AQUATOX: Linking Water Quality with Aquatic Life

February 11, 2014

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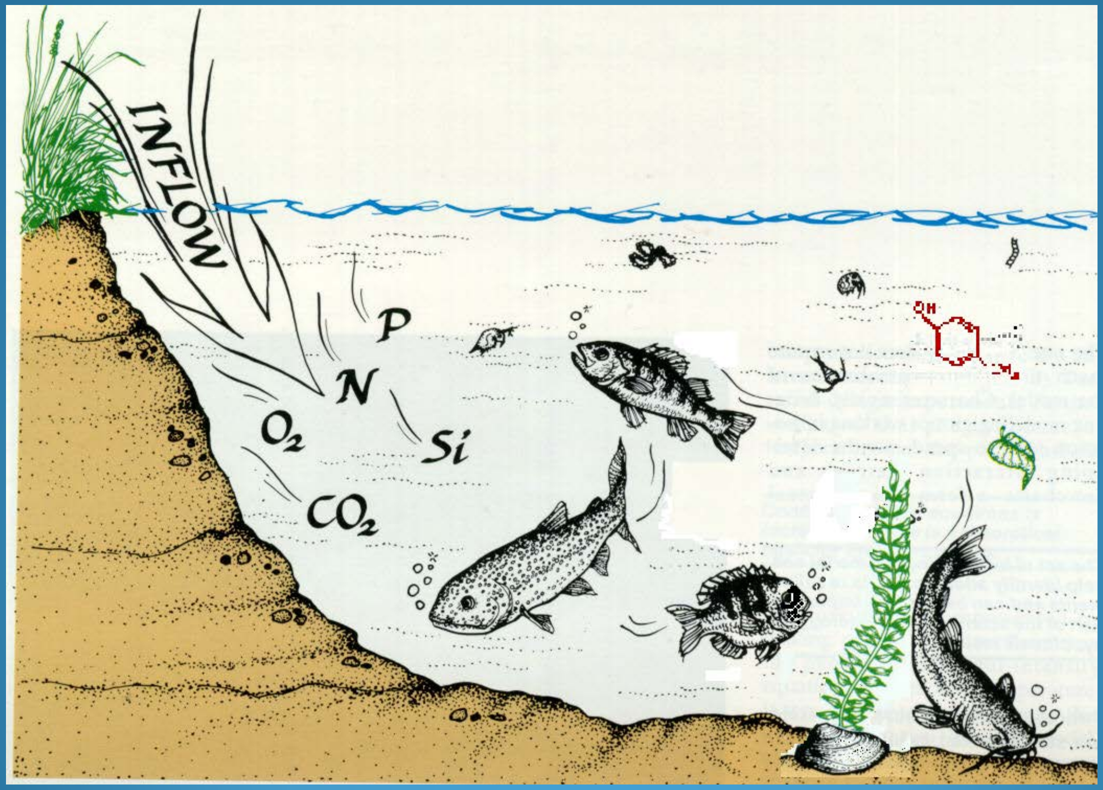


Outline

- 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

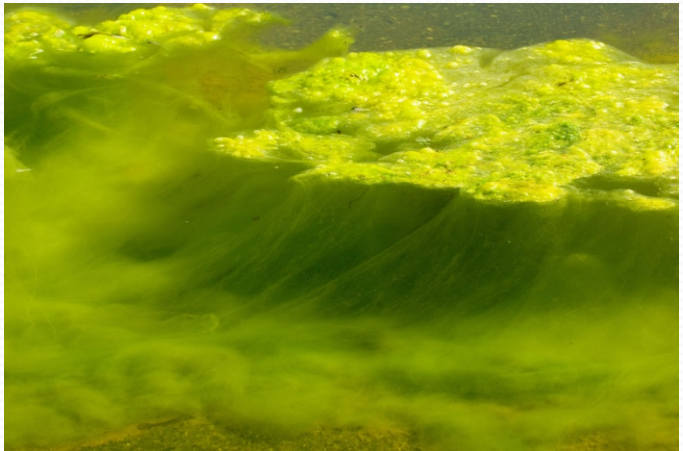
Acknowledgements

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

Introduction to AQUATOX

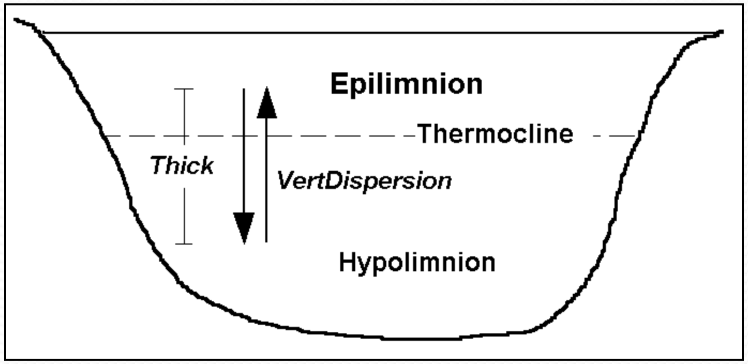
What is AQUATOX?

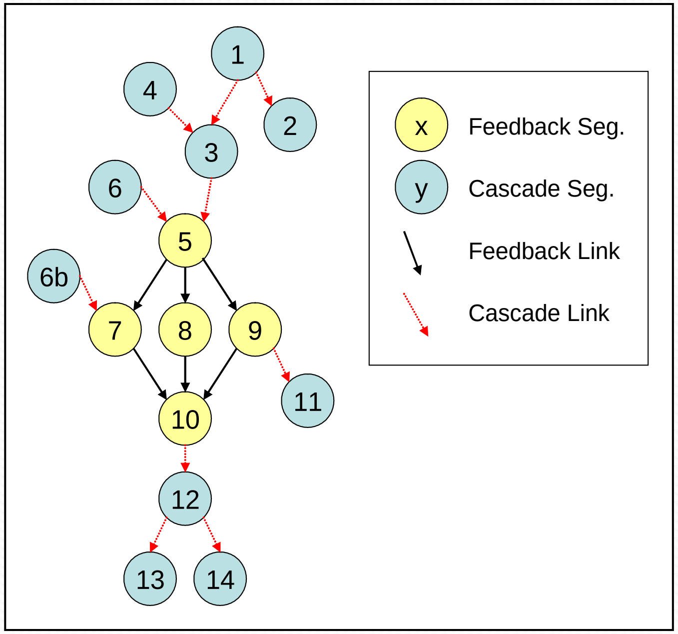
- Mechanistic simulation model for aquatic ecosystems
  - Streams, rivers, lakes, reservoirs, estuaries
- Fate and effects of multiple stressors
  - Nutrients
  - Organic toxicants
  - Suspended and bedded sediments
  - Flow
  - Temperature



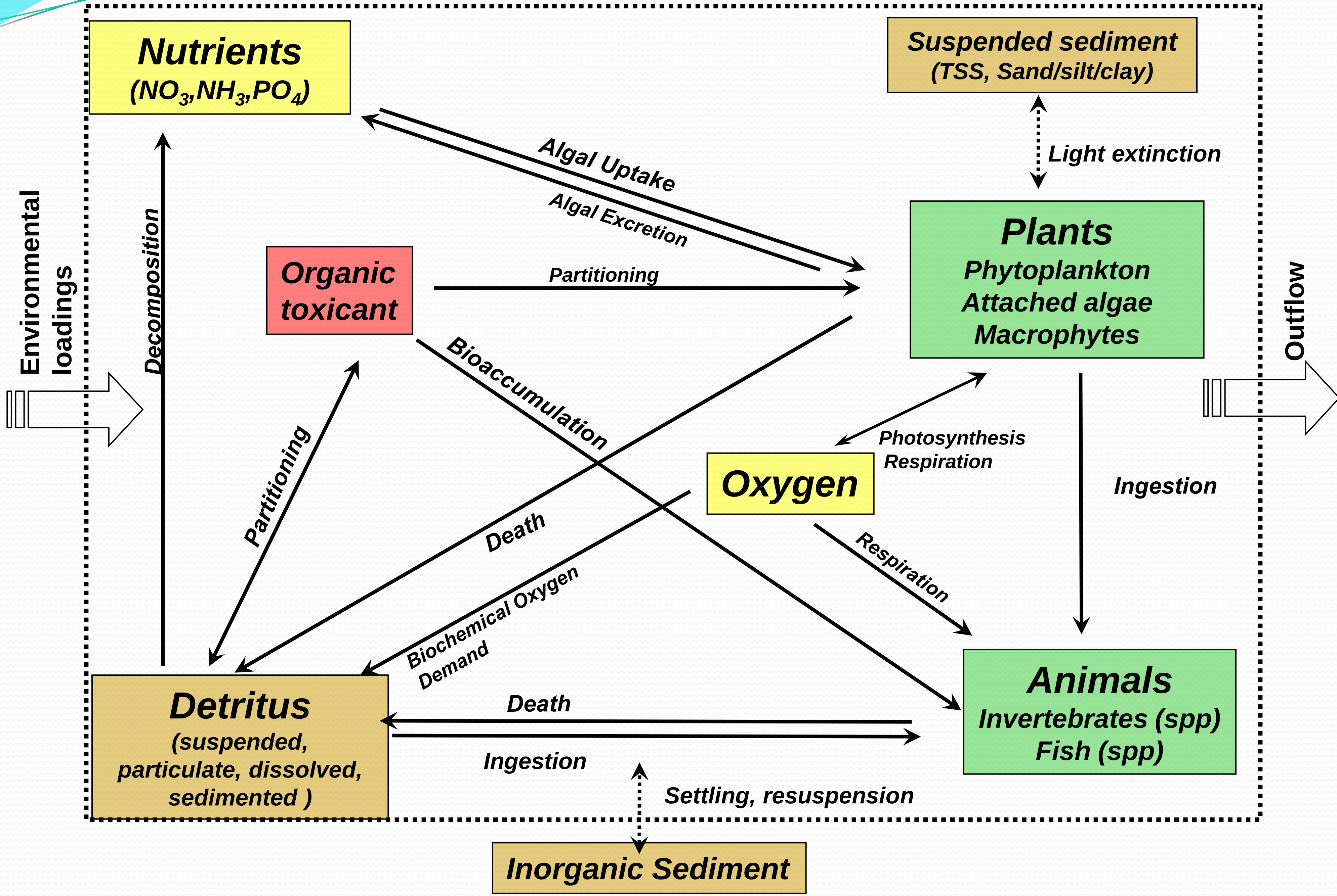
AQUATOX Structure

- 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

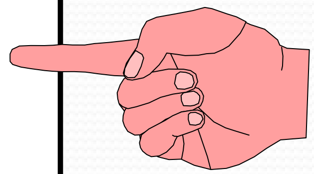


AQUATOX Inputs

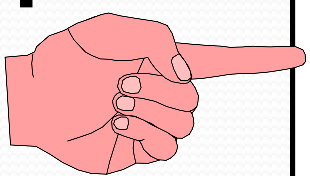
- Site characteristics
- Biological characteristics
- Chemical characteristics

default or user-supplied

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



AQUATOX Outputs



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

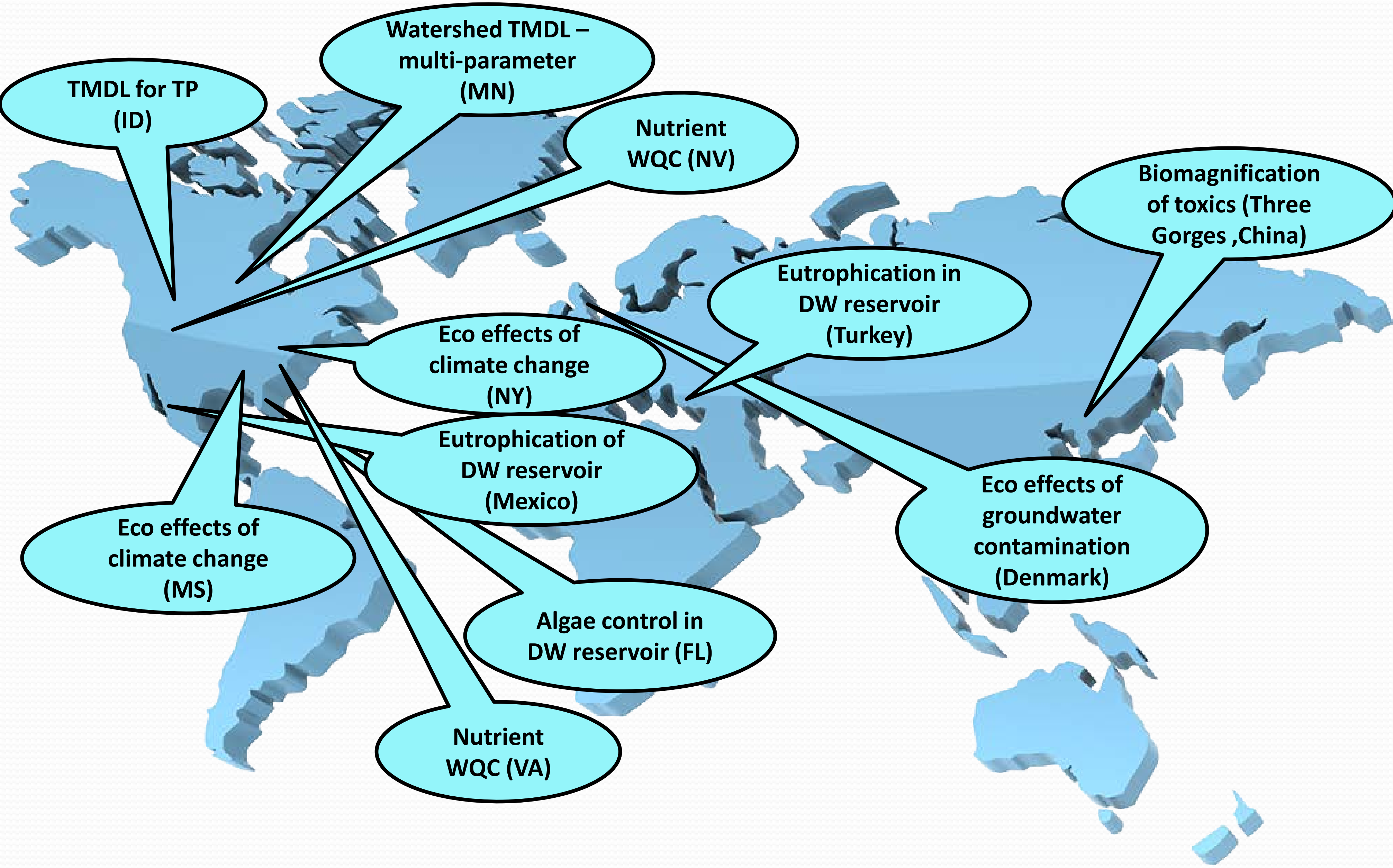
Why AQUATOX?

- 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?

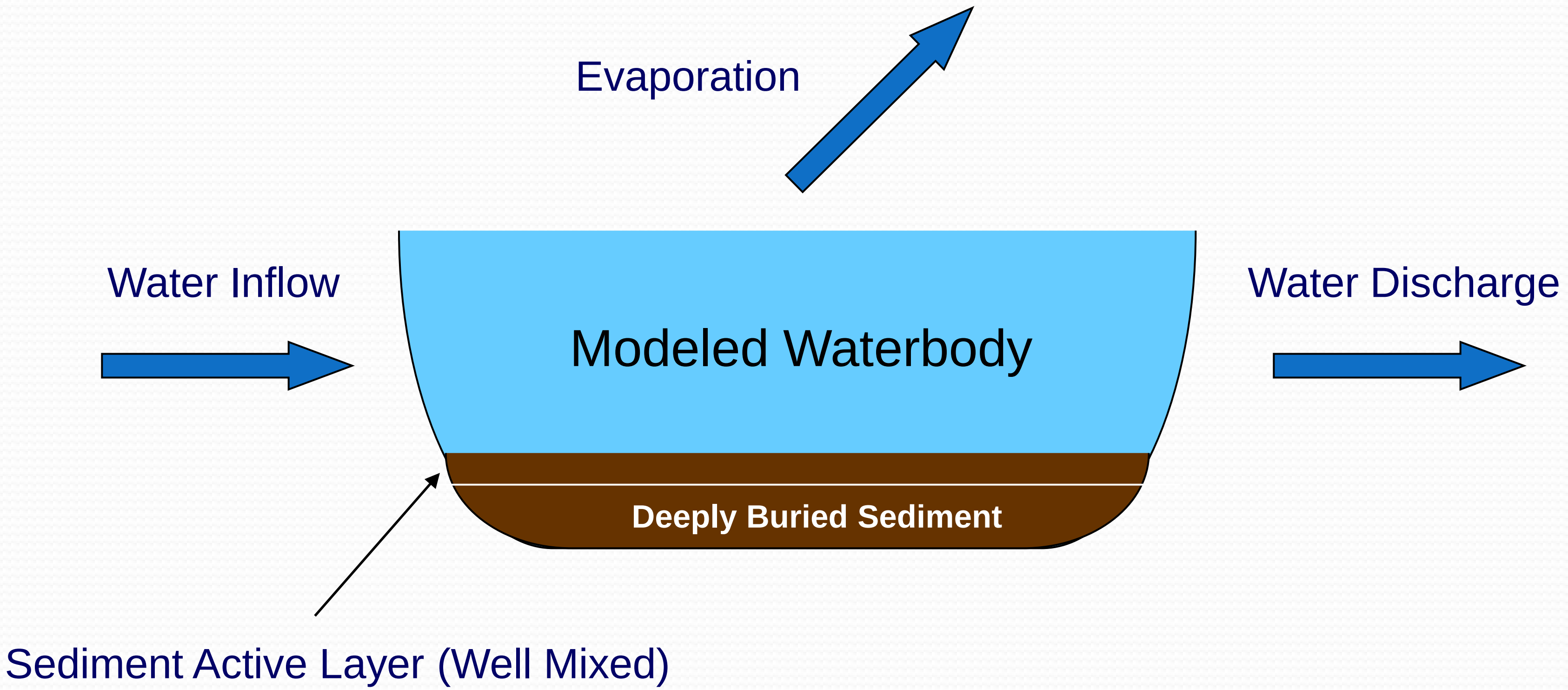
Worldwide applications



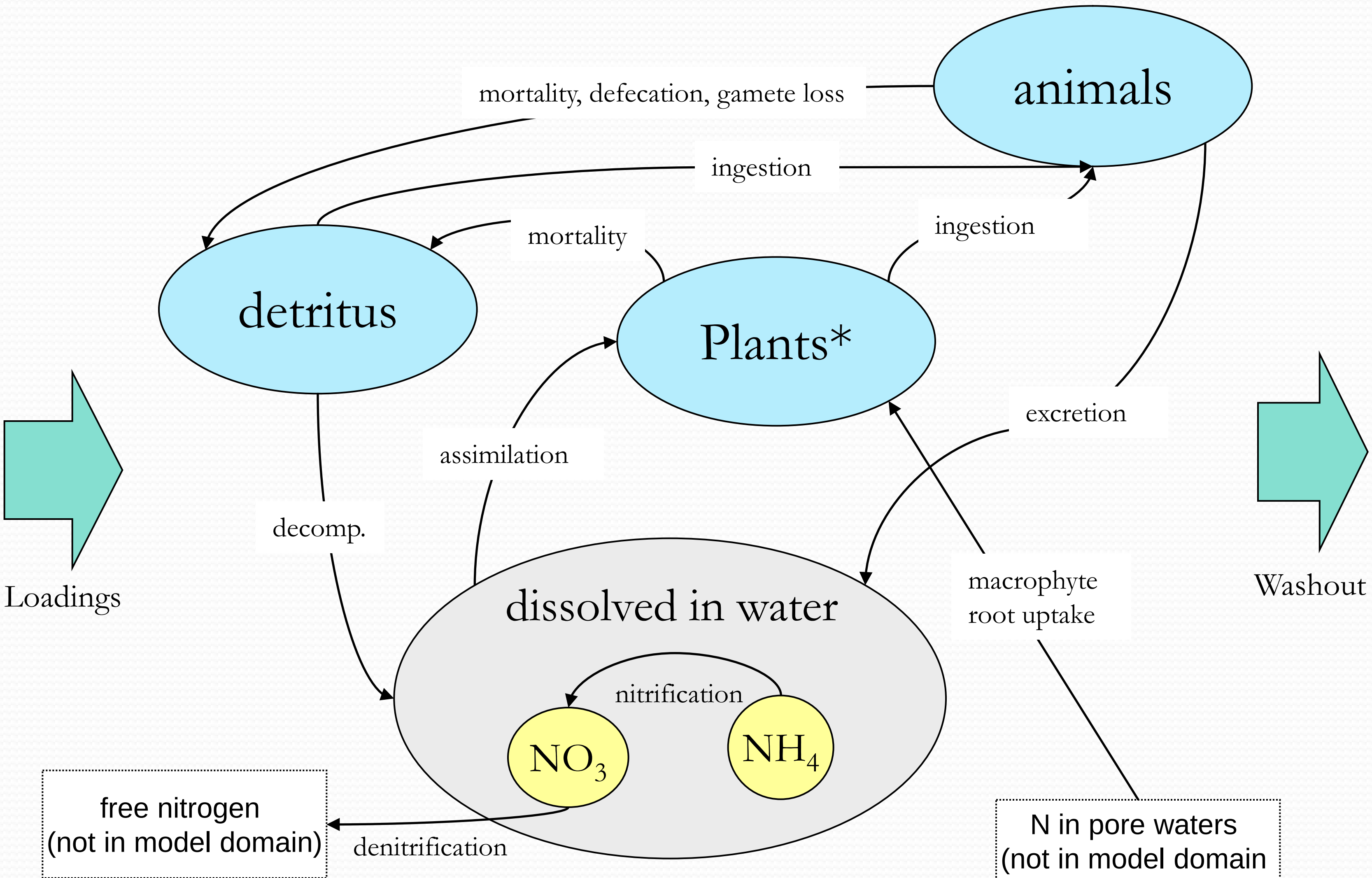
Physics and Chemistry in AQUATOX

Physical Characteristics of a Site

Water Balance and Sediment Structure



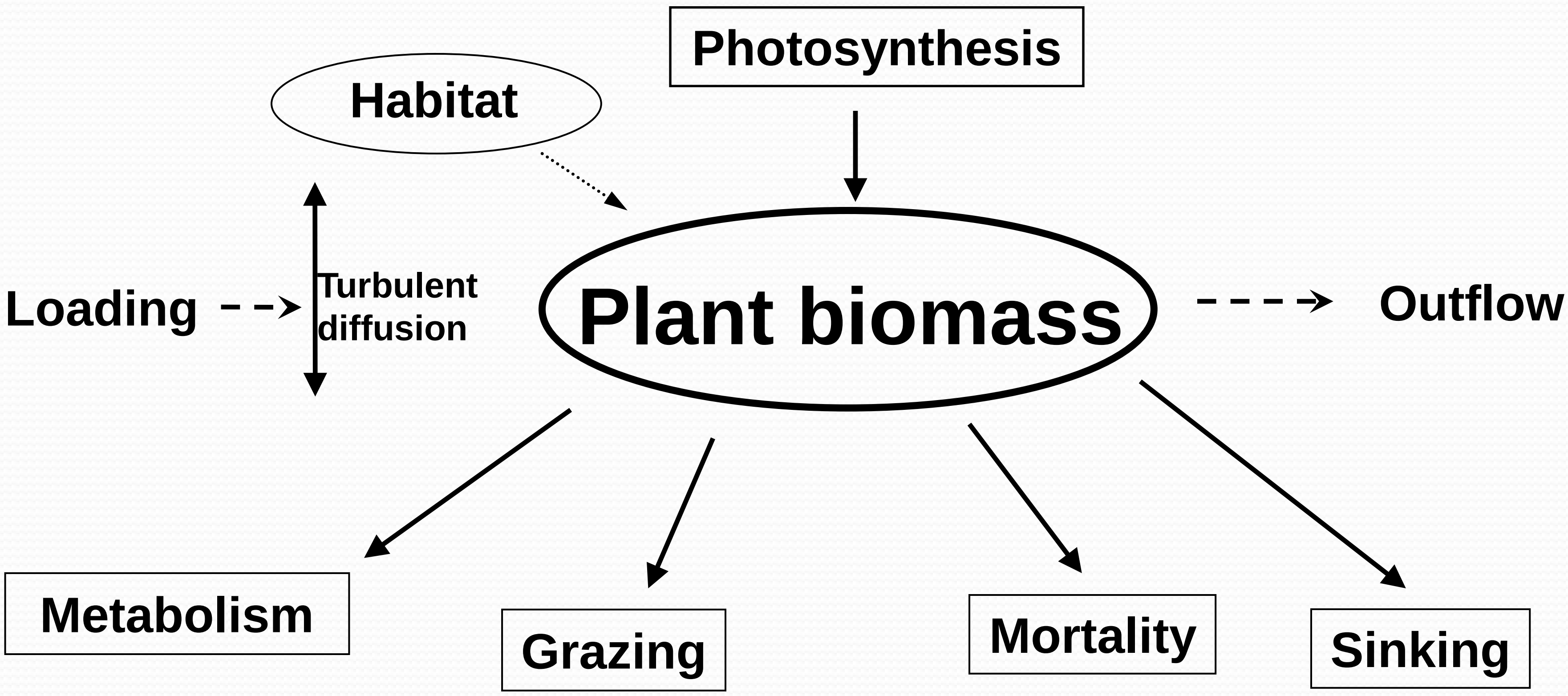
Nitrogen Cycle in AQUATOX



* : includes nitrogen fixation by cyanobacteria

Biology in AQUATOX

How AQUATOX Models Plants

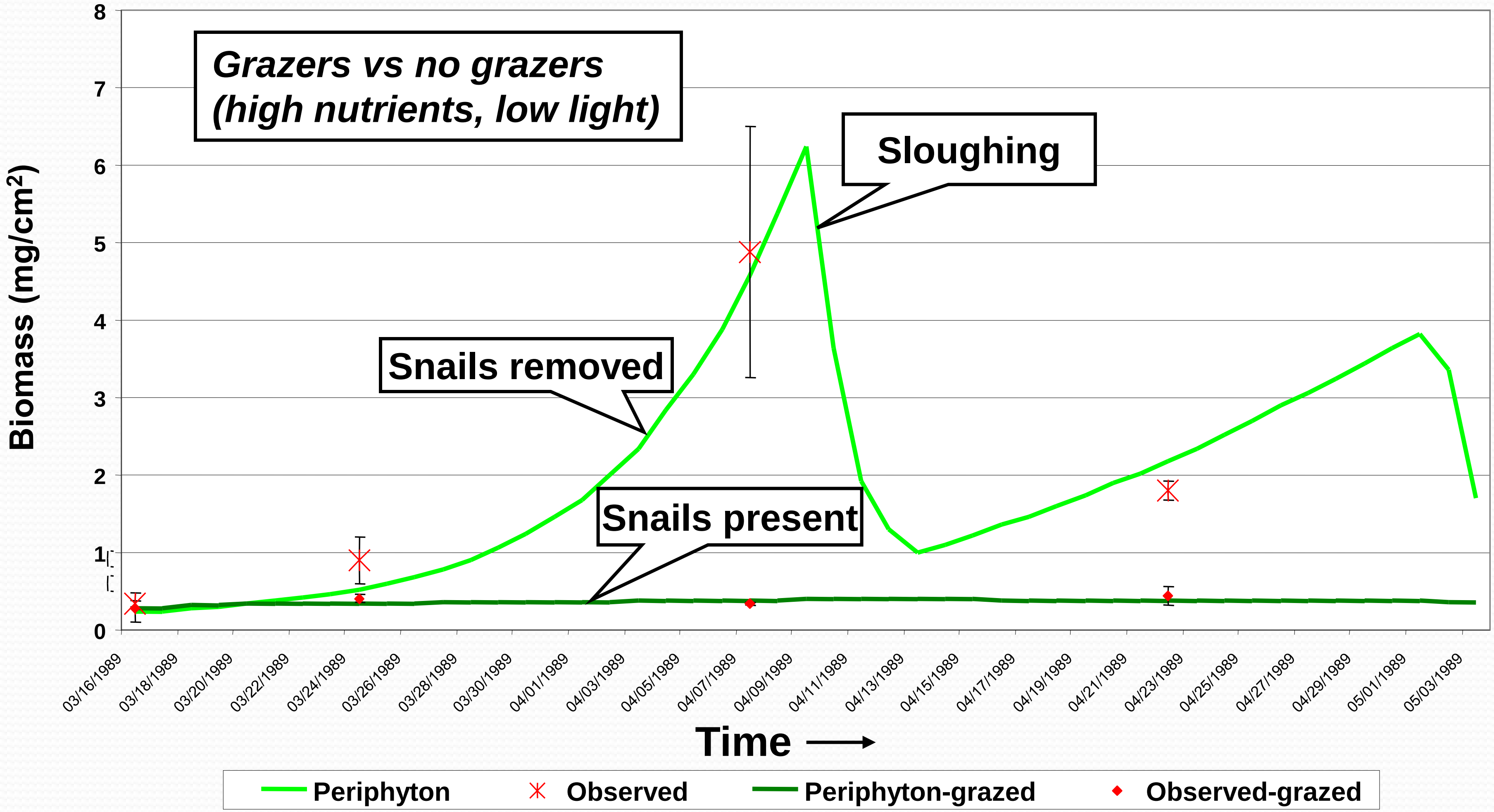


Multiple plant groups

- 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

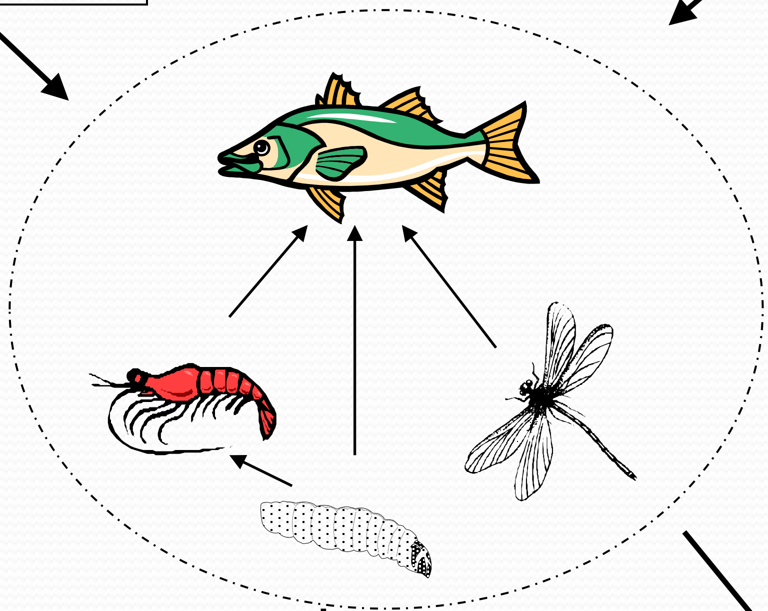


Modeling Animals in AQUATOX

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

Foodweb Model specified as Trophic Matrix

AQUATOX-- Trophic Interaction Matrix

Preference percentages are initially normalized to 100% based on species in the simulation. Renormalize

Show Preferences Show Egestion Coefficients Show Comments

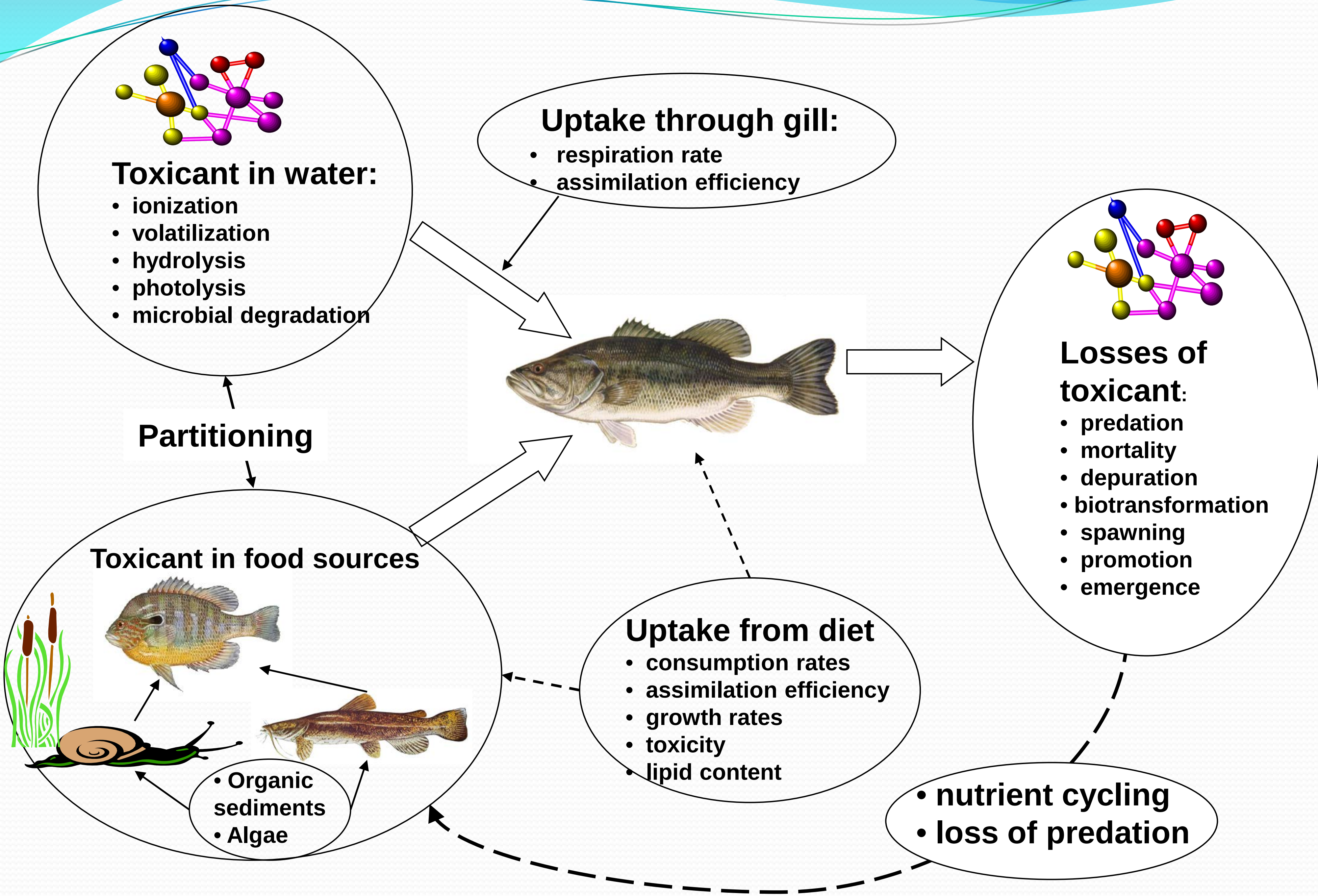
	Tubifex tubi	Daphnia	Rotifer, Brac	Predatory Z	Shad	Bluegill	White Perch	Catfish	Largemouth	Largemouth	Walleye
R detr sed	50.0							1.2			
L detr sed	50.0							4.7			
R detr part					12.5				2.1		
L detr part		30.0	40.0		12.5	3.9	0.5		2.1		
Cyclotella nan		35.0	5.0		12.5						
Greens		30.0	5.0		12.5						
Phyt, Blue-Gre					12.5						
Cryptomonad		5.0	50.0								
Tubifex tubife						9.5	29.8	46.5	40.4	0.3	1.0
Daphnia				50.0	12.5	15.7	29.9	2.9	27.7	0.3	
Rotifer, Brach				50.0	12.4	15.7					
Predatory Zoop					12.5	7.9	29.9	2.9	27.7	38.2	1.6
Shad						15.8		20.9		44.3	23.1
Bluegill										2.9	
White Perch						15.7	10.0	20.9		10.1	24.8
Catfish											24.8
Largemouth Bas						15.7					24.8
Largemouth Ba2											
Walleye										3.9	

Fate and Effects of Chemicals in AQUATOX

Modeling Toxicity

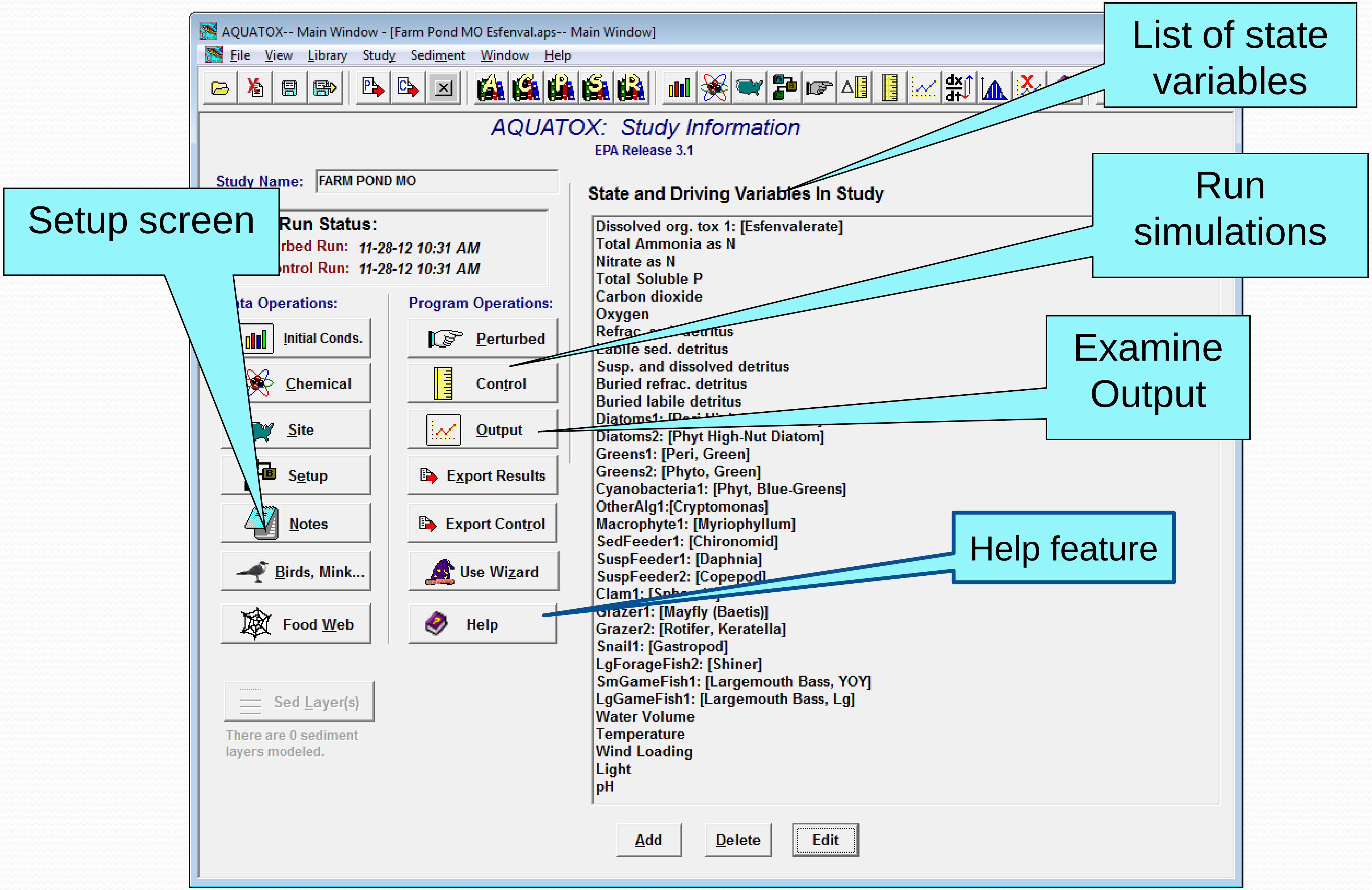
- Organic toxicants
- ≤ 20 chemicals simultaneously
- Lethal and sublethal effects
- Acute and chronic toxicity
- Effects based on total internal concentrations
- Option to model external toxicity
  - Useful if uptake and depuration are very fast (as with herbicides)
- Ecological effects – direct and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

Fate and Bioaccumulation in AQUATOX

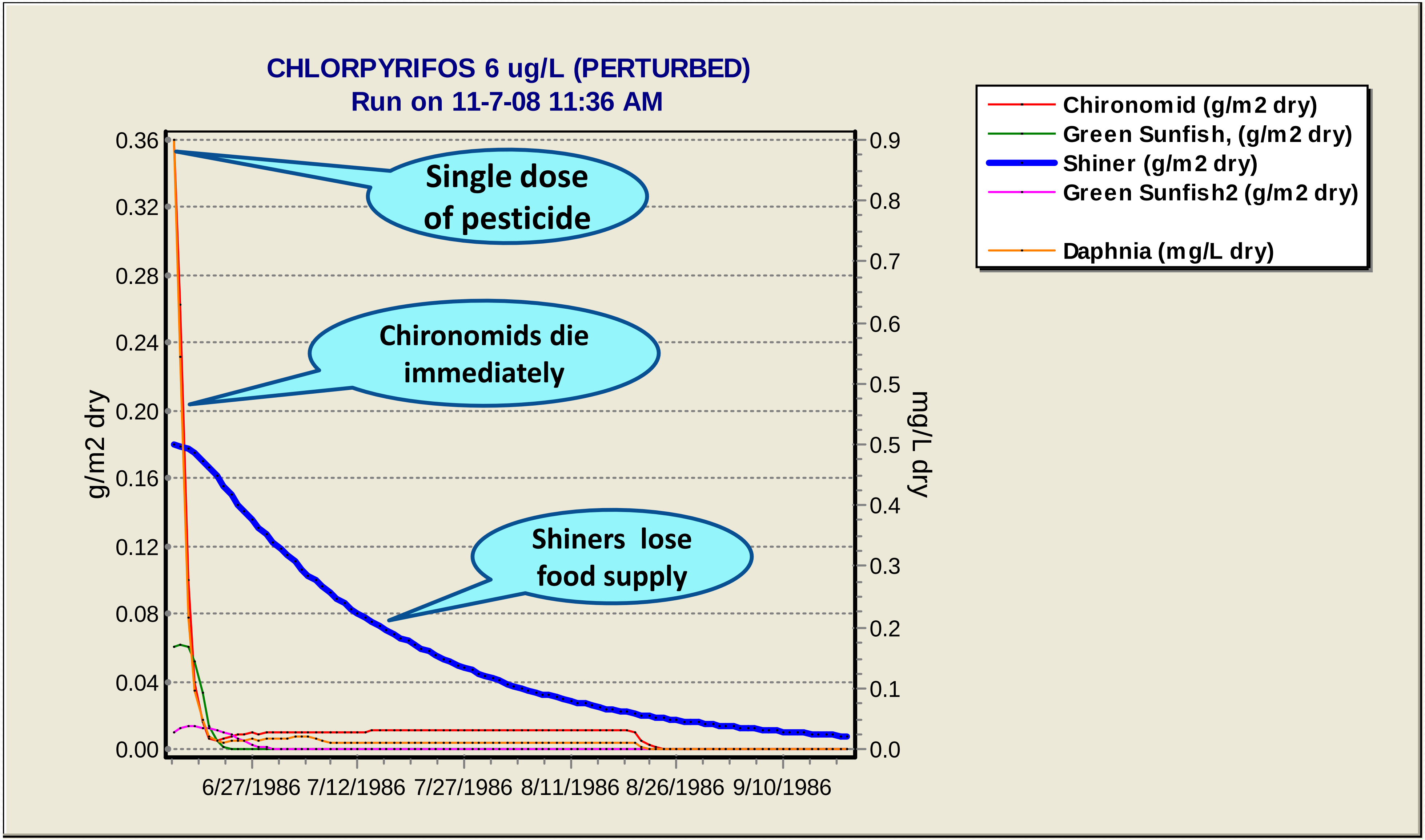


AQUATOX Interface and Output

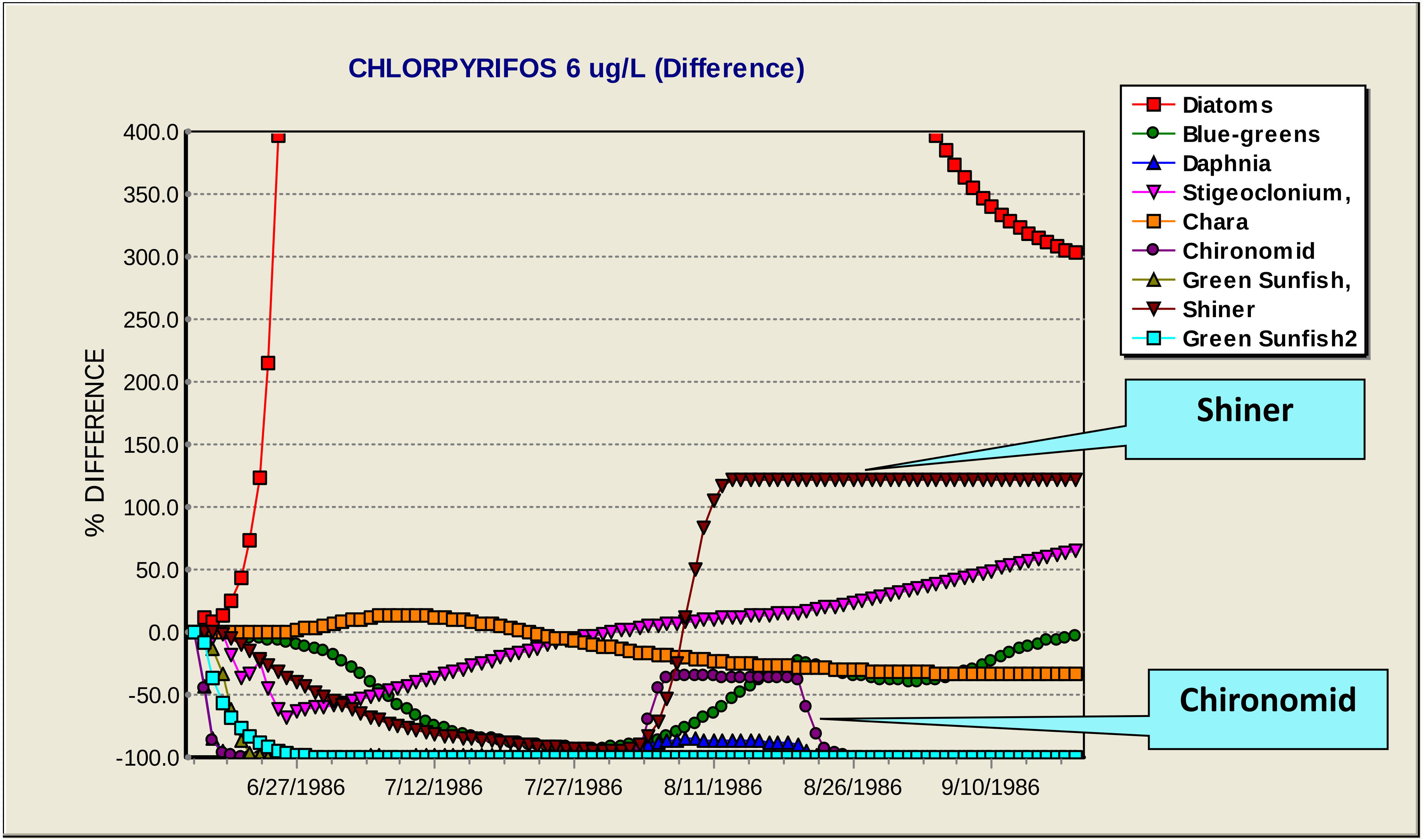
AQUATOX Interface: Main Screen



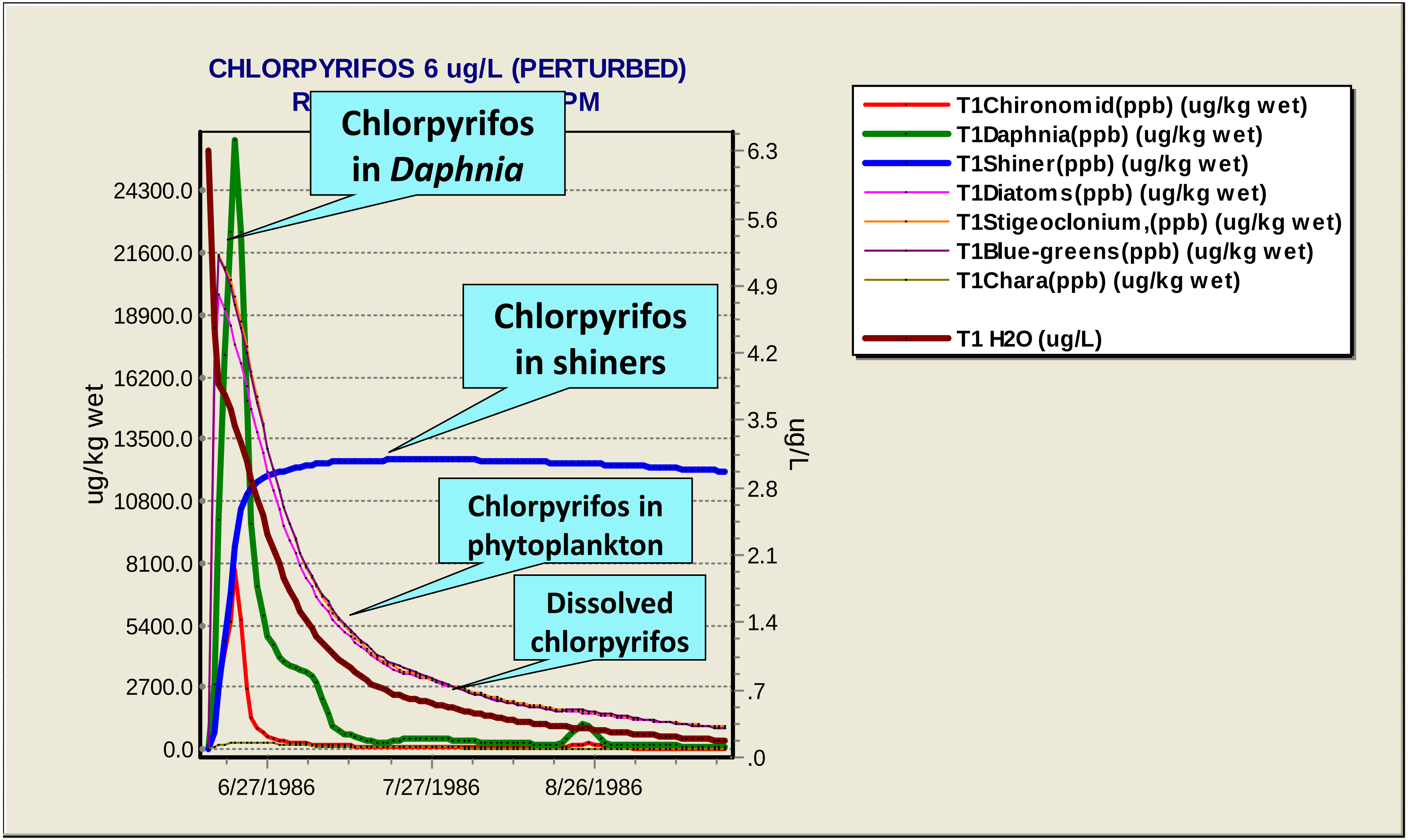
Output: Animals decline at different rates following single dose of chlorpyrifos



% Difference Graph shows relative differences



Track concentrations in tissues and water



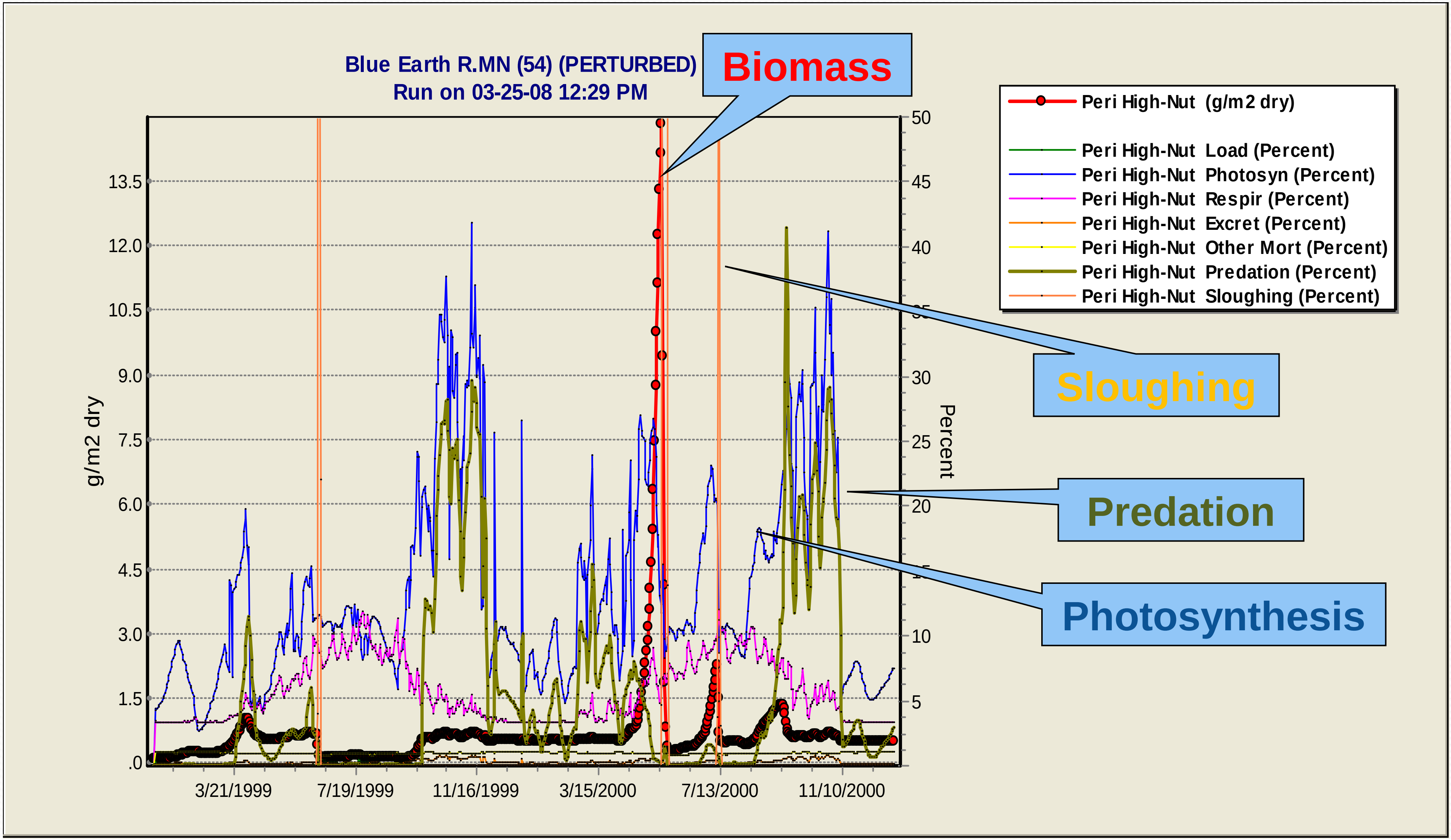
Process Rates

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

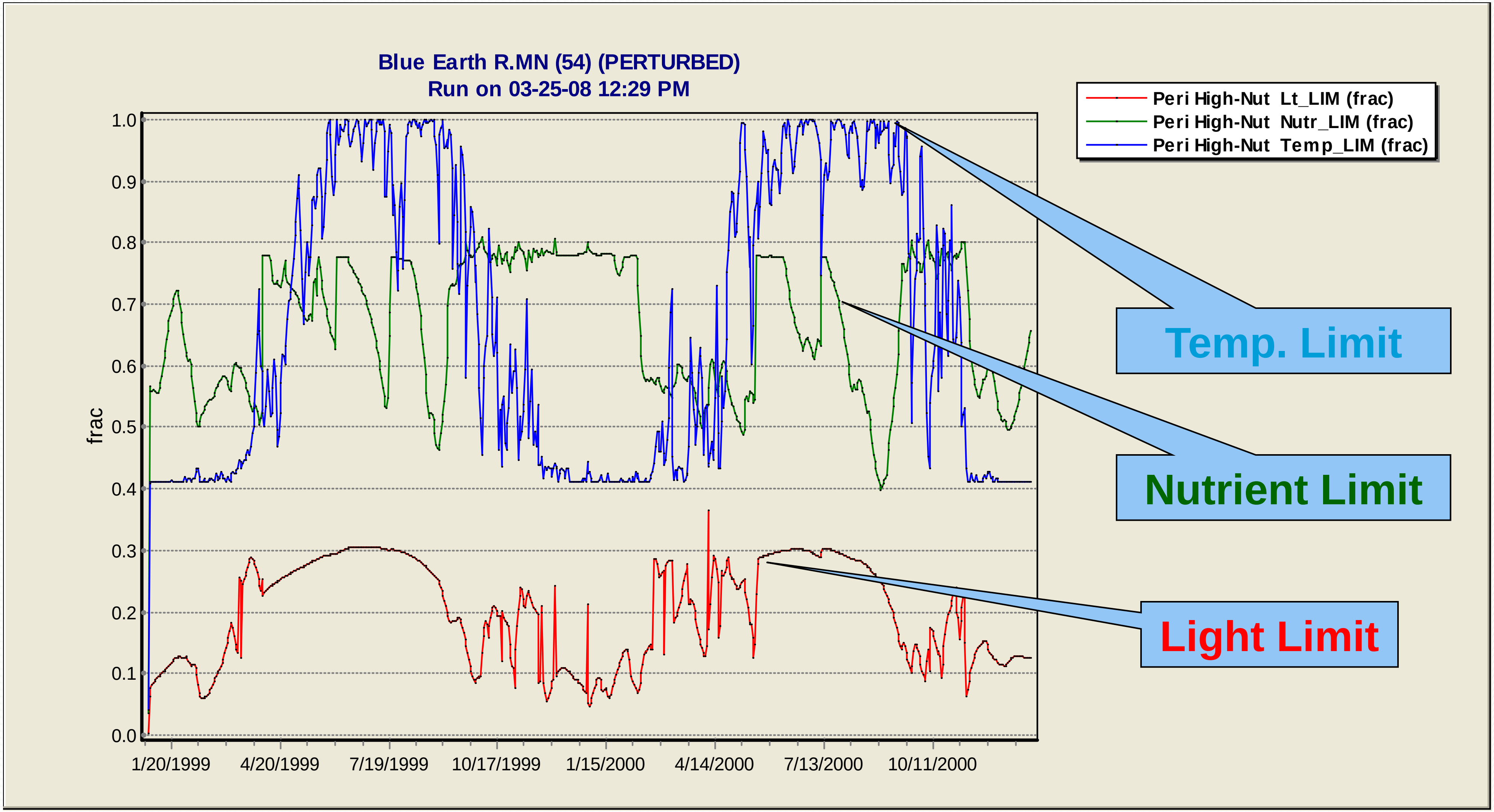
$$\frac{dBiomass_{Peri}}{dt} = Loading + Photosynthesis - Respiration - Excretion$$
$$- Mortality - Predation + Sed_{Peri} - Slough$$

- Individual terms of these equations can be saved and graphed

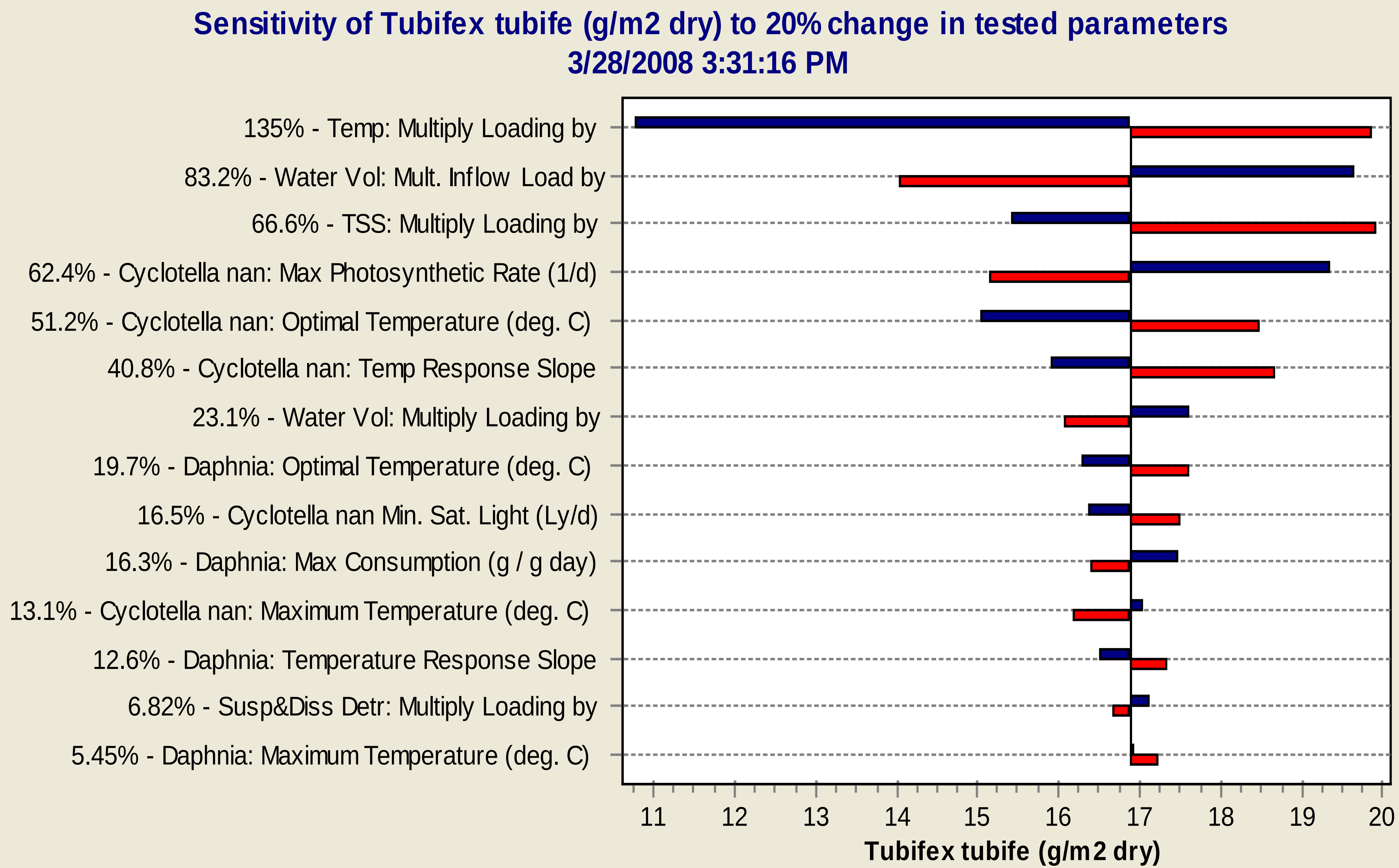
Periphyton Rates show importance of grazing and sloughing



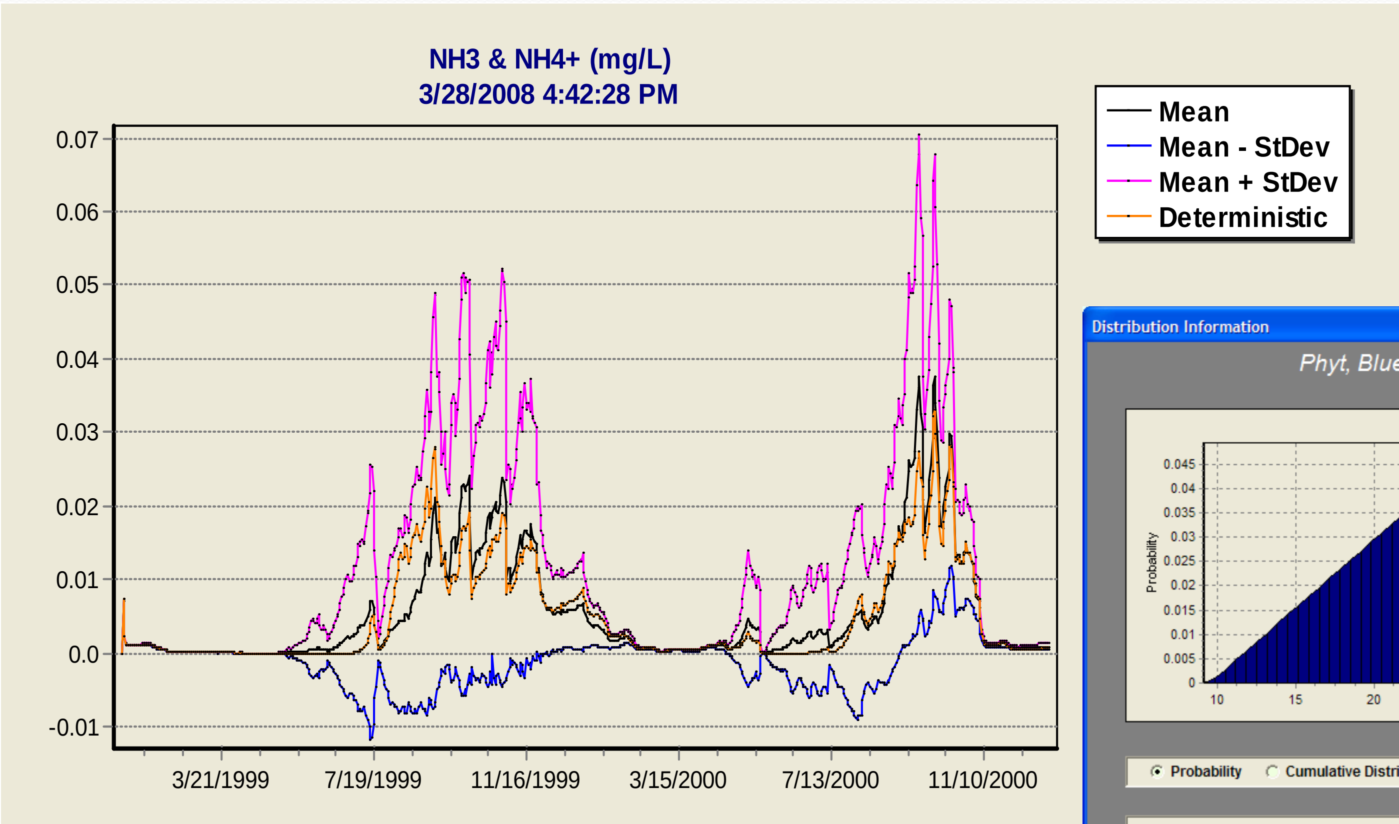
Limitations to Photosynthesis can also be Graphed

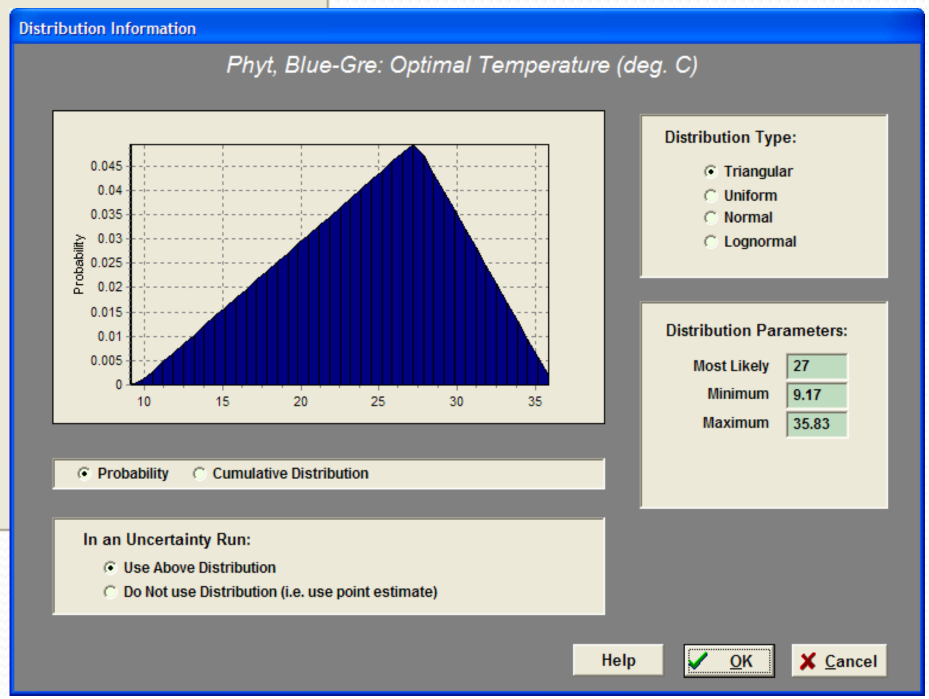


Automated Sensitivity Analysis



Integrated Uncertainty Analysis Capability





Example Applications of AQUATOX

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

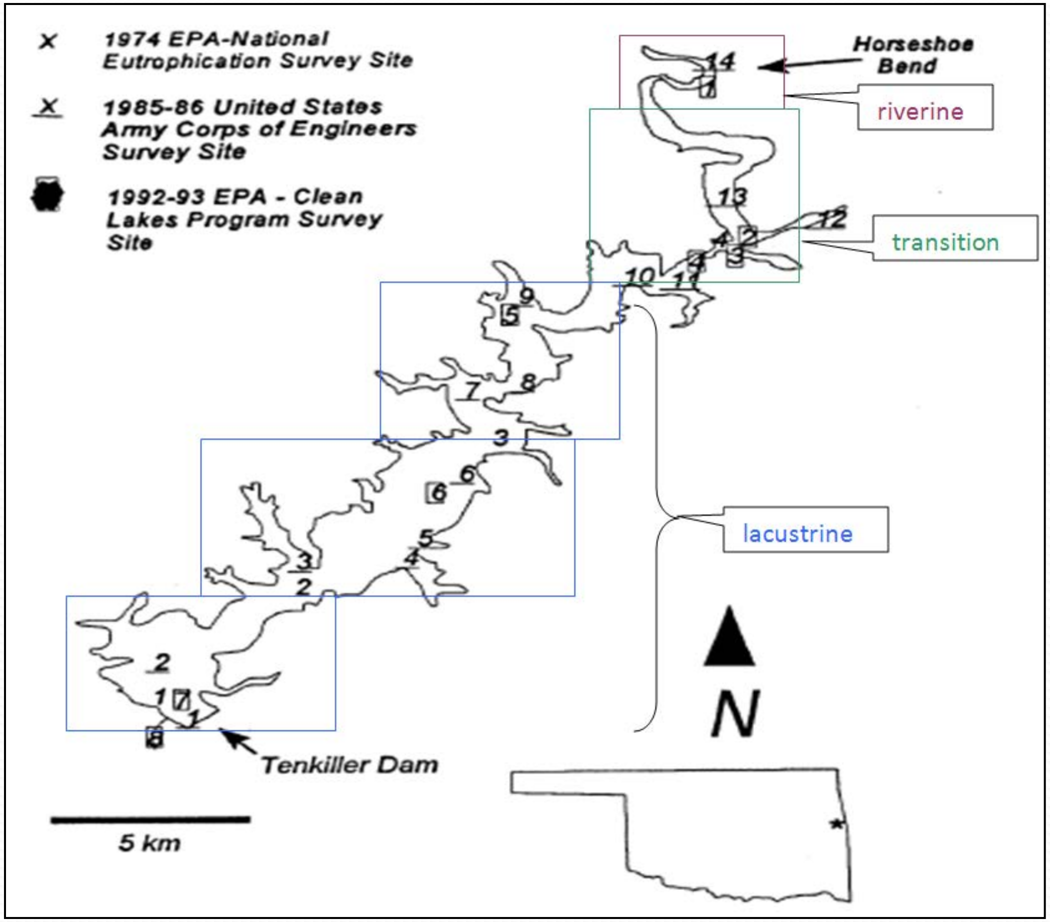
Application of AQUATOX to Eutrophic Reservoir

- 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

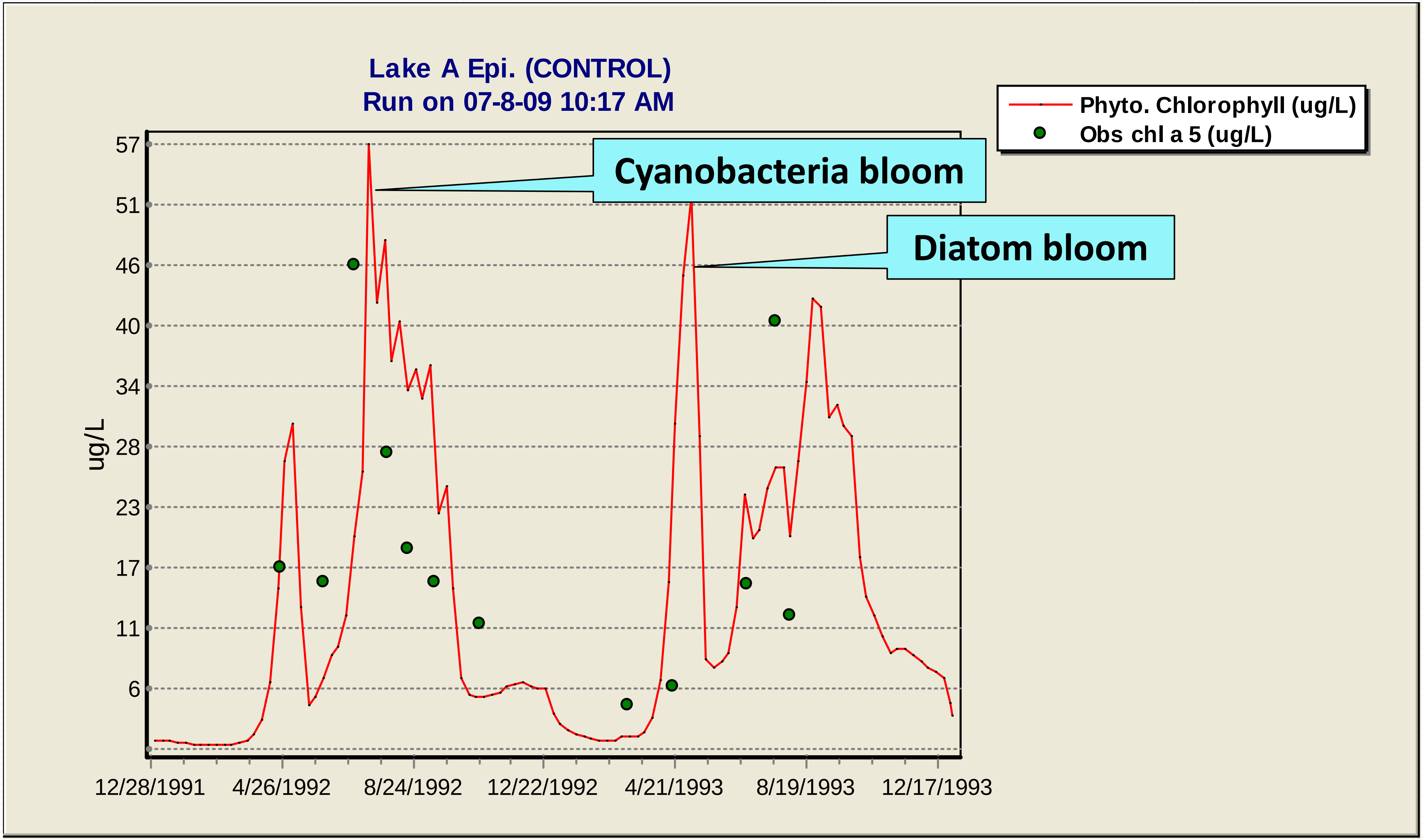
Incoming waters very rich in algae

Tenkiller Lake Application

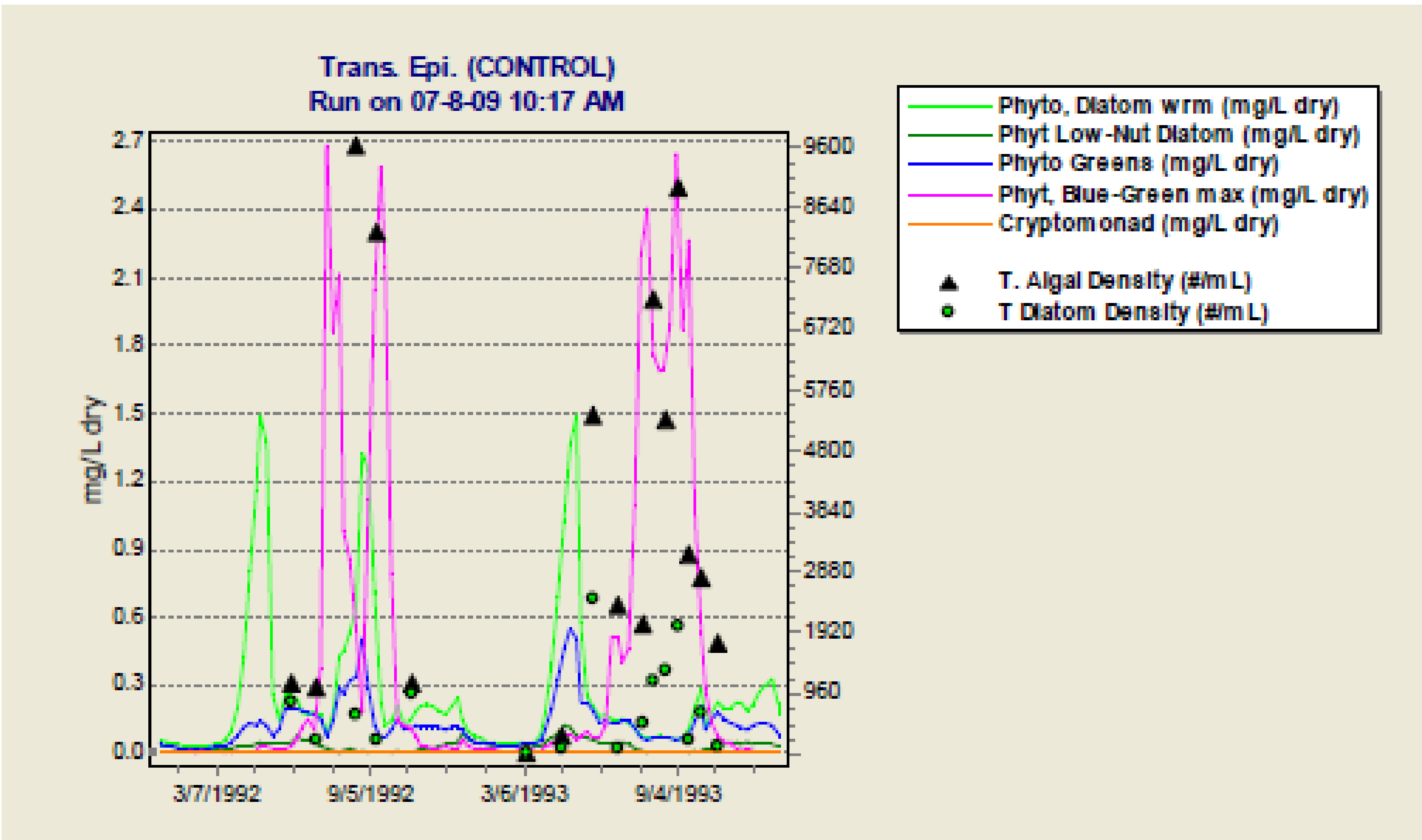
- River-reservoir system divided into nine segments
  - Riverine
  - Vertically stratified transition zone
  - Three vertically stratified lacustrine segments
- AQUATOX linked to HSPF (watershed) and EFDC (in-lake hydrology) models
- Tested scenarios to predict chlorophyll *a* levels based on different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



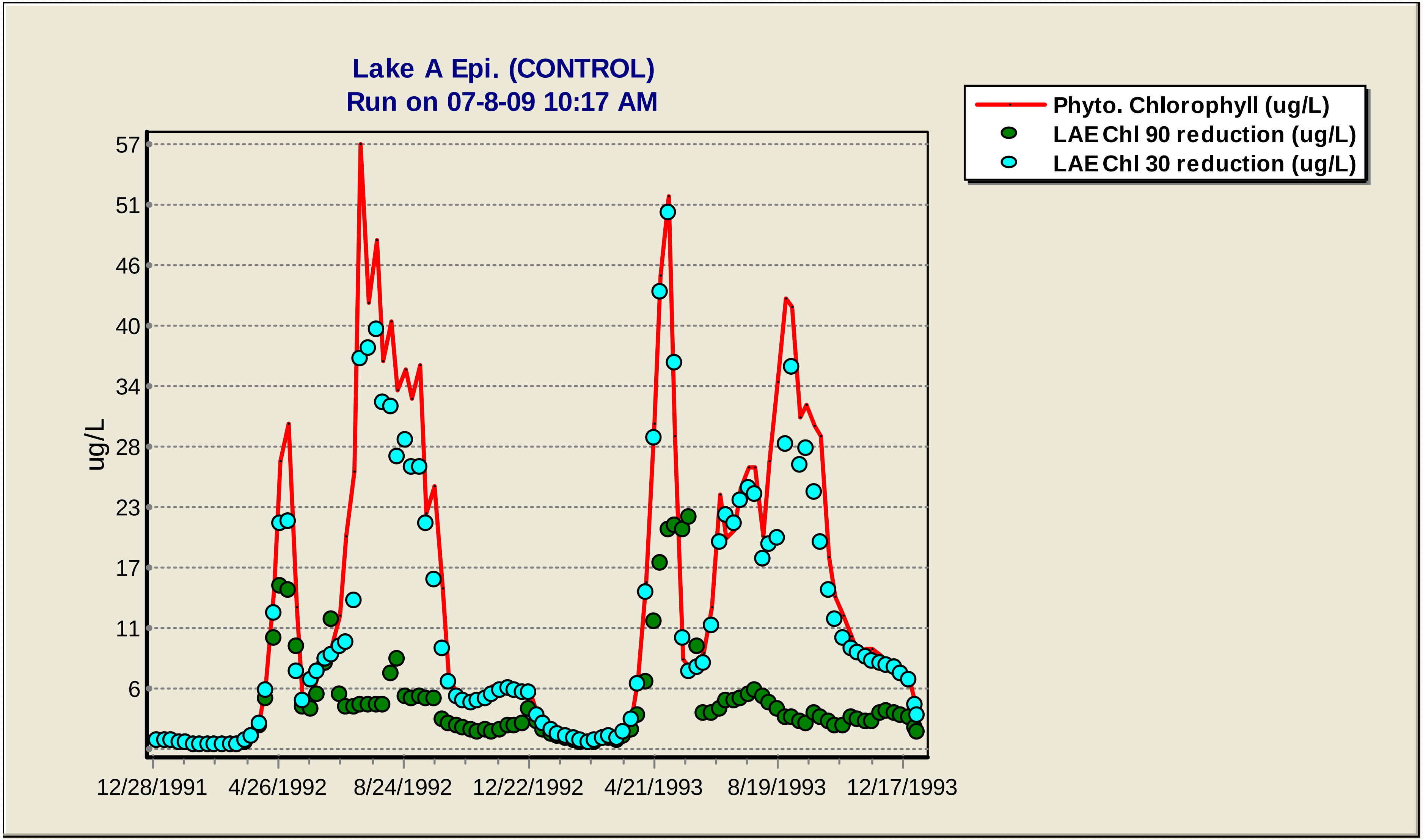
Simulated & observed chlorophyll *a*



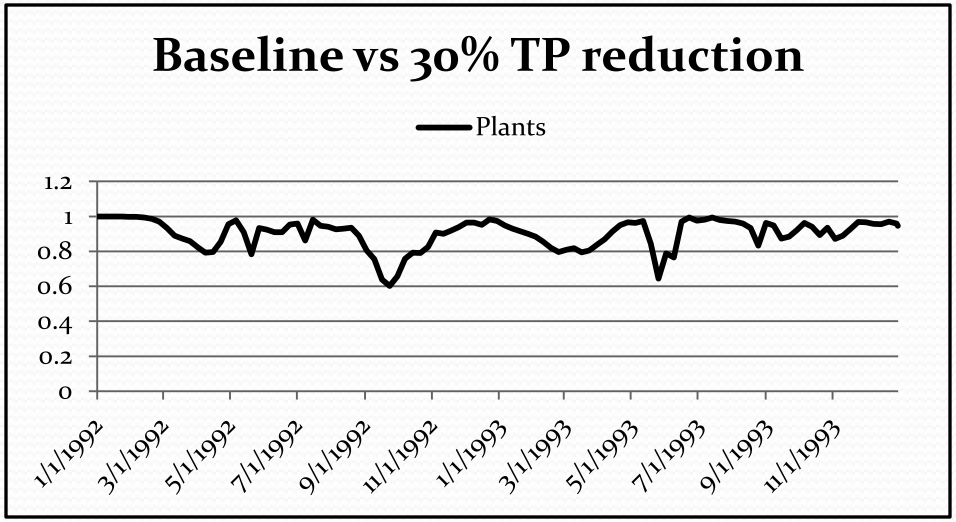
Simulated & observed algal composition

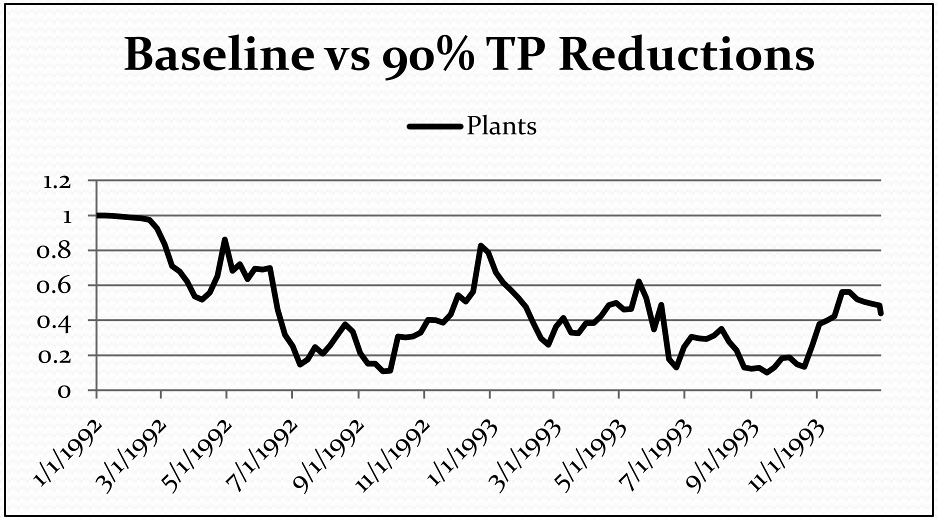


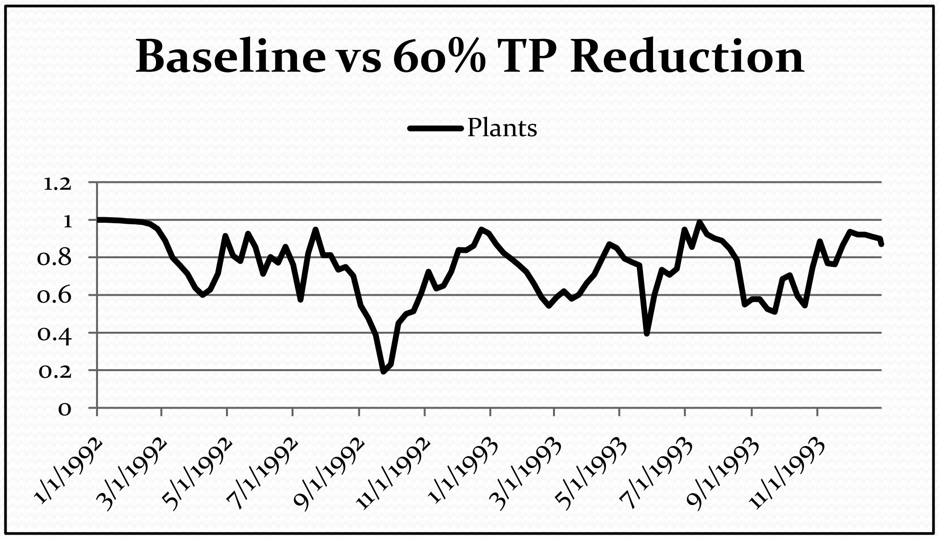
Predicted chl *a* levels under increasing load reductions of TP



Steinhaus Similarity Index illustrates increasingly dramatic changes in algal community

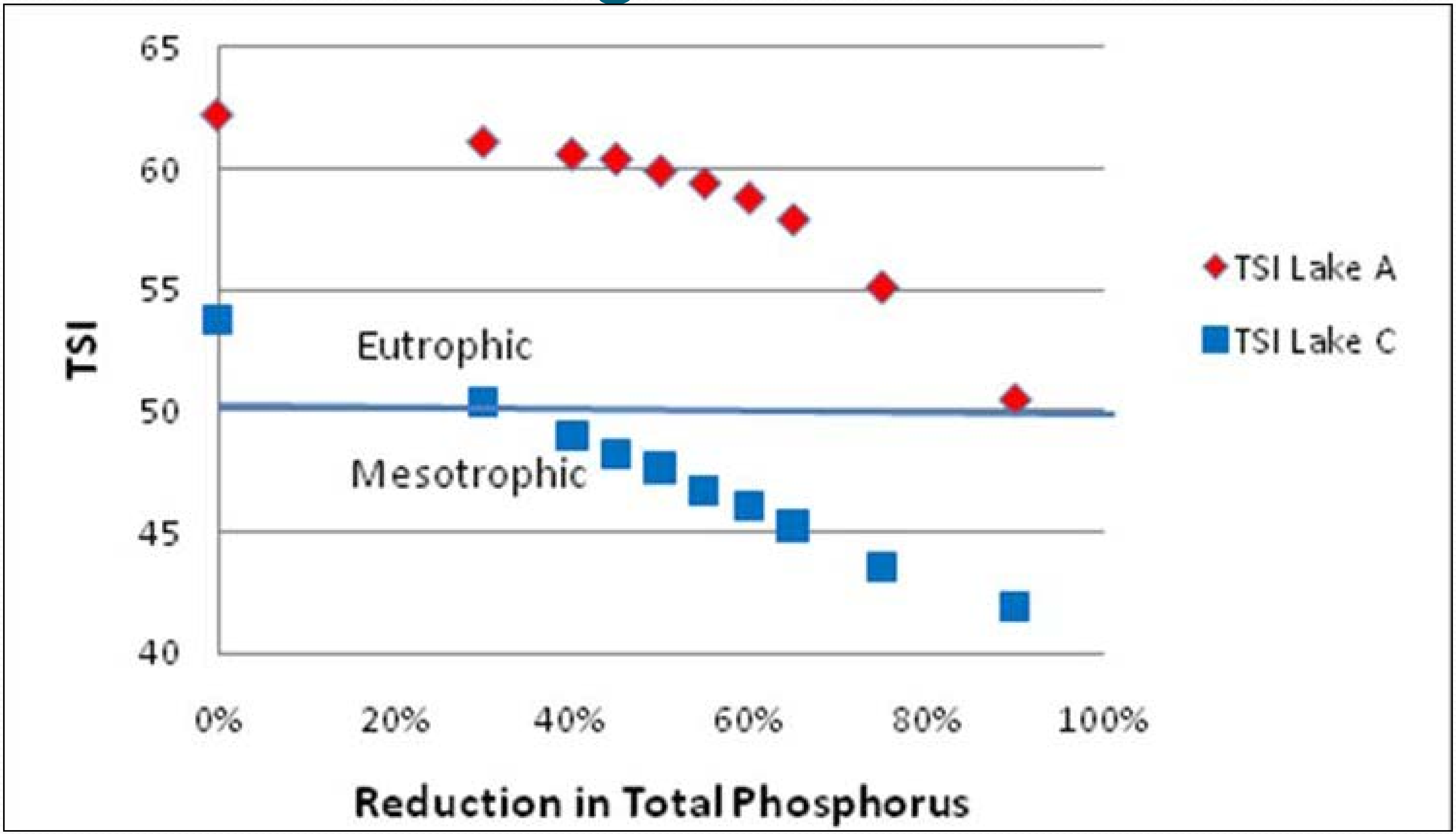






30% reduction in TP has relatively minor effect on the composition of the algal community

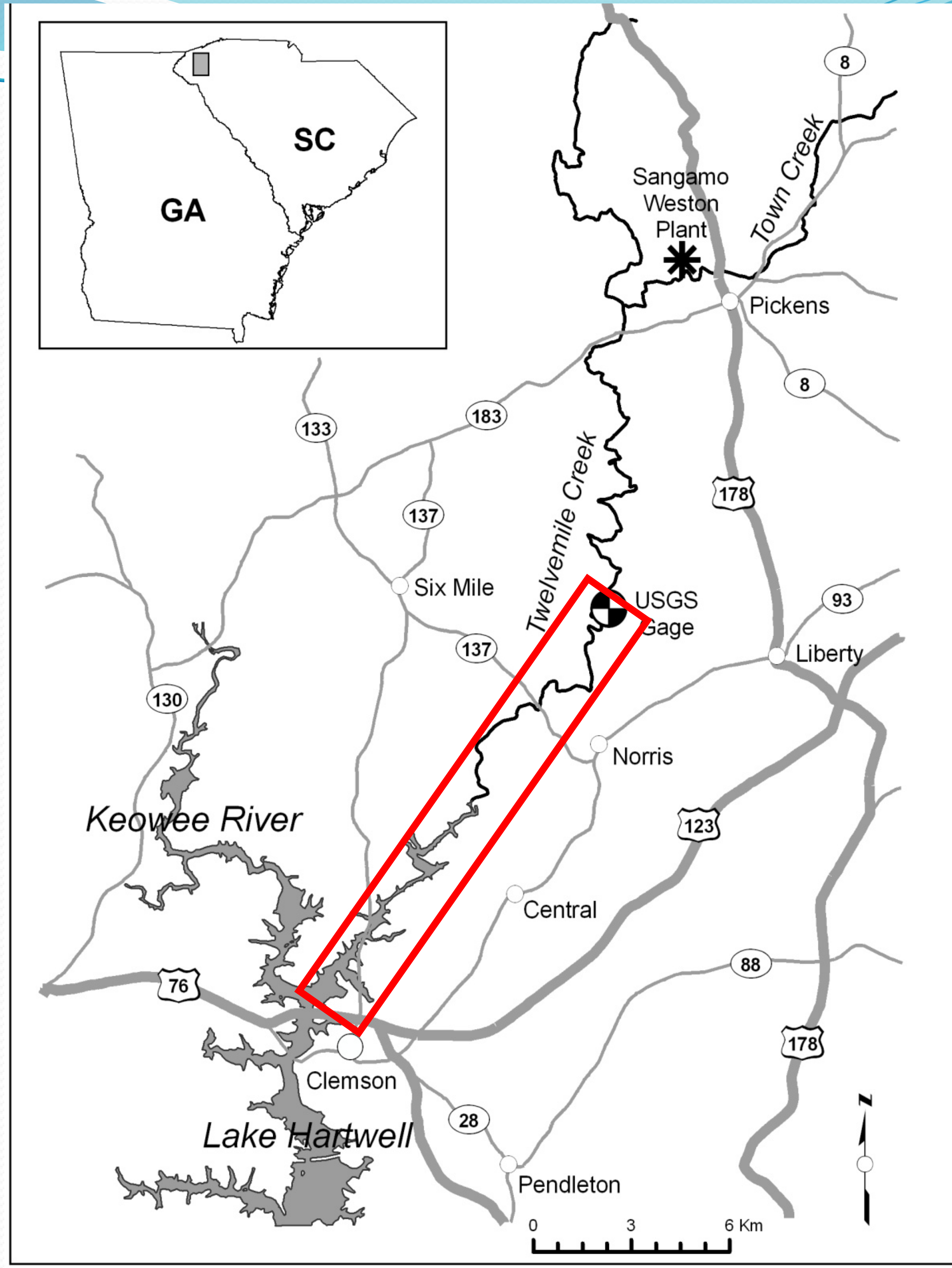
Trophic State Indices show differences between lake segments

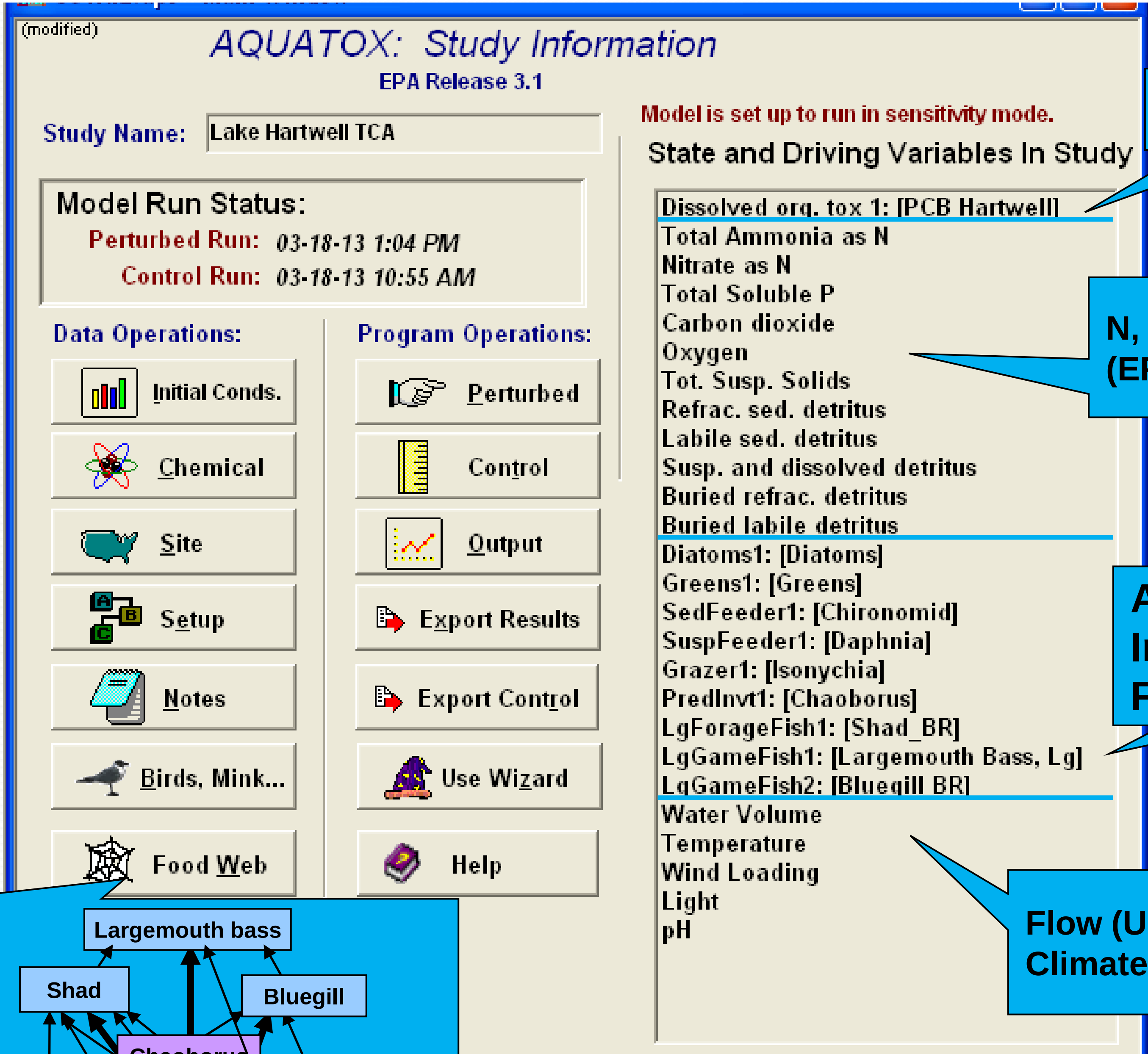


Ecosystem Modeling for PCBs in Lake Hartwell

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)



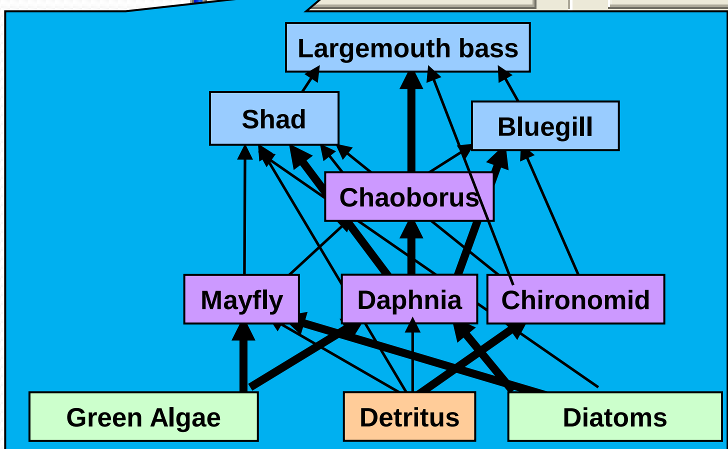


Based on data

N, P, oxygen, TSS (EPA STORET)

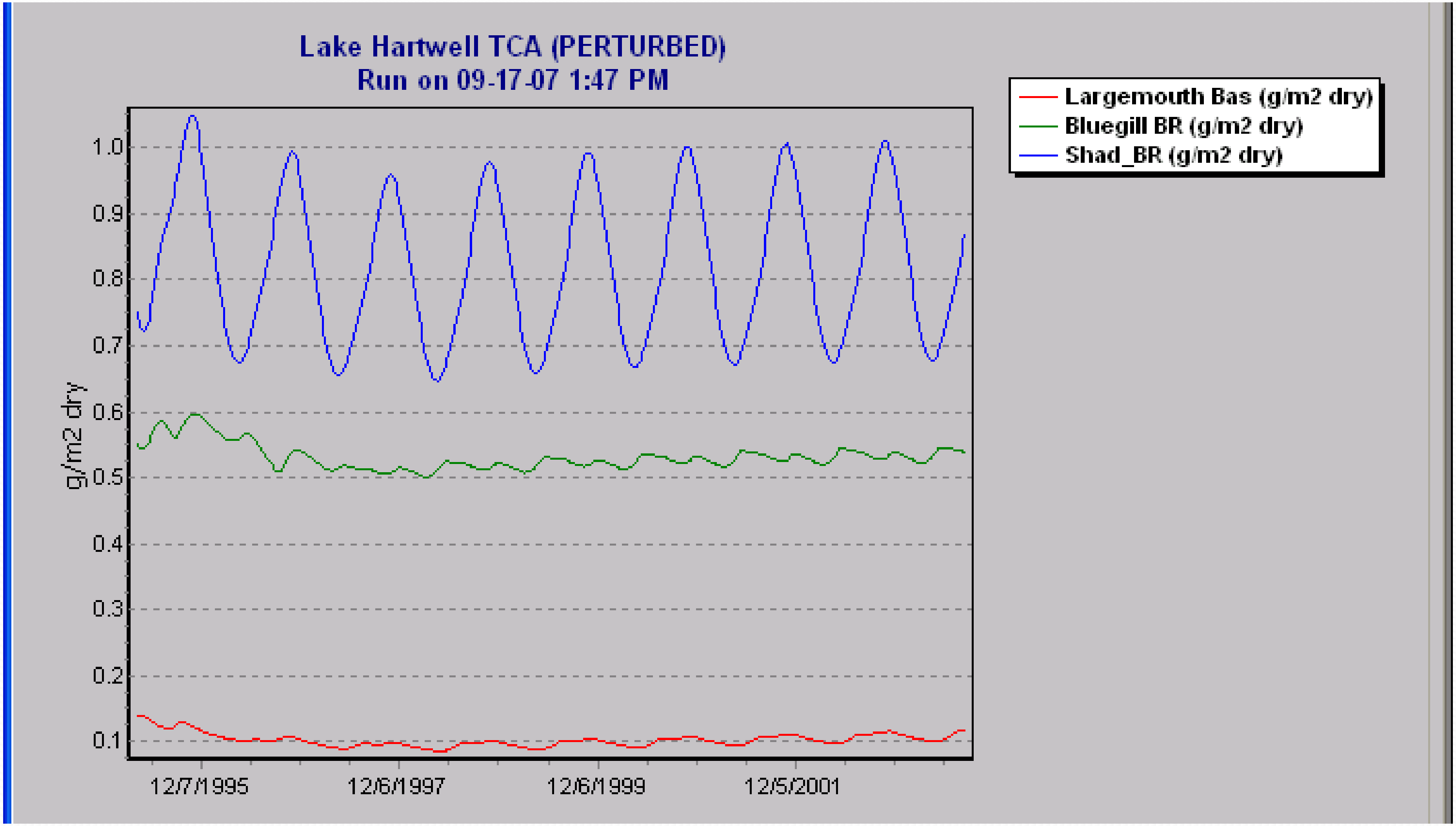
Algae
Invertebrates
Fish

Flow (USGS gage)
Climate (NOAA)

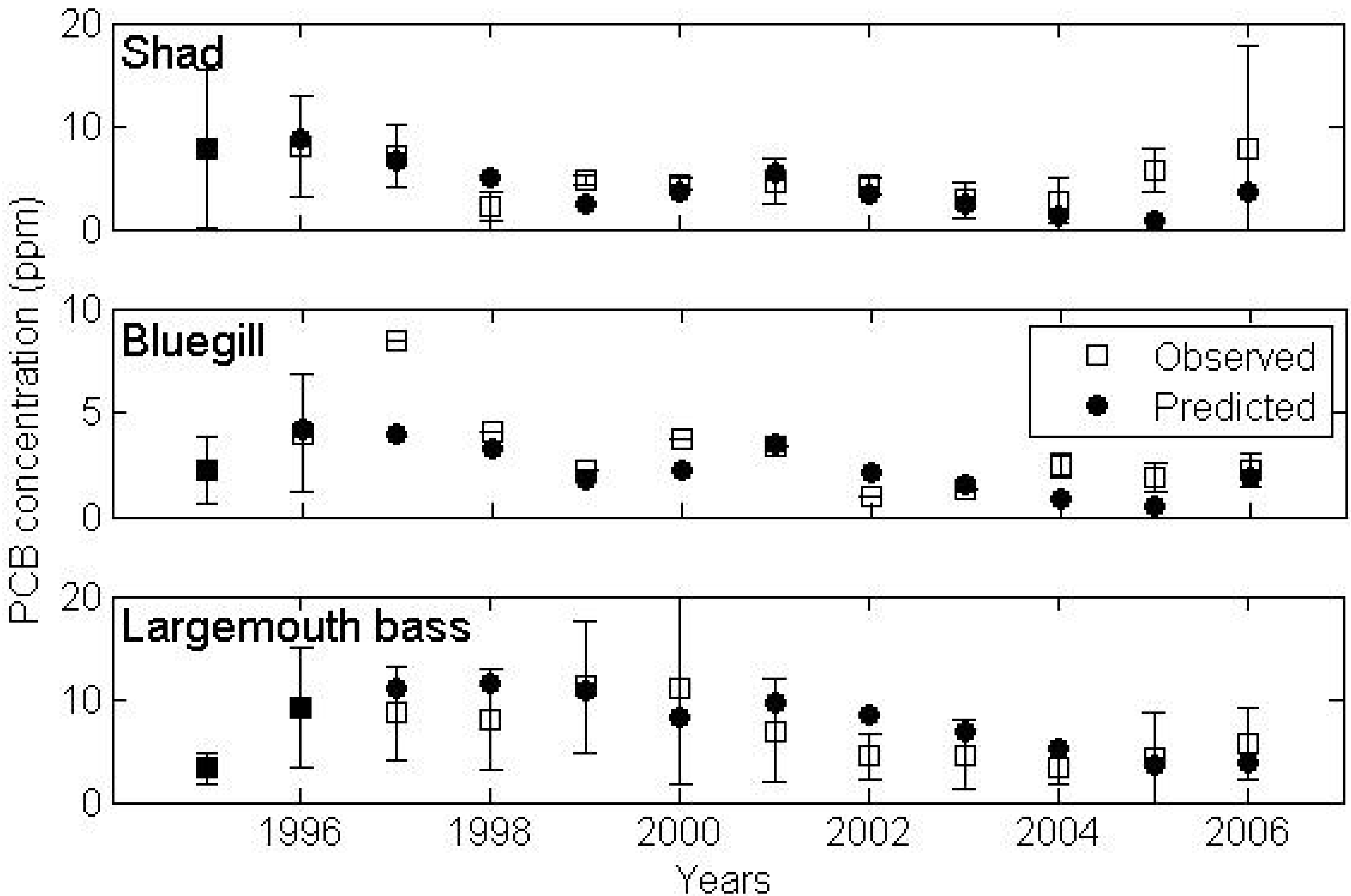


www.epa.gov/ost/models/aquatox/

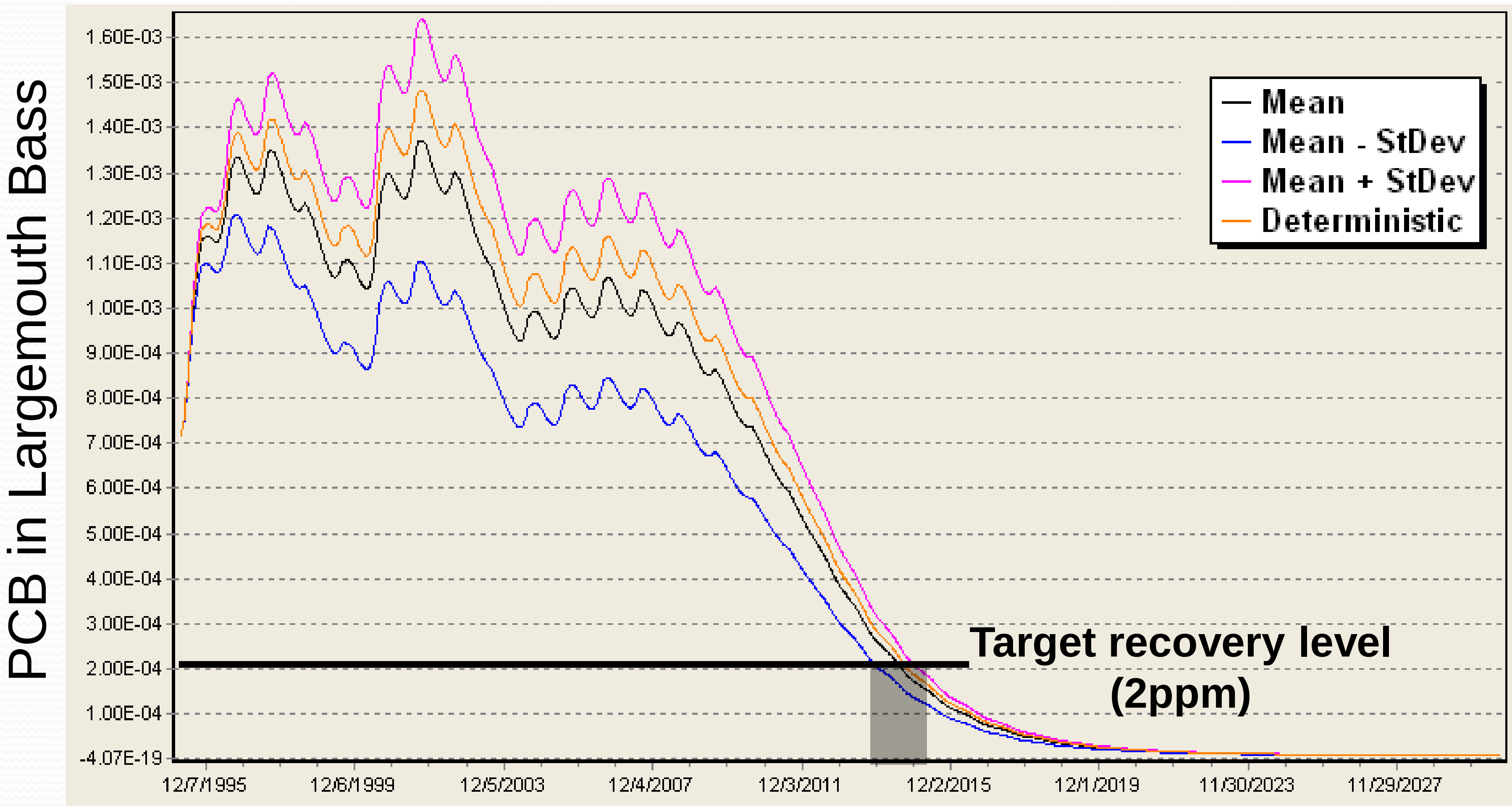
Predicted fish biomass is calibrated to observed values



Predicted PCB in fish is similar to observed

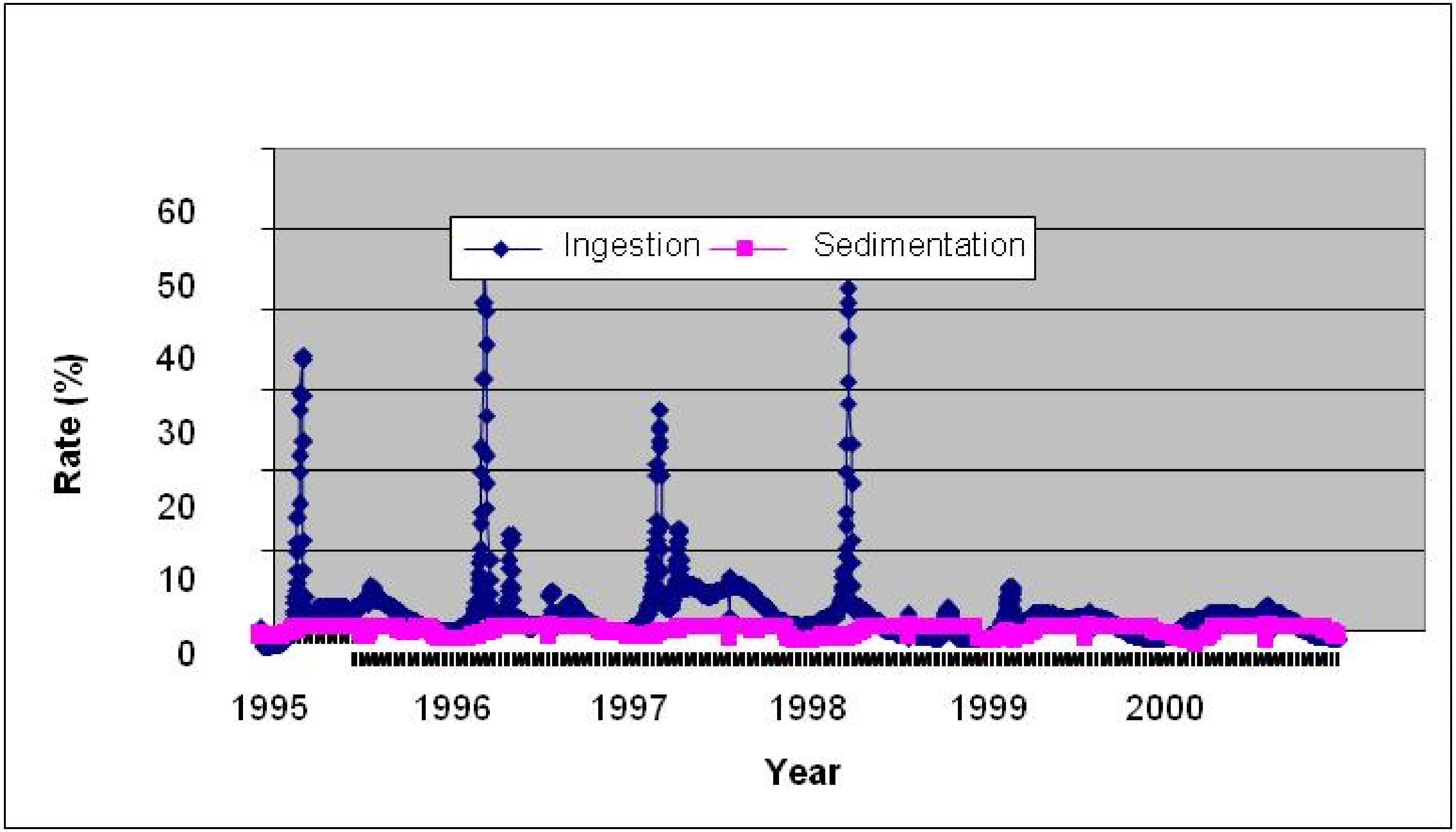


Future Prediction with Uncertainty



Fate of Input Detritus

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



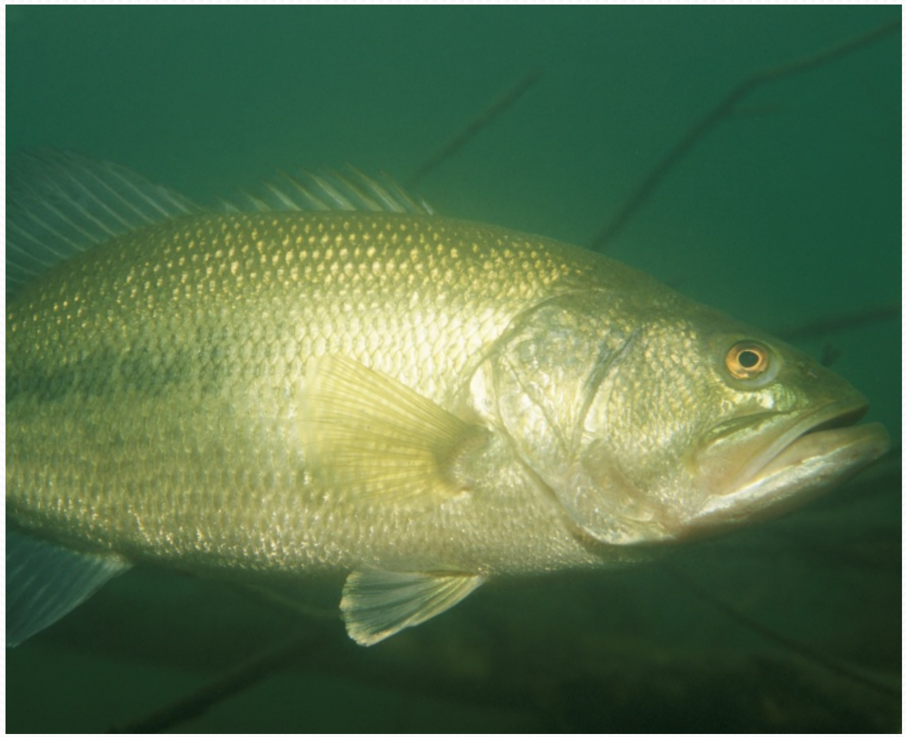
Results

When will fish recover?

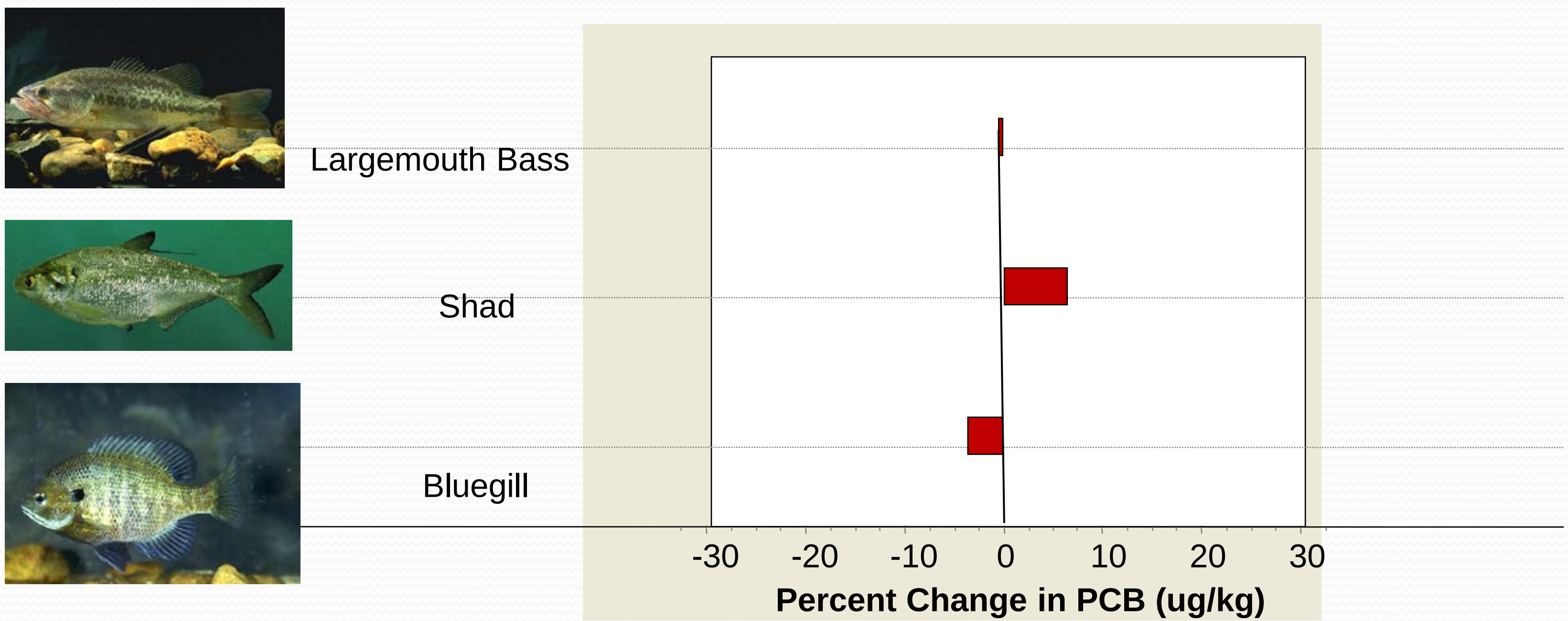
- ✓ Summer/Fall 2013

Why are fish still contaminated while sediment is recovering?

- ✓ Due to contaminated input detritus



Sensitivity of PCB Concentration in Fish to 10% ↑Temperature



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