Ohio Lake Erie Phosphorus Task Force
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Columbus, OH

# *Models Can Support Establishment of Phosphorus Loading Targets for Lake Erie*


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# Contributors

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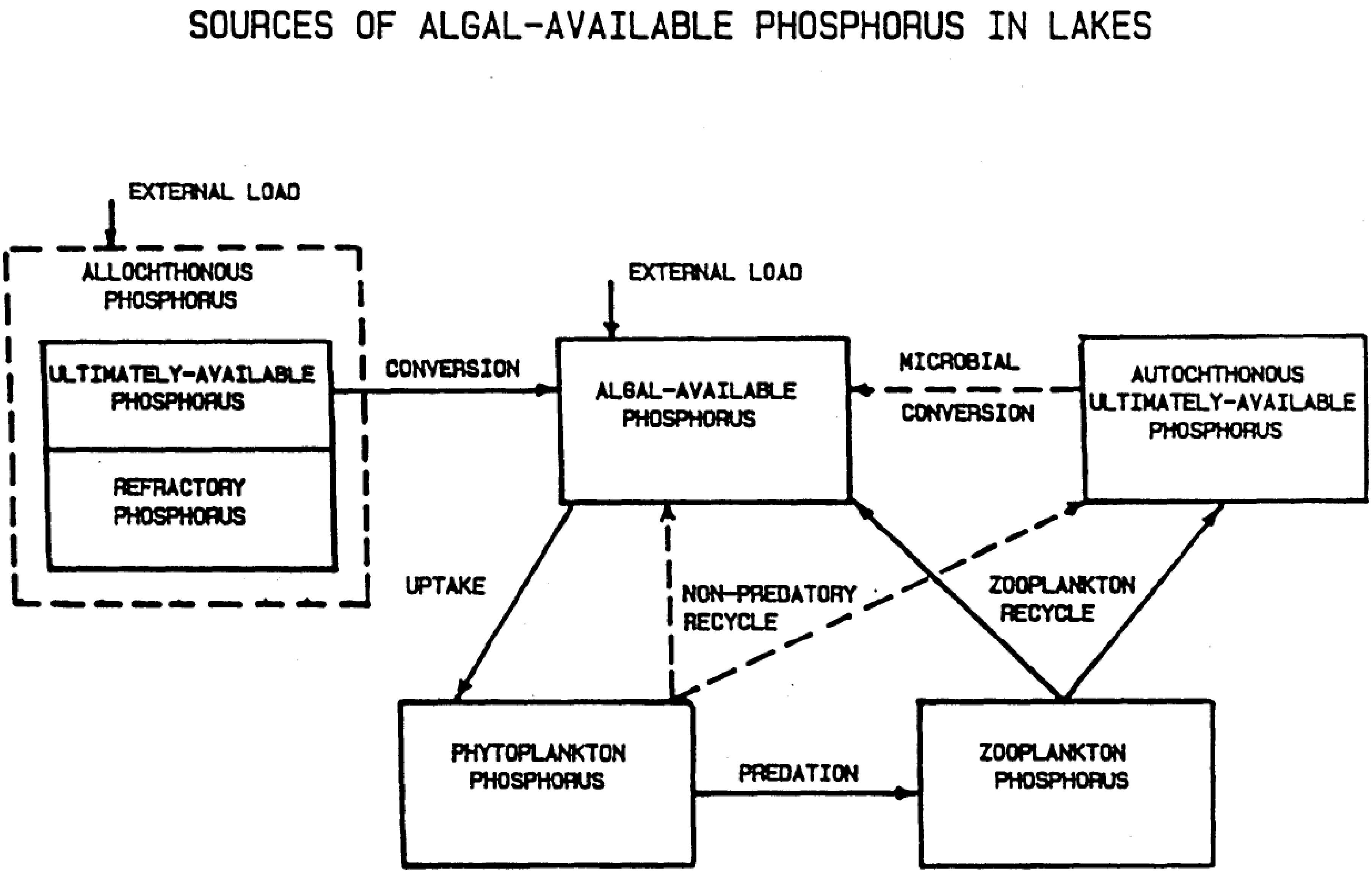
# Outline of Presentation

- Review some basic concepts
  - Algal-available phosphorus and water column cycling
  - Internal phosphorus loading (sediment feedback)
- Hypoxia modeling
  - EcoFore
  - SOD response to P load changes
  - 1D Central Basin model results
- Cyanobacteria blooms in Western Basin
  - 2011-12 comparison
  - NOAA NOS relationship
  - WLEEM – LimnoTech process model

# Algal-availability and water column recycling

# Water Column Cycling of Phosphorus



# Assessing Availability of Particulate Phosphorus in Great Lakes Tributaries

Technical Note

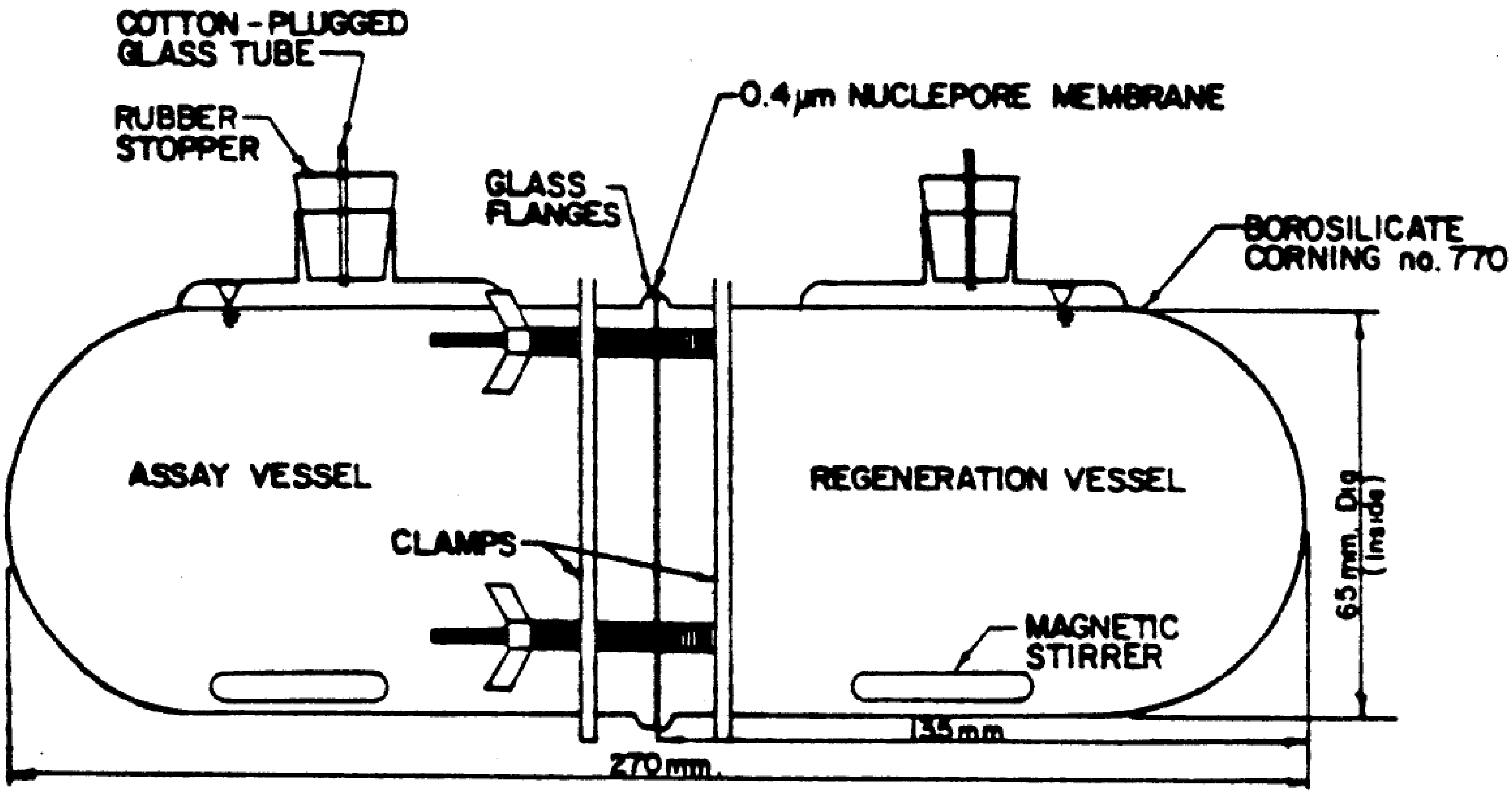



Fig. 1. Schematic of dual culture diffusion apparatus.

# Algal Uptake in DCDA Corresponds to Decrease in NaOH-extractable P

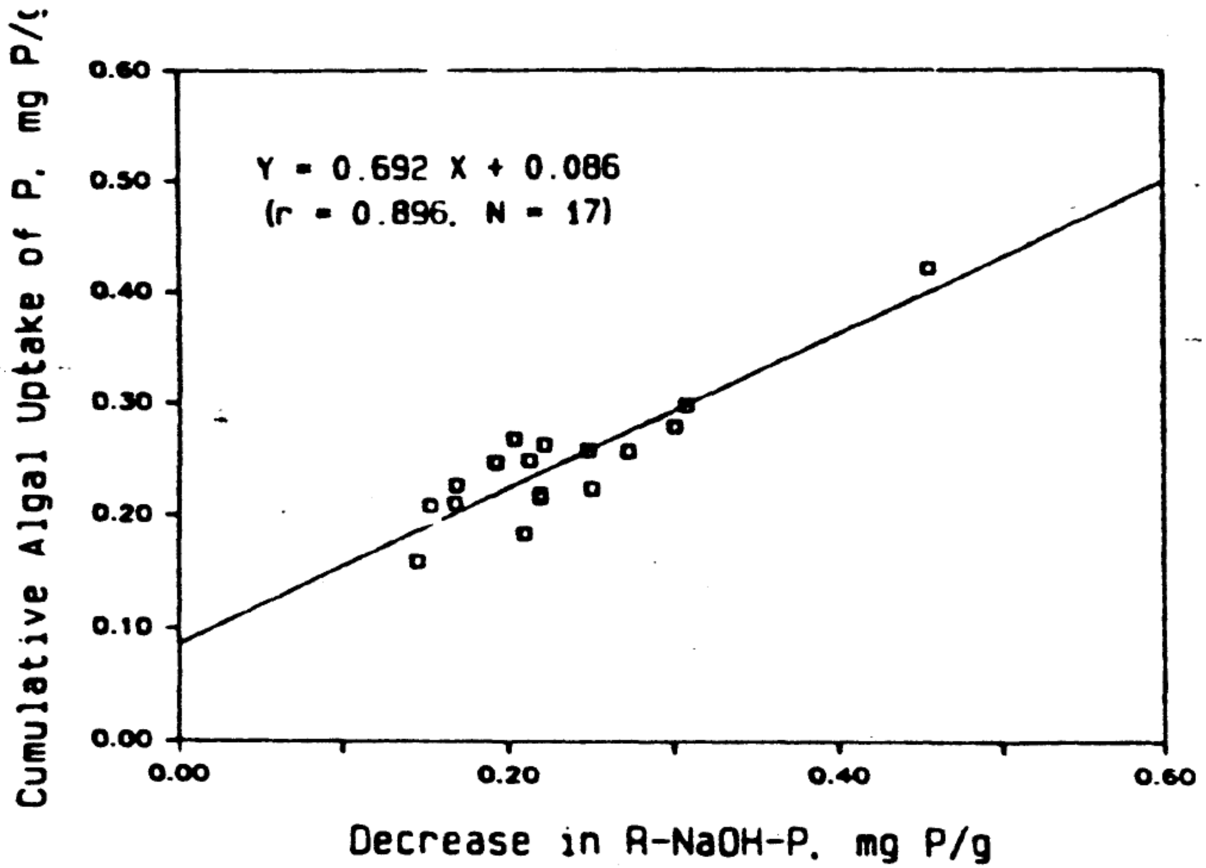



*FIG. 1. Regression of cumulative uptake of P by algae on changes in R-NaOH-P content of sediments during available P bioassays. Sediments were collected from the Maumee, Sandusky, and Cuyahoga rivers and Honey Creek (Ohio) during 1981.*

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

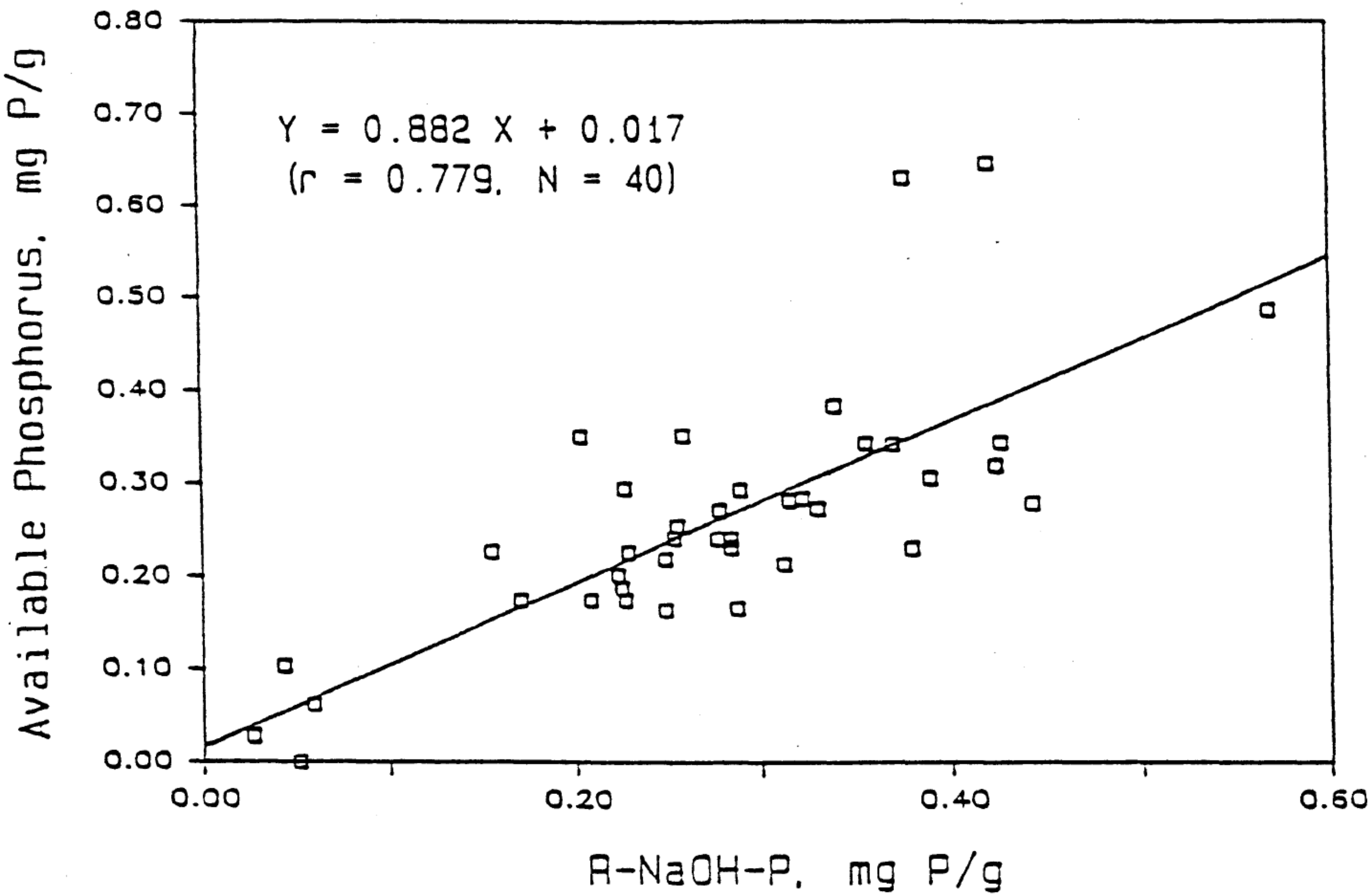



Fig. 1. Regression of algal available phosphorus on R - NaOH - P for 40 samples of suspended solids from Lower Great Lakes tributaries.

# 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)**

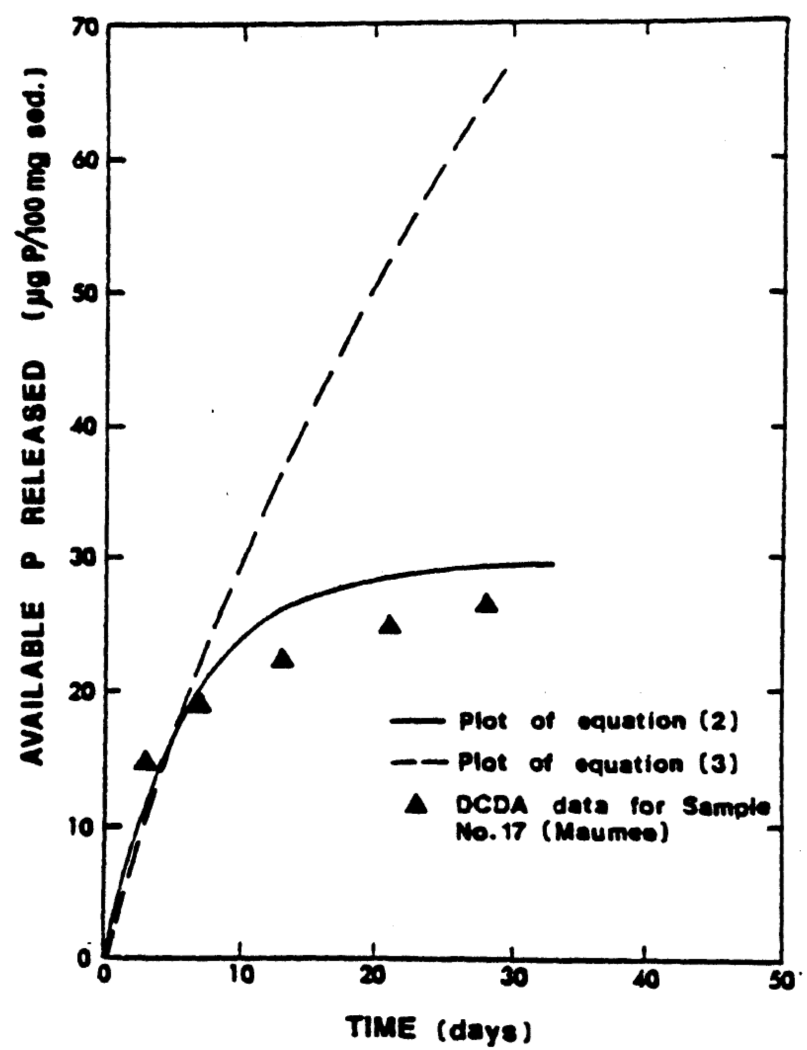



*FIG. 5. Comparison of current Great Lakes model predictions of BAPP versus time (equation (3)) with actual data for sample no. 17 and first-order fit (equation (2)).*

# Tested Three Versions of Lake Erie Model

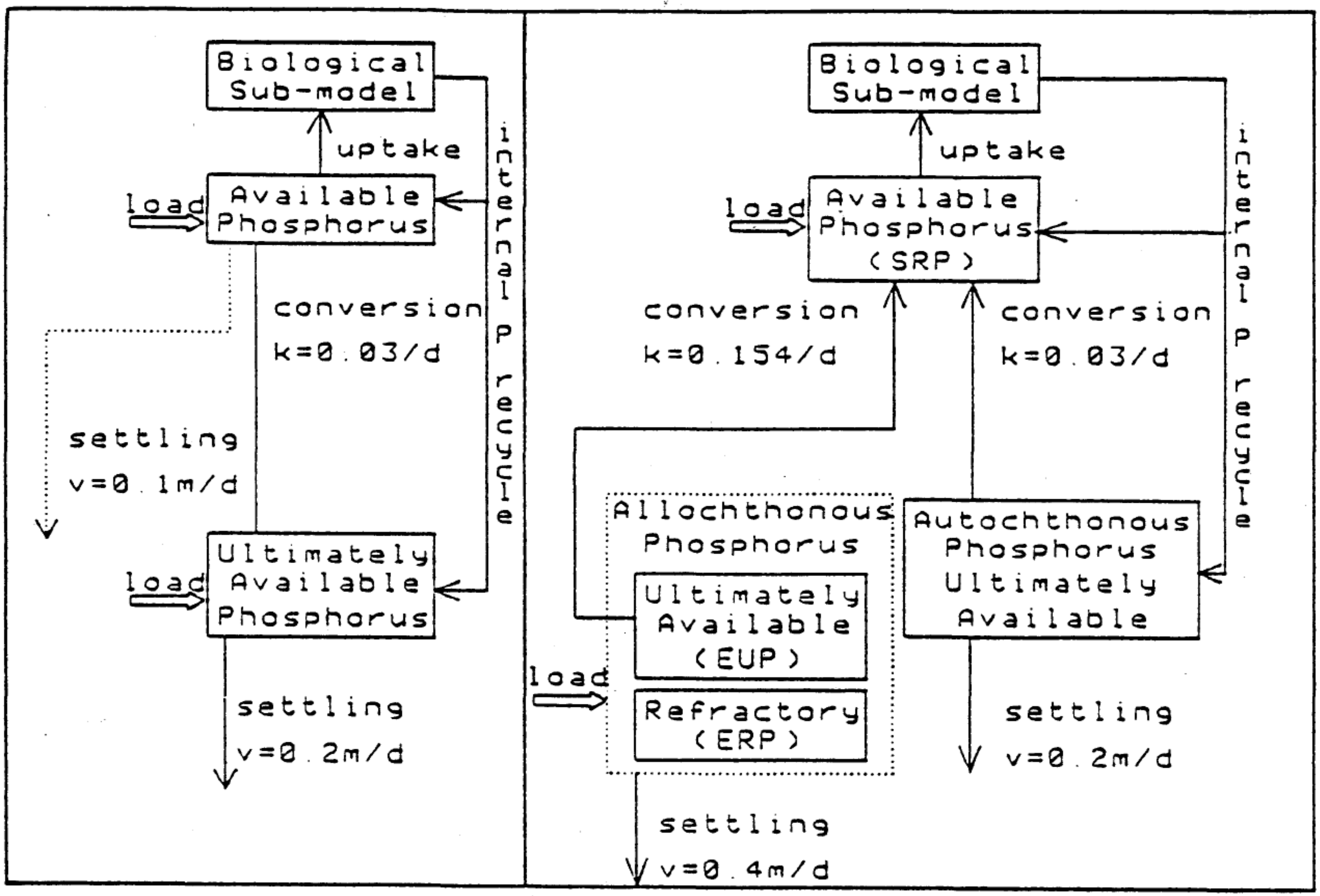



Fig. 4. Schematic diagram of P dynamics (kinetics, loading, and settling) in 3 modifications of Lake Erie phytoplankton model : LEM1 and LEM2 (left), and LEM3 (right).

# Importance of P Release from Particulates in the Water Column

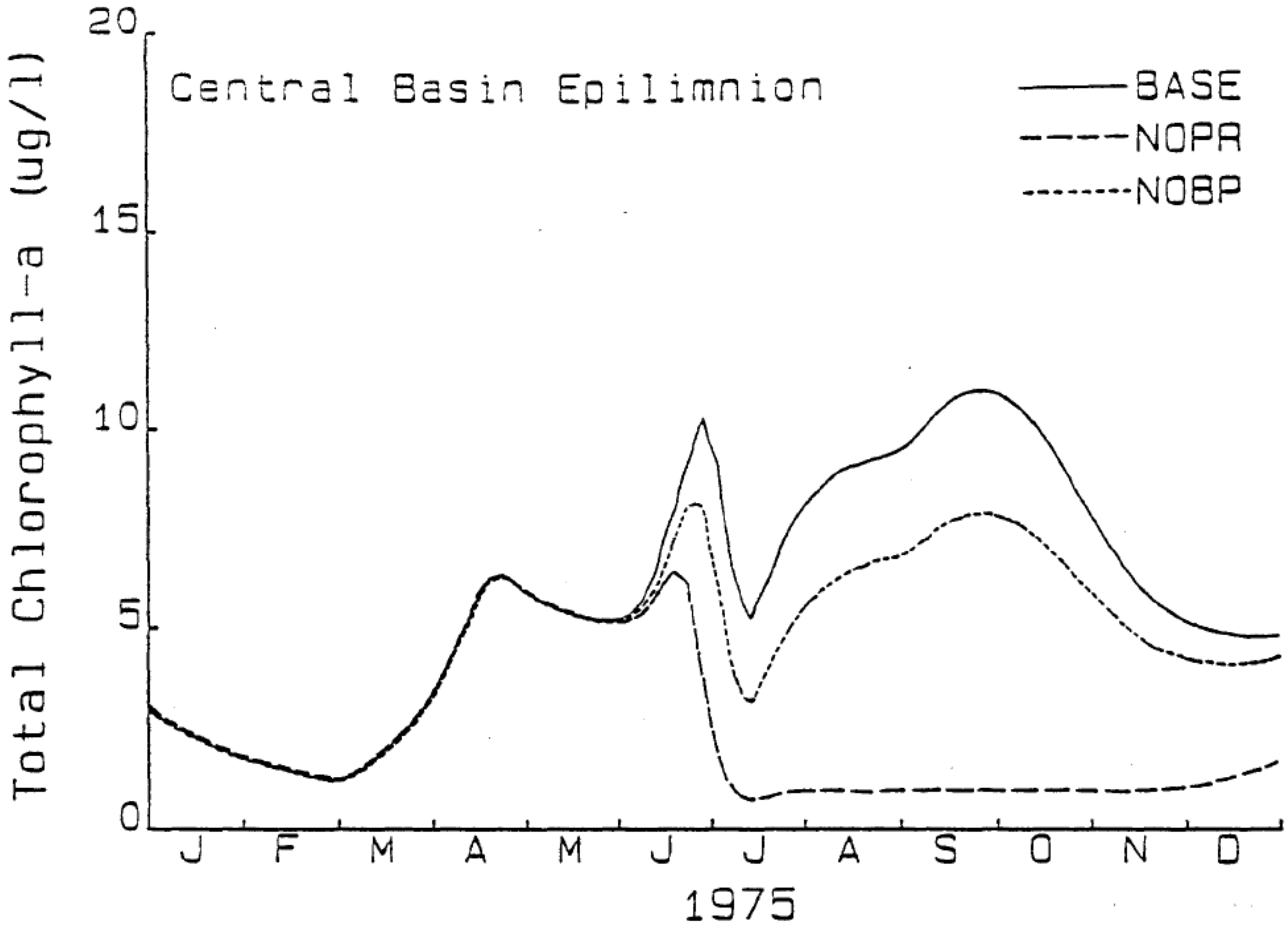



Fig. 8c. Sensitivity of Chlorophyll-a predictions by LEM3 using 1975 data for Central Basin epilimnion to exclusion of EUP conversion submodel (NOBP) and IUP recycle submodel (NOPR); BASE is LEM3 with both ultimately available P conversion submodels operating.

# Halving SRP Load Gives Bigger Response than Halving EUP Load

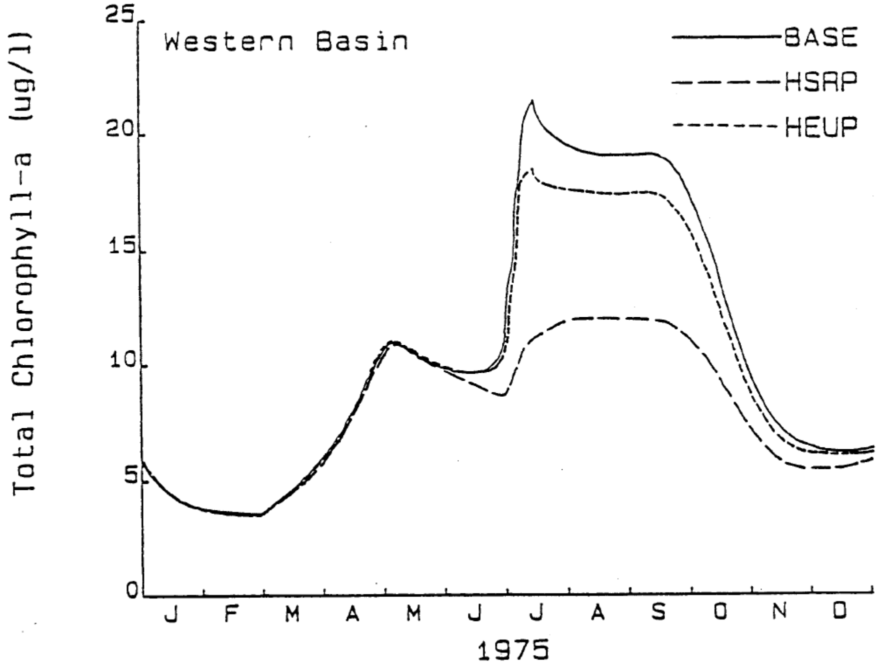



Fig. 9a. Effect on chlorophyll-*a* of halving SRP load (HSRP) or halving EUP load (HEUP) to Western Basin of Lake Erie, compared to existing loads for 1975 (BASE).

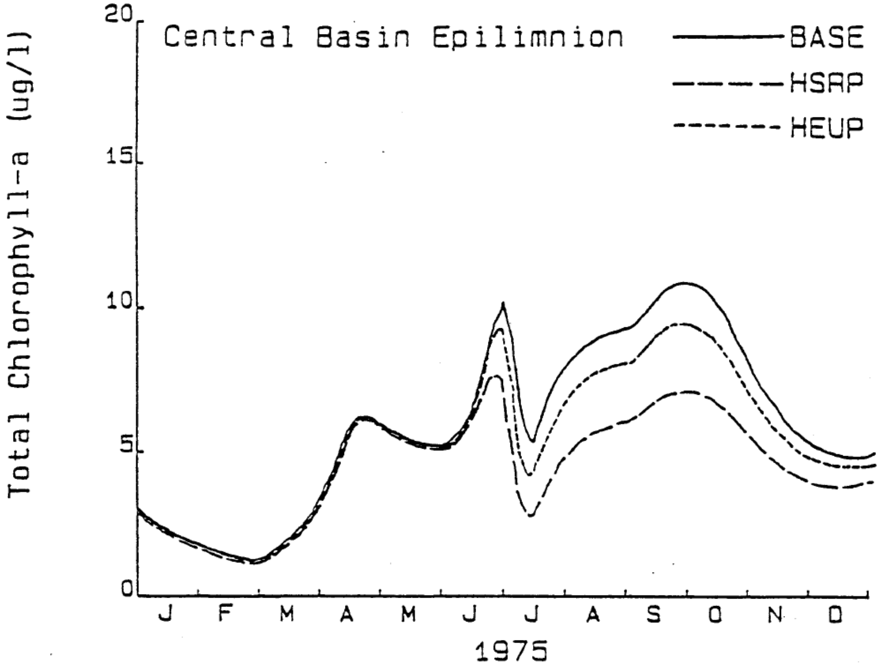


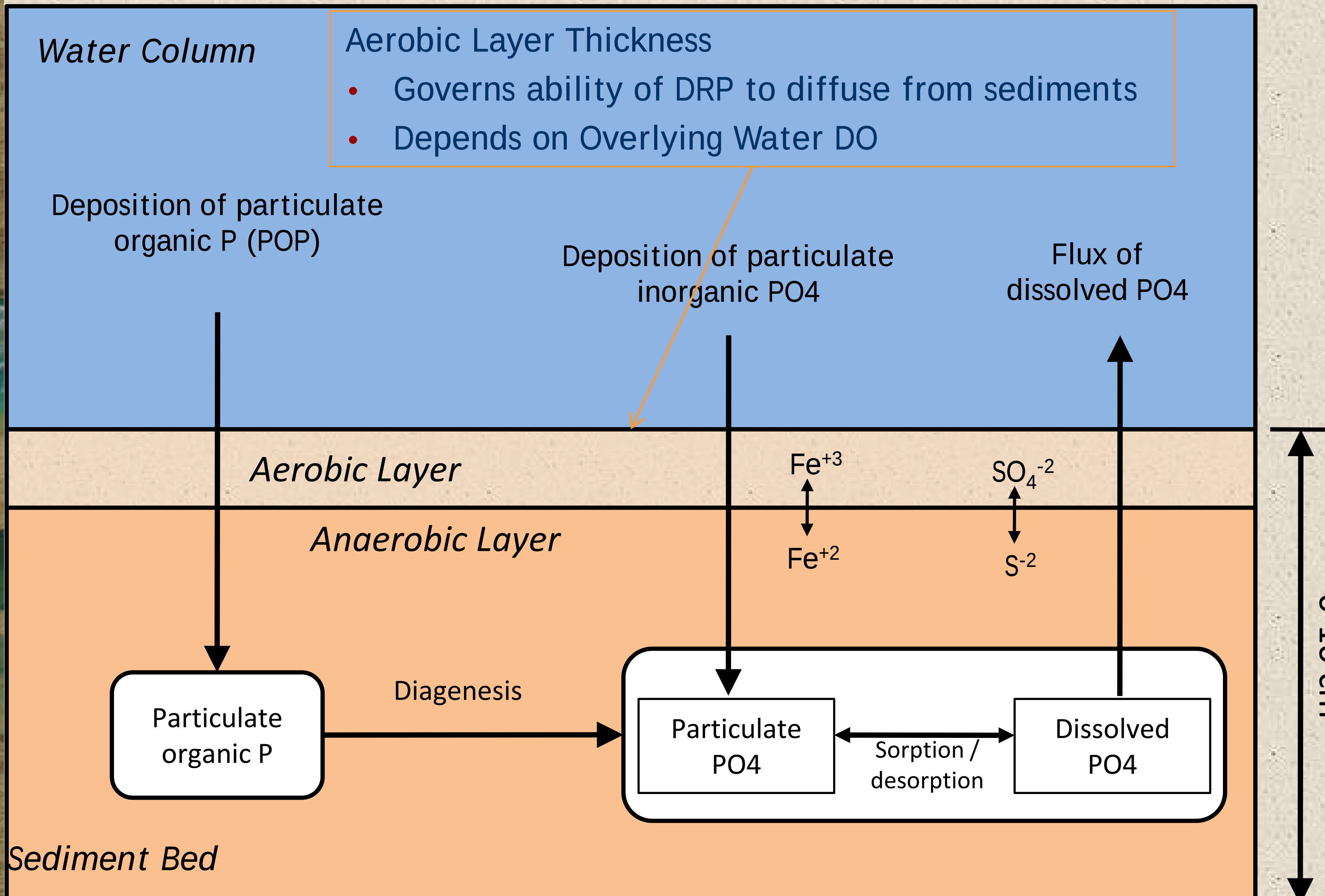

Fig. 9c. Effect on chlorophyll-*a* of halving SRP load (HSRP) or halving EUP load (HEUP) to Central Basin epilimnion, compared to existing loads for 1975 (BASE).

# Internal loading of phosphorus from sediments

# Pathways of Internal Sediment Load

- **Sediment resuspension of particulate phosphorus**
  - Driven by wind-wave bottom shear stress
  - Amount of algal available phosphorus from this process depends on relative rate of release from resuspended sediments and rate of redeposition of resuspended sediments
  - Significant in shallow areas of Western Basin
- **Pore diffusive flux of dissolved phosphorus**
  - Rate governed by gradient of dissolved phosphorus in surface sediments and diagenetic processes controlling that gradient
  - Significant in hypoxic areas of Central Basin

# Understanding of Sediment-Water Phosphorus Diffusive Flux Processes



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

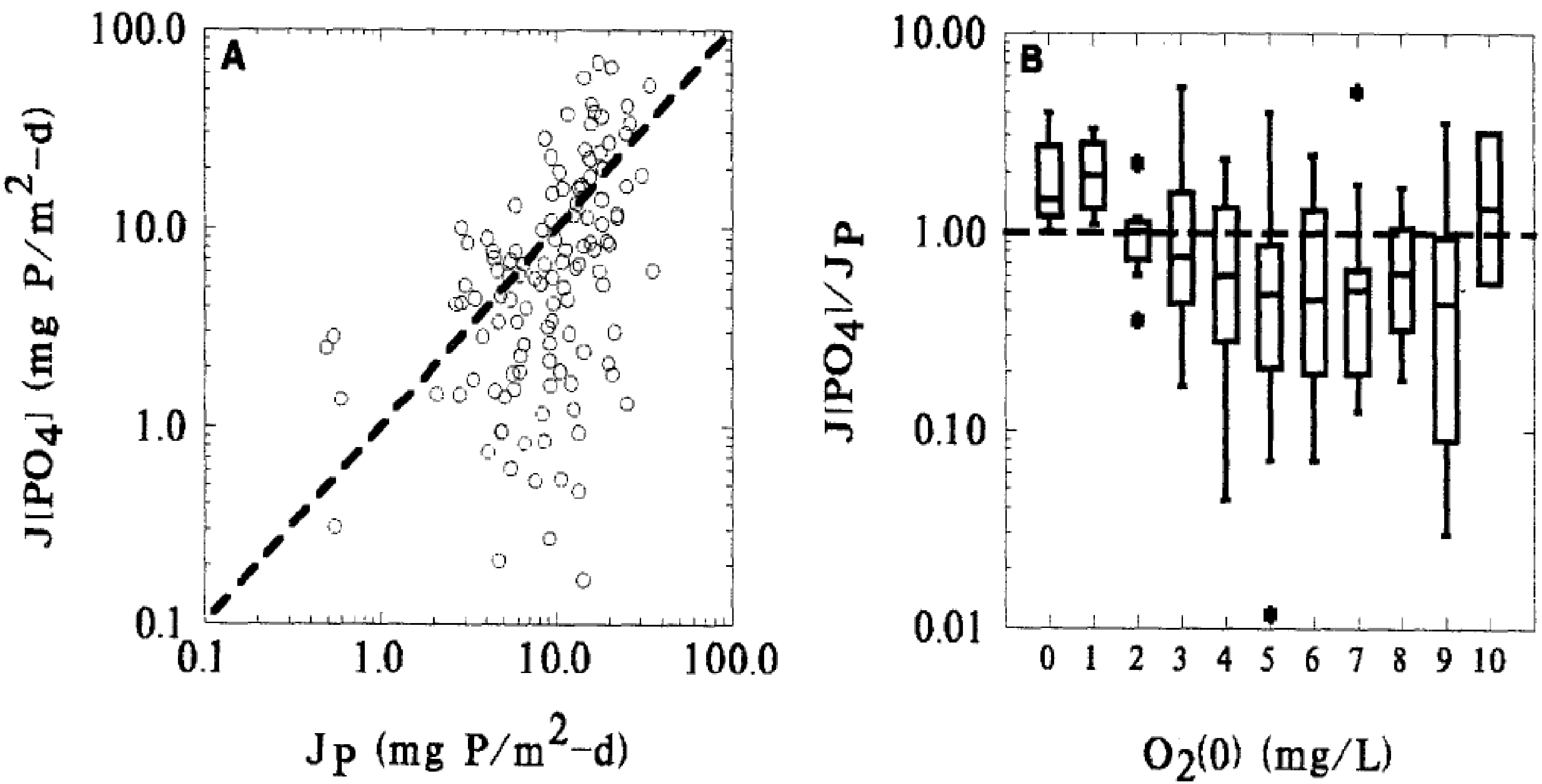
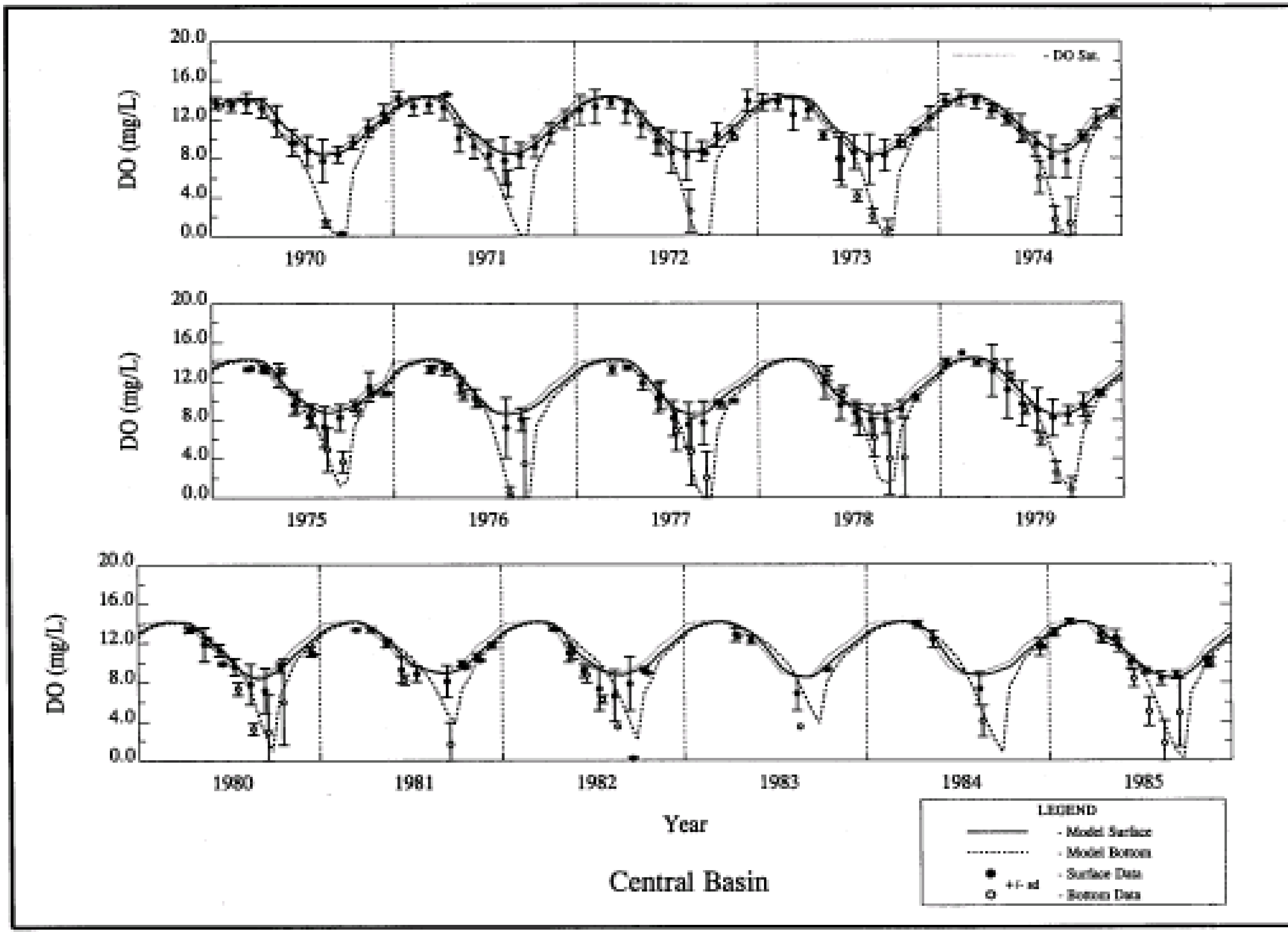
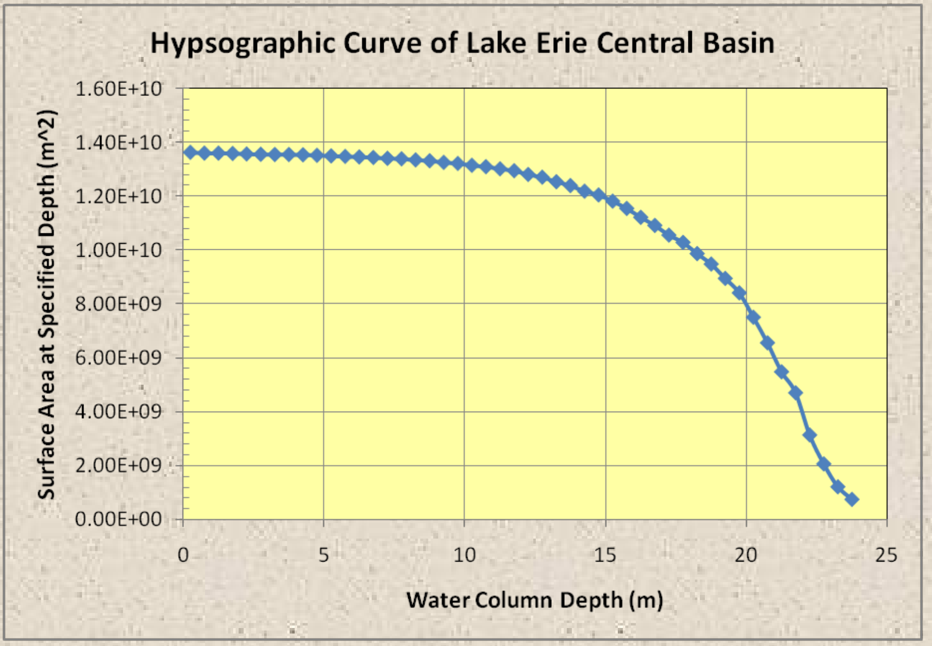



**Fig. 6.6** (A) Phosphate flux $J[PO_4]$ versus phosphorus diagenesis $J_P$. (B) Ratio of phosphate flux to phosphorus diagenesis $J[PO_4]/J_P$ versus overlying water dissolved oxygen concentration $[O_2(0)]$.

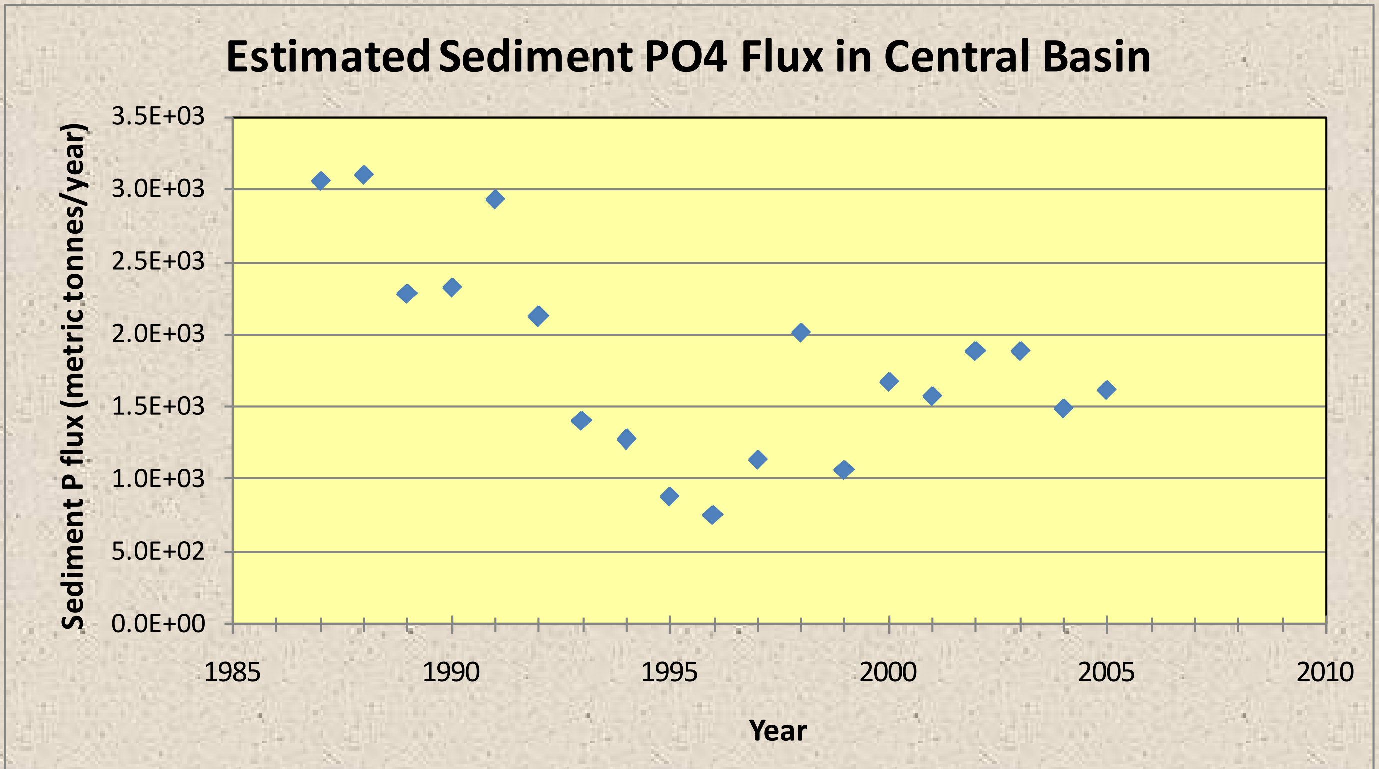
# Lake Erie Model Post-audit with updated sediment diagenesis model (Fitzpatrick, 2004



# Sediment P Flux analysis (using 1D DO model)



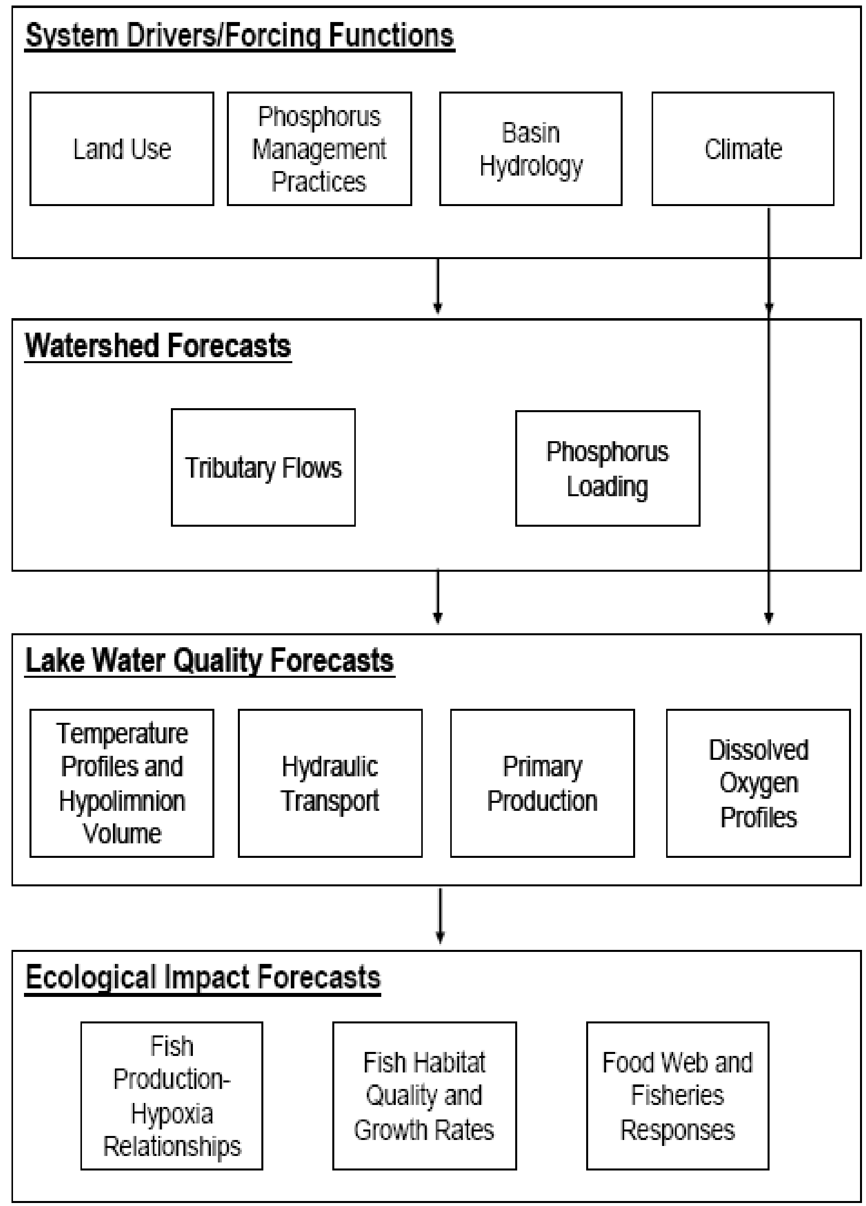

Computed from area with overlying water DO< 2 mg/L * number of days with DO< 2 mg/L * 5 mg P/m^2-d



# EcoFore Hypoxia Modeling

# Ecosystem Forecasting of Lake Erie Hypoxia

- NOAA-CSCOR funded project to assess 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**
  - Build models capable of identifying non-point and/or point-source actions to achieve X load reduction
  - Build models capable of identifying X load reduction required to achieve Y hypoxia characteristics
  - Build models relating fishery goals to Y hypoxia characteristics, based on fishery manager input.



# EcoFore Research Team

| Watershed Team | Affiliation |
|---|---|
| Dave Allan | UM |
| David Dolan | U.Wisc. |
| Peter Richards | Heidelberg |
| Nate Bosch | Grace |
| Changsheng He | WMU |

| Hypoxia Team | Affiliation |
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| Dan Rucinski | UM/LimnoTech |
| Don Scavia | UM |
| David Schwab | NOAA/GLERL |

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| Edward Rutherford | NOAA/GLERL |
| Stuart Ludsin | OSU |
| Doran Mason | NOAA/GLERL |
| Steve Bartell | E2, Inc |
| Stephen Brandt | Oregon State |

**Plus many grad students and postdocs.**

**Plus many more that have come and gone!**

# Drivers of Hypoxia in Central Basin

## Thickness of Central Basin Bottom Layer

**Air temperature, winds, length of season**

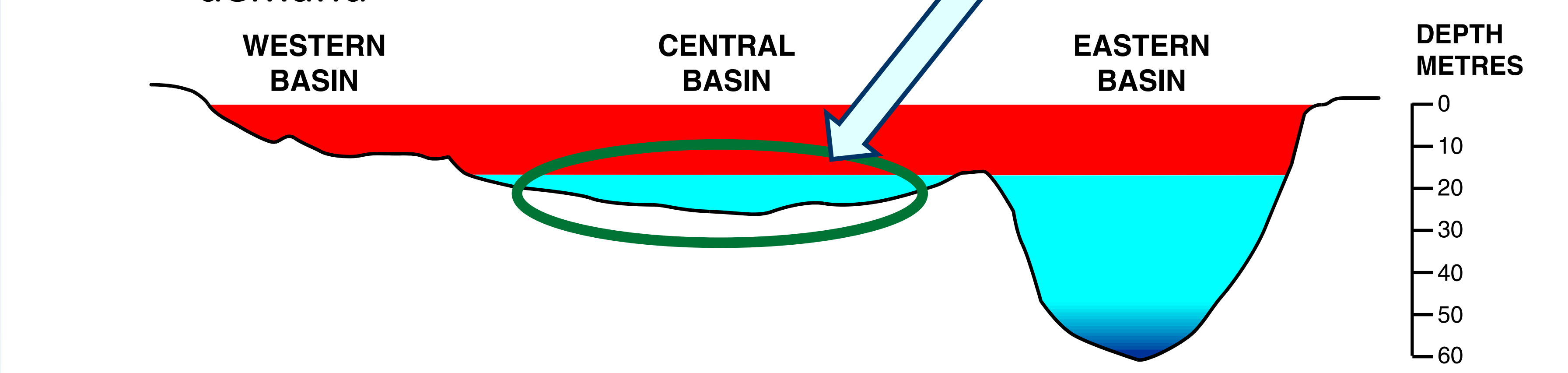
## Organic Matter Flux to the Bottom

**Algal production and settling**

- Algal-available P supply
- Length of season

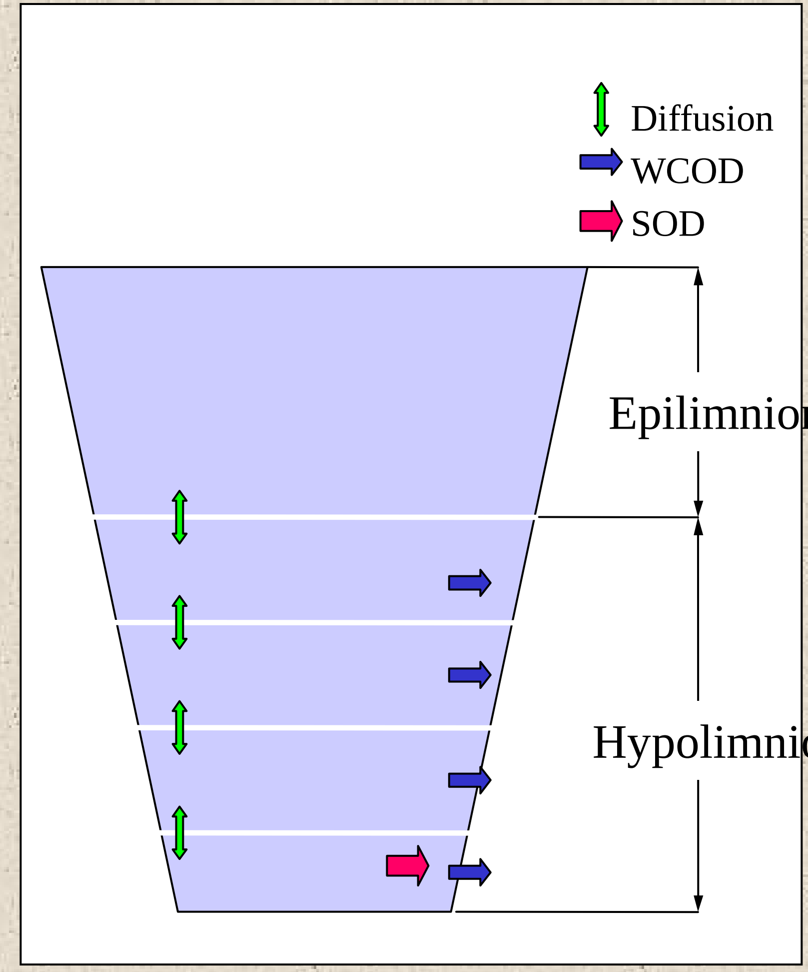
## Sediment Oxygen Demand

- contributes an average of 60% of hypolimnetic oxygen demand

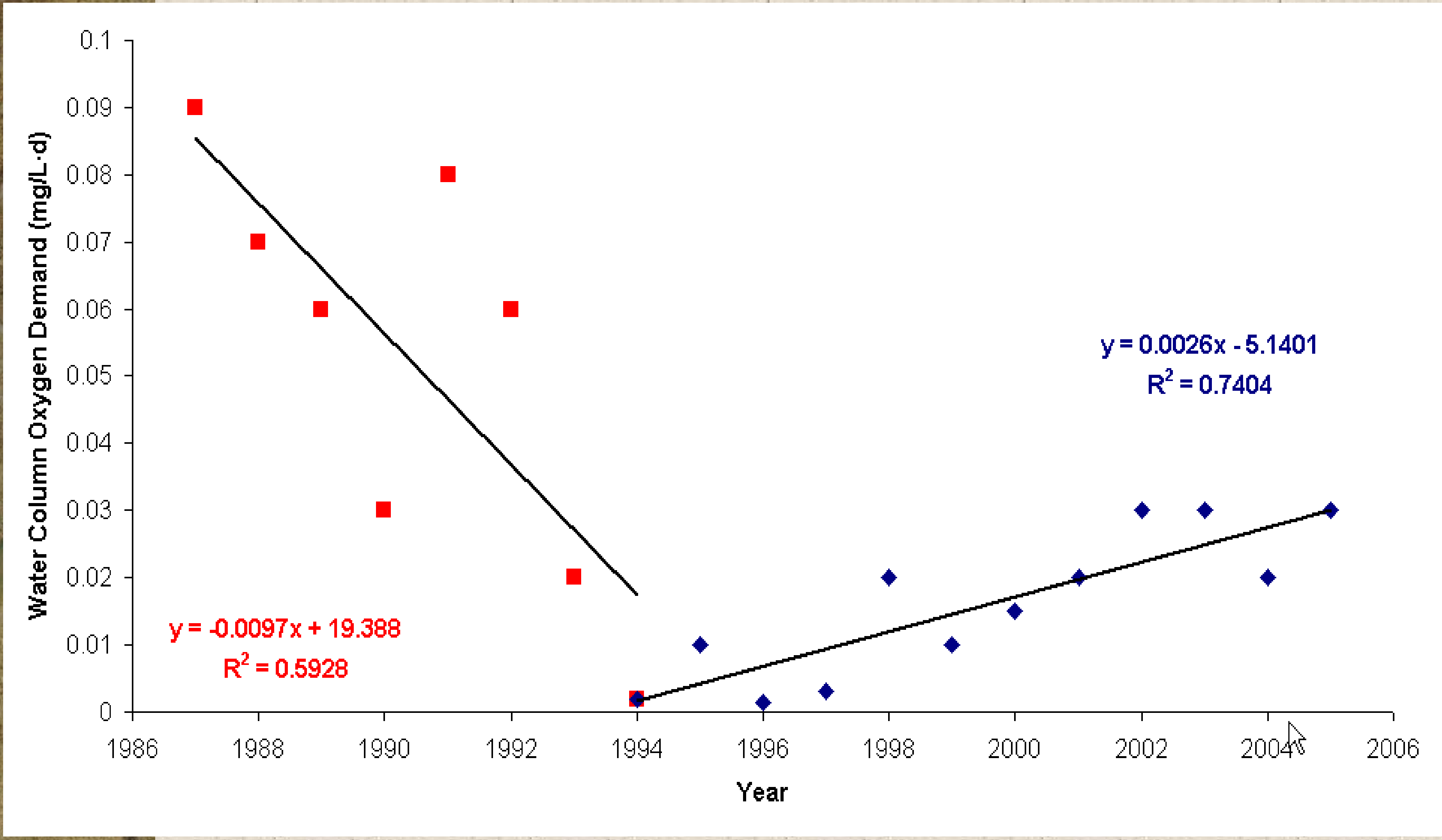


# Simple 1D DO Model for Central Basin

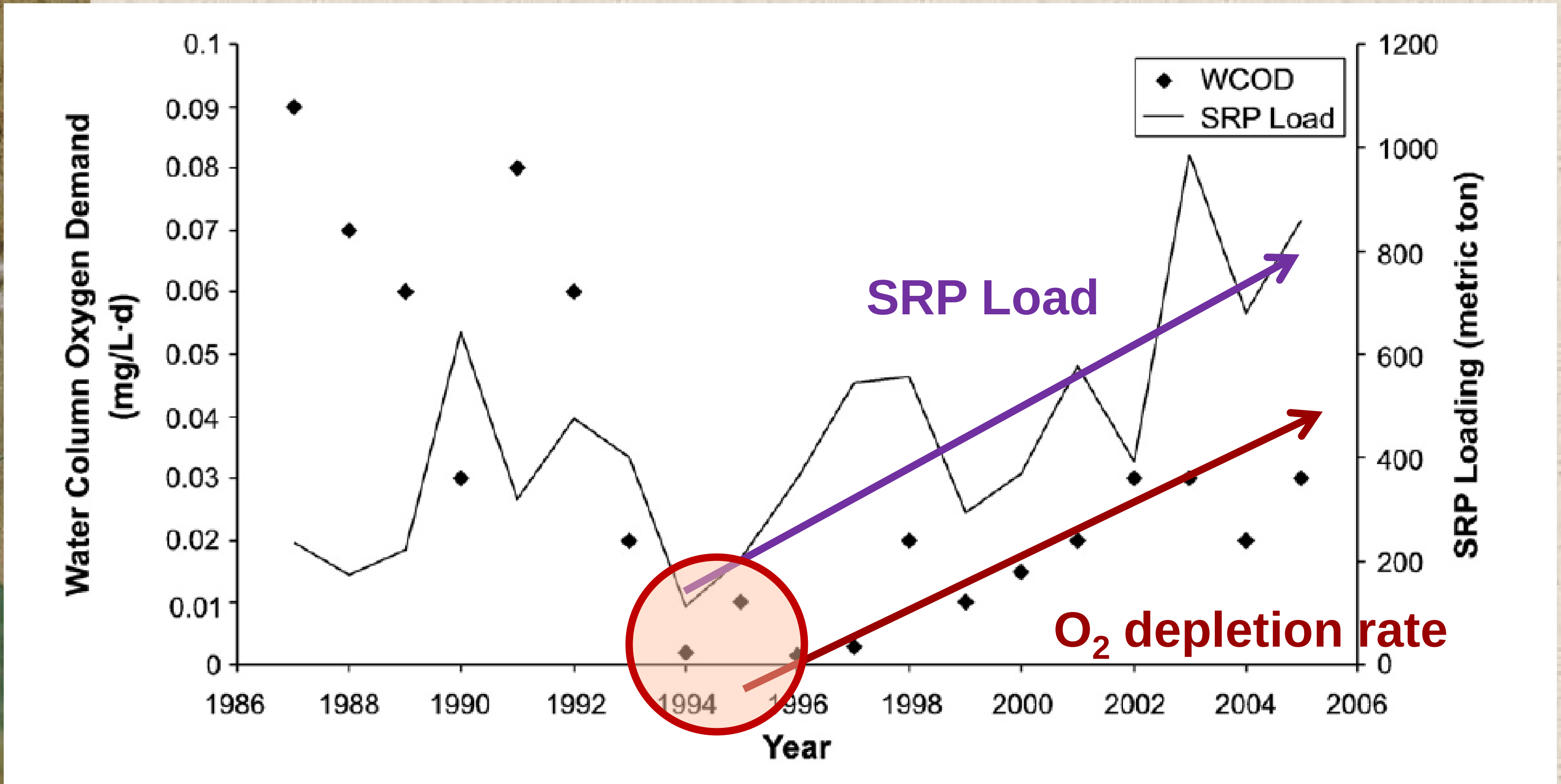
- 1D Vertical Dynamic Model for Central Basin
- Hydrodynamic model is physically driven
  - Air temp, wind speed, solar radiation
- Static Surface Level, varying thermocline depth
- 48 Vertical Layers of 0.5m thickness
- Simple Dissolved Oxygen Model linked to Hydrodynamic Model
  - DO rate term (WCOD)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



# Time-Series of Annual Calibrated WCOD Values



# Suggested that P load is important for Central Basin oxygen depletion rate




Rucinski et al 2010

# Eutrophication Model Projects

## 1D models

### Level 1 - 1D hydrodynamics with specified DO consumption rates

- Vertical thermal and mixing profiles from hydrodynamic model
- Calibrate with DO loss from water column and sediment demand

### Level 2 - 1D hydrodynamics with simple process WQ model

- Replace DO loss, etc. with "Standard" eutrophication model

## 3D models

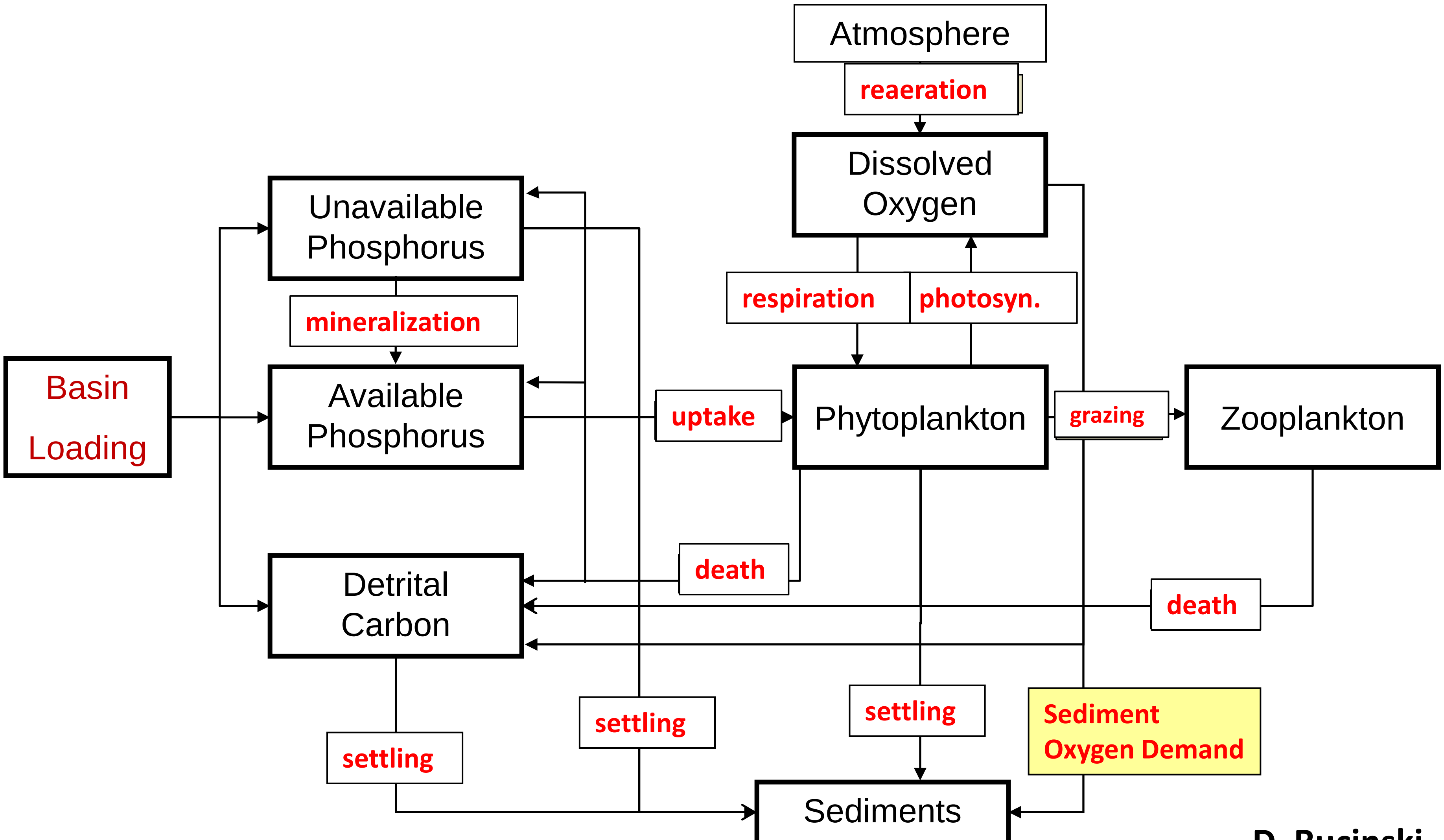
### Level 3 - 3D hydrodynamics with simple Level 2 WQ model

- Physics from full hydrodynamic model

### Level 4 - 3D hydrodynamics with complex WQ model

- Multi-class phyto-zoo, organic/inorganic nutrients, sediment digenesis, etc
- Dreissenid; Benthic algae

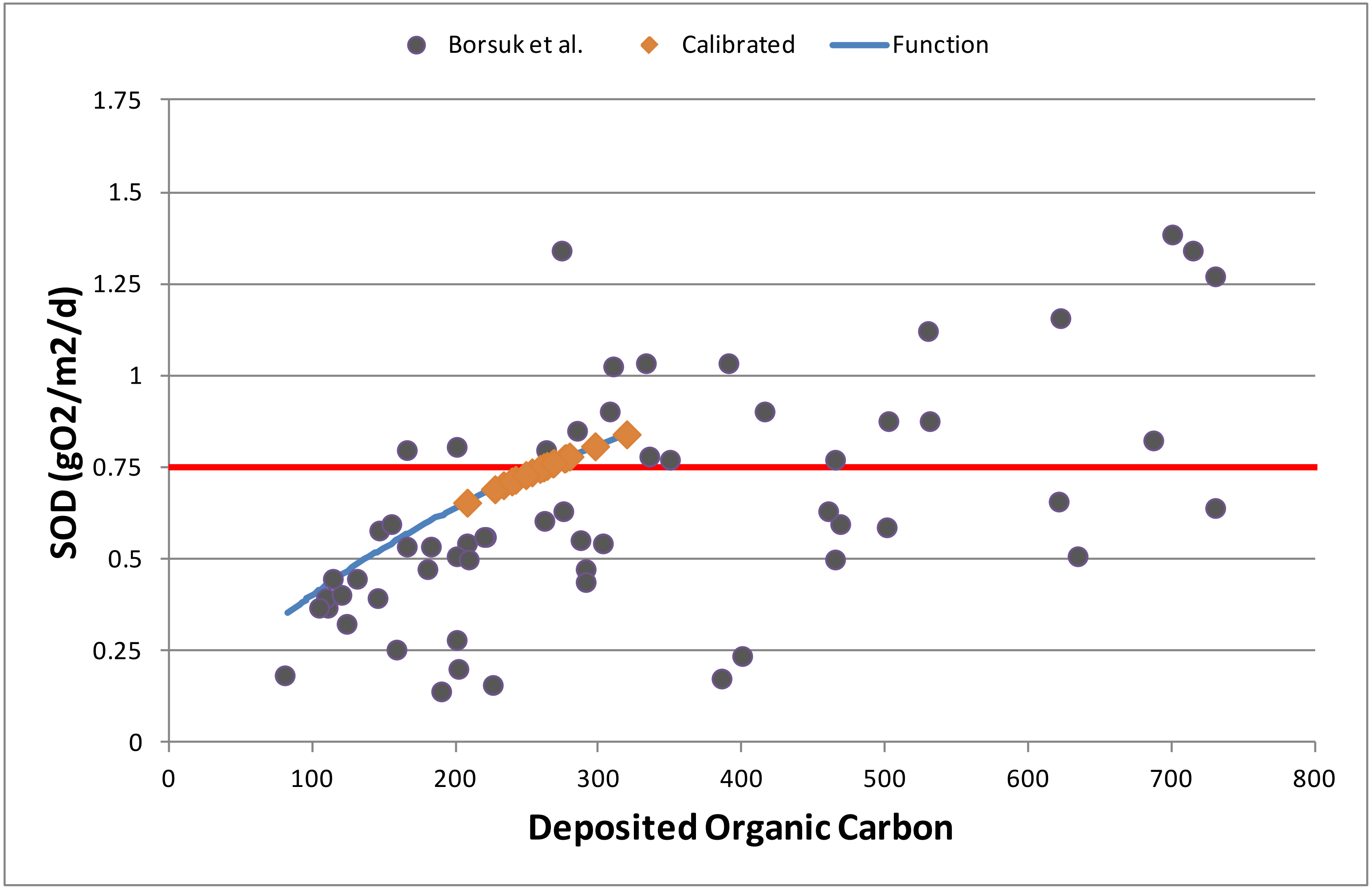
# Eutrophication Model




D. Rucinski

$$SOD = a\left(\frac{L_c}{1 + kL_c h}\right)^b$$

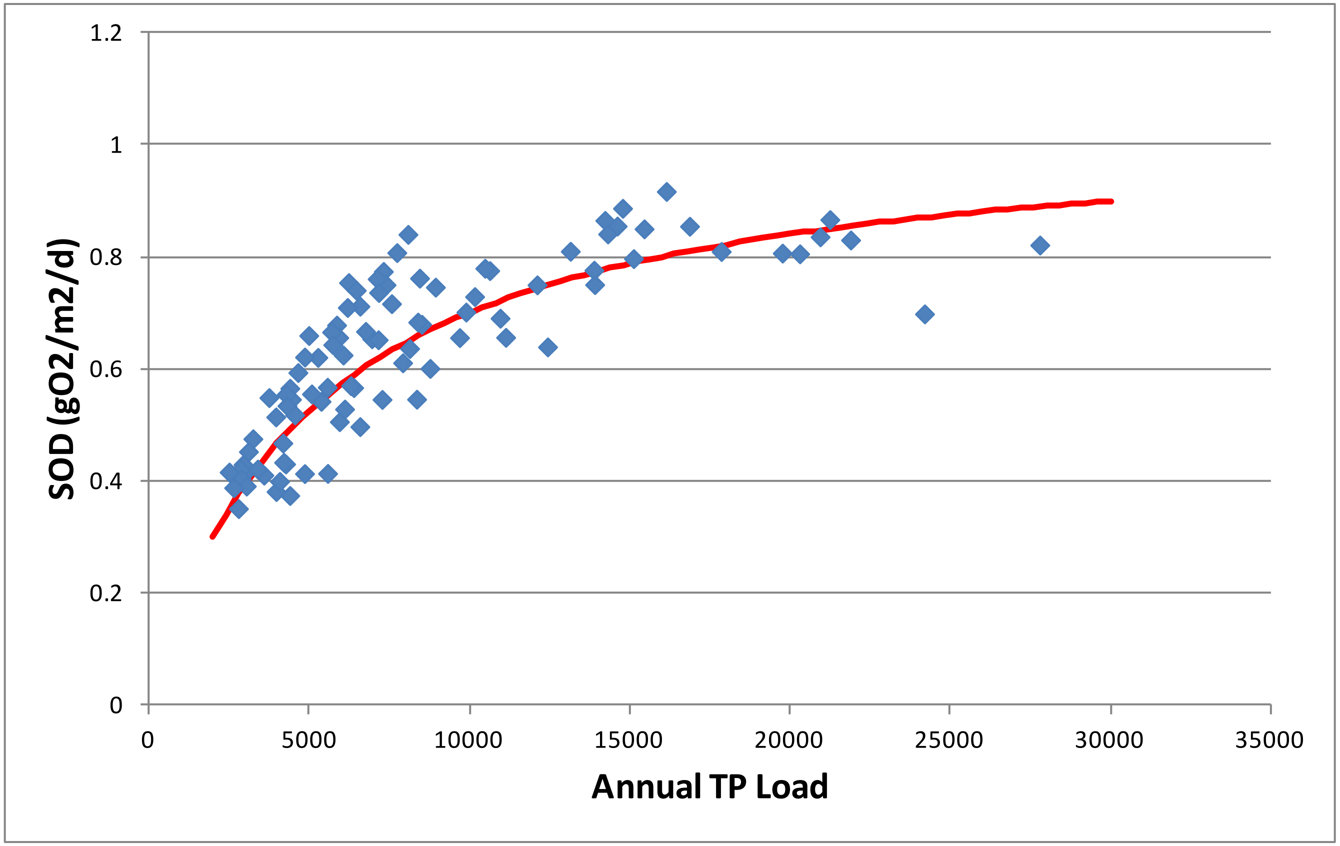
Borsuk et al. (2000) *Ecological Modeling*



# SOD Response to TP Load

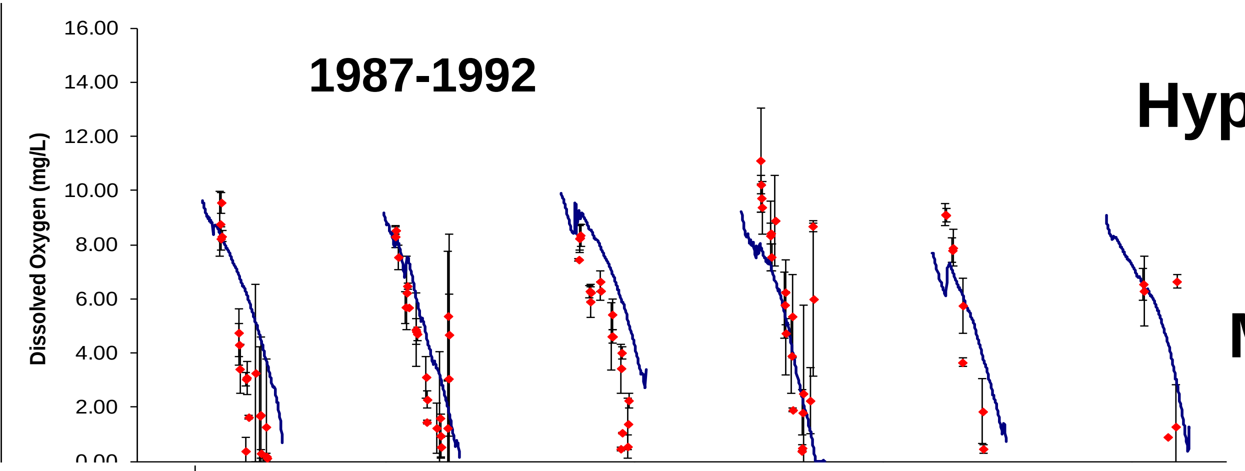
$$SOD = \frac{SOD_{max}(TP - TP_{offset})}{K_{SOD} + (TP - TP_{offset})}$$

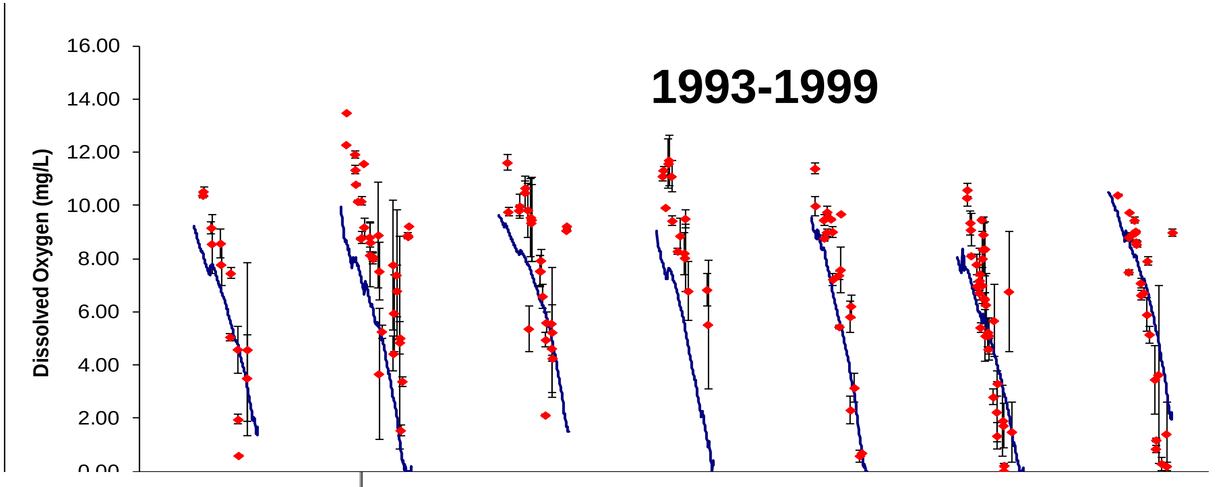
Michaelis–Menten function

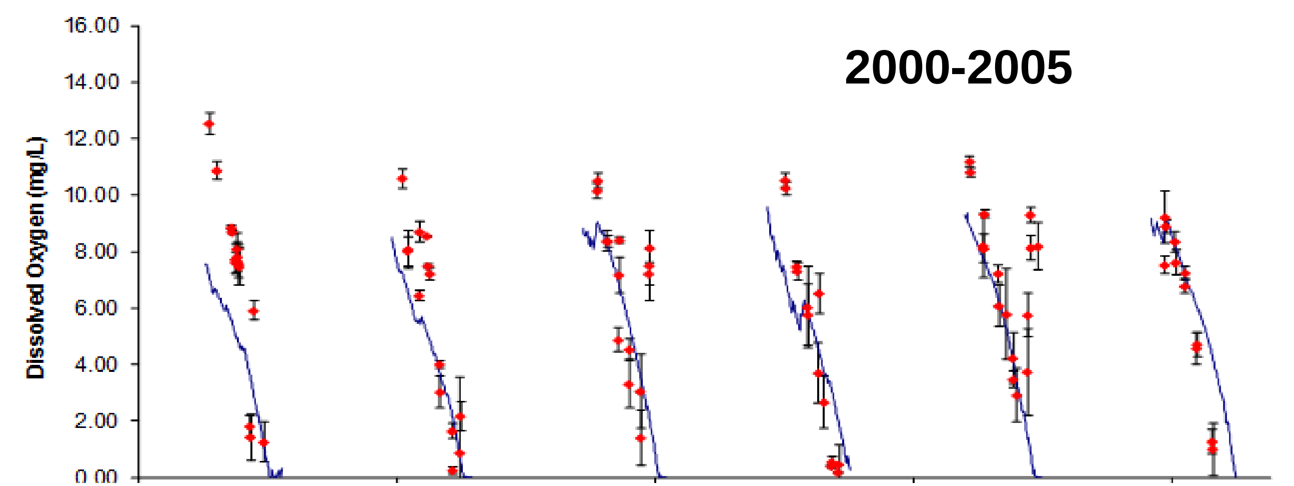


# Hypolimnetic Dissolved Oxygen

## Model Calibration

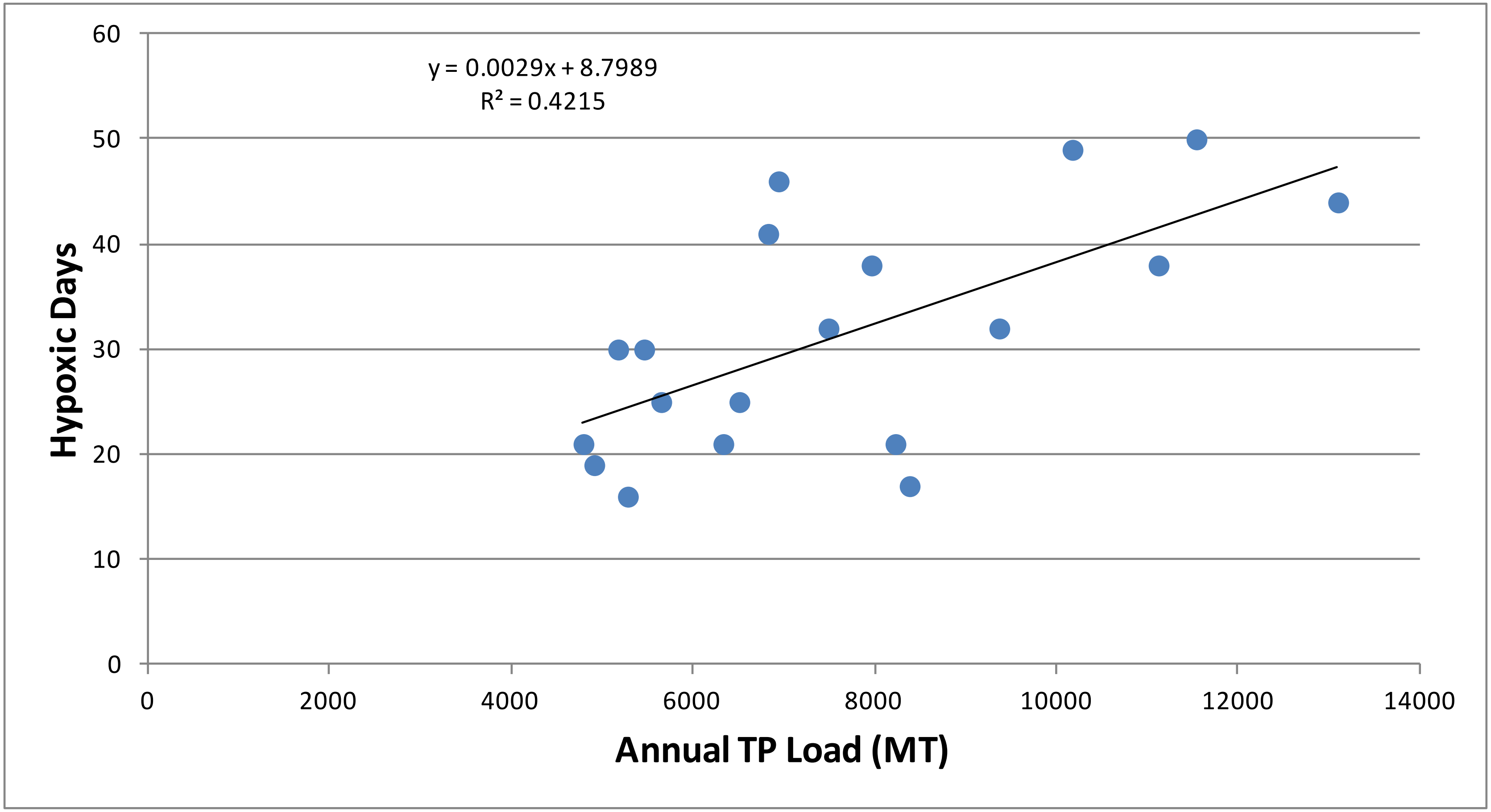


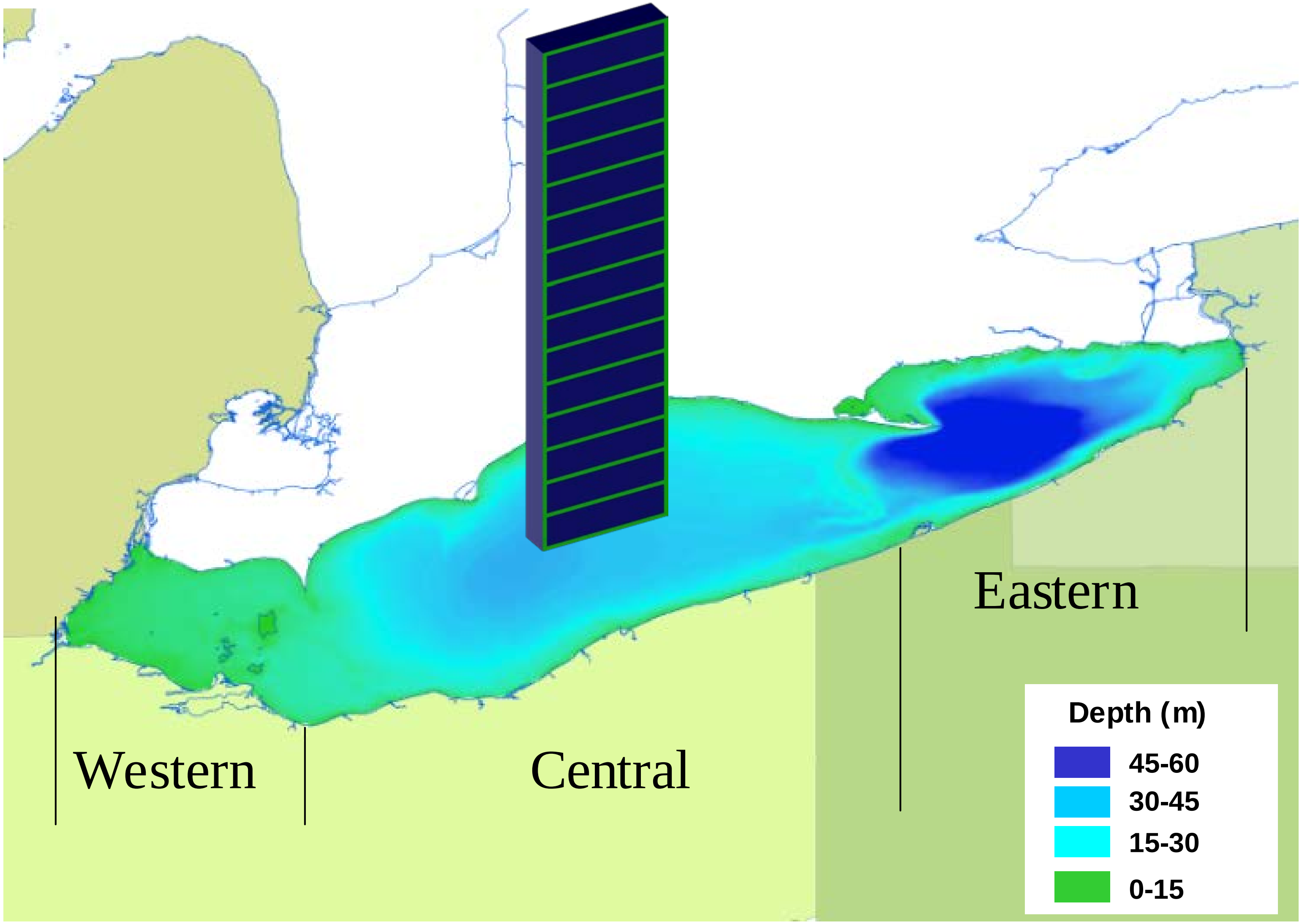

Rucinski et al.

# Central Basin Hypoxic Days as function of TP Load

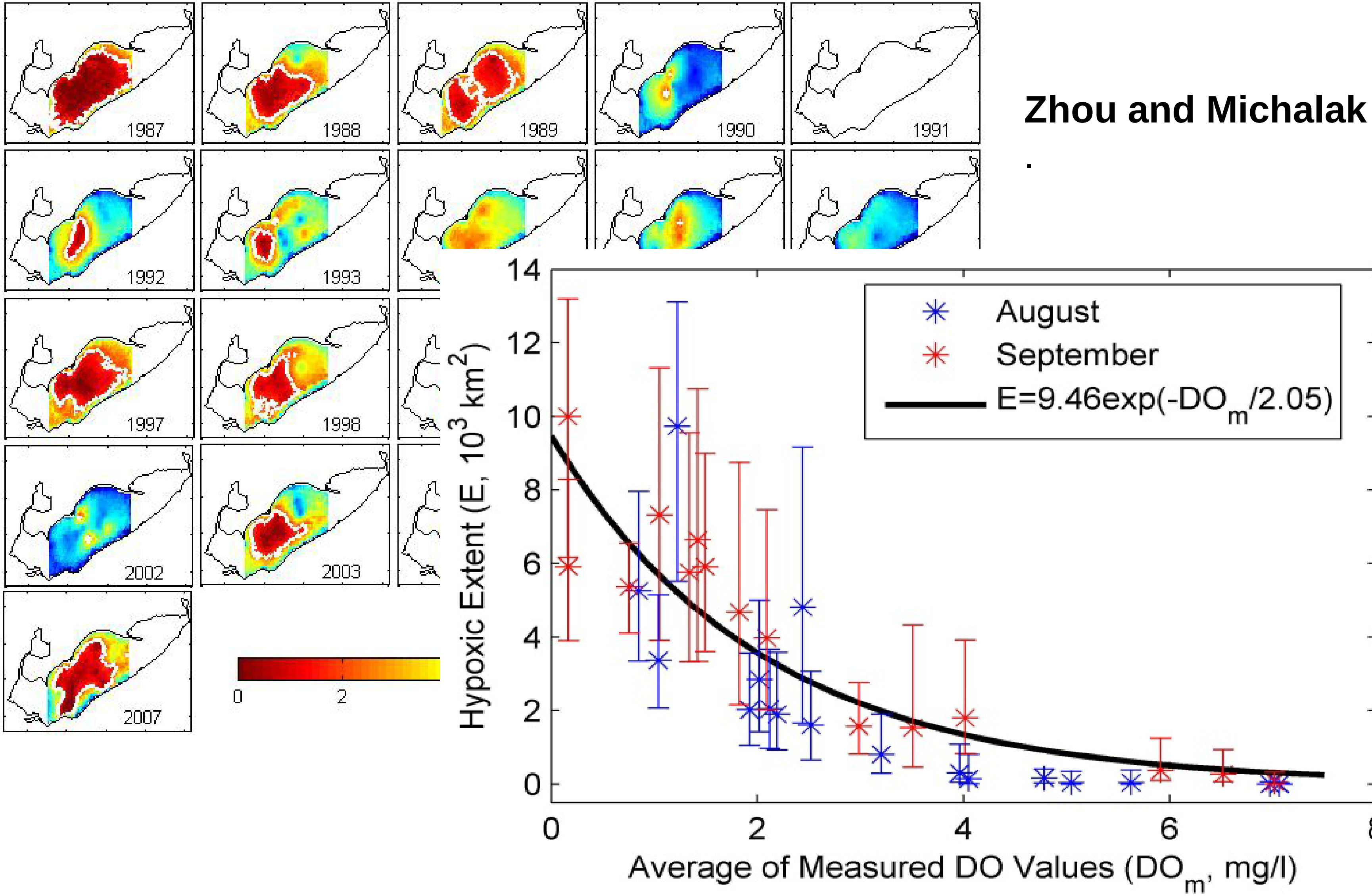



Hypoxic days = number of days with hypolimnetic DO < 2 mg/L

# How do you get from 1D Oxygen Concentration to Hypoxia Area?



# Geostatistical Conditional Realizations of Central Basin Hypoxic Area




**Zhou and Michalak**

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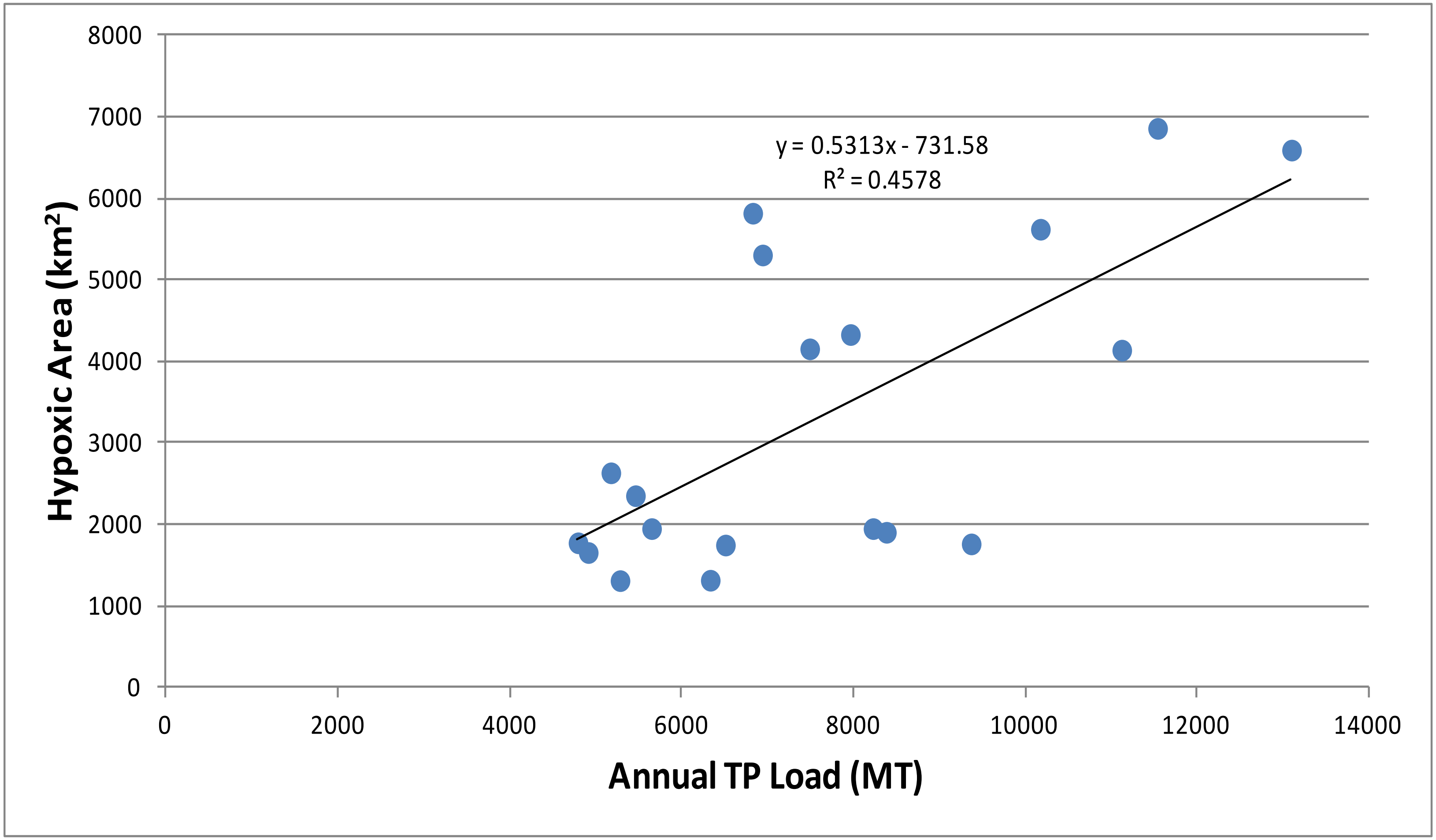
# Central Basin Hypoxic Area as function of TP Load




Hypoxic area determined using the Zhou concentration-to-area conversion

# Cyanobacteria Blooms in Western Basin

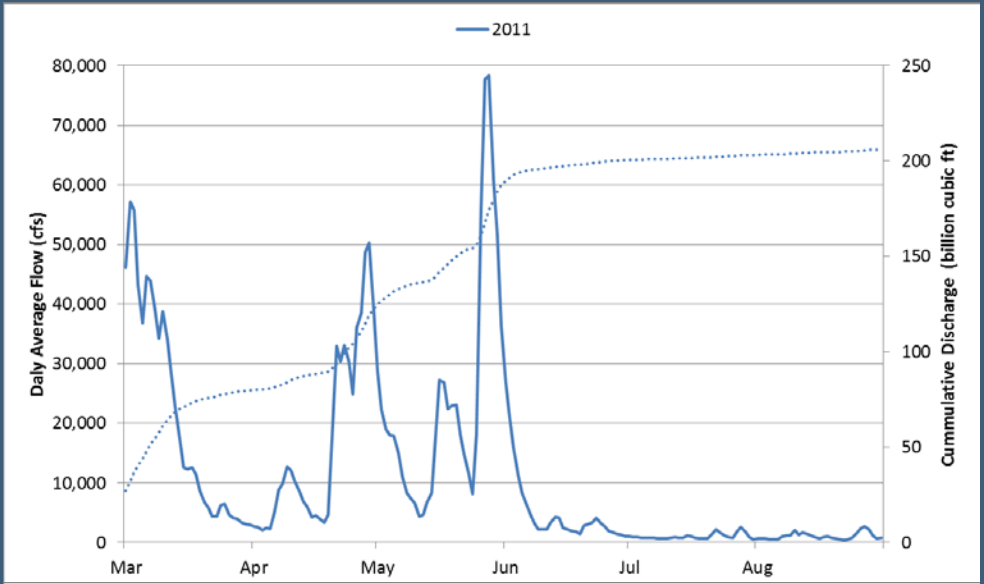
## 2011-2012 contrast
## Load – response Models

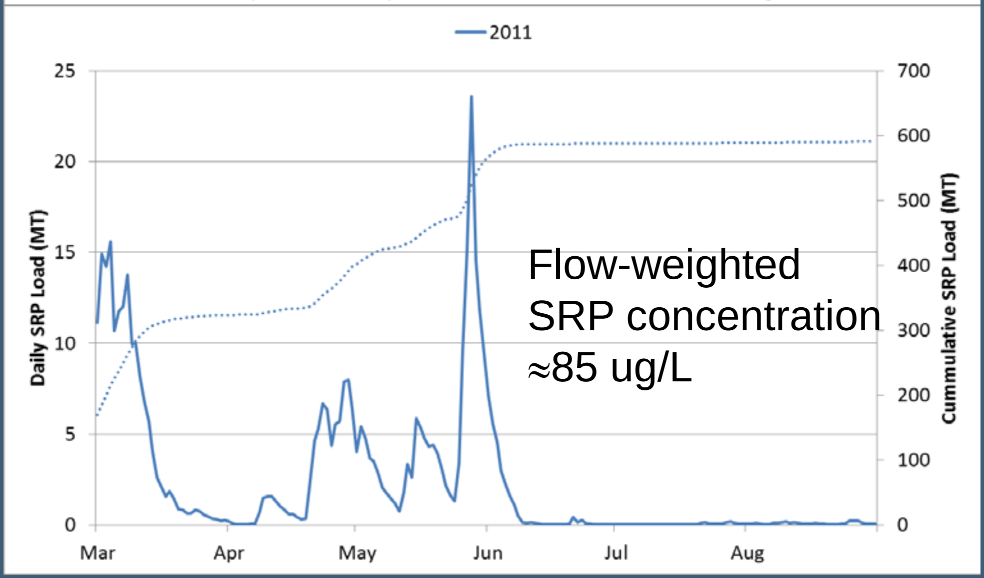
# *Microcystis* Bloom of 2011



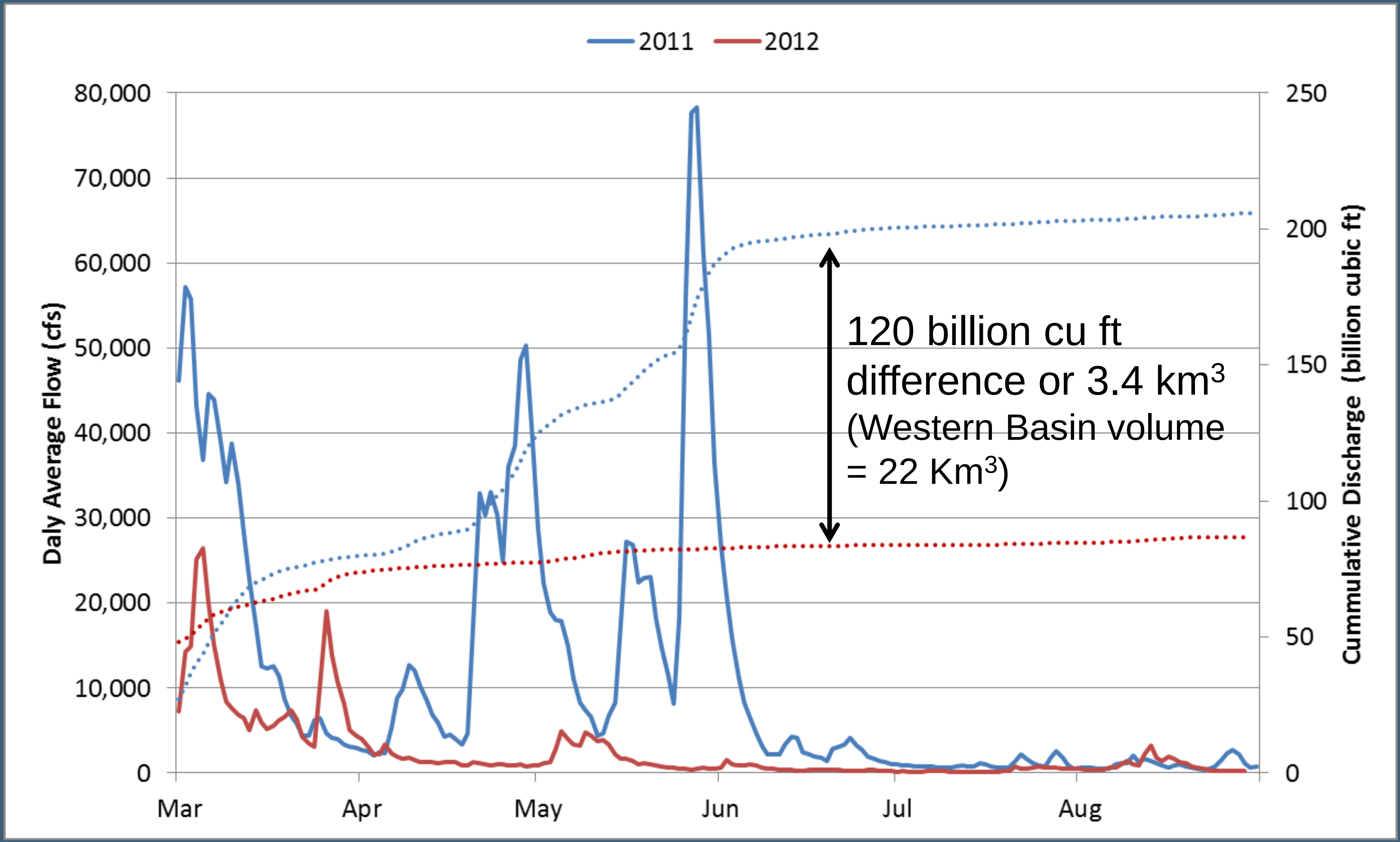
# Maumee phosphorus load fueled 2011 bloom

Several large events from March – May, followed by very low flows for rest of the summer. Very little Detroit River dilution; main plume moved to Central Basin north of Pelee Island.

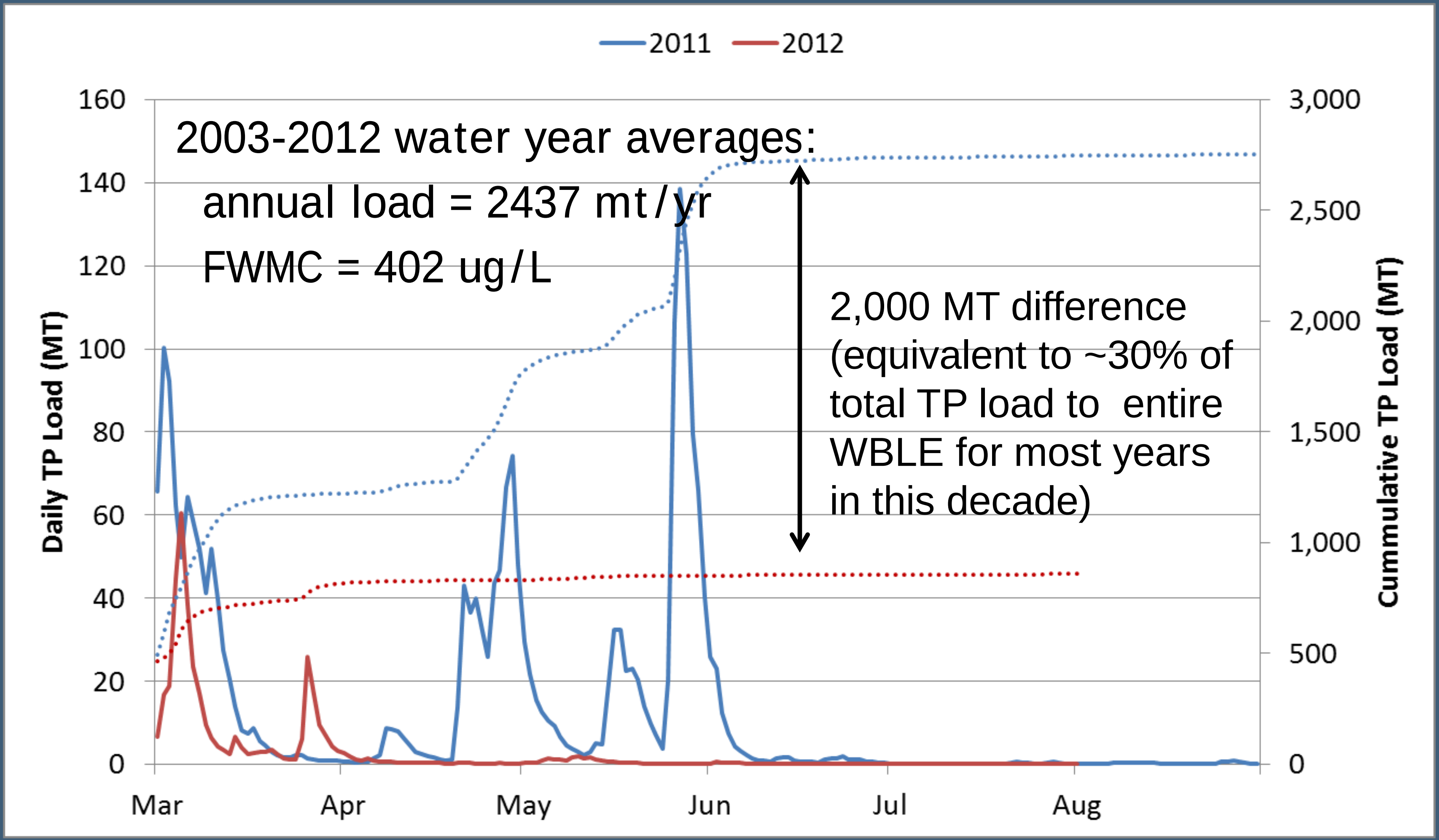



# Maumee River Discharge



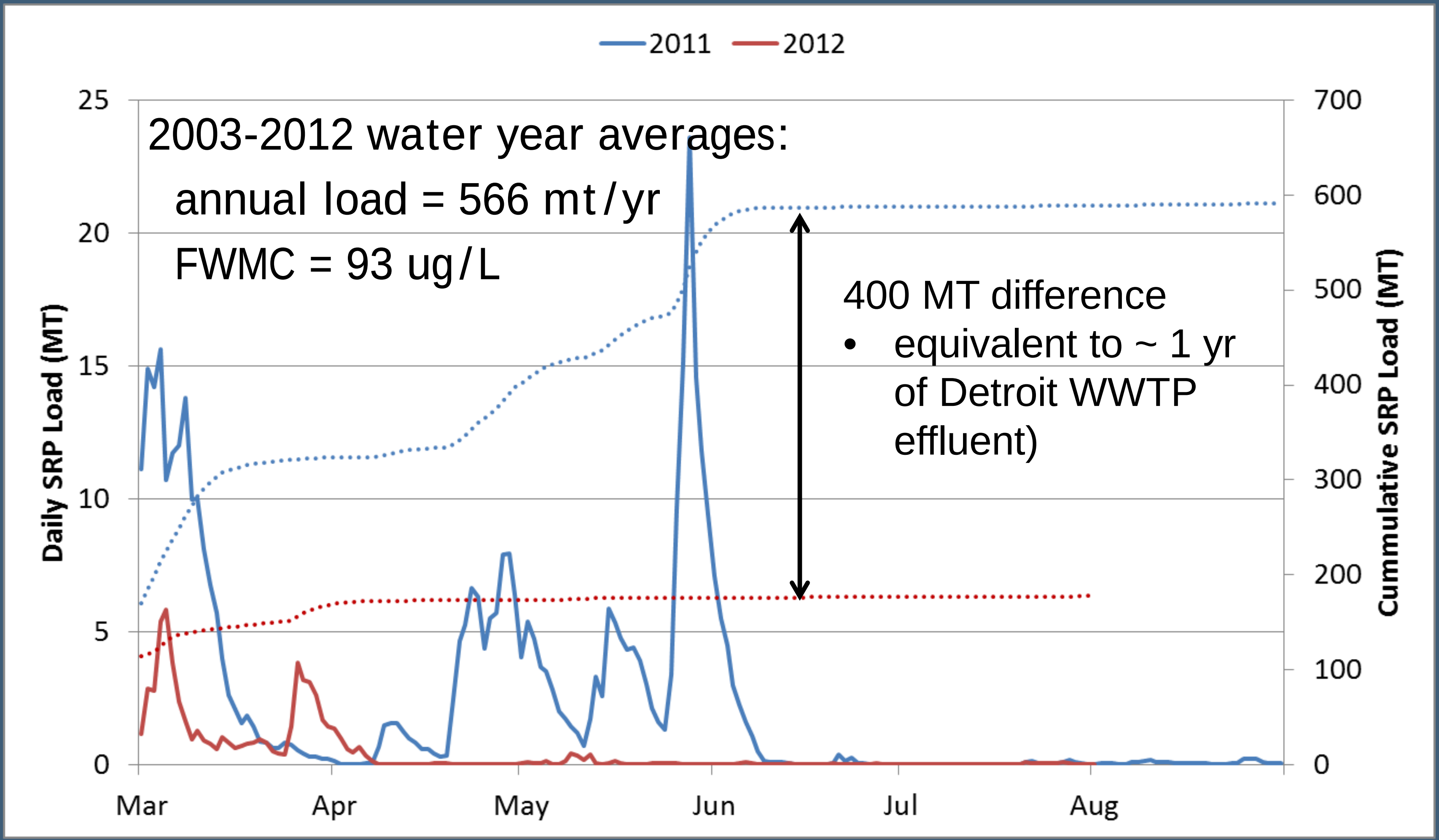

Data obtain from USGS gage at Waterville, OH

# Maumee River TP Load



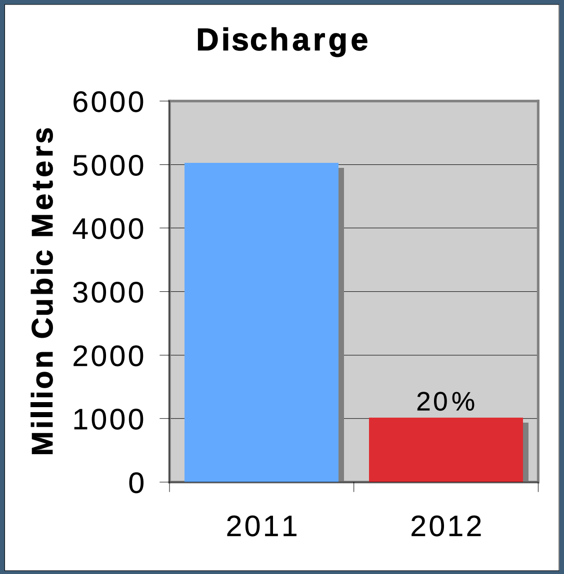

Data obtain from Heidelberg College

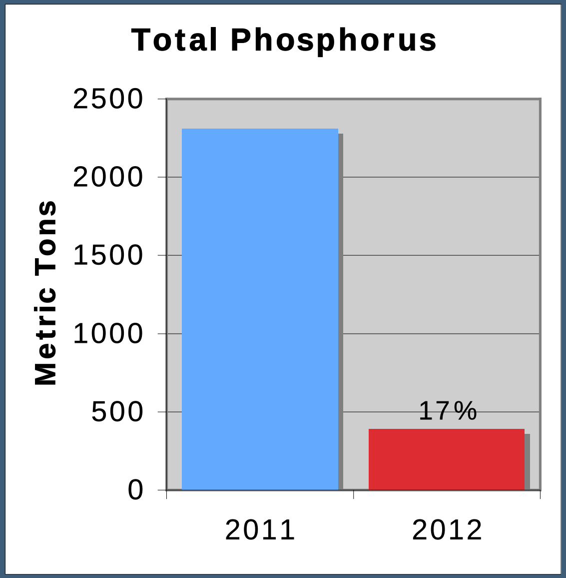
# Maumee River SRP Load

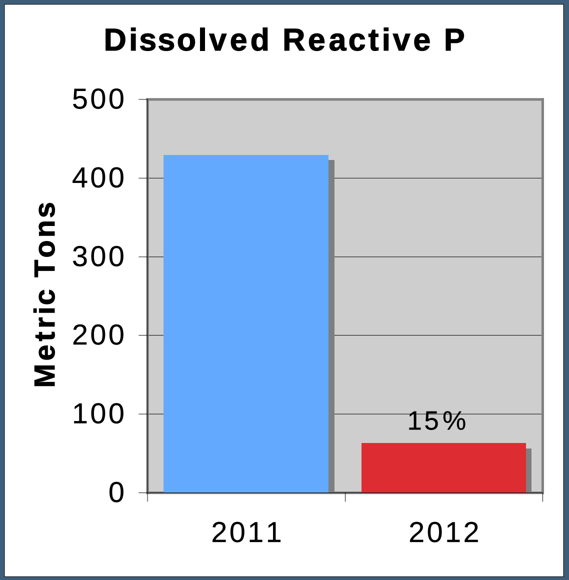


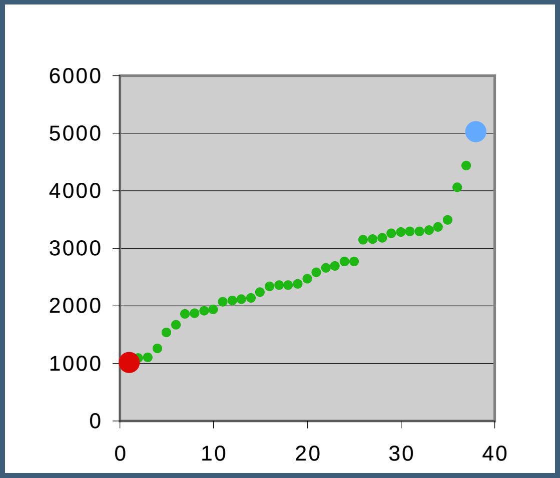

Data obtain from Heidelberg College

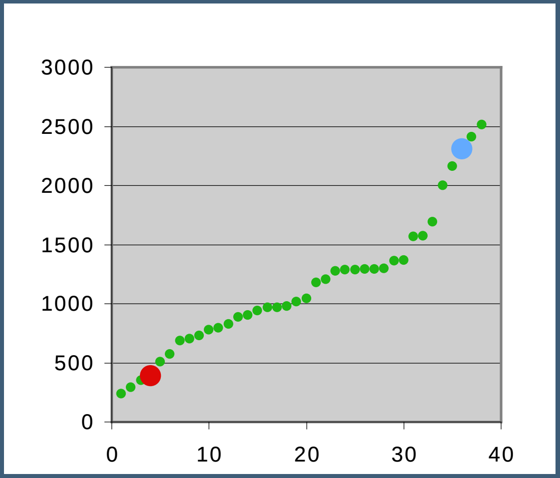
# March-June at Waterville

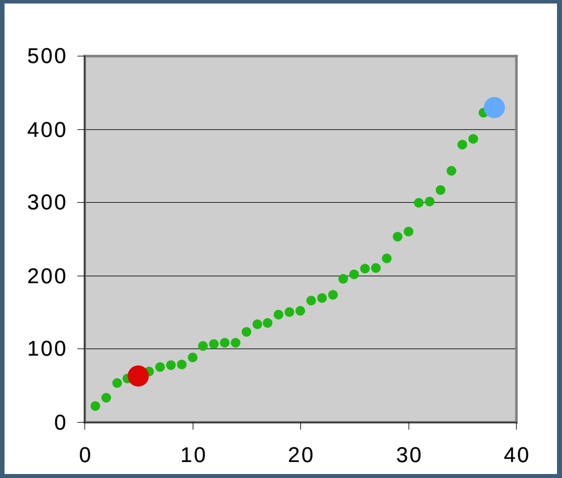


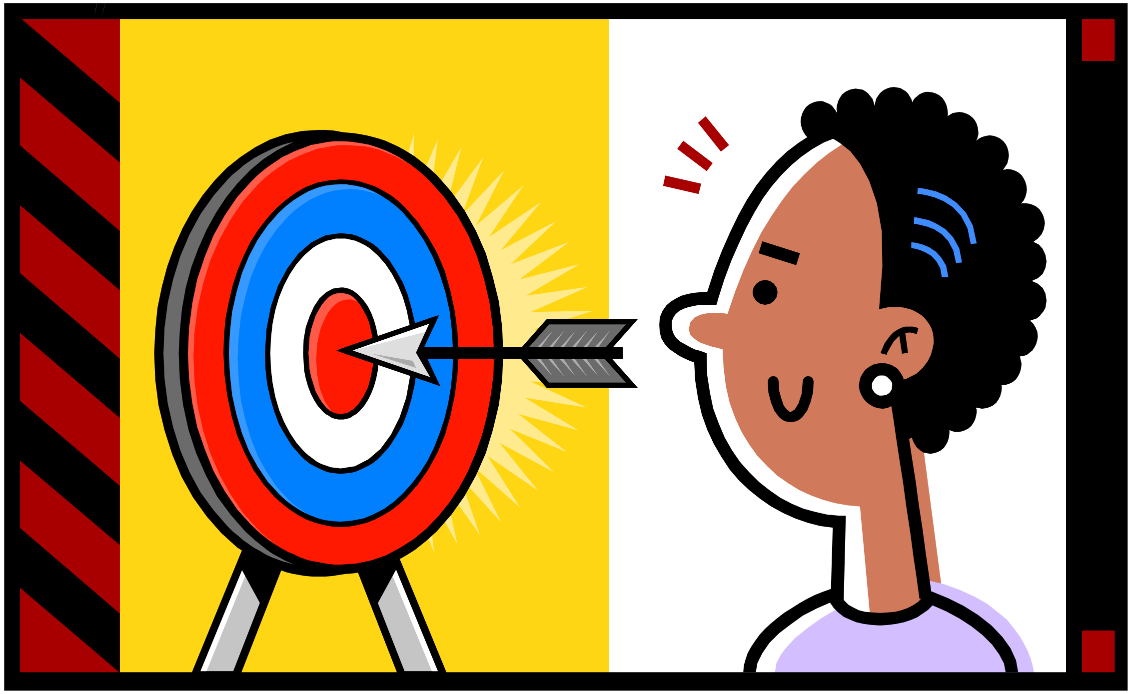




From Richards, Heidelberg University data

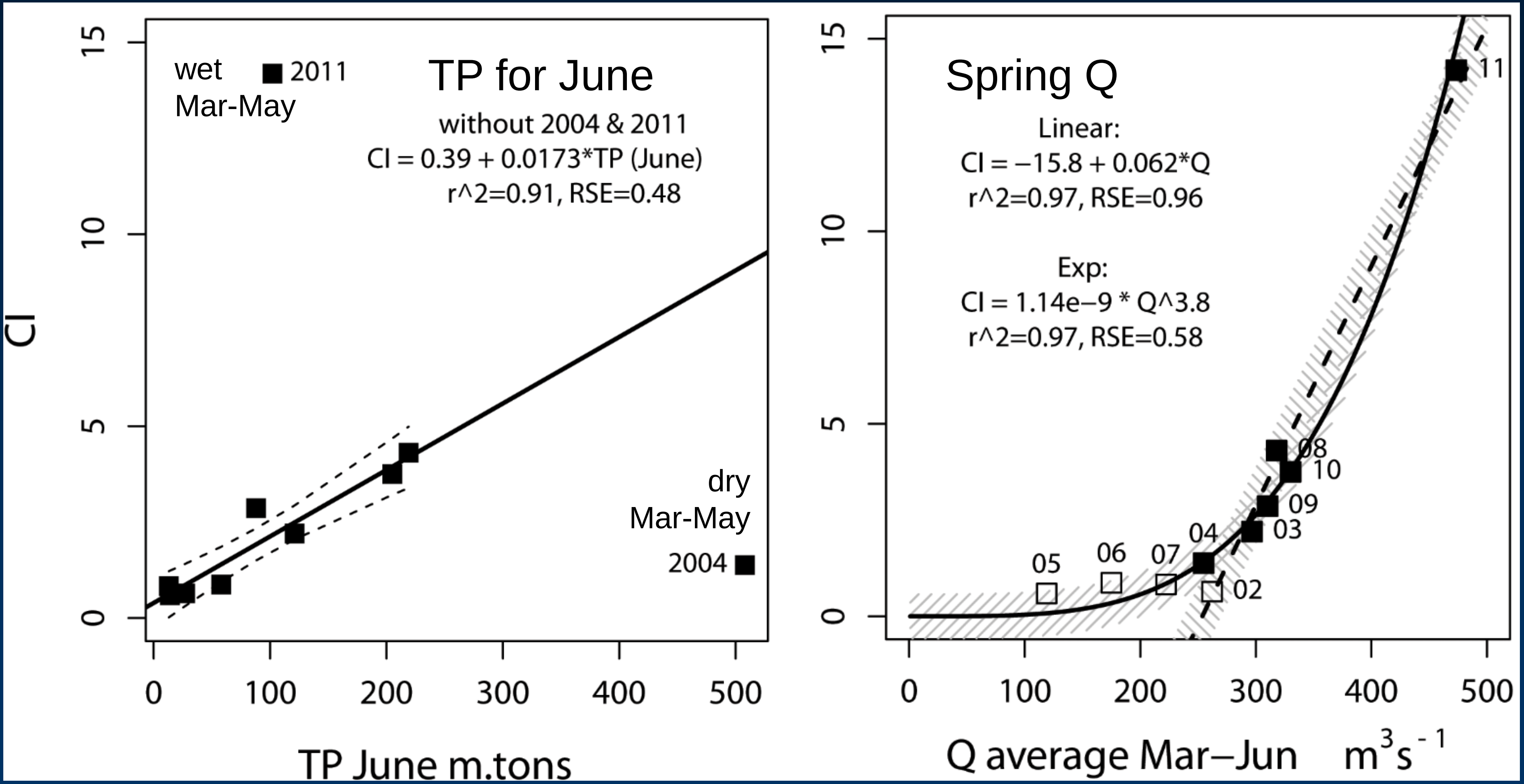
09/03/2011 (DOY=246)

08/30/2012 (DOY=243)

# Can We Set Load Targets for *Microcystis* blooms?

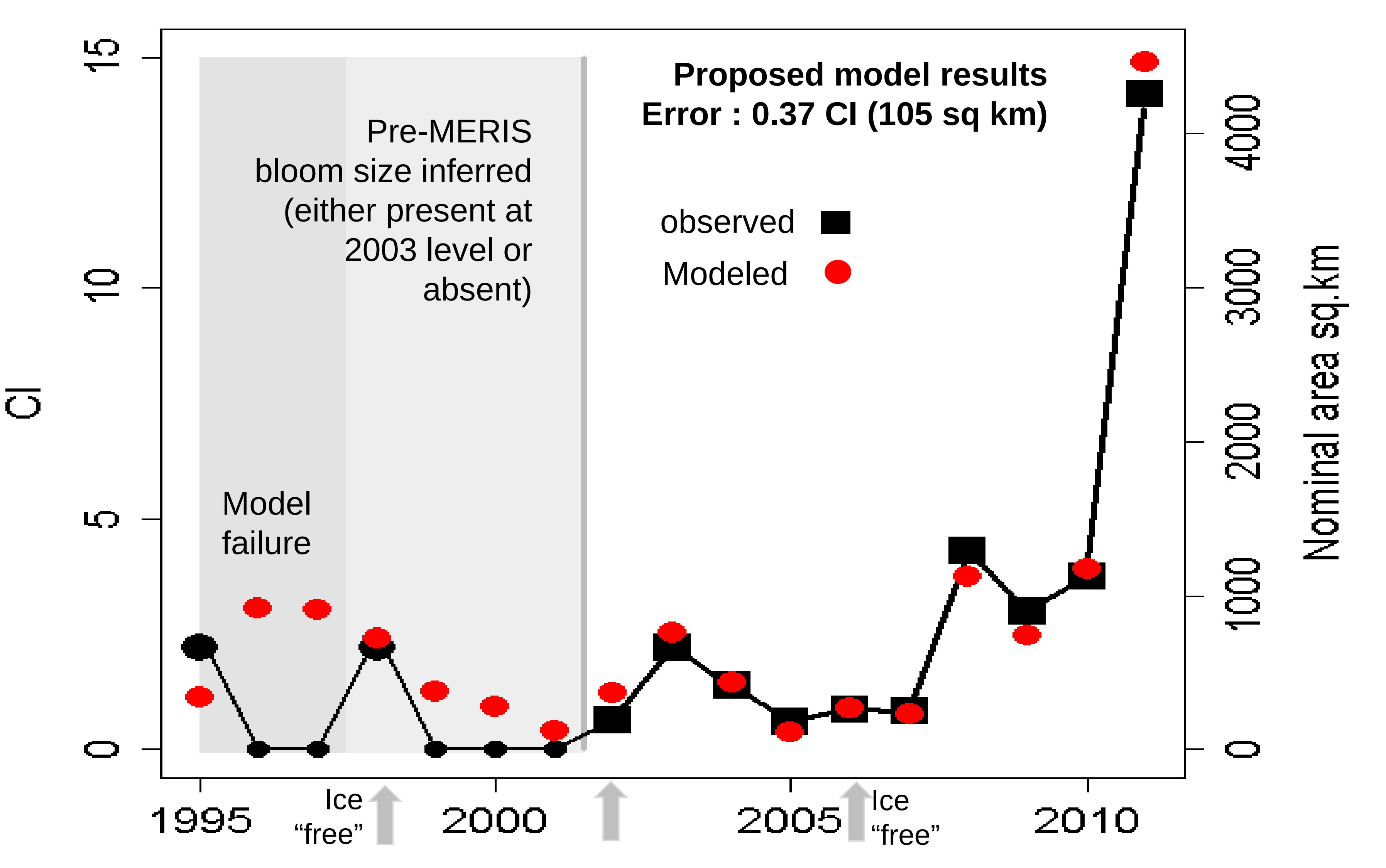


# Cyanobacteria-bloom Intensity (CI) as a function of June TP load and Spring discharge




Stumpf et al., 2012 PLoSONE.

# Spring (Mar-Jun) explains annual bloom intensity; a lag between P supply and the bloom




Stumpf et al., 2012PLoSONE.

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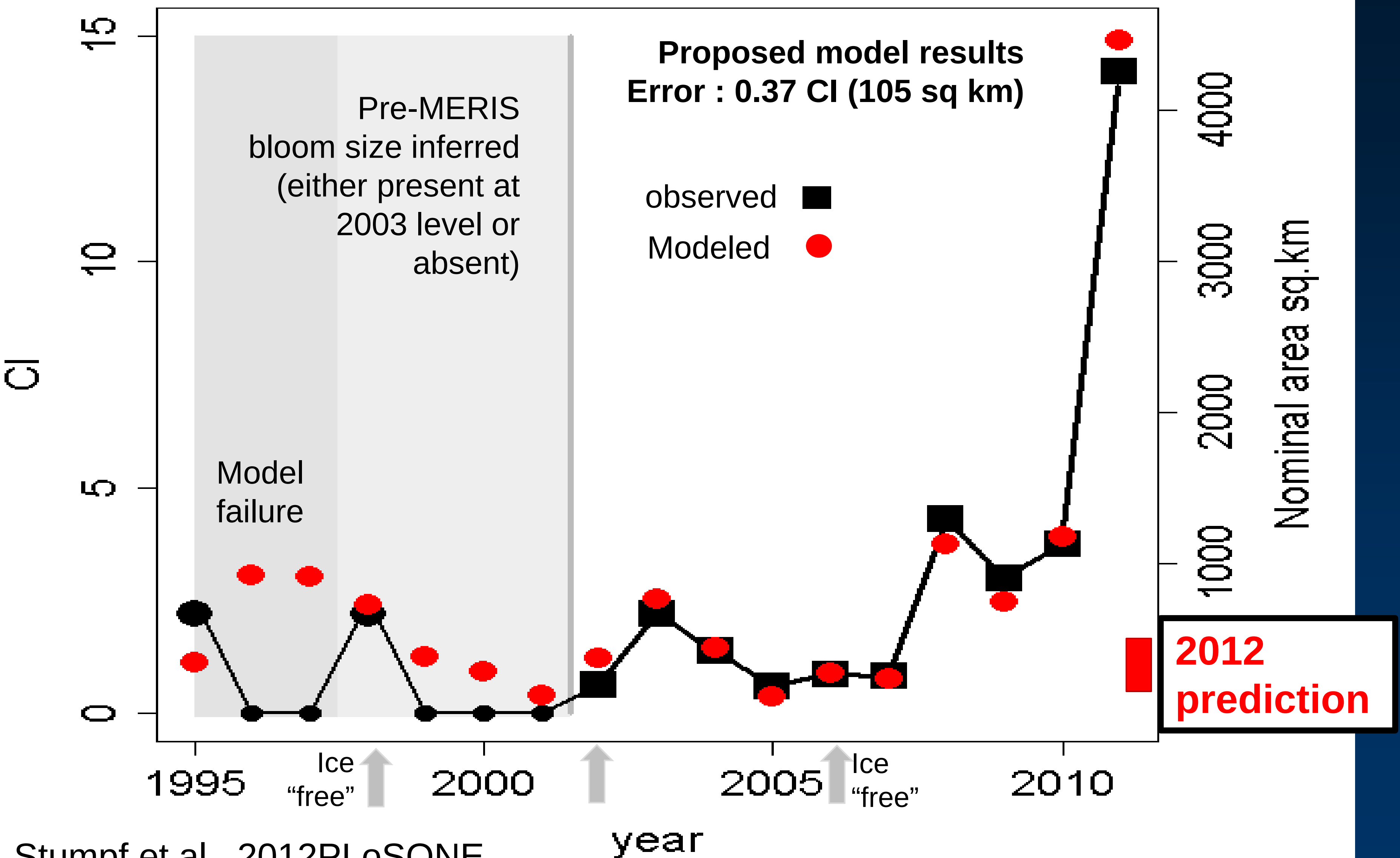
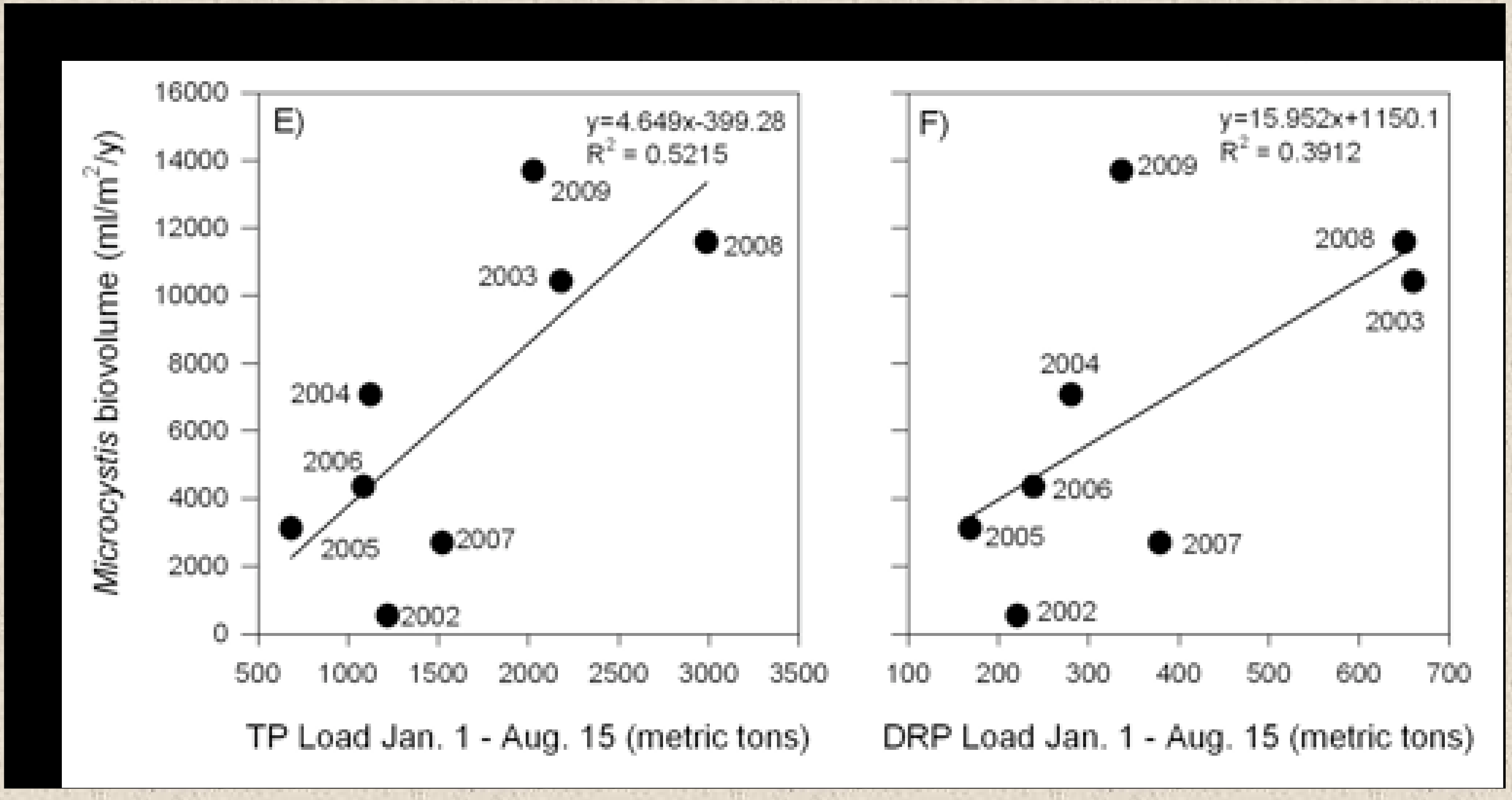



Stumpf et al., 2012PLoSONE.

# Bridgeman seeing similar relationship with his data

- Relationship of *Microcystis* biovolume to P loading
- Annual biovolume related to TP loadings during spring and early summer
- Biweekly biovolumes related to DRP loadings 4-8 weeks prior

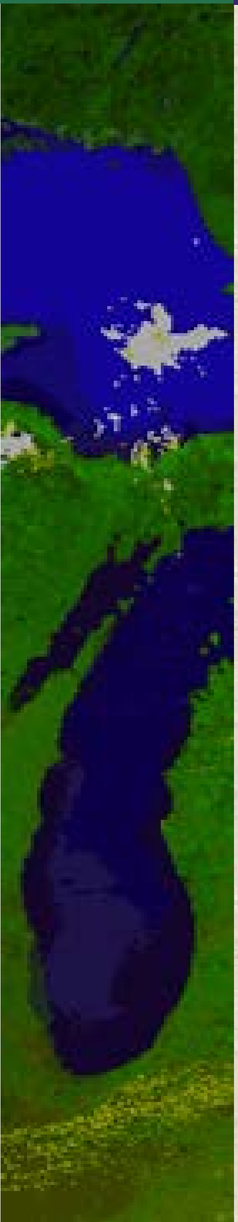


# Western Lake Erie Ecosystem Model (WLEEM)

Development and Application Funded by:

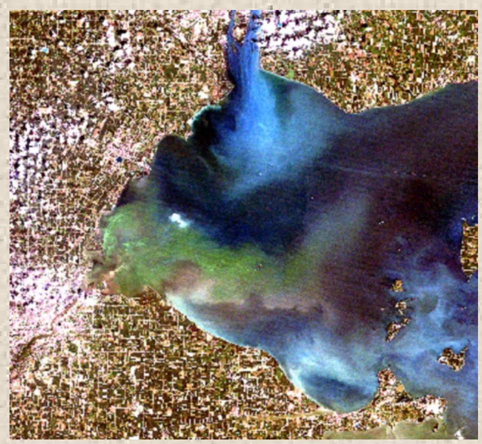
- USACE-Buffalo District (3 projects)
- NSF (subcontract to University of Michigan)
- Great Lakes Protection Fund (sub to TNC)

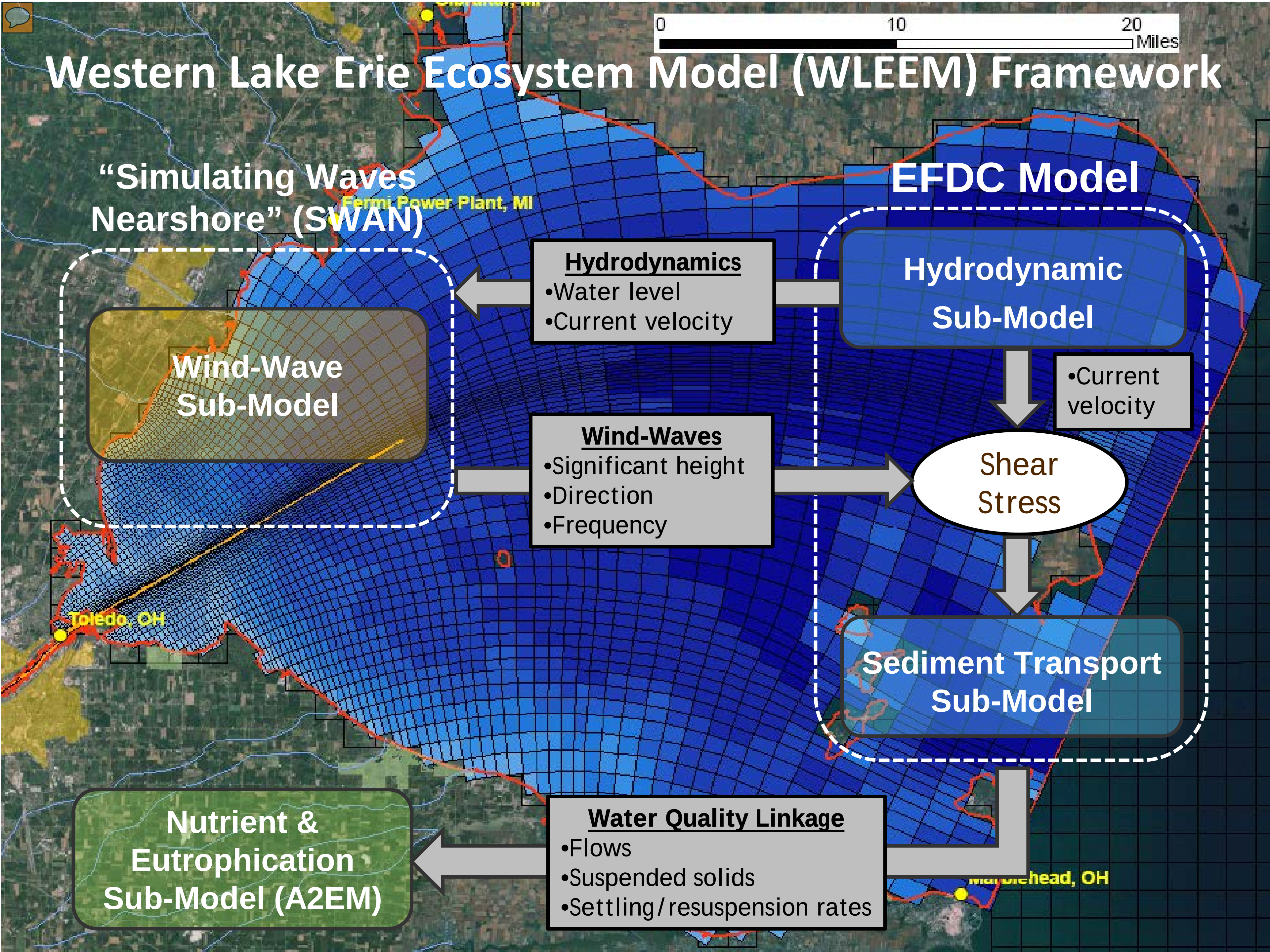
# Western Lake Erie Ecosystem Model (WLEEM) Objectives



- Model ecological response of Western Basin of Lake Erie to external (Maumee Watershed) and internal (wind-driven resuspension) sources:
  - Sediment ⇨sedimentation and turbidity
  - Nutrients ⇨nuisance & harmful algal blooms

- Support Management and Research in WLEB:
  - Link with Maumee watershed model to quantify response to current sediment and nutrient loads and to specific changes in watershed land use and management actions (e.g., BMPs)
  - Simulate in-lake responses to climate change driven extreme event scenarios
  - Support the quantification and analysis of GLRI metrics for sedimentation and harmful algal blooms in the Maumee River/Bay and Western Basin





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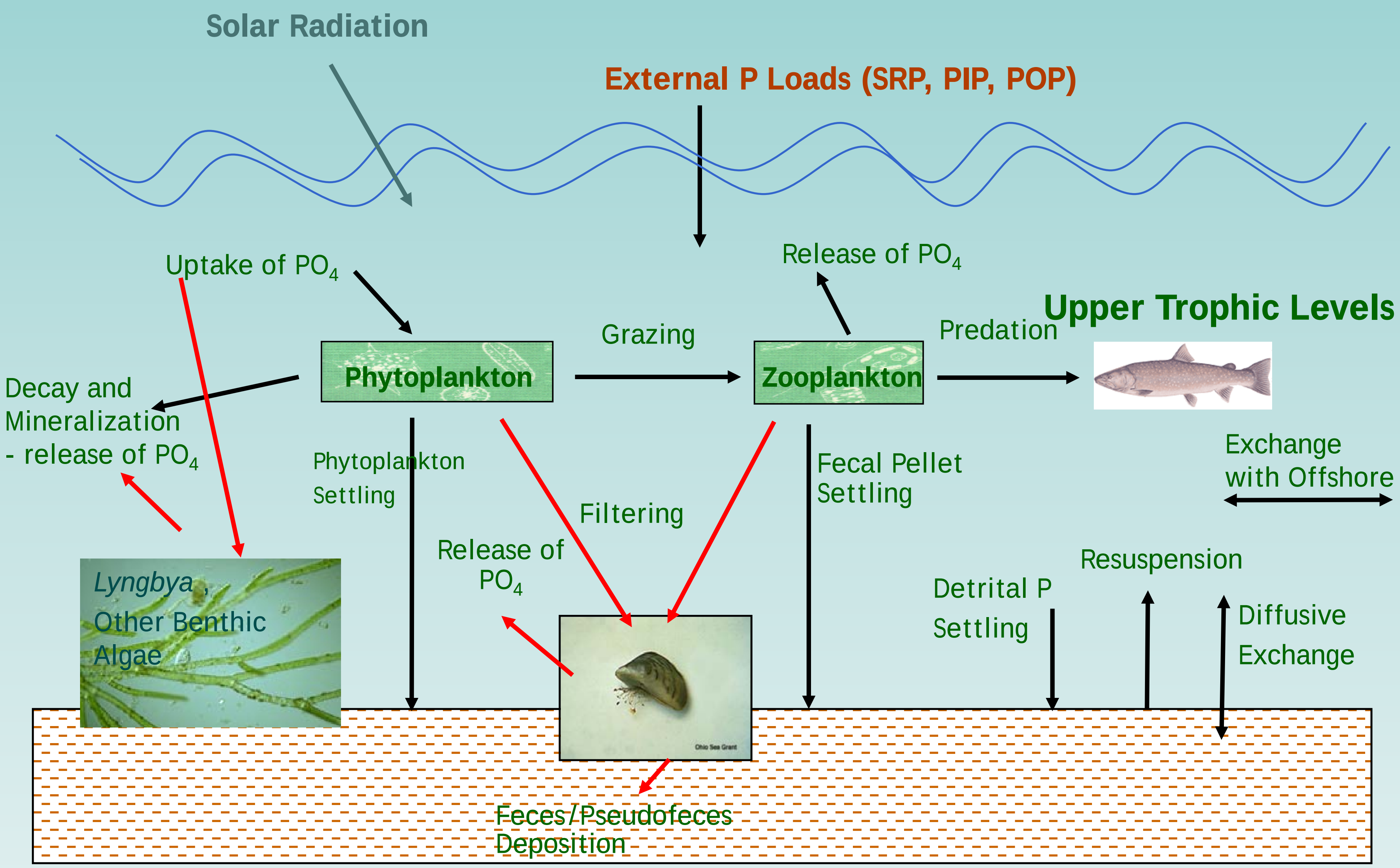
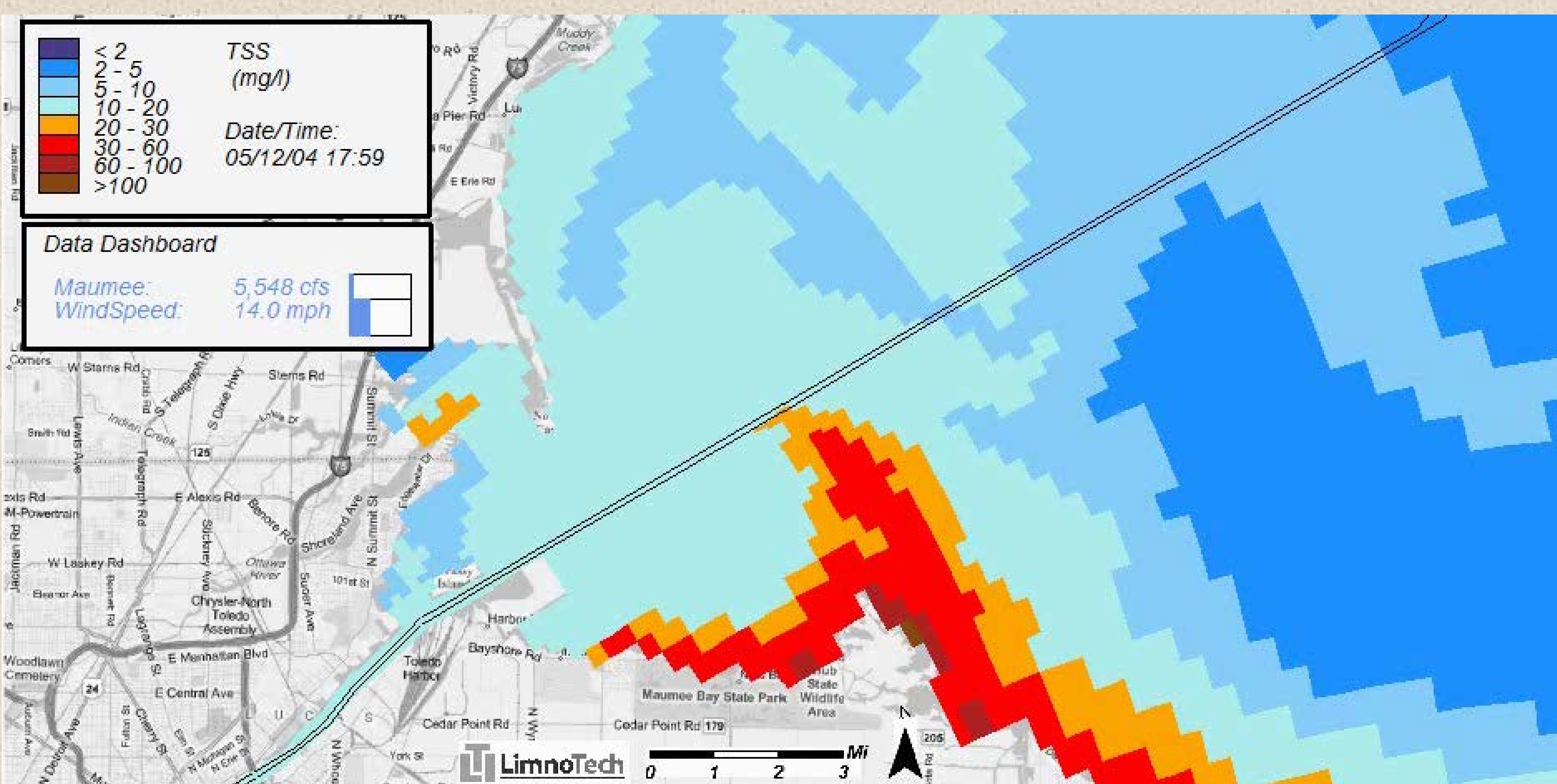
Miles
Western Lake Erie Ecosystem Model (WLEEM) Framework
"Simulating Waves Nearshore" (SWAN)
Fermi Power Plant, MI
EFDC Model
Hydrodynamics
•Water level
•Current velocity
Hydrodynamic Sub-Model
Wind-Wave Sub-Model
•Current velocity
Wind-Waves
•Significant height
•Direction
•Frequency
Shear Stress
Toledo,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

# Phosphorus Cycling in WLEEM



# Suspended Solids Animation (beginning 5/12/2004)

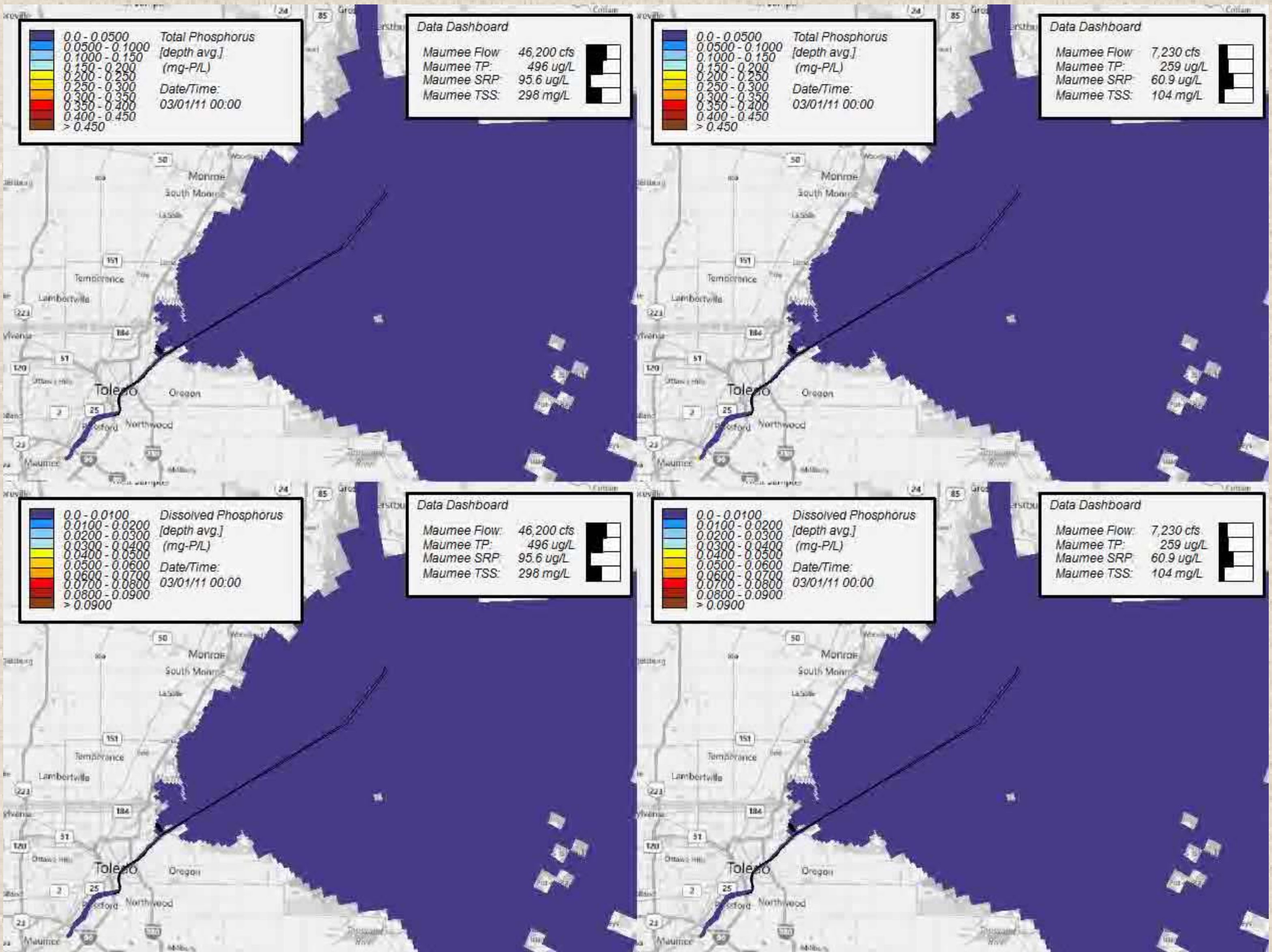



**Data provided by:**

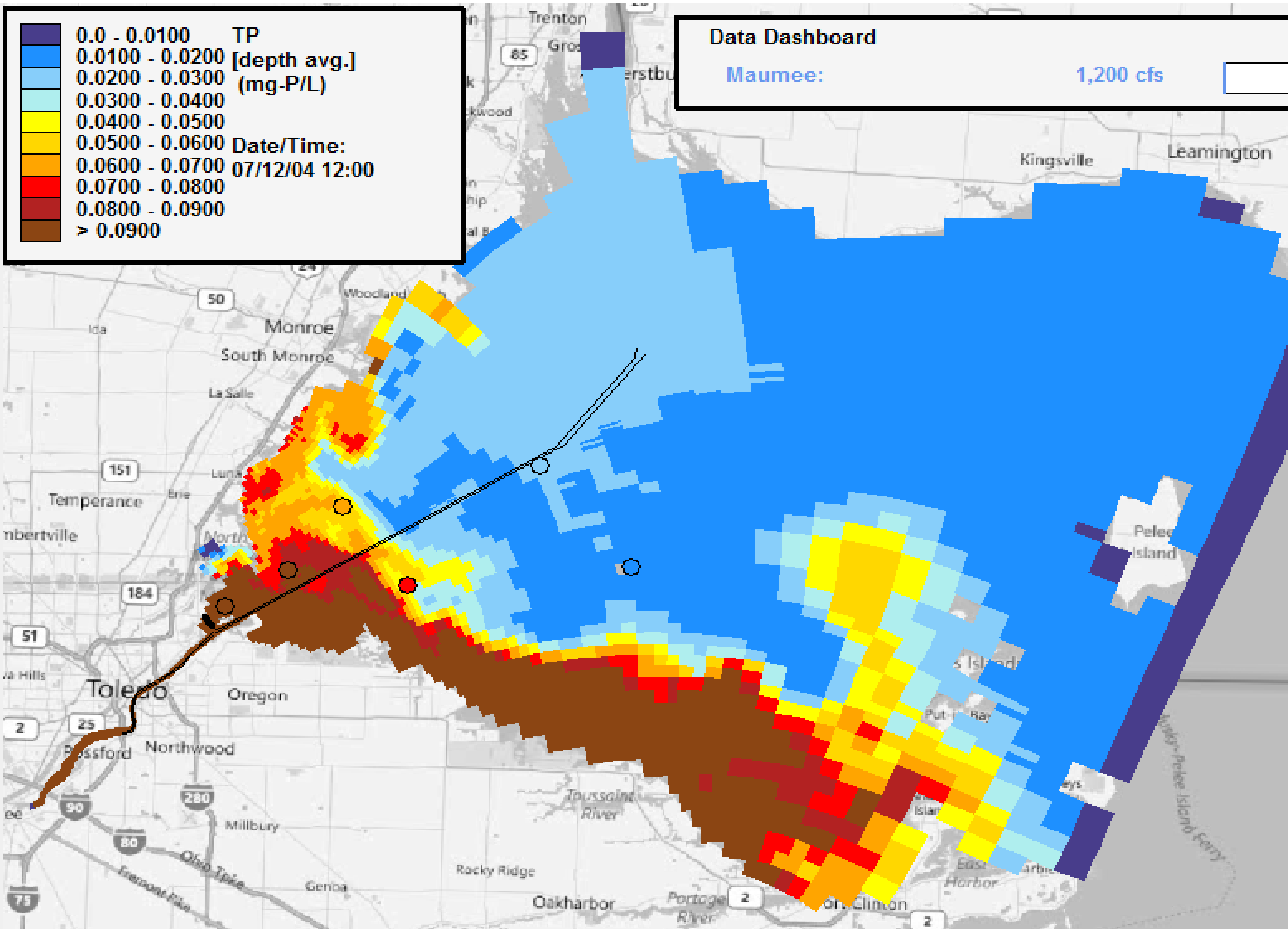
**Pete Richards and Dave Baker, Heidelberg University**

**Tom Bridgeman, University of Toledo**

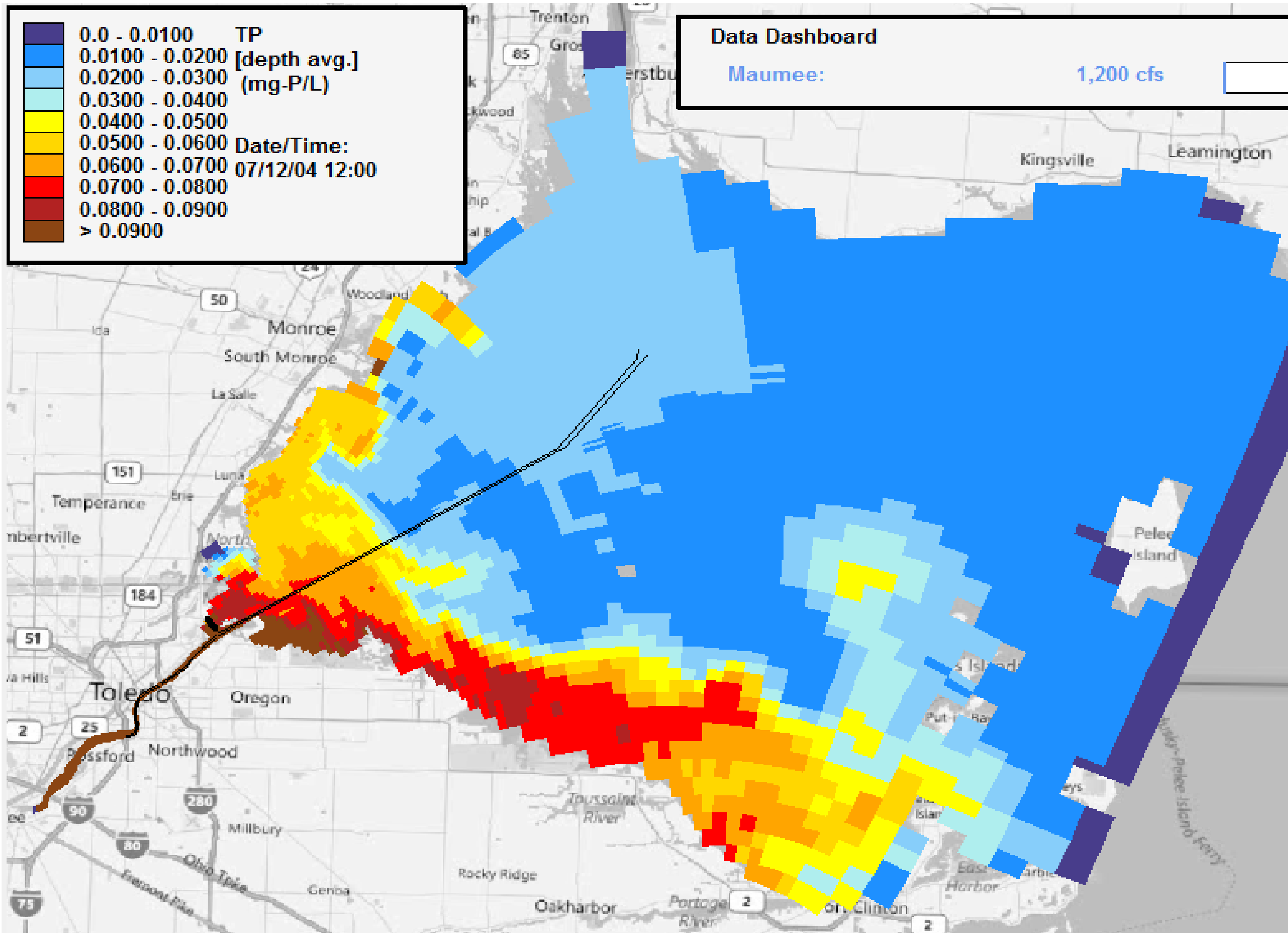
# TP and DRP Animations (comparison of 2011 and 2012)



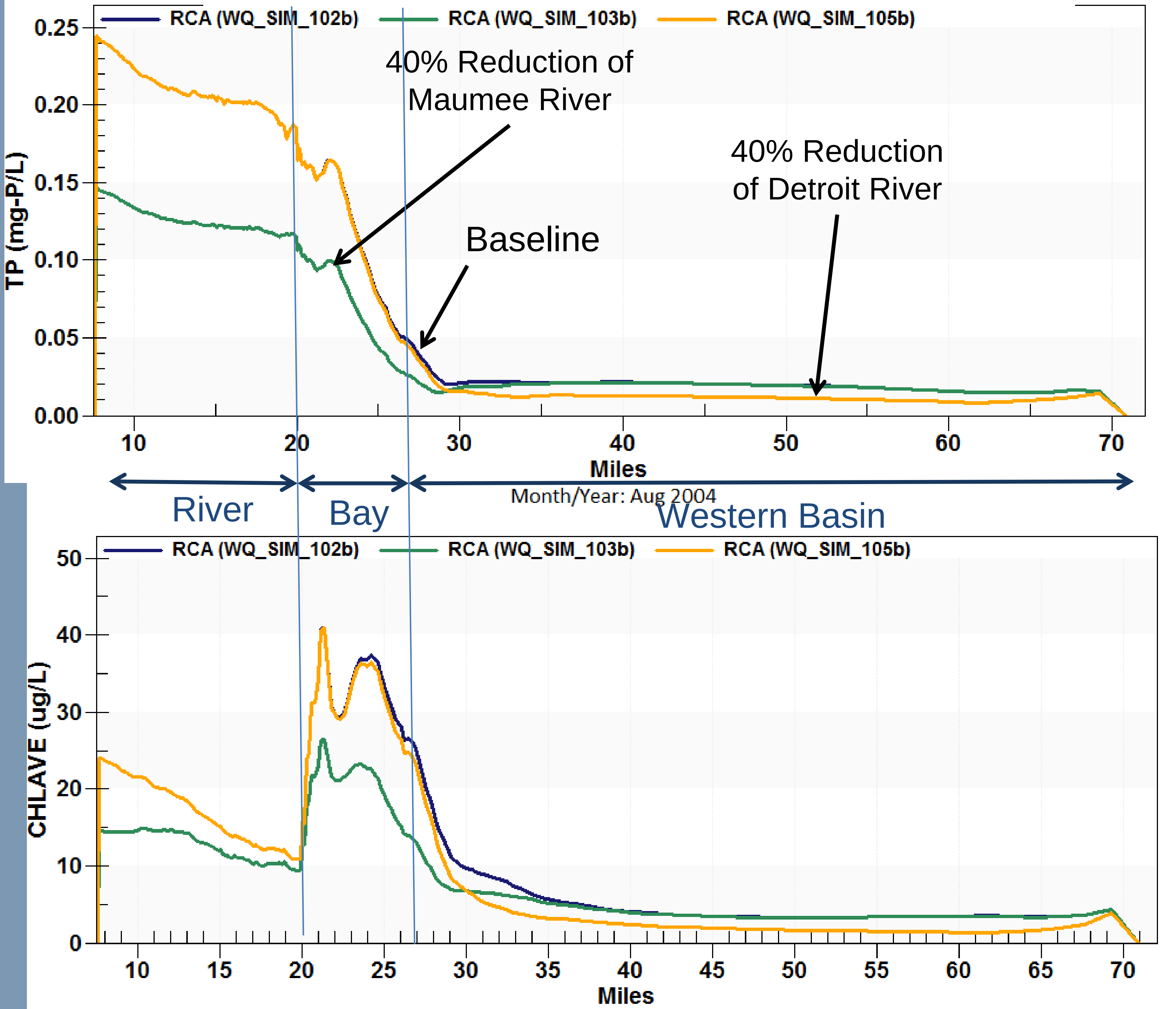
# Baseline (calibration) run of TP spatial distribution on July 12, 2004



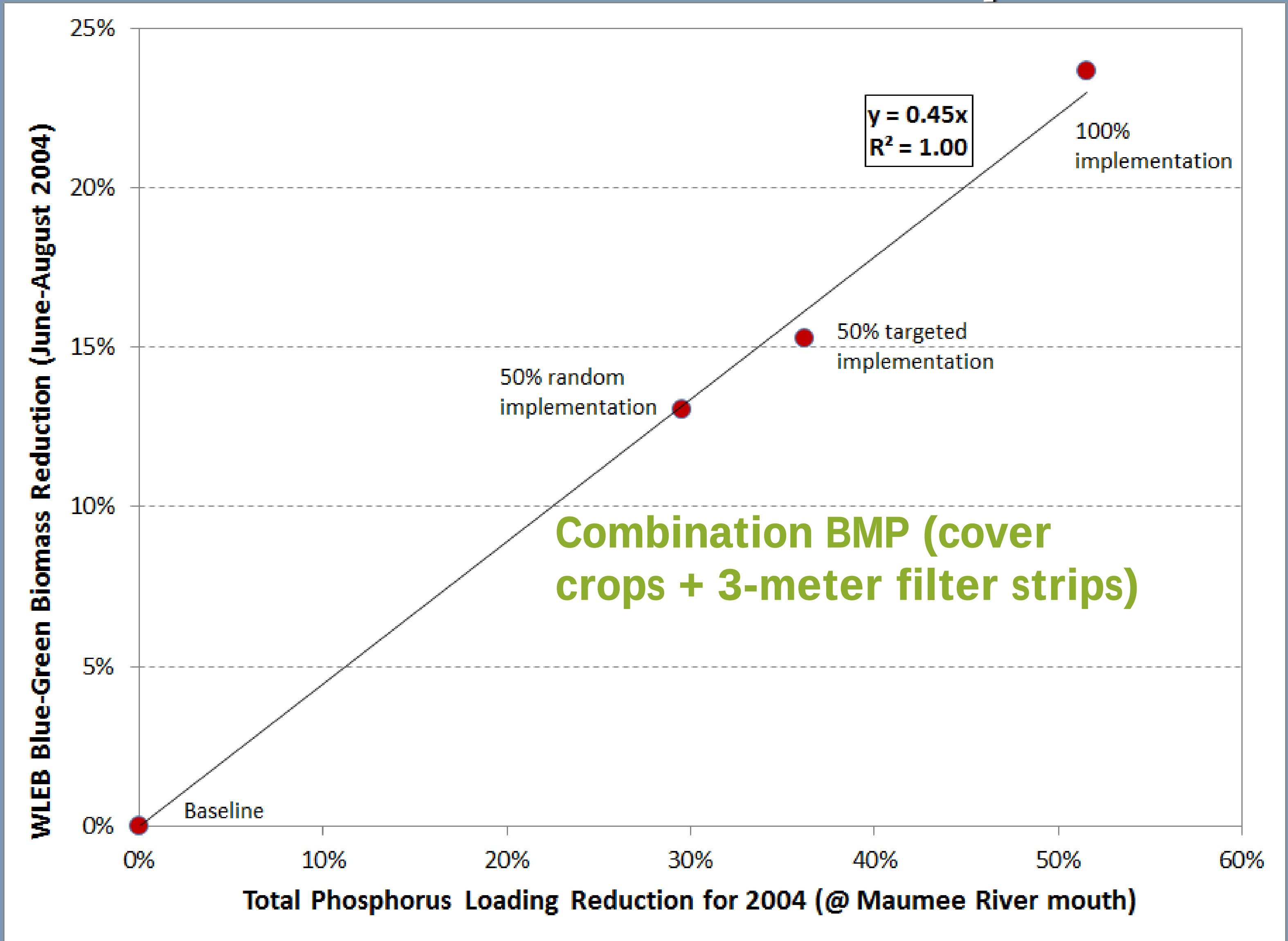
# Same model run with 40% reduction in Maumee River TP load (July 12, 2004)



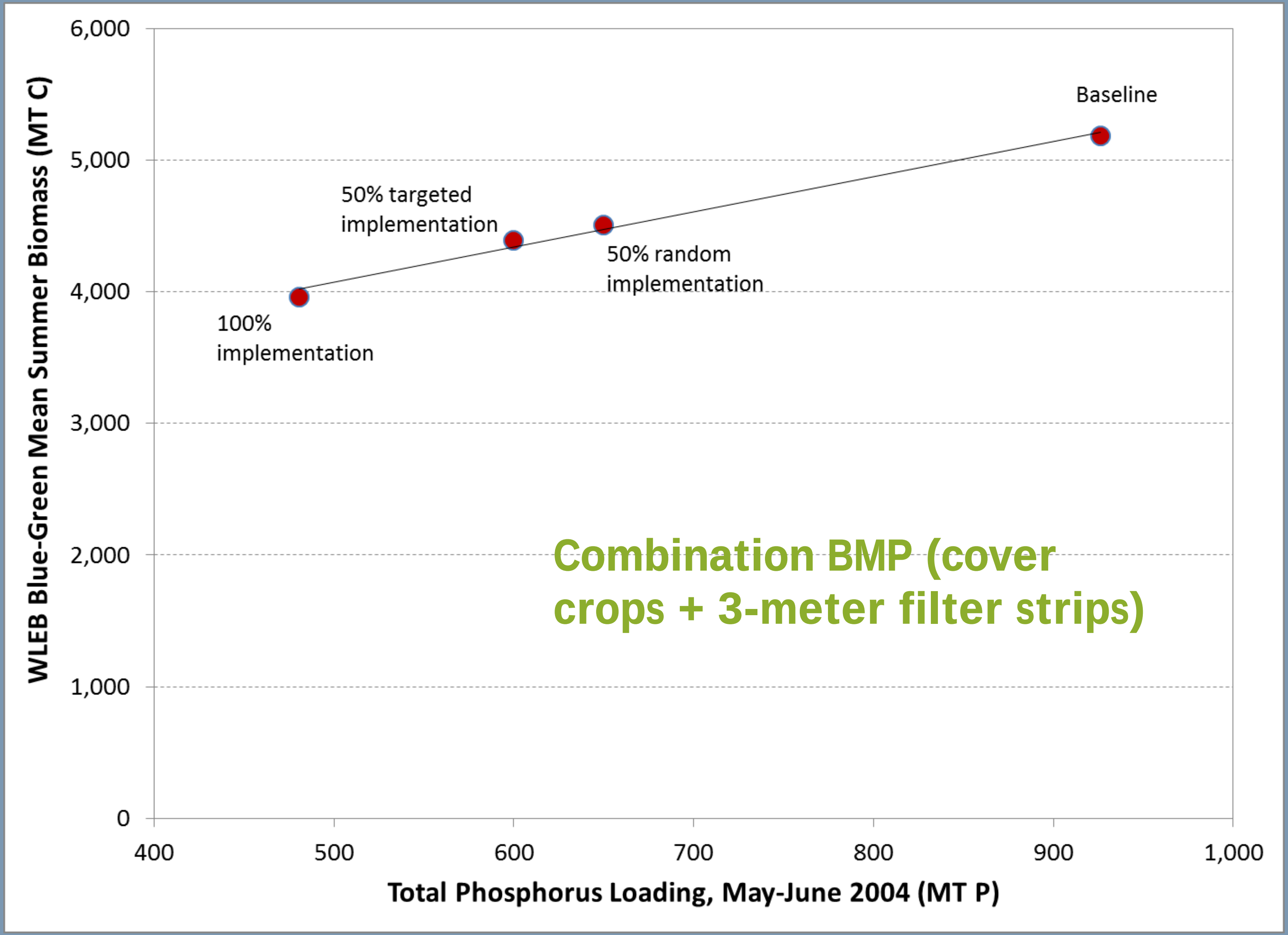
# Monthly Average TP and Chlorophyll- August 2004



# Linked Watershed-WLEEM Allows Connection between actions in Maumee watershed and In-lake Response



# Same scenarios related to spring P loading from Maumee




Keep 'em Great!