of 0.5m thickness
- Simple Dissolved Oxygen Model linked to Hydrodynamic Model
  - DO rate term (WCOD) is aggregate of production and consumption processes in the water column
  - SOD in bottom layer

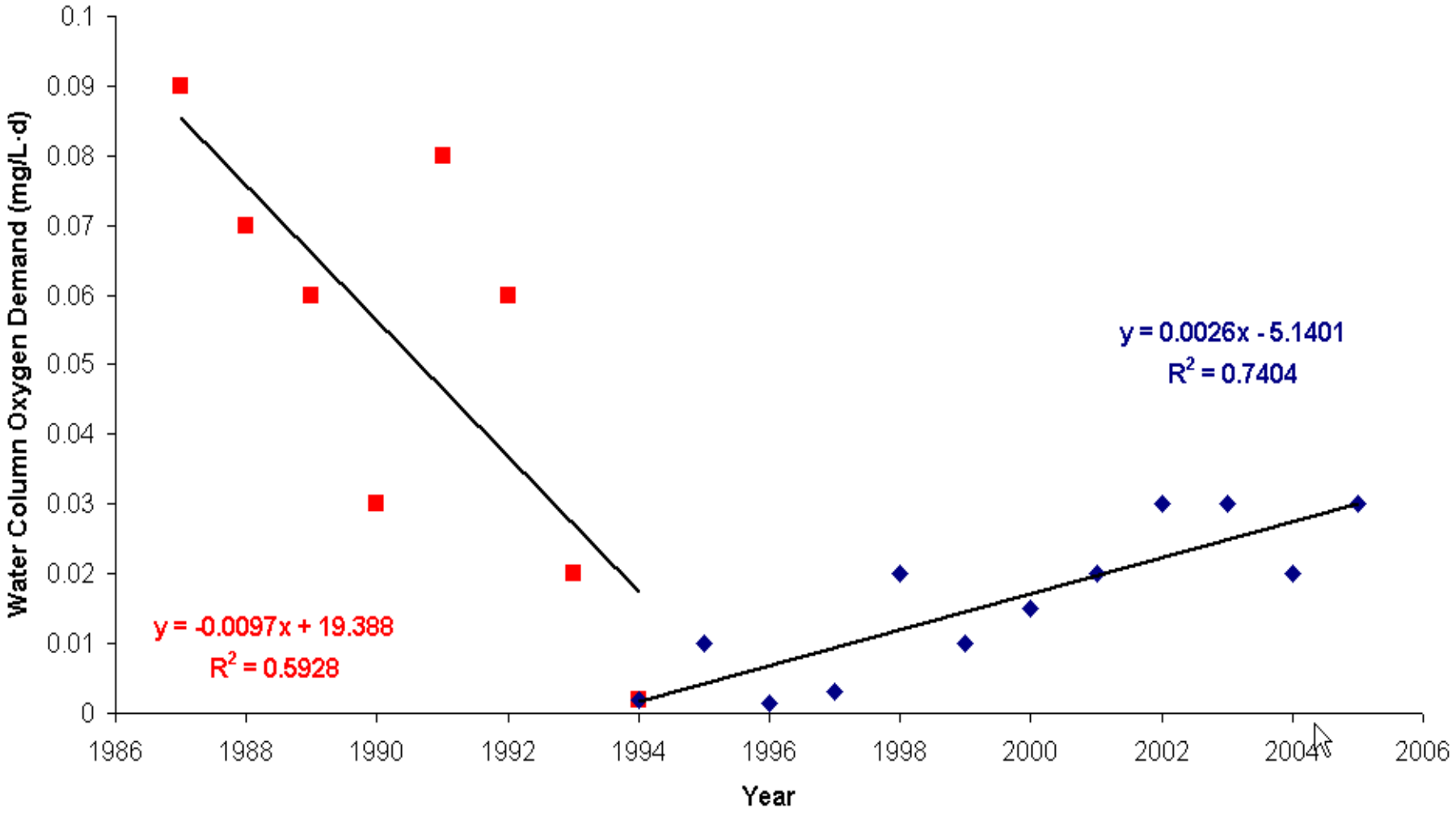


Model – Data Comparison Results

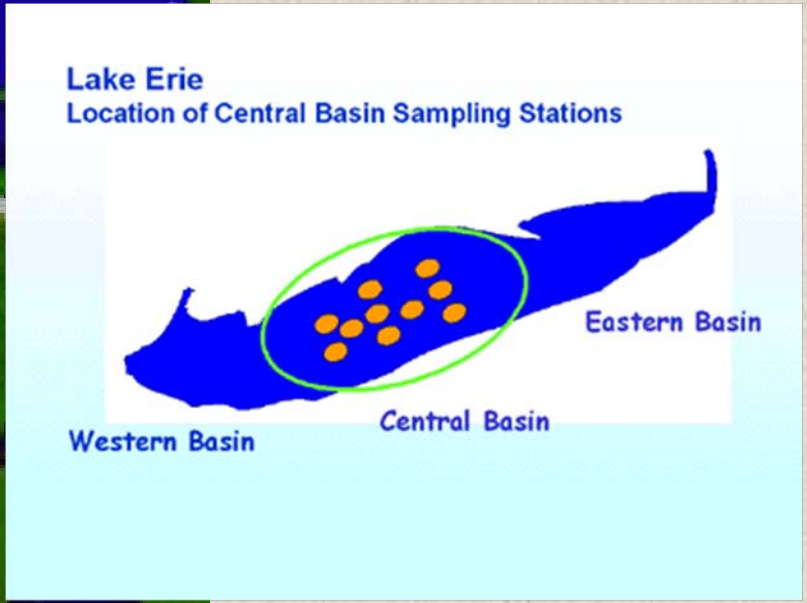
Hypolimnion DO Depletion (1987-2005)

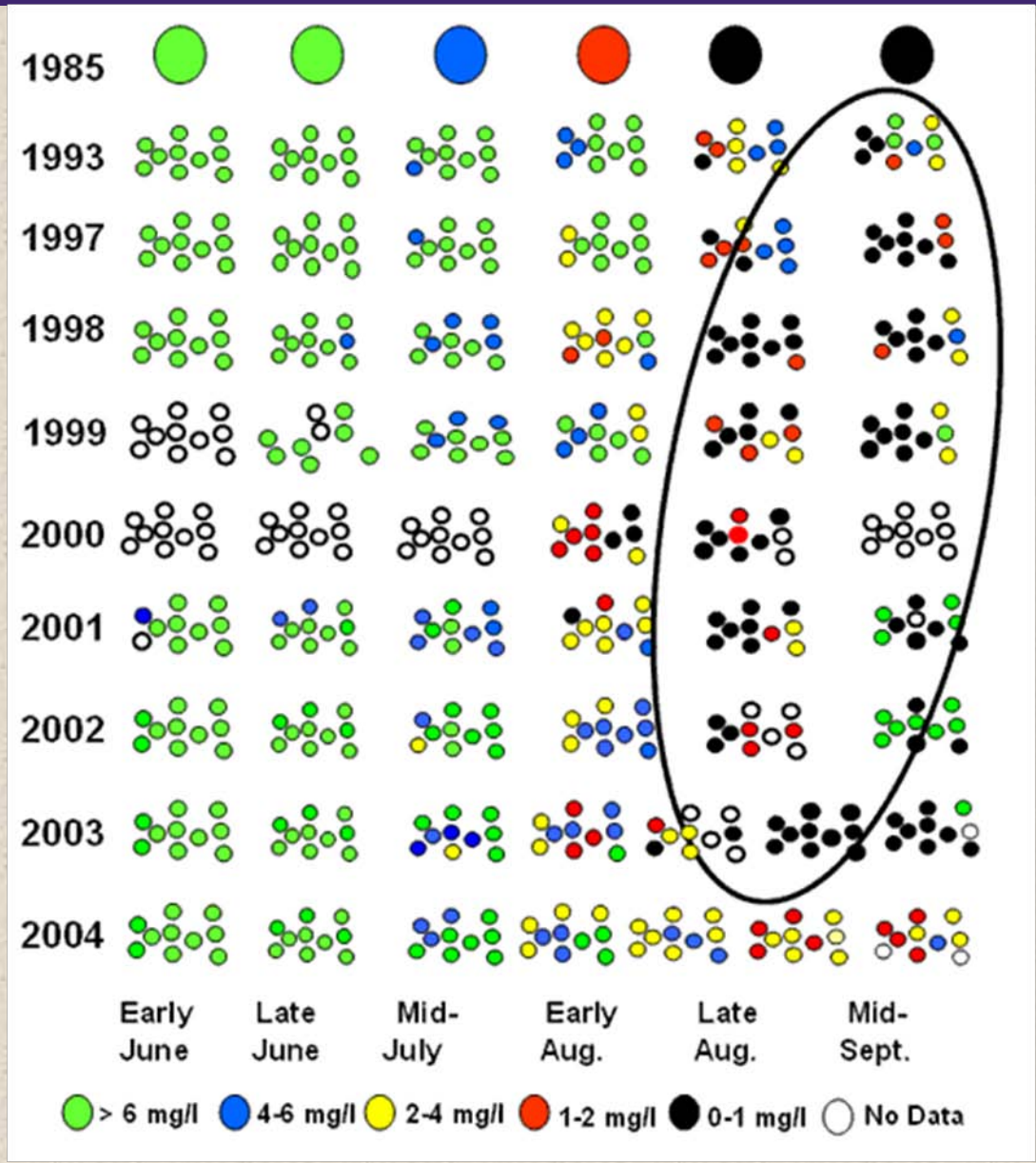


Time-Series of Annual Calibrated WCOD Values

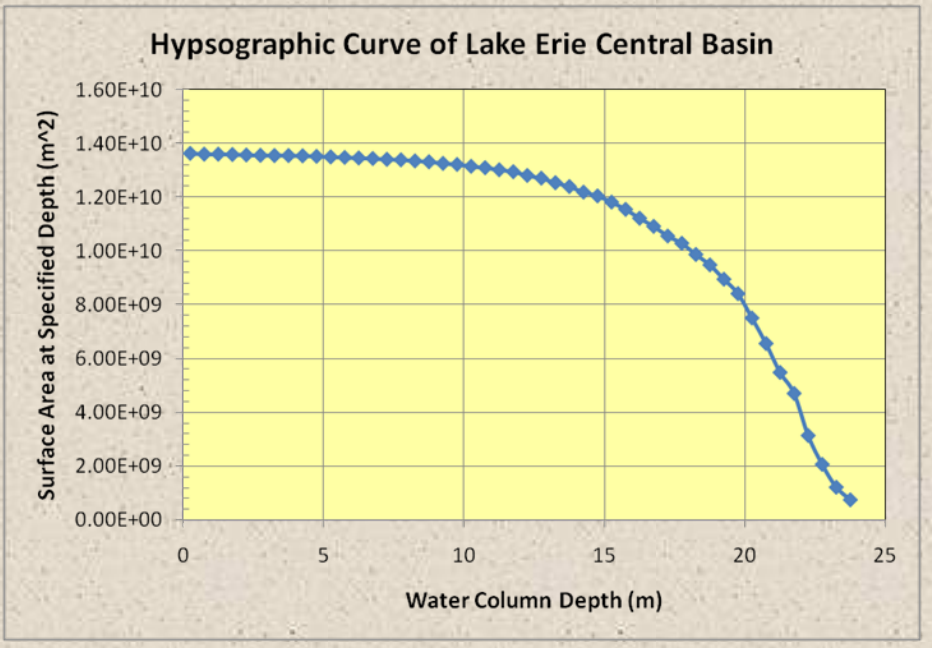


Development of Central Basin Hypoxia through the Growing Season (EPA-GLNPO)

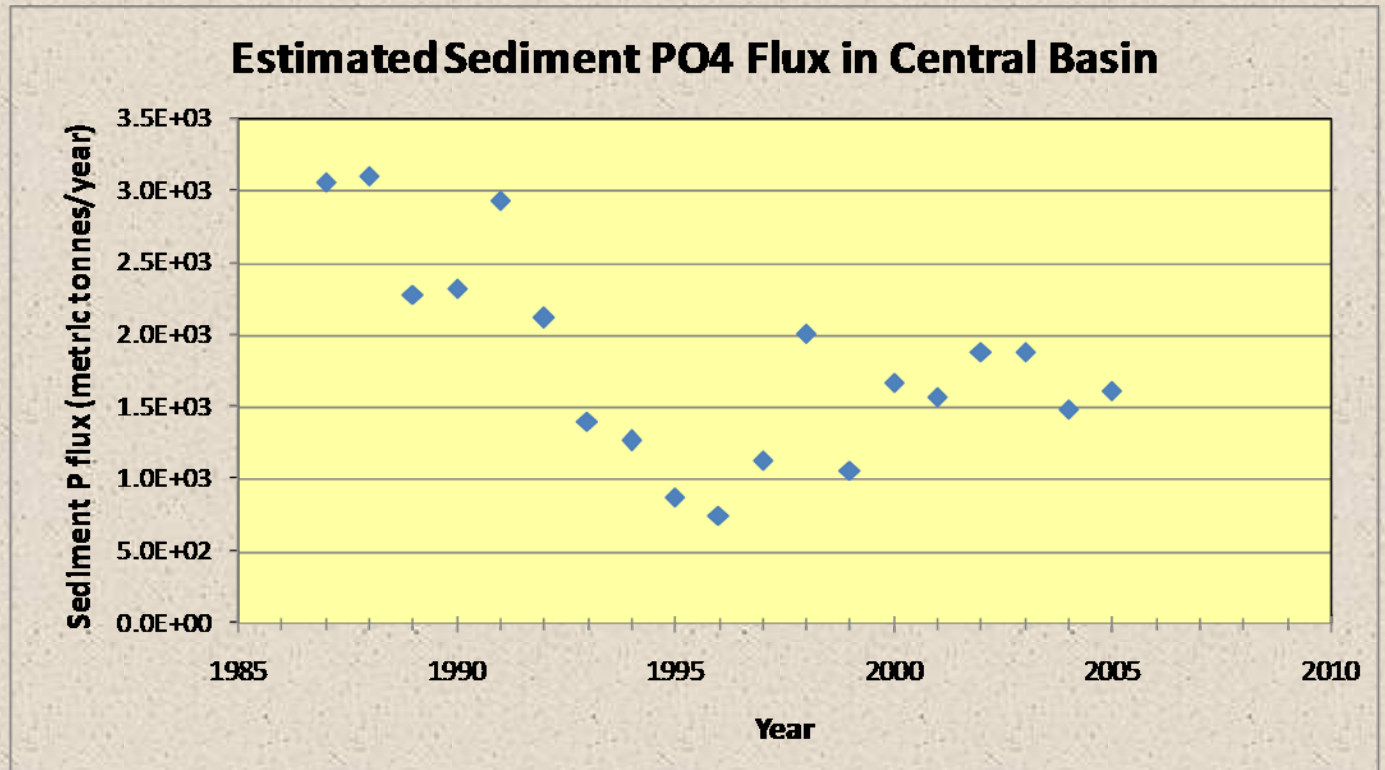




Sediment P Flux analysis (using 1D DO model)



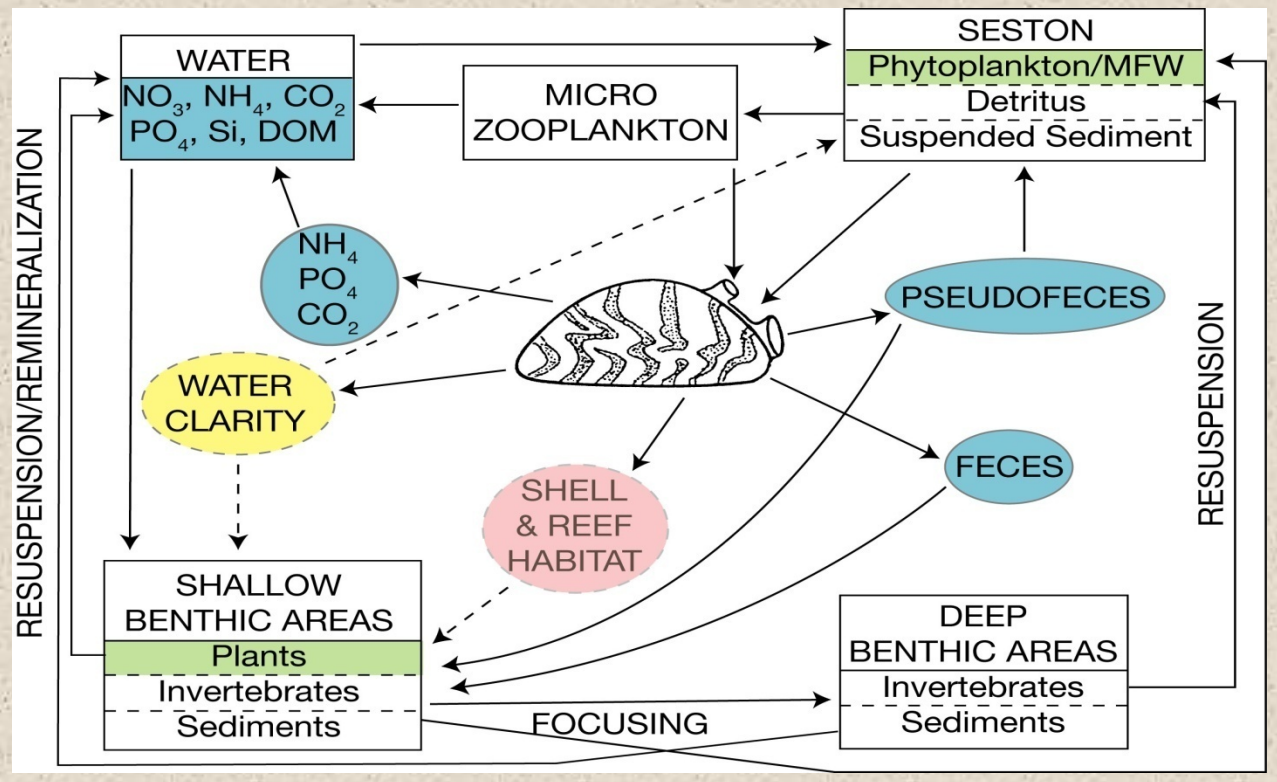
Computed from area with overlying water DO< 2 mg/L * number of days with DO< 2 mg/L * 5 mg P/m^2-d



Post Dreissenid Ecosystem Changes

- **1970s and '80s**
  - Meeting target phosphorus loads established by GLWQA
  - Virtual elimination of cyanophyte blooms and Cladophora nuisance problems
- **Late 1980's and early '90s**
  - Dreissenid invasion of Great Lakes
- **Last Decade: Apparent reversion to historical problems**
  - Reoccurrence of "Dead Zone" in Lake Erie central basin
  - Reoccurrence of *Microcystis* cyanophyte blooms
  - Reoccurrence of nearshore attached nuisance algae (Cladophora)
    - "Muck" washing up on shoreline
  - Apparent "desertification" of offshore waters of deeper lakes (Lake Michigan, Lake Huron, Lake Ontario)
- *Circumstantial or is there a dreissenid-related cause-effect relationship at work?*

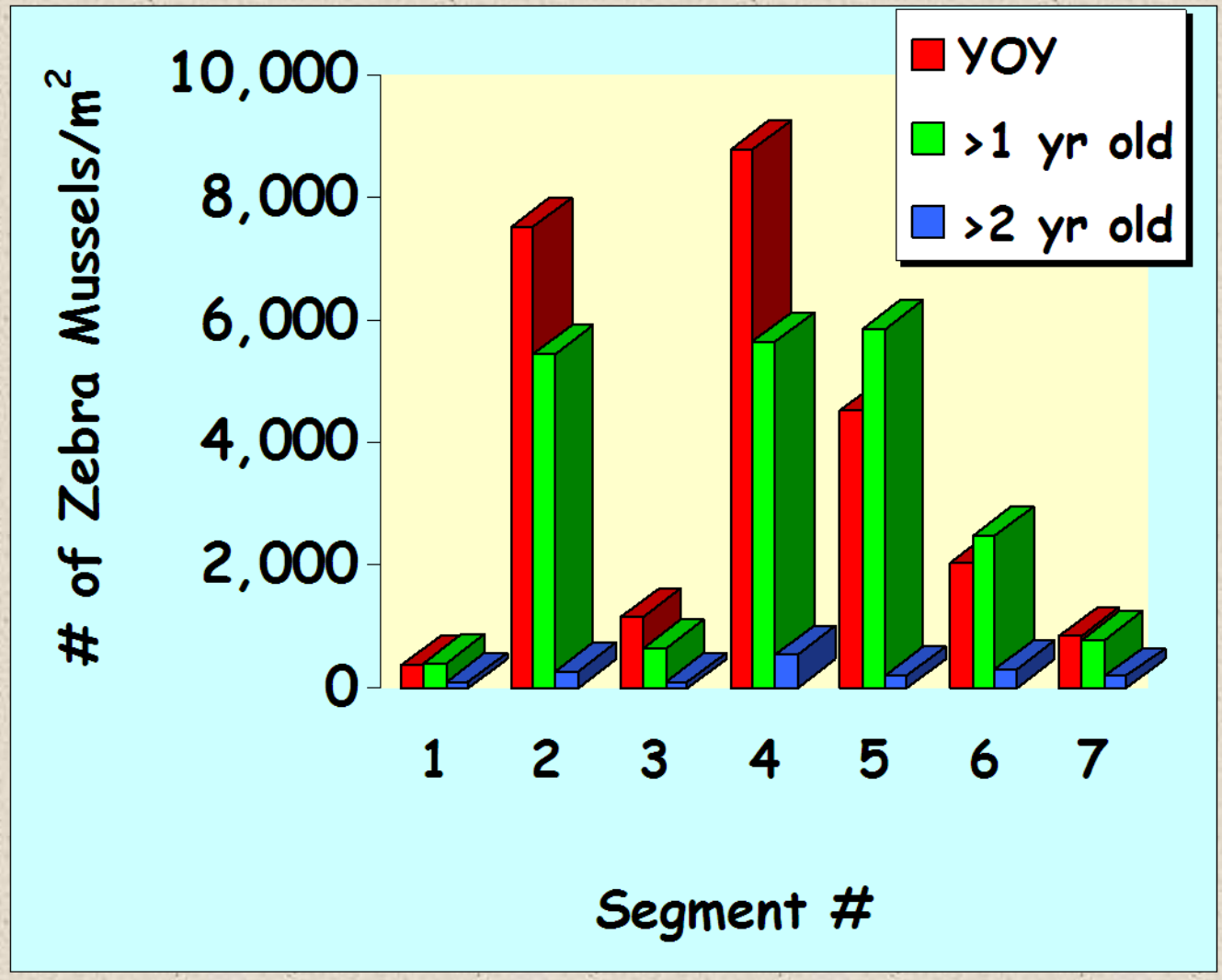
Research and Observations Suggest that Dreissenids are Effective Ecosystem Engineers



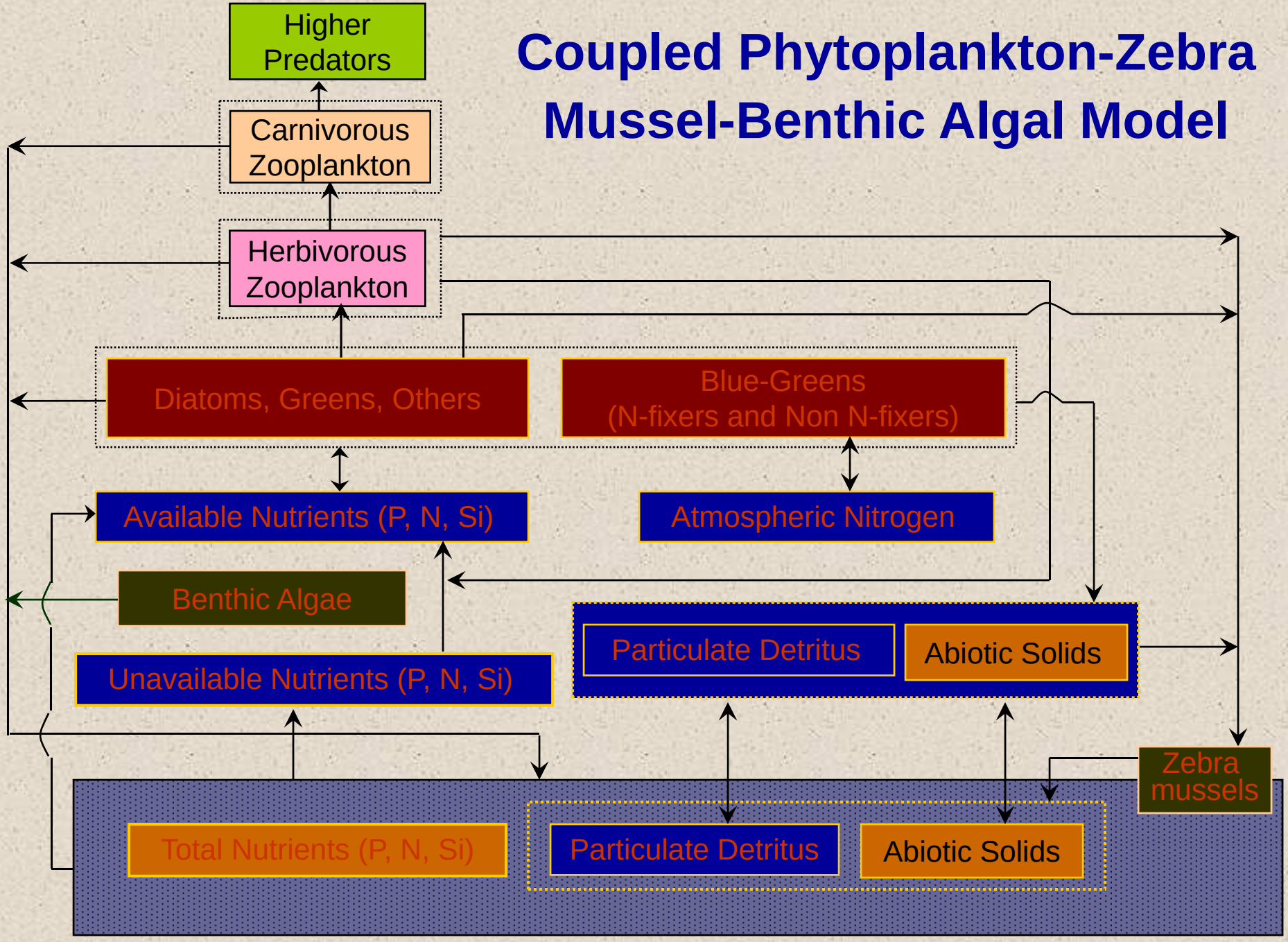
Vanderploeg, et. al., (2007)

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.

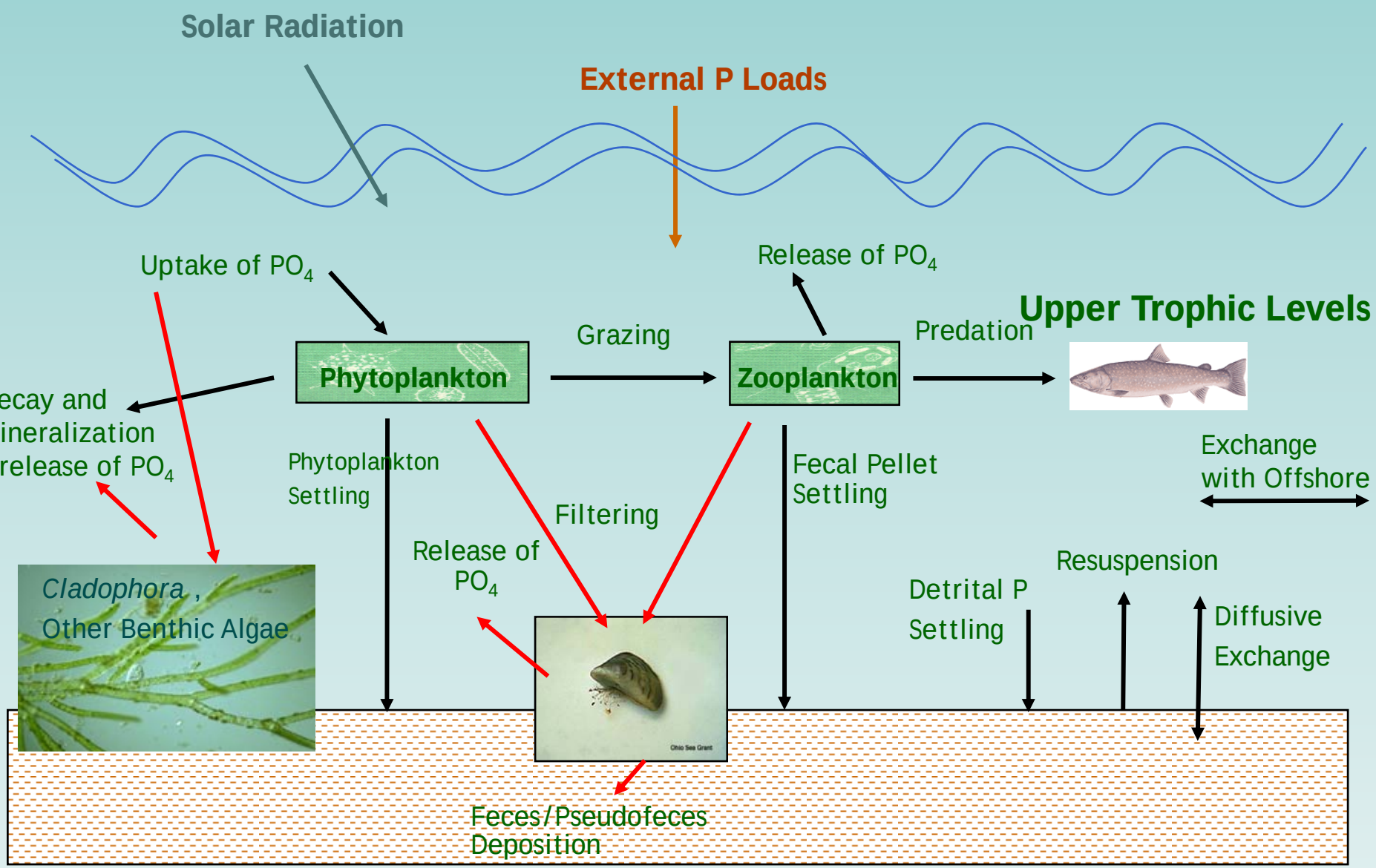
Zebra Mussel Densities in Saginaw Bay
(Avg. 1991-1995)



Coupled Phytoplankton-Zebra Mussel-Benthic Algal Model

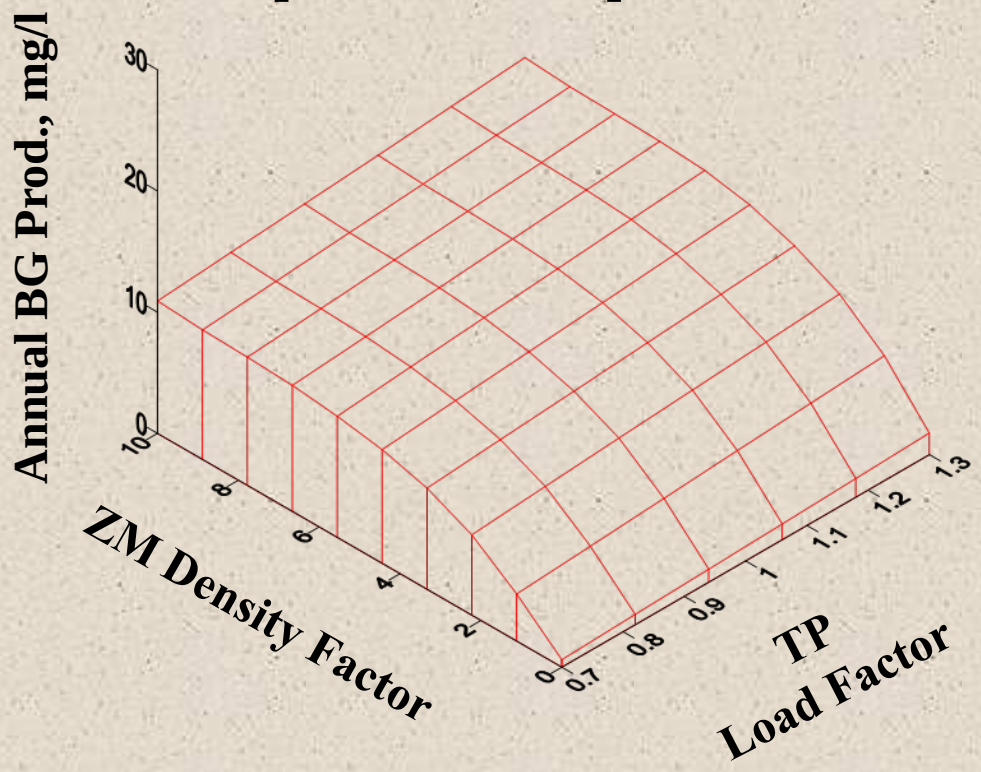


Phosphorus Cycling in New Saginaw Bay Ecosystem

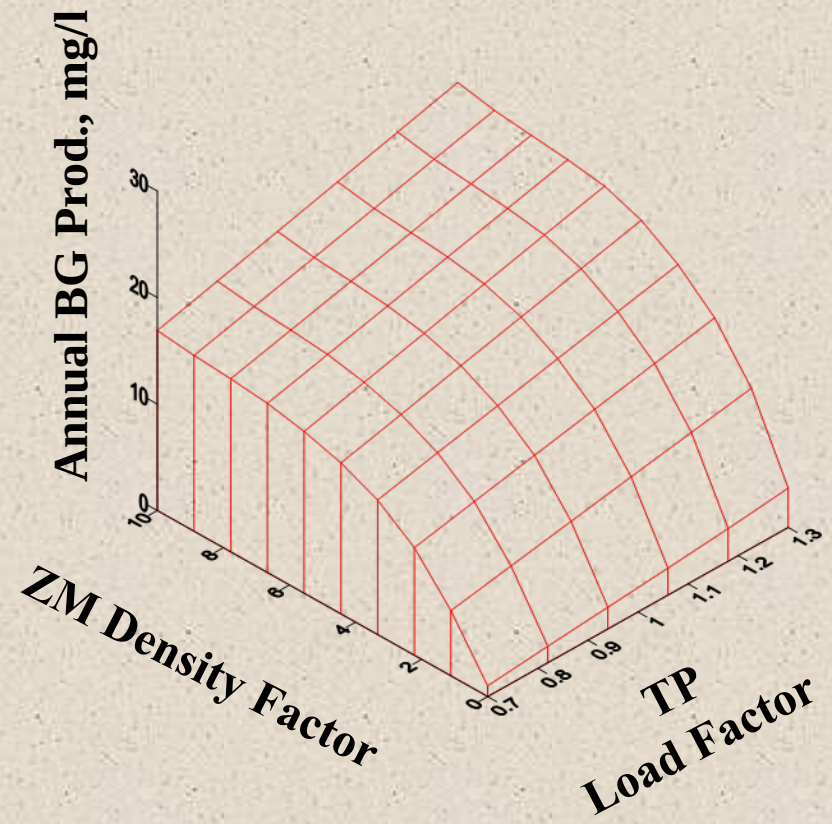


Higher phosphorus concentration and dreissenid density favors *Microcystis*

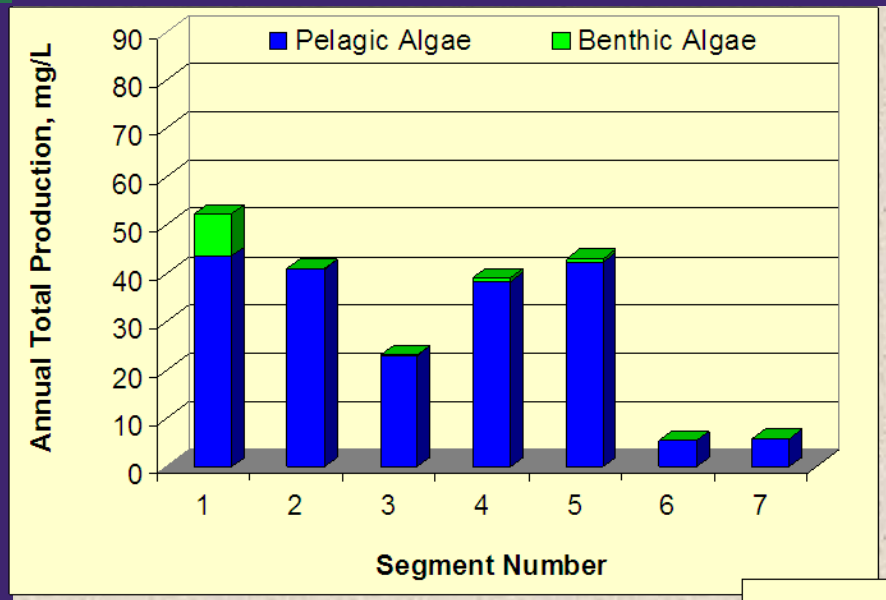
Open Water Responses



Near Shore Responses

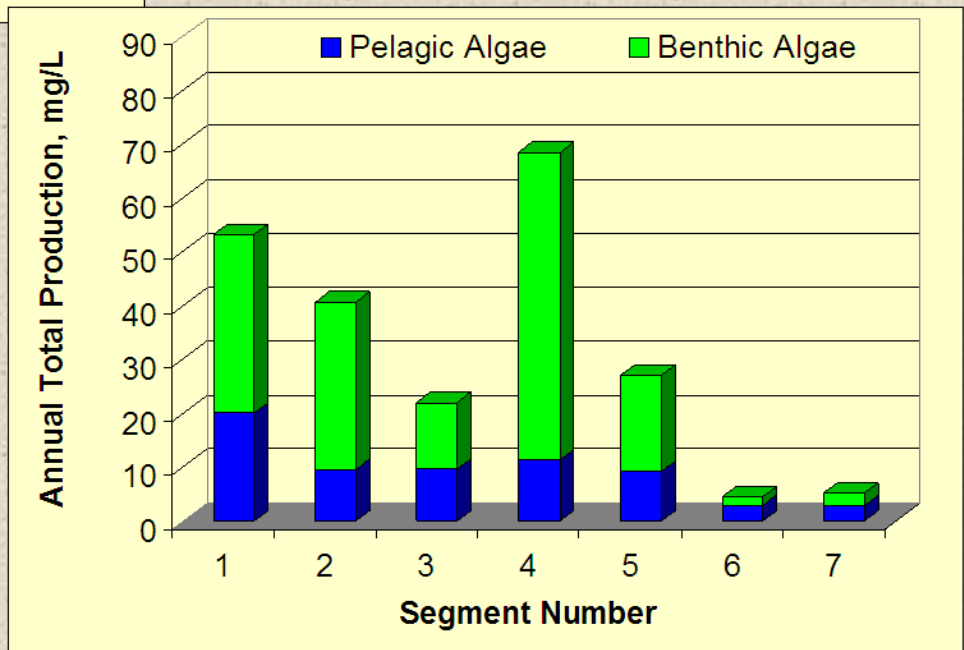


Increased Water Clarity Promotes Benthic Primary Production

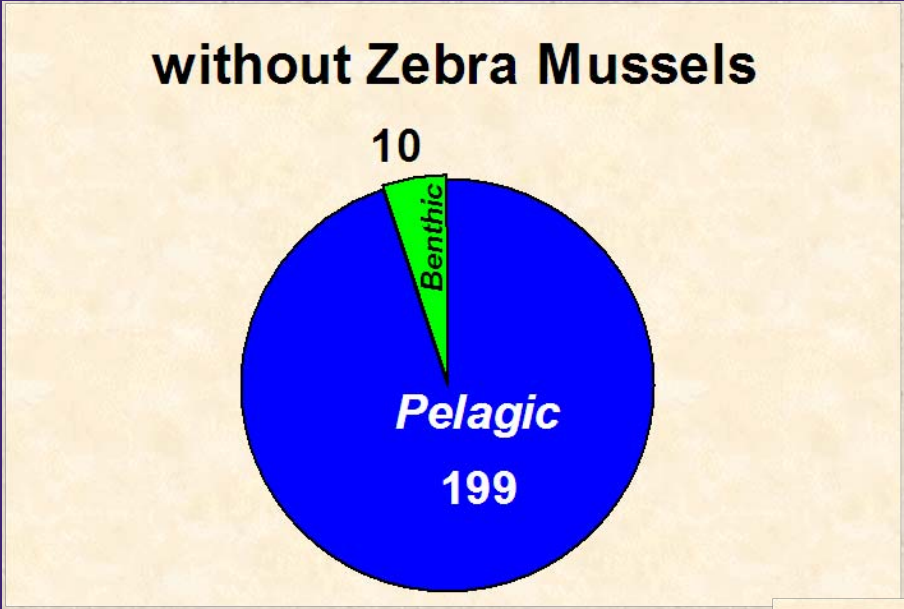


Scenario 1 – No Zebra Mussels

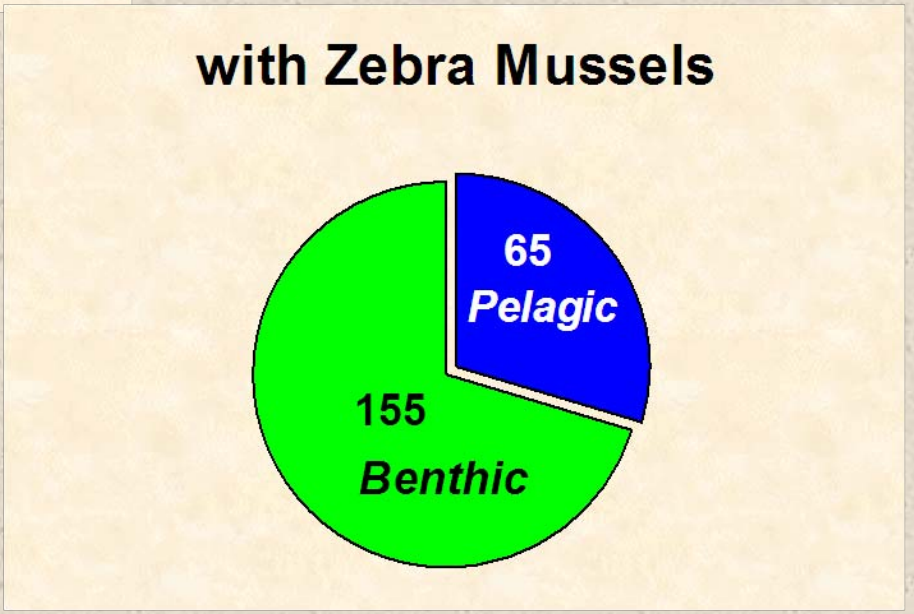
Scenario 2 – Zebra Mussels



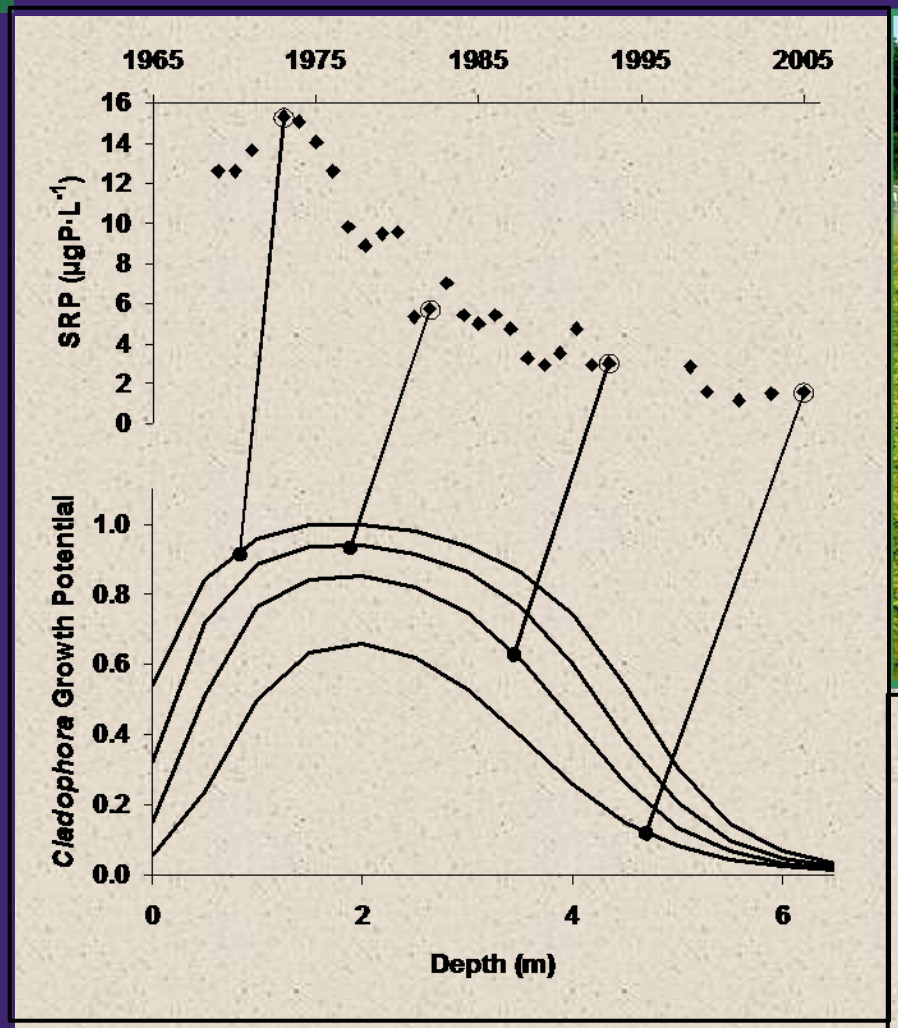
Bay-wide Primary Production shifts to benthic with dreissenids

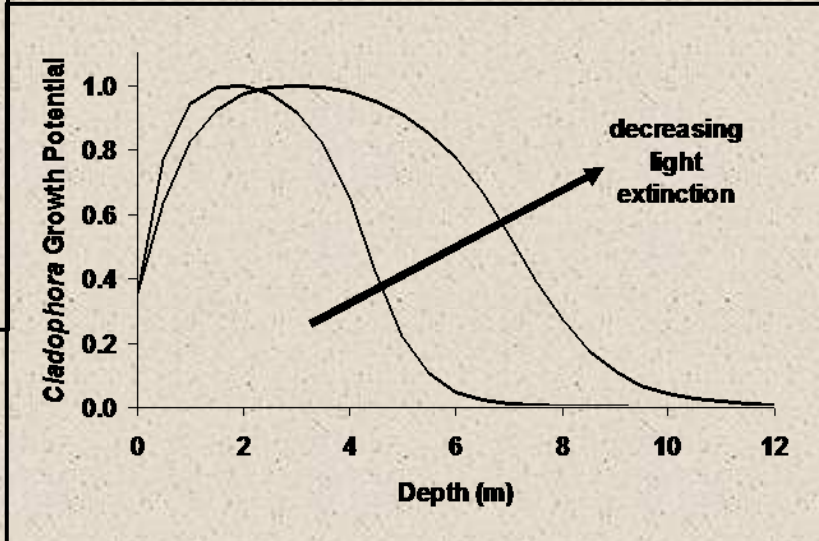


Gross Production Remained Same



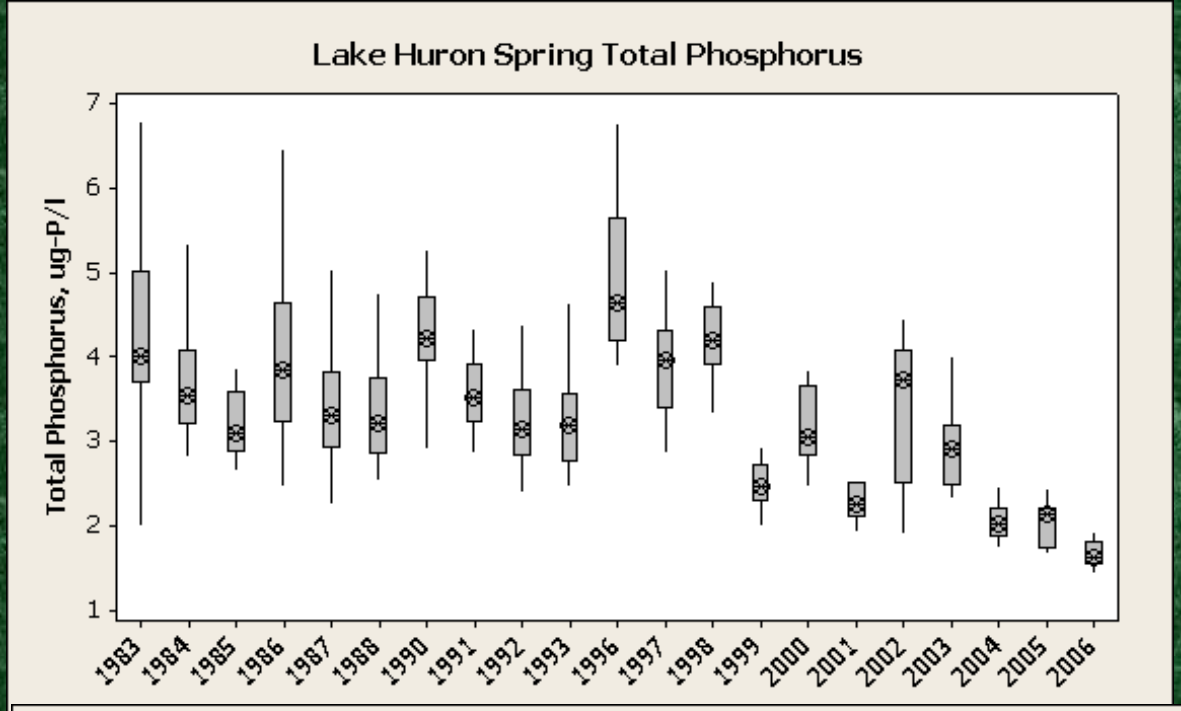
Chladophora Respond to Nearshore SRP and Light Availability (Auer, Higgins, et al.)

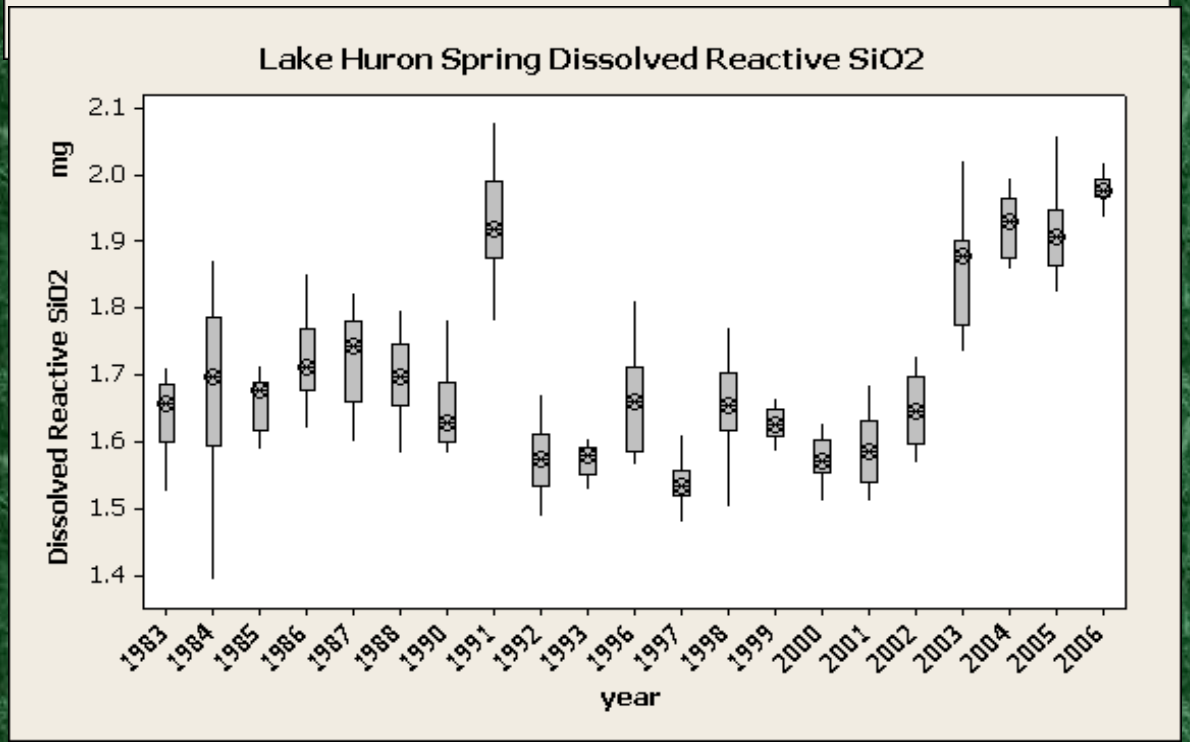


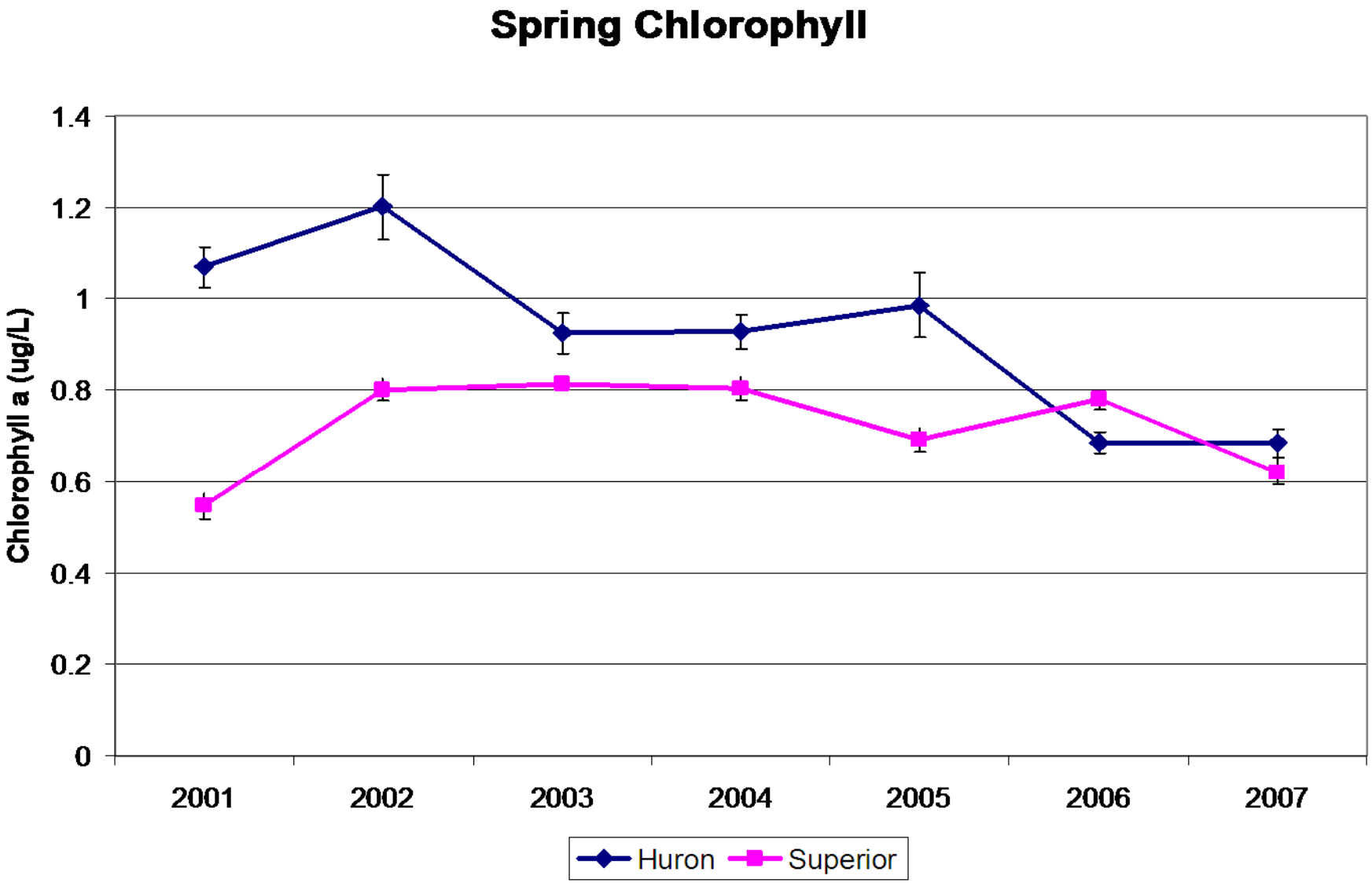


Lake Huron Data

(courtesy of GLNPO, U of W-Superior, MIRB)



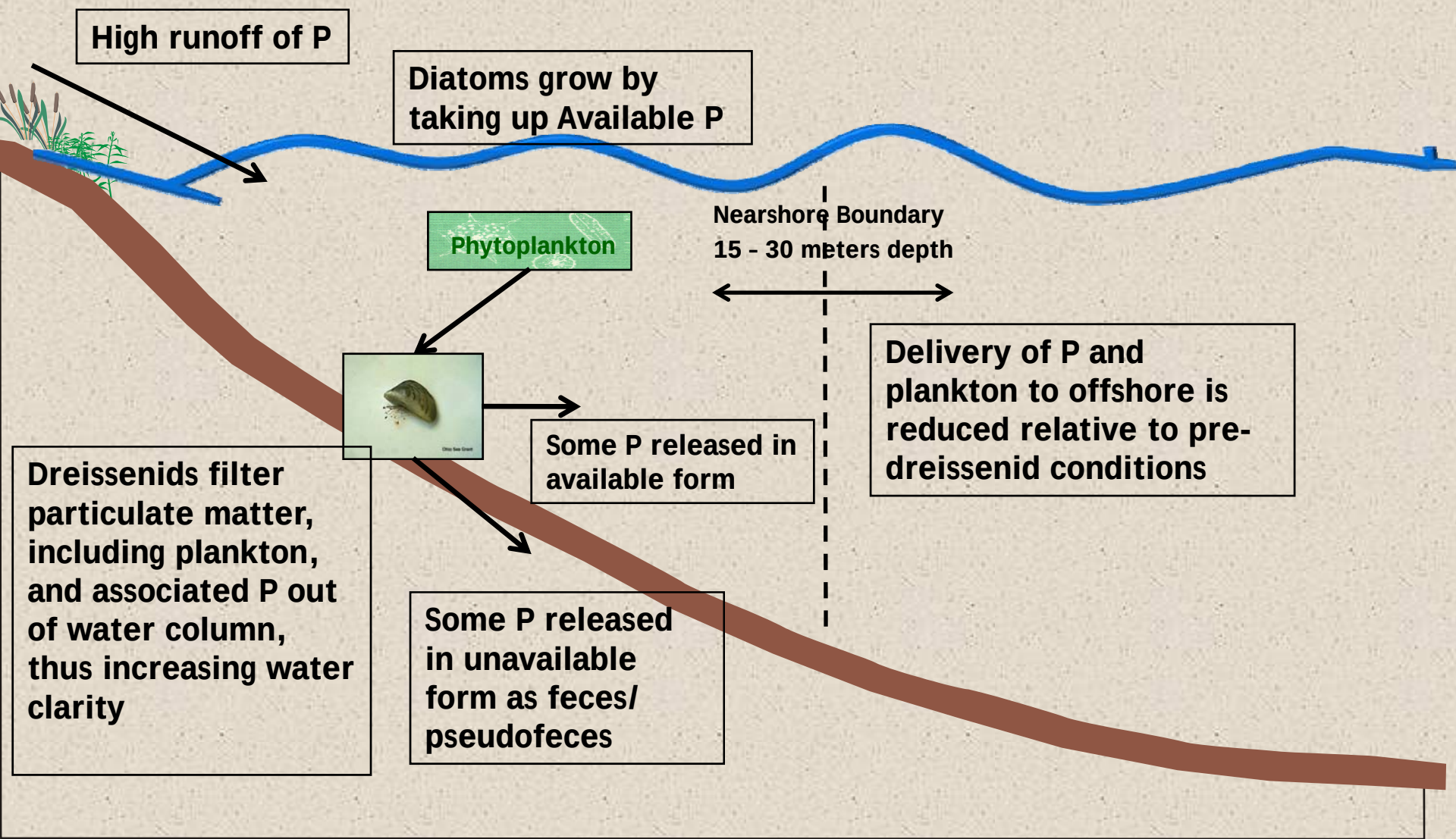




2001-06 data from U. WI - Superior, 2007 from U. Mich.

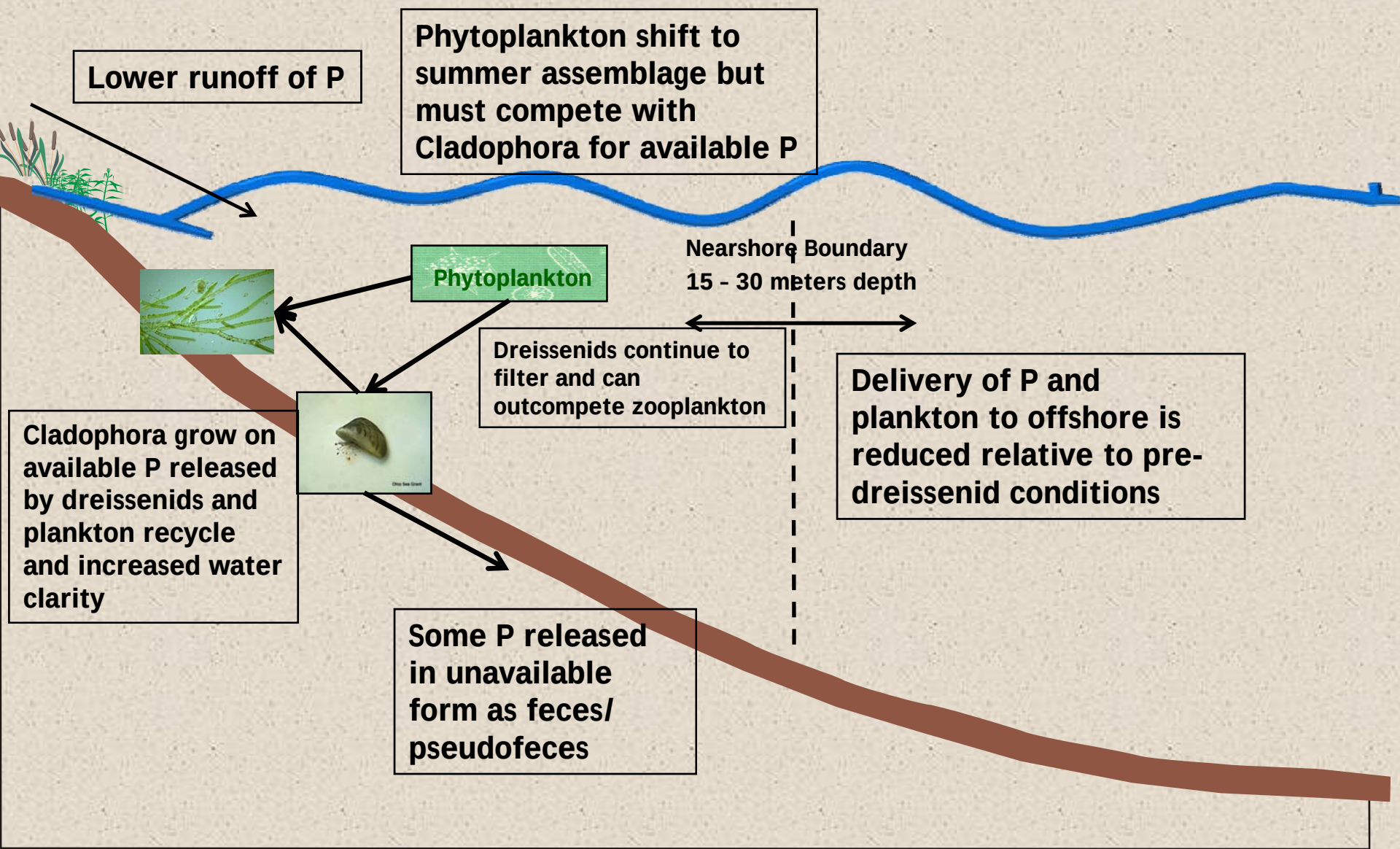
Conceptual Model of Dreissenid Impacts

Spring



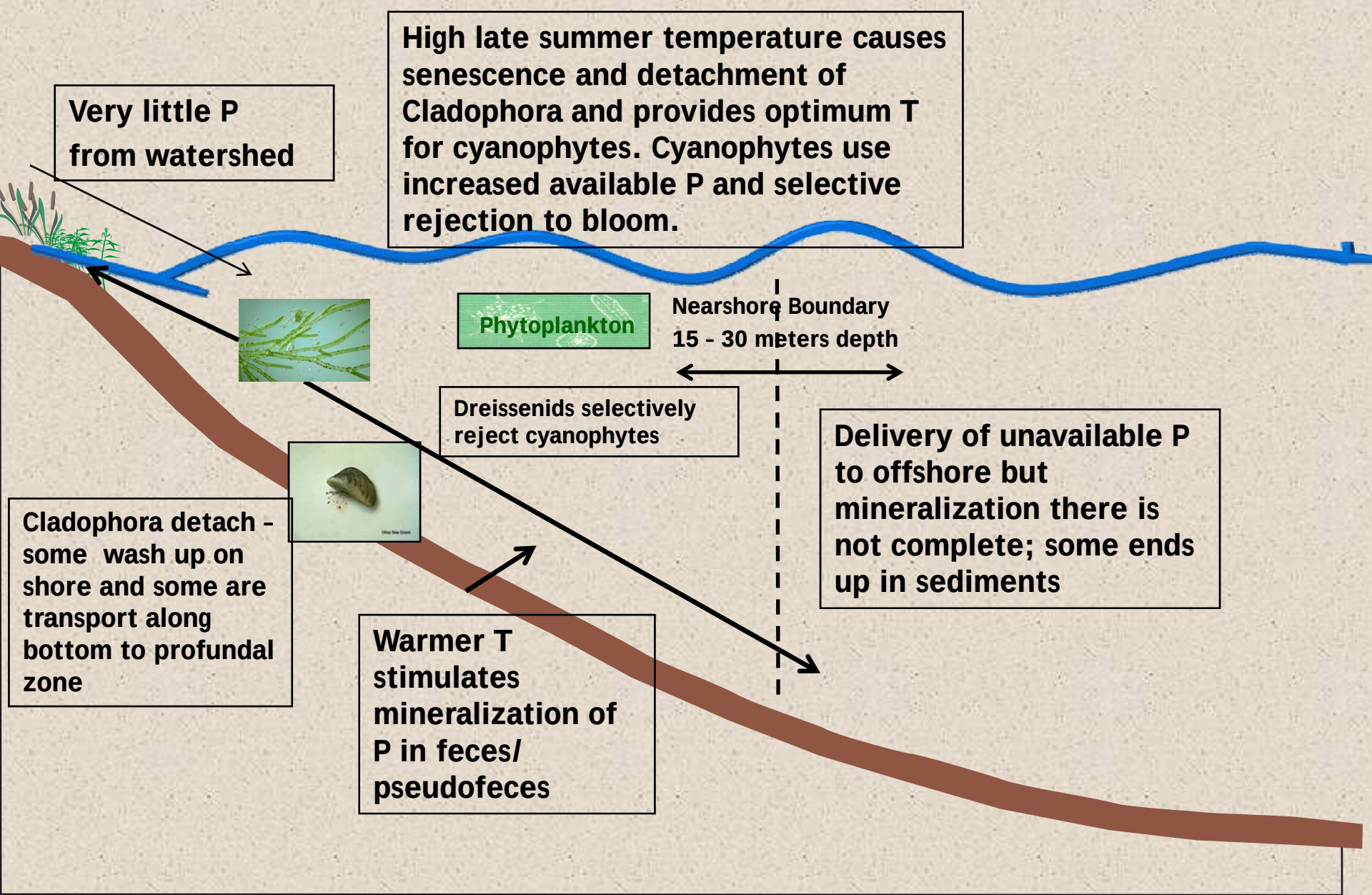
Conceptual Model of Dreissenid Impacts

Early Summer



Conceptual Model of Dreissenid Impacts

Late Summer



Summary Hypothesis

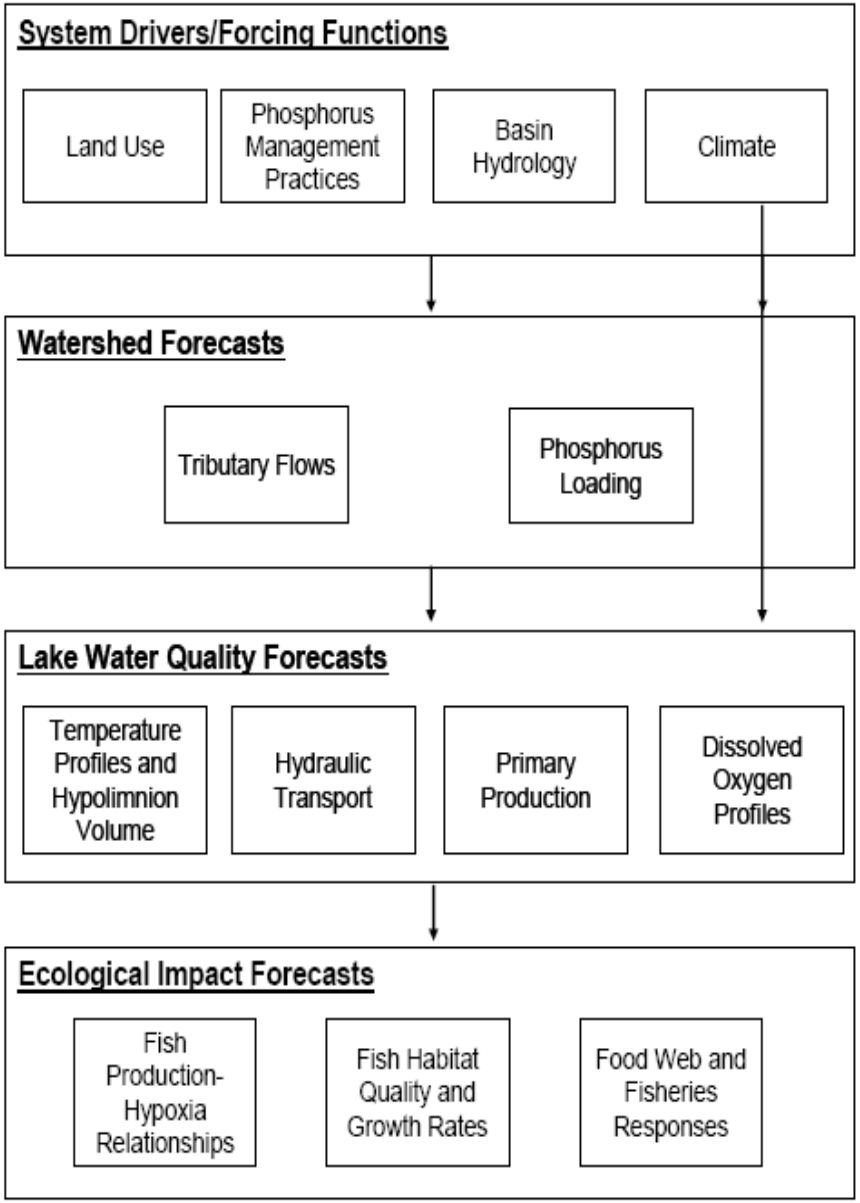
Dreissenid filtering-related impacts on water clarity and phosphorus cycling in the nearshore zones of the lakes have fueled the resurgence of Cladophora and other attached algae while at the same time greatly reducing the primary production potential of offshore waters in these systems by trapping phosphorus in the nearshore and offshore profundal environments.

Ongoing Programs

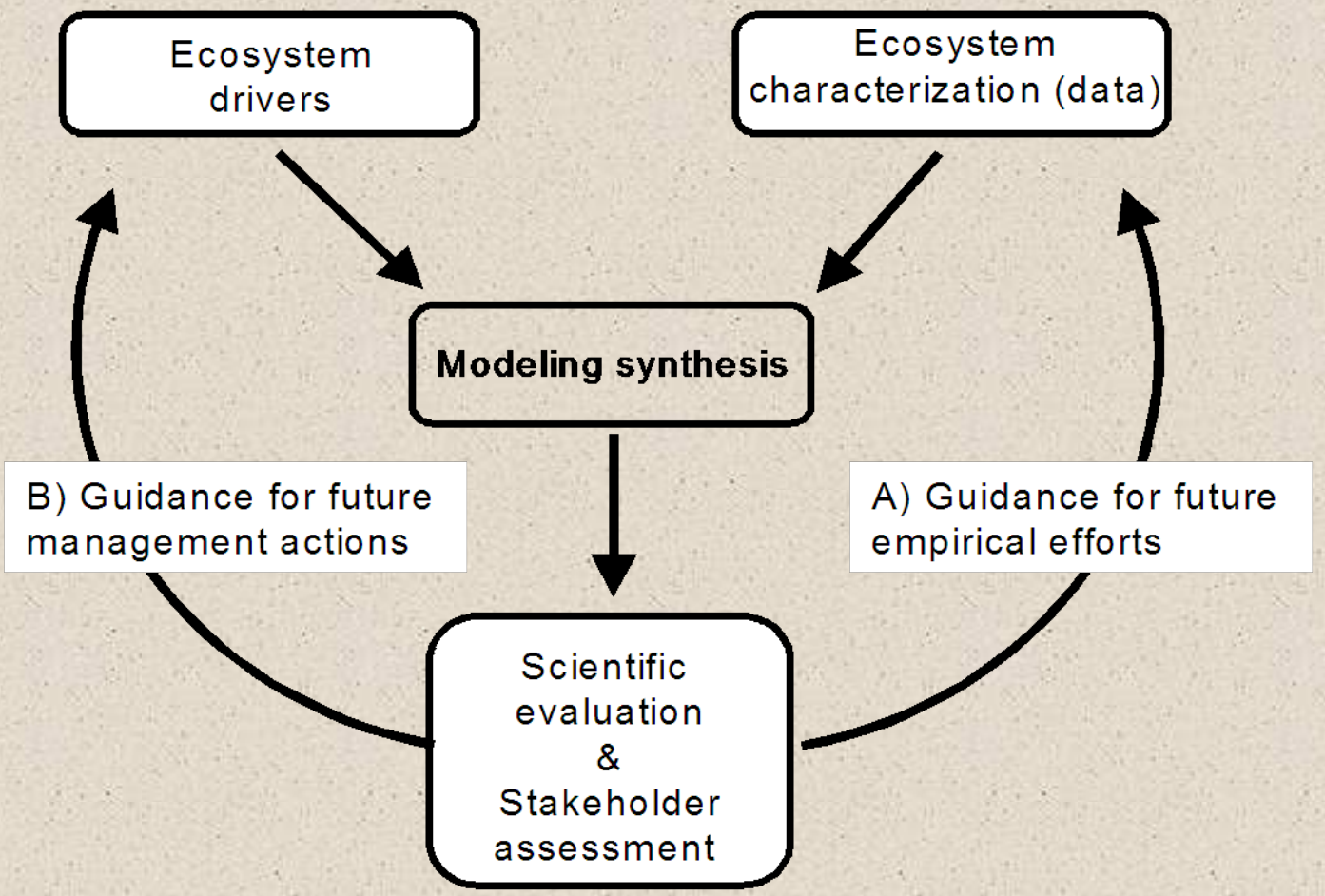
- Ecofore
  - Forecasting severity and impacts of hypoxia in Lake Erie
- Saginaw Bay multi-stressor study
  - Development of Adaptive Integrated Management
- OSU Lake Erie Biocomplexity Project
  - Range of model complexities
  - Human – lake interactions
  - Beginning complex linked hydrodynamic – eutrophication model for Sandusky Bay – nearshore Lake Erie
- Waterloo Lake Erie ecosystem modeling
  - Nearshore shunt hypothesis
- Lake Ontario ecosystem study
  - Nearshore monitoring and modeling in 2008
- EPA and collaborators developing nearshore towed sensor devices for rapid monitoring of nearshore conditions

Ecosystem Forecasting of Lake Erie Hypoxia

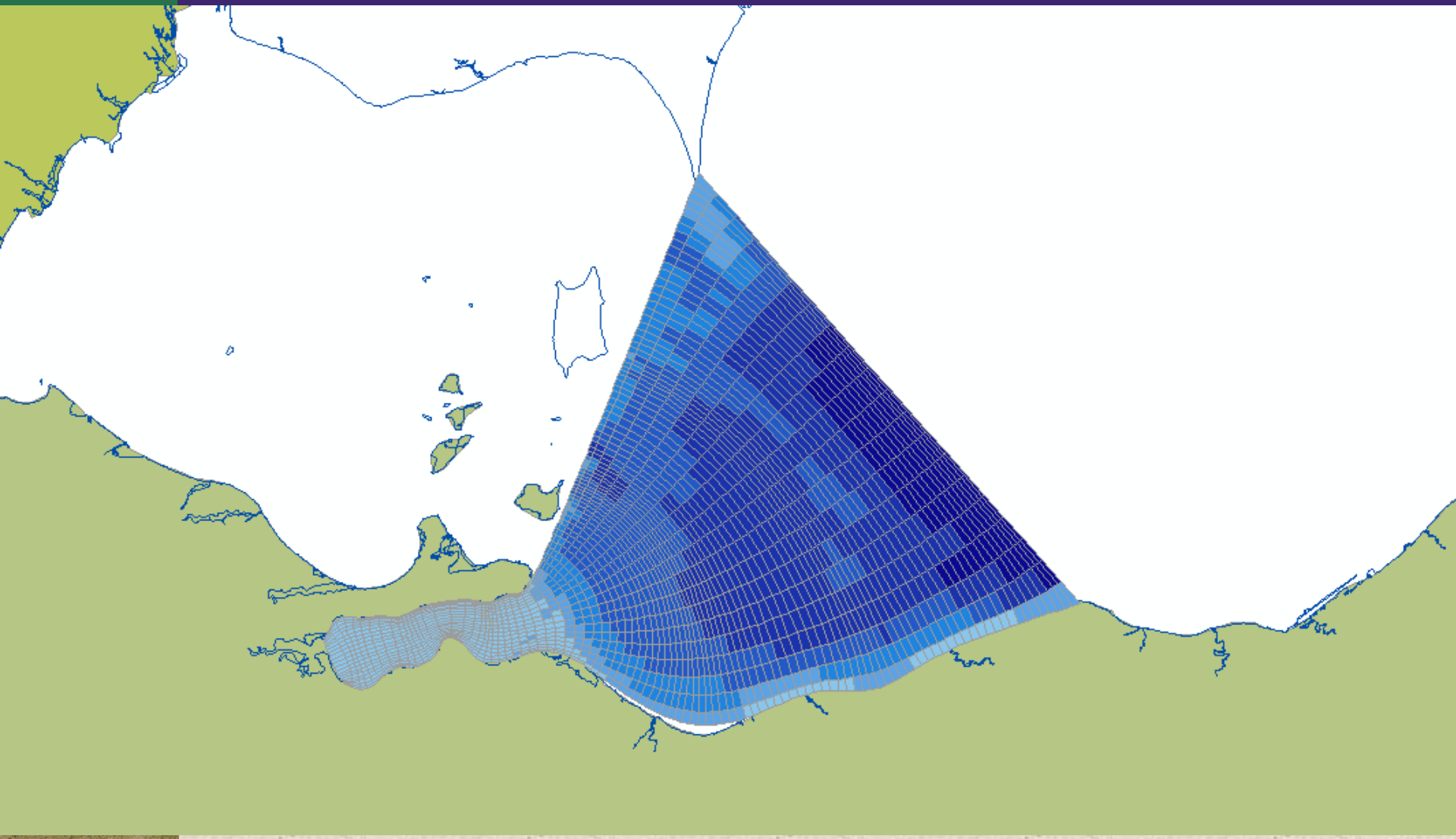
- What are the *Causes*, *Consequences*, and *Potential Remedies* of Lake Erie Hypoxia?
- Linked set of models to forecast:
  - changes in nutrient loads to Lake Erie
  - responses of central basin hypoxia to multiple stressors
    - P loads, hydrometeorology, dreissenids
  - potential ecological responses to changes in hypoxia
- Approach
  - Models with range of complexity
  - Consider both anthropogenic and natural stressors
  - Use available data – IFYLE, LETS, etc.
  - Will assess uncertainties in both drivers and models
  - Apply models within an Integrated Assessment framework to inform decision making for policy and management



Adaptive Integrated Framework for Managing Impacts of Multiple Stressors – Application to Saginaw Bay Ecosystem



Proposed Sandusky Bay/West-Central Basin Grid



2000 cells, ~200m in bay, 1km in lake

Keep 'em Great!