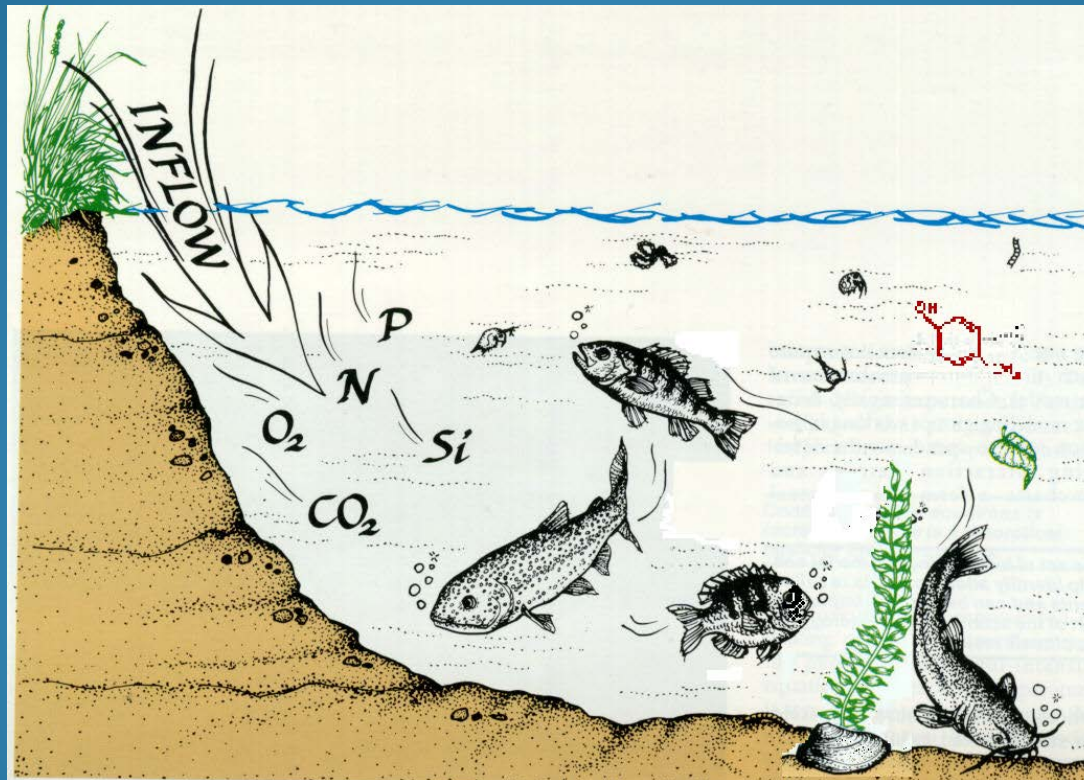


AQUATOX: Linking Water Quality with Aquatic Life

February 11, 2014

Marjorie Coombs Wellman, Office of Water, US EPA
Brenda Rashleigh, Office of Research and Development, US EPA



Outline

- Model capabilities
 - Introduction
 - Physics and Chemistry
 - Biology
 - Fate and Effects of Chemicals
 - Interface and Output
- Example Applications
 - Tenkiller Reservoir, OK
 - Lake Hartwell, GA/SC
- Wrap-up and model future

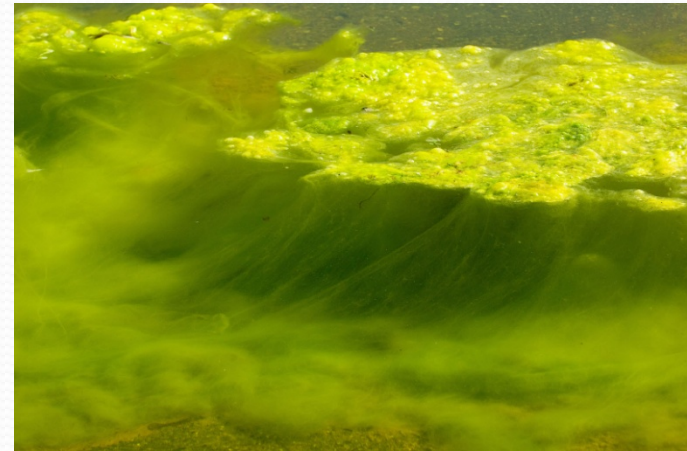
Acknowledgements

- Dr. Richard Park, Eco Modeling: model creator and developer
- Jonathan Clough, Warren Pinnacle Consulting: chief programmer

Introduction to AQUATOX

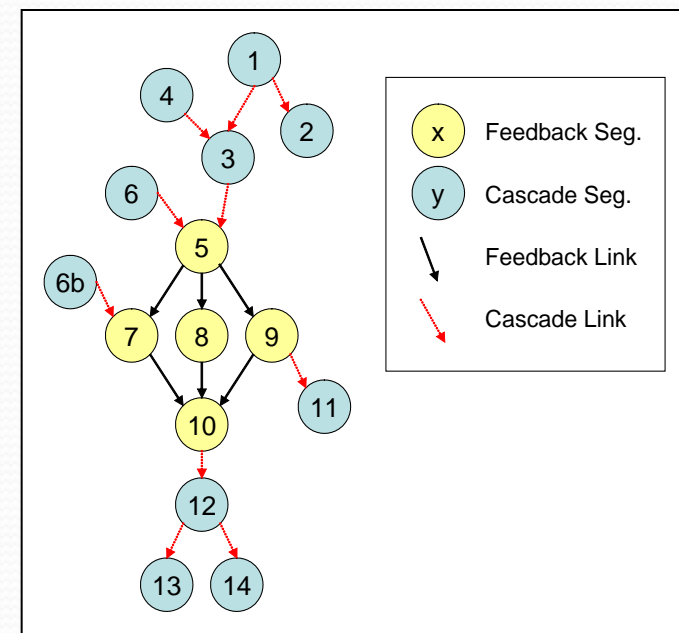
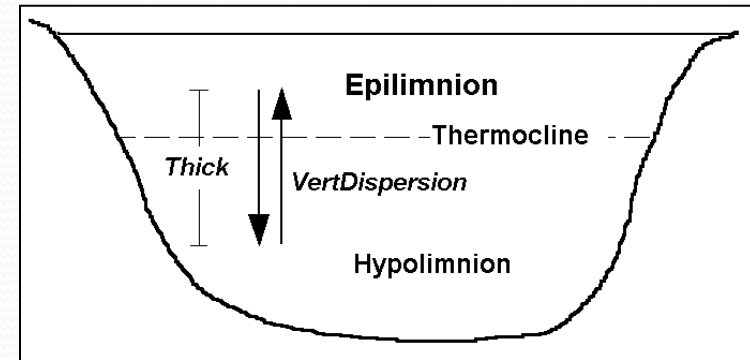
What is AQUATOX?

- Mechanistic simulation model for aquatic ecosystems
 - Streams, rivers, lakes, reservoirs, estuaries
- Fate and effects of multiple stressors
 - Nutrients
 - Organic toxicants
 - Suspended and bedded sediments
 - Flow
 - Temperature

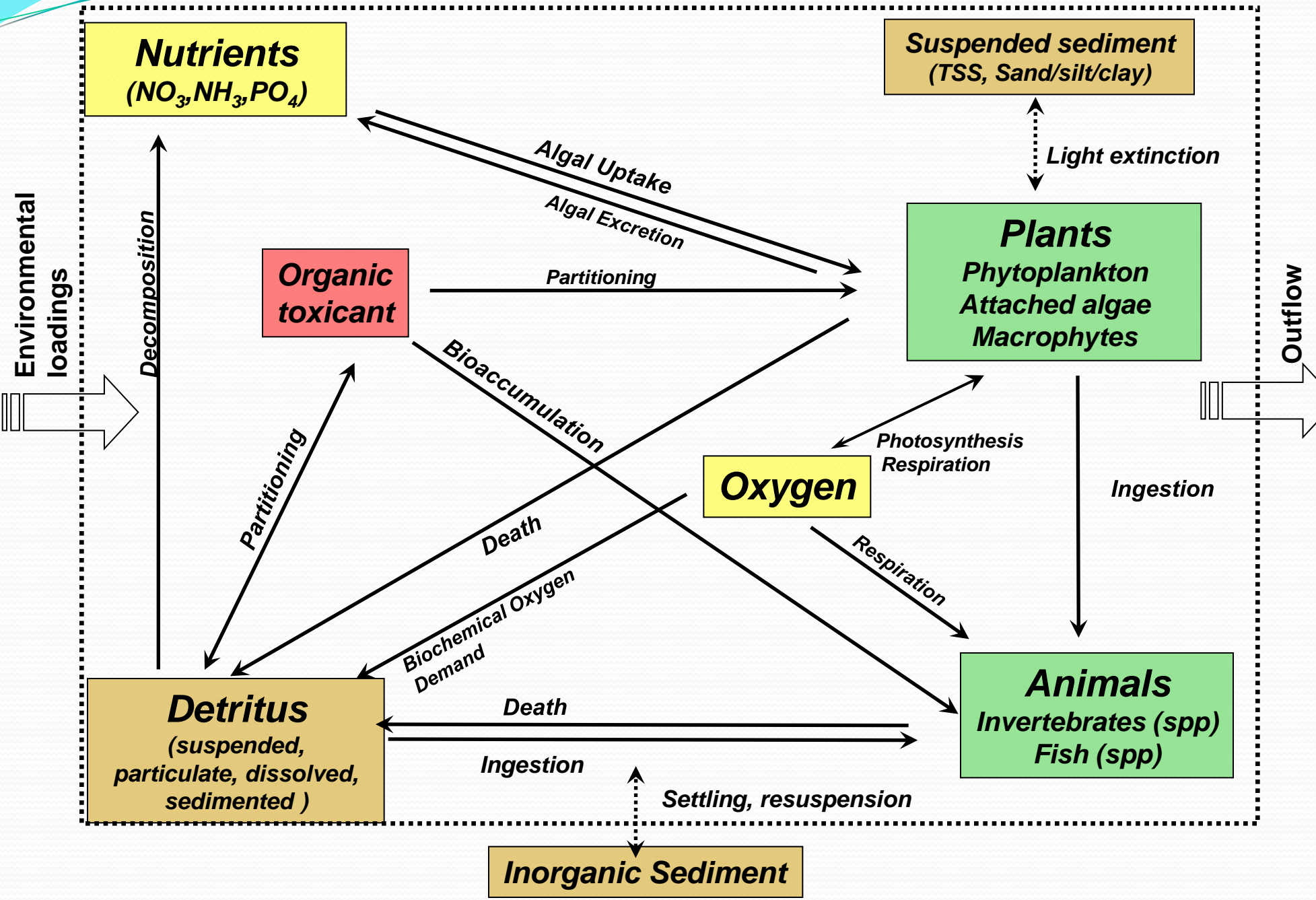


AQUATOX Structure

- Time-variable
 - usually daily reporting time step
 - can run from few days to decades
- Spatially simple, but:
 - thermal stratification
 - salinity stratification
 - can link multiple segments together
- Modular and flexible
 - model only what is necessary
 - simple to complex food web
- Control vs. perturbed simulations

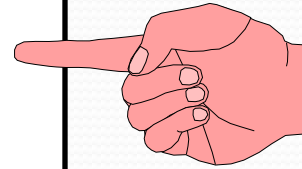


AQUATOX Simulates Ecological Processes & Effects within a Volume of Water Over Time

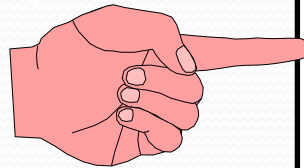


- **Site characteristics**
 - **Biological characteristics**
 - **Chemical characteristics**
 - **Environmental loadings**
 - **Multiple sources**
 - **Variable or constant**
 - **Watershed loads from BASINS (opt.)**
 - **Library or user-supplied**
- default or user-supplied

AQUATOX Inputs



AQUATOX Outputs



- **Biomass**
- **Pollutant concentrations**
- **Tissue concentrations & BAFs**
- **Process rates**
- **Direct & indirect effects**
- **Time variable**

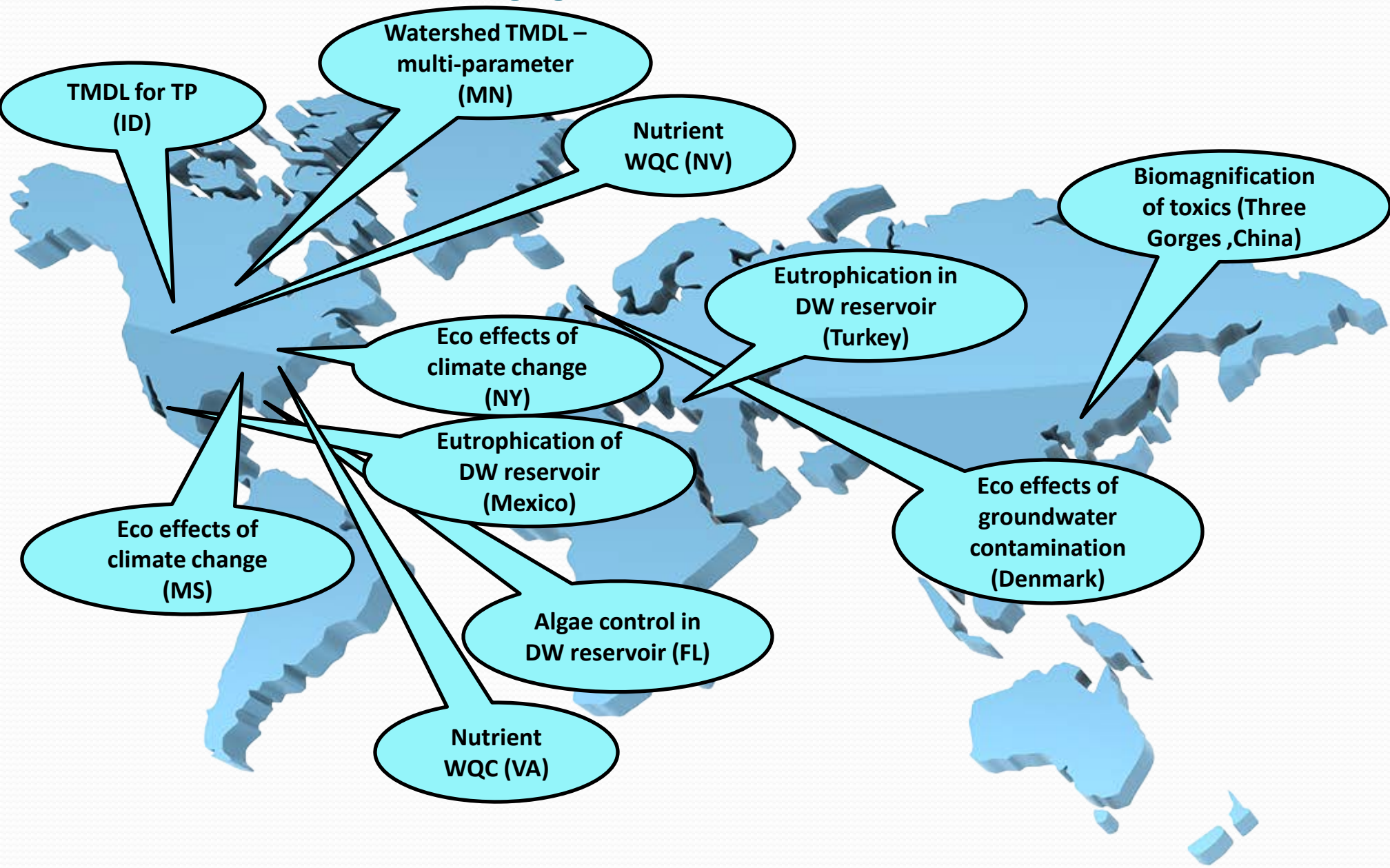
Why AQUATOX?

- A truly integrated eutrophication, contaminant fate and effect model
 - “is the most complete and versatile model described in the literature” (Koelmans et al. 2001)
- Comparison with other models
 - Includes more biological components than water quality models such as WASP7 or QUAL2K
 - CASM models toxic effects but not fate
- Comprehensive bioaccumulation model

One model, many questions

- Many waters are impaired, with multiple stressors
- To restore them we need to know:
 - Relative importance of stressors?
 - Combined effects?
 - Predicted effects of management actions?
 - Better water quality
 - Fewer and/or smaller algae blooms
 - More oxygen
 - Restore fisheries
 - Will the fish be safe to eat?
 - What is the best management scenario?
 - Which combinations of measures will work best?
 - Any unintended consequences?
 - How long will recovery take?

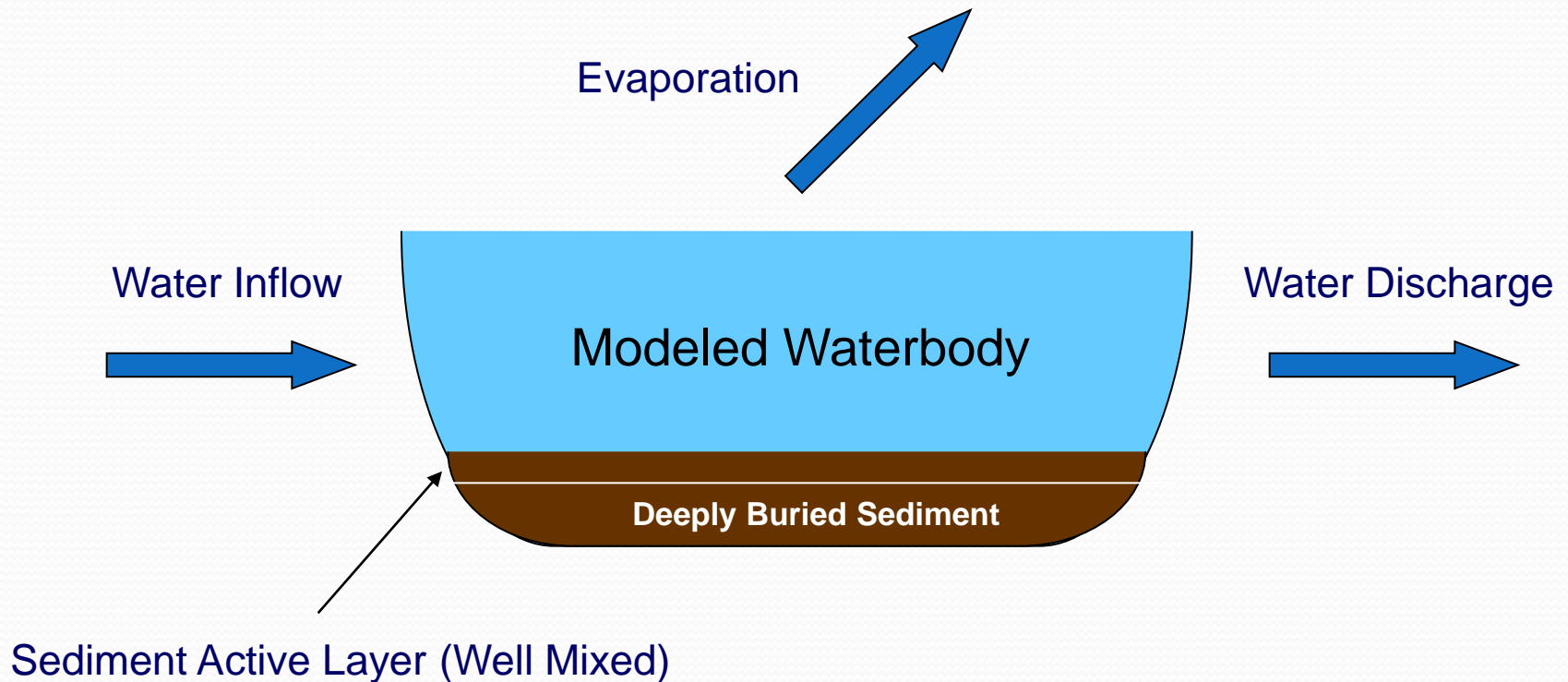
Worldwide applications



Physics and Chemistry in AQUATOX

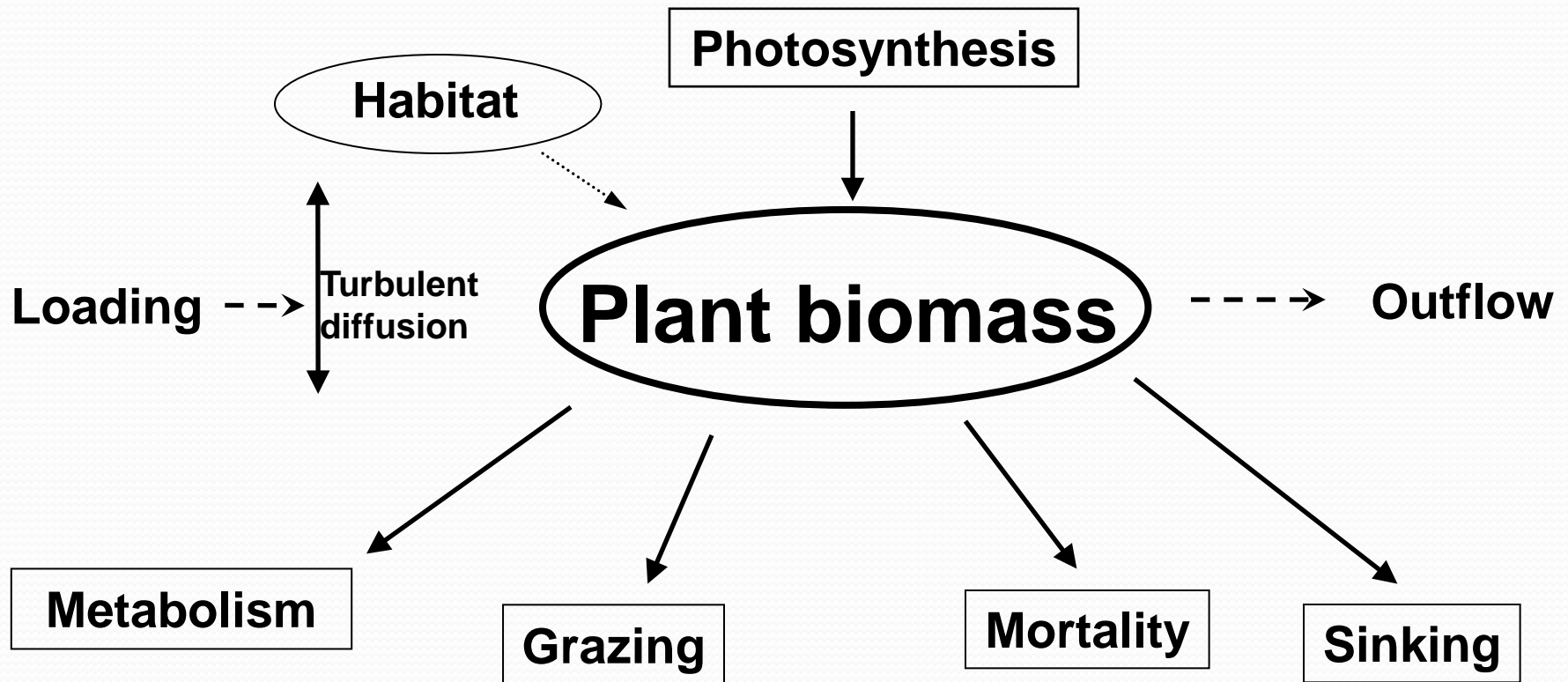
Physical Characteristics of a Site

Water Balance and Sediment Structure



Biology in AQUATOX

How AQUATOX Models Plants

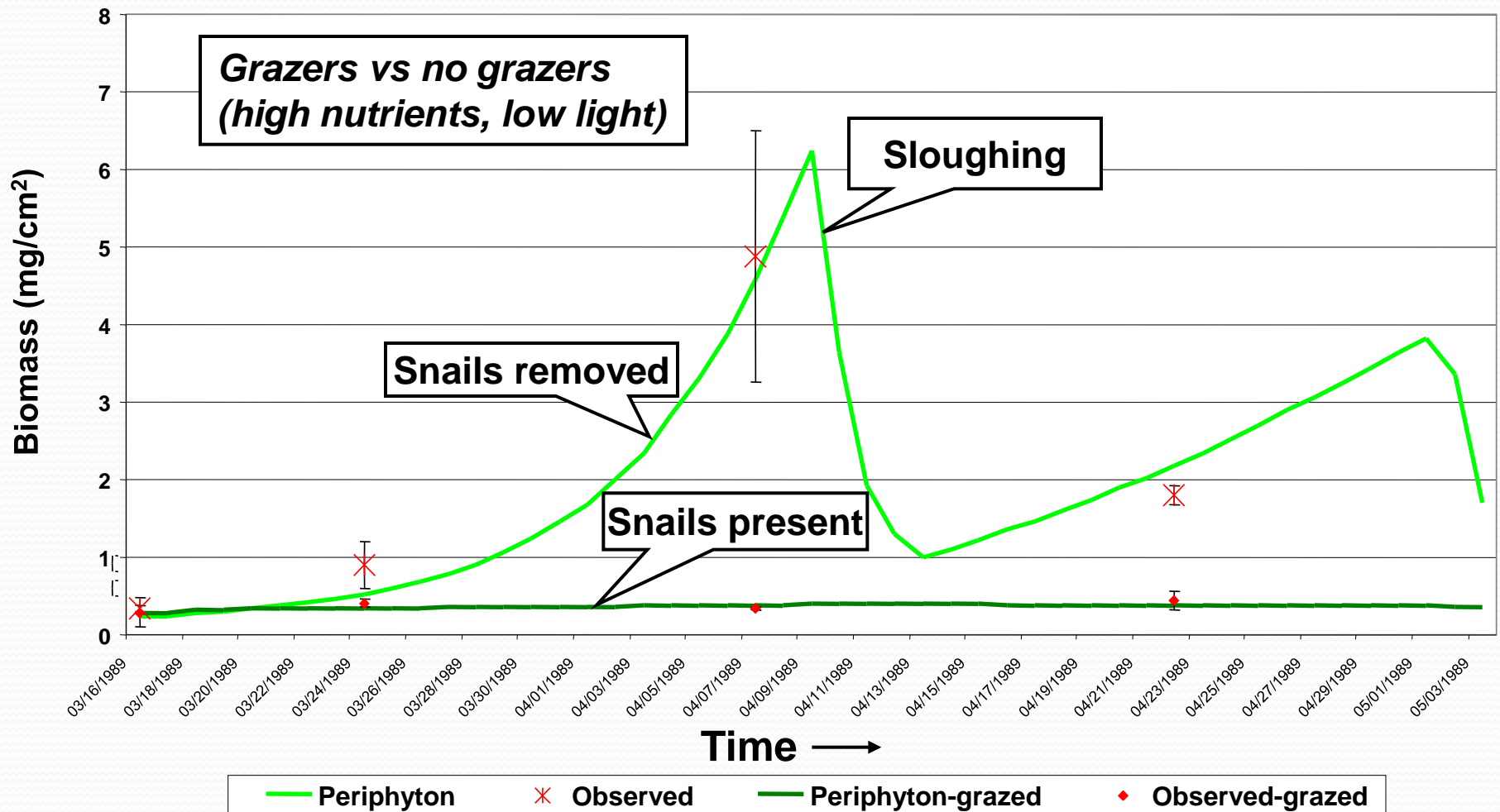


Multiple plant groups

- Phytoplankton
 - greens, cyanobacteria, diatoms or “other”
- Periphyton
 - greens, diatoms, cyanobacteria, or “other”
 - include live material and detritus
 - snails & other animals graze it heavily
 - subject to sloughing, *even at relatively low velocity*
- Macrophytes
 - benthic, rooted-floating, or free-floating
 - heavy growths have significant effect on light climate
 - may act as refuge from predation for animals
 - leaves can provide significant surface area for periphyton growth

Periphyton Controlled by Multiple Independent Factors

One important factor is grazing by snails
another is sloughing



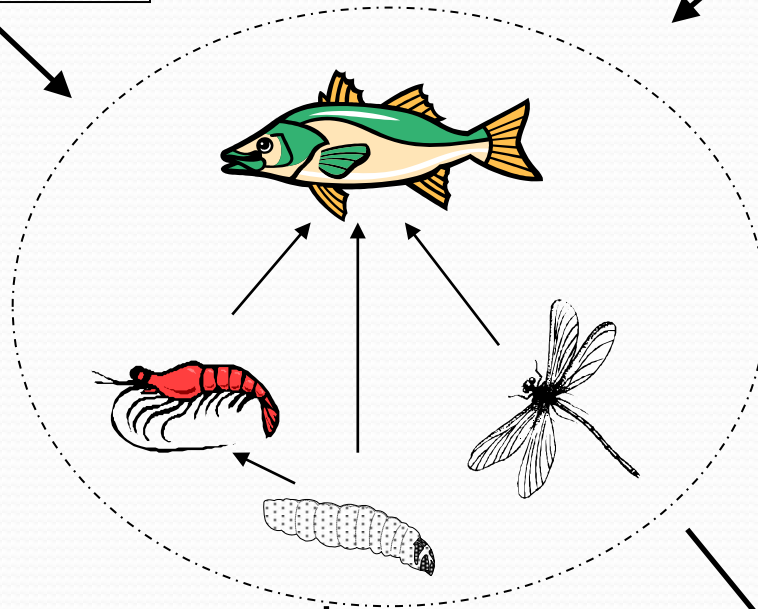
Modeling Animals in AQUATOX

Consumption

- maximum feeding rates
- availability & preferences
- reductions due to stress

Vertical migration

Loadings - - - ->



- - - -> Washout

Metabolism

- defecation
- excretion
- respiration

Mortality

- predation
- natural mortality
- toxicity

Reproduction

- gamete loss
- promotion
- emergence

Multiple Animal Groups

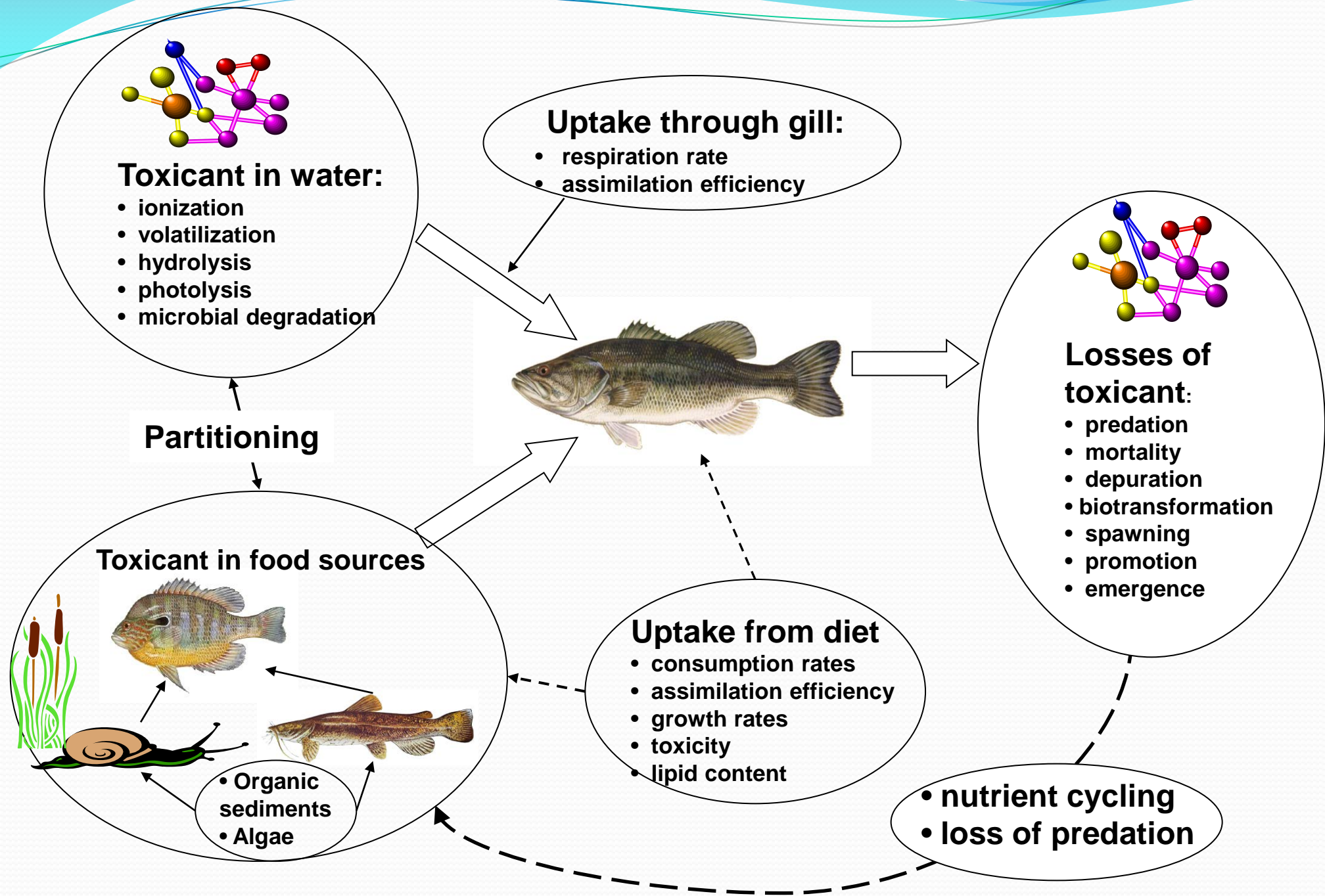
- Zooplankton
- Benthic invertebrates
- Benthic insects
- Fish, with multiple year classes

Fate and Effects of Chemicals in AQUATOX

Modeling Toxicity

- Organic toxicants
- ≤ 20 chemicals simultaneously
- Lethal and sublethal effects
- Acute and chronic toxicity
- Effects based on total internal concentrations
- Option to model external toxicity
 - Useful if uptake and depuration are very fast (as with herbicides)
- Ecological effects – direct and indirect
 - Non-target organisms
 - Food web disturbances
 - Unintended consequences?

Fate and Bioaccumulation in AQUATOX



AQUATOX Interface and Output

AQUATOX Interface: Main Screen

The screenshot shows the AQUATOX software interface. At the top, the title bar reads "AQUATOX-- Main Window - [Farm Pond MO Esfenval.aps-- Main Window]". Below the title bar is a menu bar with "File", "View", "Library", "Study", "Sediment", "Window", and "Help". A toolbar with various icons is located below the menu bar. The main window is titled "AQUATOX: Study Information" and "EPA Release 3.1".

The interface is divided into several sections:

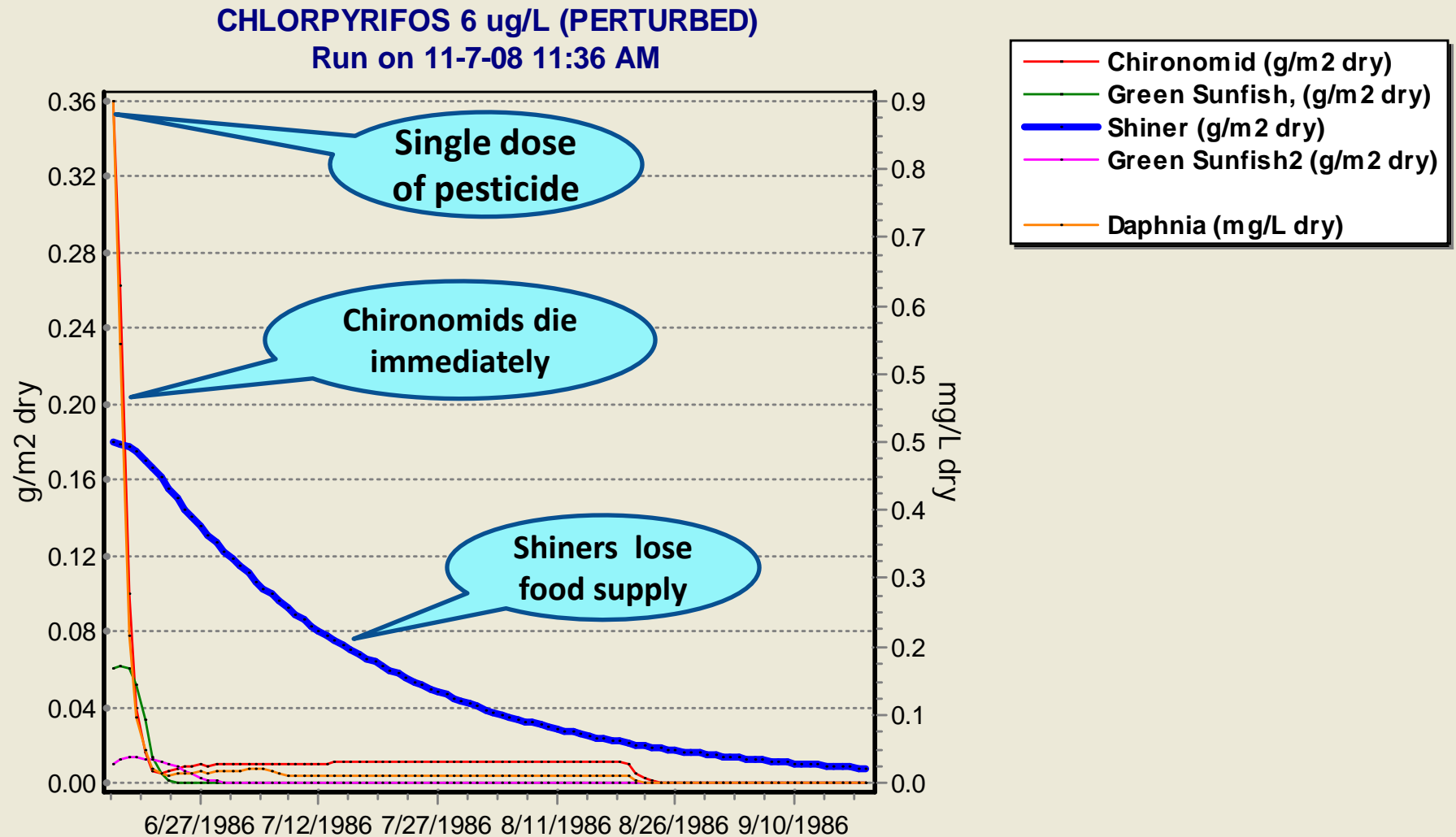
- Study Name:** FARM POND MO
- Run Status:** Perturbed Run: 11-28-12 10:31 AM, Control Run: 11-28-12 10:31 AM
- Data Operations:** Initial Conds., Chemical, Site, Setup, Notes, Birds, Mink..., Food Web
- Program Operations:** Perturbed, Control, Output, Export Results, Export Control, Use Wizard, Help
- State and Driving Variables In Study:** A list of variables including Dissolved org. tox 1: [Esfenvalerate], Total Ammonia as N, Nitrate as N, Total Soluble P, Carbon dioxide, Oxygen, Refrac. detritus, Labile sed. detritus, Susp. and dissolved detritus, Buried refrac. detritus, Buried labile detritus, Diatoms1: [Diatom], Diatoms2: [Phyt High-Nut Diatom], Greens1: [Peri, Green], Greens2: [Phyto, Green], Cyanobacteria1: [Phyt, Blue-Greens], OtherAlg1: [Cryptomonas], Macrophyte1: [Myriophyllum], SedFeeder1: [Chironomid], SuspFeeder1: [Daphnia], SuspFeeder2: [Copepod], Clam1: [Sepia], Grazer1: [Mayfly (Baetis)], Grazer2: [Rotifer, Keratella], Snail1: [Gastropod], LgForageFish2: [Shiner], SmGameFish1: [Largemouth Bass, YOY], LgGameFish1: [Largemouth Bass, Lg], Water Volume, Temperature, Wind Loading, Light, pH.
- Sed Layer(s):** There are 0 sediment layers modeled.

At the bottom of the window are three buttons: "Add", "Delete", and "Edit".

Callout boxes with arrows point to the following elements:

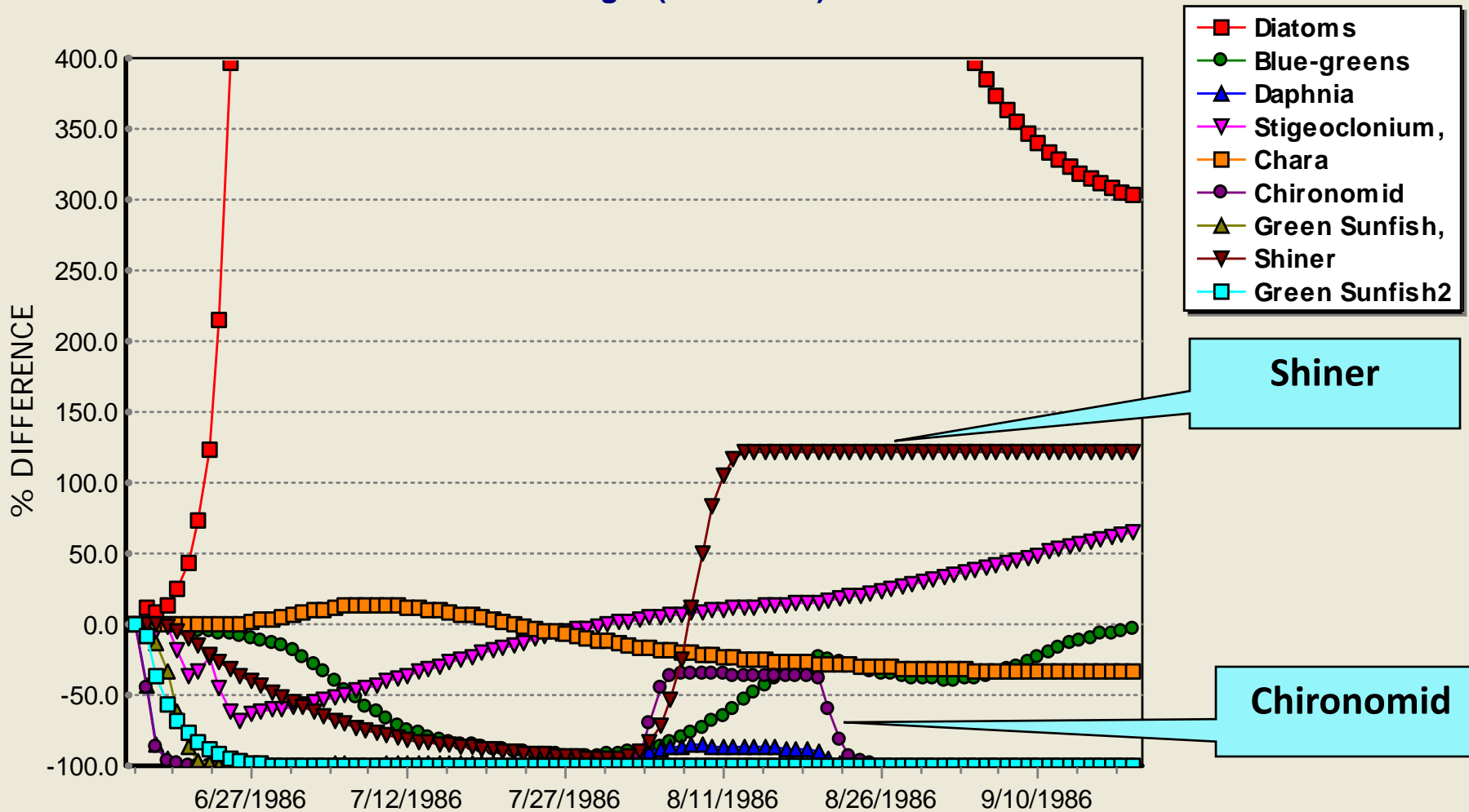
- Setup screen:** Points to the "Setup" button in the Data Operations section.
- List of state variables:** Points to the "State and Driving Variables In Study" list.
- Run simulations:** Points to the "Control" button in the Program Operations section.
- Examine Output:** Points to the "Output" button in the Program Operations section.
- Help feature:** Points to the "Help" button in the Program Operations section.

Output: Animals decline at different rates following single dose of chlorpyrifos

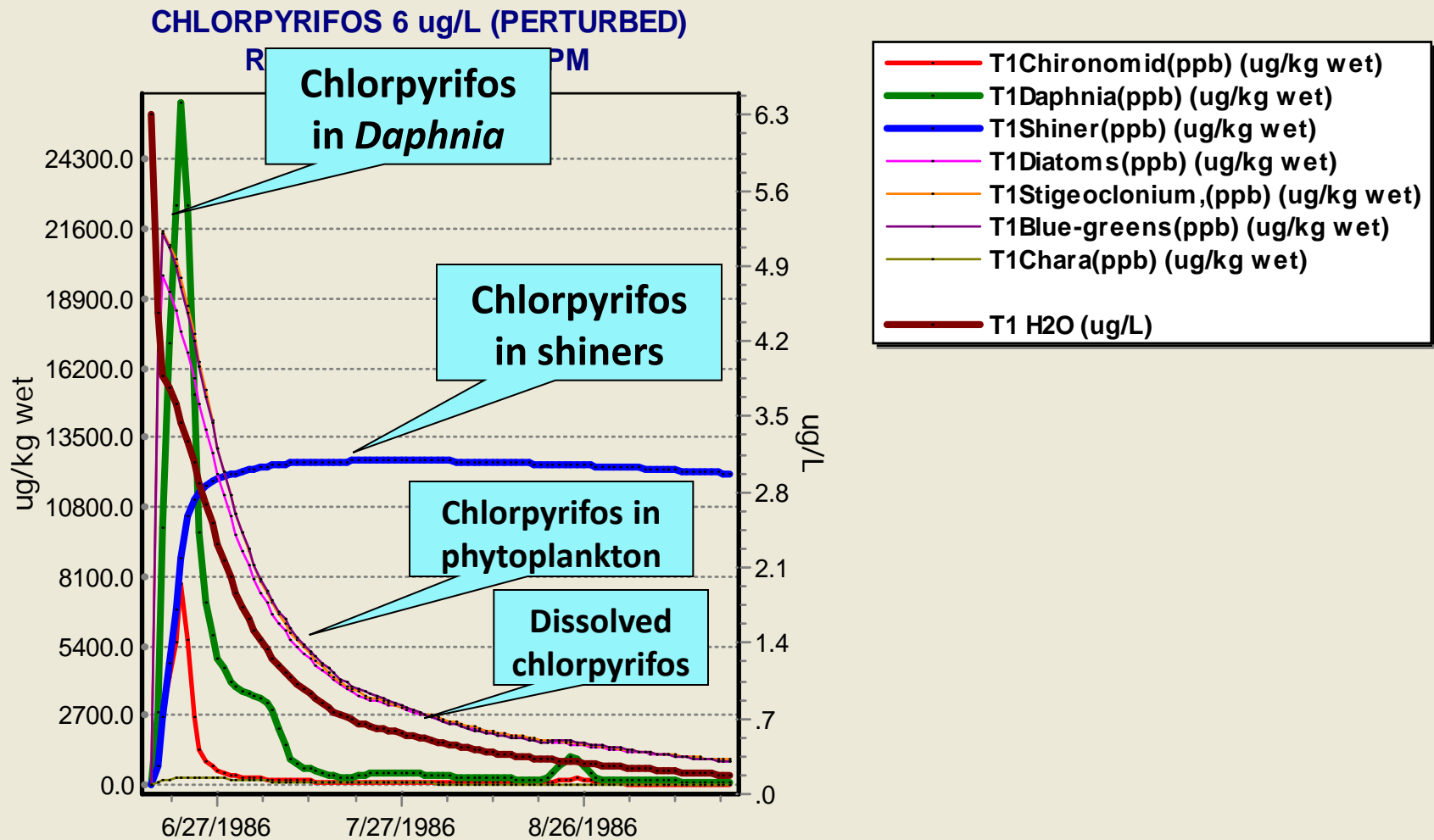


% Difference Graph shows relative differences

CHLORPYRIFOS 6 ug/L (Difference)



Track concentrations in tissues and water



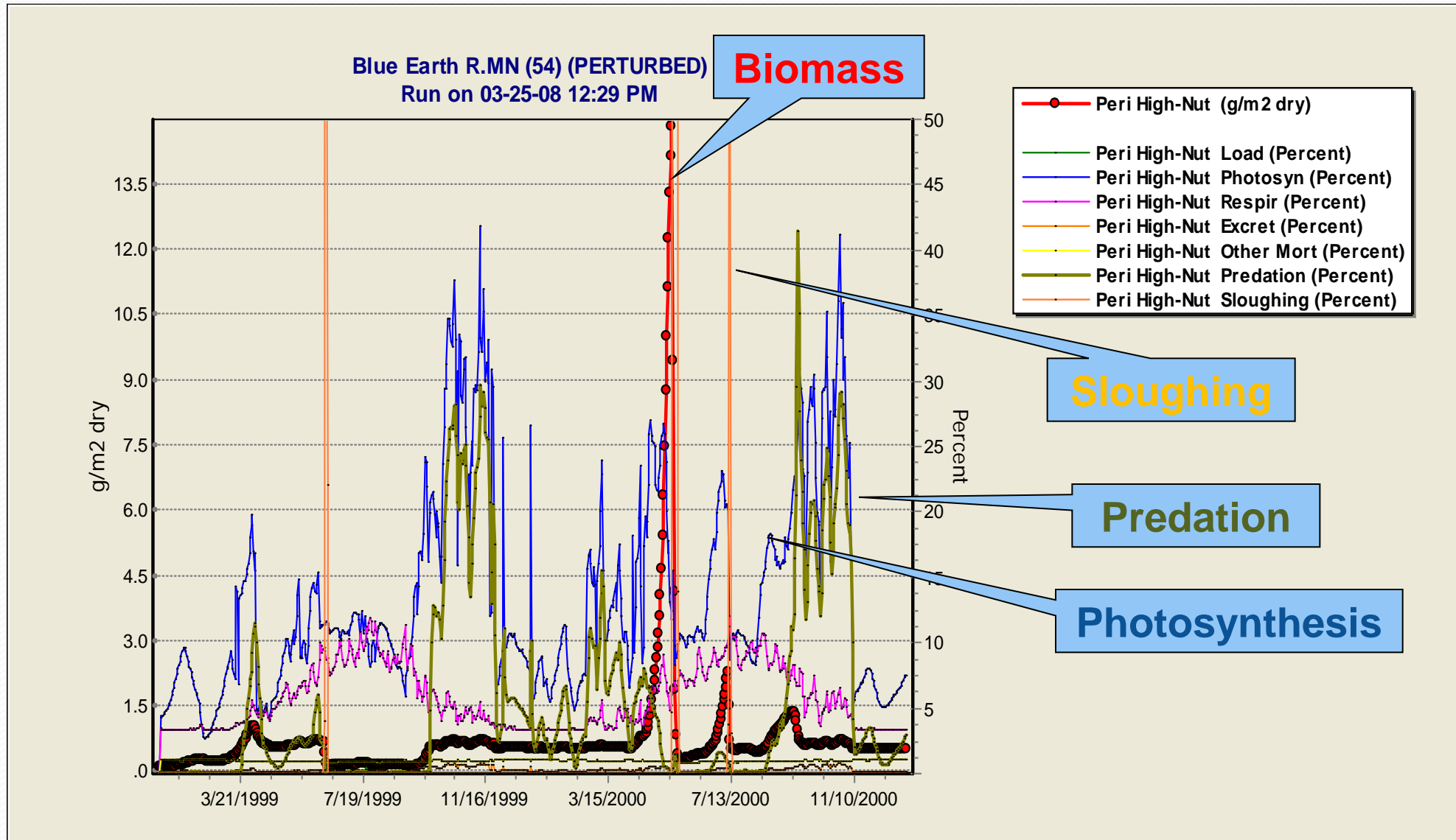
Process Rates

- Concentrations of state variables are solved using differential equations
 - Equation for periphyton concentrations is:

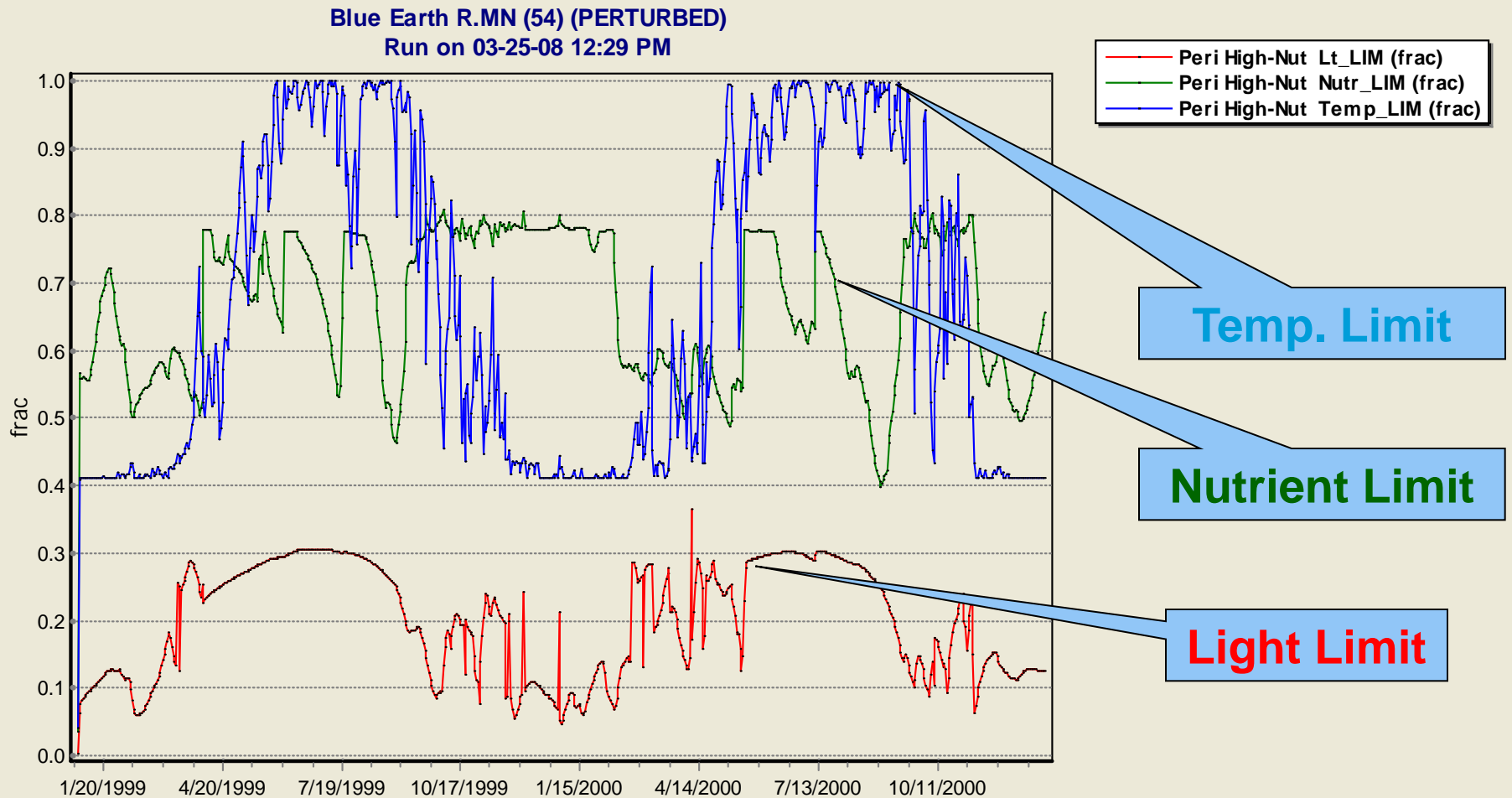
$$\frac{dBiomass_{Peri}}{dt} = Loading + Photosynthesis - Respiration - Excretion - Mortality - Predation + Sed_{Peri} - Slough$$

- Individual terms of these equations can be saved and graphed

Periphyton Rates show importance of grazing and sloughing

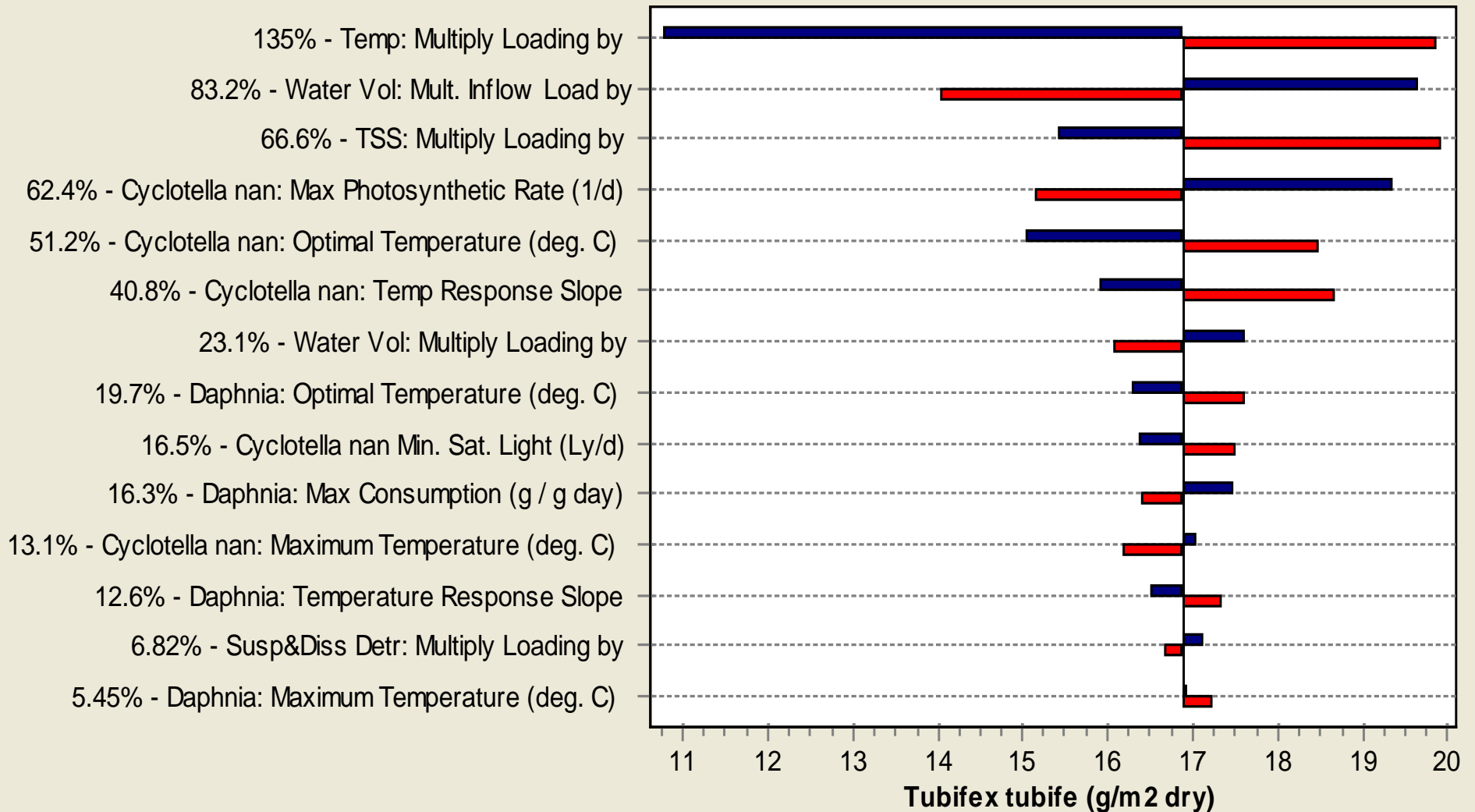


Limitations to Photosynthesis can also be Graphed



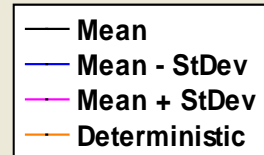
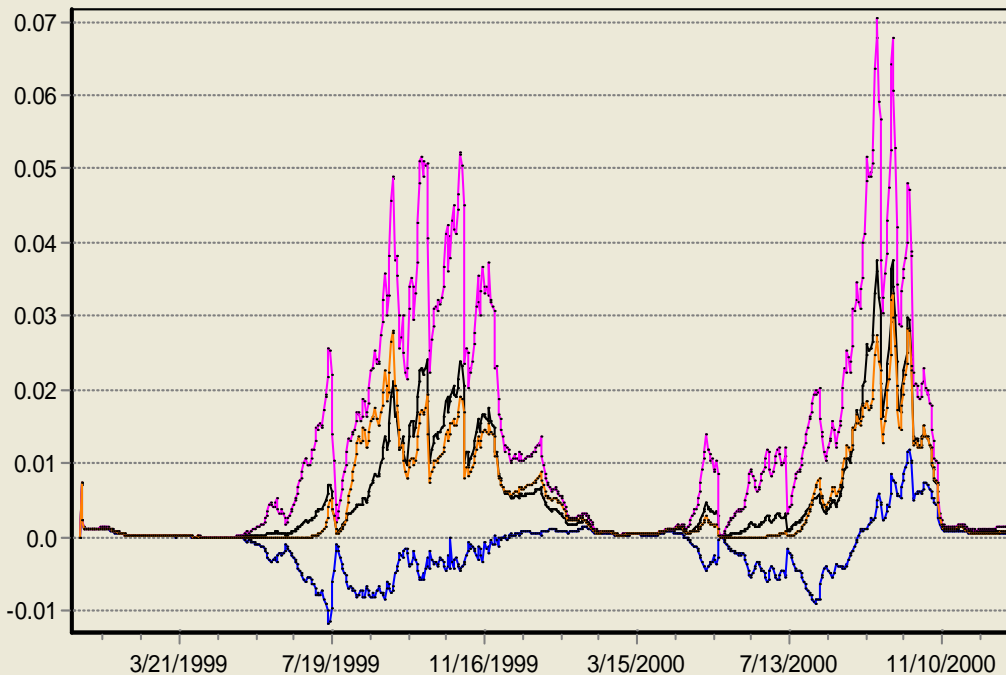
Automated Sensitivity Analysis

Sensitivity of Tubifex tubife (g/m2 dry) to 20% change in tested parameters
3/28/2008 3:31:16 PM



Integrated Uncertainty Analysis Capability

NH3 & NH4+ (mg/L)
3/28/2008 4:42:28 PM



Distribution Information

Phyt, Blue-Gre: Optimal Temperature (deg. C)

A triangular distribution plot showing Probability on the y-axis (0 to 0.045) and temperature in degrees Celsius on the x-axis (10 to 35). The distribution is a blue triangle with a peak at approximately 27 degrees Celsius.

Distribution Type:

- Triangular
- Uniform
- Normal
- Lognormal

Distribution Parameters:

Most Likely	27
Minimum	9.17
Maximum	35.83

Probability Cumulative Distribution

In an Uncertainty Run:

- Use Above Distribution
- Do Not use Distribution (i.e. use point estimate)

Help OK Cancel

Example Applications of AQUATOX

- Eutrophication in TenKiller Lake Reservoir, OK
- PCB bioaccumulation in Lake Hartwell, SC/GA

Application of AQUATOX to Eutrophic Reservoir

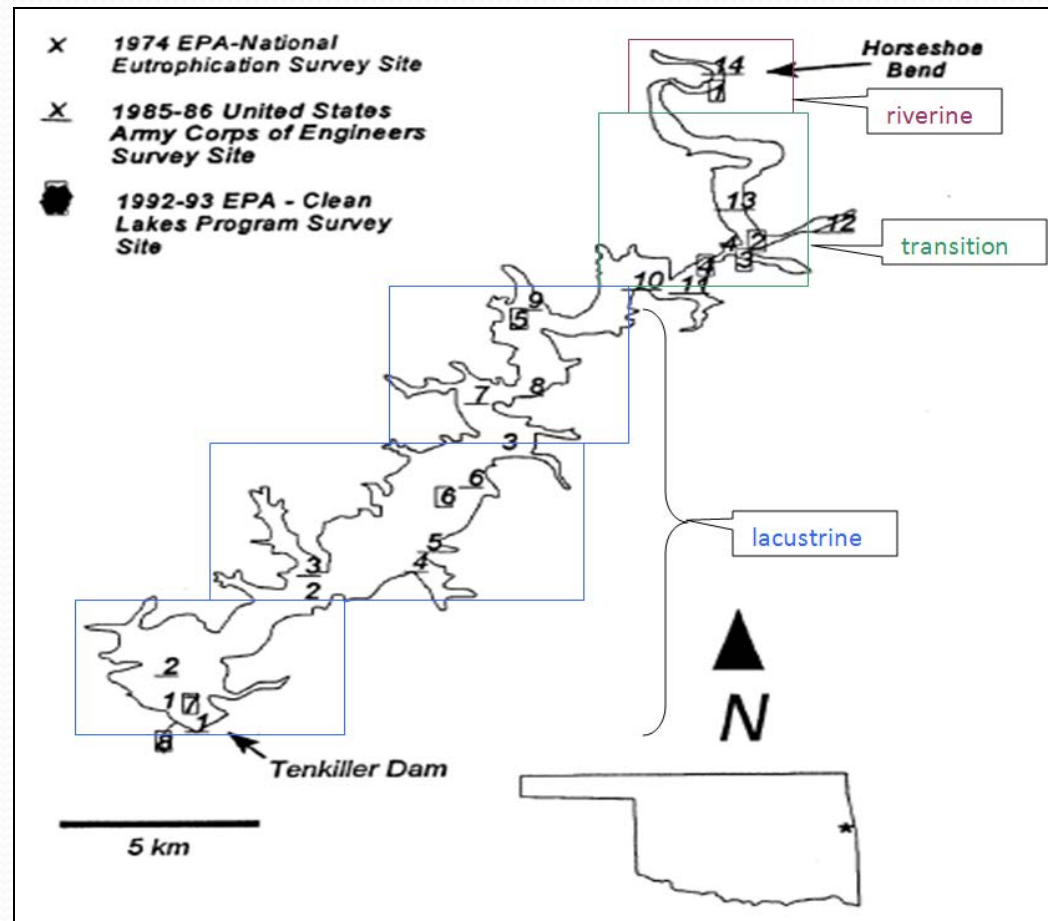
- Tenkiller Lake in eastern Oklahoma formed by the damming of the Illinois River
- On Oklahoma's 303d list as impaired for phosphorus
- Nutrient concentrations and water clarity indicate eutrophic conditions
- Example of:
 - Multiple linked segments (complex system)
 - Linkage to watershed and hydrodynamic model
 - Scenario testing

Incoming waters very rich in algae



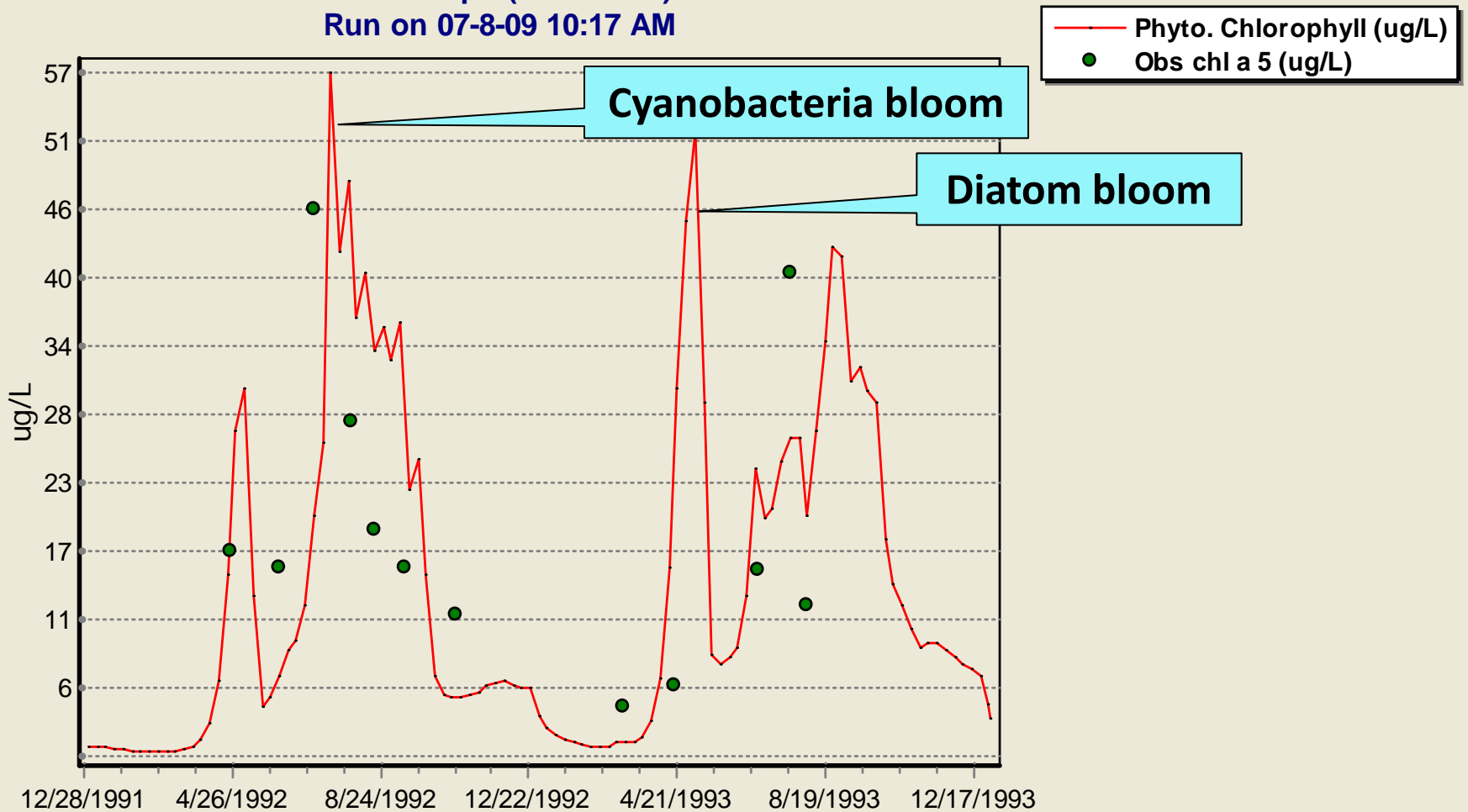
Tenkiller Lake Application

- River-reservoir system divided into nine segments
 - Riverine
 - Vertically stratified transition zone
 - Three vertically stratified lacustrine segments
- AQUATOX linked to HSPF (watershed) and EFDC (in-lake hydrology) models
- Tested scenarios to predict chlorophyll *a* levels based on different nutrient, BOD and sediment loadings (BMPs)

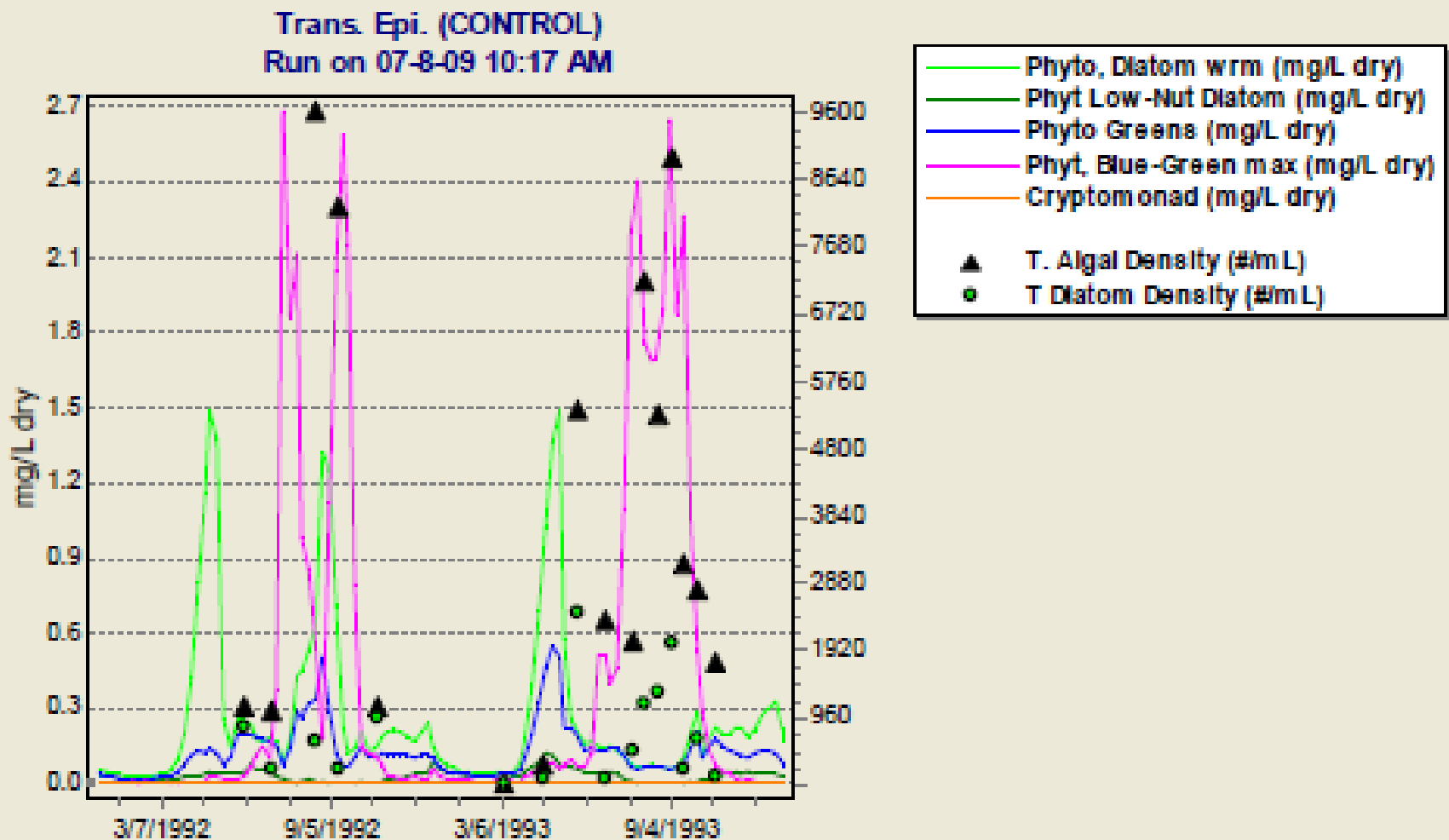


Simulated & observed chlorophyll *a*

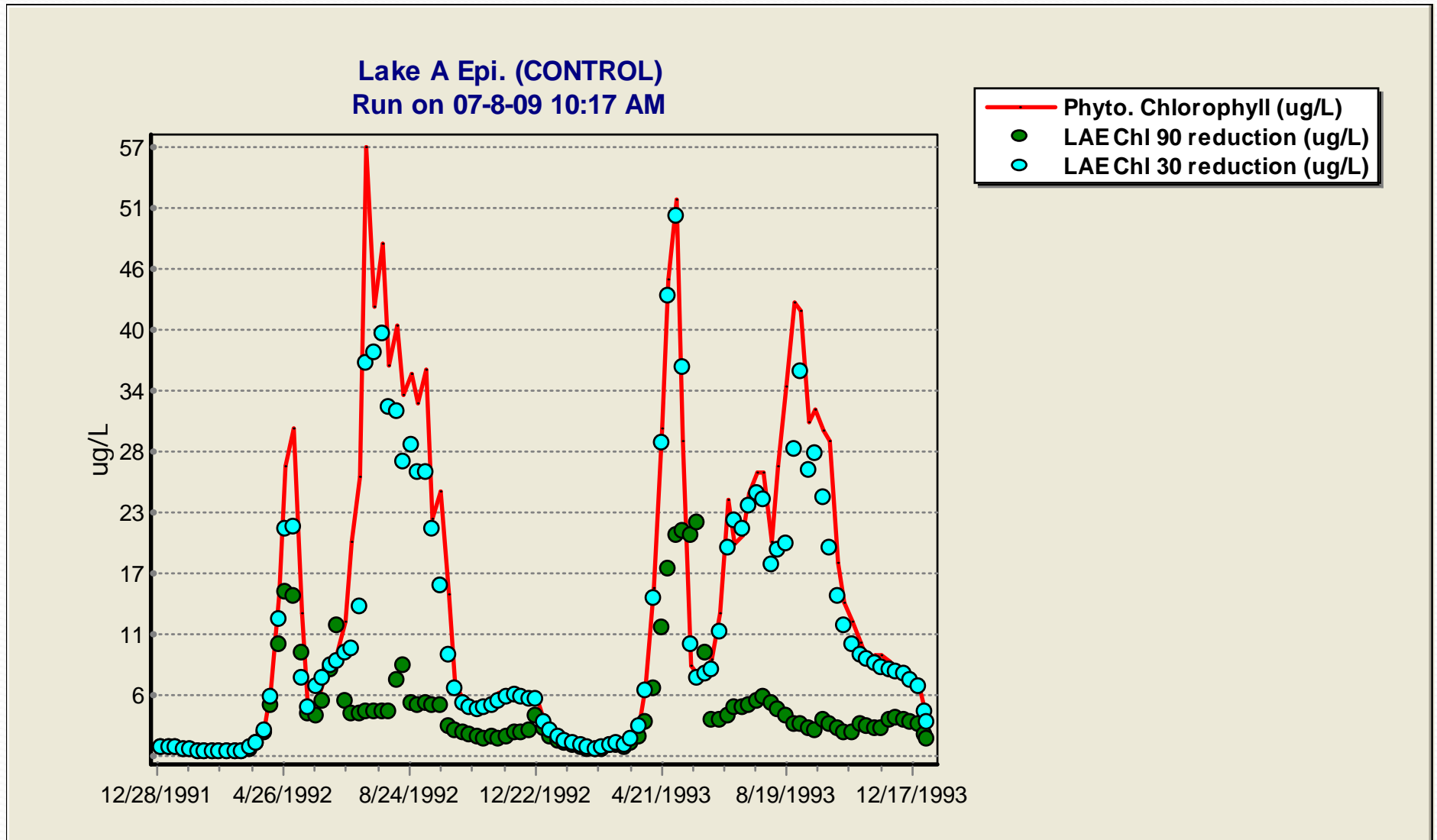
Lake A Epi. (CONTROL)
Run on 07-8-09 10:17 AM



Simulated & observed algal composition

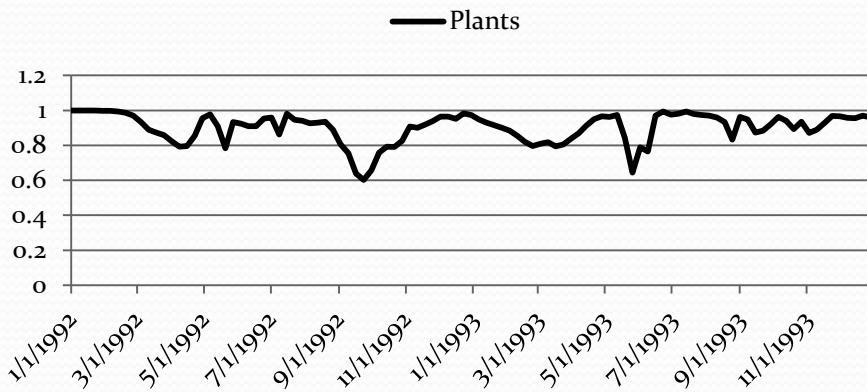


Predicted chl *a* levels under increasing load reductions of TP

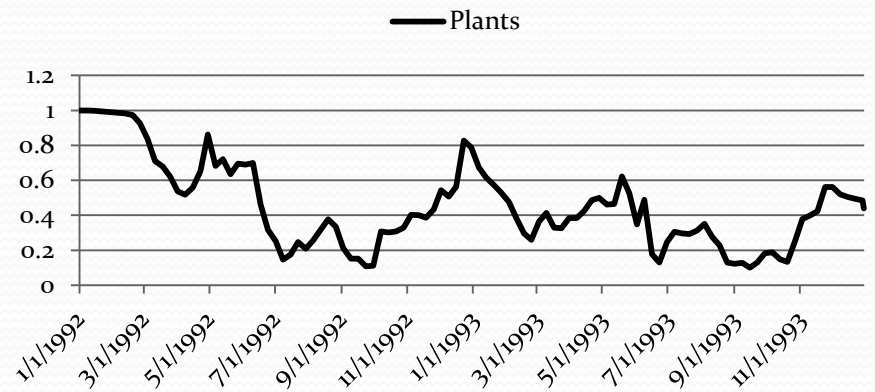


Steinhaus Similarity Index illustrates increasingly dramatic changes in algal community

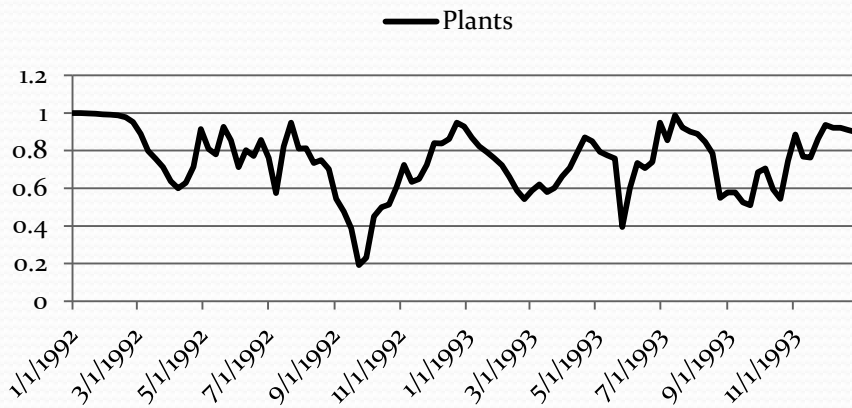
Baseline vs 30% TP reduction



Baseline vs 90% TP Reductions

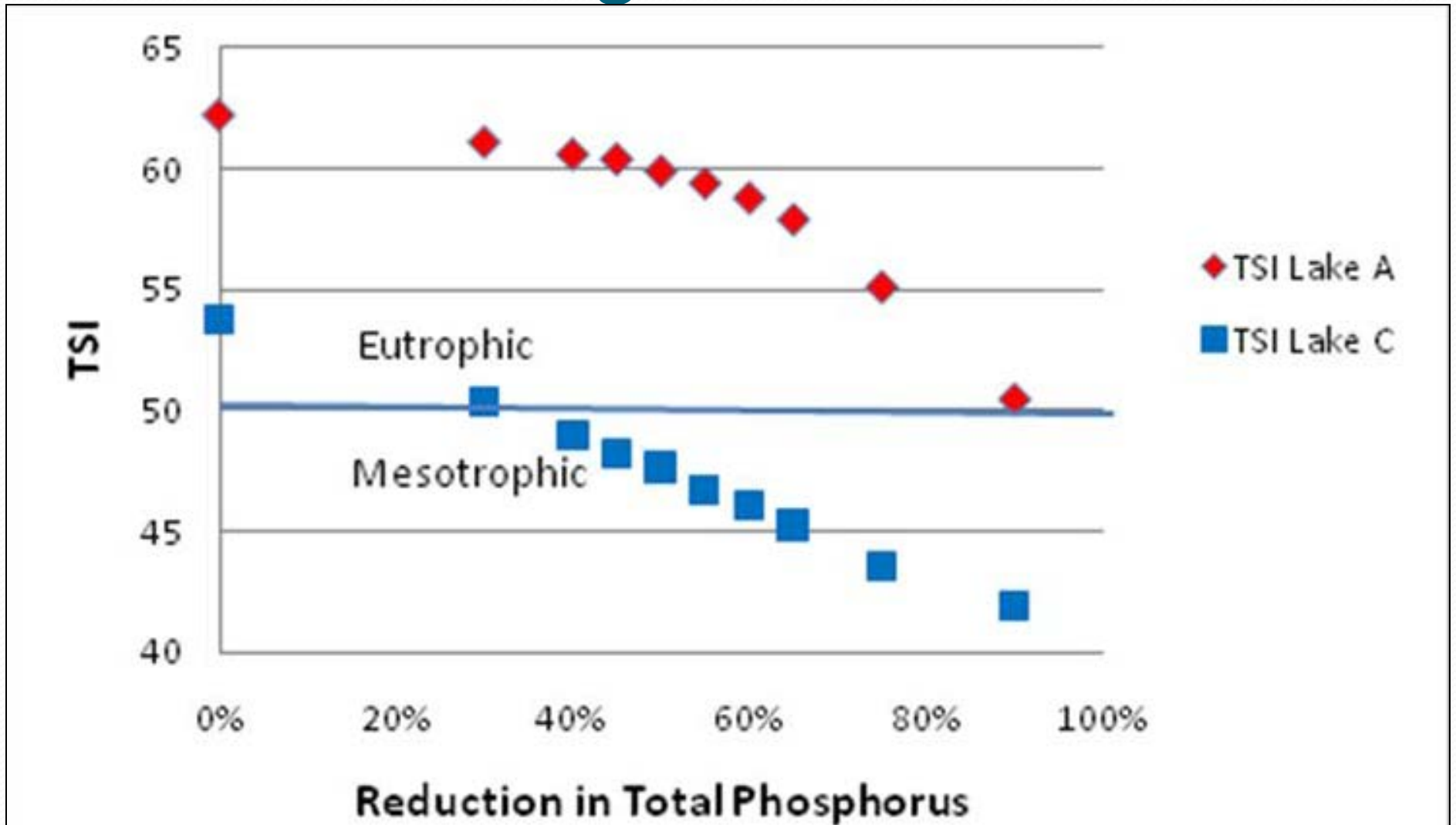


Baseline vs 60% TP Reduction



30% reduction in TP has relatively minor effect on the composition of the algal community

Trophic State Indices show differences between lake segments

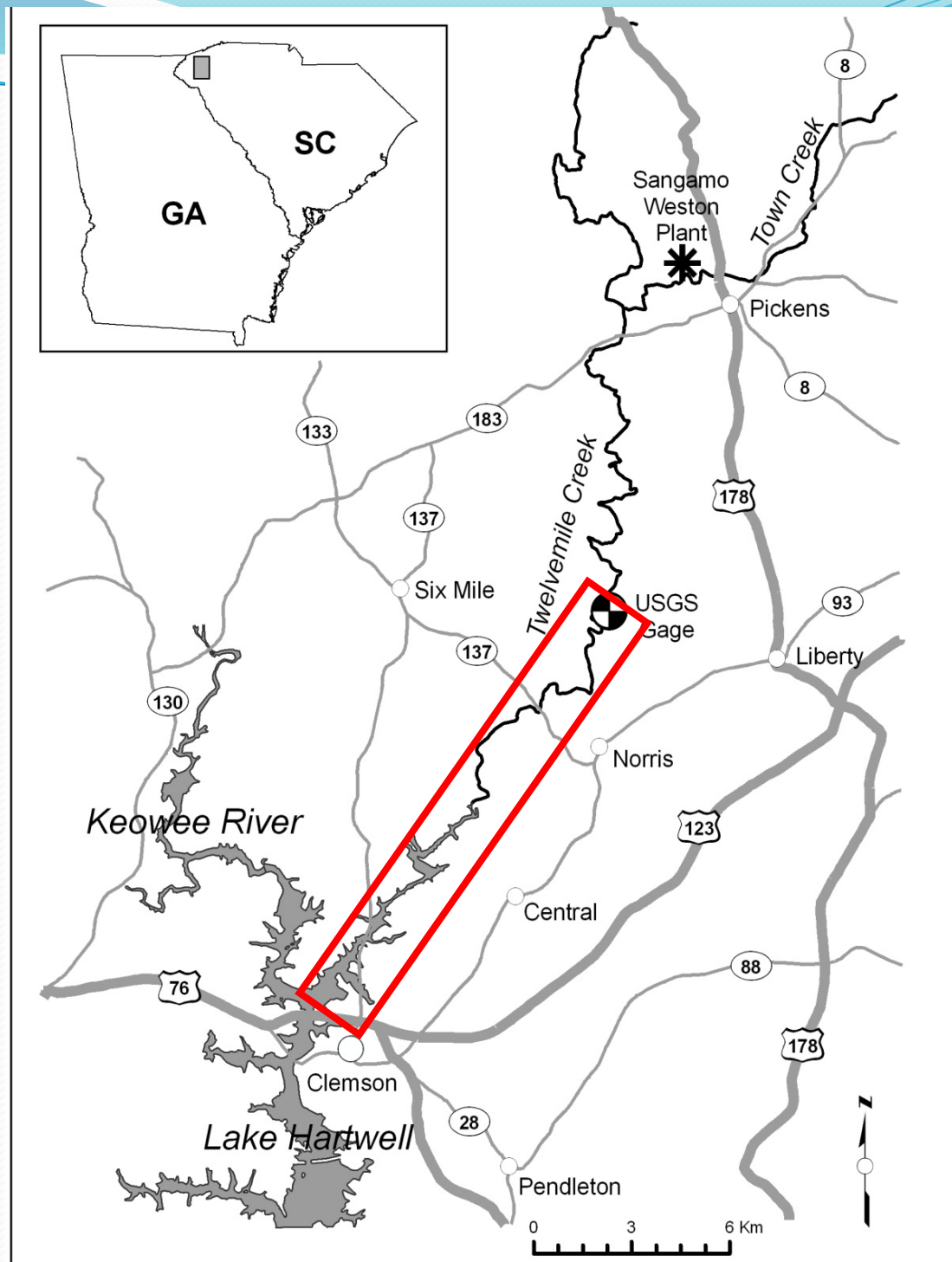


Ecosystem Modeling for PCBs in Lake Hartwell



Study Site

- Sangamo-Weston Superfund Site discharged 400,000 lbs of PCBs in creek from 1955-1990s
- Creek/lake treated via Monitored Natural Recovery
- PCBs have declined since 1995 in lake sediment but not in all fishes (5-10ppm)



(modified) **AQUATOX: Study Information**
 EPA Release 3.1

Study Name:

Model Run Status:
 Perturbed Run: 03-18-13 1:04 PM
 Control Run: 03-18-13 10:55 AM

Data Operations:

- Initial Conds.
- Chemical
- Site
- Setup
- Notes
- Birds, Mink...
- Food Web

Program Operations:

- Perturbed
- Control
- Output
- Export Results
- Export Control
- Use Wizard
- Help

Model is set up to run in sensitivity mode.

State and Driving Variables In Study

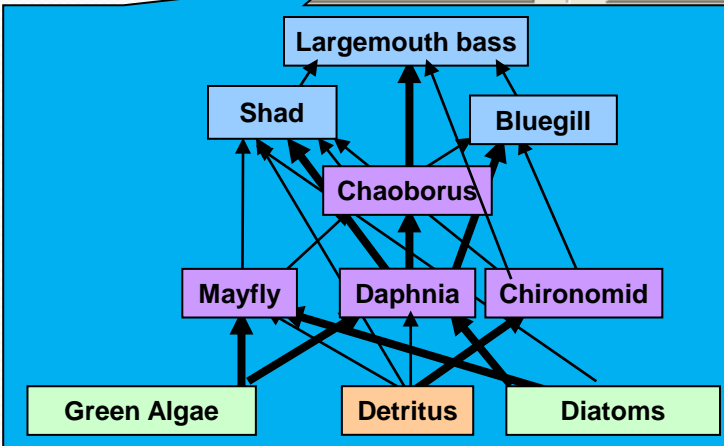
- Dissolved org. tox 1: [PCB Hartwell]
- Total Ammonia as N
- Nitrate as N
- Total Soluble P
- Carbon dioxide
- Oxygen
- Tot. Susp. Solids
- Refrac. sed. detritus
- Labile sed. detritus
- Susp. and dissolved detritus
- Buried refrac. detritus
- Buried labile detritus
- Diatoms1: [Diatoms]
- Greens1: [Greens]
- SedFeeder1: [Chironomid]
- SuspFeeder1: [Daphnia]
- Grazer1: [Isonychia]
- PredInv1: [Chaoborus]
- LgForageFish1: [Shad_BR]
- LgGameFish1: [Largemouth Bass, Lg]
- LqGameFish2: [Bluegill BR]
- Water Volume
- Temperature
- Wind Loading
- Light
- pH

Based on data

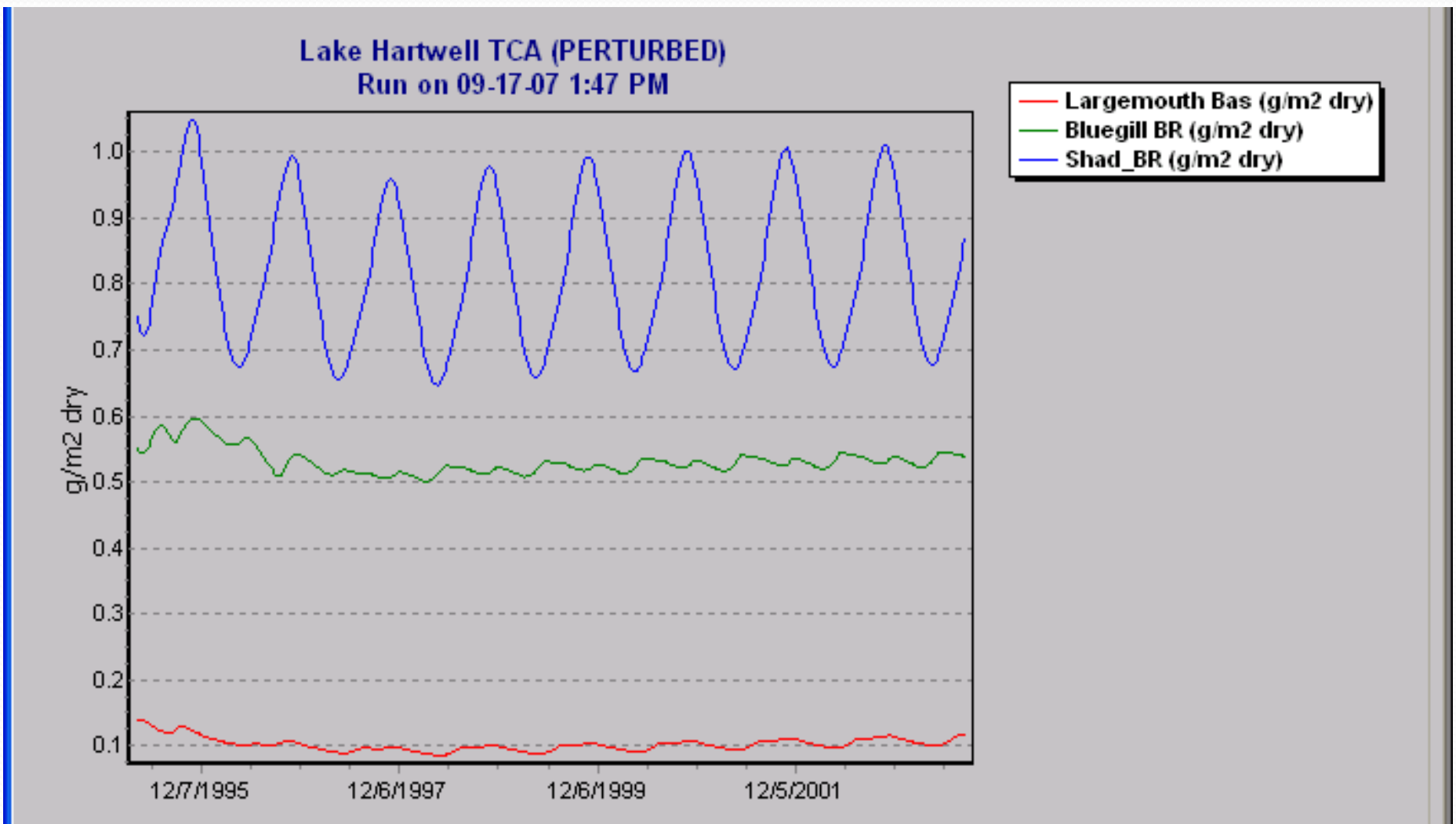
N, P, oxygen, TSS
(EPA STORET)

Algae
Invertebrates
Fish

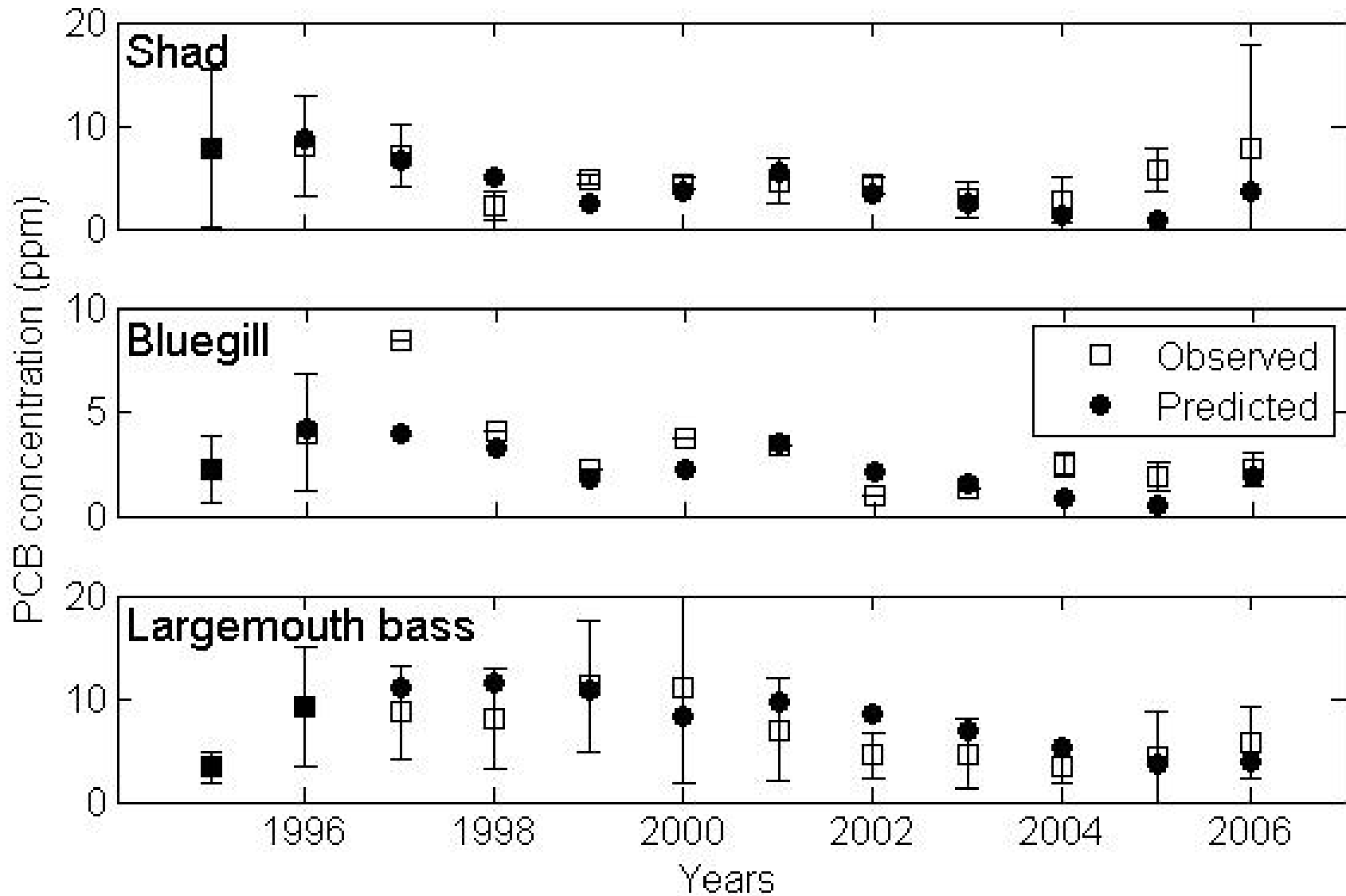
Flow (USGS gage)
Climate (NOAA)



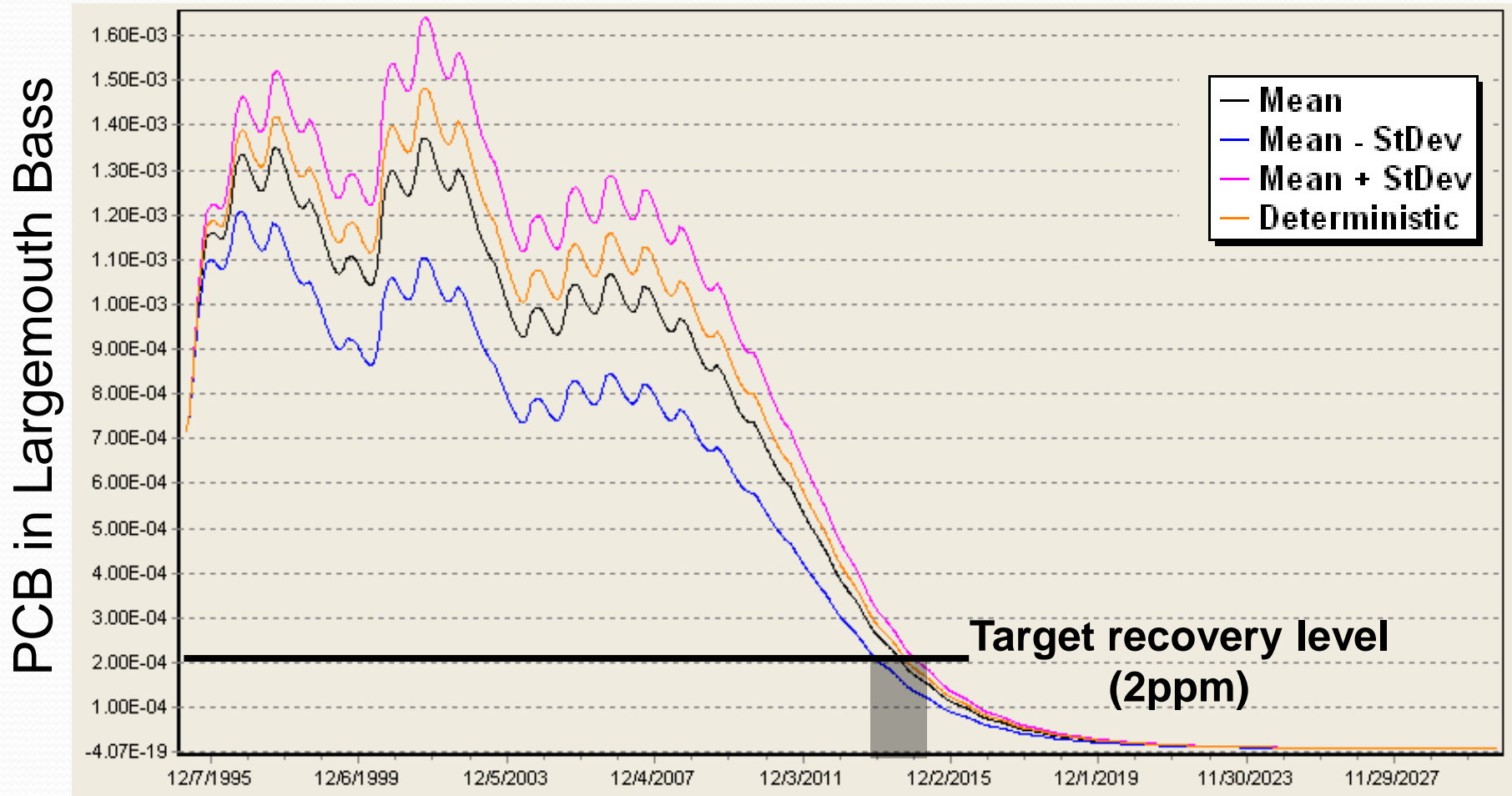
Predicted fish biomass is calibrated to observed values



Predicted PCB in fish is similar to observed

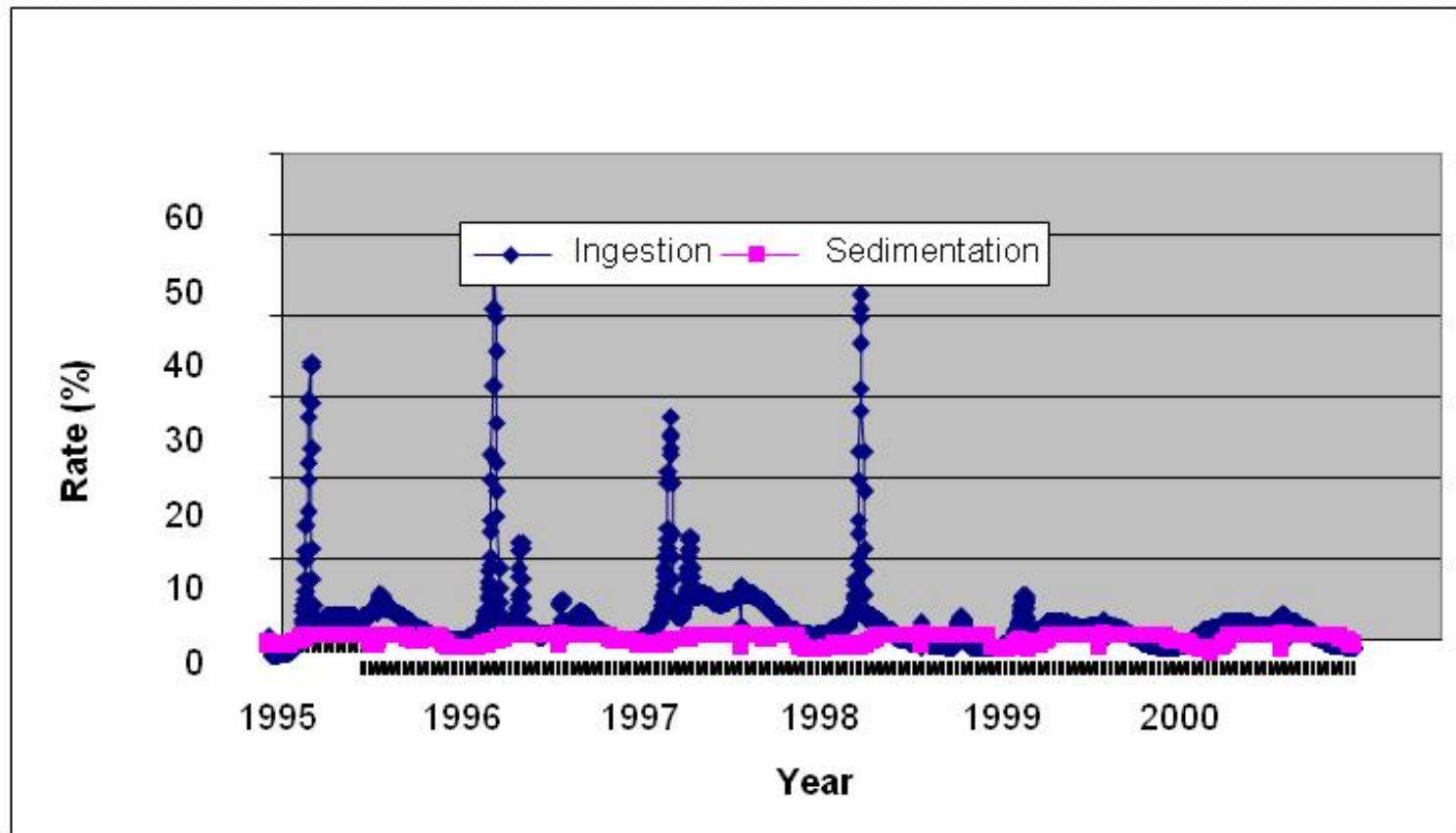


Future Prediction with Uncertainty



Fate of Input Detritus

- Ingested (14%) > Sedimented (4%)



Results

When will fish recover?

✓ Summer/Fall 2013

Why are fish still contaminated while sediment is recovering?

✓ Due to contaminated input detritus



Sensitivity of PCB Concentration in Fish to 10% ↑ Temperature



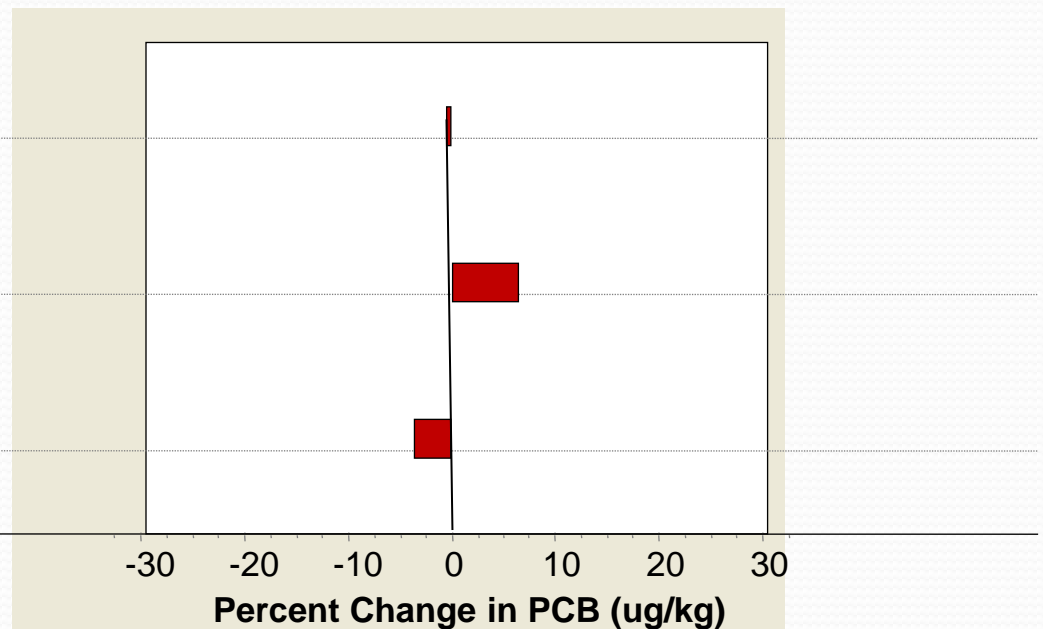
Largemouth Bass



Shad



Bluegill



Wrap-up and Model Future

User Support

- Technical support materials on web site
<http://water.epa.gov/scitech/datait/models/aquatox/index.cfm>
 - Technical notes
 - Data sources
 - Workshop materials
 - Annotated bibliography (*newly updated*)
 - Sensitivity analysis report (*new*)
 - Set up guide (*in draft*)
- AQUATOX listserver (>350 subscribers)
- One-on-one technical support available (subject to future funding)

Applicability to Sustainable and Healthy Communities Research Program

- *Contaminated sites*
- *Nitrogen plus climate change*
- *Ecosystem Services*
 - *Food and Recreation*
 - *Biodiversity and Wildlife habitat*
 - *Aesthetic*



Thanks For Your Attention

- Marjorie Coombs Wellman, Office of Water, US EPA, wellman.marjorie@epa.gov
- Brenda Rashleigh, Office of Research and Development, US EPA, rashleigh.brenda@epa.gov
- <http://water.epa.gov/scitech/datait/models/aquatox/index.cfm>