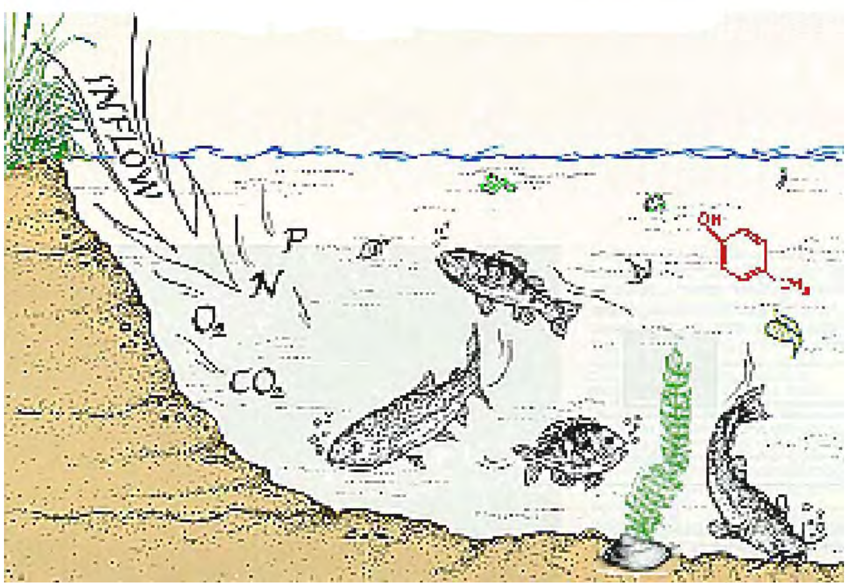
# AQUATOX Short Course

## SETAC Meeting, Tampa Florida
## November 16, 2008


Richard A. Park, Eco Modeling, Diamondhead MS
dickpark@CableOne.net
Jonathan S. Clough, Warren Pinnacle Consulting, Warren VT
jclough@warrenpinnacle.com
Marjorie Coombs Wellman, Office of Water, US EPA, Washington DC
wellman.marjorie@epamail.epa.gov

# Introduction to Course, Organization

- Schedule and administrative details
- CD organization
  - Directory Setup
  - For those with laptops, files to look at during the day

# Overview: What is AQUATOX?

- Simulation model that links pollutants to aquatic life
- Integrates fate & ecological effects
  - nutrient & eutrophication effects
  - fate & bioaccumulation of organics
  - food web & ecotoxicological effects
- Predicts effects of multiple stressors
  - nutrients, organic toxicants
  - temperature, suspended sediment, flow
- Can be evaluative (with “canonical” or representative environments) or site-specific
- Peer reviewed by independent panels and in several published model reviews
- Distributed by US EPA, Open Source code

# 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)
  - CATS-5 (Traas et al. 2001) is similar; models microcosms
  - CASM (Bartell et al. 1999) models toxic effects but not fate
- Can simulate many more types of organisms with more realism than most other water quality models
  - WASP6 models total phytoplankton and "benthic algae" (Wool et al. 2004); zooplankton are just a grazing term
  - QUAL2K models phytoplankton and "bottom algae" (Chapra and Pelletier 2003); no animals
- Very comprehensive bioaccumulation model

# Acceptance of AQUATOX

- Has gone through 2 EPA-sponsored peer reviews (following quotes from 2008 review):
  - “model enhancements have made AQUATOX one of the most exciting tools in aquatic ecosystem management”
  - “this is the first model that provides a reasonable interface for scientists to explore ecosystem level effects from multiple stressors over time”
  - “the integration of ICE data into AQUATOX makes this model one of the most comprehensive aquatic ecotoxicology programs available”
  - it “would make a wonderful textbook for an ecotoxicology class”
- Is gradually appearing in open literature

# Potential Applications for AQUATOX

- Many waters are impaired biologically as well as chemically
- Managers need to know:
  - Which of several stressors is causing the impairment?
  - Will proposed pollution control actions reach their goals?
    - restoration of desirable aquatic community
    - improved chemical water quality
  - Will there be any unintended consequences?
  - How long will recovery take?

# Regulatory Endpoints Modeled

- nutrient and toxicant concentrations
- biomass
  - plant, invertebrate, fish
- chlorophyll a
  - phytoplankton, periphyton, moss
- total suspended solids, Secchi depth
- dissolved oxygen
  - daily min. and max. in Rel. 3
- biochemical oxygen demand
- bioaccumulation factors
- half-lives of organic toxicants

# Potential Applications *nutrients*

- Develop nutrient targets for rivers, lakes and reservoirs subject to nuisance algal blooms
- Evaluate which factor(s) is controlling algae levels
  - nutrients, suspended sediments, grazing, herbicides, flow
- Using the linkage to BASINS, evaluate effects of agricultural practices
  - Will target chlorophyll *a* concentrations be attained after BMPS are implemented?
  - Will land use changes from agriculture to residential use increase or decrease eutrophication effects?

# Potential Applications of AQUATOX *toxic substances*

- Ecological risk assessment
  - Will non-target organisms be harmed?
    - Will sublethal effects cause game fish to disappear?
  - Will there be disruptions to the food web?
    - Will reduction of zooplankton reduce the food supply for beneficial fish?
    - Or will it lead to nuisance algae blooms?
- Calculate bioaccumulation factors and tissue concentrations
- Estimate time until fish are safe to eat following remediation

# Potential Applications
# *aquatic life support*

- Estimate recovery time for fish or invertebrates after reducing pollutant loads
- Evaluate potential ecosystem responses to invasive species and mitigation measures
  - Will native species disappear?
  - Will there be changes in ecosystem “services”?
  - What are the potential effects and half-life of a biocide?
- *Coordinate with biological criteria program*
  - *Estimate biological metrics*
  - *Simulate reference conditions where none exist*
  - *Evaluate biological potential*

# Comparison of Dynamic Risk Assessment Models

| State Variables & Processes | AQUATOX | CATS | CASM | Qual2K | WASP7 | EFDC-HEM3D | QEAFdChn | BASS | QSim |
|---|---|---|---|---|---|---|---|---|---|
| Nutrients | X | X | X | X | X | X | | | X |
| Sediment Diagenesis | X | | | X | X | X | | | |
| Detritus | X | X | X | X | X | X | | | X |
| Dissolved Oxygen | X | | X | X | X | X | | | X |
| DO Effects on Biota | X | | | | | | | | X |
| pH | X | | | X | | | | | X |
| NH4 Toxicity | X | | | | | | | | |
| Sand/Silt/Clay | X | | | | X | X | | | |
| SABS Effects | X | | | | | | | | |
| Hydraulics | | | | | | X | | | X |
| Heat Budget | | | | X | X | X | | | X |
| Salinity | X | | | | X | X | | | |
| Phytoplankton | X | X | X | X | X | X | | | X |
| Periphyton | X | X | X | X | X | | | | X |
| Macrophytes | X | X | X | | | | | | X |
| Zooplankton | X | X | X | | | | | | X |
| Zoobenthos | X | X | X | | | | | | X |
| Fish | X | X | X | | | | | X | X |
| Bacteria | | | X | | | | | | X |
| Pathogens | | | | X | | X | | | |
| Organic Toxicant Fate | X | X | | | X | | | X | |
| Organic Toxicants in: | | | | | | | | | |
| Sediments | X | X | | | X | X | | | |
| Stratified Sediments | X | | | | X | X | | | |
| Phytoplankton | X | X | | | | | | | |
| Periphyton | X | X | | | | | | | |
| Macrophytes | X | X | | | | | | | |
| Zooplankton | X | X | | | | | X | | |
| Zoobenthos | X | X | | | | | X | | |
| Fish | X | X | | | | | X | X | |
| Birds or other animals | X | X | | | | | | | |
| Ecotoxicity | X | X | X | | | | | X | |
| Linked Segments | X | | | X | X | X | X | | X |

# Comparison of Bioaccumulation Models: Biotic State Variables

**Table 3.2. Comparison of Bioaccumulation State Variables**

| | AQUATOX Release 2 | BASS v 2.1 | Biotic Ligand 1.0.0 | Ecofate 1.0b1, Gobas | EMCM 1.0 | RAMAS Ecosystem | QEAFDCHN 1.0 | TRIM.FaTE v 3.3 |
|---|---|---|---|---|---|---|---|---|
| BIOTIC STATE VARIABLES | | | | | | | | |
| Plants | | | | | | | | |
| Single Generalized Water Column Algal Species | ★ | 7 | | ★ | ★ | | | ★ |
| Multiple Generalized Water Column Algal Species | ★ | | | | | | | |
| Green Algae | ★ | | | | | | | |
| Blue-green Algae | ★ | | | | | | | |
| Diatoms | ★ | | | | | | | |
| Single Generalized Benthic Algal Species | ★ | 7 | | | | | | |
| Multiple Generalized Benthic Algal Species | ★ | | | | | | | |
| Periphyton | ★ | 7 | | | ★ | | | |
| Macrophytes | ★ | | | | ★ | | | ★ |
| Animals | | | | | | | | |
| Generalized Compartments for Invertebrates or Fish | | | | | | ★ | ★ | |
| Generalized Zooplankton Species | ★ | 7 | | ★ | ★ | | ★ | |
| Detritivorous Invertebrates | ★ | | | ★ | 4 | | ★ | |
| Herbivorous Invertebrates | ★ | | 3 | ★ | | | ★ | ★ |
| Predatory Invertebrates | ★ | | | | | | ★ | |
| Single Generalized Fish Species | ★ | ★ | | ★ | ★ | | ★ | |
| Multiple Generalized Fish Species | ★ | ★ | | ★ | ★ | | ★ | |
| Bottom Fish | ★ | ★ | | ★ | ★ | | ★ | ★ |
| Forage Fish | ★ | ★ | 3 | ★ | ★ | | ★ | ★ |
| Small Game Fish | ★ | ★ | | ★ | ★ | | ★ | ★ |
| Large Game Fish | ★ | ★ | 3 | ★ | ★ | | ★ | ★ |
| Fish Organ Systems | | | 6 | | | | | |
| Age / Size Structured Fish Populations | ★ | ★ | | ★ | ★ | 5 | ★ | |
| Marine Birds | ★ | | | ★ | | | | ★ |
| Additional Mammals | | | | | | | | ★ |

Imhoff et al. 2004

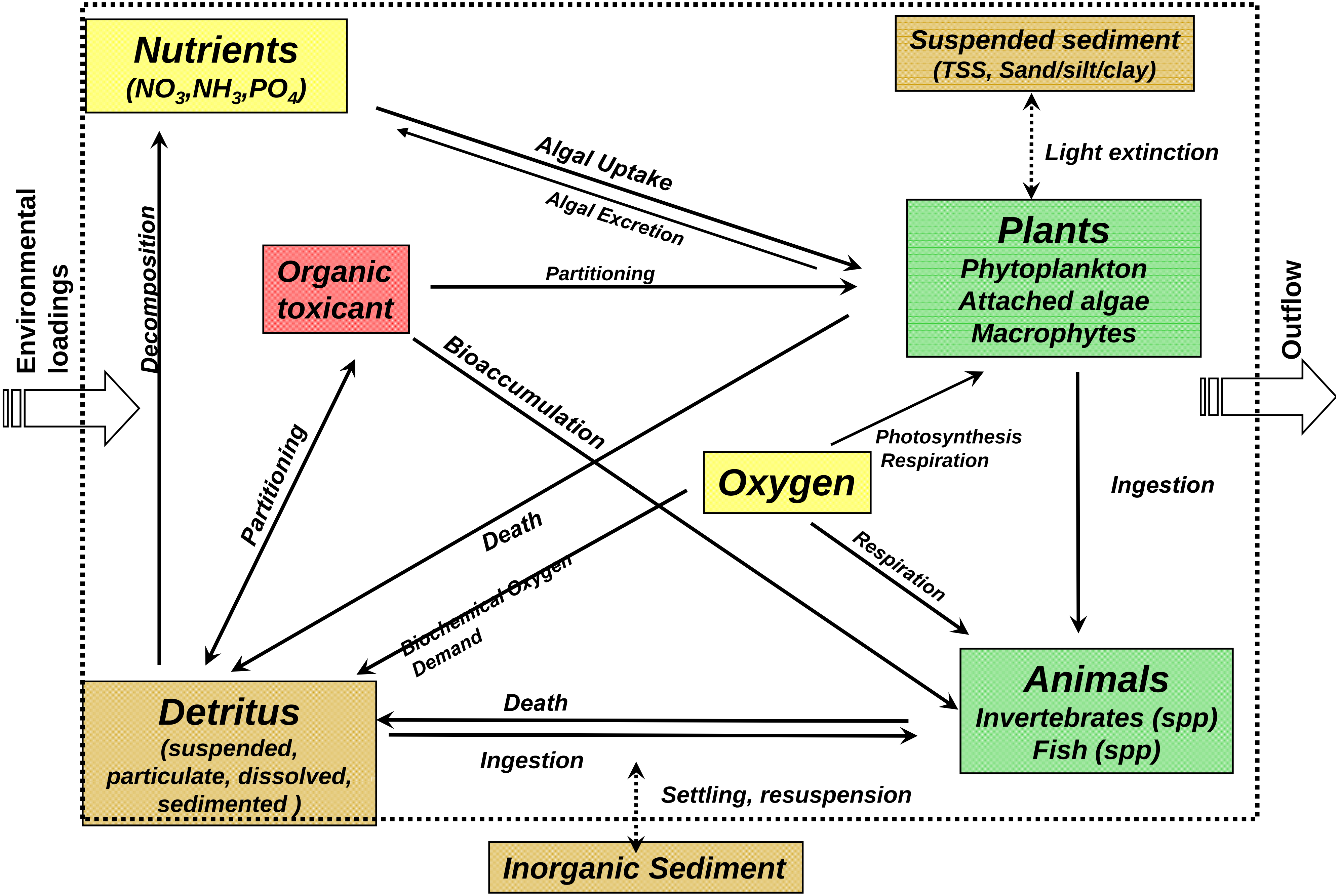
# What AQUATOX does *not* do

- It does not model metals
  - **Hg was attempted, but unsuccessful**
- It does not model bacteria or pathogens
  - **microbial processes are implicit in decomposition**

# AQUATOX Structure

- Time-variable
  - variable-step 4th-5th order Runge-Kutta
    - usually daily reporting time step
    - can use hourly time-step and reporting step in Rel. 3
- Spatially simple unless linked to hydrodynamic model
  - thermal stratification
  - salinity stratification (based on salt balance in Rel 3)
- Modular and flexible
  - written in object Pascal (Delphi)
  - model only what is necessary (flask to river)
  - multi-threaded, multiple document interface
- Control vs. perturbed simulations

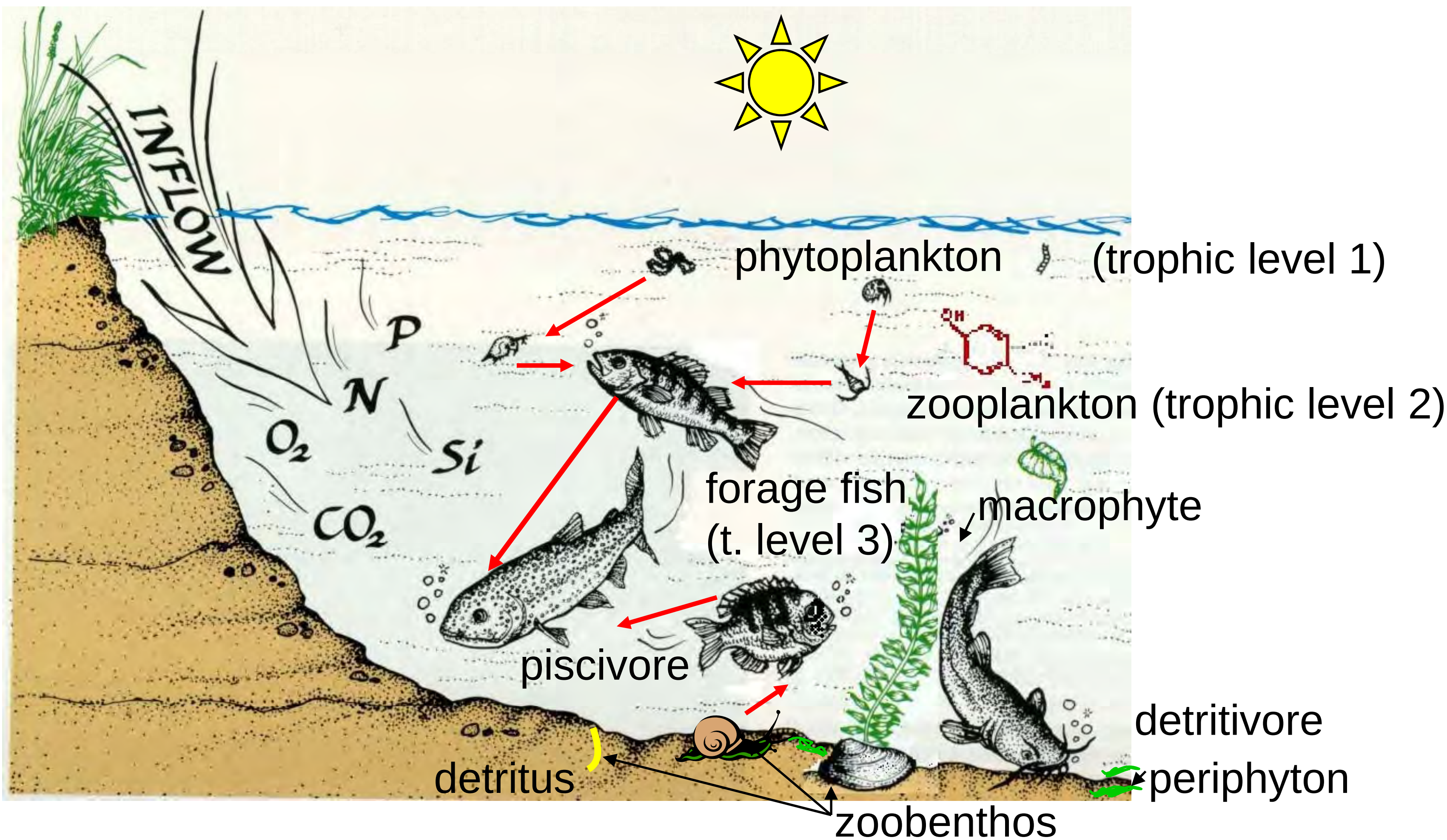
# AQUATOX Simulates Ecological Processes & Effects within a Volume of Water Over Time



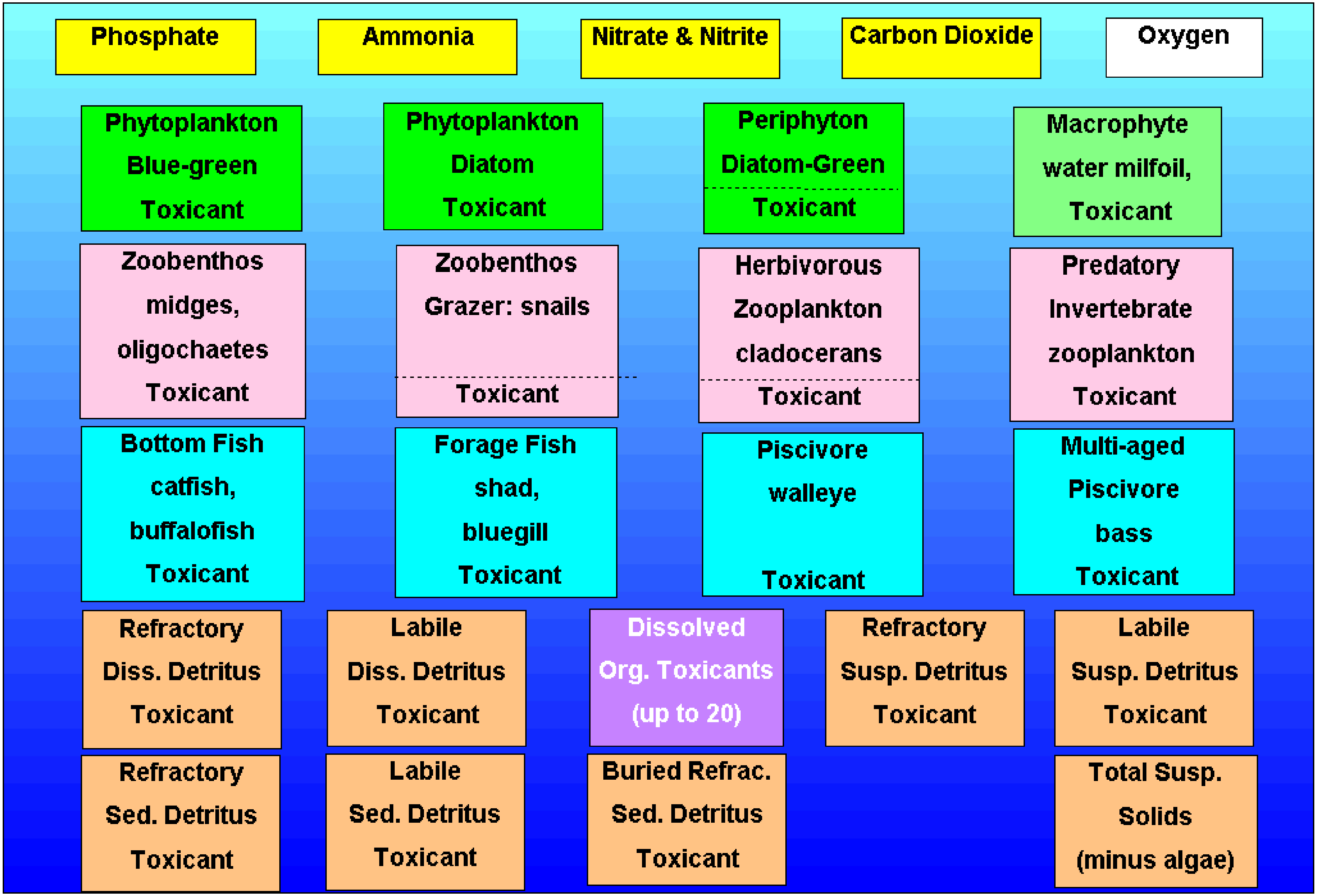
# Processes Simulated

- Bioenergetics
  - feeding, assimilation
  - growth, promotion, emergence
  - reproduction
  - mortality
  - trophic relations
  - toxicity (acute & chronic)
- Environmental fate
  - nutrient cycling
  - oxygen dynamics
  - partitioning to water, biota & sediments
  - bioaccumulation
  - chemical transformations
  - biotransformations
- Environmental effects
  - direct & indirect

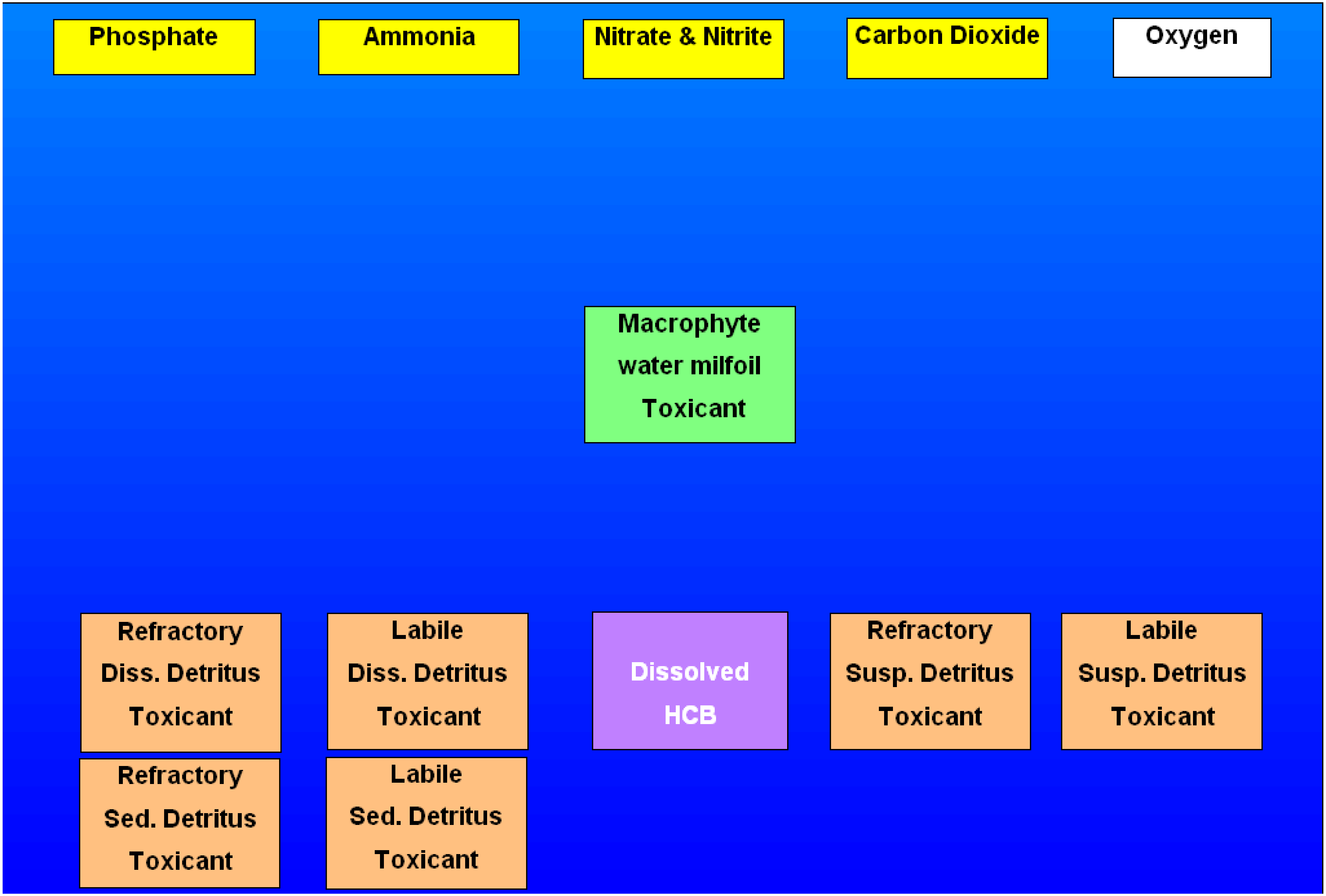
# Ecosystem components



# State Variables in Coralville, Iowa, Study



# State Variables in Experimental Tank



# AQUATOX Capabilities

## *(Release 3 in red)*

- Ponds, lakes, reservoirs, streams, rivers, estuaries
- Riffle, run, and pool habitats for streams
- Completely mixed, thermal stratification, or salinity stratification
- Linked segments, tributary inputs
- Multiple sediment layers with pore waters
- Sediment Diagenesis Model
- Diel oxygen and low oxygen effects, ammonia toxicity
- Interspecies Correlation Estimation (ICE) toxicity database
- Variable stoichiometry, nutrient mass balance, TN & TP
- Dynamic pH
- Biota represented by guilds, key species
- Constant or variable loads
- Latin hypercube uncertainty, nominal range sensitivity analysis
- Wizard & help files, multiple windows, task bar
- Links to HSPF and SWAT in BASINS

# Demonstration 1

## How is AQUATOX used? Overview of user-friendly graphical interface

- Installation Considerations
- The “APS” file unit
- Looking at a few Parameters
- Libraries of Parameters
- Looking at Model Output vs. Observed
- Setup Screen
- Integrated Help-File and Users Manual

# What are the Analytical Capabilities?

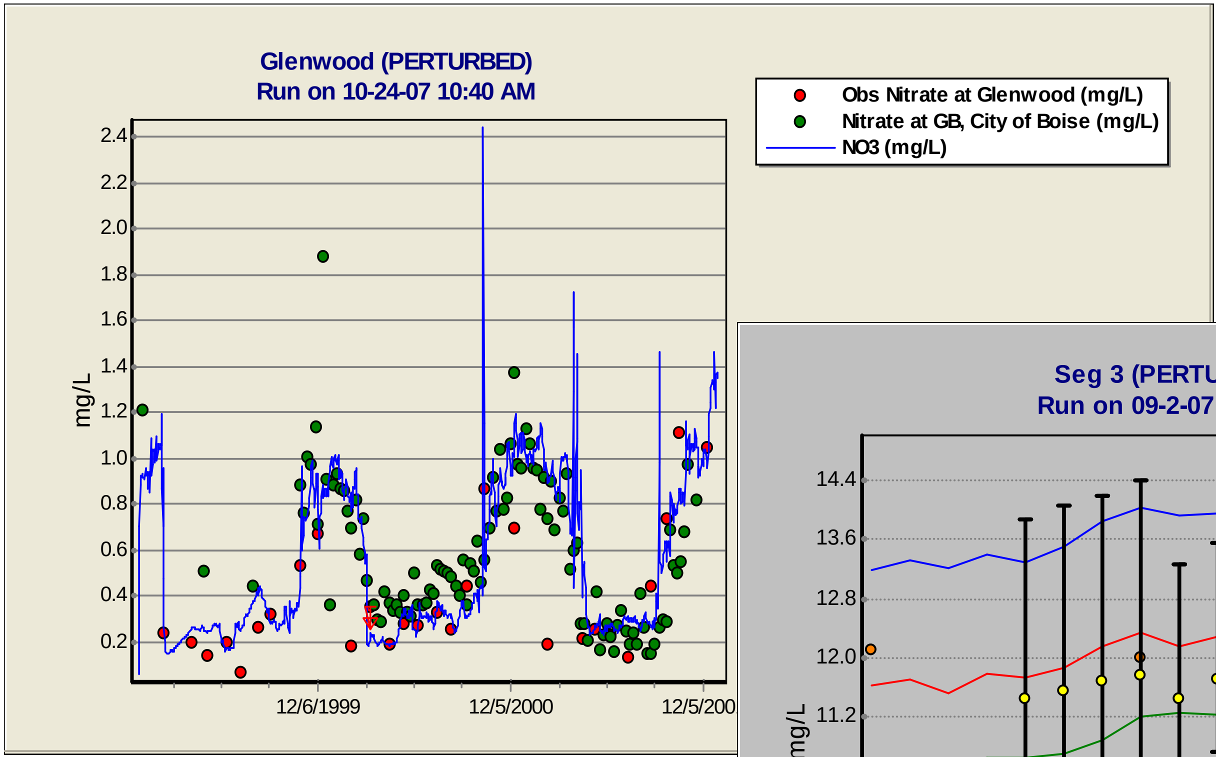
- Graphical Analysis
  - Comparison of model results to Observed Data
  - Graph types and graph libraries
- Control-Perturbed Comparisons
- Process Rates
- Sensitivity Analysis
- Uncertainty Analysis

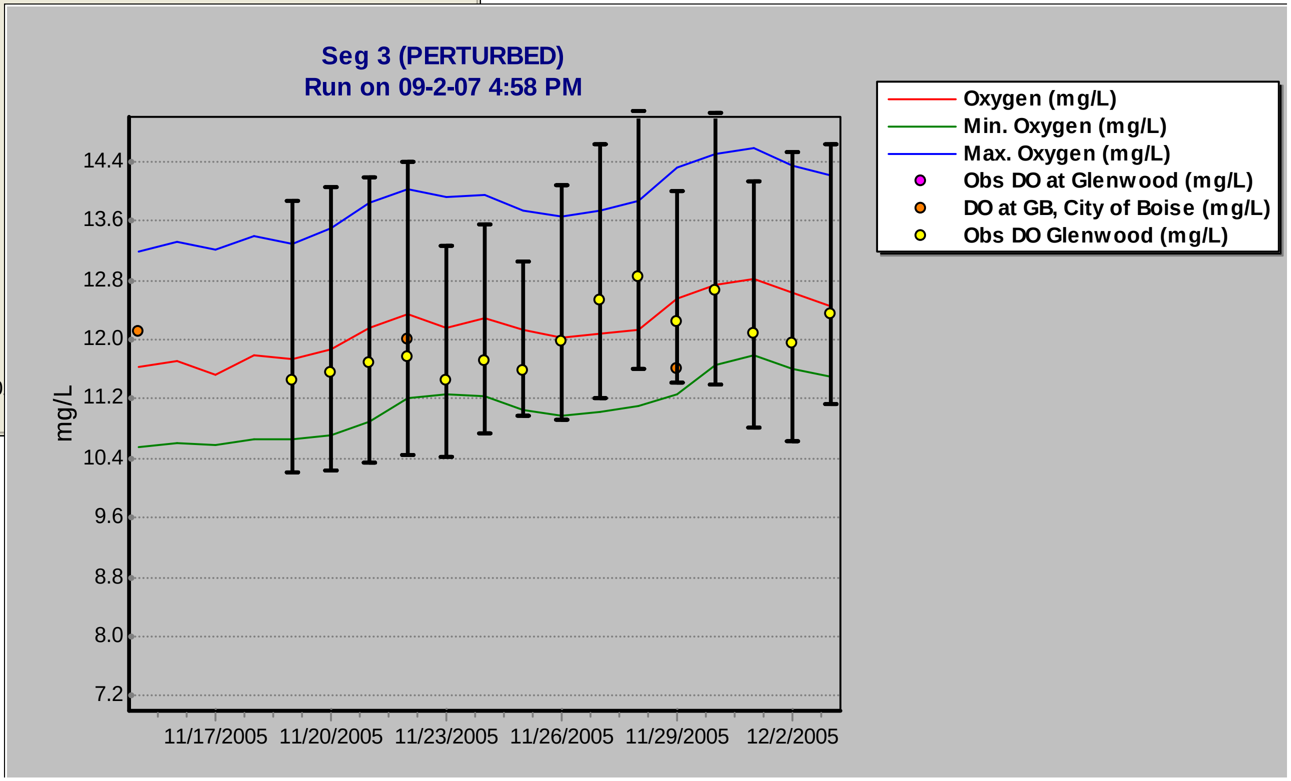
# The Many Types of AQUATOX Output
(in order of output list)

- Concentrations of State Variables
  - toxicants in water
  - nutrients and gasses
  - organic matter, plants, invertebrates, fish
- Physical Characteristic State Variables
  - water volume, temperature, wind, light, pH
- Mass of Toxicants within State Variables (normalized to water vol.)
  - T1-T20 in organic matter, plants, invertebrates, and fish
- Additional Model Calculations
  - Secchi depth, chlorophyll *a*, velocity, TN, TP
- Toxicant PPB
  - T1-T20 (PPB) in organic matter, plants, invertebrates, and fish
- Nitrogen and Phosphate Mass Tracking Variables
- Bioaccumulation Factors

# Graphical Analysis

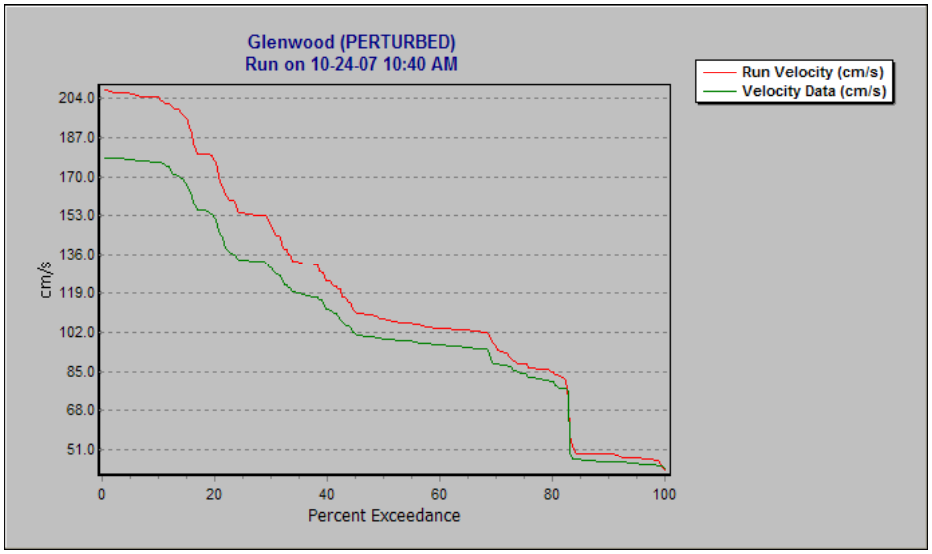
Compare observed data to model output

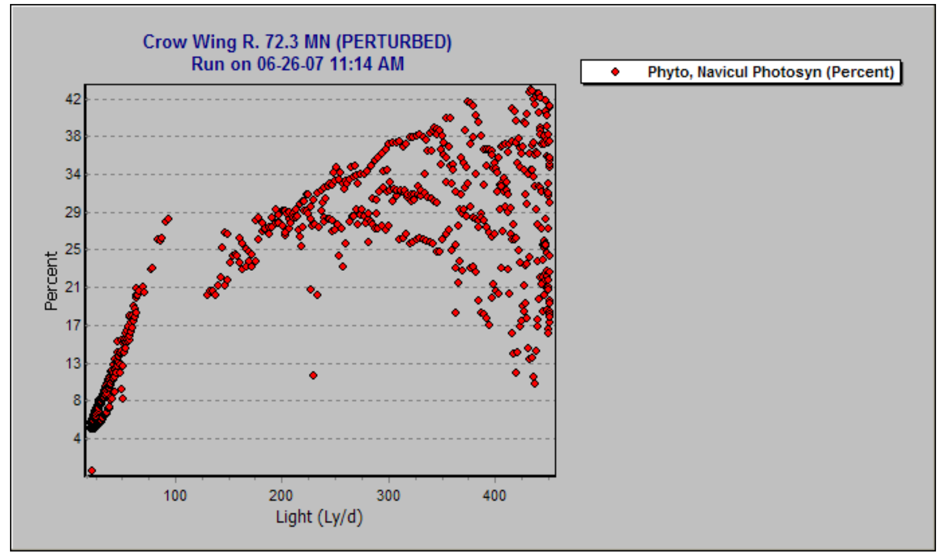


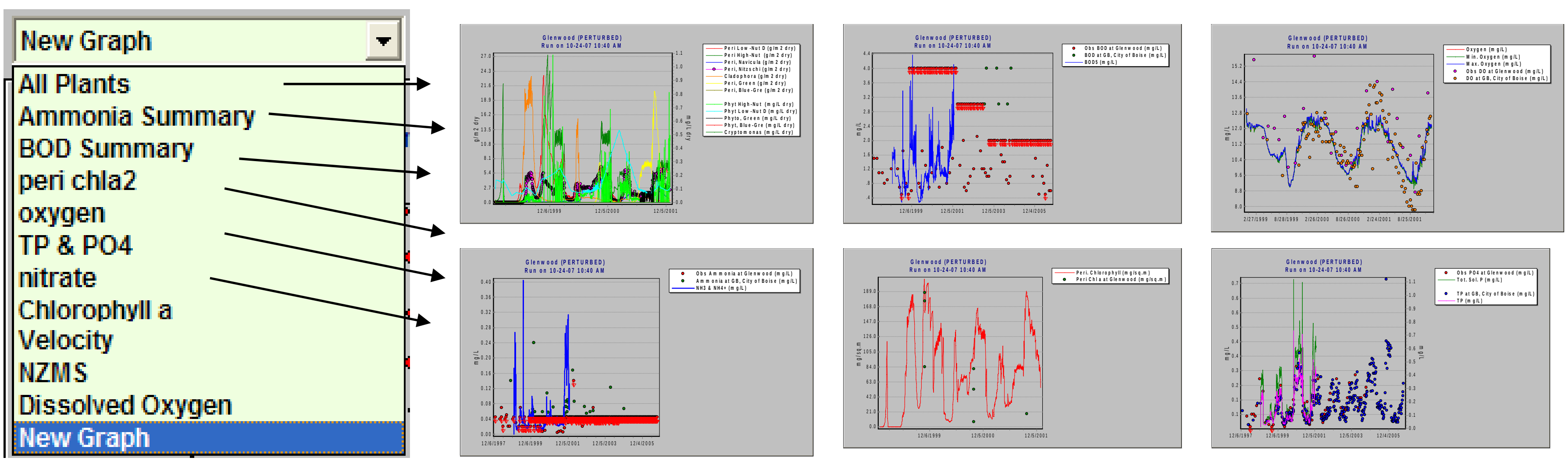
# Graphical Analysis

## Percent exceedance, duration, scatter plots, log-scale graphs



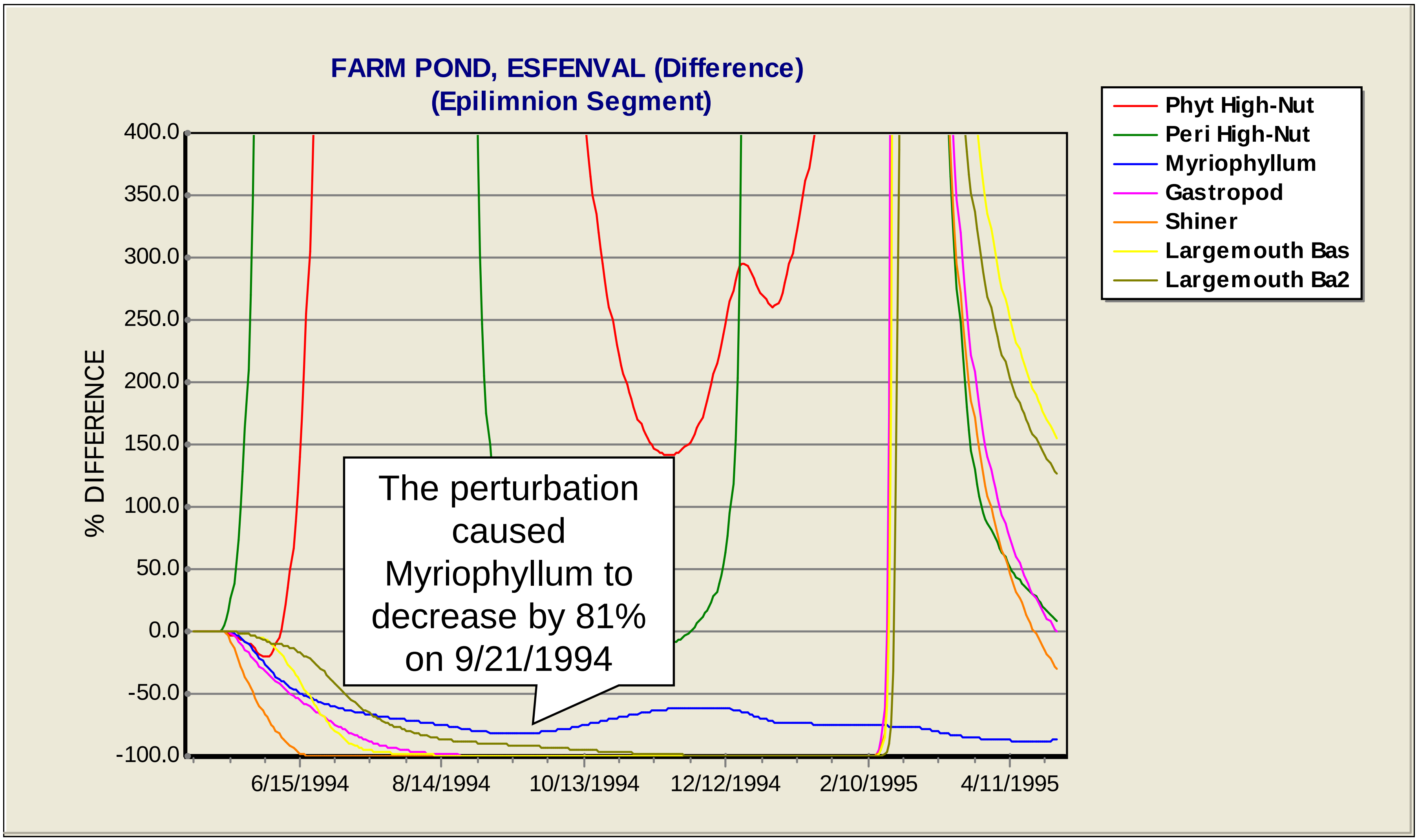

## Graph Library saved within simulation



# Comparing Scenarios: the "Difference" Graph

Difference graph designed to capture the percent change in results due to perturbation:

$$\%\ Difference = \left( \frac{Result_{Perturbed} - Result_{Control}}{Result_{Control}} \right) \cdot 100$$



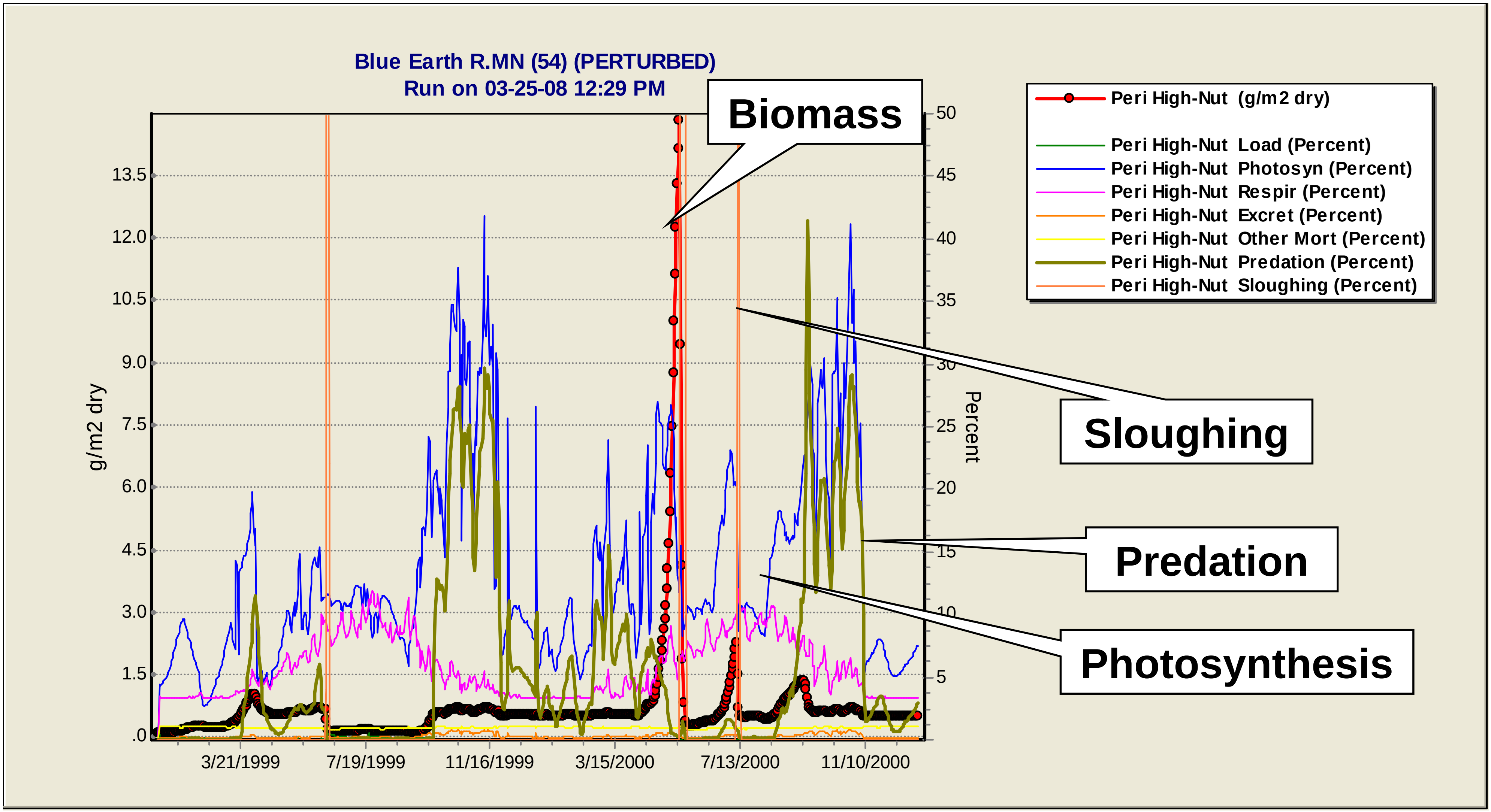
# Process Rates

- concentrations of state variables are solved using partial differential equations (Tech. Doc.)
- e.g. the equation for periphyton concentrations is

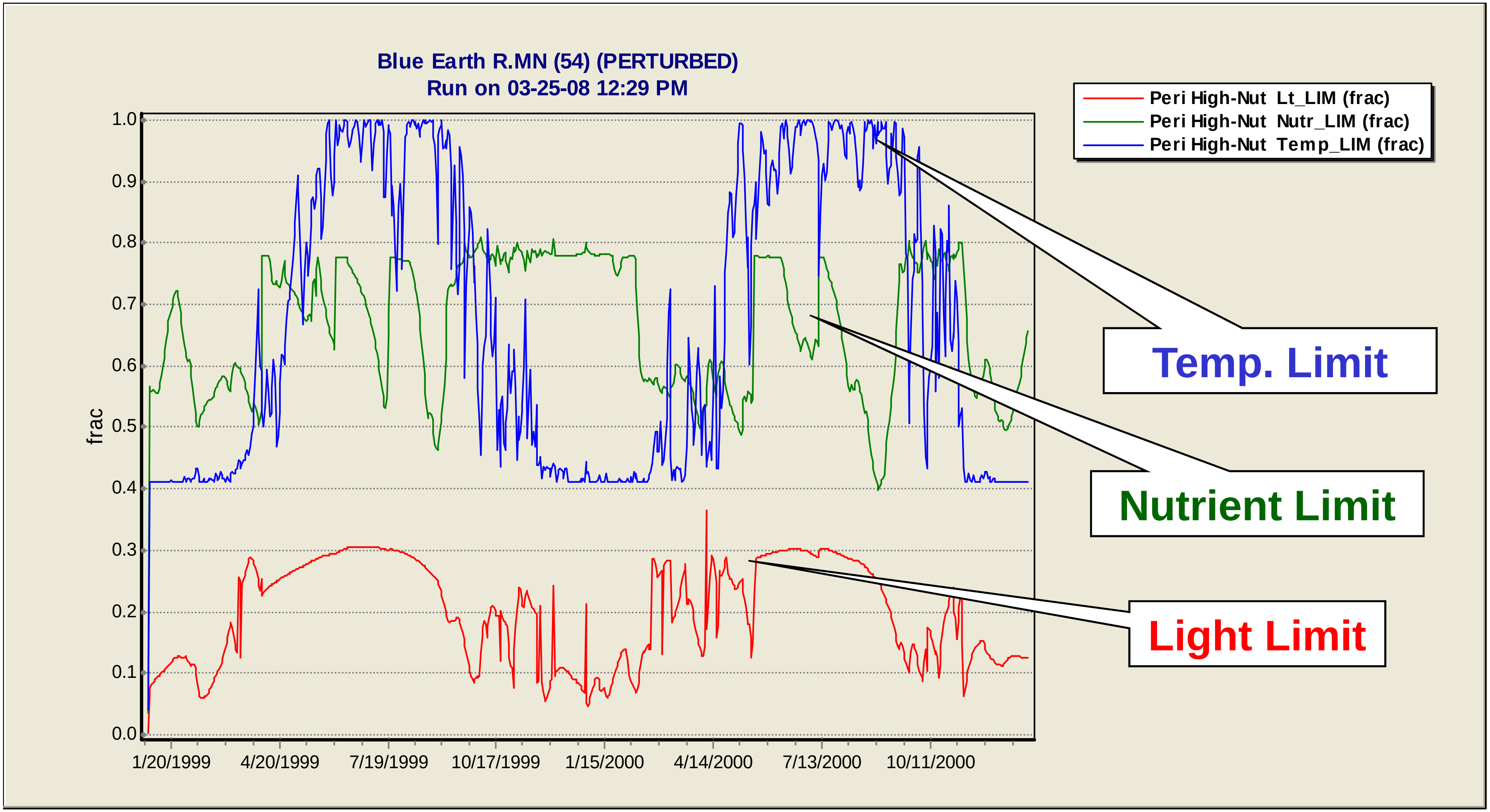
$$\frac{dBiomass_{Peri}}{dt} = Loading + Photosynthesis - Respiration - Excretion$$
$$- Mortality - Predation + Sed_{Peri}$$

- individual components of these equations may be saved internally, and graphed to understand the basis for various predictions

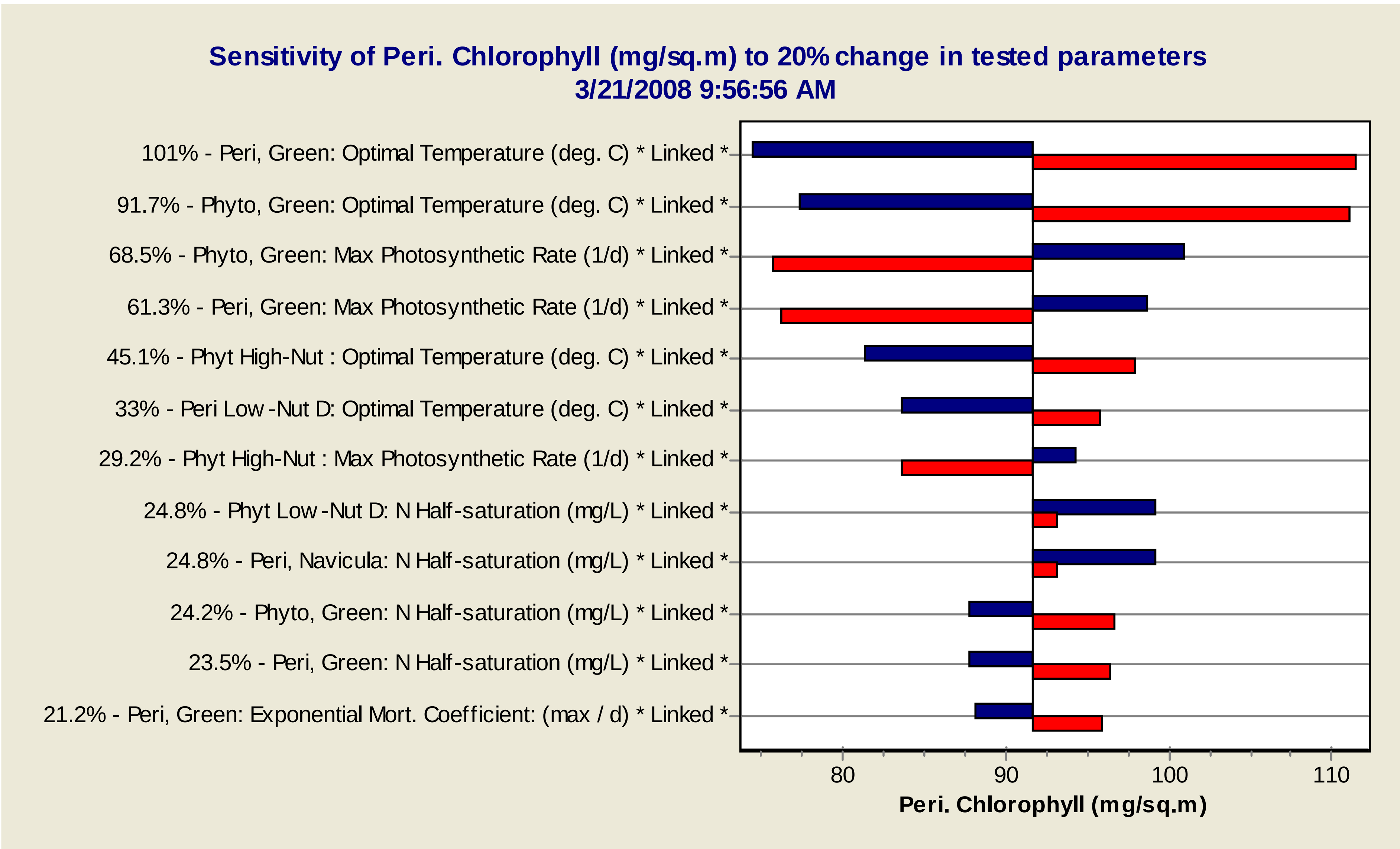
# Rates Plot Example: Periphyton



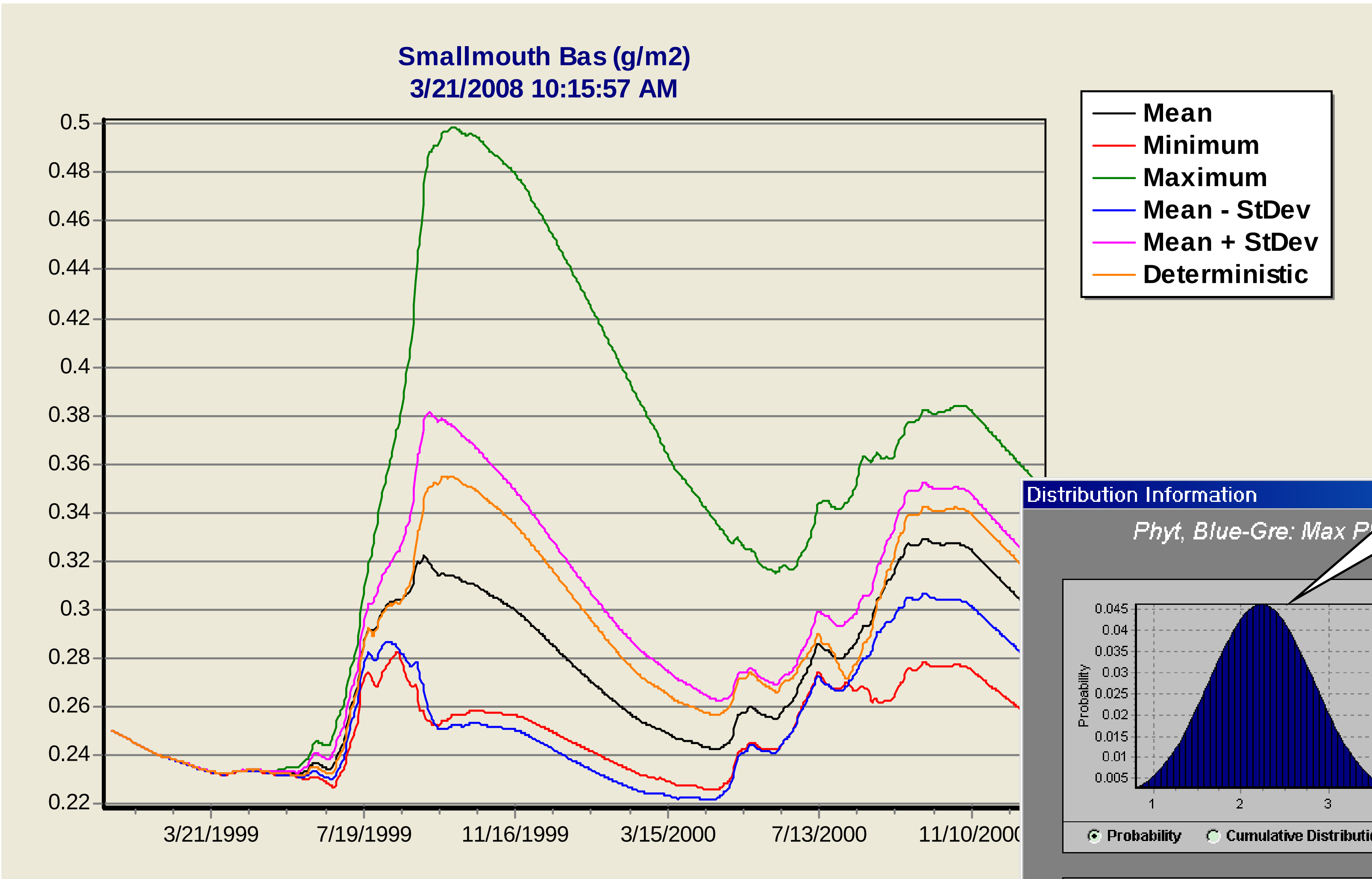
# Limitations to Photosynthesis May also be Graphed



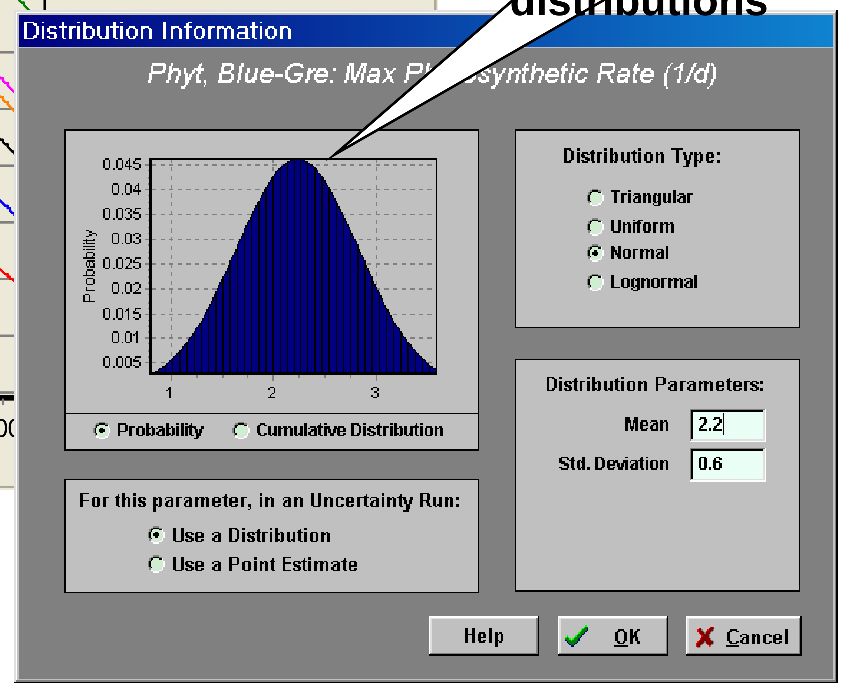
# Integrated Nominal Range Sensitivity Analysis with Graphics



# Integrated Latin Hypercube Uncertainty Analysis with Graphics




**can represent all "point estimate" parameters as distributions**



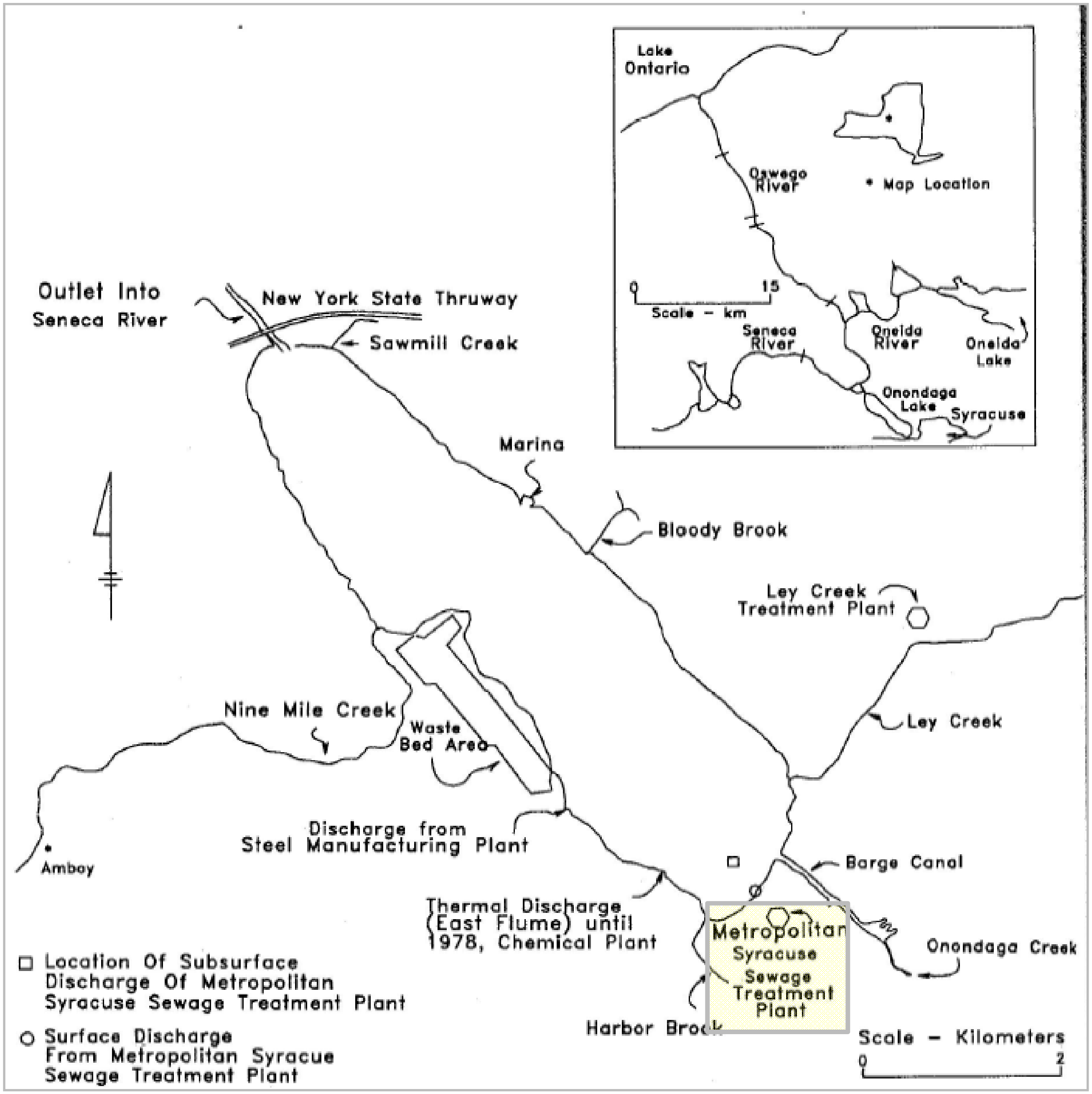
# Applications in Nutrient Analysis

- Lake Onondaga, NY
- Rum, Blue Earth, Crow Wing Rivers, MN
- Cahaba River, AL
- Lower Boise River, ID
- Lake Tenkiller, OK

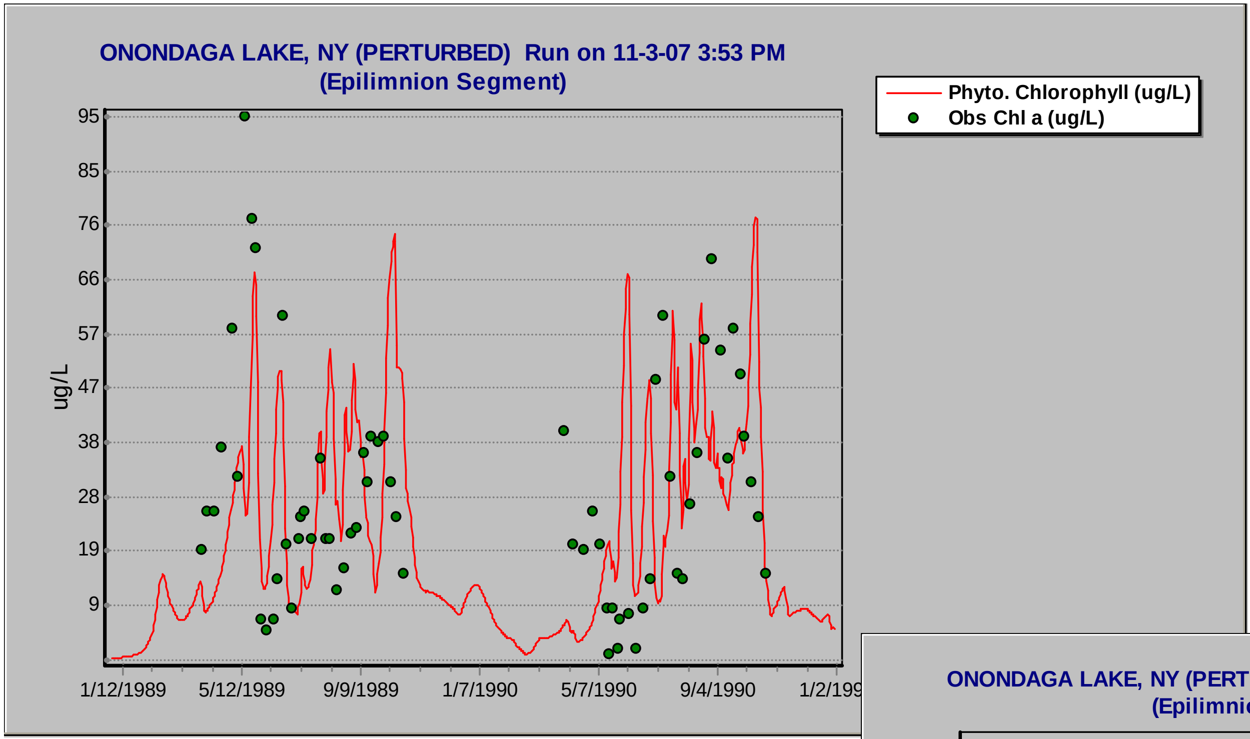
# Lake Onondaga, NY

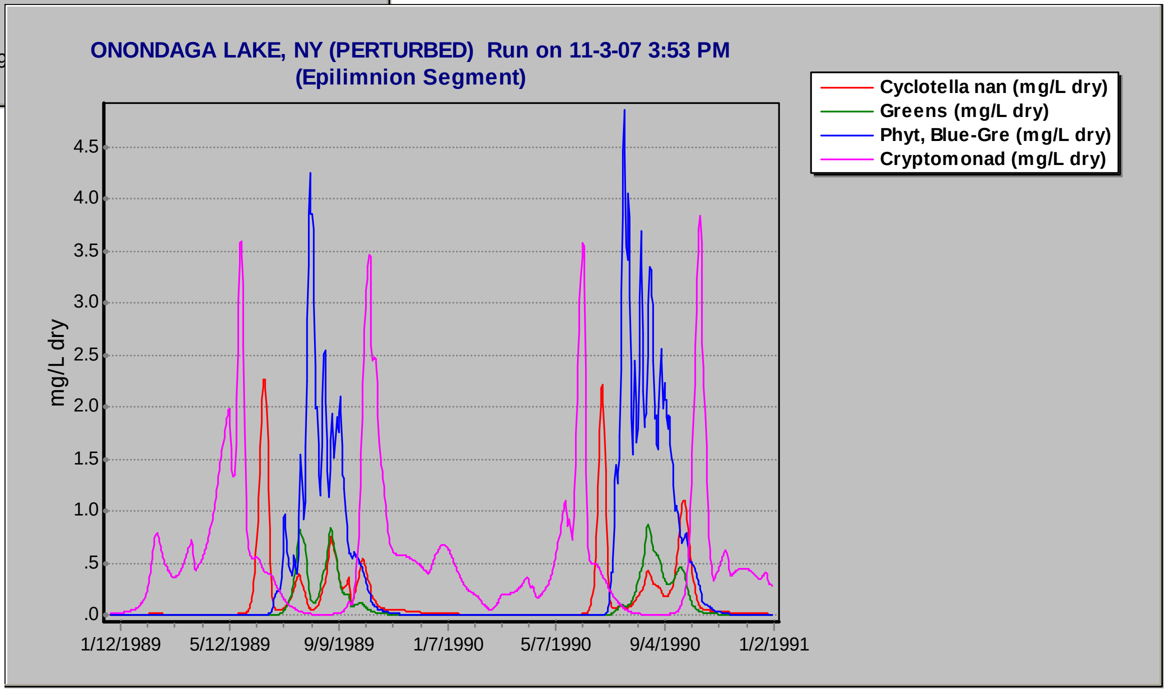
- AQUATOX Validation Site
- "Most polluted lake in U.S."
  - nutrient inputs from wastewater treatment plant ("Metro") & combined sewers
  - successive algal blooms
  - hypoxia in hypolimnion
  - build-up of organic sediments in bottom
  - high mercury levels (not modeled at present)
  - high salinity

# Lake Onondaga NY, heavily polluted



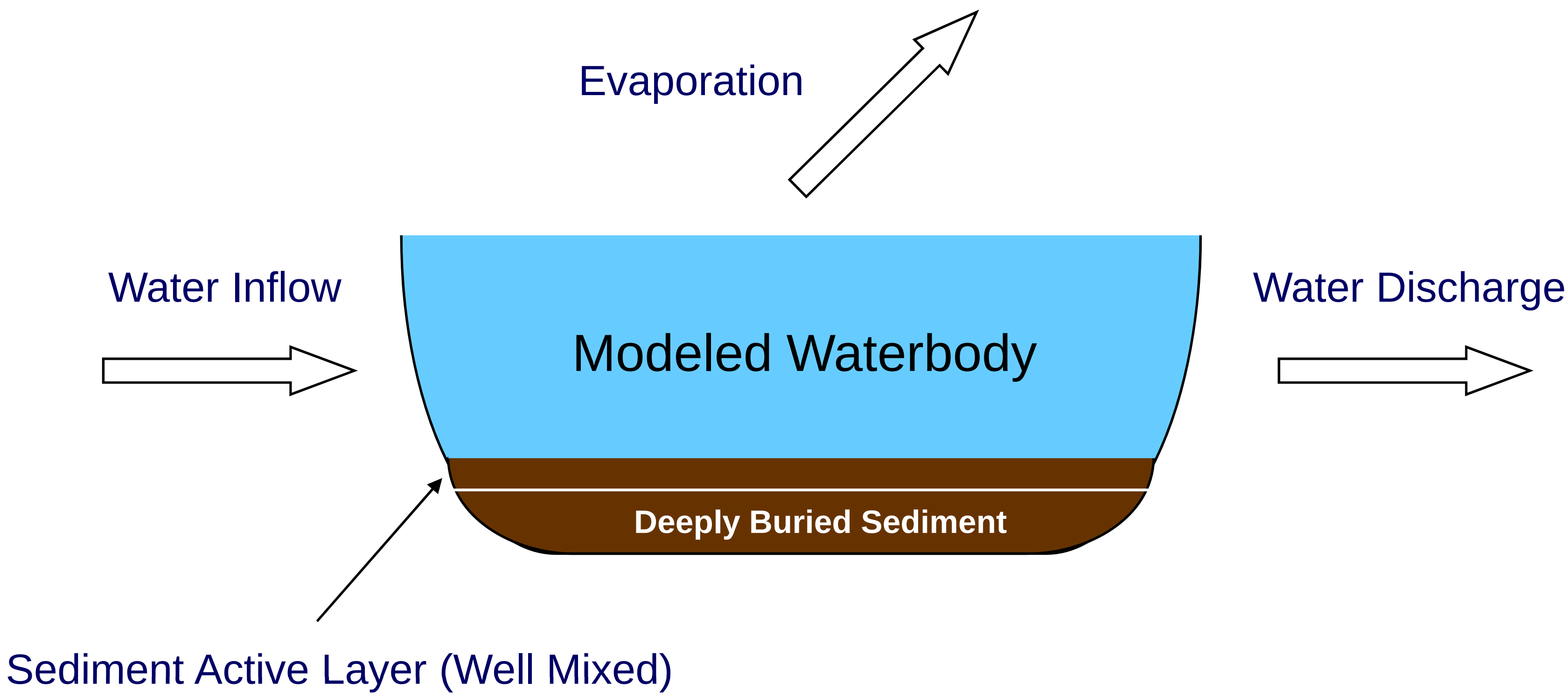
# Lake Onondaga is very productive with succession of algal groups



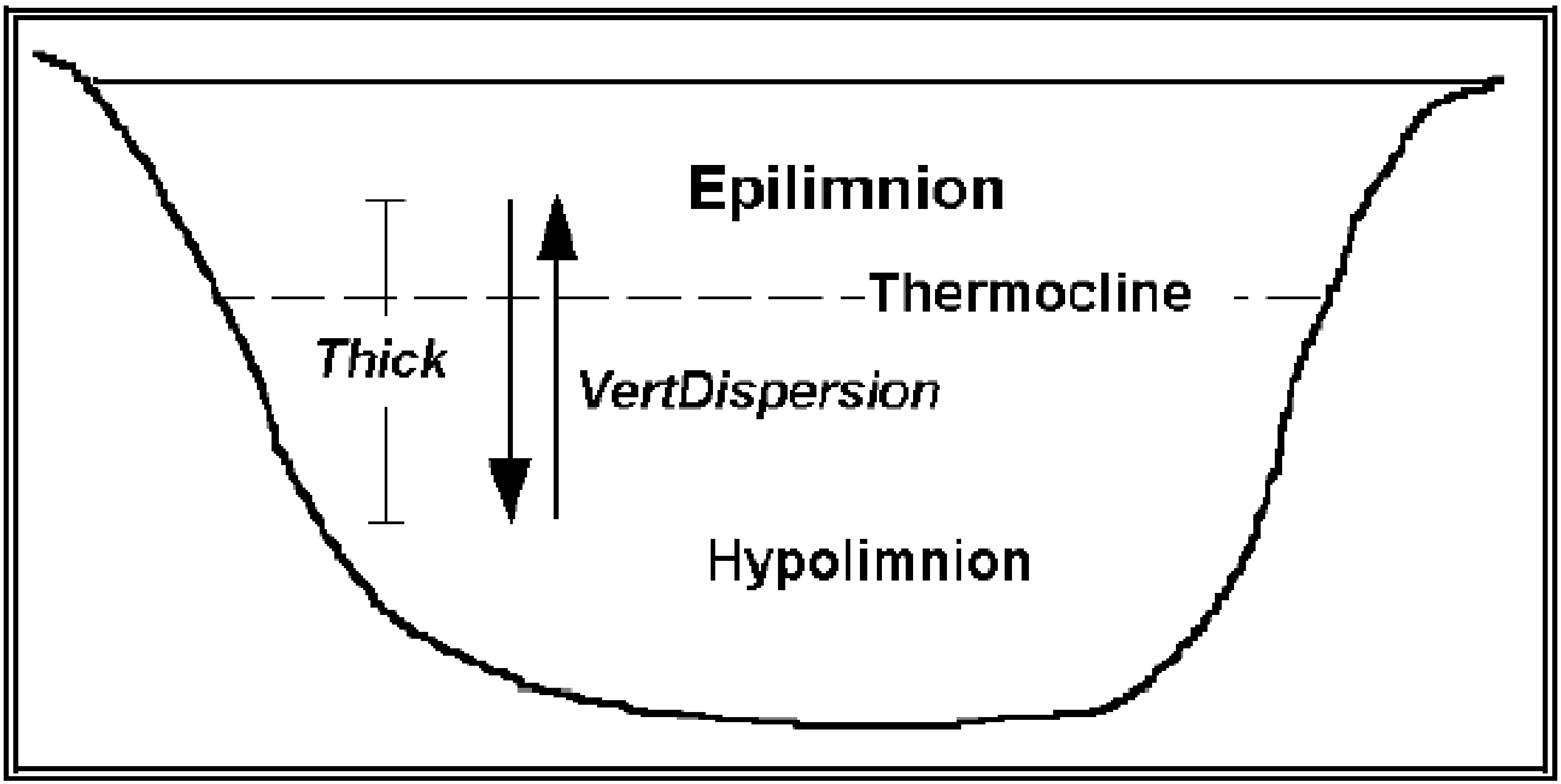



# Physical Characteristics of a Site

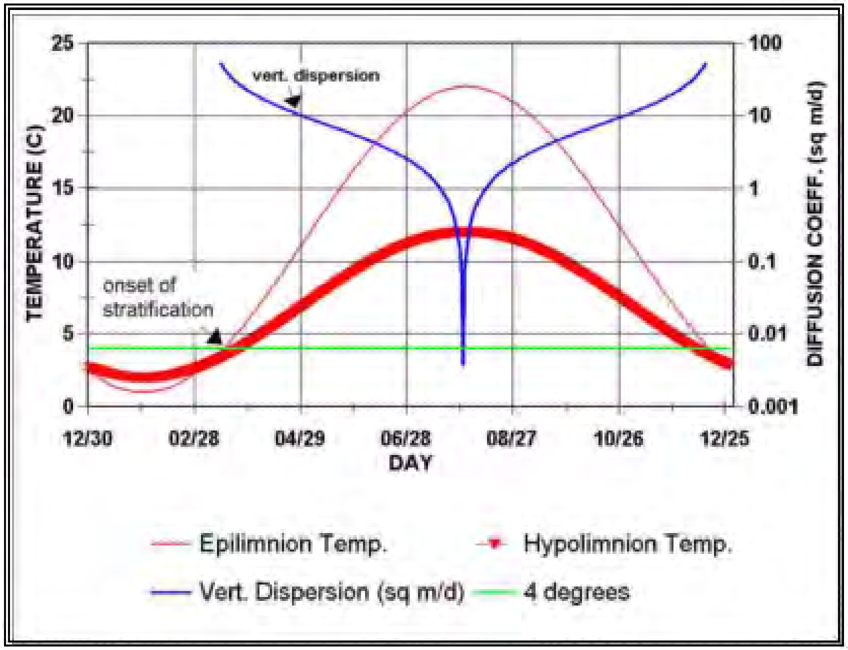
## Water Balance and Sediment Structure



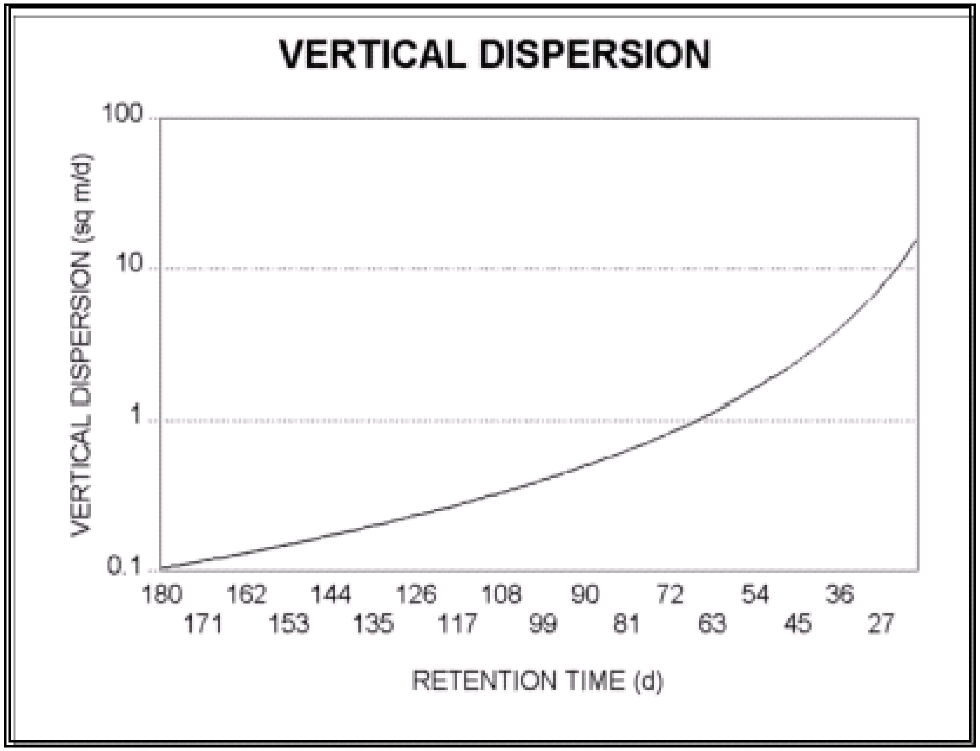
# Thermal Stratification in a Lake



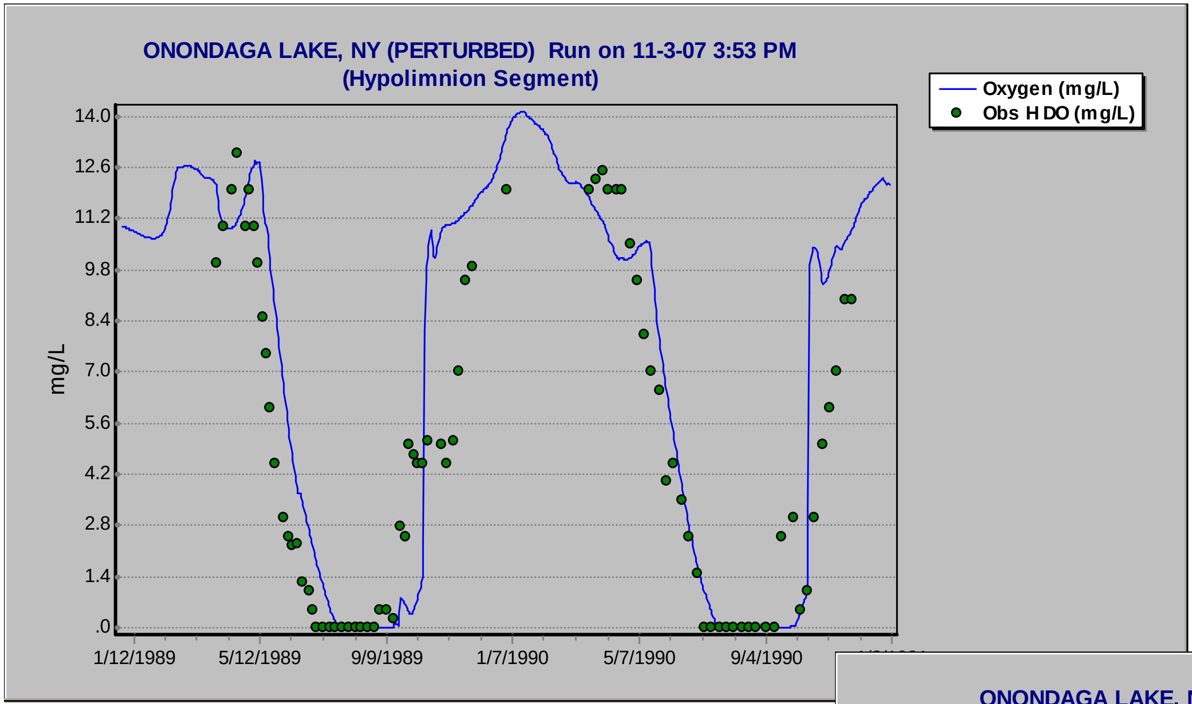
# Stratification is a Function of Temperature Differences

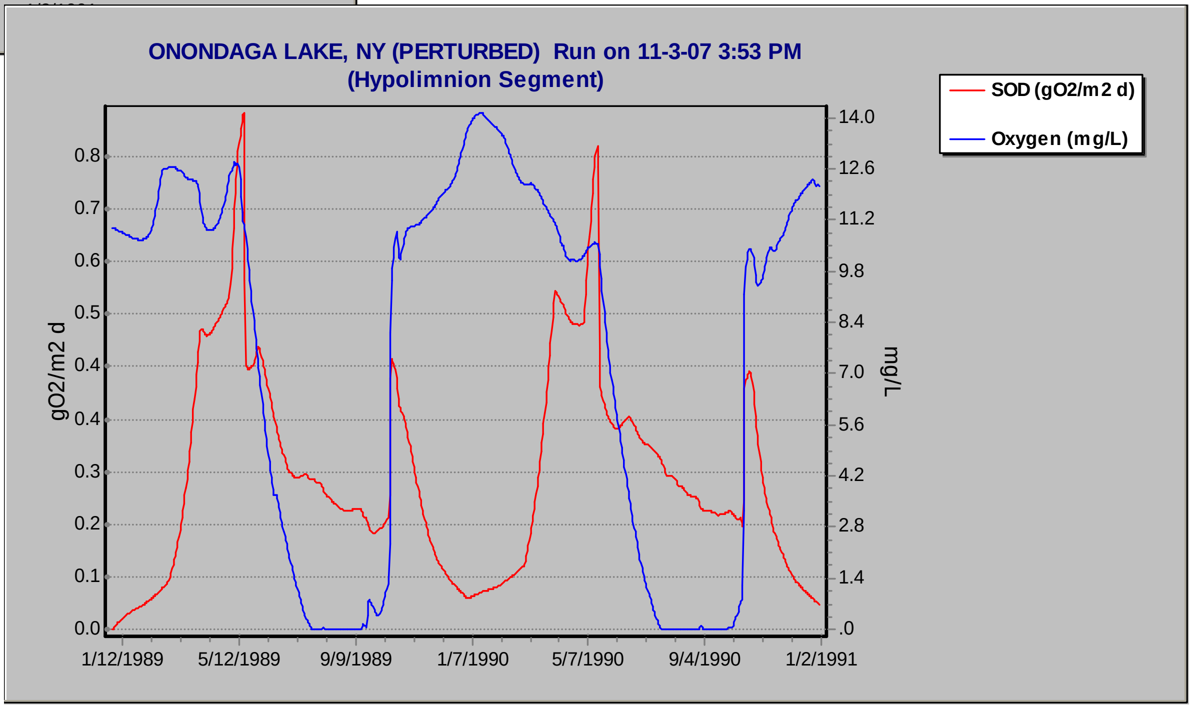



# Stratification is also a Function of Discharge

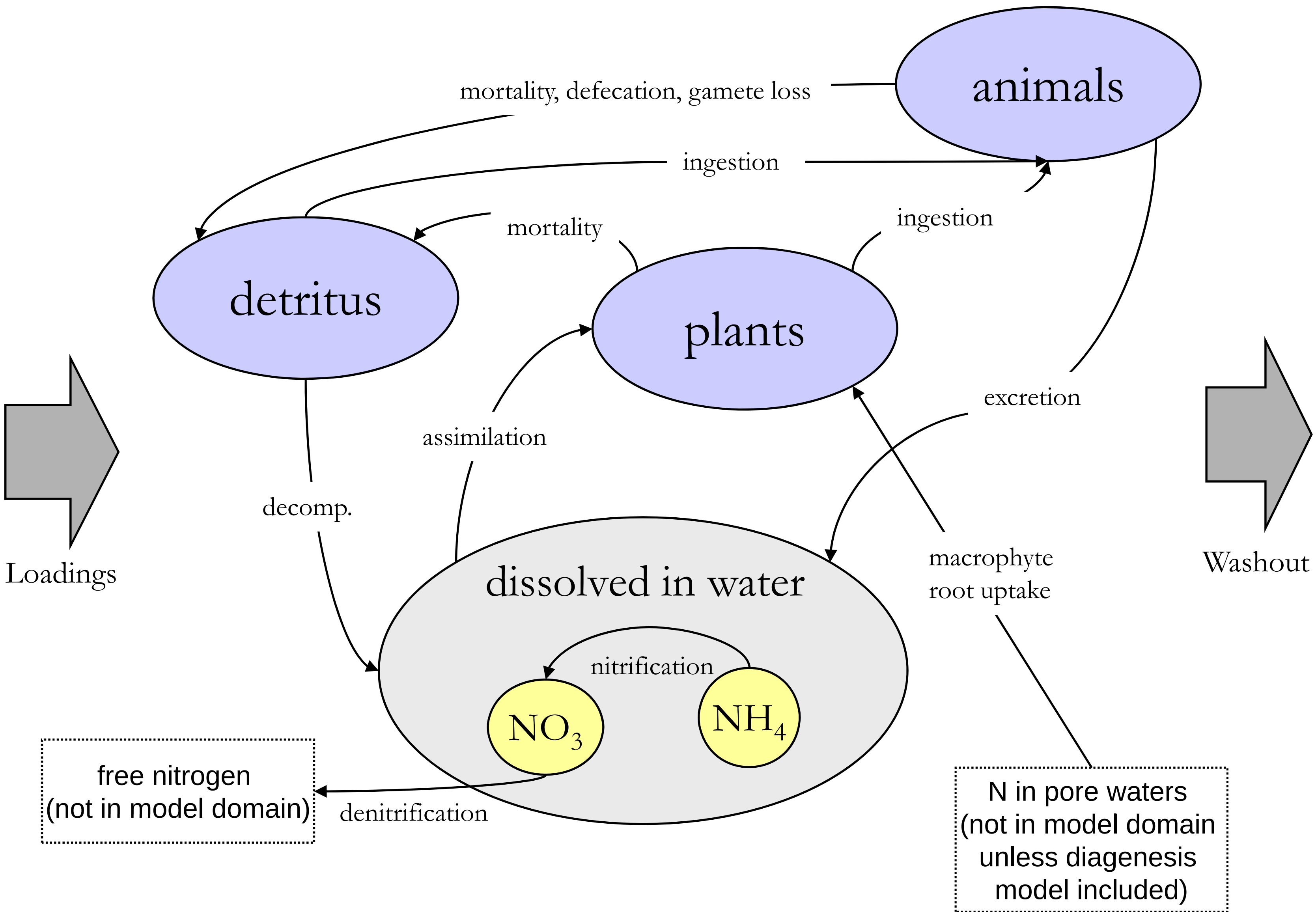


# Hypolimnion goes anoxic with high SOD



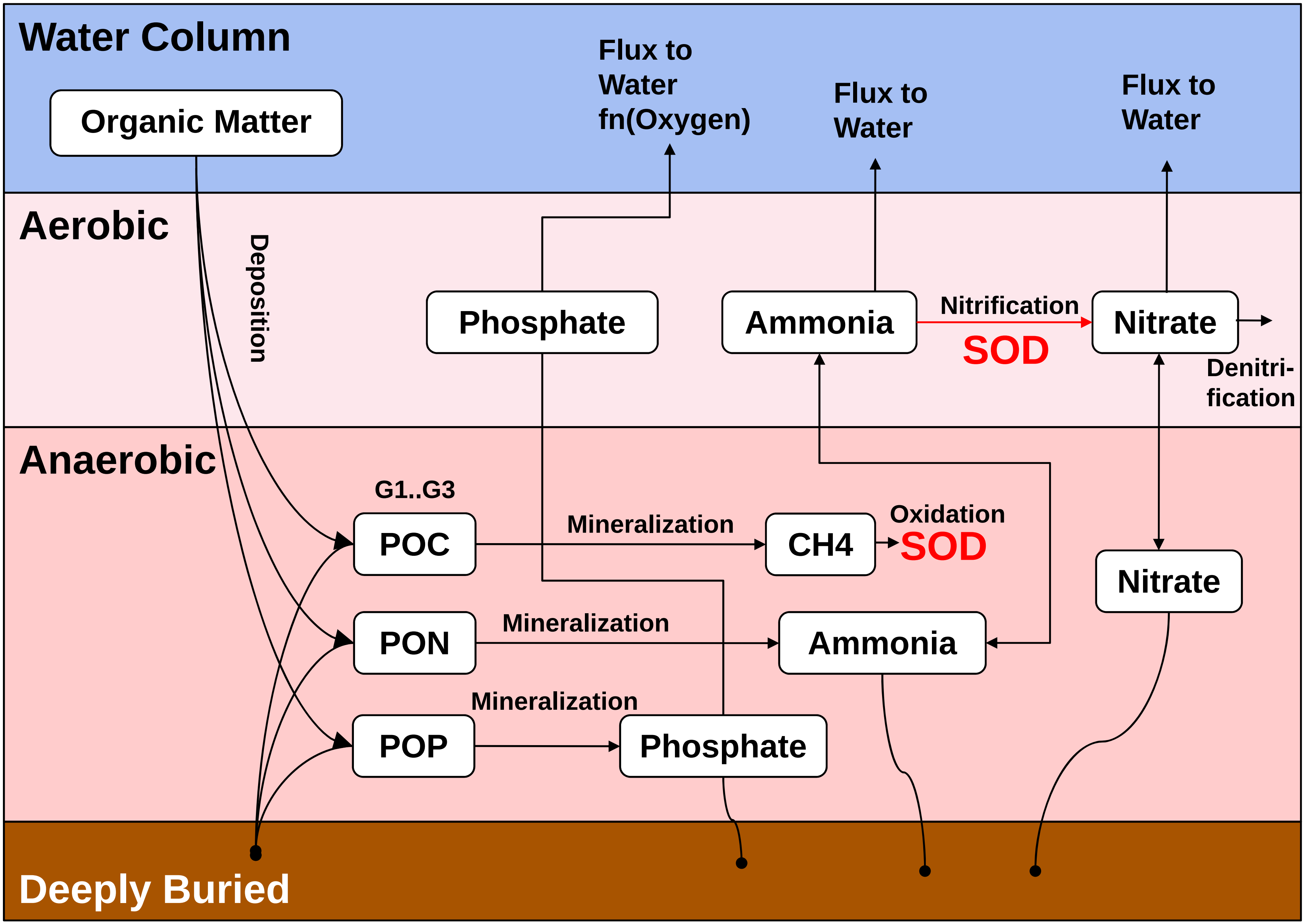



# Nutrient Cycle in AQUATOX (Nitrogen)



# Release 3: Optional Sediment Diagenesis Model

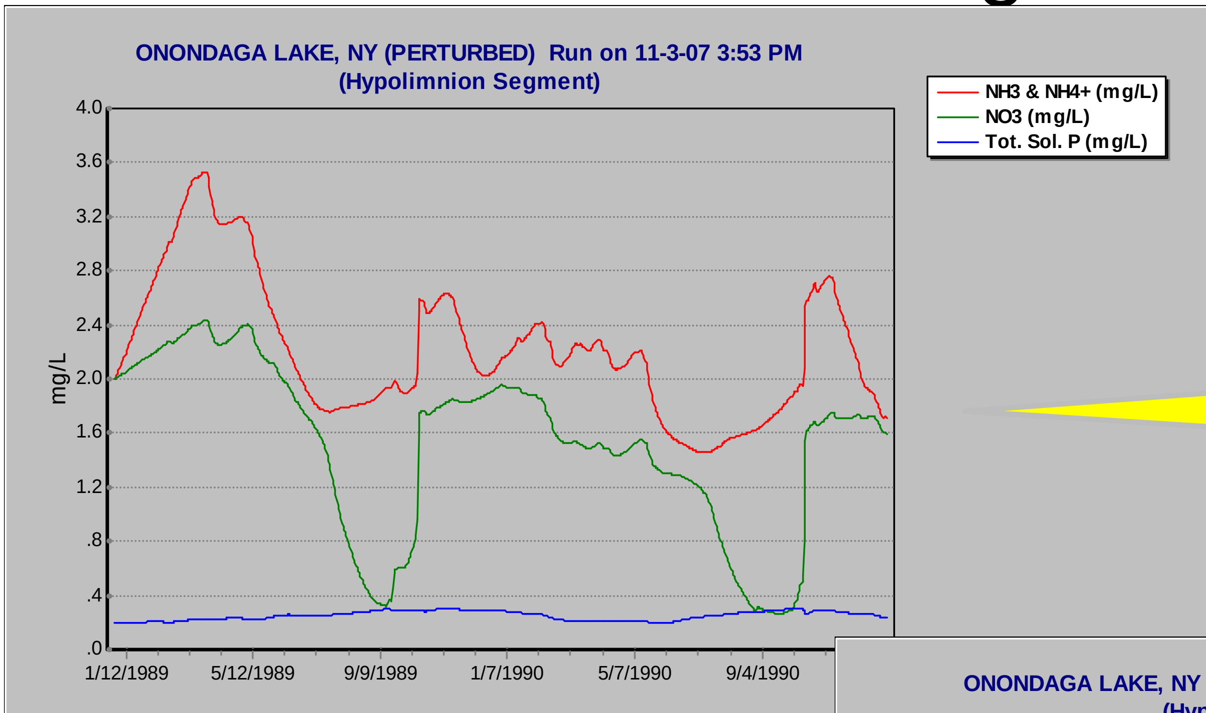
A complex model of nutrient regeneration in the sediment bed based on decay of POM and nutrient reactions in the pore waters (DiToro, 2001)



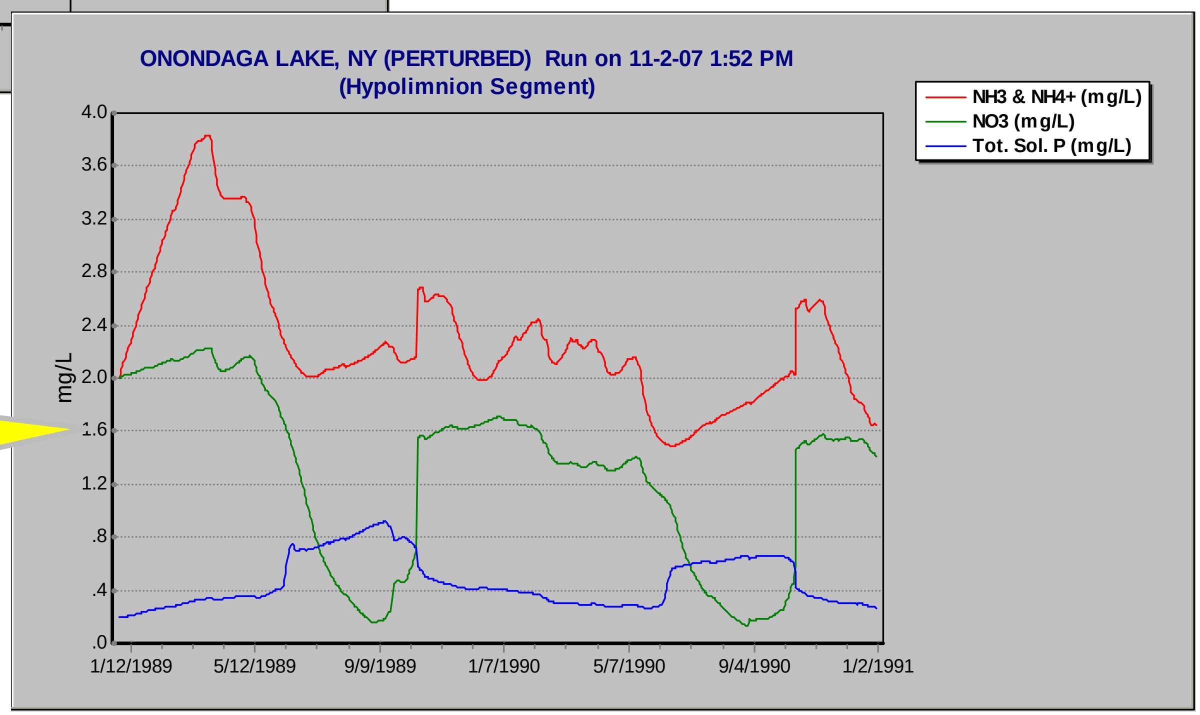
# Key Points: Diagenesis Model

- Two sediment layers: thin aerobic and thicker anaerobic
- When oxygen is present, the diffusion of phosphorus from sediment pore waters is limited
  - Strong P sorption to oxidated ferrous iron in the aerobic layer (iron oxyhydroxide precipitate)
  - Under conditions of anoxia, phosphorus flux from sediments dramatically increases.
- Sediment oxygen demand (SOD) a function of specific chemical reactions following the decomposition of organic matter
  - methane or sulfide production
  - nitrification of ammonia

# Hypolimnion $PO_4$ is better modeled by sediment diagenesis model




"Classic" AQUATOX model

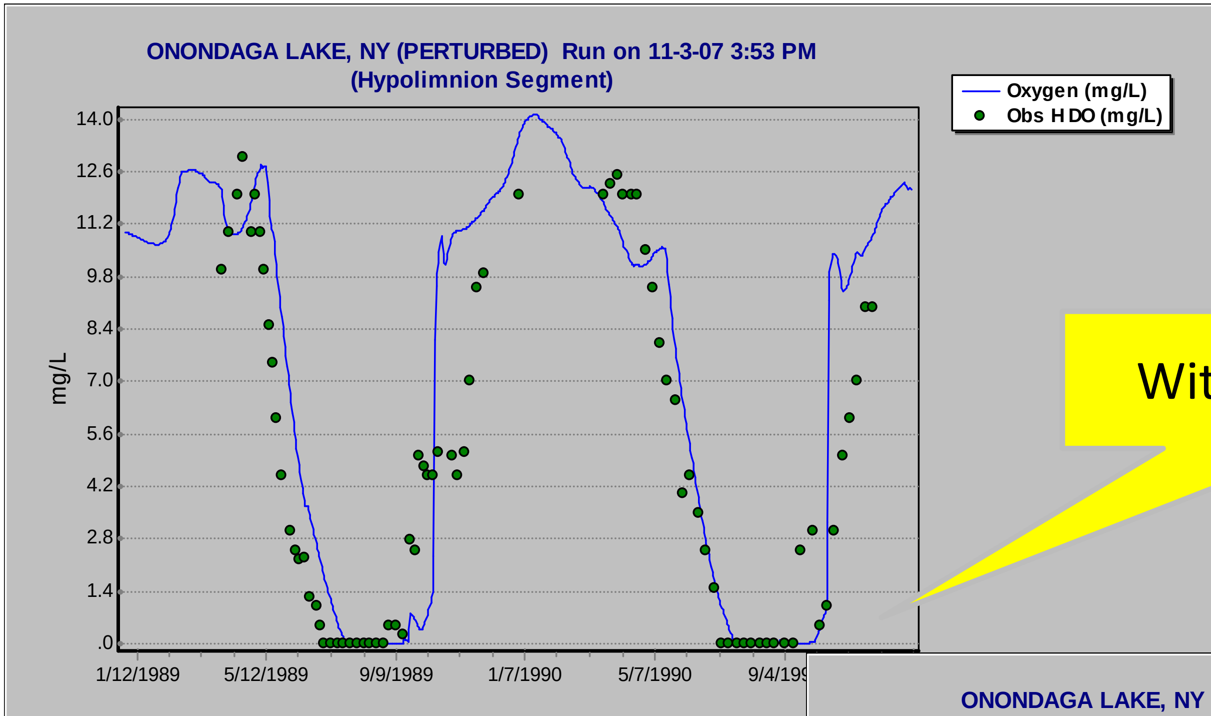



Sediment diagenesis model

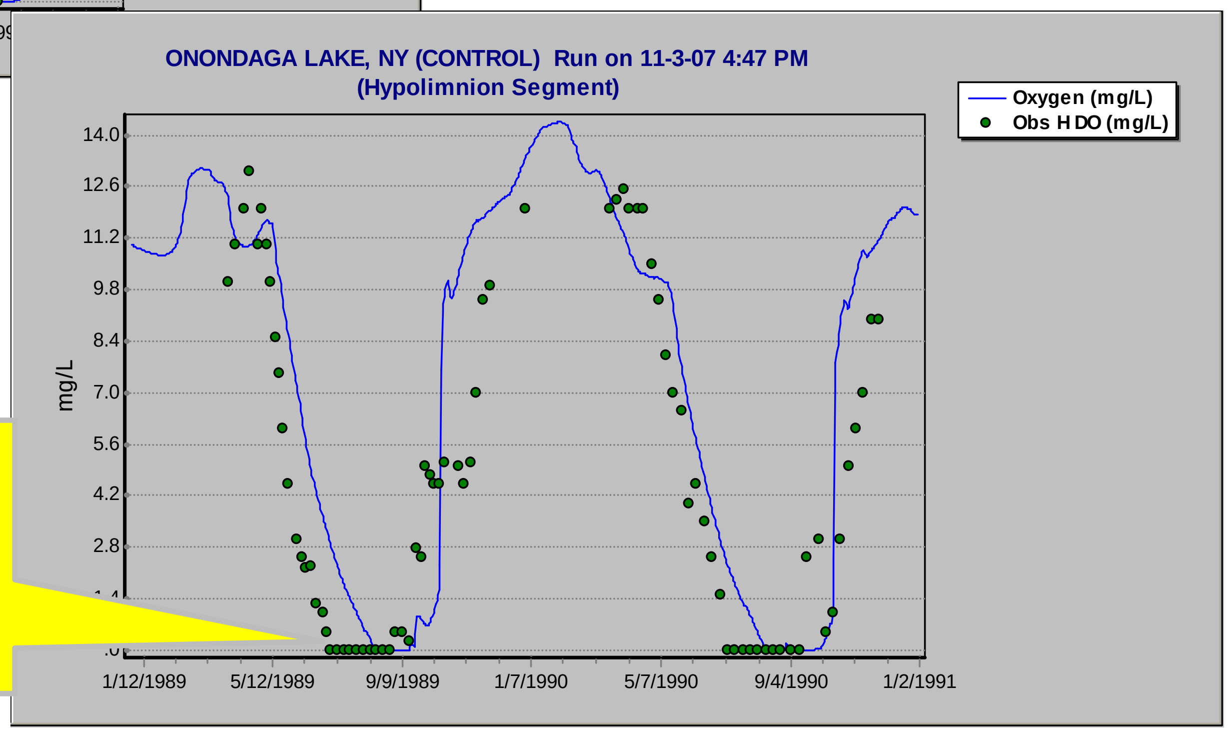
# Nutrient Effects on Simulations

- Direct effects on algal growth rates
  - Maximum growth rates often limited by nutrients
  - Degree of limitation may be tracked and plotted
- Indirect repercussions throughout the foodweb due to bottom-up effects
- Light climate changes due to algal blooms
- Algal composition will be affected
- Decomposition of organic matter affects oxygen concentrations

# What if Metro WWTP effluent were diverted?

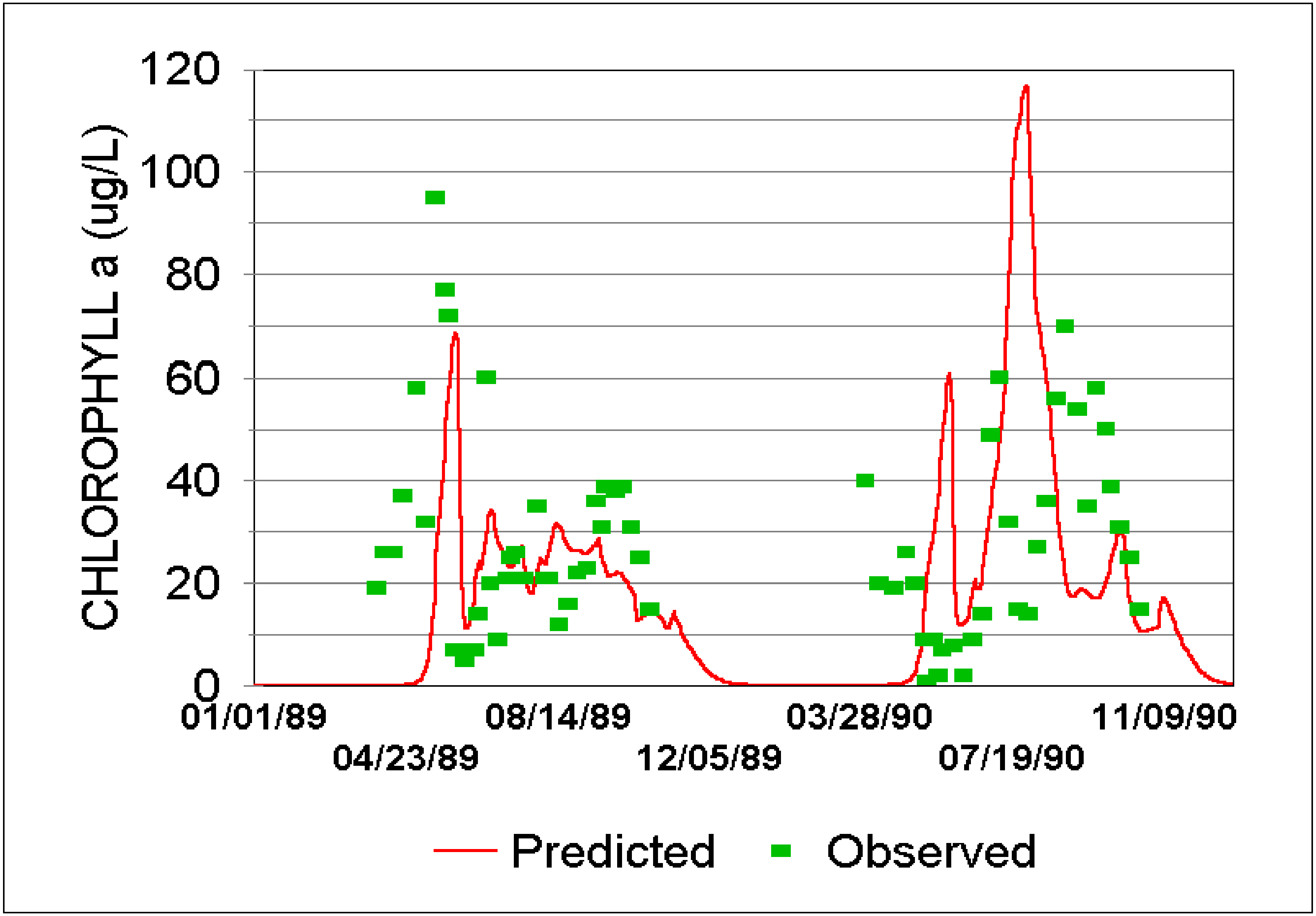



With Metro effluent

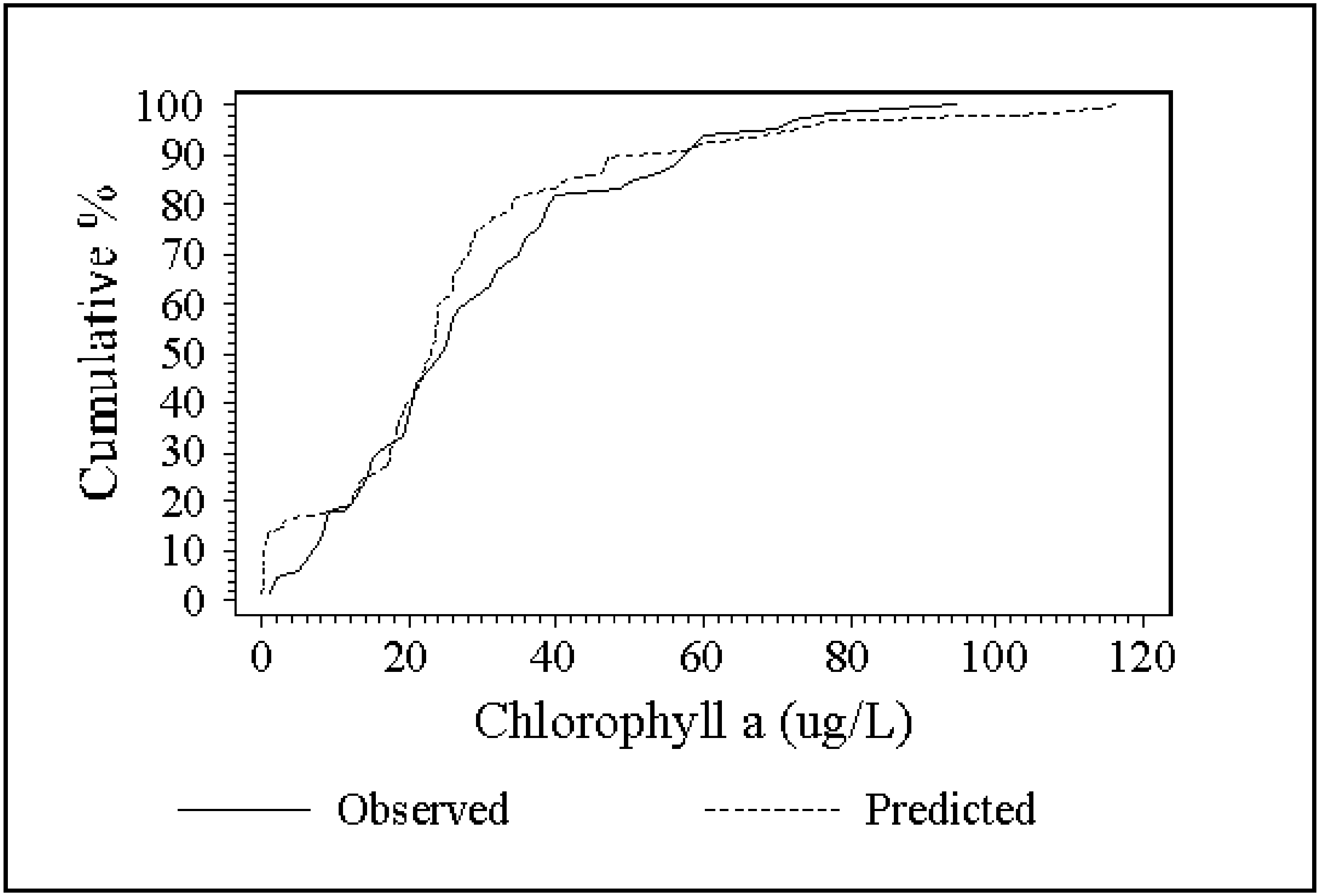



With Metro diversion, in first 2 years anoxia is delayed 1 month

# Validation of AQUATOX with Lake Onondaga Data—visual test



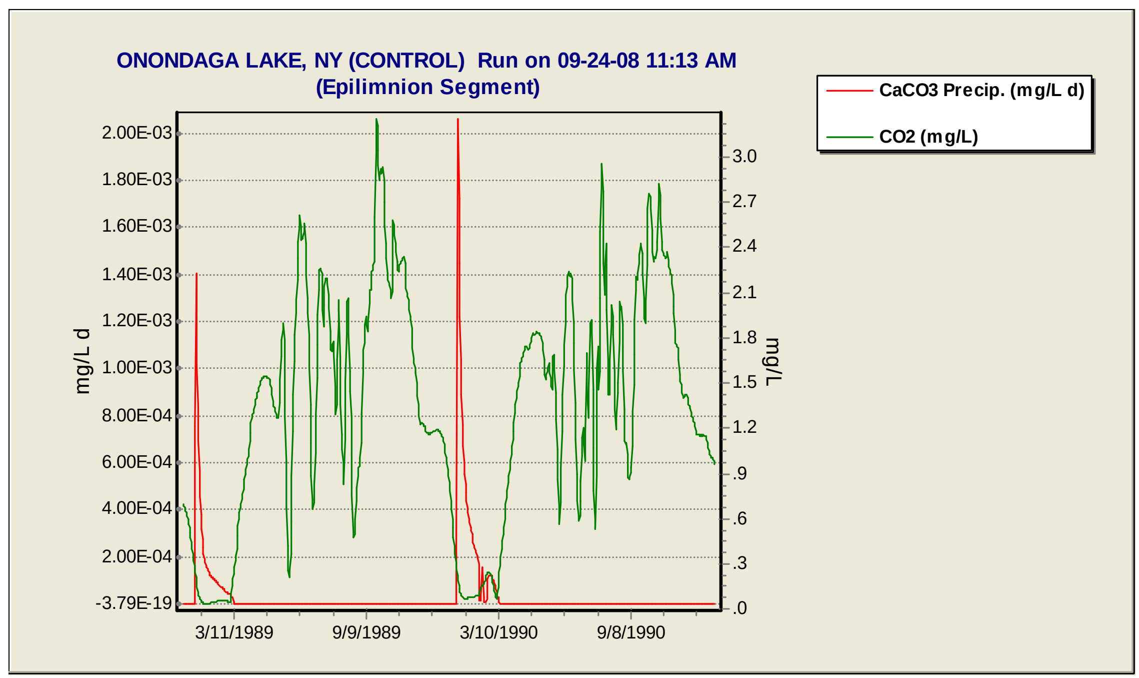
# Validation with chlorophyll a in Lake Onondaga, NY



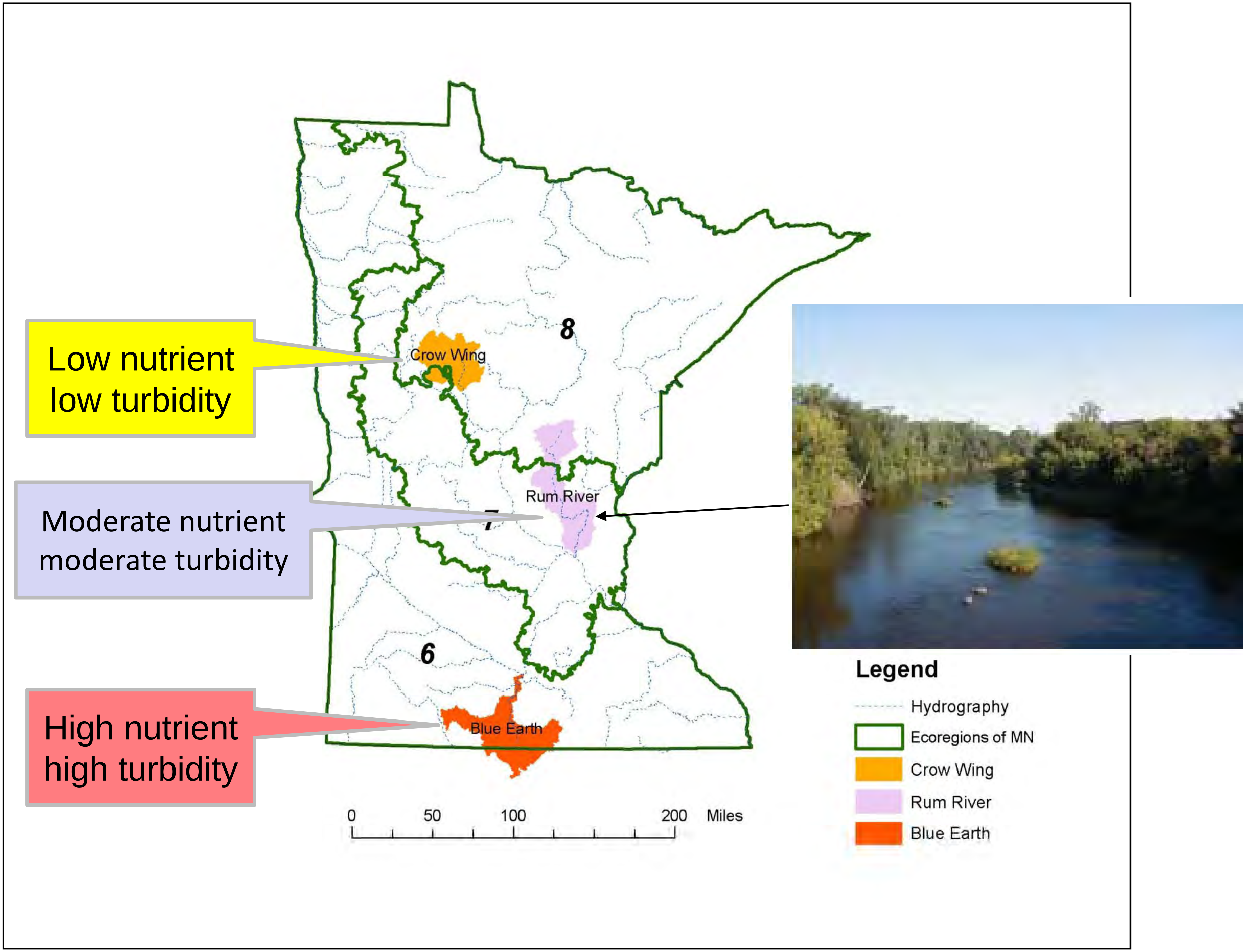

*Kolmogorov-Smirnov p statistic = 0.319 (not sign. different)*

# Release 3 Addition: Calcium Carbonate Precipitation

- Predicted as a function of pH and algae type
  - When pH exceeds 8.25, precipitation is predicted
  - Precipitation rate is dependent on photosynthesis rate in precipitating algae
- $CaCO_3$ sorbs phosphate from the water column



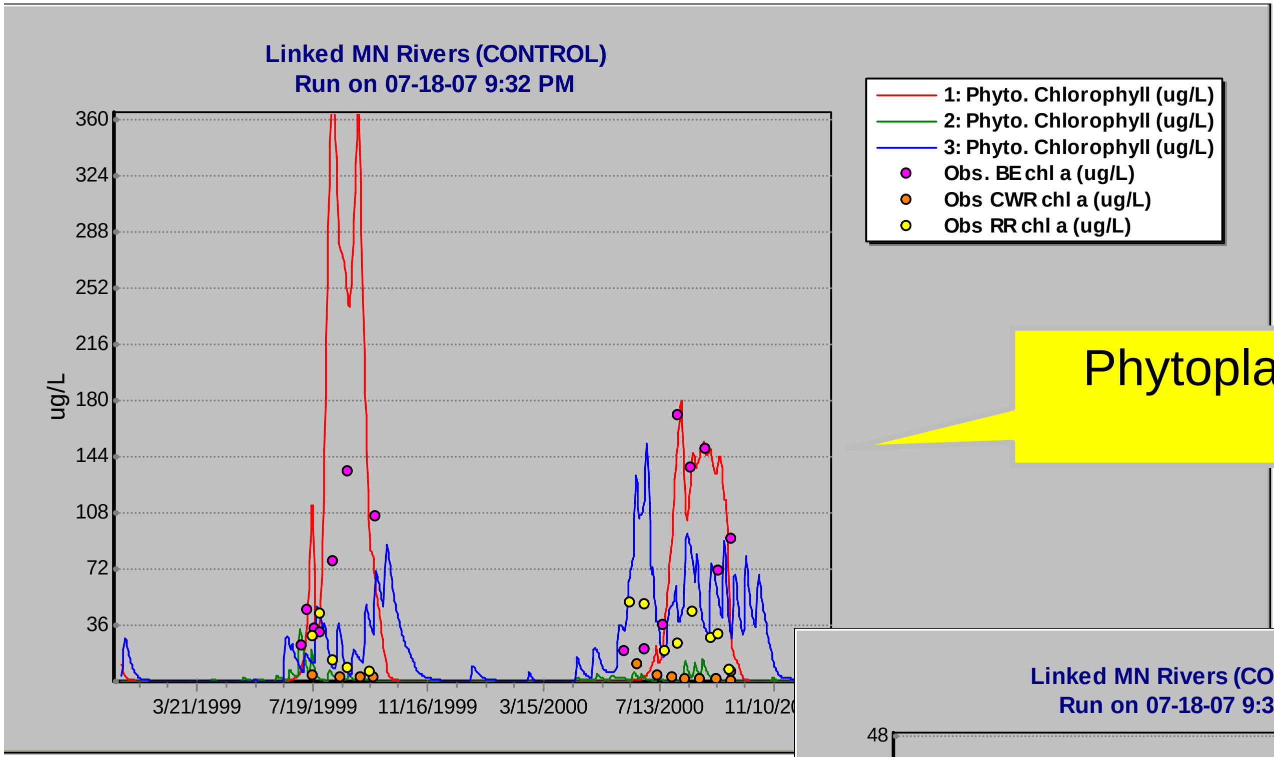
# Minnesota Nutrient Sites



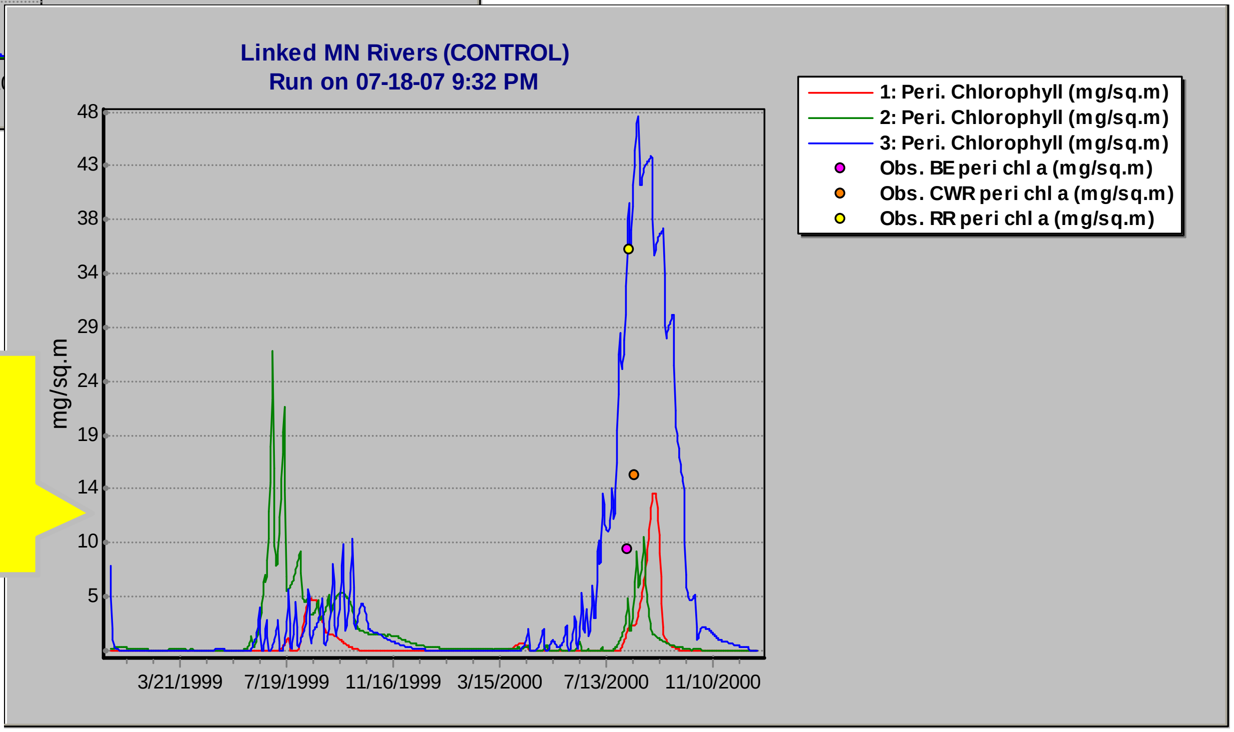
# Calibration Strategy for Minnesota Rivers

- Must be able to simulate *changing* conditions!
- Add plants and animals representative of both low- (Crow Wing) and high-nutrient (Blue Earth) rivers
- Iteratively calibrate key parameters for each site and cross-check to make sure they still hold for other site
- When goodness-of-fit is acceptable for both sites, apply to an intermediate site (Rum River) and reiterate calibration across all three sites
- Parameter set was validated with Cahaba River AL data

# Chlorophyll *a* Trends in MN Rivers




Phytoplankton follow nutrient trend




Periphyton reach maximum in Rum River with moderate nutrients and turbidity

# Modeling Phytoplankton

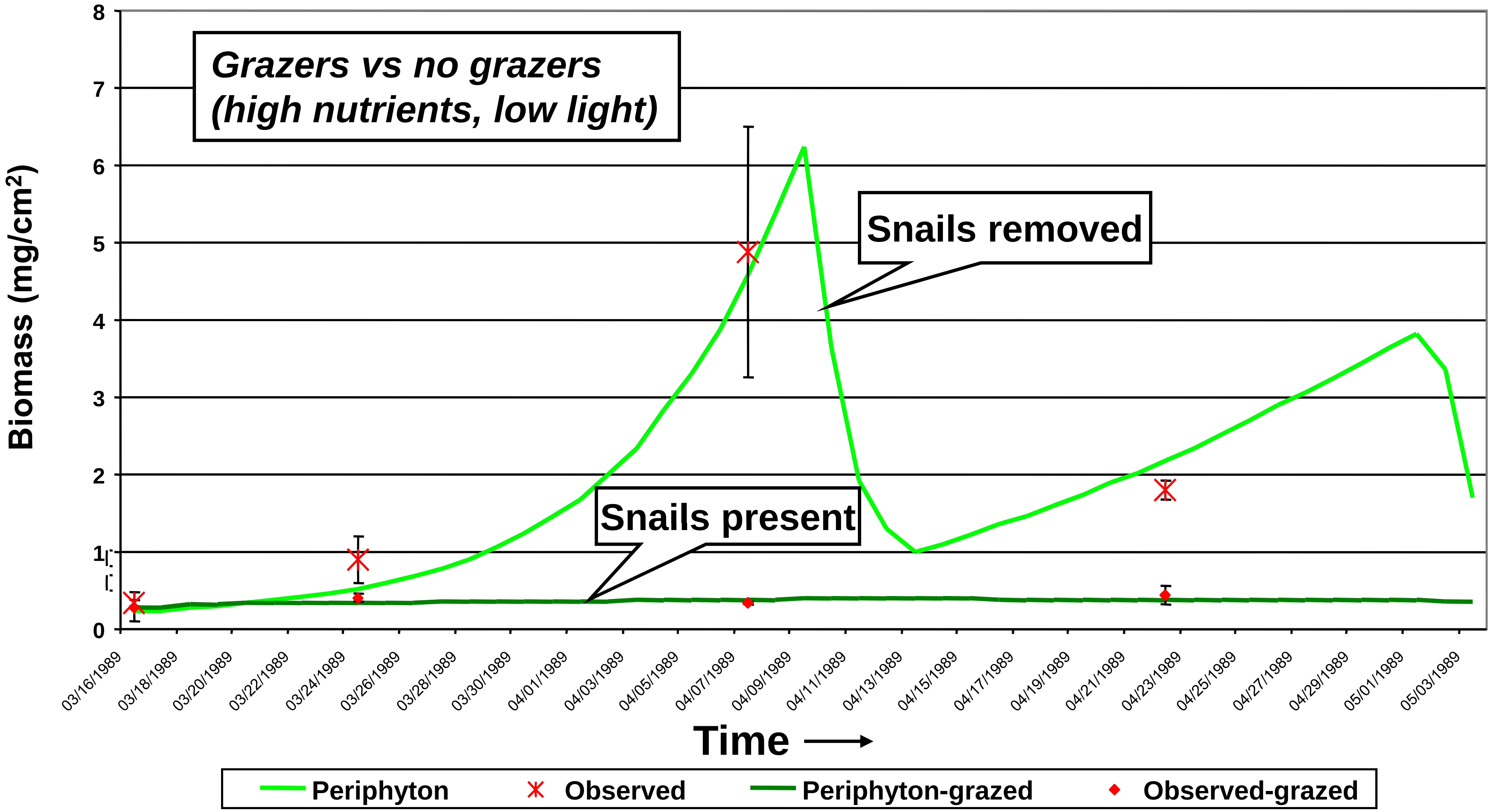
- Phytoplankton may be greens, blue-greens, diatoms or “other algae”
- Subject to sedimentation, washout, and turbulent diffusion
- In stream simulations, assumptions about flow and upstream production are important

# Modeling Periphyton

- Periphyton are not simulated by most water quality models
- Periphyton are difficult to model
  - include live material and detritus
  - stimulated by nutrients
  - snails & other animals graze it heavily
  - riparian vegetation reduces light to stream
  - build-up of mat causes stress & sloughing, *even at relatively low velocity*
- Many water body impairments due to periphyton

# Several Independent Factors Affect Periphyton

**One important factor is Grazing by Snails**



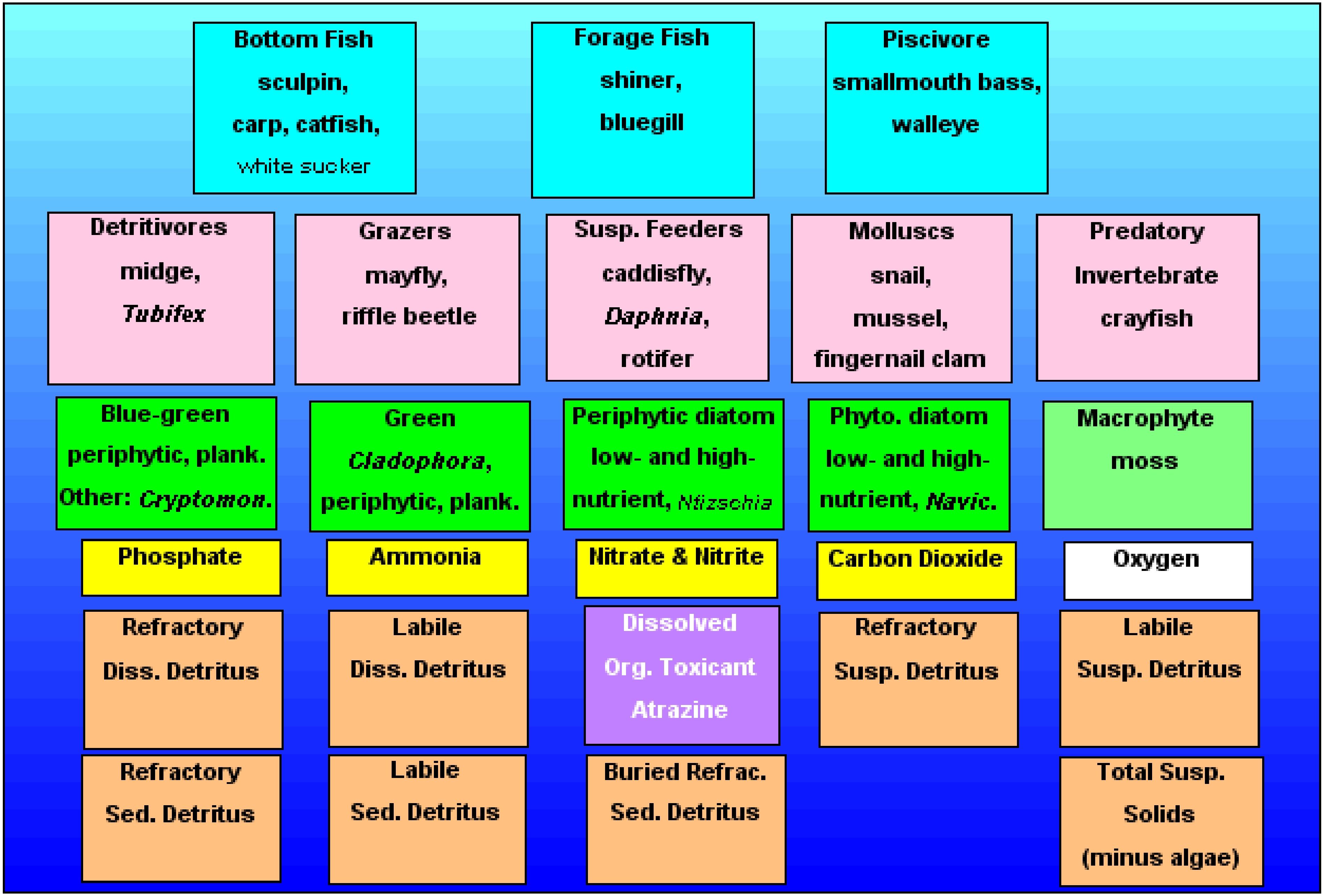
# Modeling Macrophytes

- Macrophytes may be specified as benthic, rooted-floating, or free-floating
- Macrophytes can have significant effect on light climate and other algae communities
- Root uptake of nutrients is assumed and mass balance tracked
- May act as refuge from predation for animals
- Moss are a special category

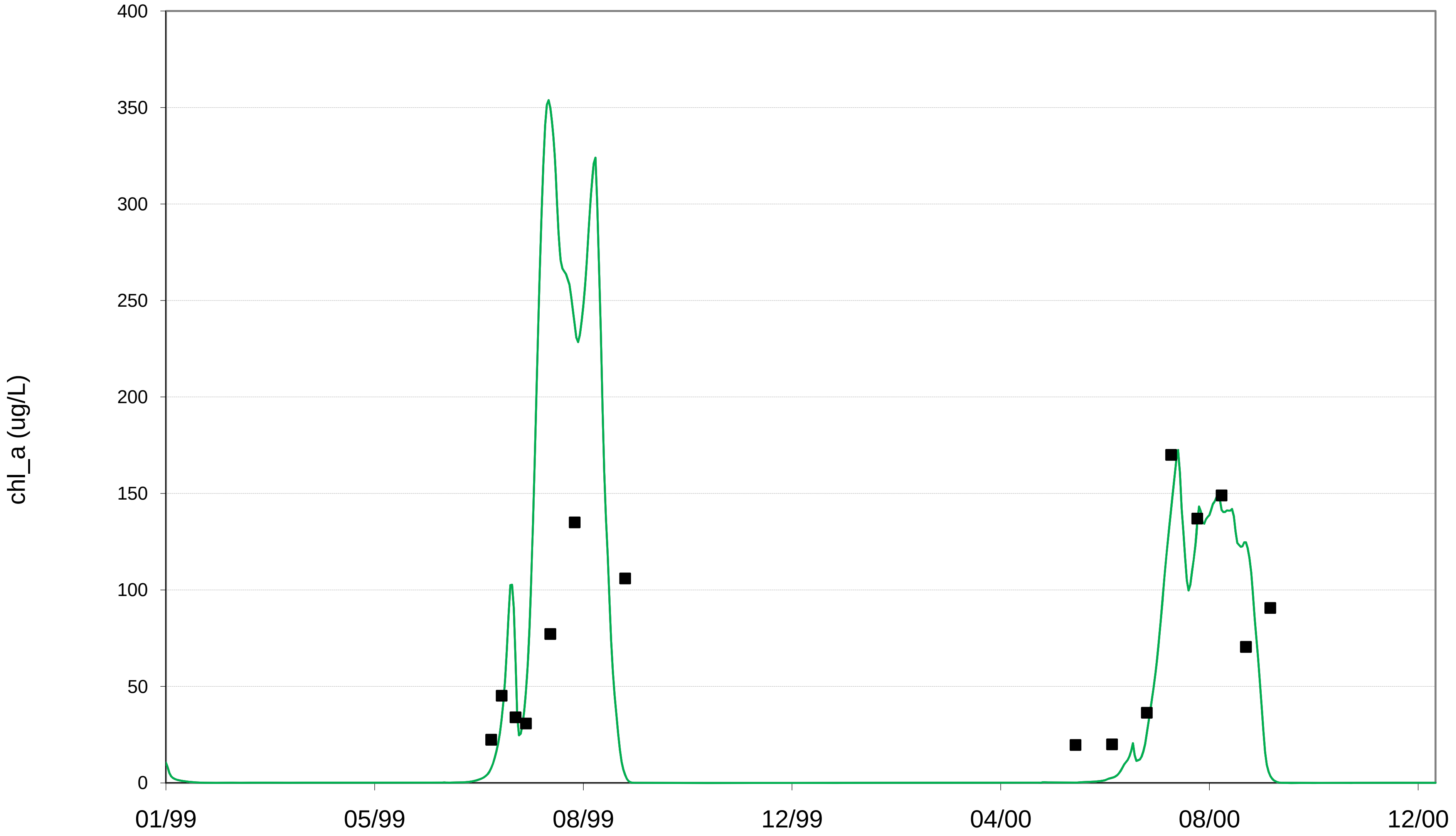
# Calibration of Plants

- algae are differentiated on basis of:
  - nutrient half-saturation values
  - light saturation values
  - maximum photosynthesis
- MN project has developed new parameter sets that span nutrient, light, and PMax
- phytoplankton sedimentation rates differ between running and standing water
- critical force for periphyton scour and TOpt may need to calibrated for other sites

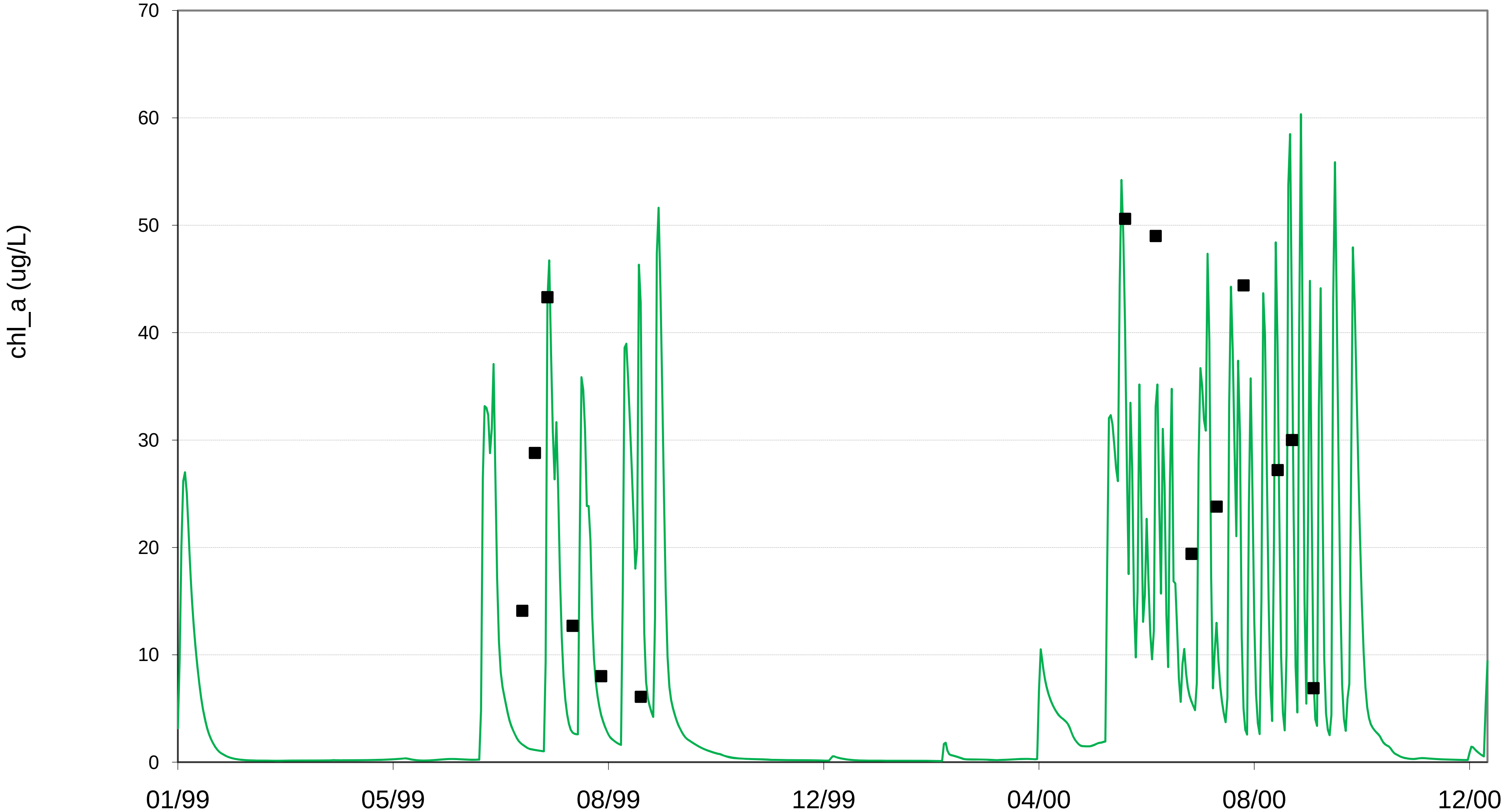
# State variables in MN rivers simulations



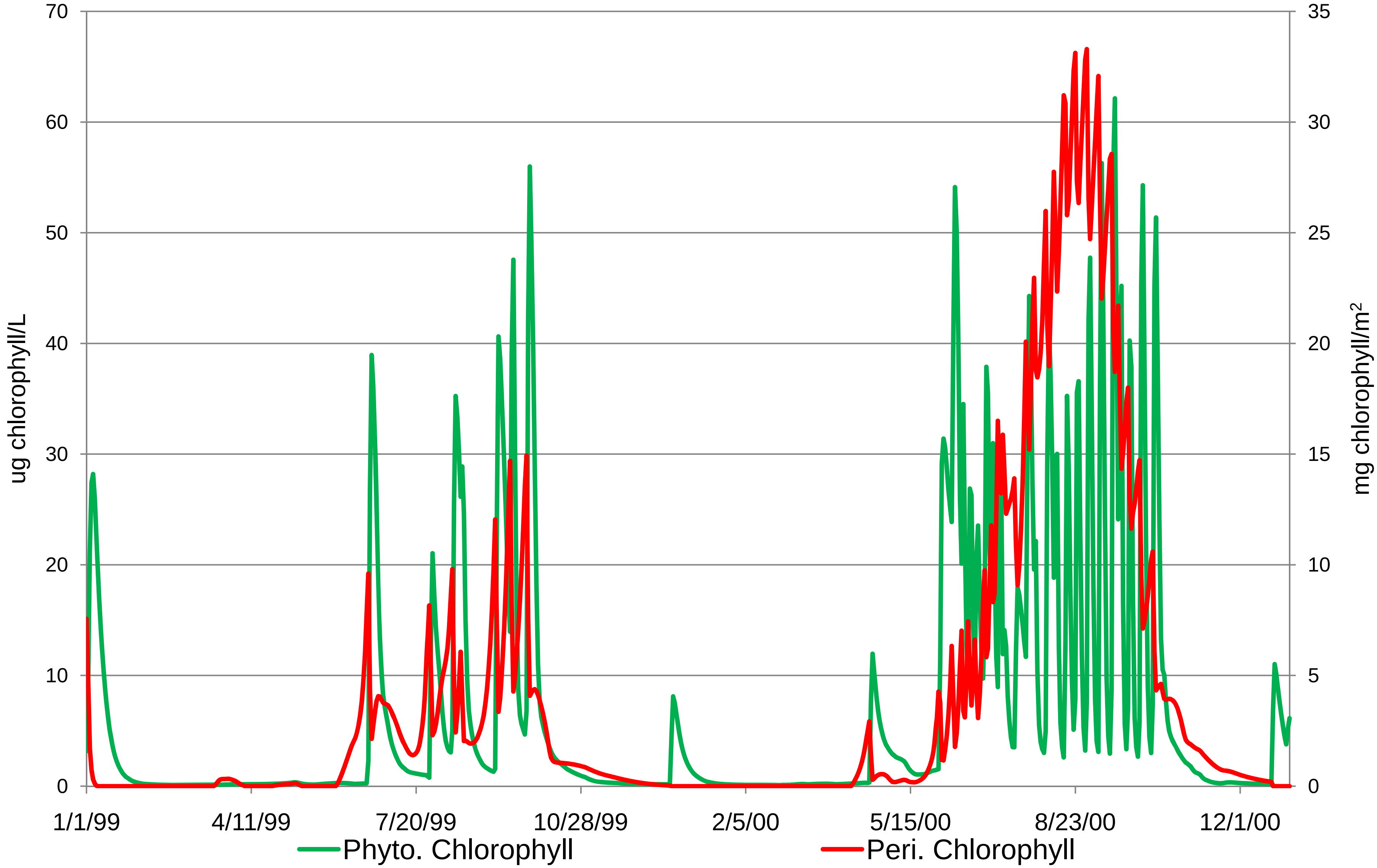
# Observed (symbols) and calibrated AQUATOX simulations (lines) of chlorophyll *a* in Blue Earth River at mile 54



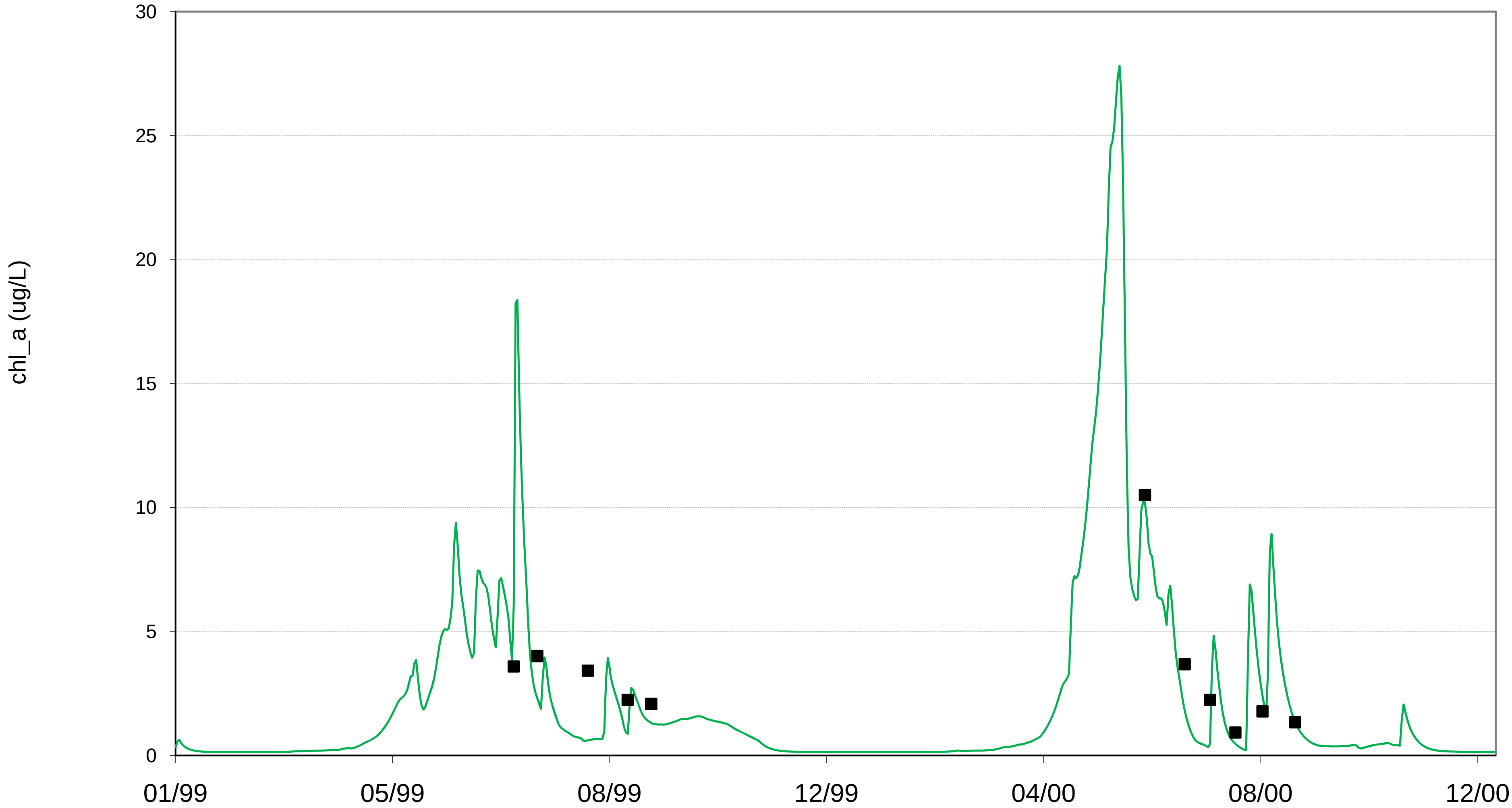
# Observed (symbols) and calibrated AQUATOX simulations (lines) of chlorophyll *a* in Rum River at mile



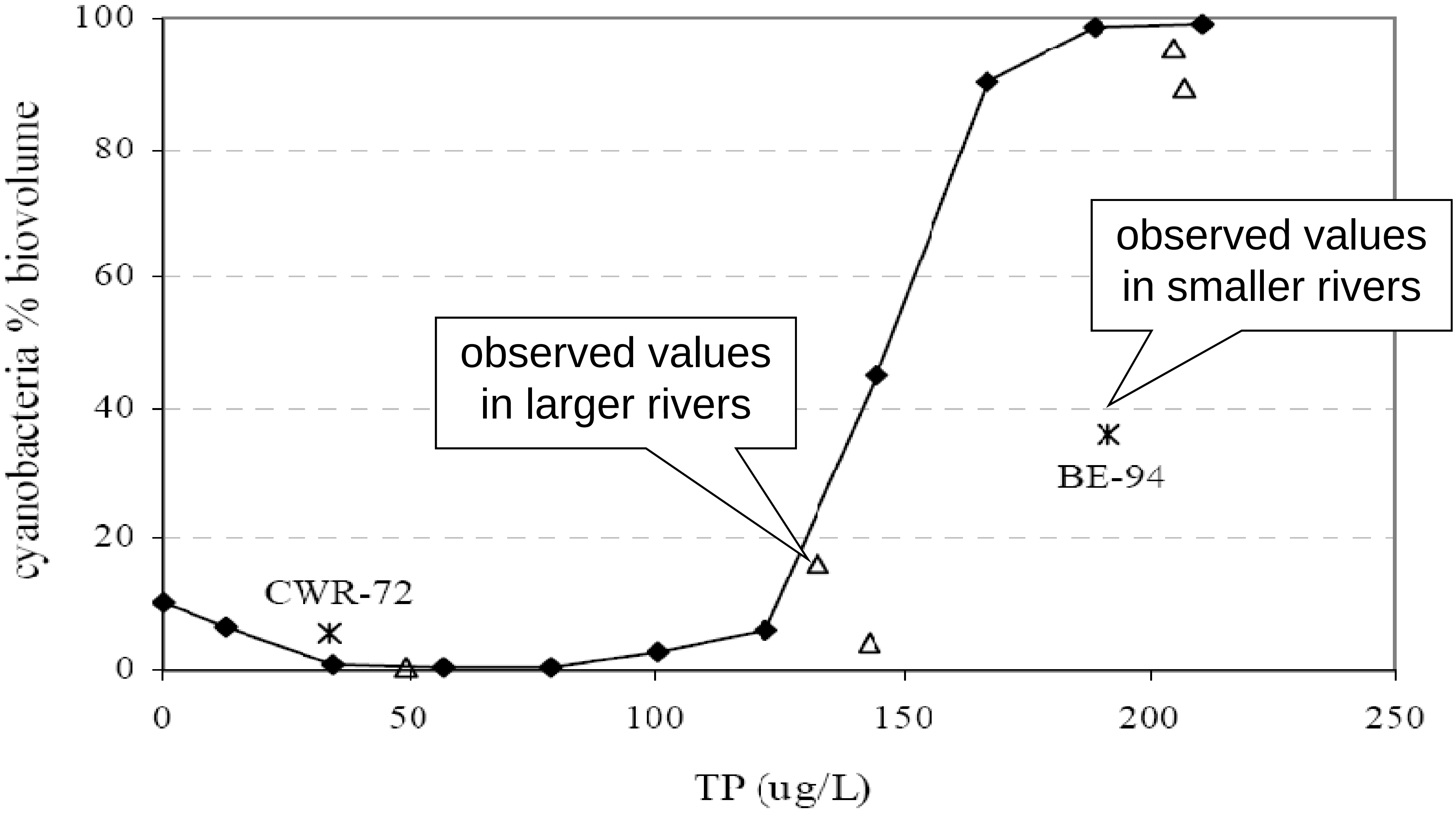
# Sestonic algae are largely a result of sloughed periphyton in this shallow river



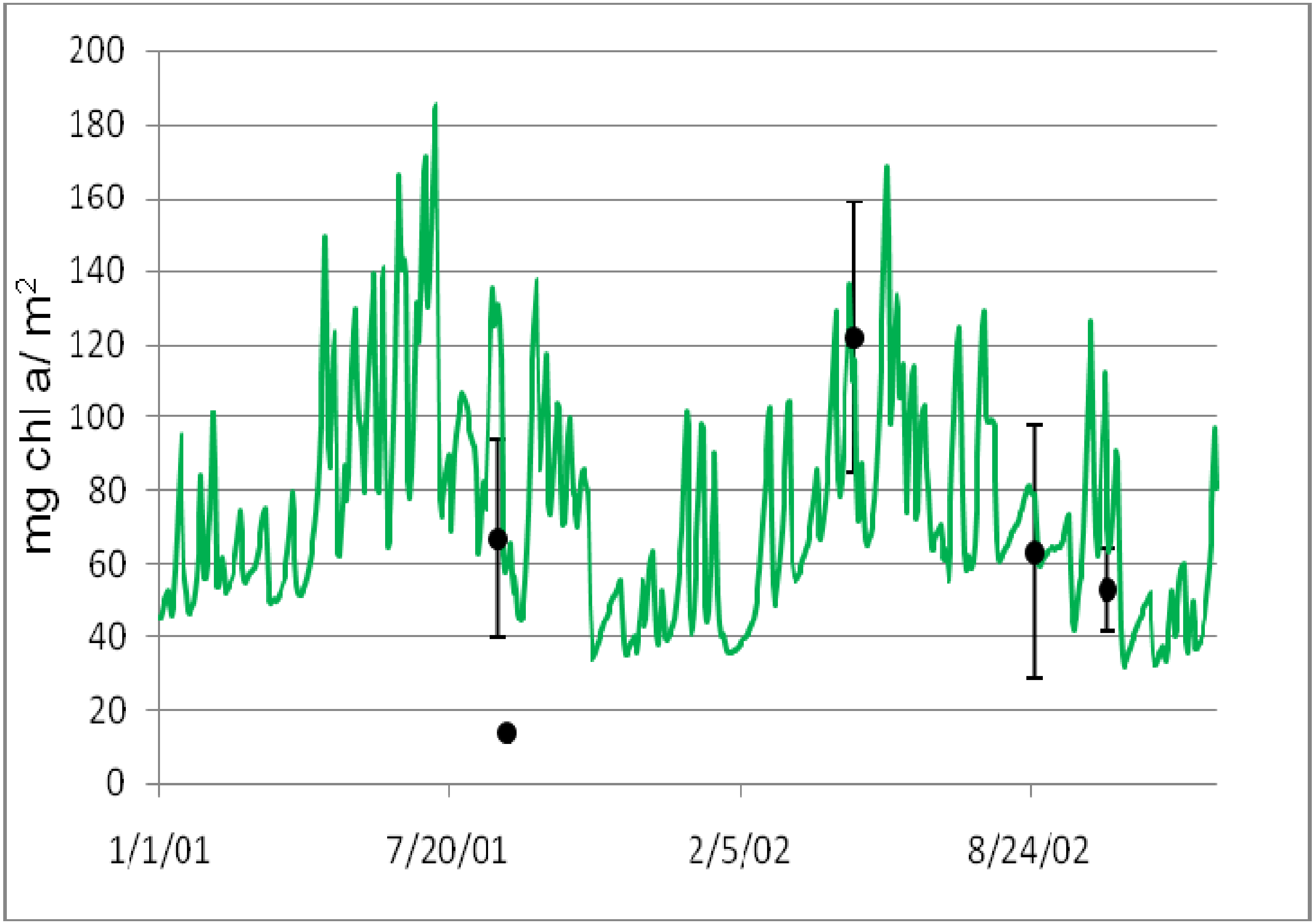
# Observed (symbols) and calibrated AQUATOX simulations (lines) of chlorophyll *a* in Crow Wing at mile 72



# Summer mean percent Phytoplankton composed of cyanobacteria-- BE-54 simulations with fractional multipliers on TP, TN, and TSS



Validation: observed (symbols) and AQUATOX simulation (line) of periphytic chlorophyll *a* in Cahaba River AL



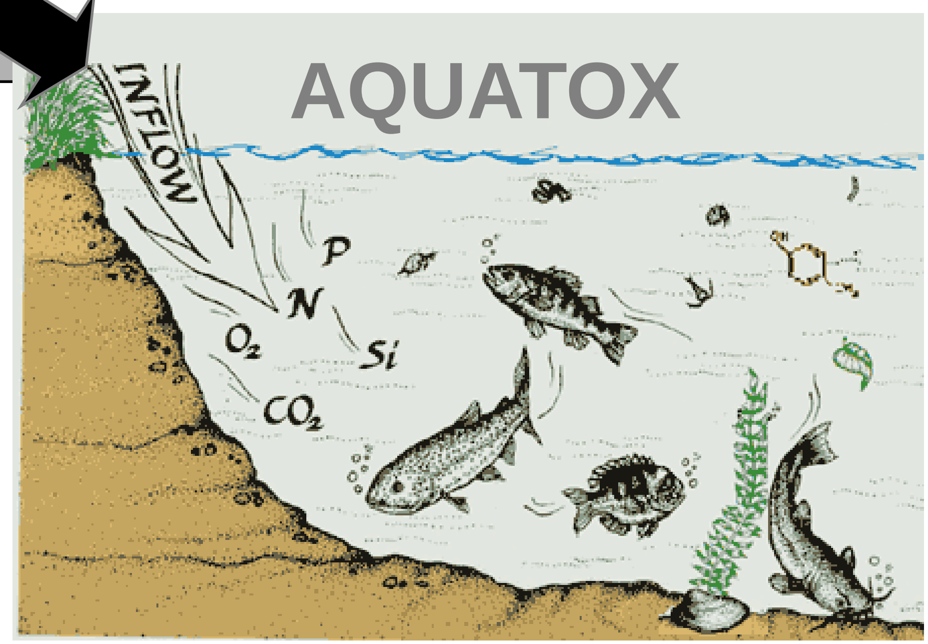
# AQUATOX BASINS Linkage

BASINS
Better Assessment
Science Integrating Point
and Nonpoint Sources

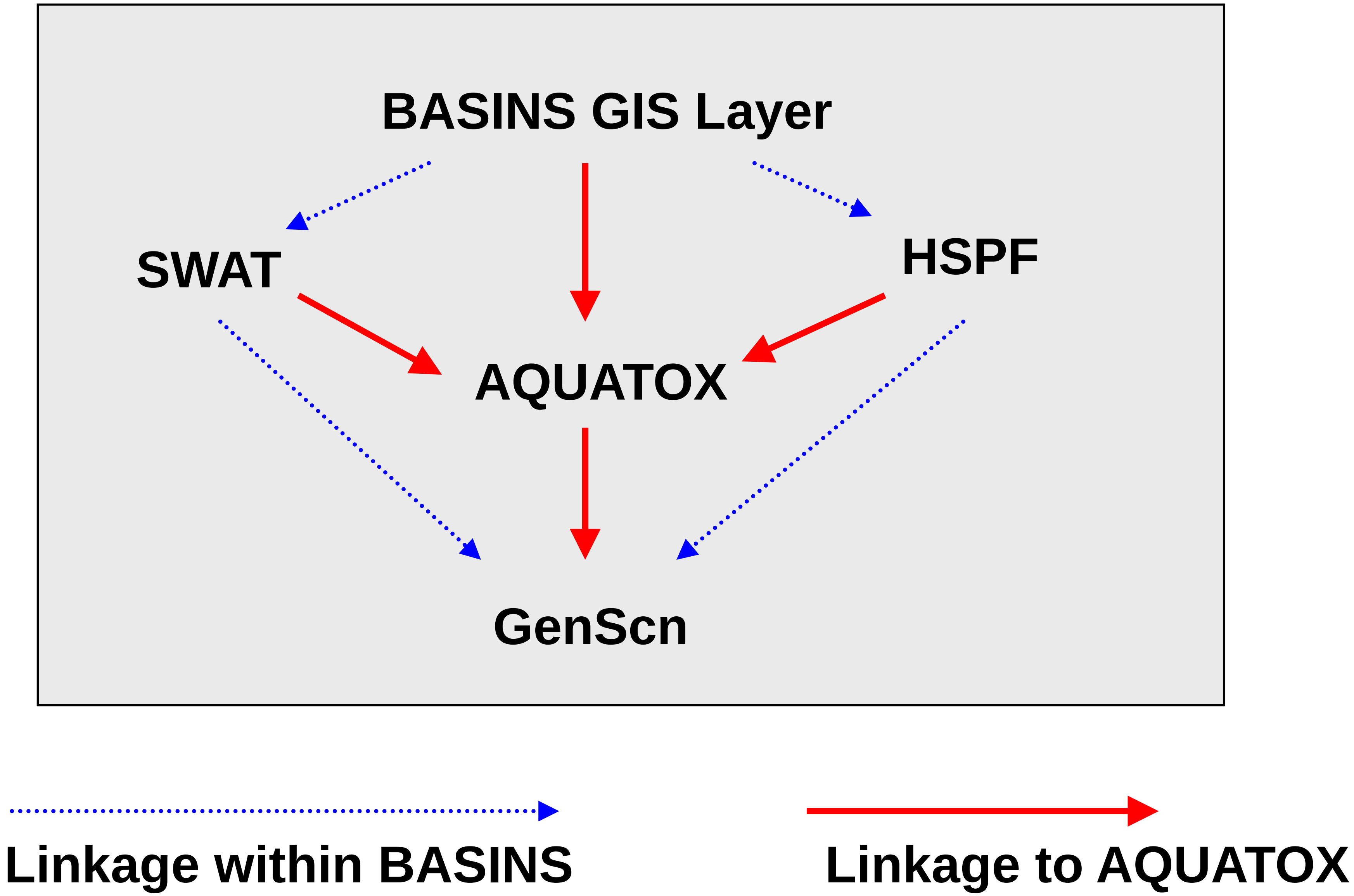
**Integrates point/nonpoint source analysis with effects on receiving water and biota**

**Provides time series loading data and GIS information to AQUATOX**

**Creates AQUATOX simulations using physical characteristics of BASINS watershed**



# Linkages Between Models

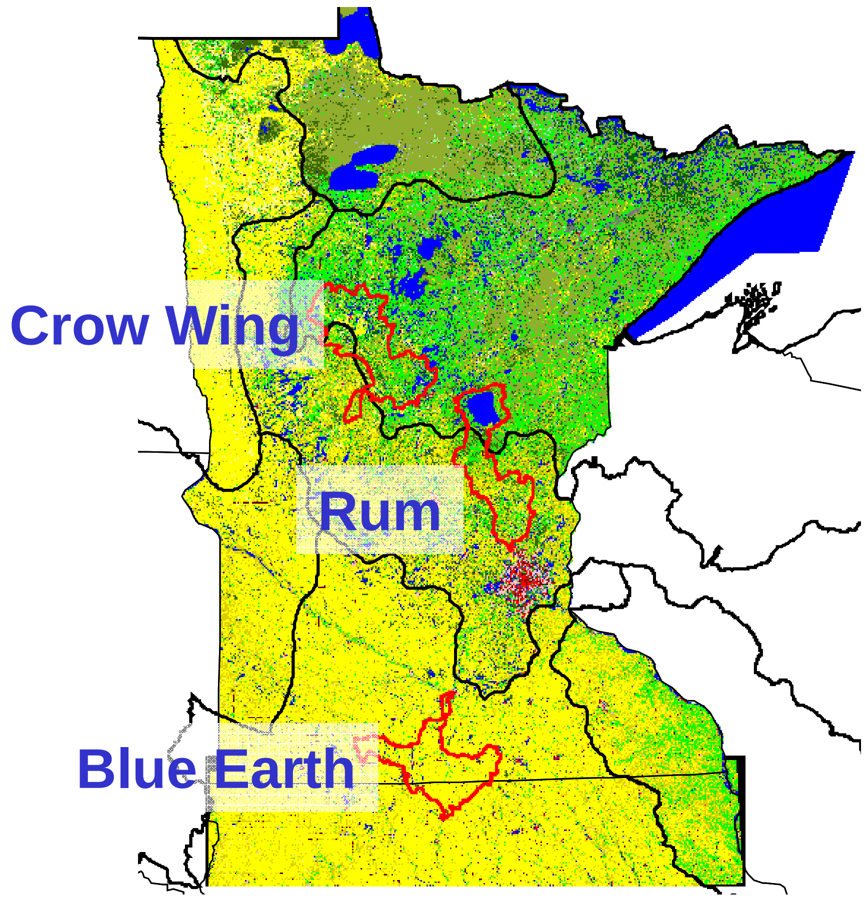


# Use of AQUATOX in development of water quality criteria

- 2008 peer review suggests AQUATOX is suited to support existing approaches used to develop water quality standards and criteria
  - One tool among many that should be used in a weight of evidence approach
- AQUATOX enables the evaluation of multiple stressor scenarios
  - What is the most important stressor driving algal response?
- Go beyond chlorophyll *a* to evaluate quality, not just quantity, of algal responses (e.g., reduction of blue-green algae blooms)

# Modeling Case Study: Minnesota

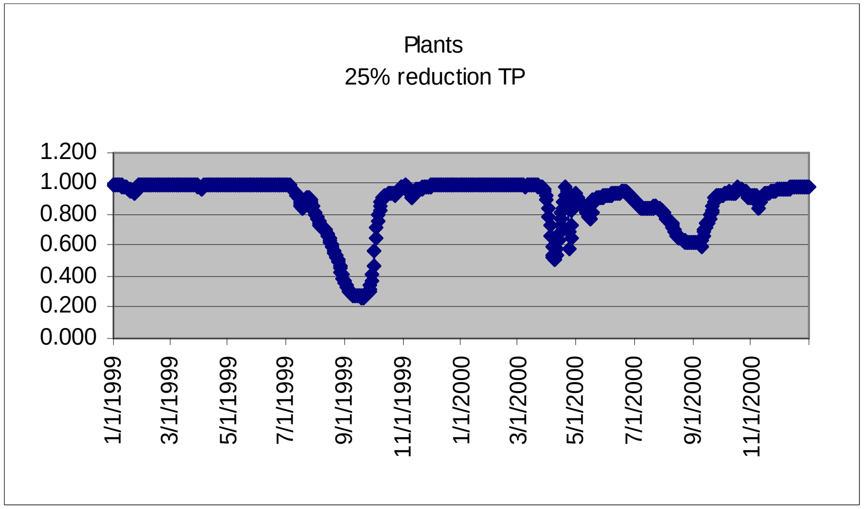
- MPCA collected monitoring data from rivers in different ecoregions:
  - nutrients, BOD, water clarity, chlorophyll a
  - phytoplankton, periphyton, fish & invertebrate IBI scores.



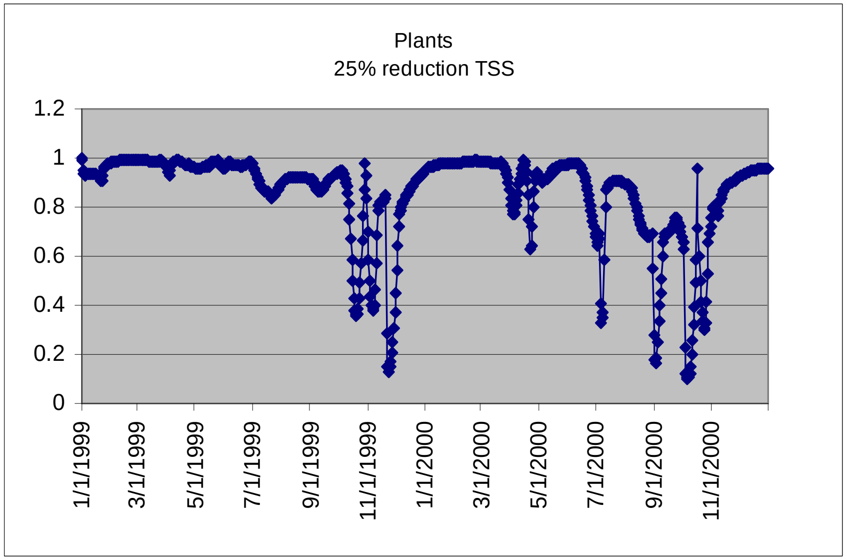
# Example Nutrient Analyses from MN

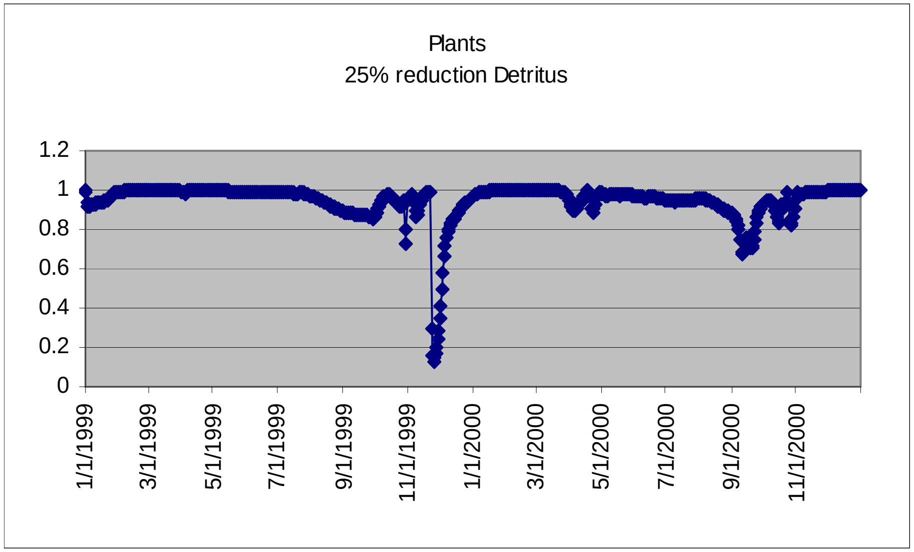
- Calibrated AQUATOX across nutrient gradient
- Set up HSPF, linked loadings to AQUATOX
- Ran iterative simulations with various nutrient reductions
- Applied 2 ways of developing nutrient target
  - Accept the ecoregion chl *a* target, use AQUATOX to get corresponding TP level
  - Use AQUATOX to develop chl *a* and TP target based on algal species composition
- Ran HSPF with various likely pollutant reductions from BMPs
  - Will chl *a* and/or TP target be achieved under any of these scenarios?

# Steinhaus Similarity Indices show changes in algal community




**Differences in TSS and TP loadings have significant effects on algal community; BOD appears to have some effect, though of much shorter duration**



# What reductions in TP will result in attainment of long term chl. *a* target?

***Start with reference condition chl. a value (7.85 ug/L)***

| Parameter | Reported min | Reported max | 25th Percentile (all seasons) | AQUATOX 6-yr average |
|---|---|---|---|---|
| **TP (ug/L)** | 11.25 | 1720 | **118.13** | **268** |
| **Chl a (ug/L)** | 3.76 | 90.6 | **7.85** | **18.3** |

# Effect of Load Reductions on Blue Earth Mean Chlorophyll *a*

| TP/TSS multiplier | TP (ug/L) | Mean chl_*a* (ug/L) |
|---|---|---|
| 1.0 | 268 | 18.3 |
| 0.8 | 214 | 11.0 |
| 0.6 | 161 | 9.5 |
| 0.4 | 107 | 8.2 |
| 0.2 | 54 | 8.0 |
| 0.0 | 0* | 0.2 |

**7.85 ug/L** (between 0.2 and 0.0 rows)

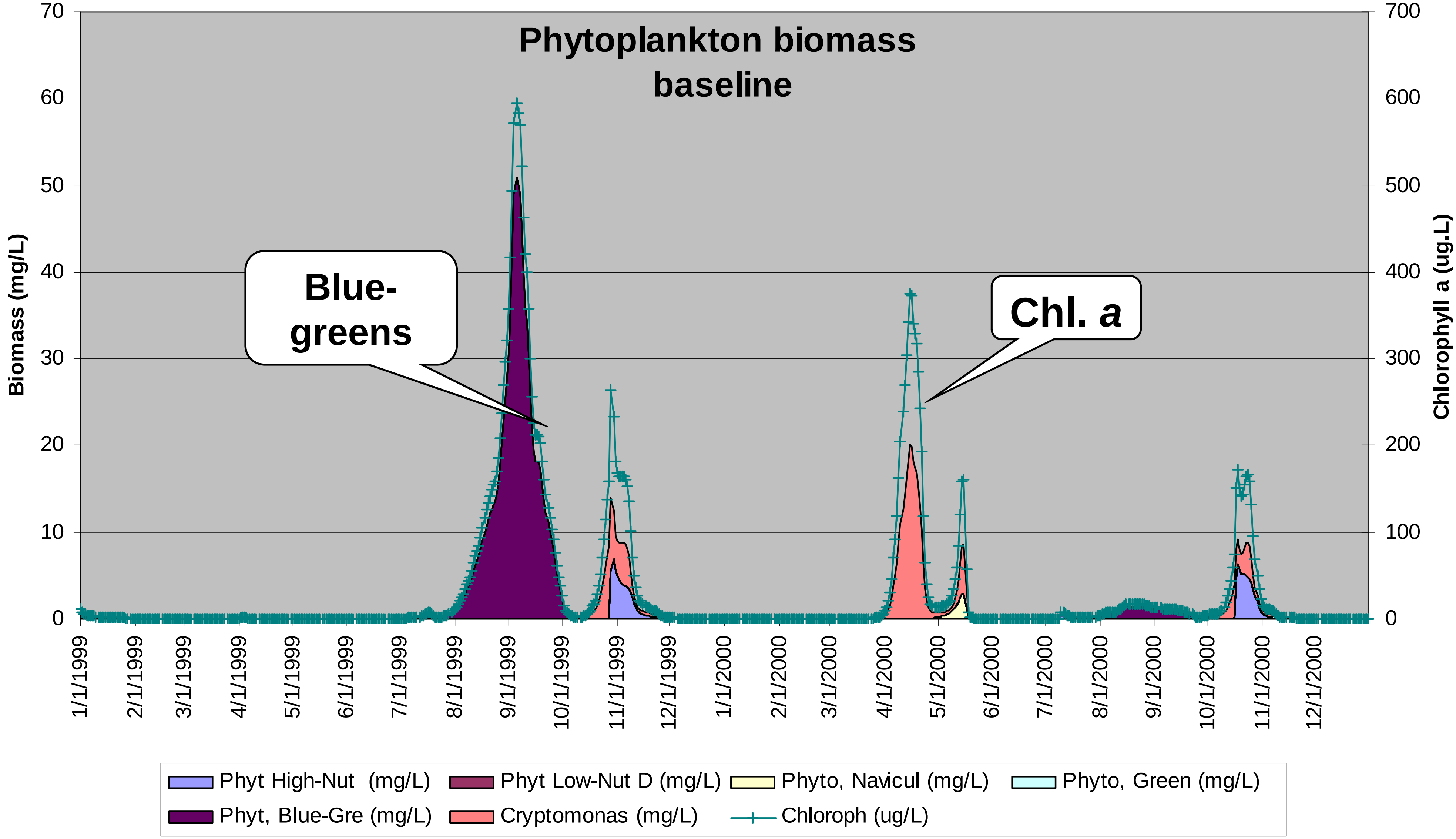
# Target Development
## Method #1

- Model results suggest that **> 80%** reduction of TP (coupled with TSS reductions) required to attain 7.85 ug/L
- 304(a) recommendations suggest a **56%** reduction of TP would be necessary

# Target Development Method #2

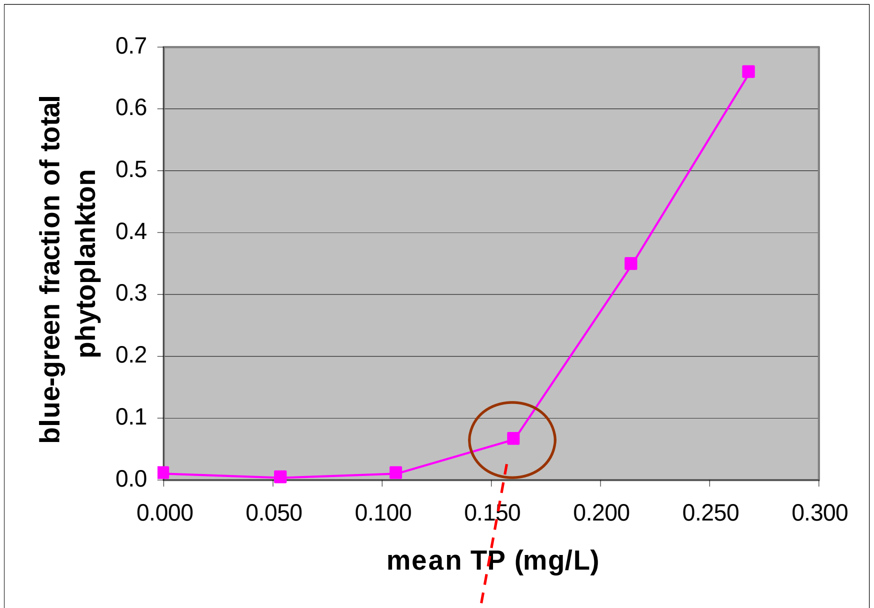
- Focus on specific algal response, not just total chl a
  - Especially blue greens, as blooms can be noxious and cause taste & odor problems
  - At what levels do blue greens reach an "acceptable" proportion of total algae?
- Where do there appear to be shifts in species composition?

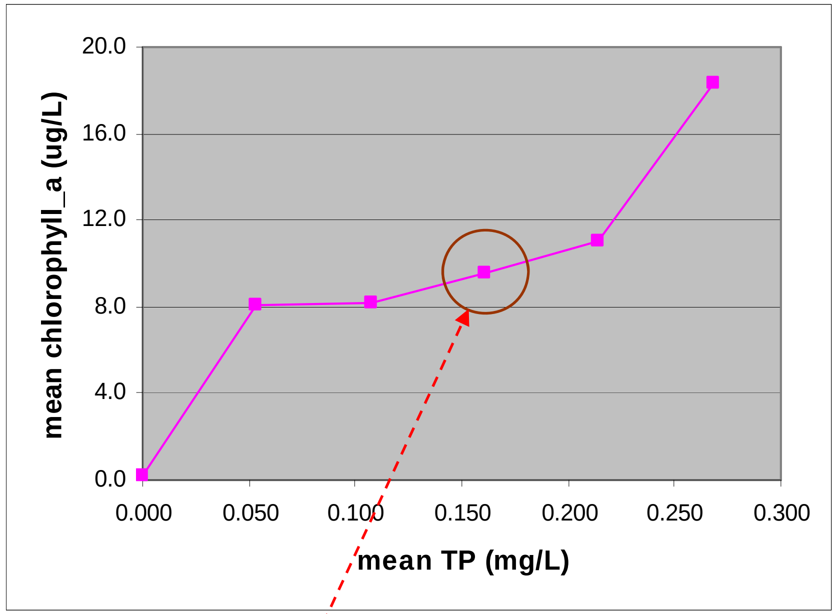
# Baseline conditions include large blooms, especially in 1st year



# Target Development

- **<u>Method 2</u>: Use AQUATOX to estimate chl_*a* concentration associated with a shift in dominance between blue-greens and more desirable algae.**




***<u>Inflection point</u> – corresponds with 9.5 ug/L mean chl_a, 0.161 mg/L TP, and blue-greens <10% of total water column phytoplankton.***

***Represents ~40% reduction in TP and TSS.***

# Method #2 Target

- Results suggest that a 40% reduction of TP, if coupled with a corresponding reduction in TSS as well, would result in an algal community with a much reduced proportion of noxious blue green algae

# Summary of Minnesota Analysis

- **<u>Stressor-response linkage</u>: Algal responses linked quantitatively with TP and TSS concentrations.**
- **<u>Criteria development</u>: Derived alternative hypothetical criteria, one based on ecologically meaningful endpoint (e.g. blue-green fraction of total phytoplankton).**
- **<u>Attainability</u>: Results suggest both 304(a) and hypothetical criteria in Blue Earth river may be very difficult to achieve, even with heavy use of BMPs.**

# Other Possible Analyses to Support Development of Water Quality Targets

- For different target concentrations you could compare differences in:
  - Duration of hypoxia or anoxia in hypolimnion
  - Duration of algal blooms
  - Secchi depth
  - Fish and invertebrate species composition

# Modeling Animals with AQUATOX

- Overview
- Parameters
- Zooplankton
- Zoobenthos
- Fish
- Trophic Interaction Matrices

# Animal Modeling Overview

- Animal biomasses calculated dynamically
  - **Gains** due to consumption and boundary-condition loadings
  - **Losses** due to defecation, respiration, excretion, mortality, predation, boundary condition losses
- Careful specification of feeding preferences required
- Bioenergetic modeling for fish

# Animal Parameters

Animal: Mtn. whitefish adult | Species Data | Help

Animal Type: Fish

Toxicity Record: Trout | Edit All

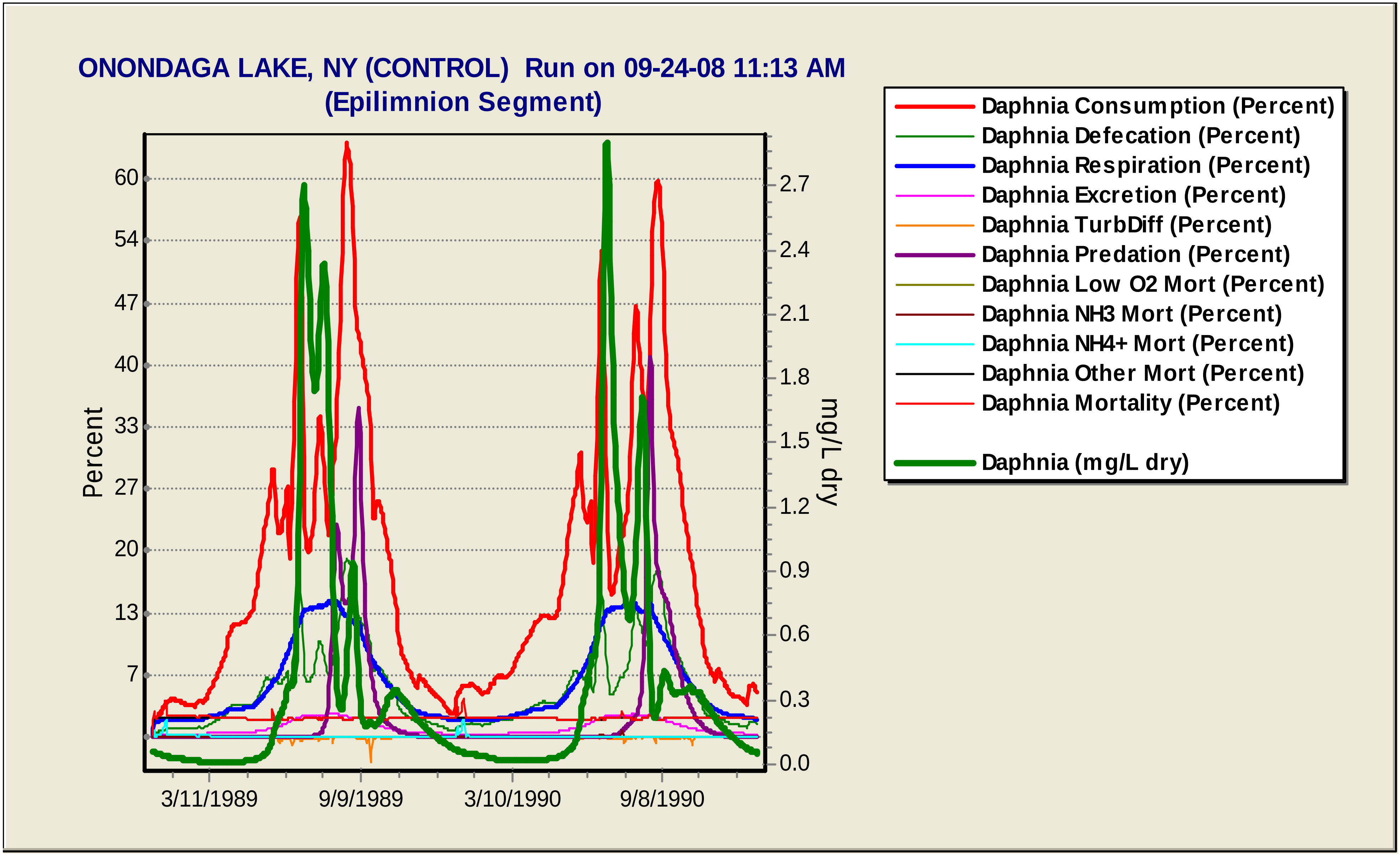
Taxonomic Type or Guild: Game Fish

Trophic Interactions

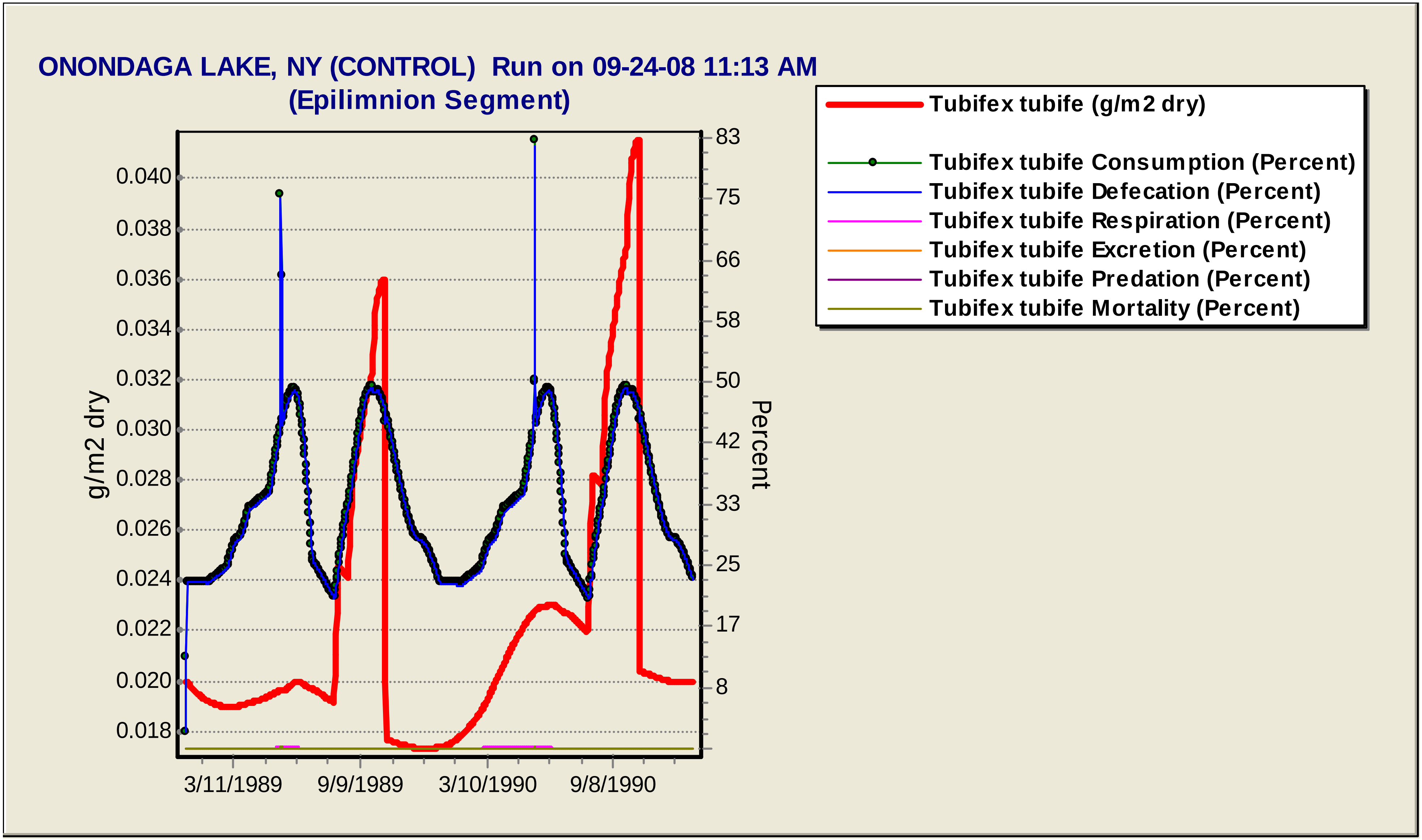
*Animal Data:*

| | Parameter | Value | Units | *References:* |
|---|---|---|---|---|
| | Half Saturation Feeding | 0.3 | mg / L | Leidy & Jenkins 77 (cf. salmon) |
| ★ | Maximum Consumption | 0.01 | g / g·d | calc. from Hewett & Johnson '92, l. trout |
| ★ | Min Prey for Feeding | 0.1 | g/sq.m | bottom feeder |
| | Temp. Response Slope | 2.3 | | |
| ★ | Optimum Temperature | 12 | °C | Essig, 1998; see also Sauter et al. 2001 |
| | Maximum Temperature | 23 | °C | FishBase |
| | Min Adaptation Temp. | 0 | °C | Sauter et al. 2001, based on spawning |
| ★ | Endogenous Respiration | 0.0015 | 1 / d | calc. from Hewett & Johnson '92 prms. |
| | Specific Dynamic Action | 0.172 | (unitless) | cf. Hewett & Johnson '92 |
| | Excretion : Respiration | 0.05 | ratio | default |
| | N to Organics | 0.1 | frac. dry | Sterner 2000 |
| | P to Organics | 0.031 | frac. dry | Sterner 2000 |
| | Wet to Dry | 5 | ratio | default |

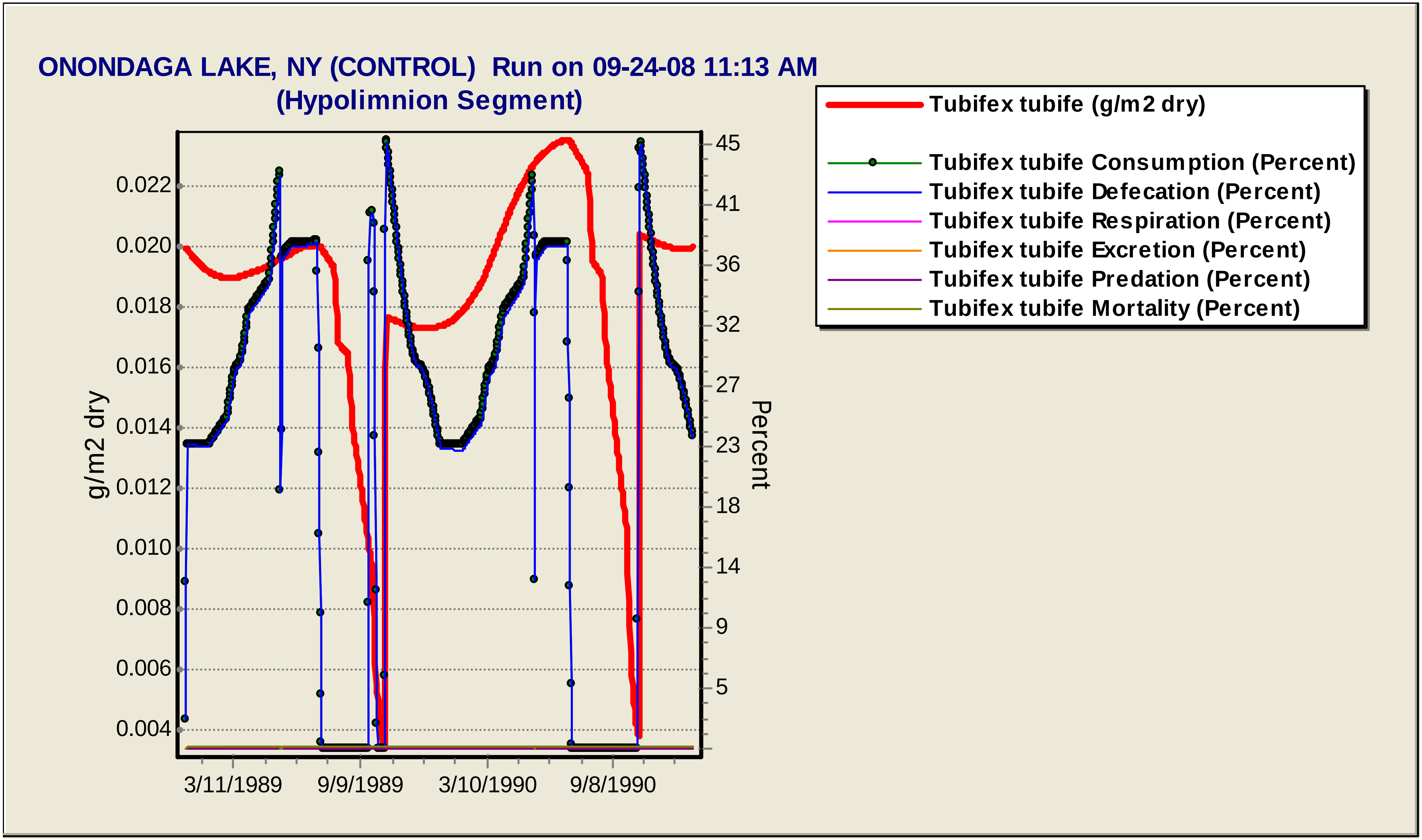
# Zooplankton consumption is tied to phytoplankton productivity



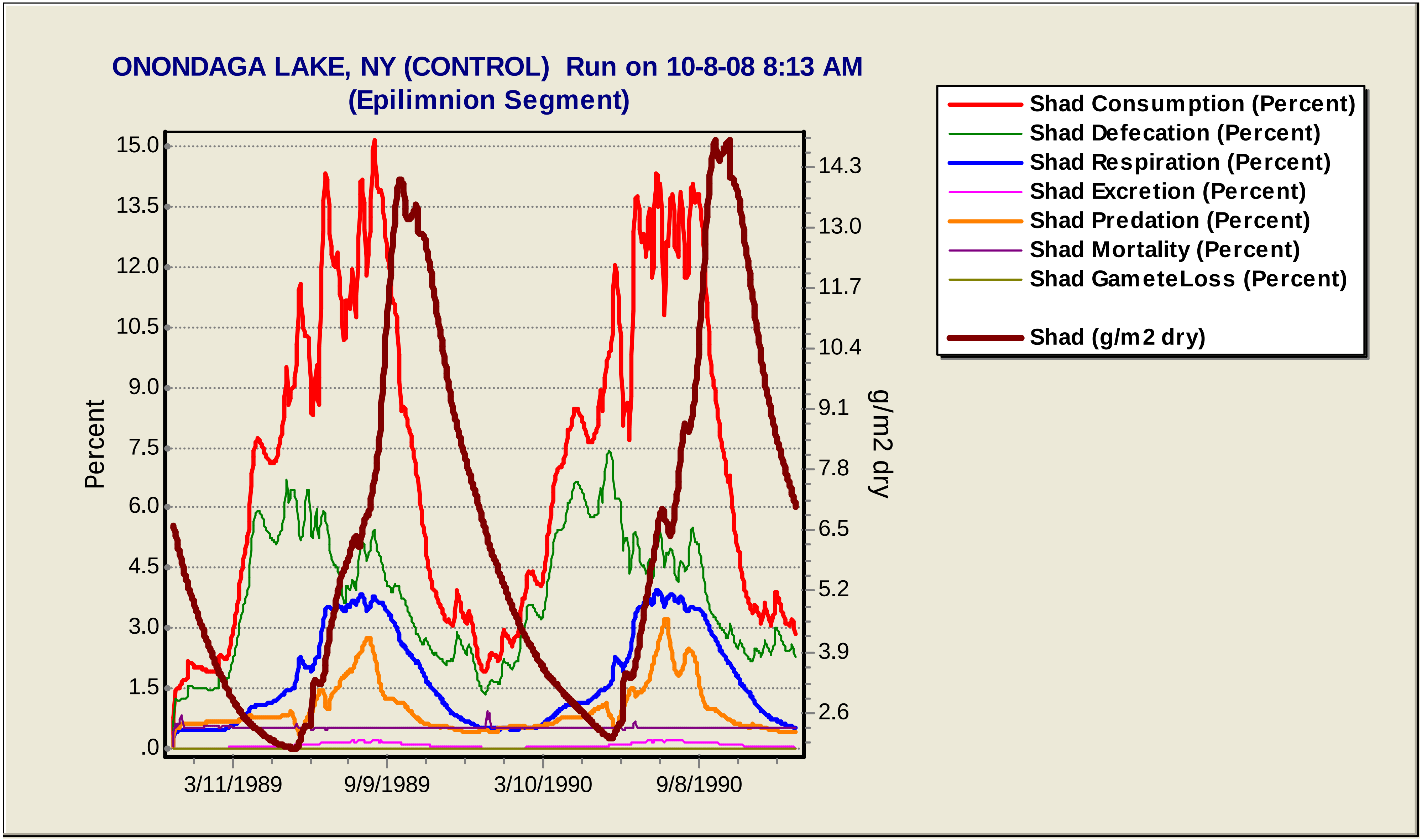
# Benthic invertebrates are also tied to phytoplankton productivity through detritus



# *Tubifex* in hypolimnion are tolerant of anoxia but stop feeding and slowly decline



# Fish exhibit seasonal patterns based on food availability and temperature



# Foodweb Model specified as Trophic Matrix

## Interactions are normalized to 100%

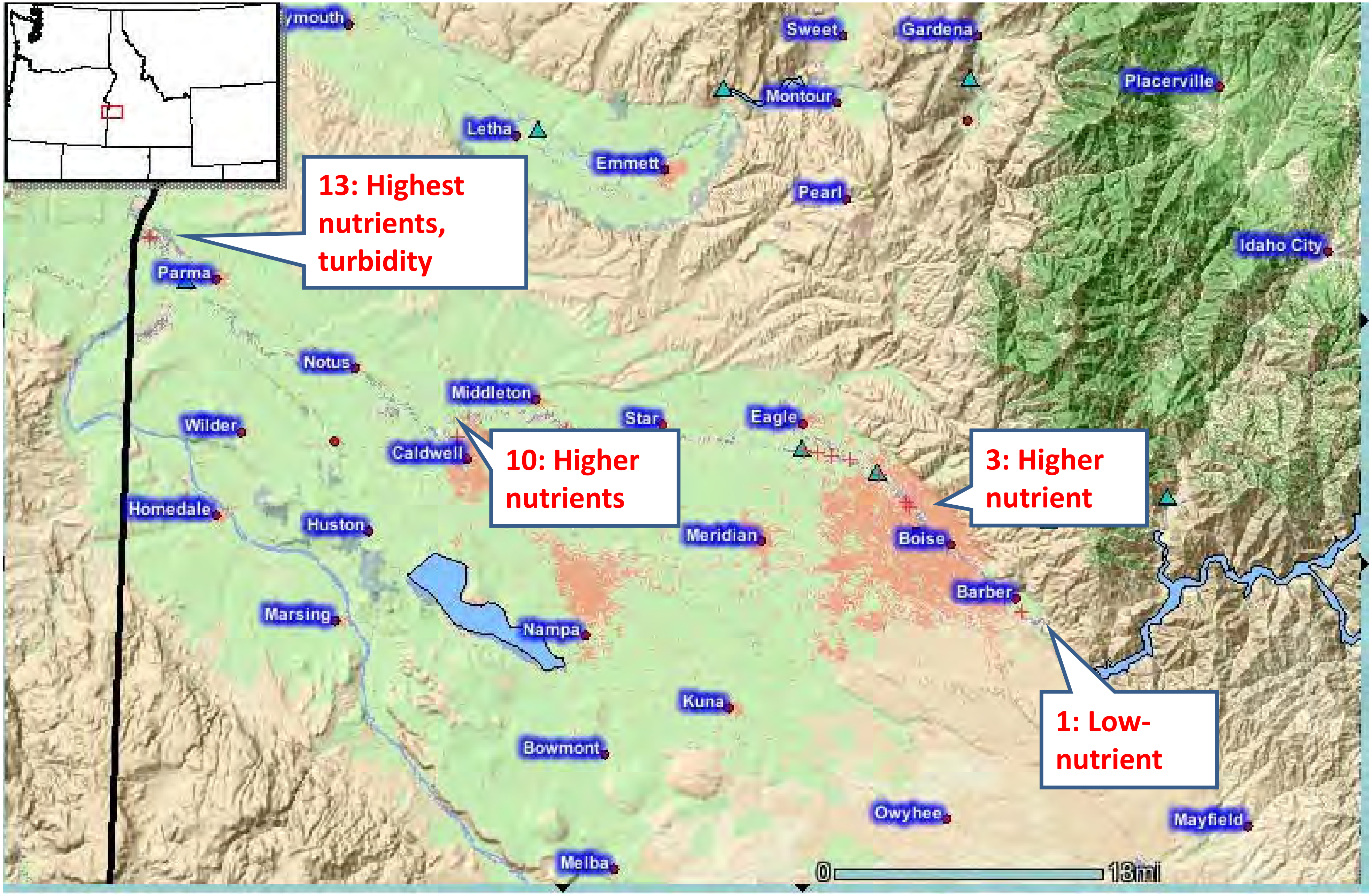
AQUATOX-- Trophic Interaction Matrix

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 | |

# Lower Boise River, Idaho
# with WWTPs & agricultural drains

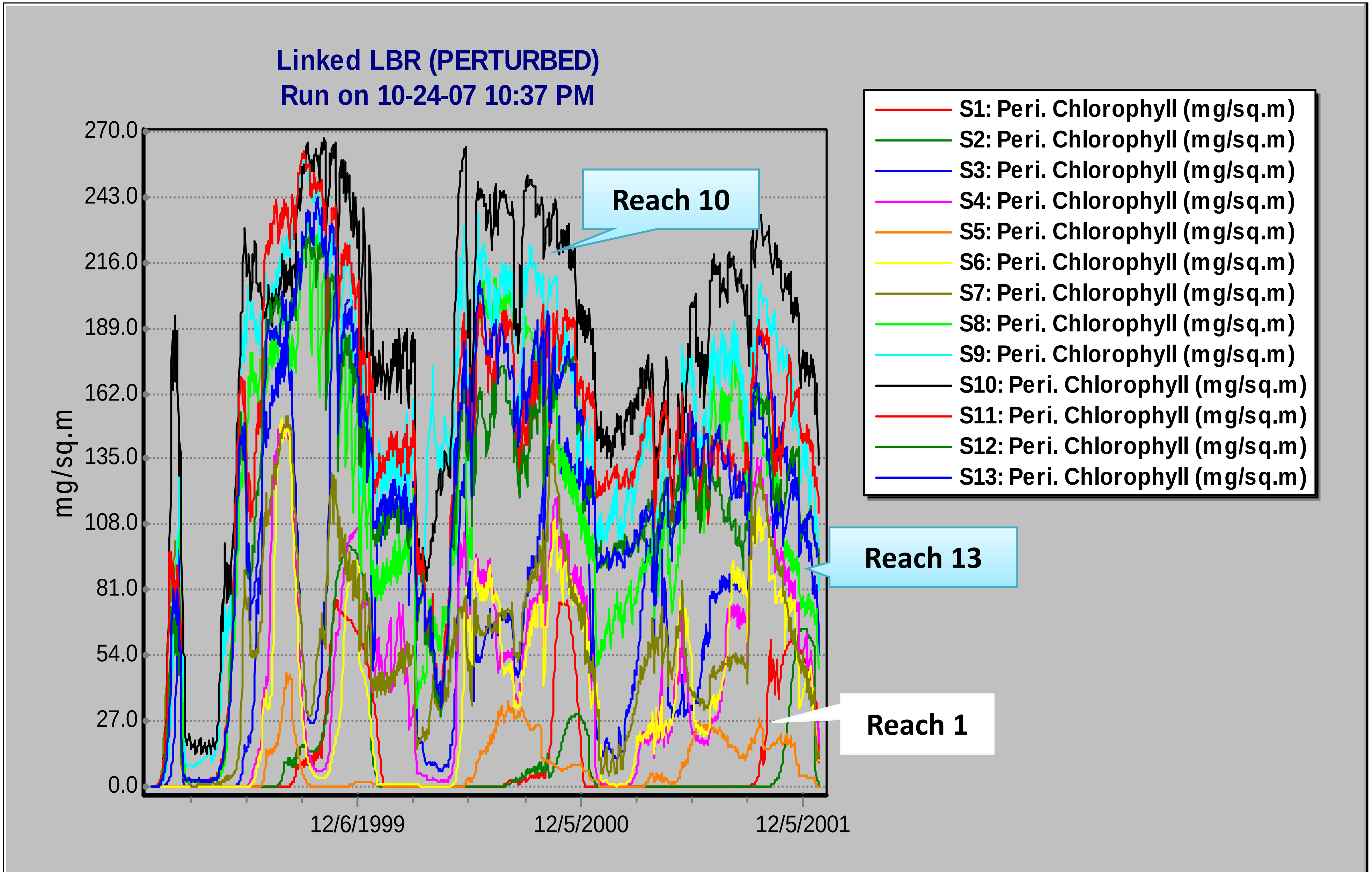


# Lower Boise River in Boise, Idaho

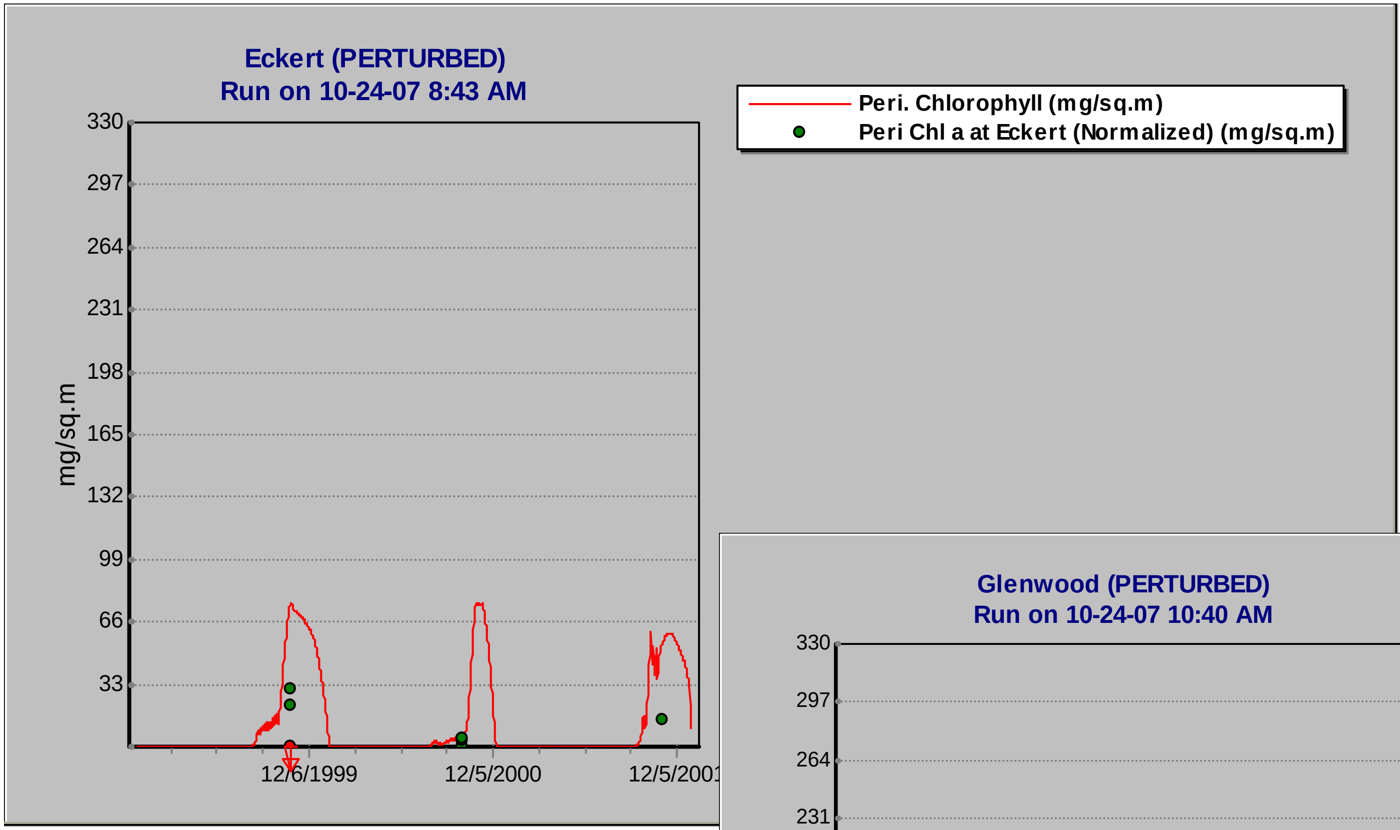
# Complex Linked Model

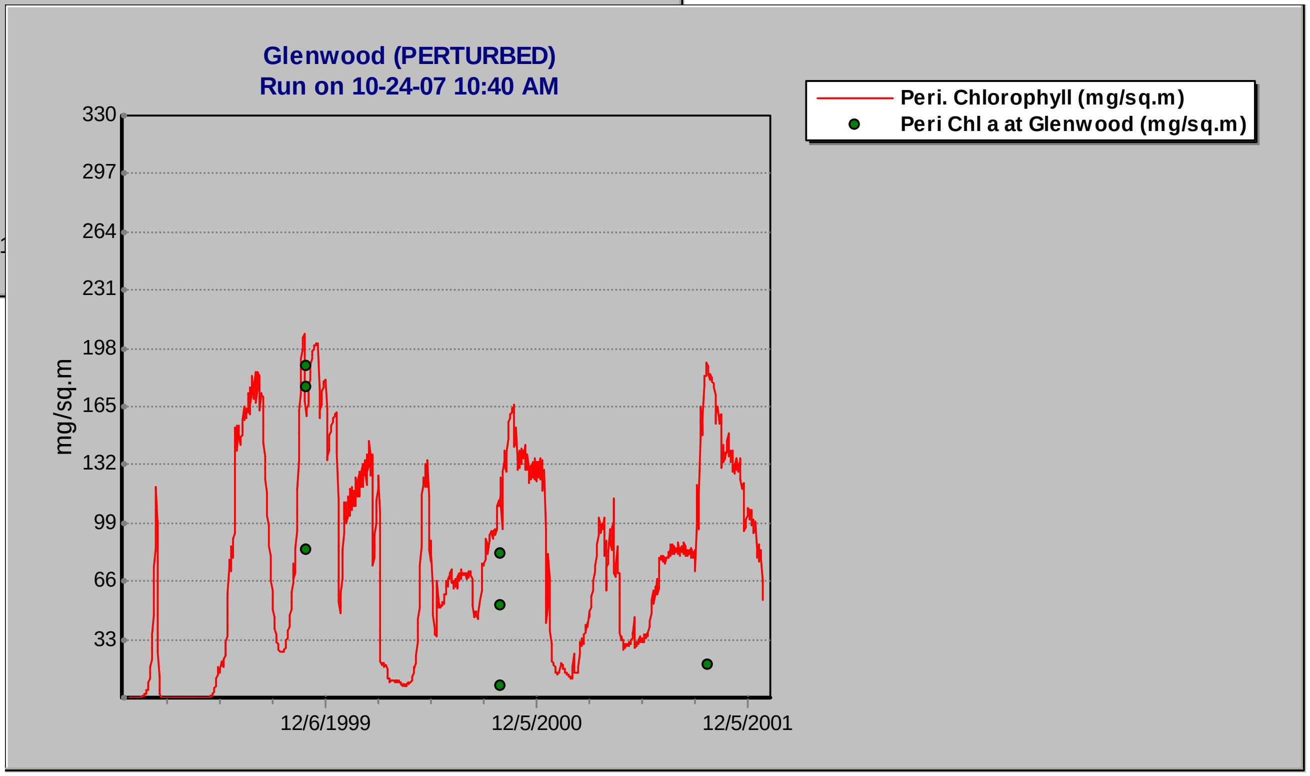
- 13 main-stem segments modeled
- 26 “tributary inputs”
  - Groundwater inputs
  - Waste Water Treatment Facilities
  - Input drains and tributaries
- Extensive water withdrawals
- Complex water-balance model
- Nutrients are integrated within main-stem

# LBR Downstream Periphyton Trend

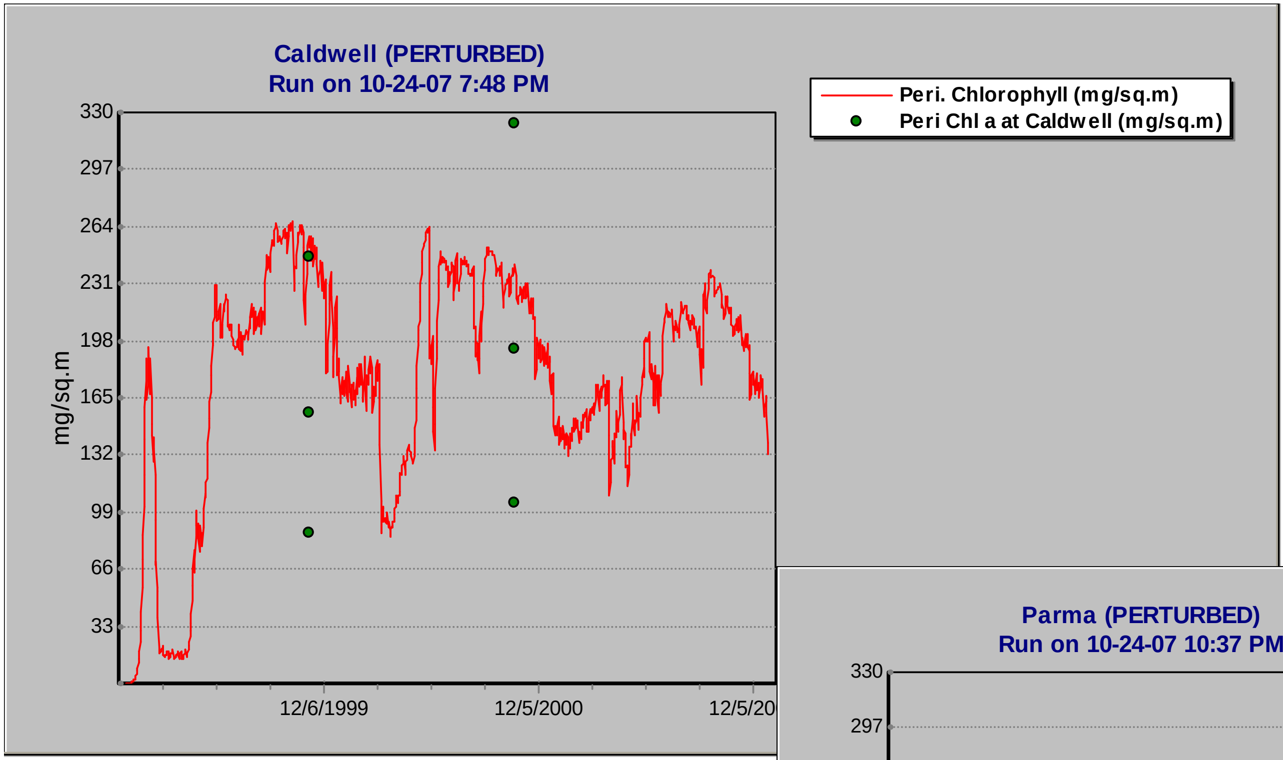


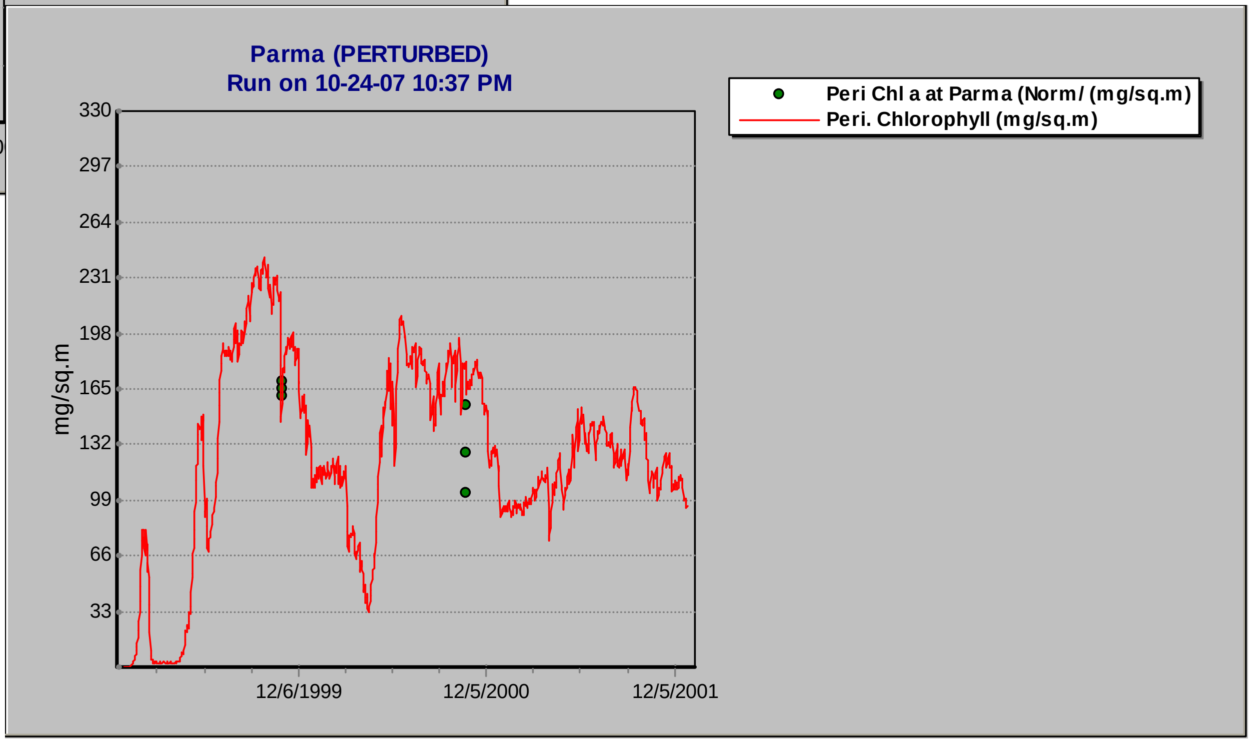
# Periphyton in Reaches 1 and 3, LBR



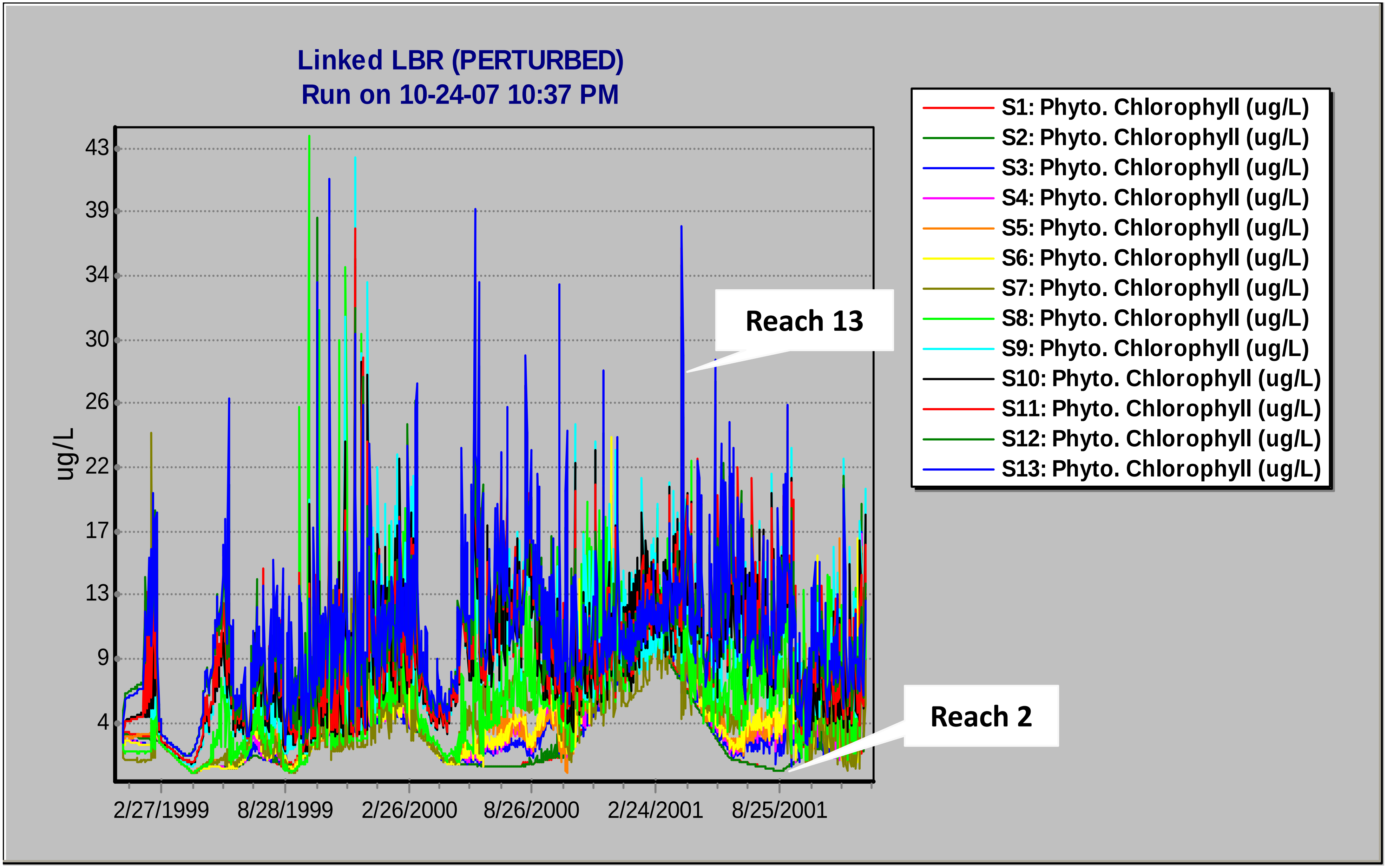



# Periphyton in Reaches 10 and 13, LBR

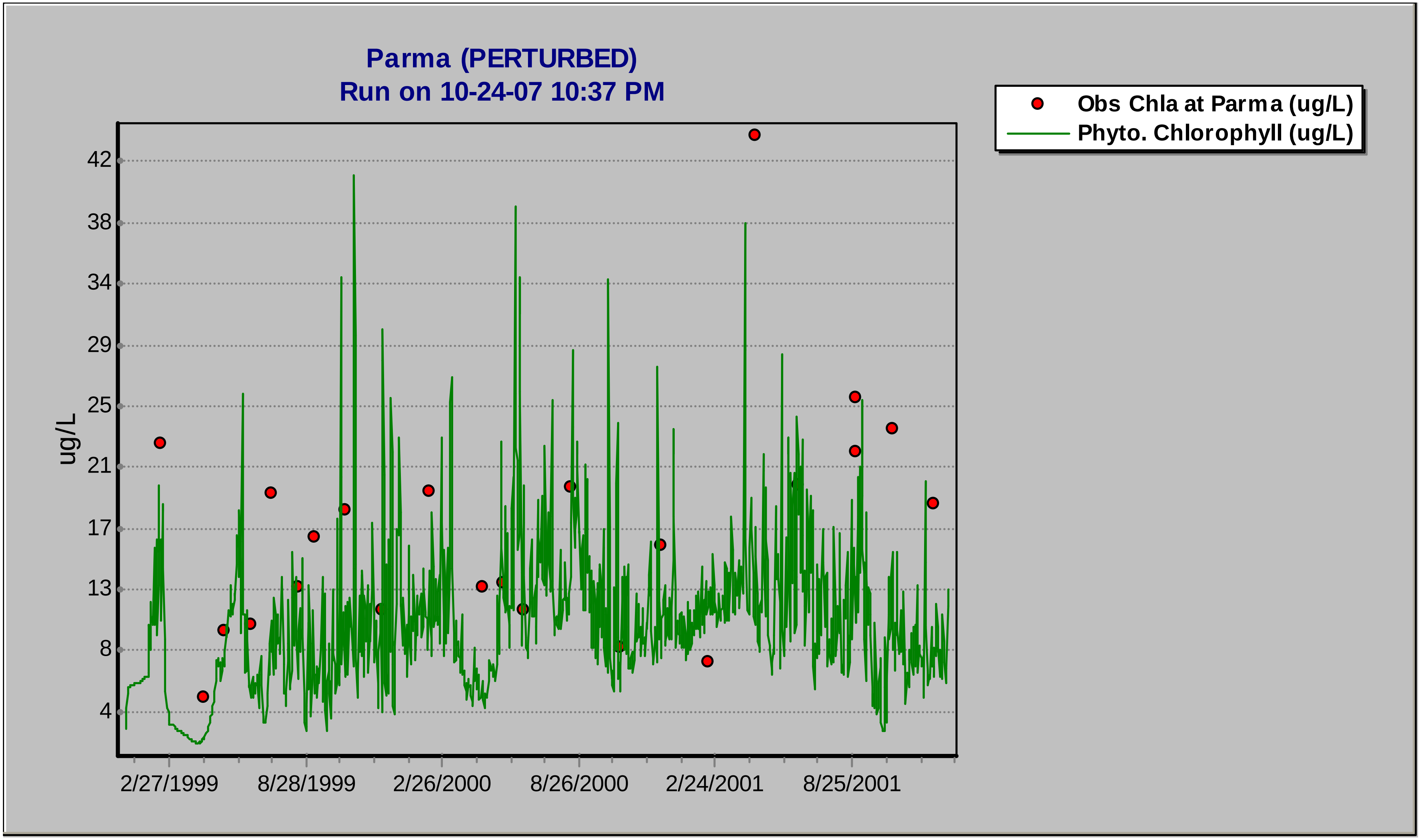


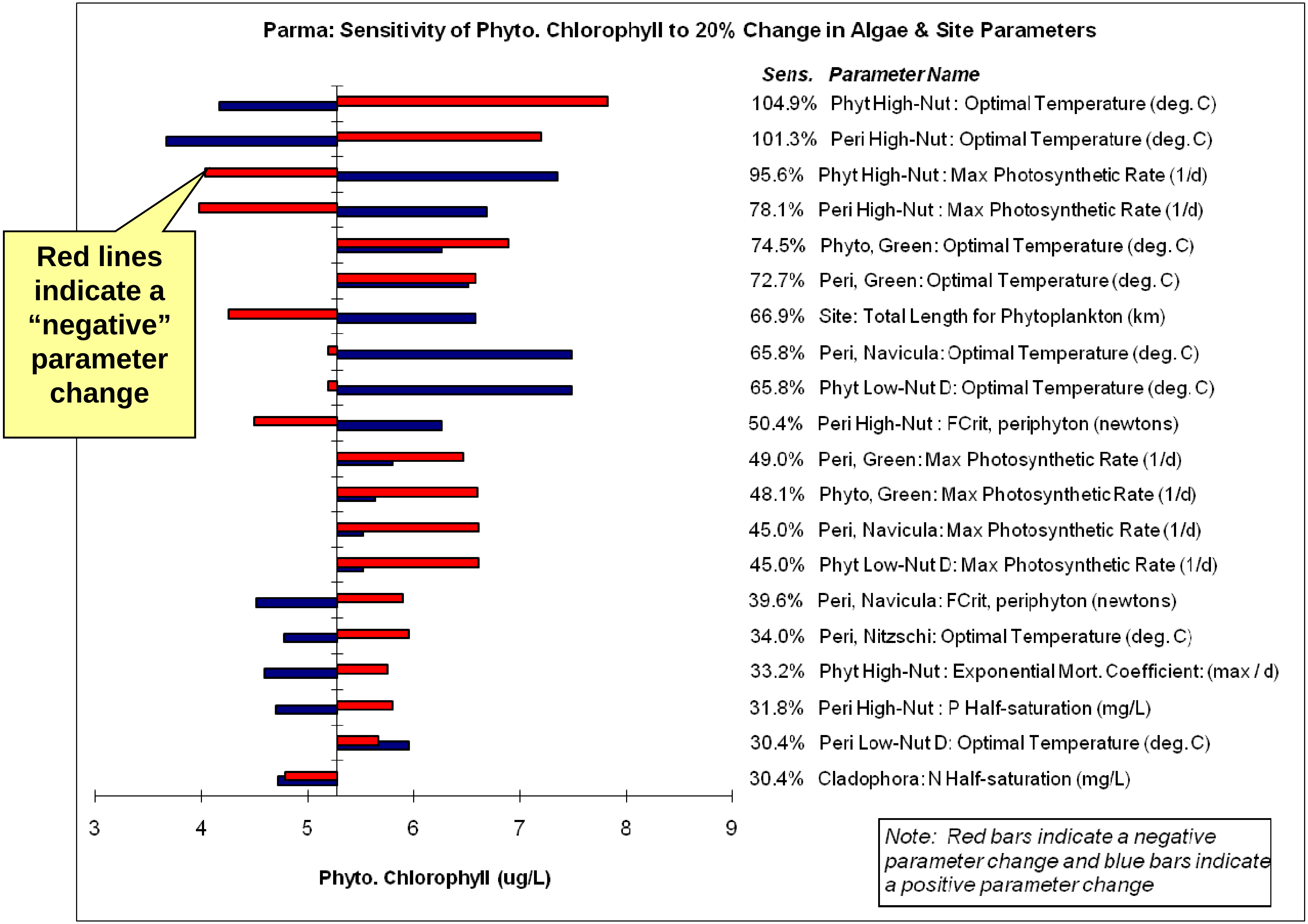
# LBR Downstream Phytoplankton Trend



# Sestonic algae at Parma (Reach 13), both upstream loadings and periphyton sloughing



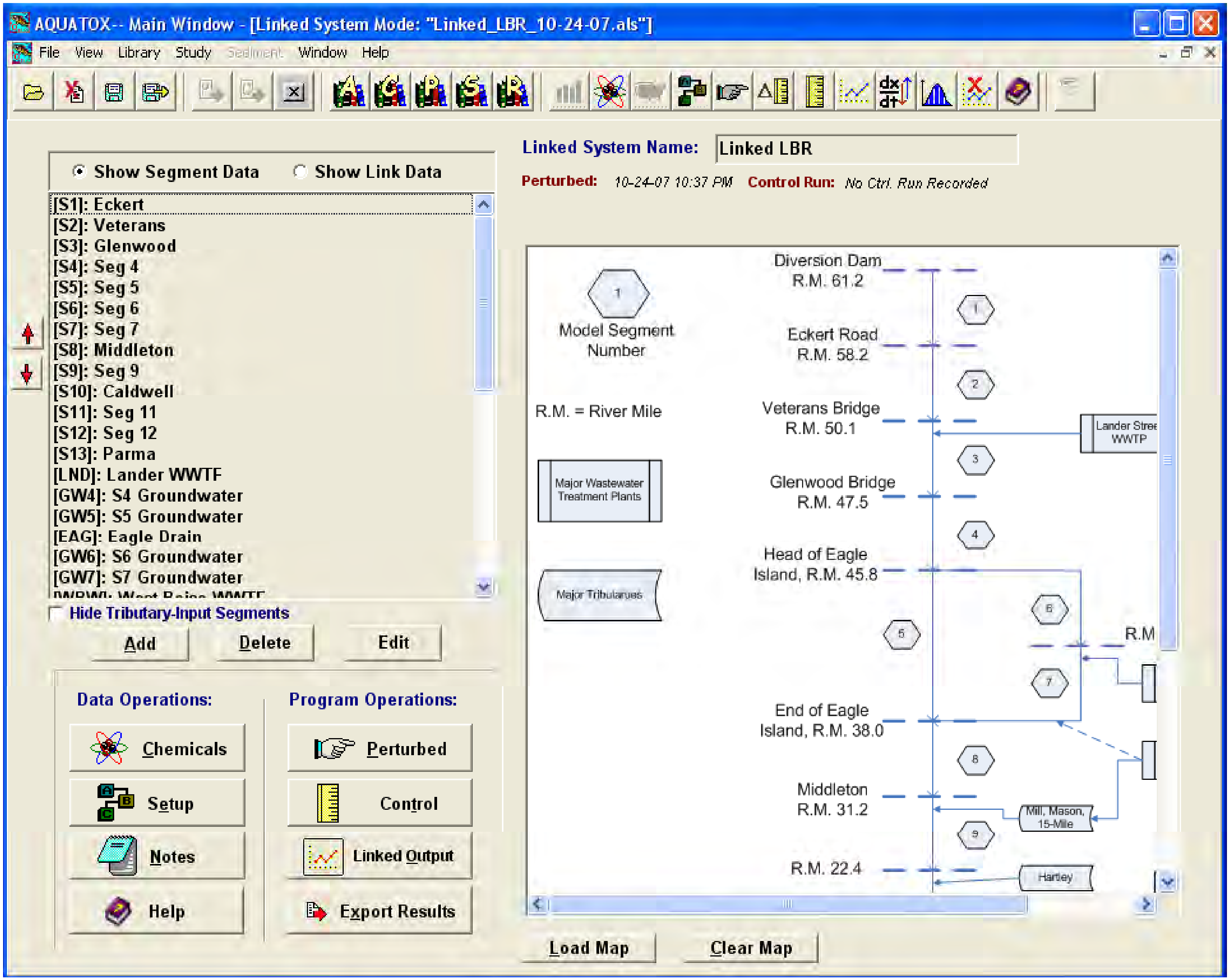
# Phytoplankton Sensitivity, Parma LBR could choose parameters for better fit



# Demonstration 2: Linked Segment Version

- Developed as part of a Superfund project; now part of Release 3
- Allows the capability to model multiple linked segments--converting AQUATOX into a two dimensional model
- State variables move from one linked segment to the next through water flow, diffusion, bed-load, and migration.

# Segmented Version can Represent Dynamically Linked Multiple Segments



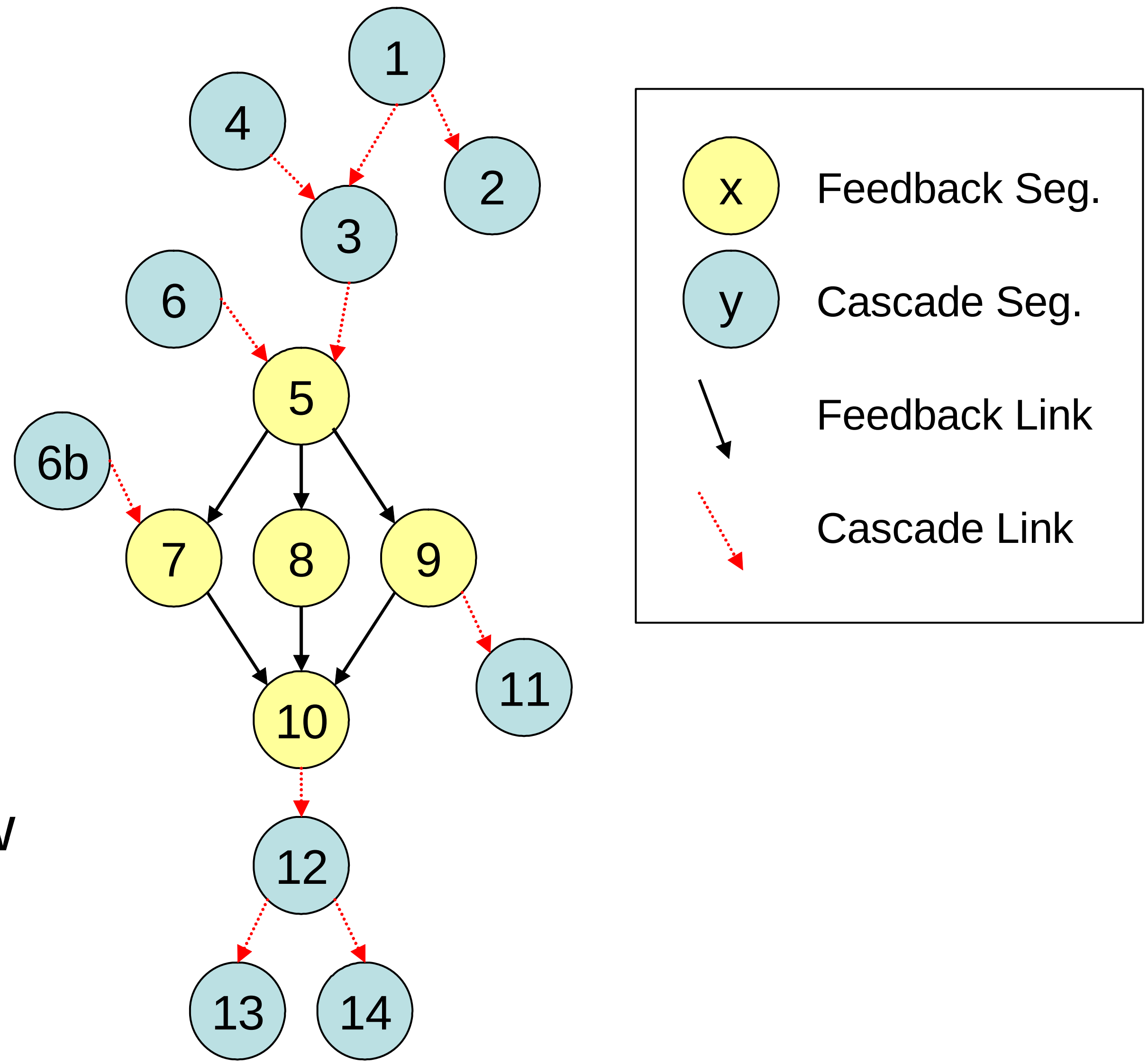
# Cascade & Feedback Linkages

<u>Cascade Linkages:</u>

One-way linkages with no backwards flow or diffusion across segment boundaries

<u>Feedback Linkages:</u>

Two-way linkages that allow for backwards flow and diffusion

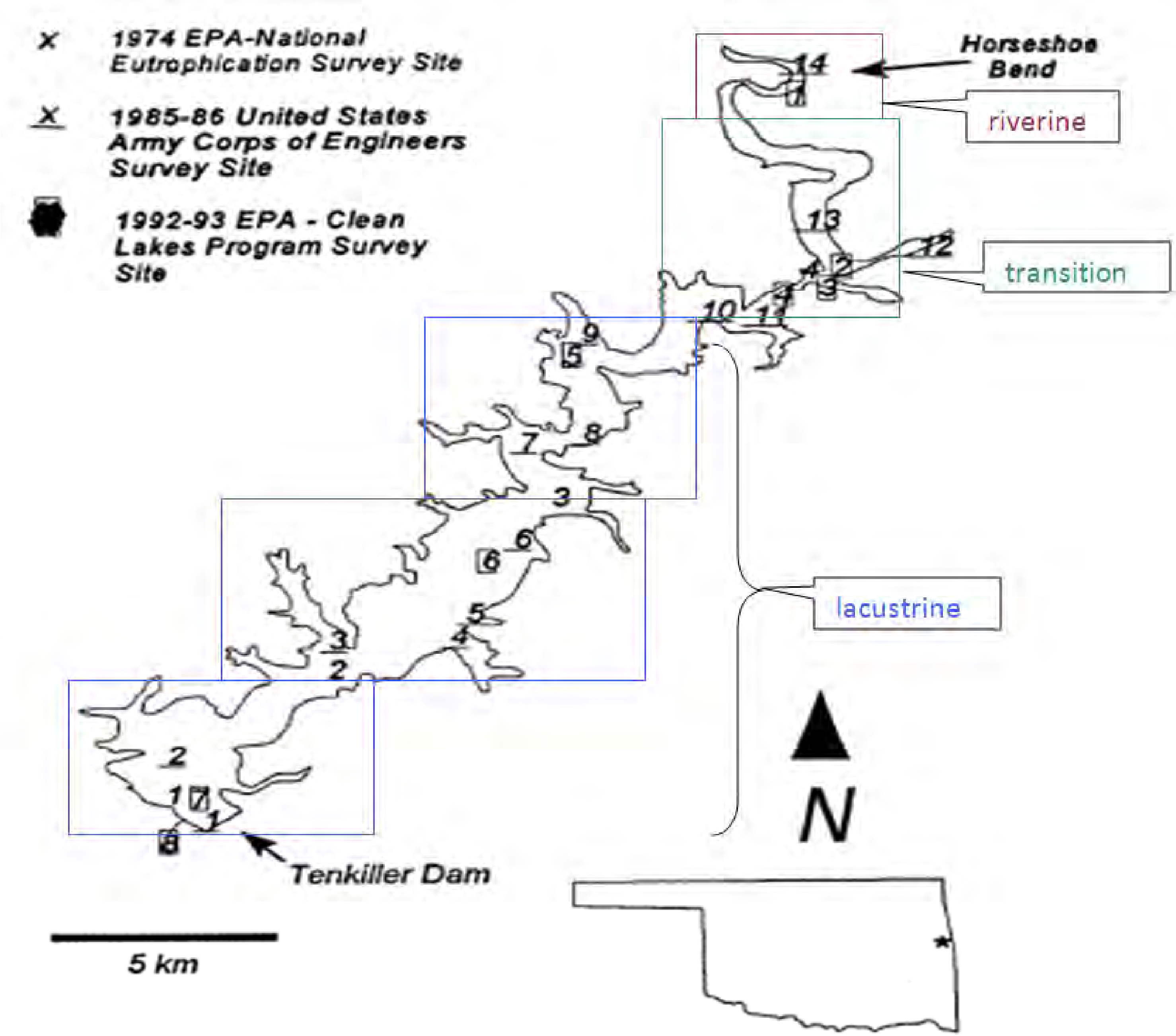


## Linked Segment Model Data Requirements

- Water flows between segments
- Initial conditions for all state variables for each segment modeled
- Inflows, point-sources and non-point-source loadings for each segment
- Tributary or groundwater inputs and/or any withdrawals

**Interface Demonstration to follow**

# Tenkiller Lake, OK



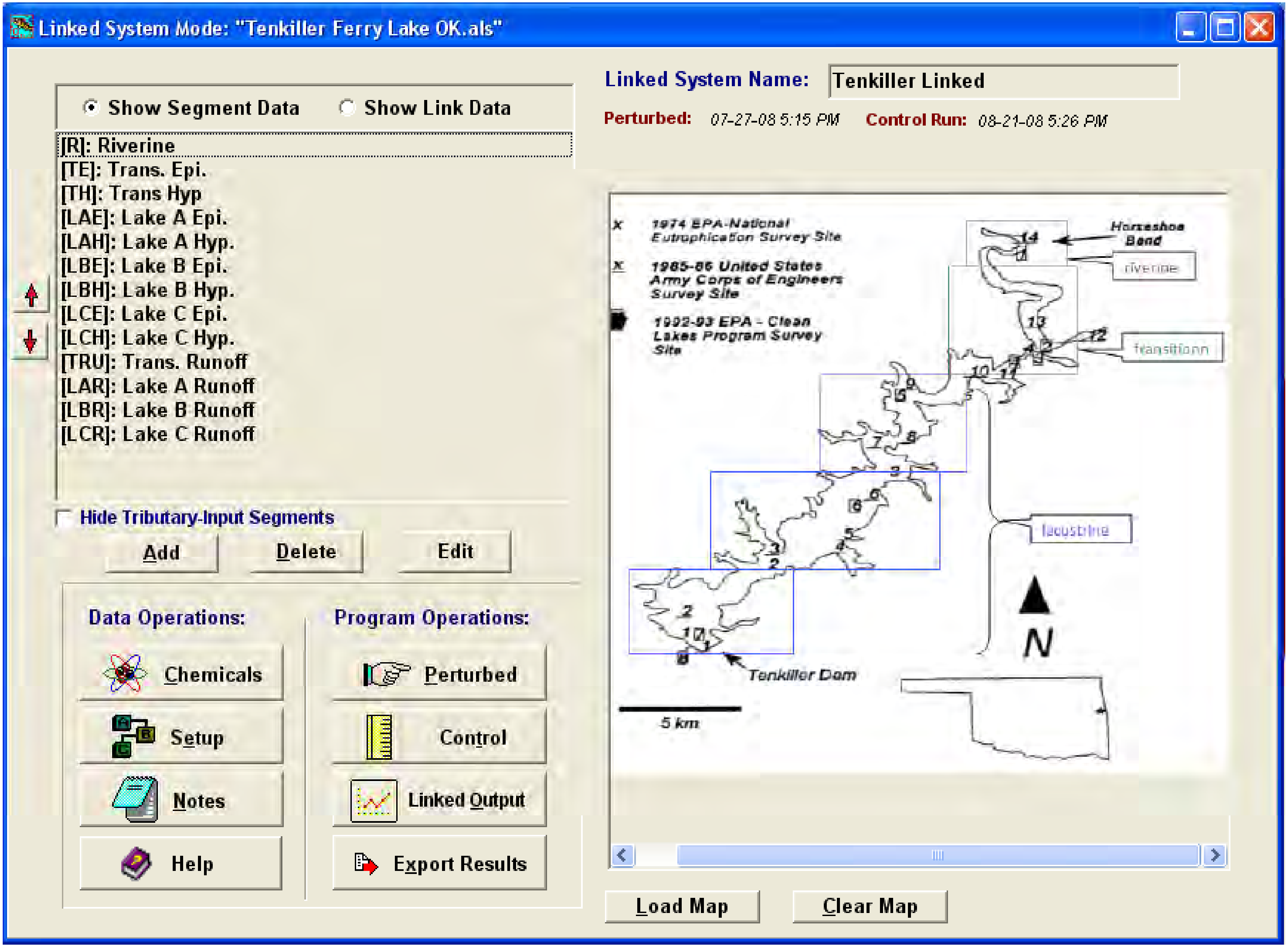
# Tenkiller Lake Background

- Reservoir in eastern Oklahoma formed by the damming of the Illinois River (1947-1952)
- Identified on Oklahoma's 1998 303(d) list as impaired (nutrients)
- High-priority target for TMDL development
- 1996 Clean Lakes Study: nutrient concentrations and water clarity are indicative of eutrophic conditions

# Tenkiller Lake Application

- Linked Model application includes nine segments
  - Riverine segment
  - Vertically stratified transitional segment
  - Three vertically stratified lacustrine segments
- Model linkage to HSPF (watershed) and EFDC (in-lake hydrology) models
- Model can predict chlorophyll *a* levels based on nutrient loadings (BMPs)

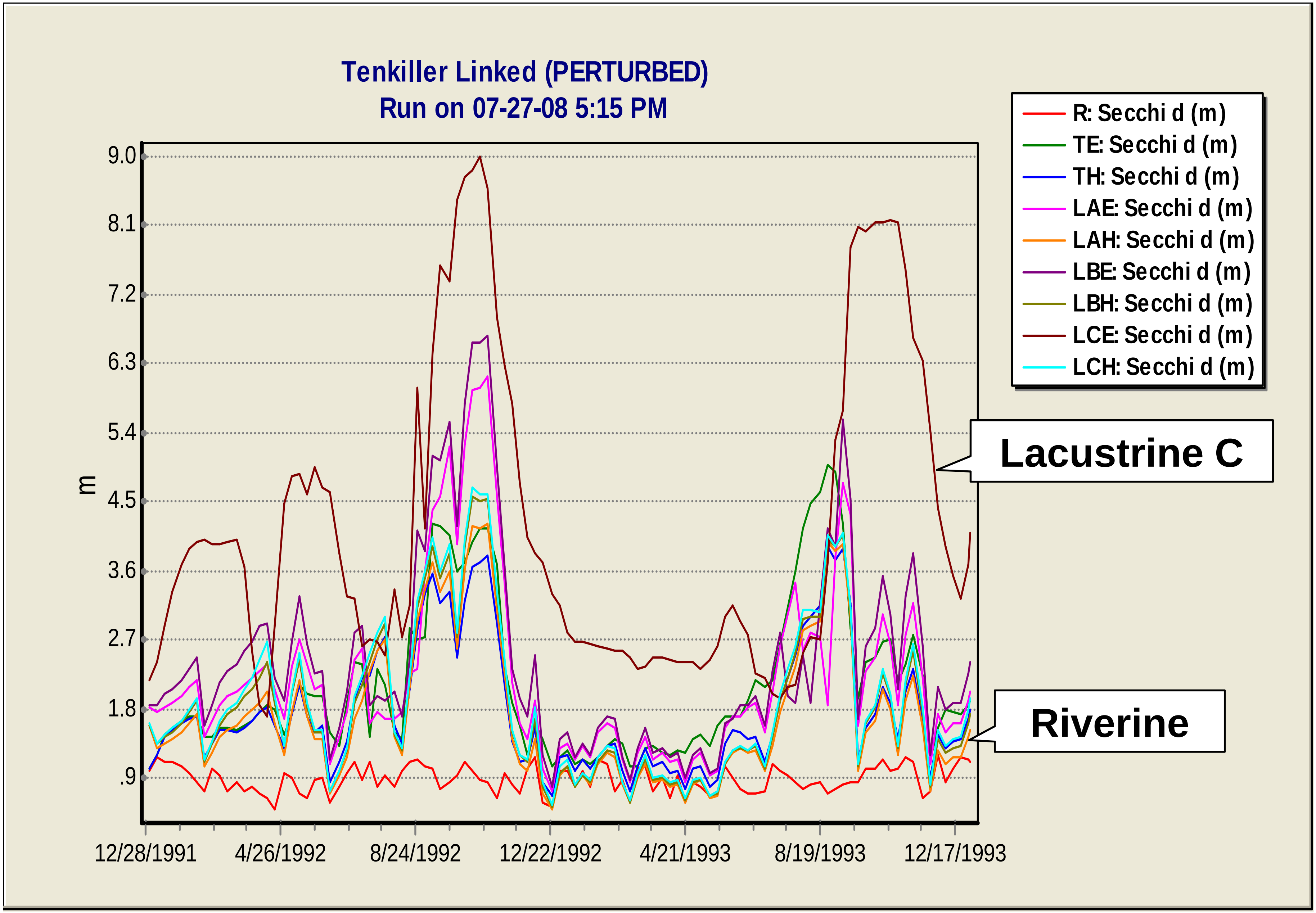
# Tenkiller Lake OK



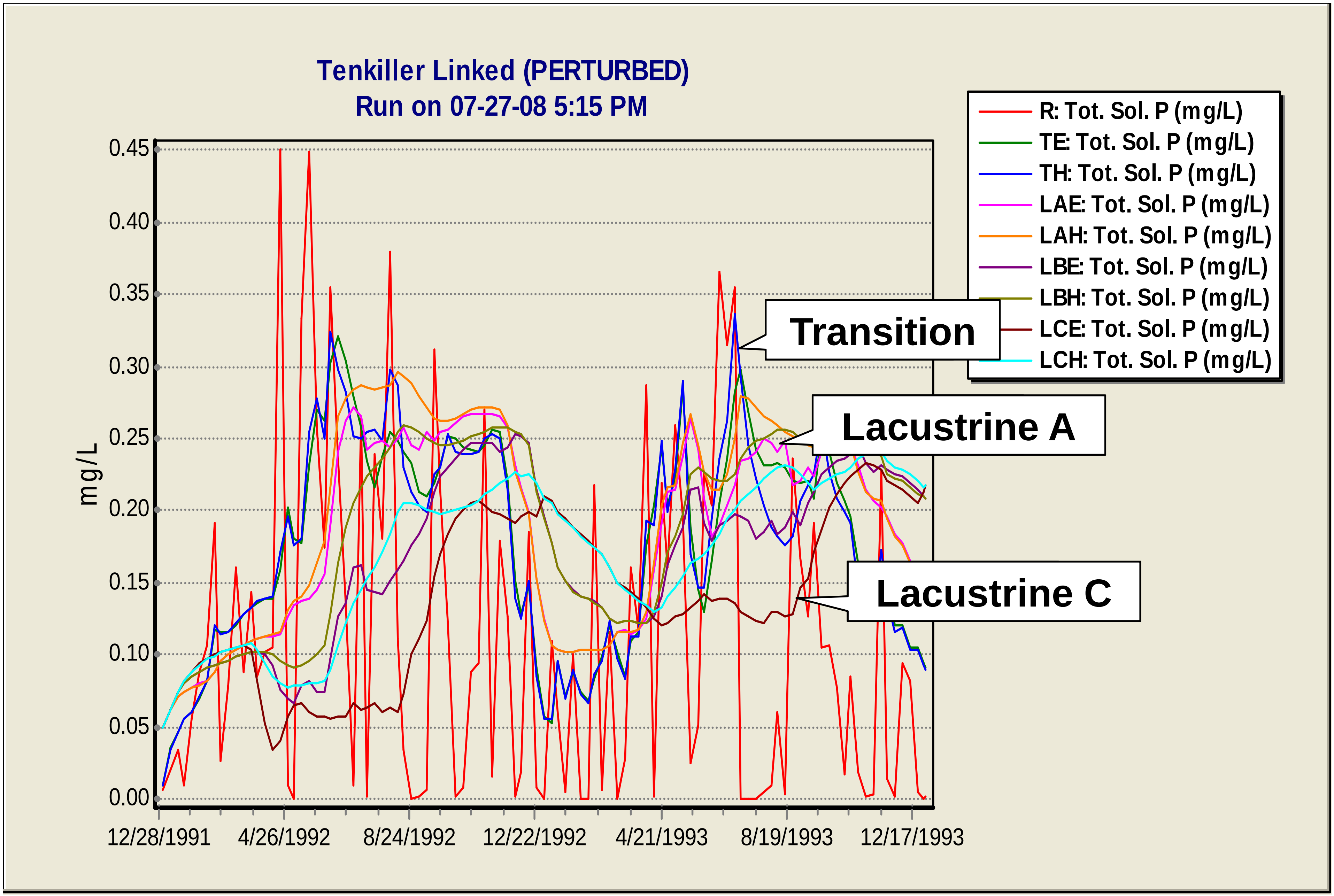
# Storm-water plume, algae-rich riverine segment

**duckweed (*Lemna* sp.) forms surface scum at the interface**

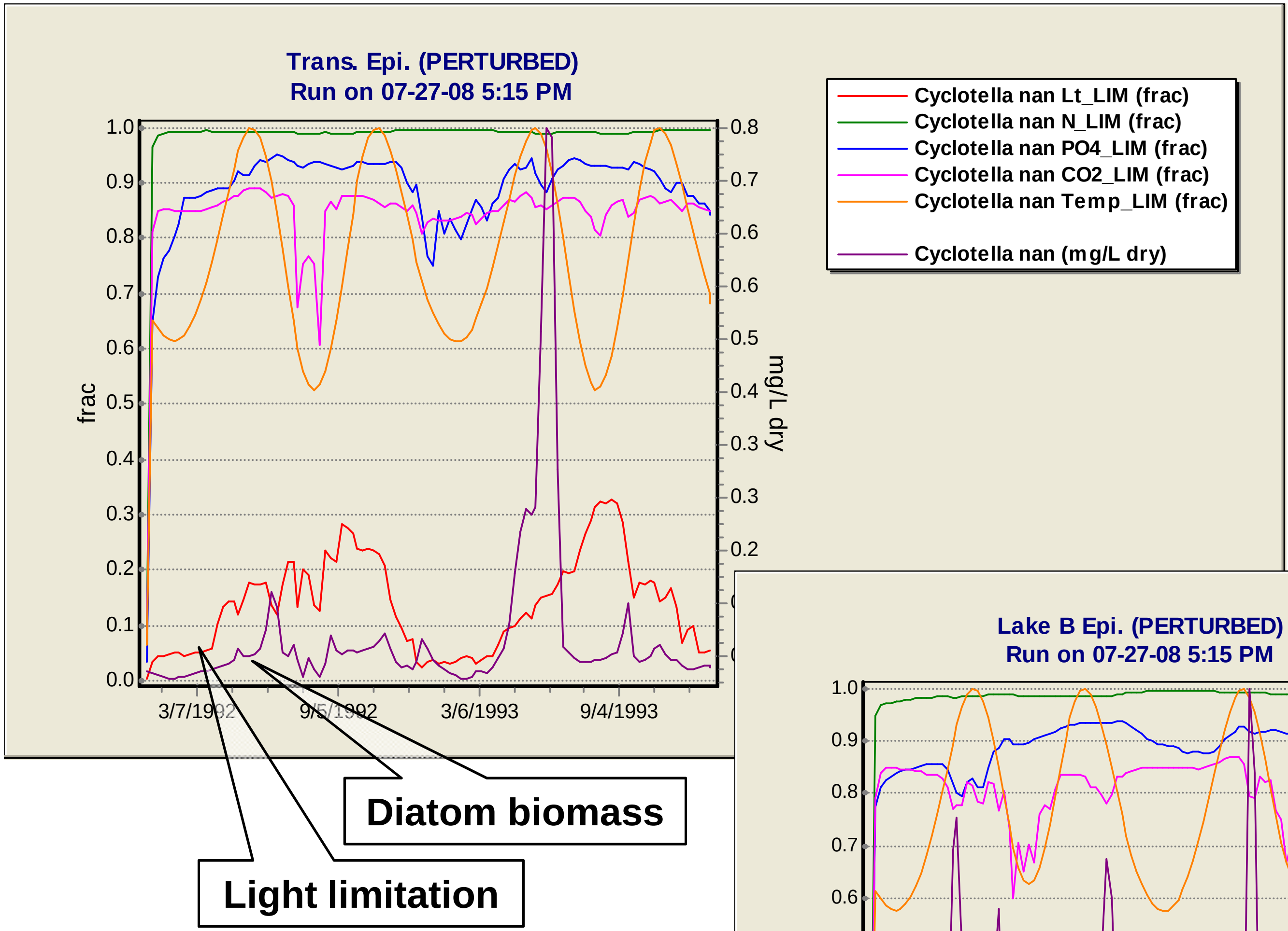
# Known for its clarity, Tenkiller Lake Secchi depth increases down reservoir

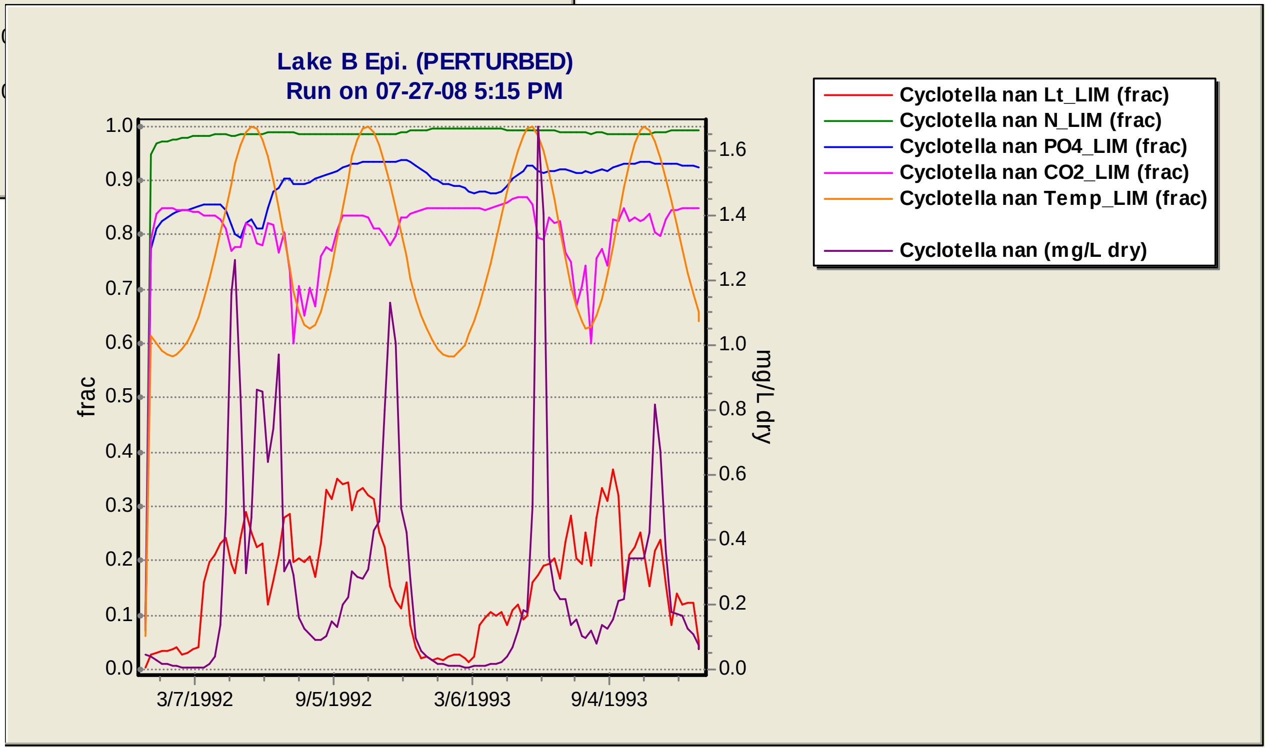


# Peak phosphorus decreases down reservoir

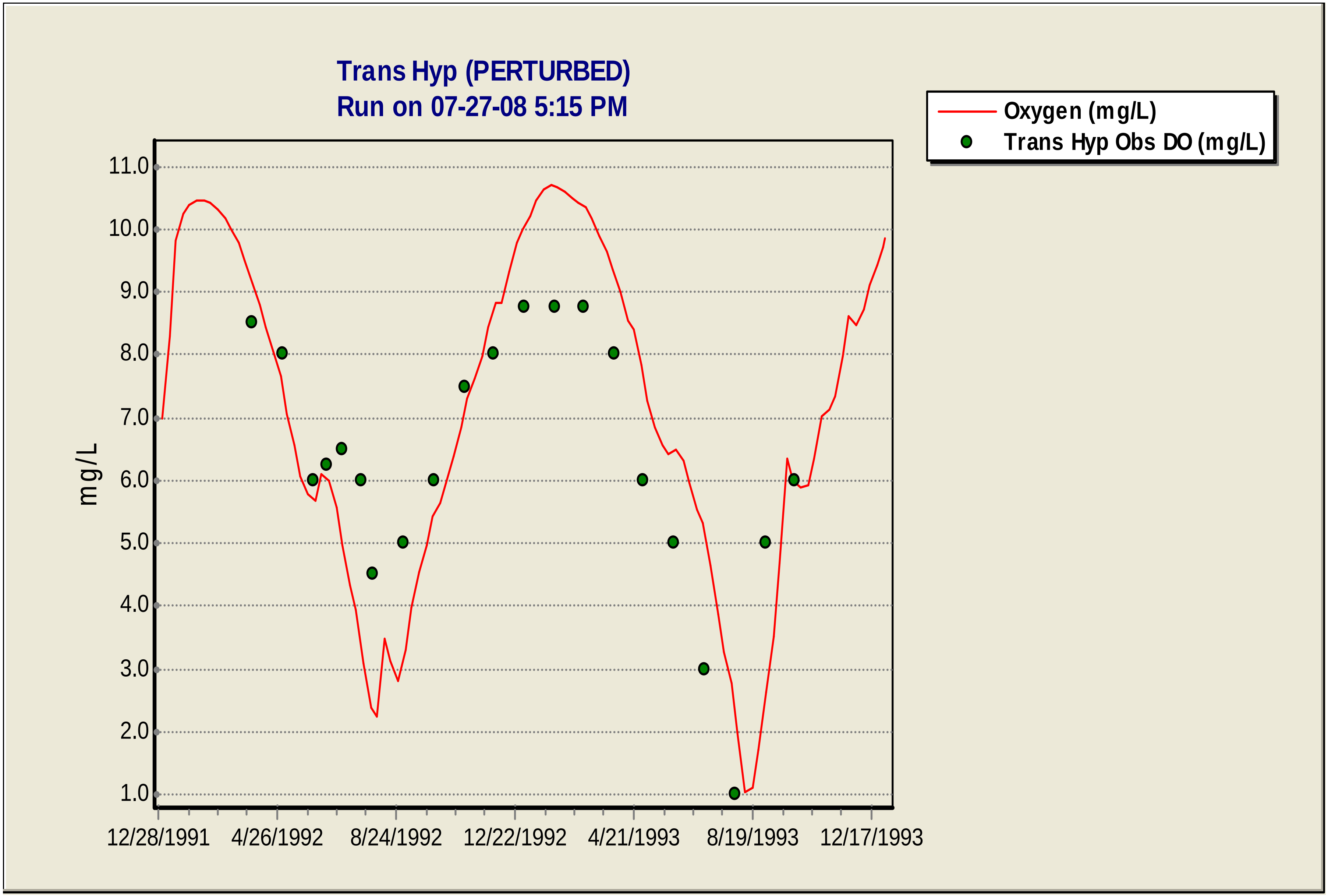


# Transition diatoms suppressed by turbidity



# Transition hypolimnion exhibits hypoxia



# AQUATOX– Chemical Fate Overview

- Can model up to twenty chemicals simultaneously
- Fate processes:
  - ionization
  - volatilization
  - hydrolysis
  - photolysis
  - sorption
  - microbial degradation
- Biotransformation—can model daughter products
- Bioaccumulation

# Chemical fate clarified using half-Lives and DT95

Time-to-loss Estimated Using Loss Rates at a given time

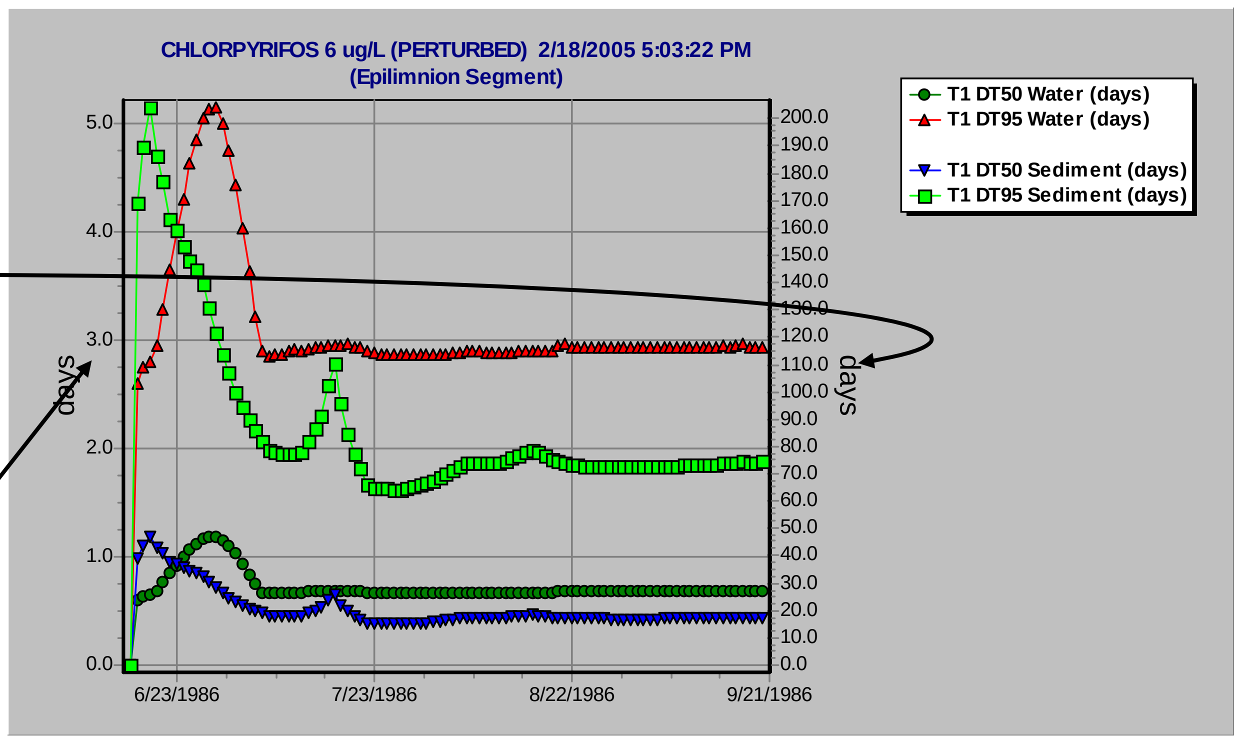
$$Loss_{Water} = \frac{Hydrolysis_{Water} + Photolysis + Microbial_{Water} + Washout + Volat. + Sorption}{Mass_{Water}}$$

$$Loss_{Sed} = \frac{Microbial_{Sed} + Hydrolysis_{Sed} + Desorption}{Mass_{Sed}}$$

For this Chlorpyrifos Study:

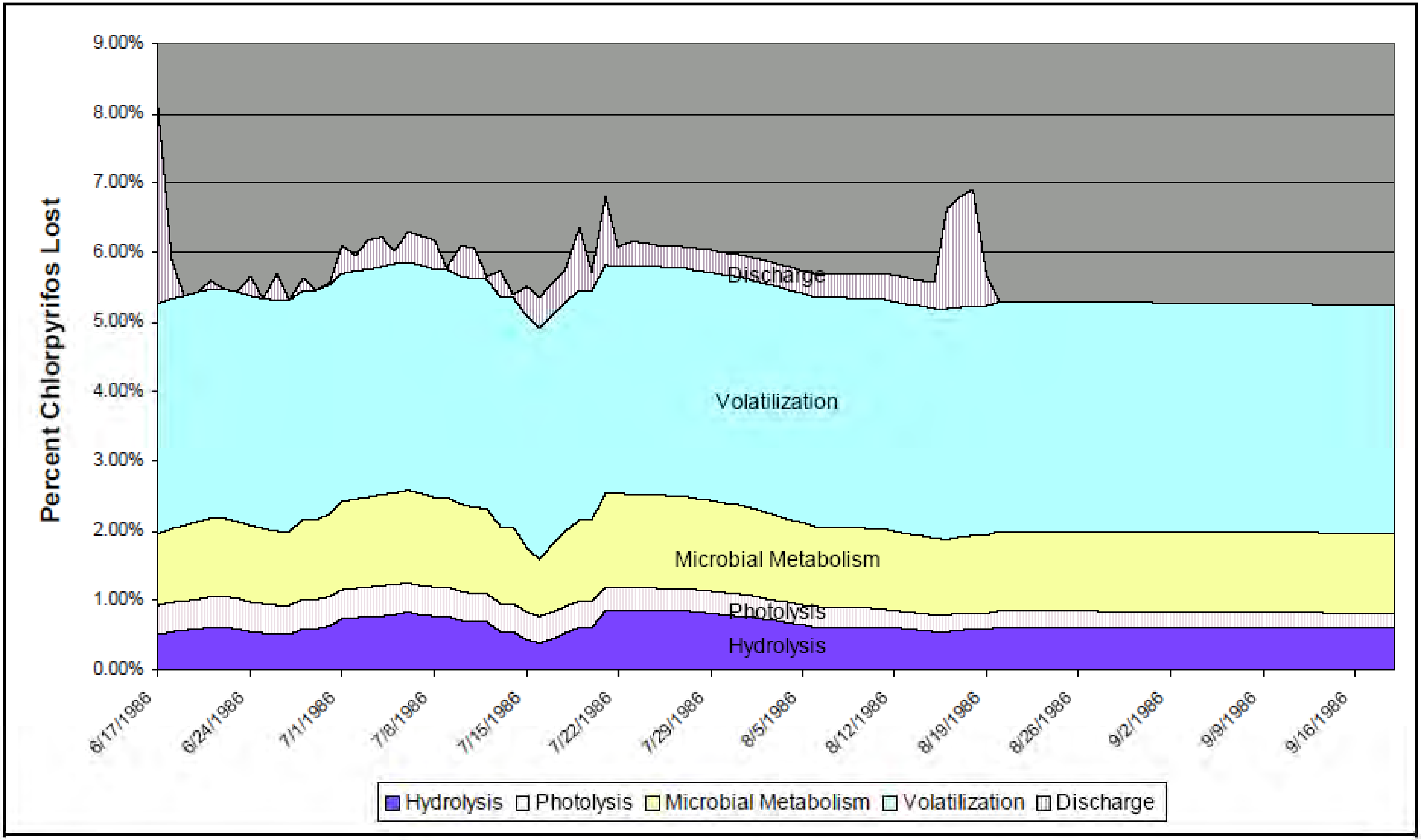
Half-life in Sediment of roughly 20 days
DT95 of roughly 75 days

Half-life in water of roughly 16 hours, DT95 in water is roughly 3 days



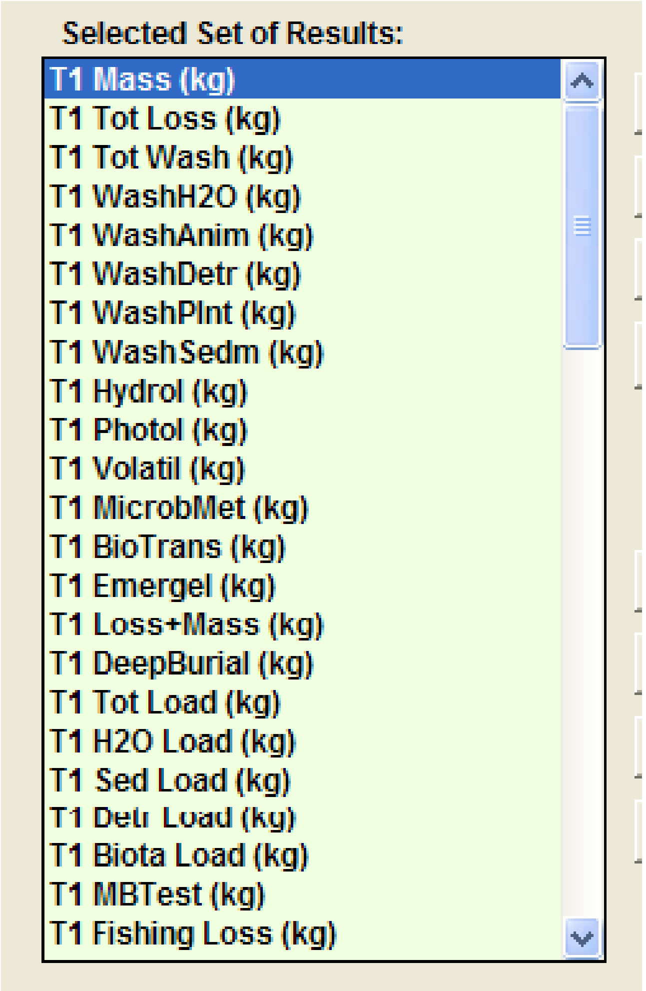
# Chemical rates may be tracked

Predicted In-situ Degradation Rates for Chlorpyrifos in Pond



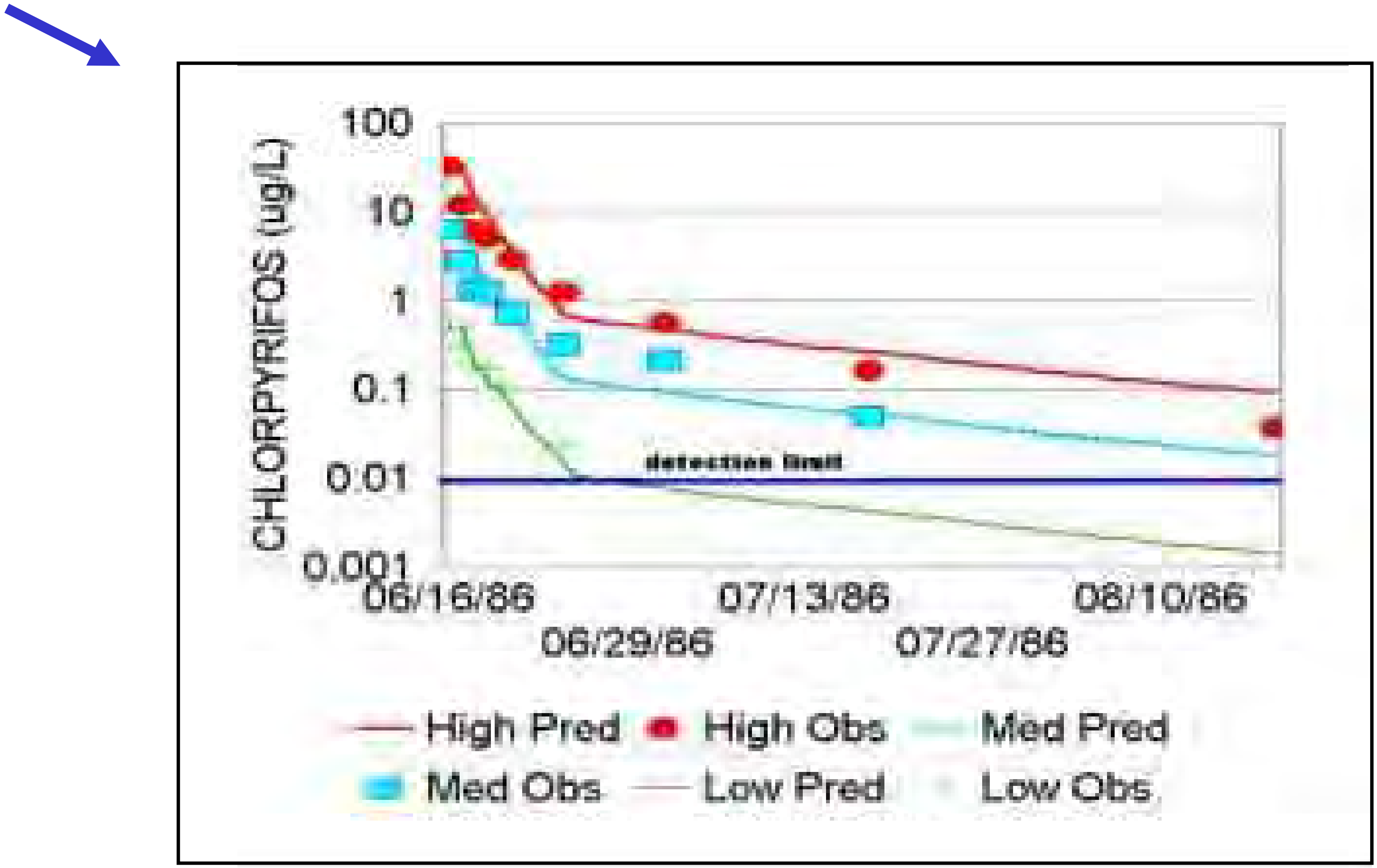
# Toxicant mass balance tracking

- Extensive set of model outputs
- Provides mass accounting of total toxicant loadings to and total toxicant losses from the system
- Provides accounting of toxicants within the system at a given time
- Provides assurance of model mass balance throughout the complex cycling processes



# Fate of Chlorpyrifos in the Duluth MN Pond was Predicted Successfully

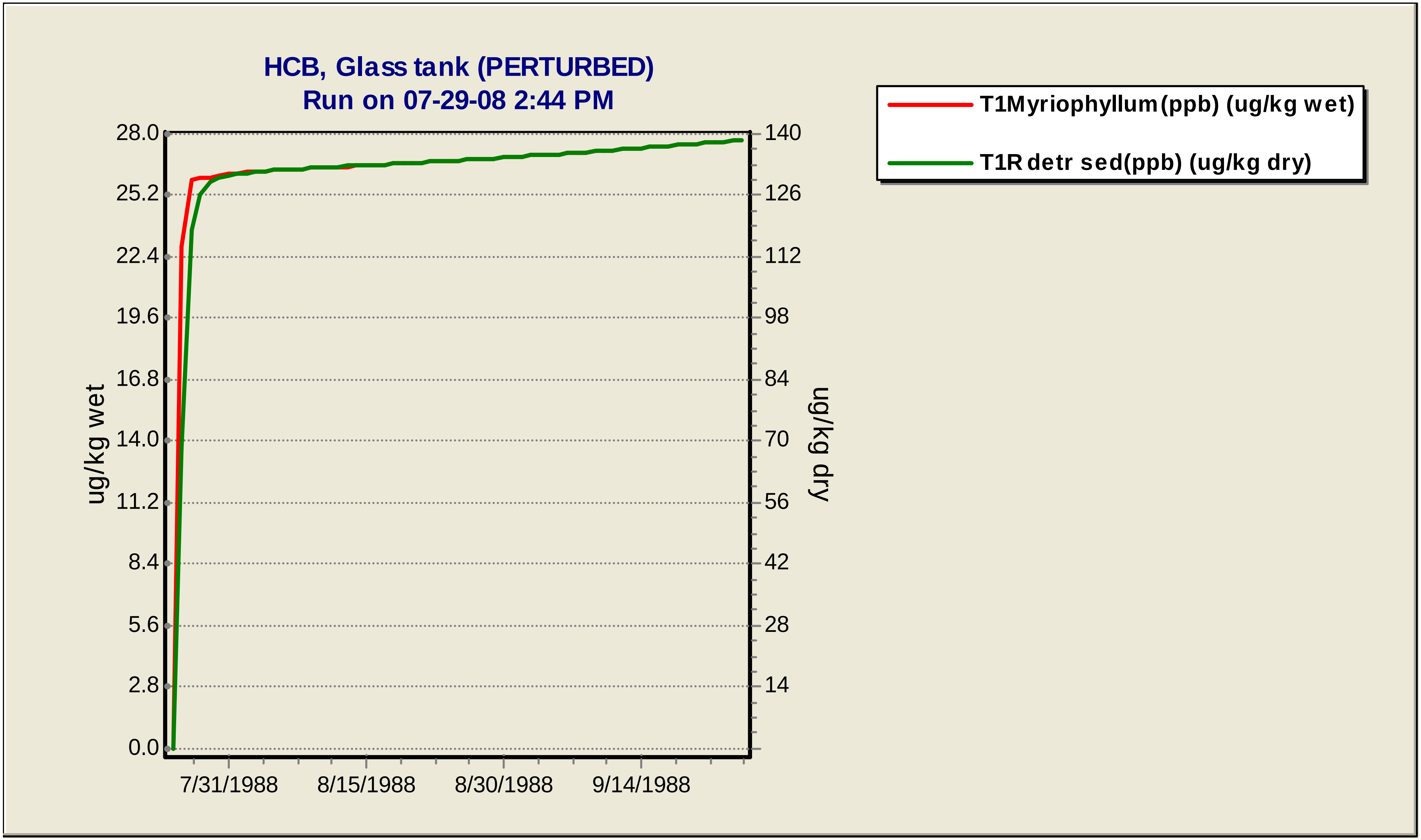
**Multiple Dosing Levels**



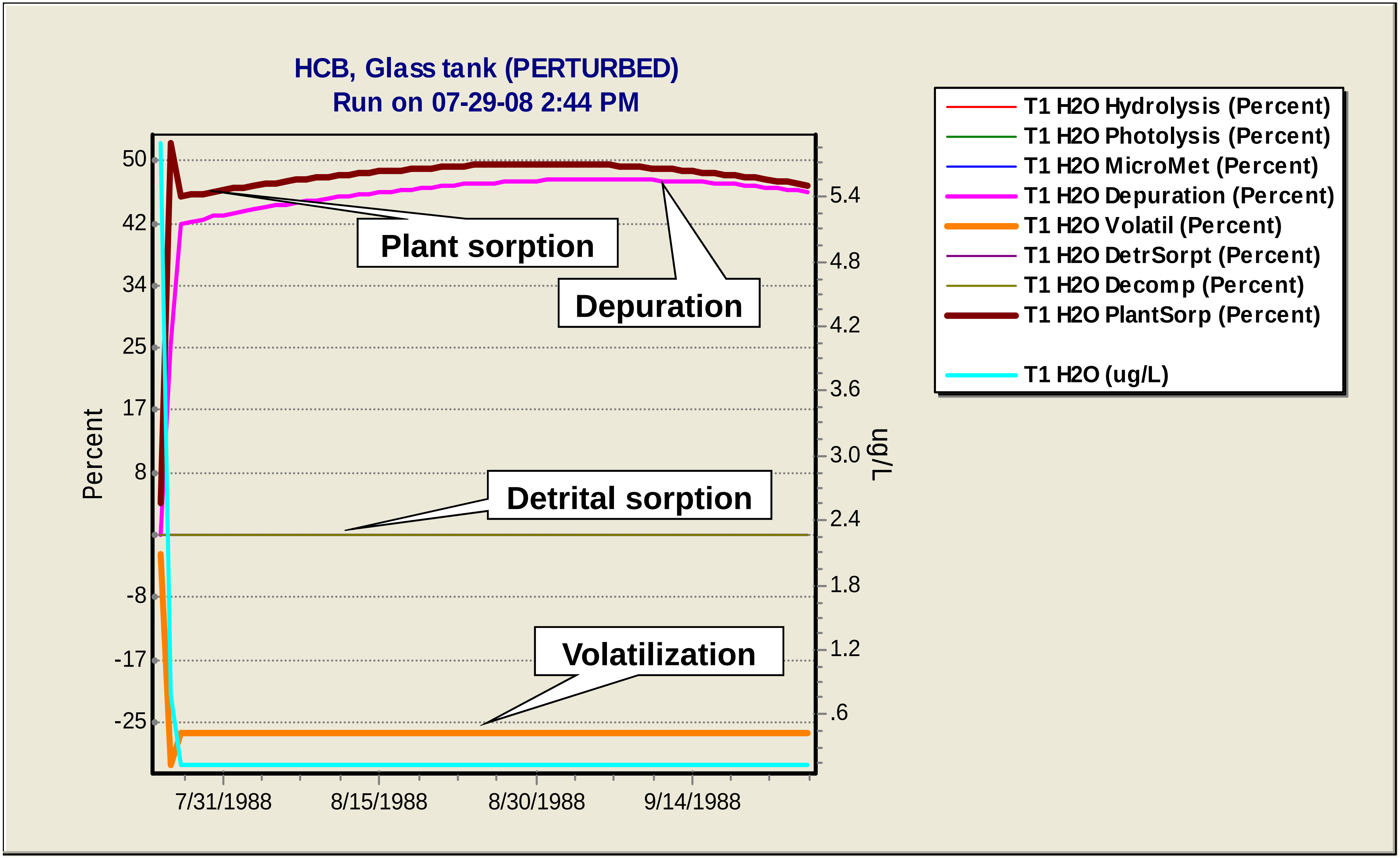
# HCB in tank

- Reproduces experimental results (Gobas) in which macrophytes are enclosed in an aquarium tank
- A single dose of hexachlorobenzene is applied at the beginning of the simulation
- Simplest type of AQUATOX model setup

# HCB is taken up rapidly by macrophyte and by organic sediments



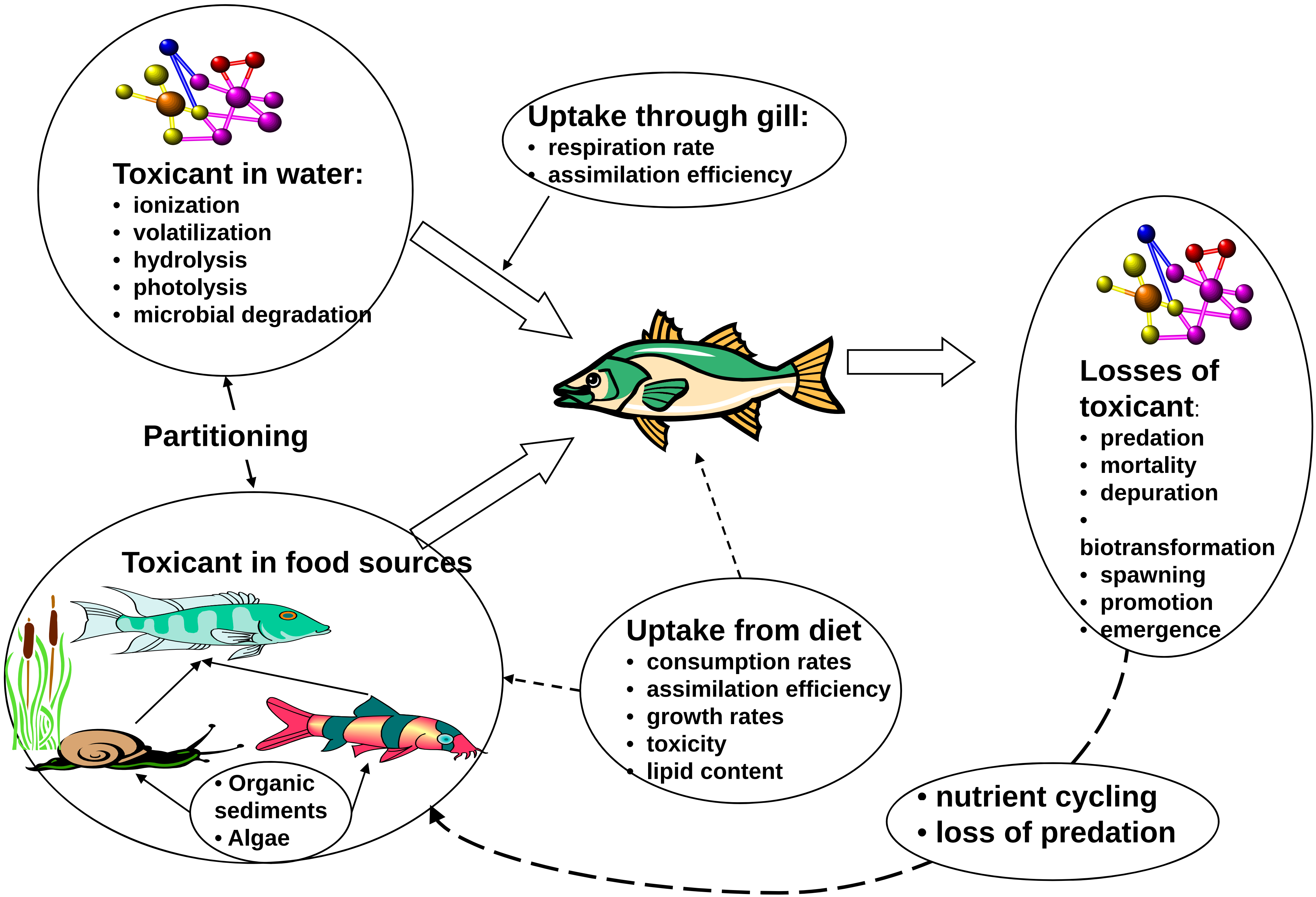
# HCB loss rates can be plotted, showing that sorption to detritus is negligible (due to mass)



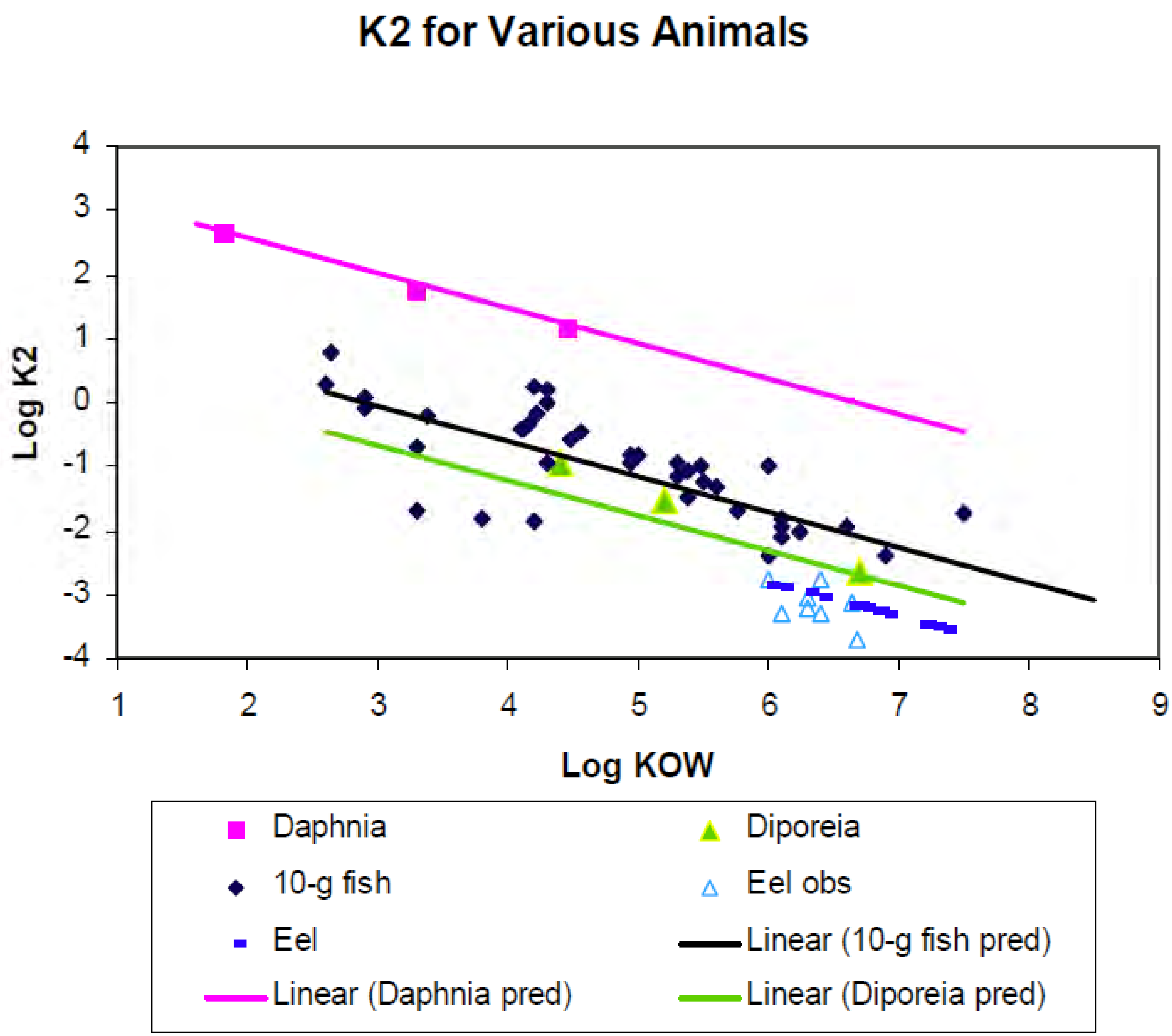
# Chemical Bioaccumulation Overview

- Kinetic model of uptake and depuration
  - Uptake through gill
  - Uptake through diet
    - Consumption rate
    - Assimilation efficiency
  - Loss through depuration, biotransformation, growth dilution (implicit)
- Alternative (simple) BCF model available

# Bioaccumulation in AQUATOX



# Depuration Rate Constants for Invertebrates and Fish



# Alternative Chemical Uptake Model

The user may enter two of the three factors defining uptake (BCF, K1, K2) and the third factor is calculated:

$$BCF \ (\mathrm{L/kg}) = \frac{K1 \ (\mathrm{L/kg \cdot d})}{K2 \ (\mathrm{1/d})}$$

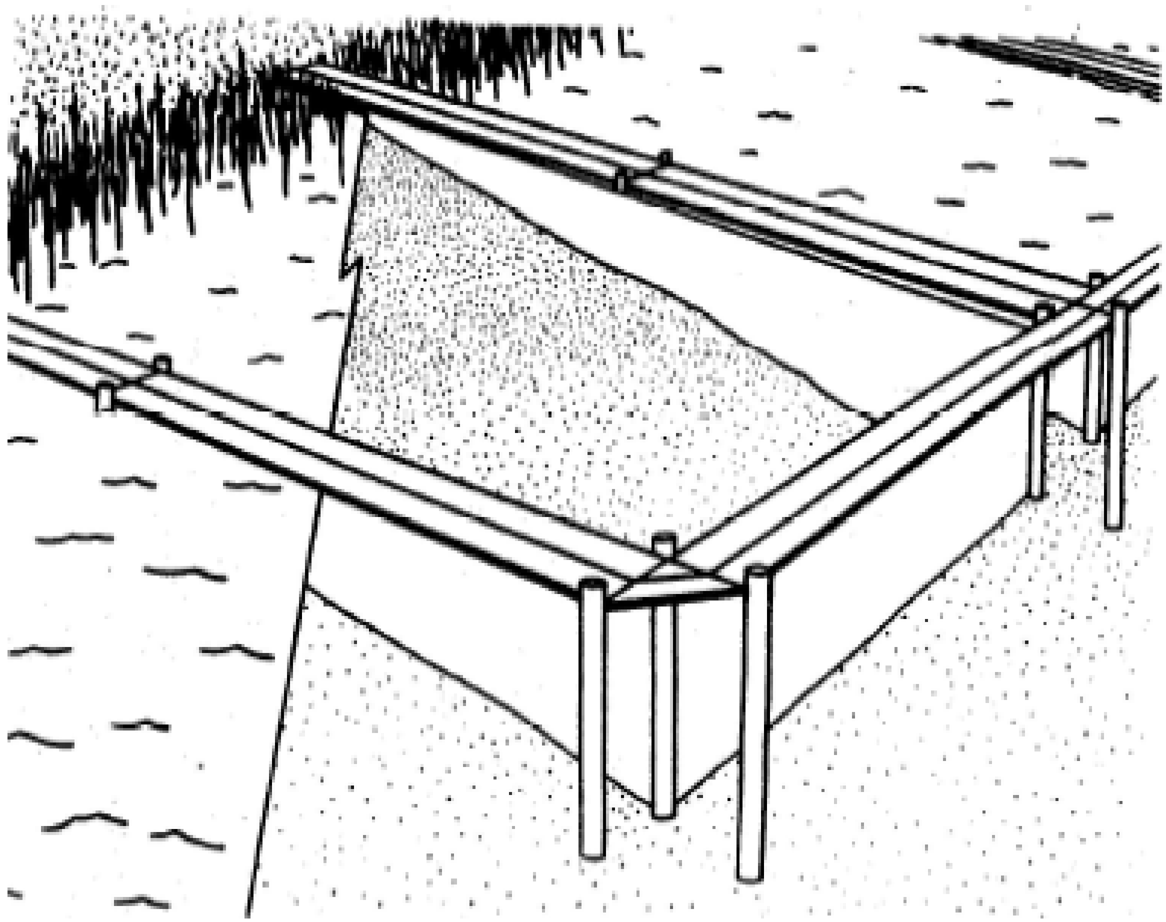
Given these parameters, AQUATOX calculates uptake and depuration in plants and animals as kinetic processes.

Dietary uptake of chemicals by animals is not affected by this alternative parameterization.

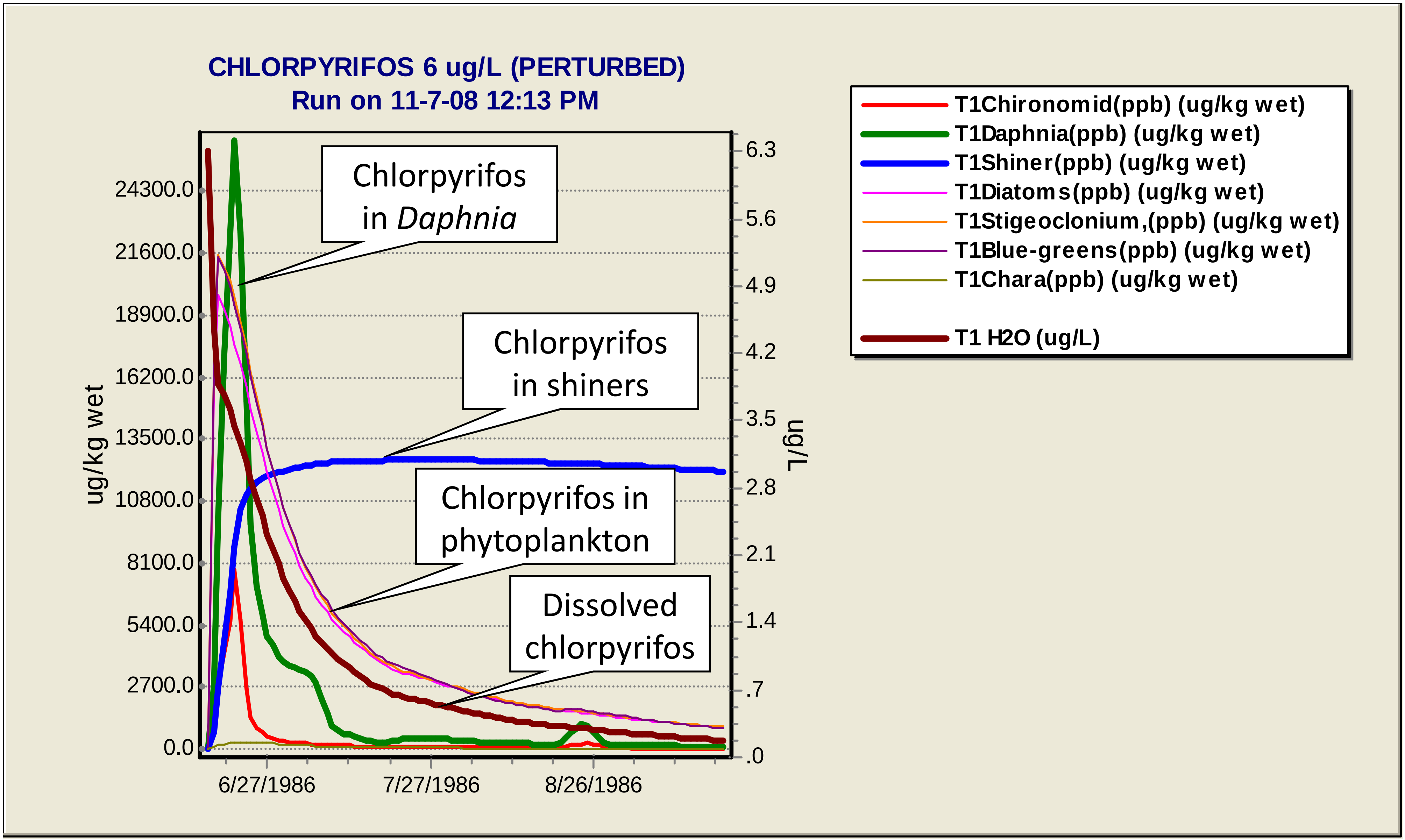
# Chlorpyrifos in Pond

- Pond enclosure dosed with chlorpyrifos at EPA Duluth lab
- A single dose of chlorpyrifos is applied at the beginning of the simulation
- Additional biotic compartments
  - diatoms, greens, invertebrates,
  - sunfish, shiner

# Chlorpyrifos-dosed pond enclosures at Duluth MN used to validate fate and effects model

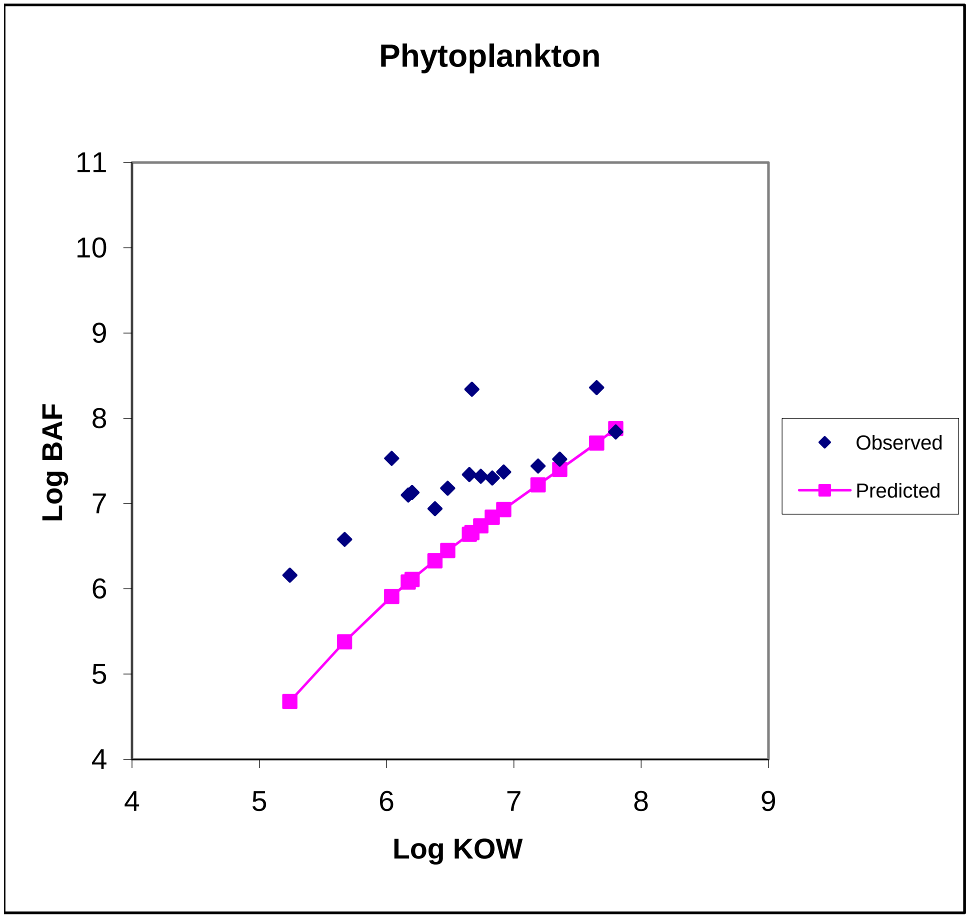


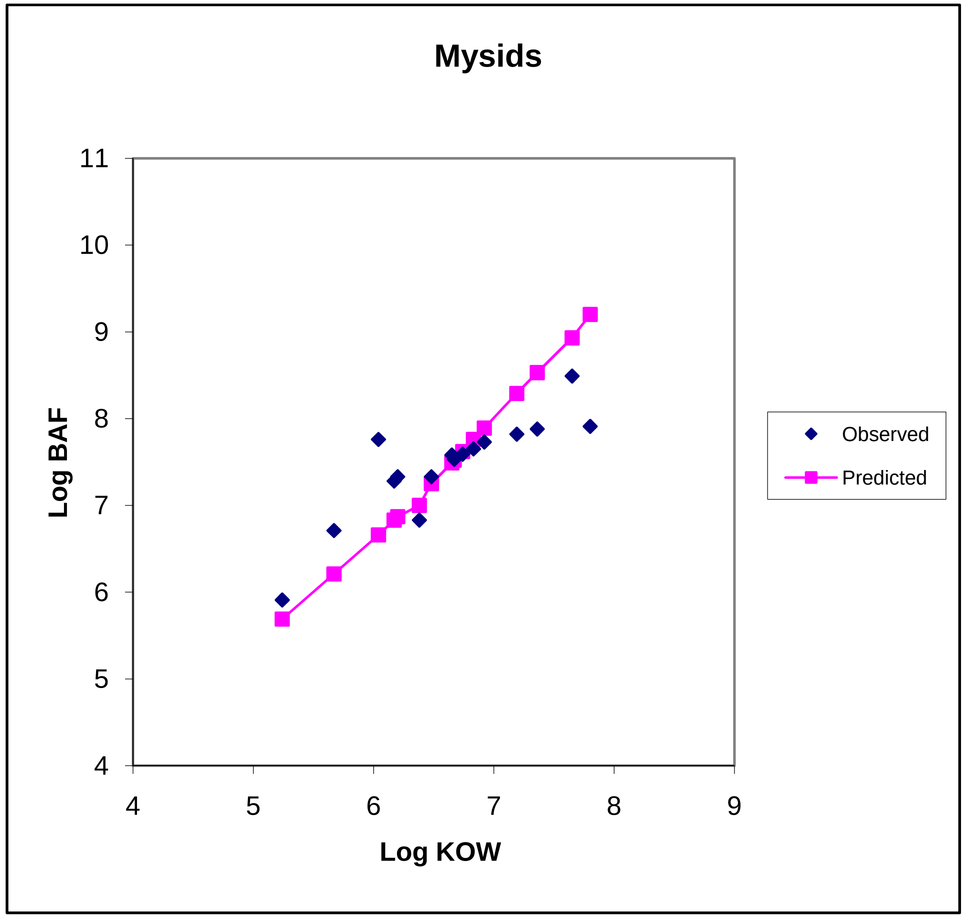
# Can trace how the toxicant is partitioned in the biota



# Lake Ontario Bioaccumulation

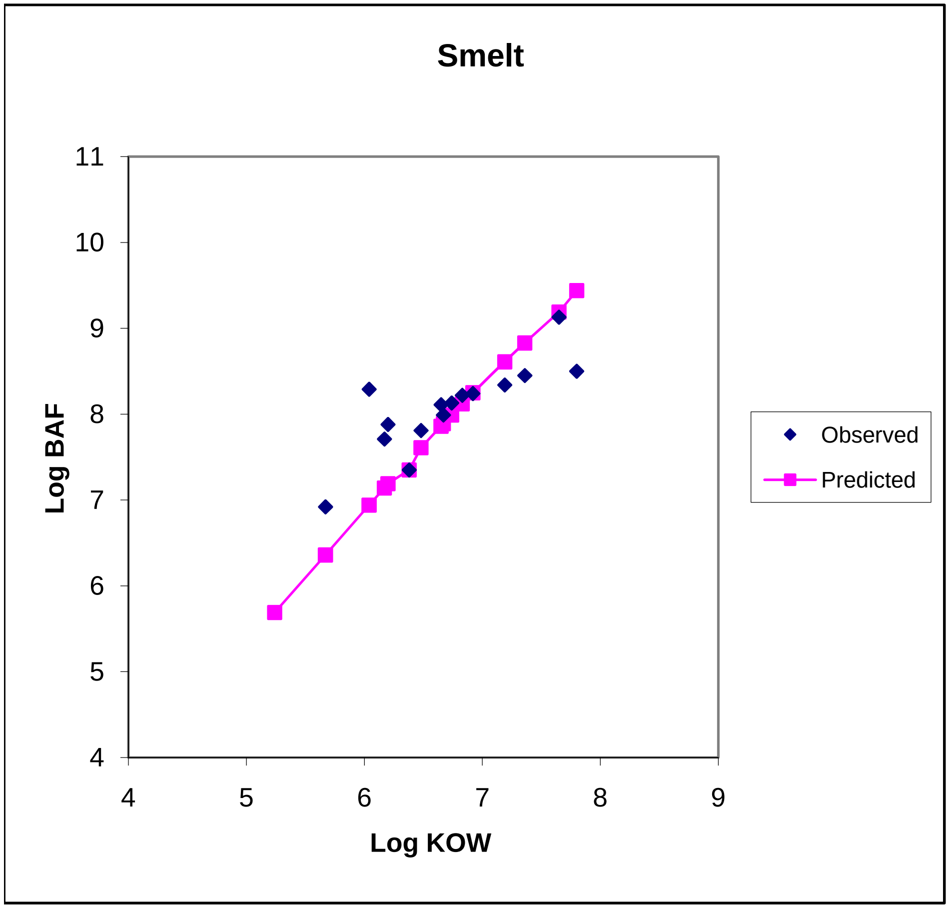
Observed and predicted lipid-normalized and freely dissolved BAFs for PCBs in Lake Ontario ecosystem components.

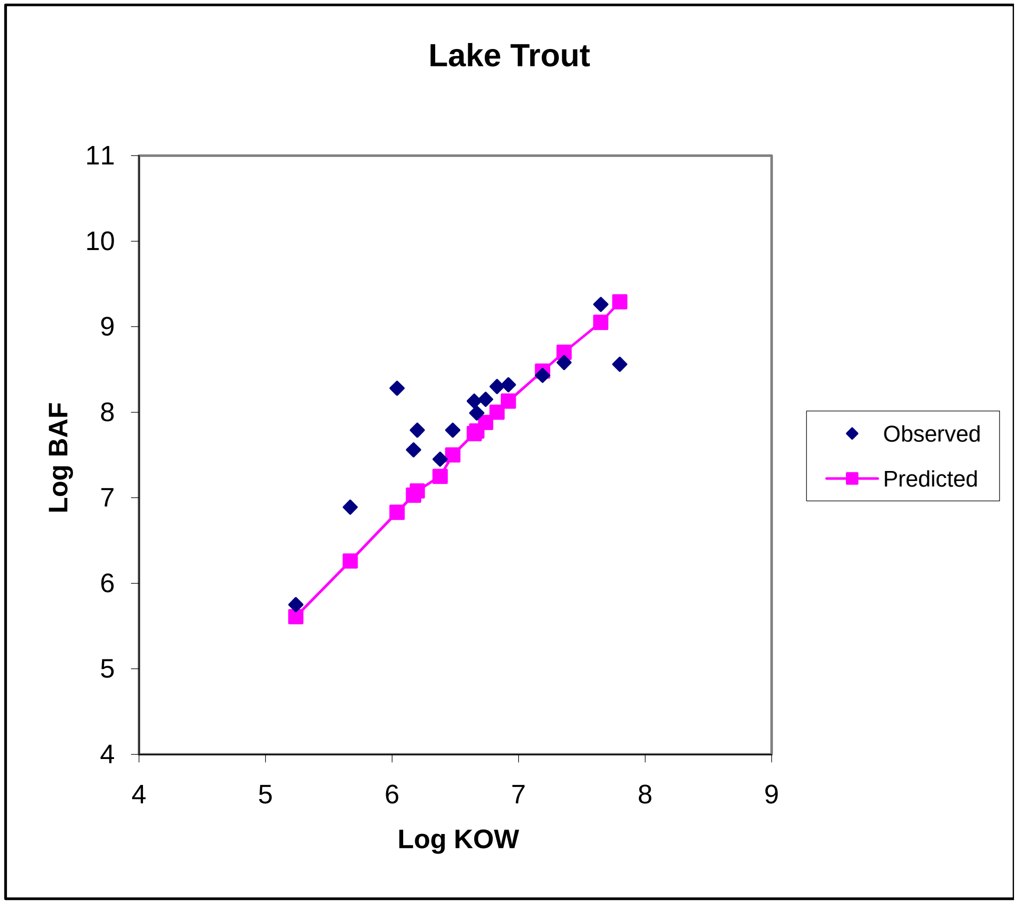


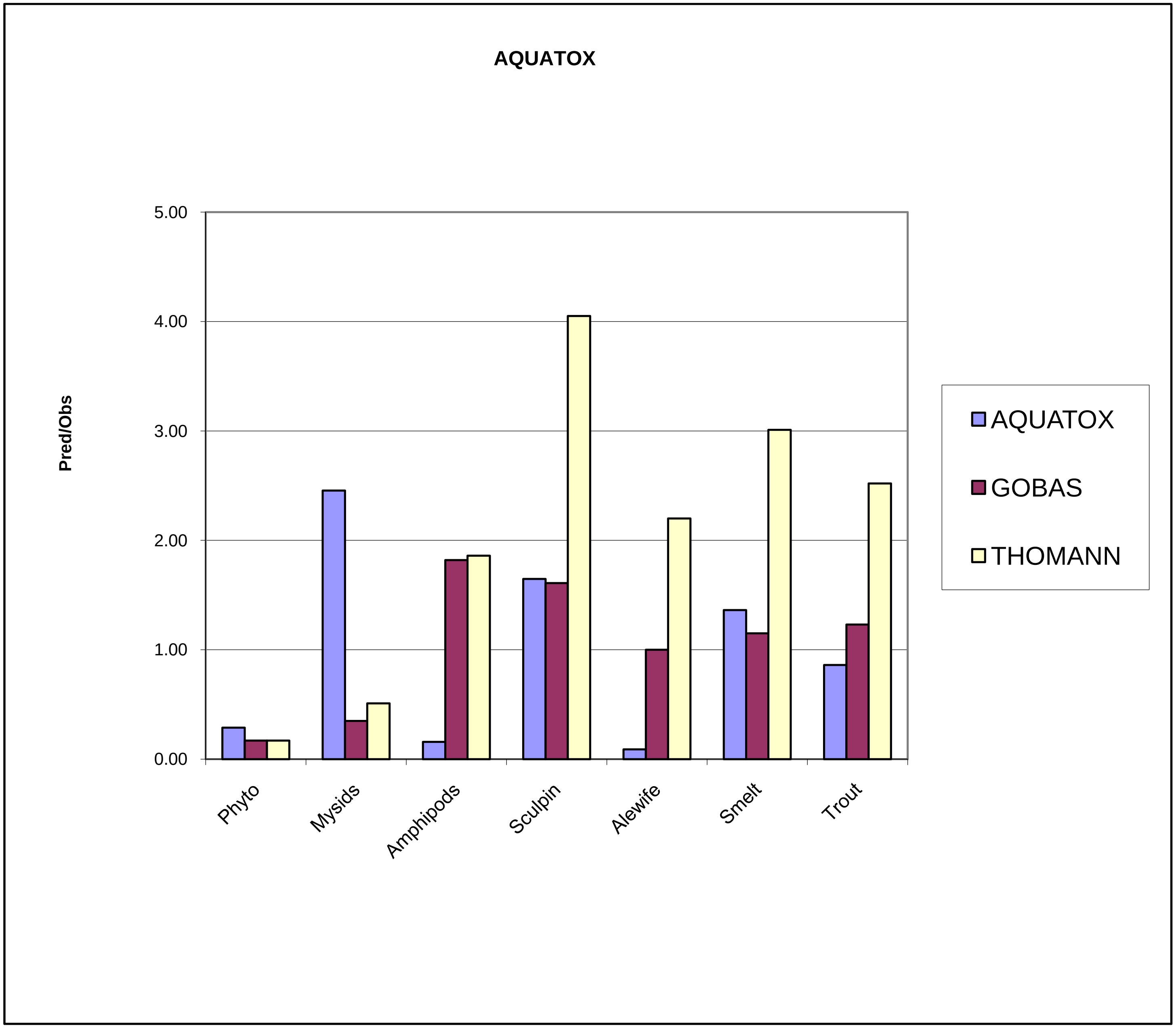
# Lake Ontario Bioaccumulation

Observed and predicted lipid-normalized and freely dissolved BAFs for PCBs in Lake Ontario ecosystem components.



# Lake Ontario BAF model comparison

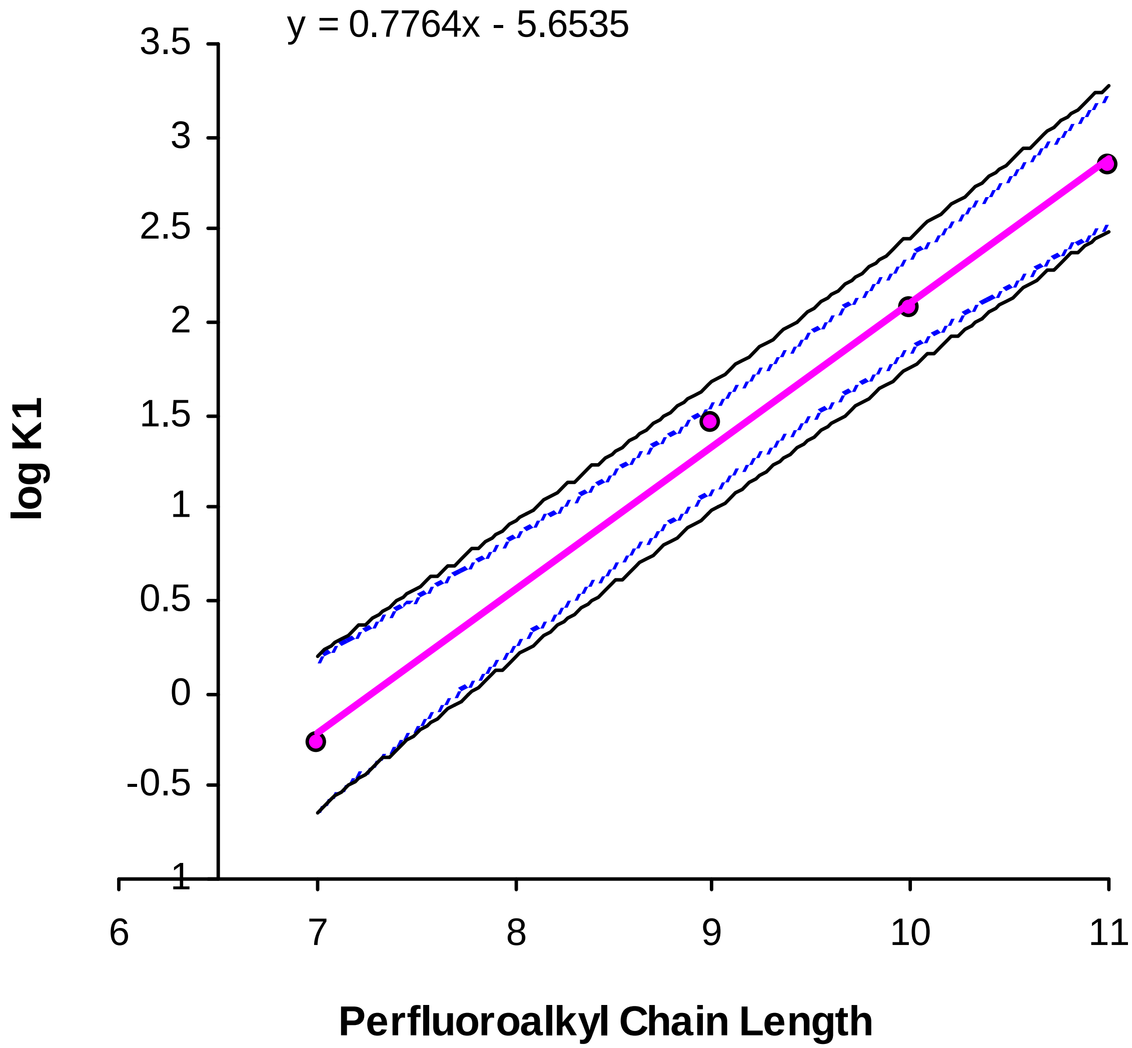


## Perfluorinated Surfactants (PFAs)

- Originally developed as part of estuarine model
  - Sorption modeled using empirical approach
  - Animal Uptake/Depuration a function of chain length and PFA type (sulfonate/ carboxylate)
  - Biotransformation can be modeled

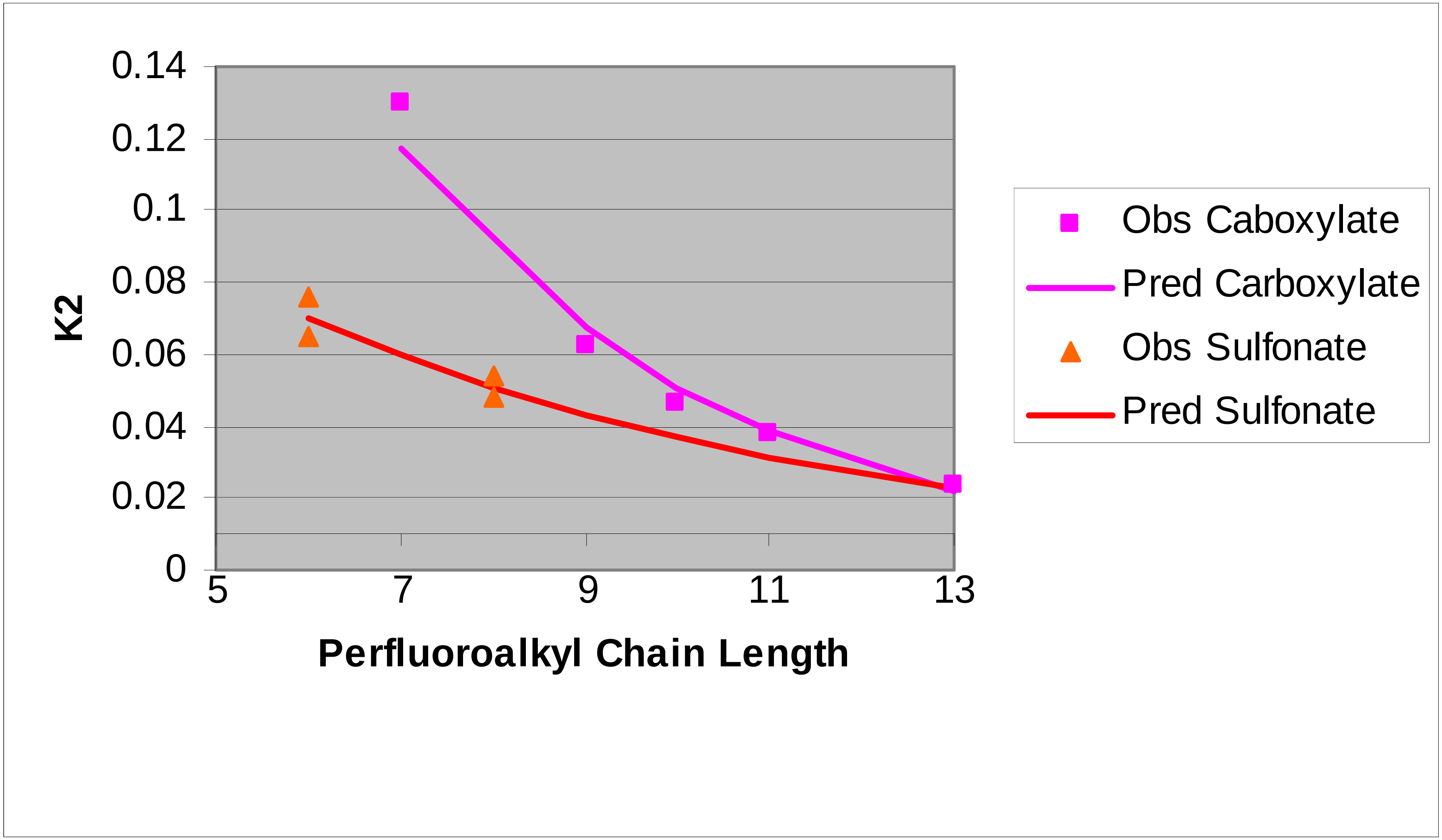
# Uptake of carboxylates can be predicted by chain length

*data from Martin et al., 2003*



# Depuration rate is also a function of chain length

*data from Martin et al., 2003*

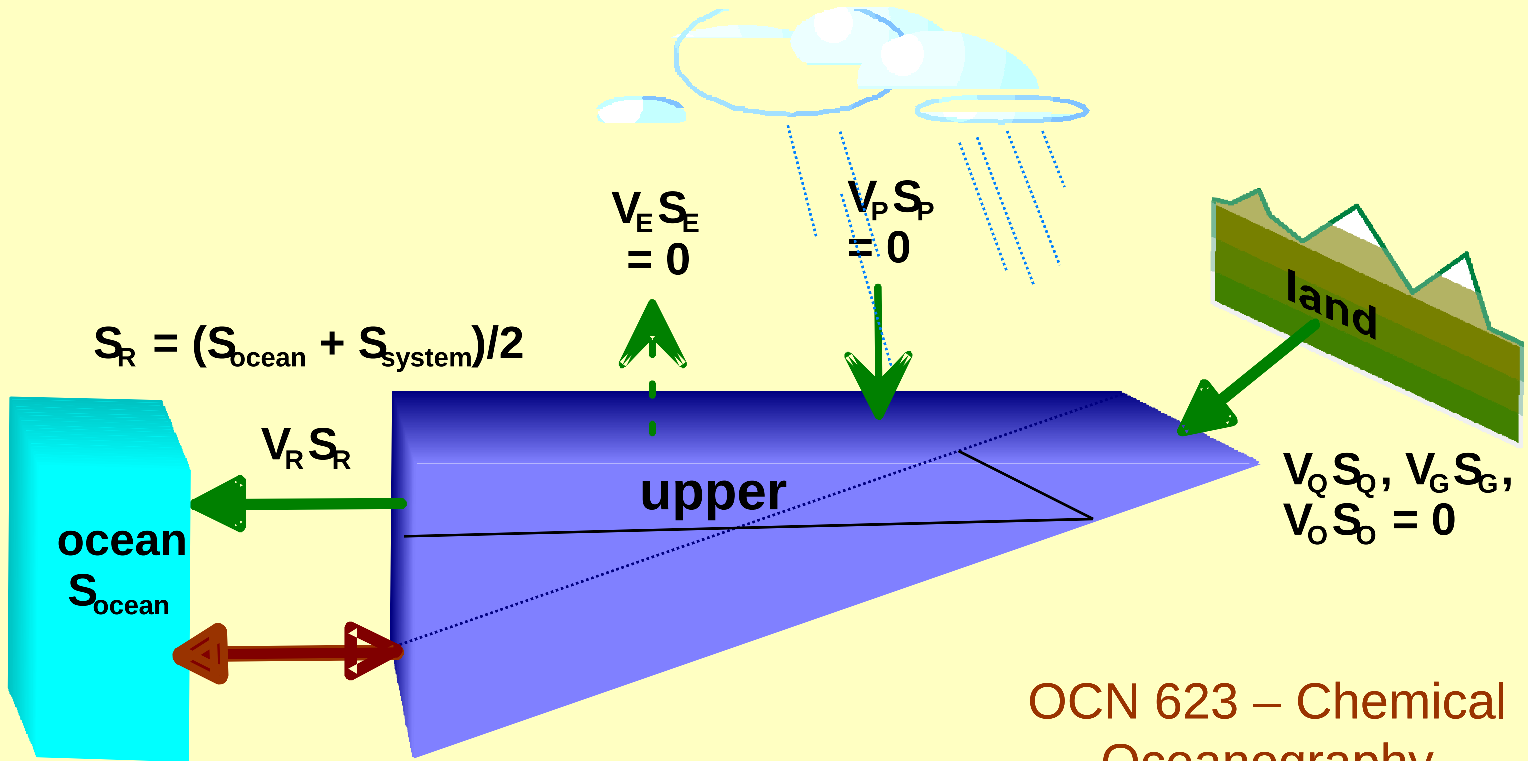


# Estuarine version applied to Galveston Bay, Texas, to evaluate toxicants

Photo Courtesy NASA Johnson Space Center

# Estuarine Features

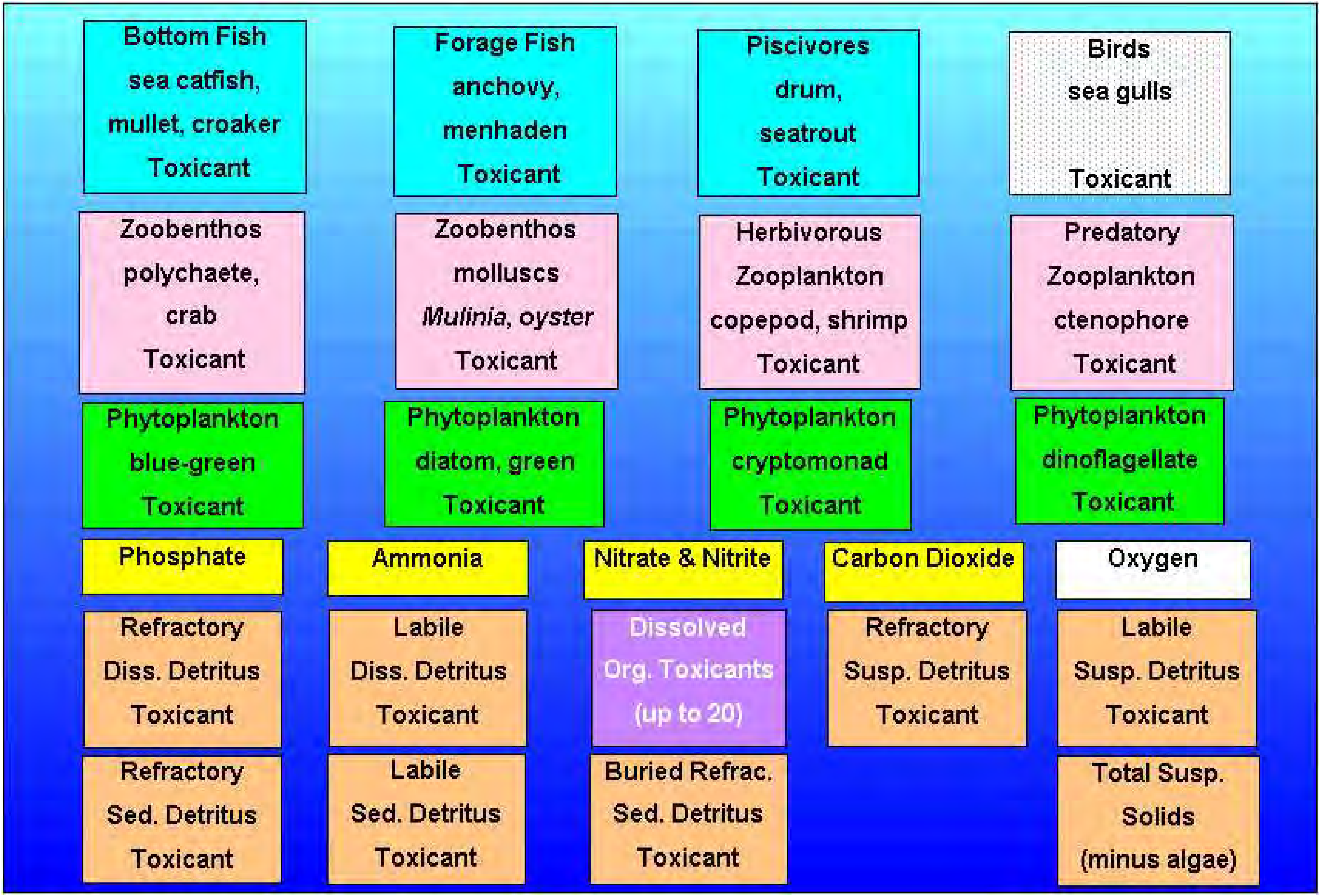
- Stratification – salt wedge
- Water Balance – salt balance approach
- Entrainment Process – lower to upper layers



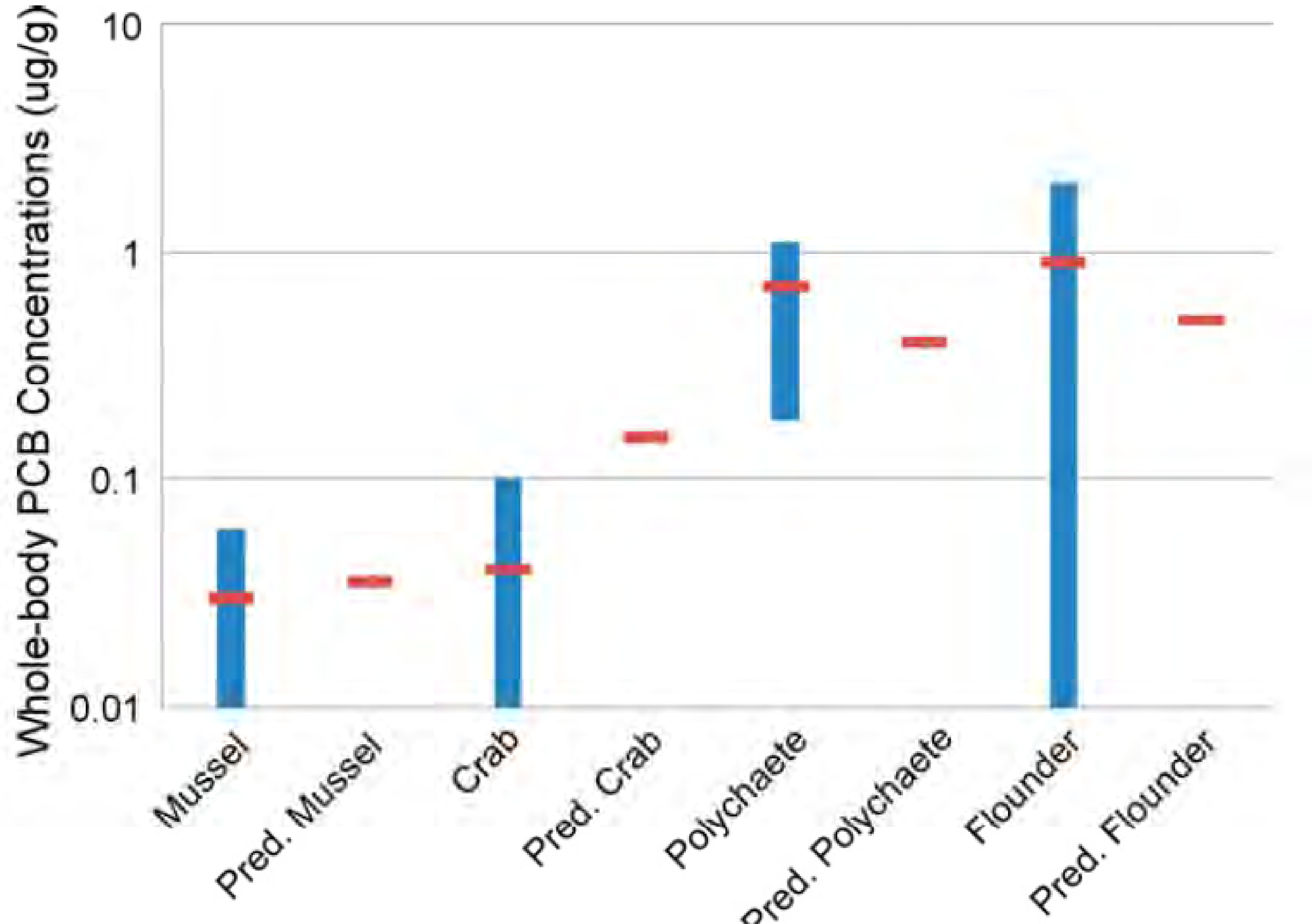
# Estuary Model Data Requirements

- Time series of “Upper Layer” and “Lower Layer” salinities at mouth for Salt Wedge Model
- Tidal range model parameters
  - “harmonic constants”, often available from NOAA website
- Estuary site width
- Loadings of freshwater inflow

# Galveston Bay, Texas, compartments

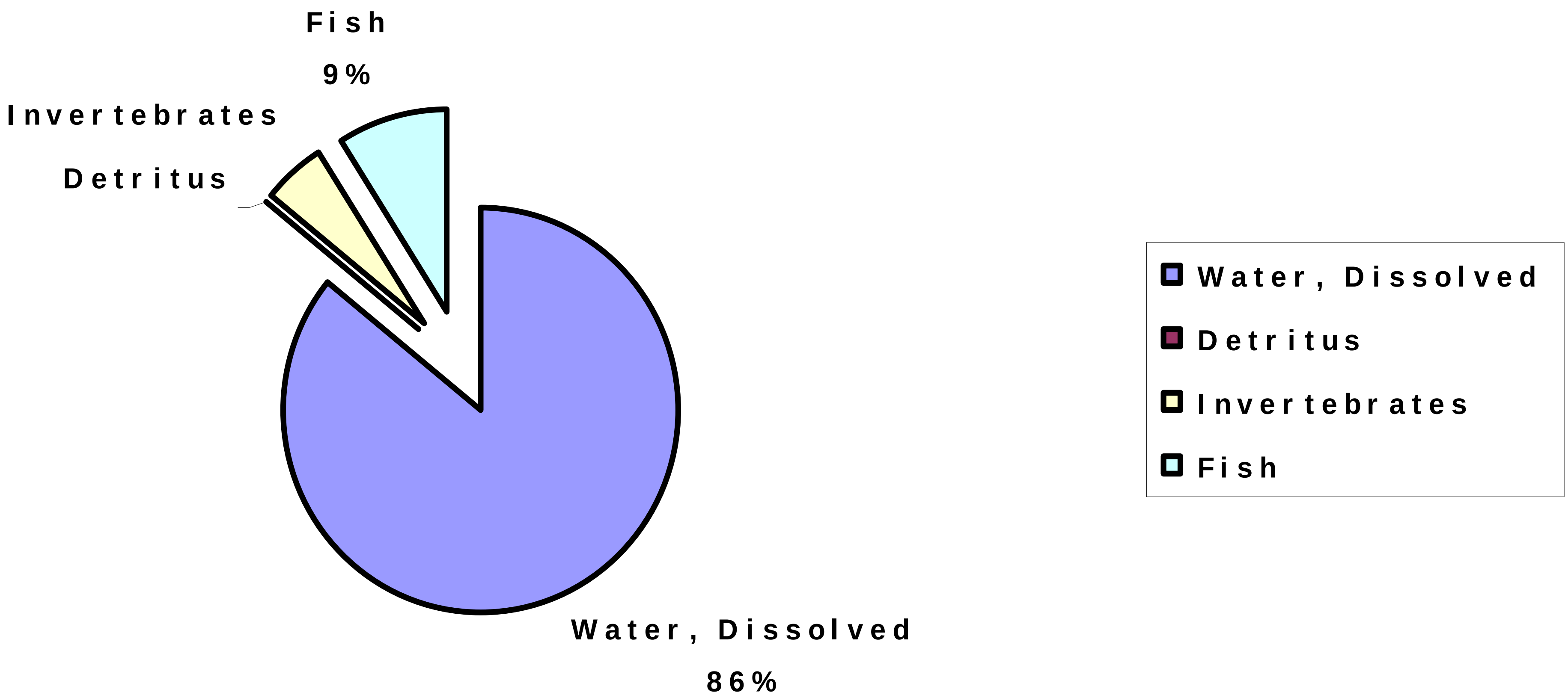


# Validation: New Bedford Harbor MA, observed & predicted PCB values are comparable




Park et. al, 2008, Figure 7, data from Connolly, 1991

# Predicted distribution of PFOS among major compartments in Galveston Bay at end of year



# Modeling Toxicity of Chemicals

- Lethal and sublethal effects are represented
- Chronic and acute toxicity are both represented
- Effects based on total internal concentrations
- Uses the critical body residue approach (McCarty 1986, McCarty and Mackay 1993)
- Can also model external toxicity
  - Useful if uptake and depuration are very fast (as with herbicides)

# Toxicity Models within Bioaccumulation Models

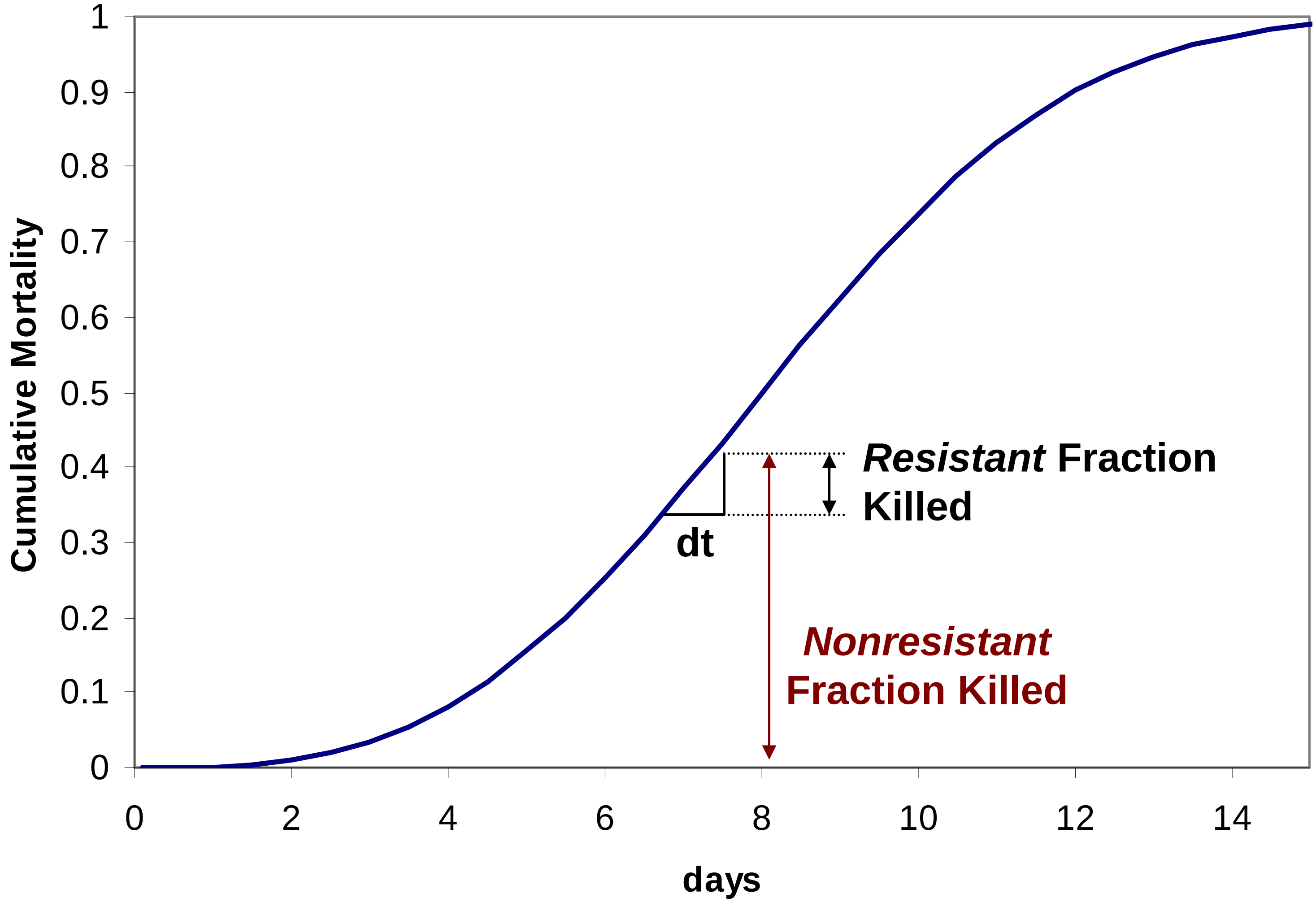
| Table 3.5. Toxicity Models | AQUATOX Release 2 | BASS v 2.1 | Biotic Ligand 1.0.0 | RAMAS Ecosystem |
|---|---|---|---|---|
| **Domain of Toxicity Models** | | | | |
| Acute Toxicity | ★ | ★ | ★ | ★ |
| Chronic Toxicity | ★ | ★ | | ★ |
| Sub-Lethal Effects | ★ | | | |
| Toxicity Effects Feed Back to Bioconcentration Model | ★ | ★ | | ★ |
| **Toxicity Mechanisms** | | | | |
| Based on Total Internal Concentrations | ★ | ★ | | ★ |
| Based on Concentrations in Organs | | | ★ | |
| **User Input Required** | | | | |
| LC50 values | ★ | ★ | | — |
| EC50 values | ★ | — | — | ★ |
| Weibull Shape Parameter | ★ | | | ★ |

Imhoff et al. 2004

# Steps Taken to Estimate Toxicity

- Enter $LC_{50}$ and $EC_{50}$ values
  - $LC_{50}$ estimators are available for species
- Compute internal $LC_{50}$
- Compute infinite $LC_{50}$ (time-independent)
- Compute t-varying internal lethal concentration
- Compute cumulative mortality
- Compute biomass lost per day by disaggregating cumulative mortality
- Sublethal toxicity is related to lethal toxicity through an application factor
- Option has been added to use external concentration.

# Disaggregation of Cumulative Mortality



# New Option to Model with External Concentrations

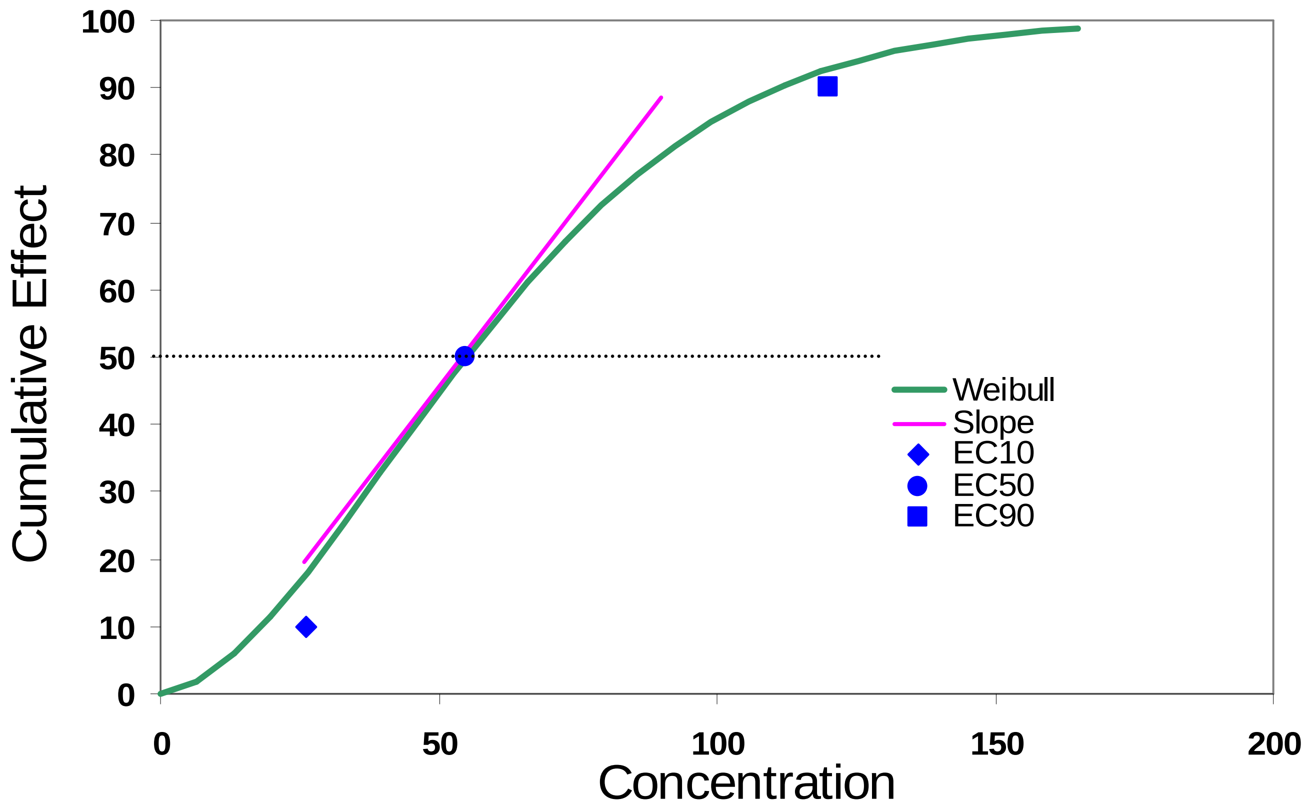
Two-parameter Weibull distribution as in Christiensen and Nyholm (1984)

$$CumFracKilled = 1 - \exp(-kz^{\eta})$$

Two Required Parameters:

LC50 (or EC50)

“Slope Factor” = Slope at LC50 multiplied by LC50

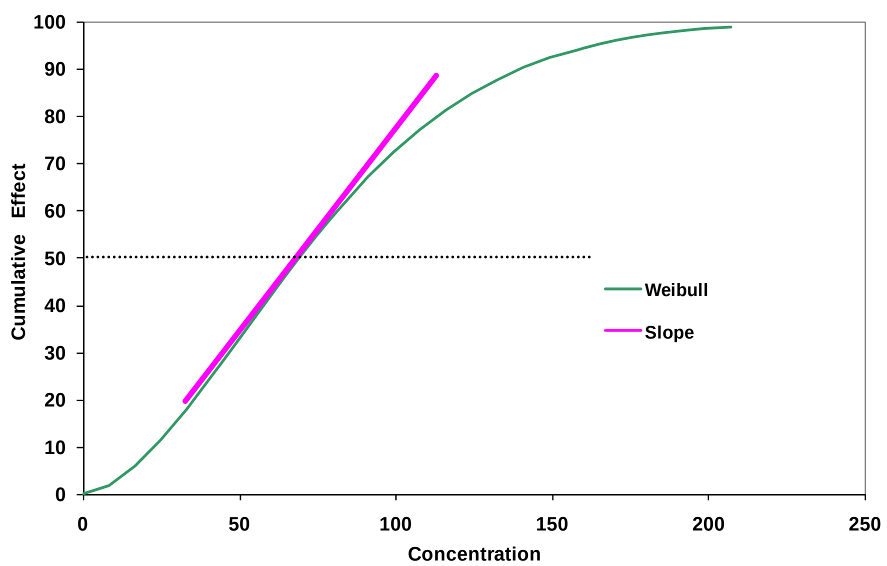


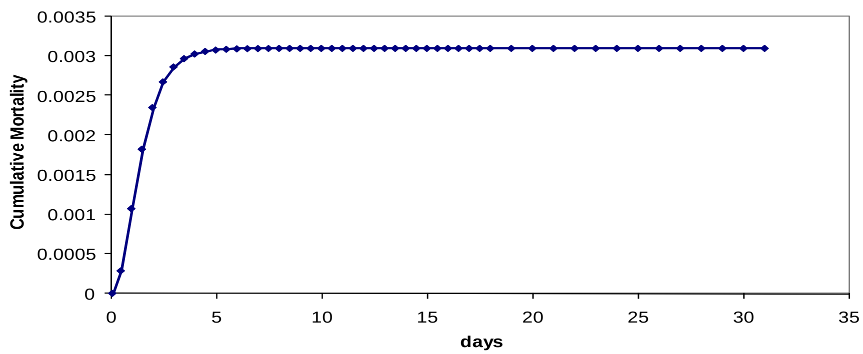
# Spreadsheet Demo

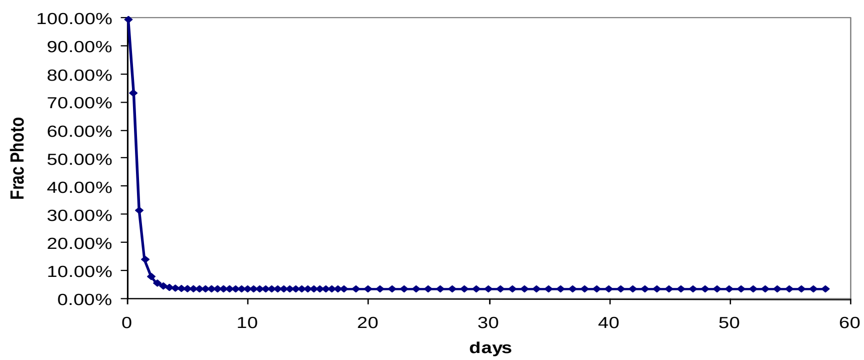
AQUATOX is distributed with two spreadsheets useful in understanding the model's toxicity components

**AQUATOX_Internal_Toxicity_Model.xls**

**AQUATOX_External_Toxicity_Model.xls**



# Chemical Toxicity Screen

**Chemical Toxicity Parameters -- Chlorpyrifos**

## *Animal Toxicity Data*

**Add Animal Toxicity Record** | Export Grid to Excel (to print)

To delete a record, press <Ctrl> <Del>

Drift Threshold only relevant to zoobenthos

| Animal name | LC50 (ug/L) | LC50 exp. time (h) | LC50 comment | K2 Elim. rate const (1/d) | K1 Uptake const (L/kg d) | BCF (L/kg) | Biotrnsfm. rate (1/d) | EC50 growth (ug/L) | Gro |
|---|---|---|---|---|---|---|---|---|---|
| Trout | 8.701 | 96 | Regression on Bluegill | 1.9E-03 | | | 0 | 0.71 | |
| Bluegill | 2.4 | 96 | EPA Duluth '88, p. 124 | 7.6E-03 | | | 0 | 0.17 | |
| Bass | 9.849 | 96 | Regression on Bluegill | 3.3E-03 | | | 0 | 1.2439 | |
| Catfish | 387.174 | 96 | Regression on Bluegill | 3.7E-03 | | | 0 | 28 | |
| Minnow | 203 | 96 | Holcombe et al., 1982 | 1.85E-02 | | | 0 | 20.3 | |
| Daphnia | 0.17 | 24 | EPA '87, p. 42 (Duluth) | 9.15E-02 | | | 0 | 0.09 | |
| Chironomid | 1.416 | 24 | Regression on Daphnia | 5.32E-02 | | | 0 | 0.5798 | |
| Stonefly | 10 | 96 | Mayer & Ellersieck, 1982 | 4.03E-02 | | | 0 | 1 | |
| Ostracod | 2.055 | 24 | Regression on Daphnia | 6.93E-02 | | | 0 | 0.5776 | |
| Amphipod | 0.29 | 48 | EPA '87, p. 42 (Duluth) | 6.93E-02 | | | 0 | 0.011 | |
| Other | 0 | 96 | | 0E+00 | | | 0 | 0 | |

(•) Enter or Estimate K2, Calculate K1 and BCF (default behavior) ( ) Enter K1 and K2, Calculate BCF ( ) Enter K1 and BCF, Calculate K2 ( ) Enter K2 and BCF, Calculate K1

## *Plant Toxicity Data*

**Add Plant Toxicity Record** | Export Grid to Excel (to print)

| Plant name | EC50 photo (ug/L) | EC50 exp. time (h) | EC50 dislodge (ug/L) | EC50 comment | K2 Elim. rate const (1/d) | K1 Uptake Const (L/kg d) | BCF (L/kg) | Biotrnsfm. rate (1 |
|---|---|---|---|---|---|---|---|---|
| Greens | 0 | 96 | 0 | | 2.4 | | | |
| Diatoms | 0 | 96 | 0 | | 2.4 | | | |
| Bluegreens | 0 | 96 | 0 | | 2.4 | | | |
| Macrophytes | 0 | 96 | 0 | | 0.3247 | | | |

(•) Enter or Estimate K2, Calculate K1 and BCF (default behavior) ( ) Enter K1 and K2, Calculate BCF ( ) Enter K1 and BCF, Calculate K2 ( ) Enter K2 and BCF, Calculate K1

K1, BCF entered on a dry weight basis; lipid frac. is wet wt.

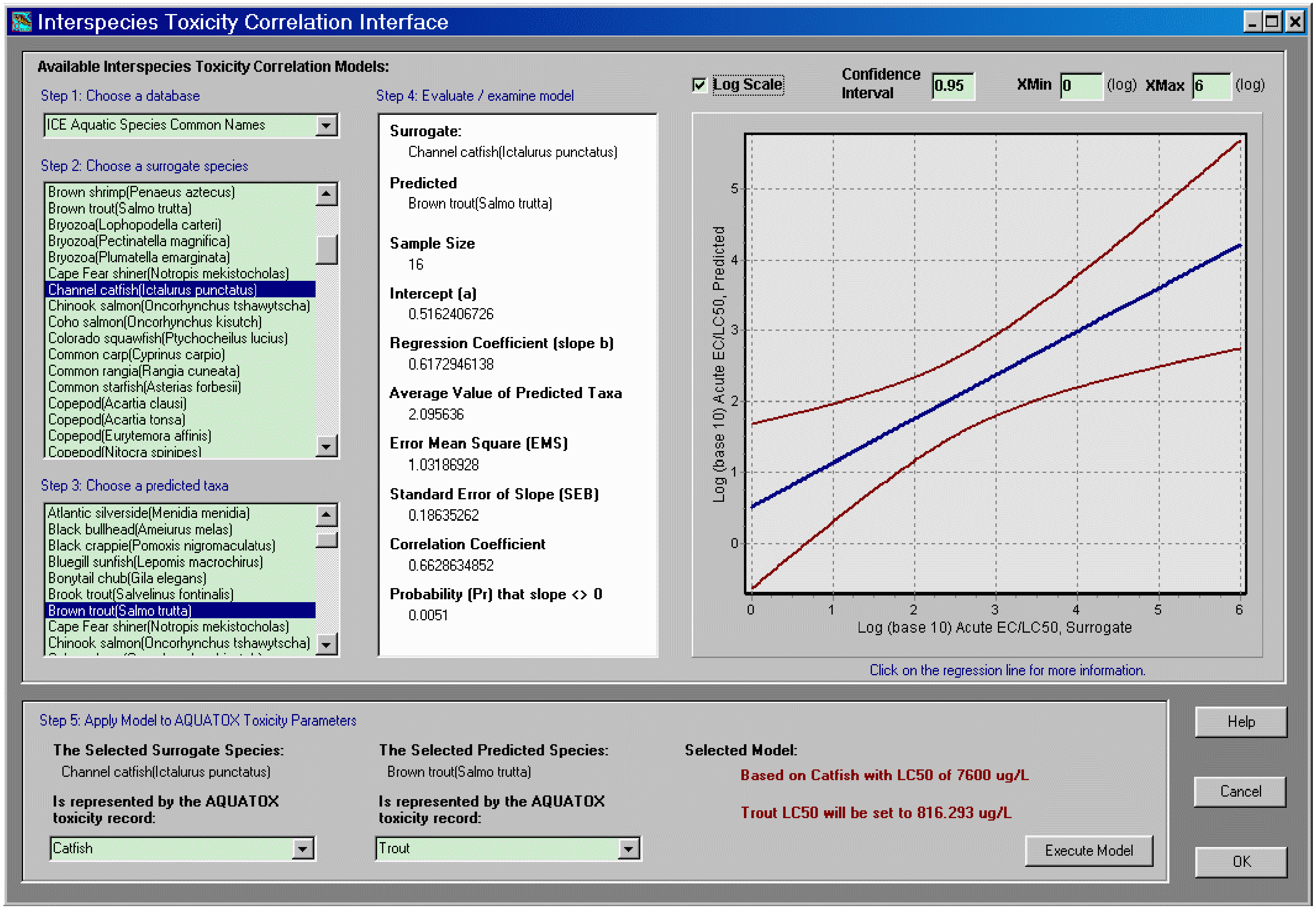
Estimate Animal K2s using Kow | Estimate Plant K2s using Kow | Interspecies Toxicity Correlation Models

Estimate plant LC50s using EC50 to LC50 ratio

Estimate animal EC50s using LC50 to EC50 ratio | **Help** | ✓ **O.K.**

# Release 3: Additional Toxicity Features

- Integration with ICE: a large EPA database of toxicity regressions

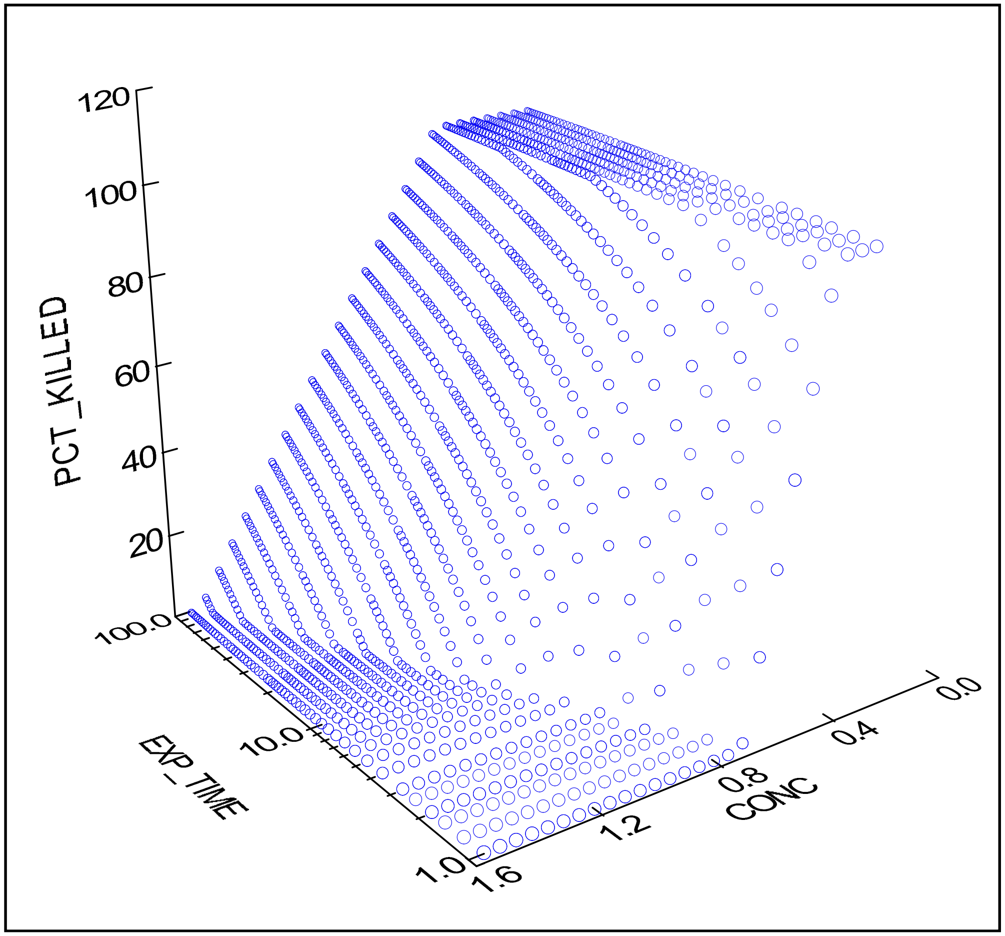


# Release 3: Additional Toxicity Features

- Integration with ICE: a large EPA database of toxicity regressions
- DO effects

A 3D model of effects that is a function of exposure time and oxygen concentration.

Includes non-lethal effects on consumption and reproduction

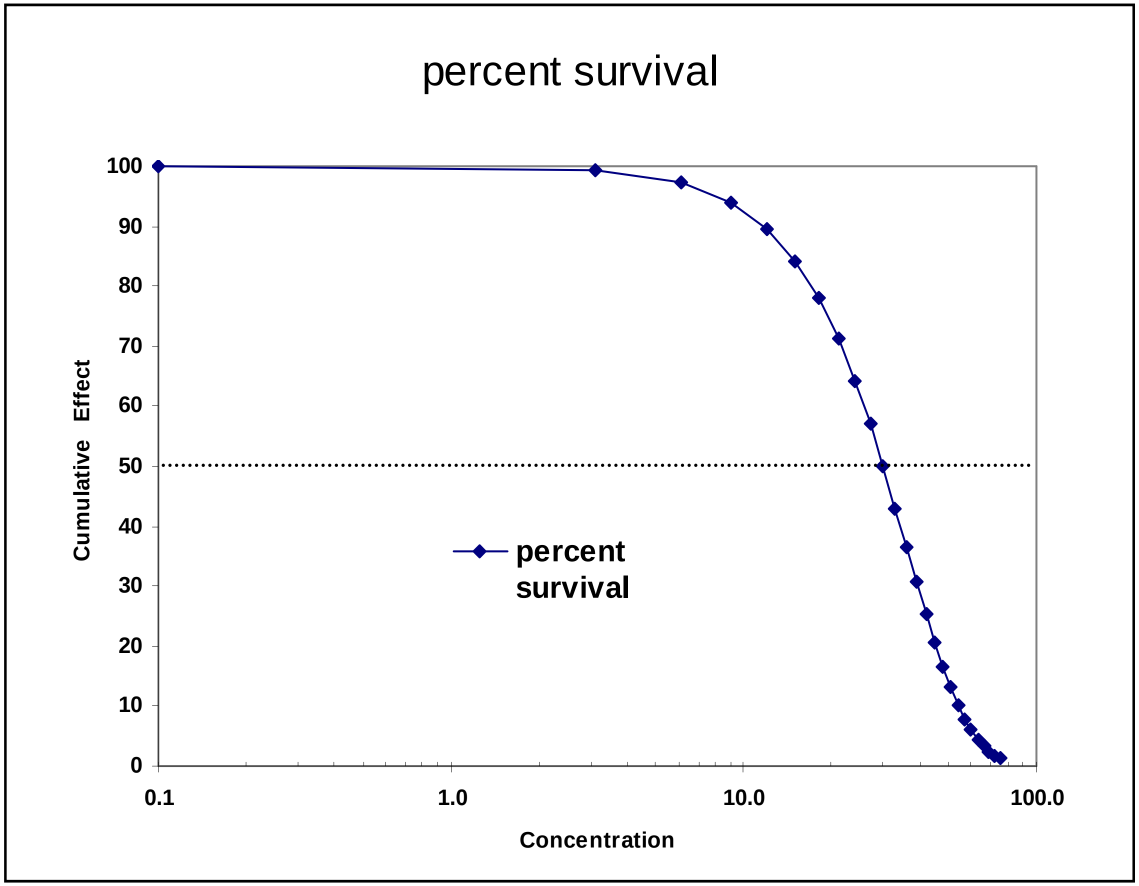


# Release 3: Additional Toxicity Features

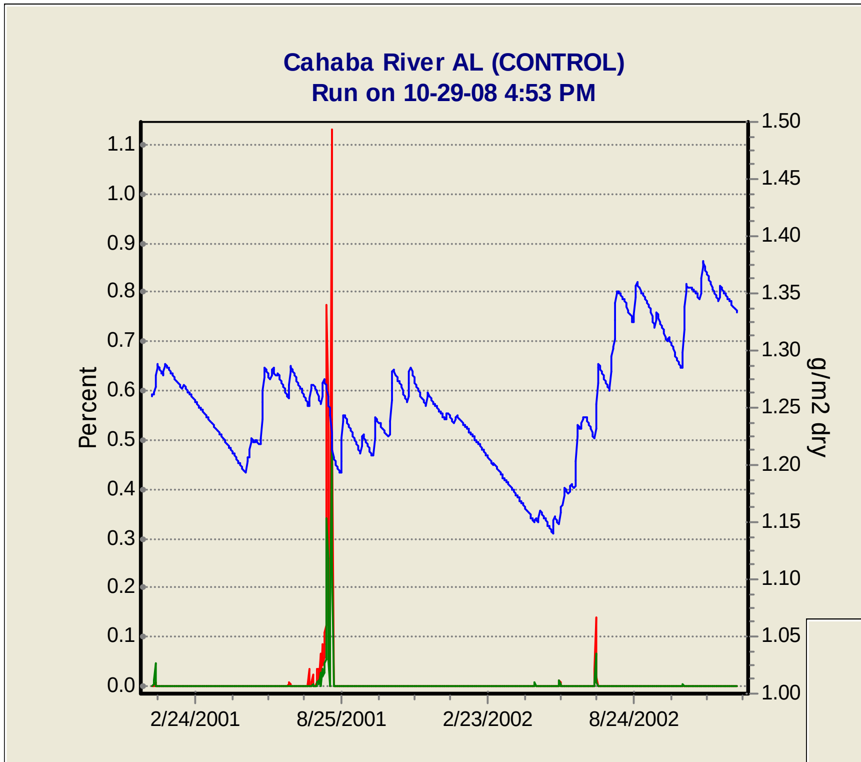
- Integration with ICE: a large EPA database of toxicity regressions
- DO effects
- Ammonia effects

External Toxicity Model Utilized

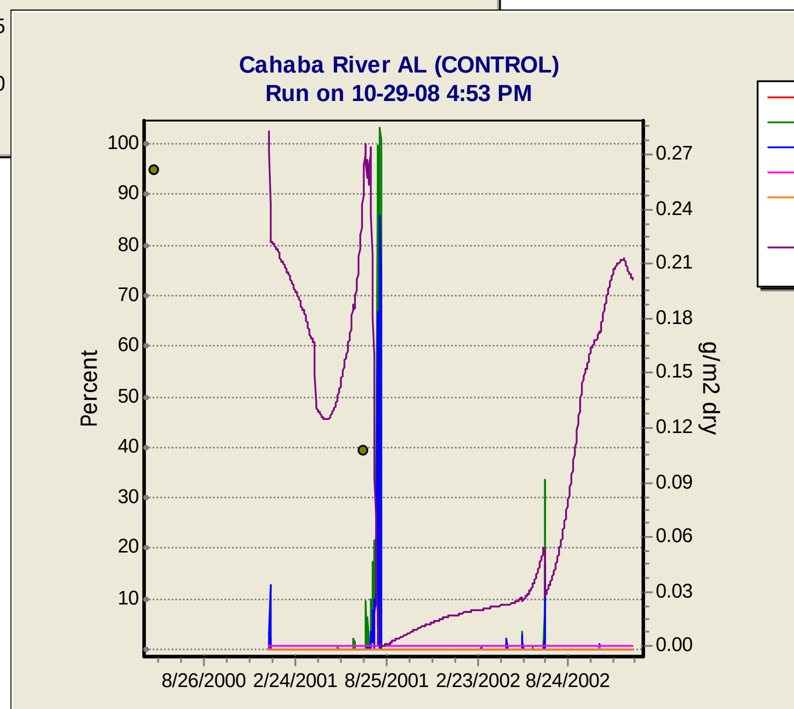
Effects from un-ionized and
ionized ammonia are additive



# Predicted ammonia toxicity in Cahaba River AL

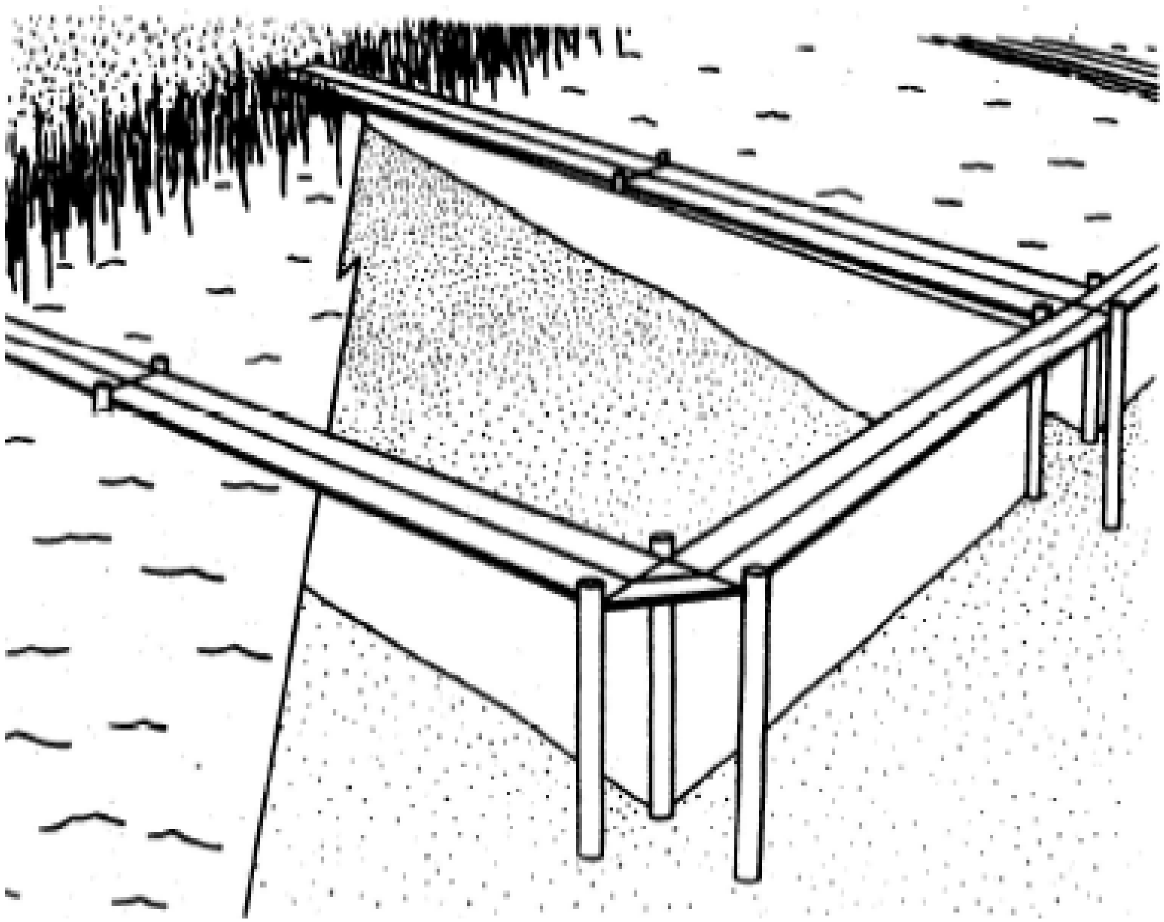



**1% mortality in mussels**

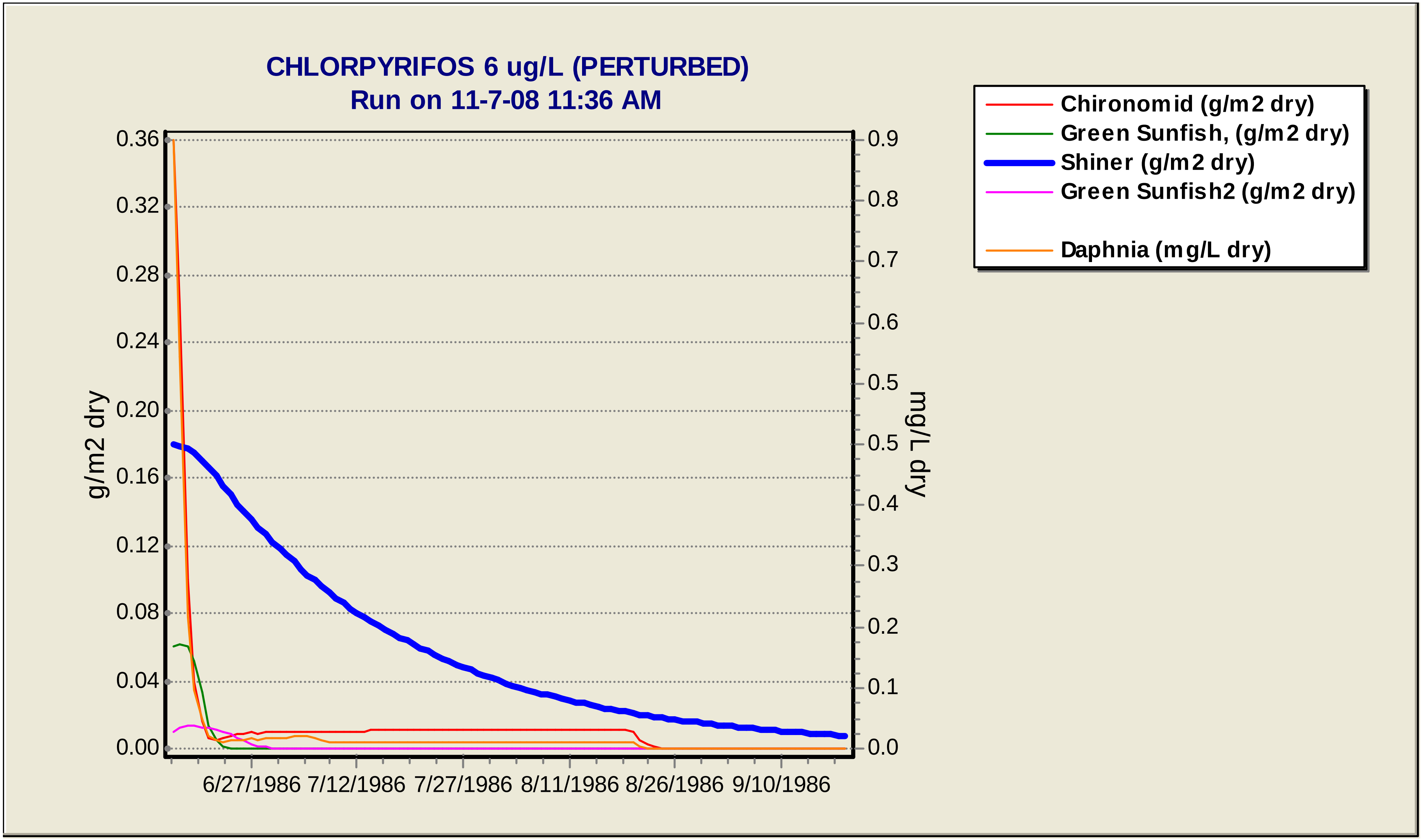



**100% mortality In bluegills**

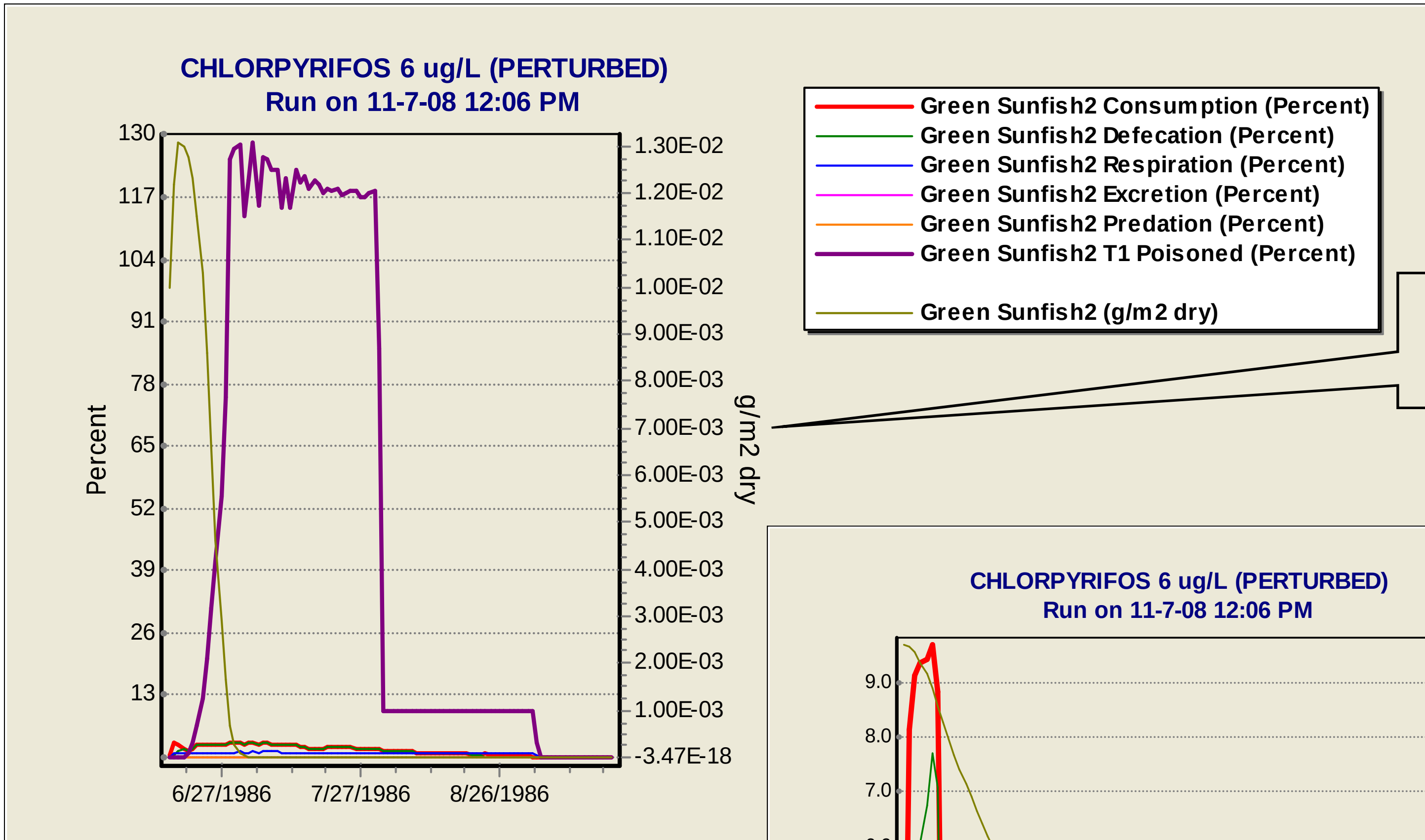
# Returning to the Limnocorral in Duluth MN . . .



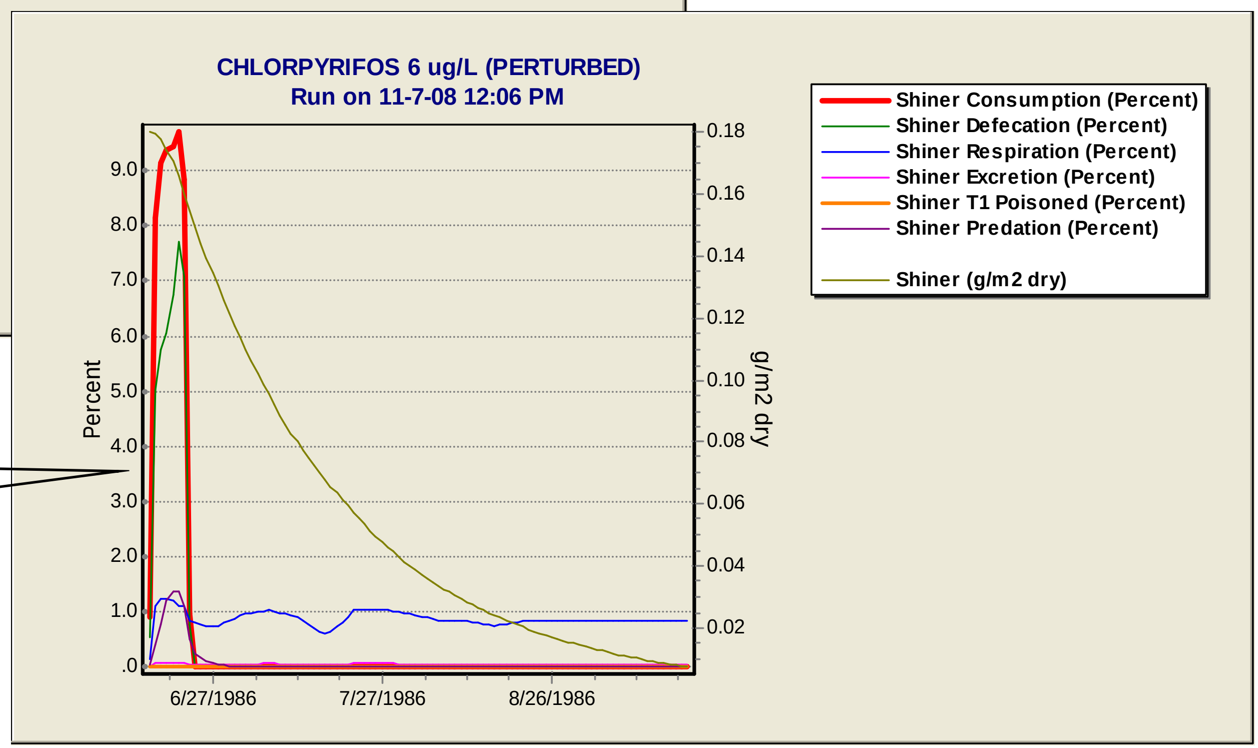
# Animals all decline at varying rates following a single initial dose of chlorpyrifos



# Sunfish have acute toxicity, shiners have chronic toxicity to chlorpyrifos

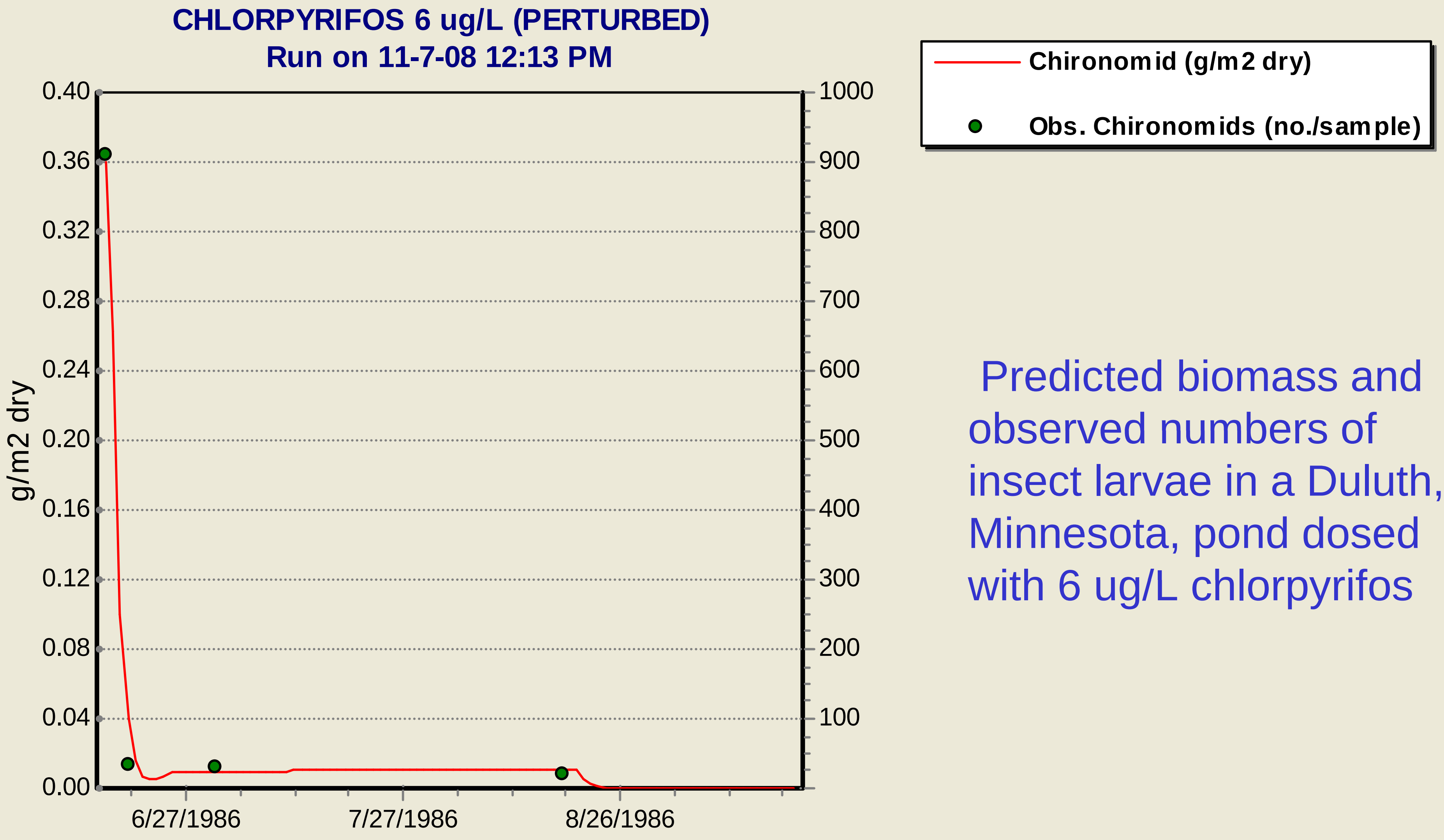



Sunfish with acute toxicity



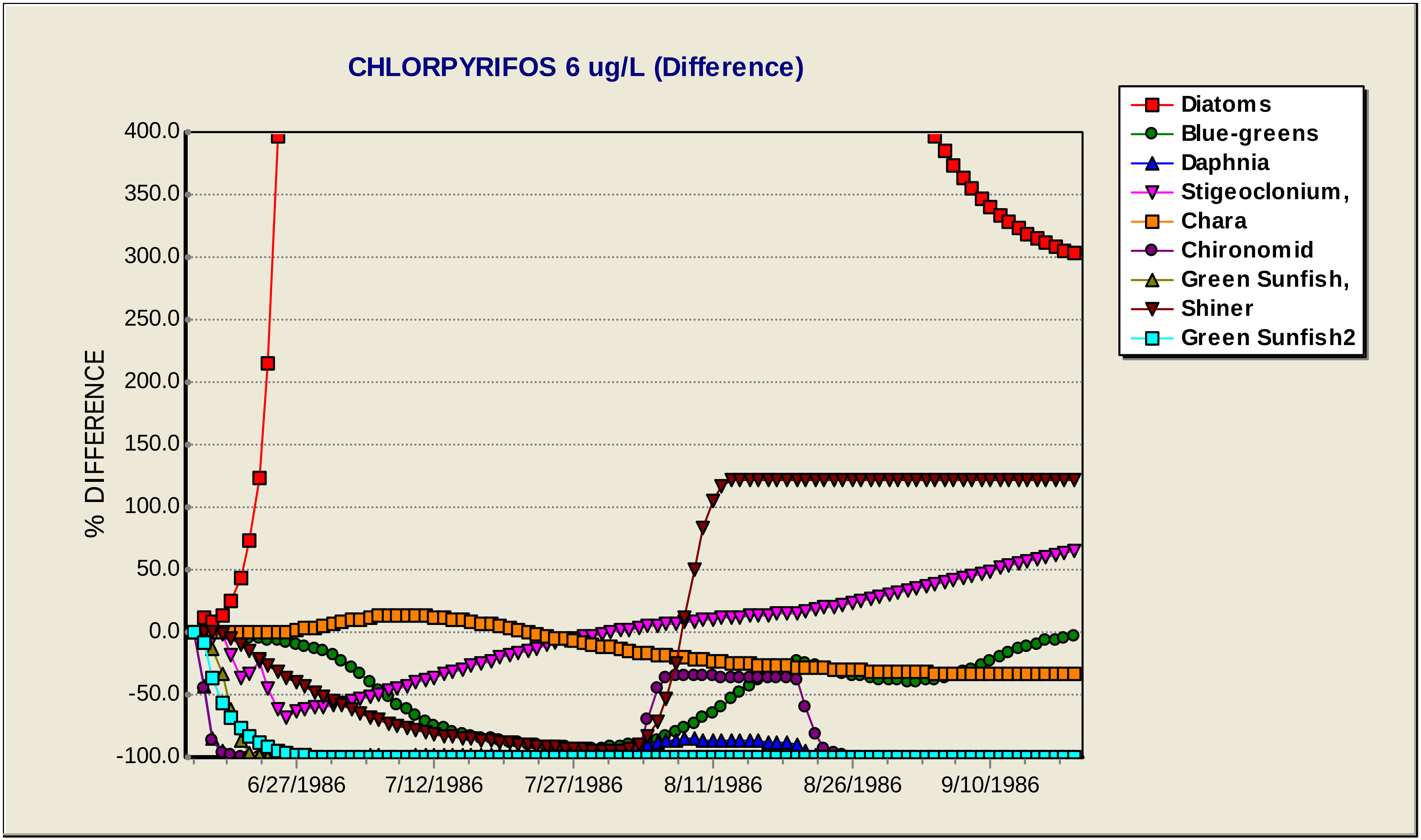

Shiner with chronic toxicity only

# Toxic effects of Chlorpyrifos in Duluth pond

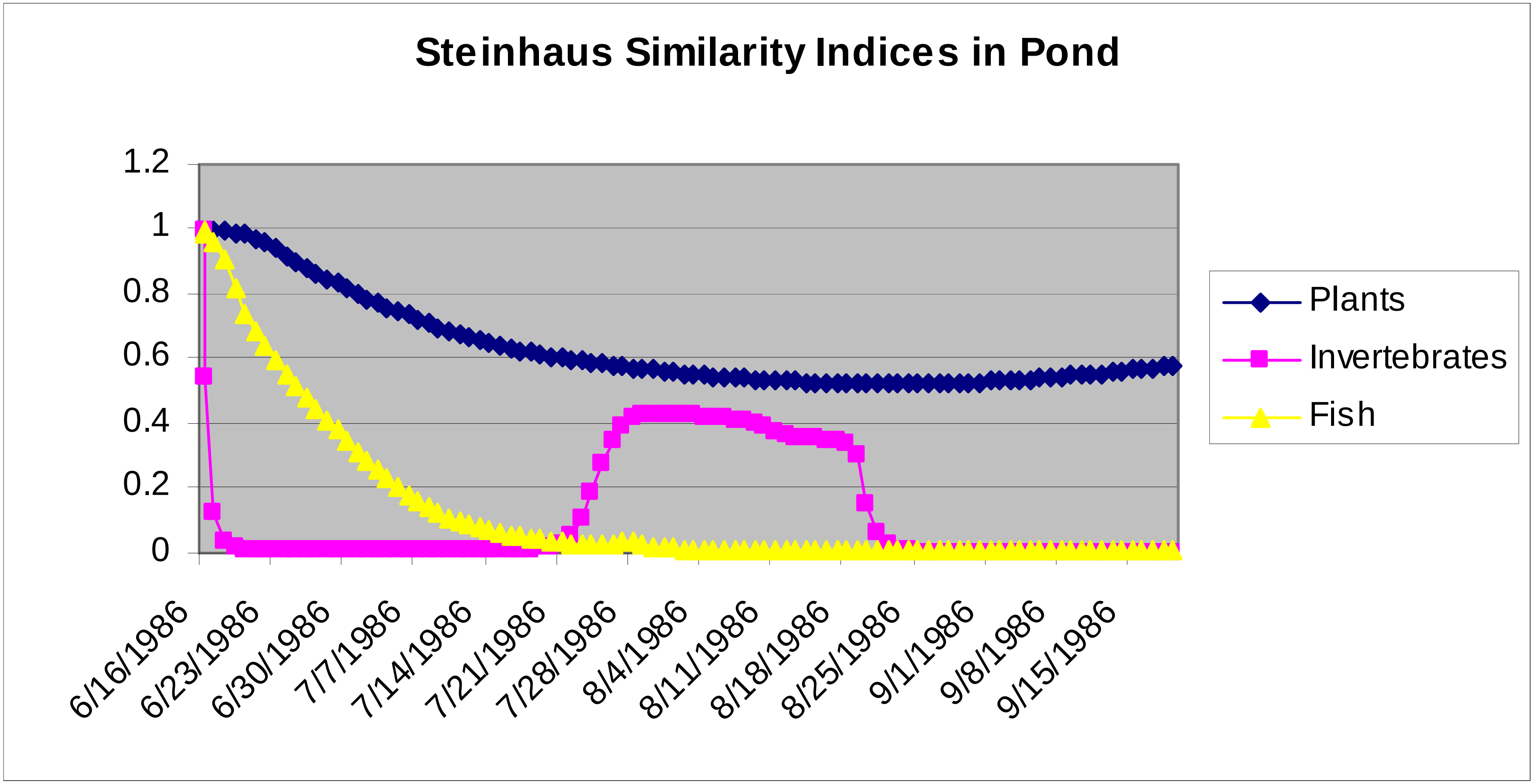



Predicted biomass and observed numbers of insect larvae in a Duluth, Minnesota, pond dosed with 6 ug/L chlorpyrifos

# % Difference Graph shows differences in species response to toxicant



# Steinhaus Indices show ecosystem impacts predicted by the model




$$S = \frac{2 * \sum_{k=1}^{n} Min(a_{1,k}, a_{2,k})}{\sum_{k=1}^{n} a_{1,k} + \sum_{k=1}^{n} a_{2,k}}$$

# Chlorpyrifos in Stream

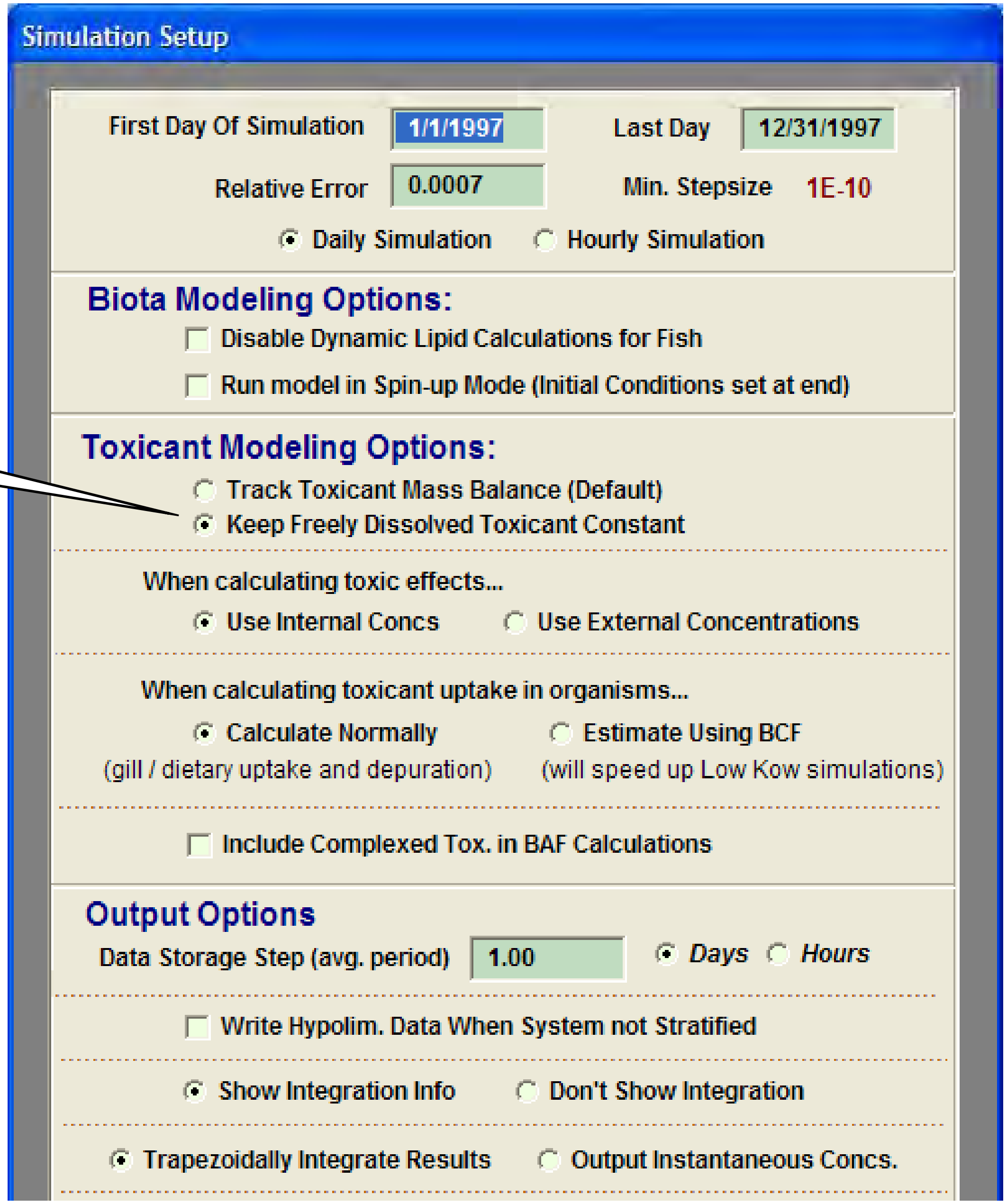
Objective: analyze direct and indirect ecotoxicological effects with model

- Assessment of chlorpyrifos in a generic stream
  - small stream in corn belt
  - exposure to constant level of Chlorpyrifos assessed (0.4 ug/L)

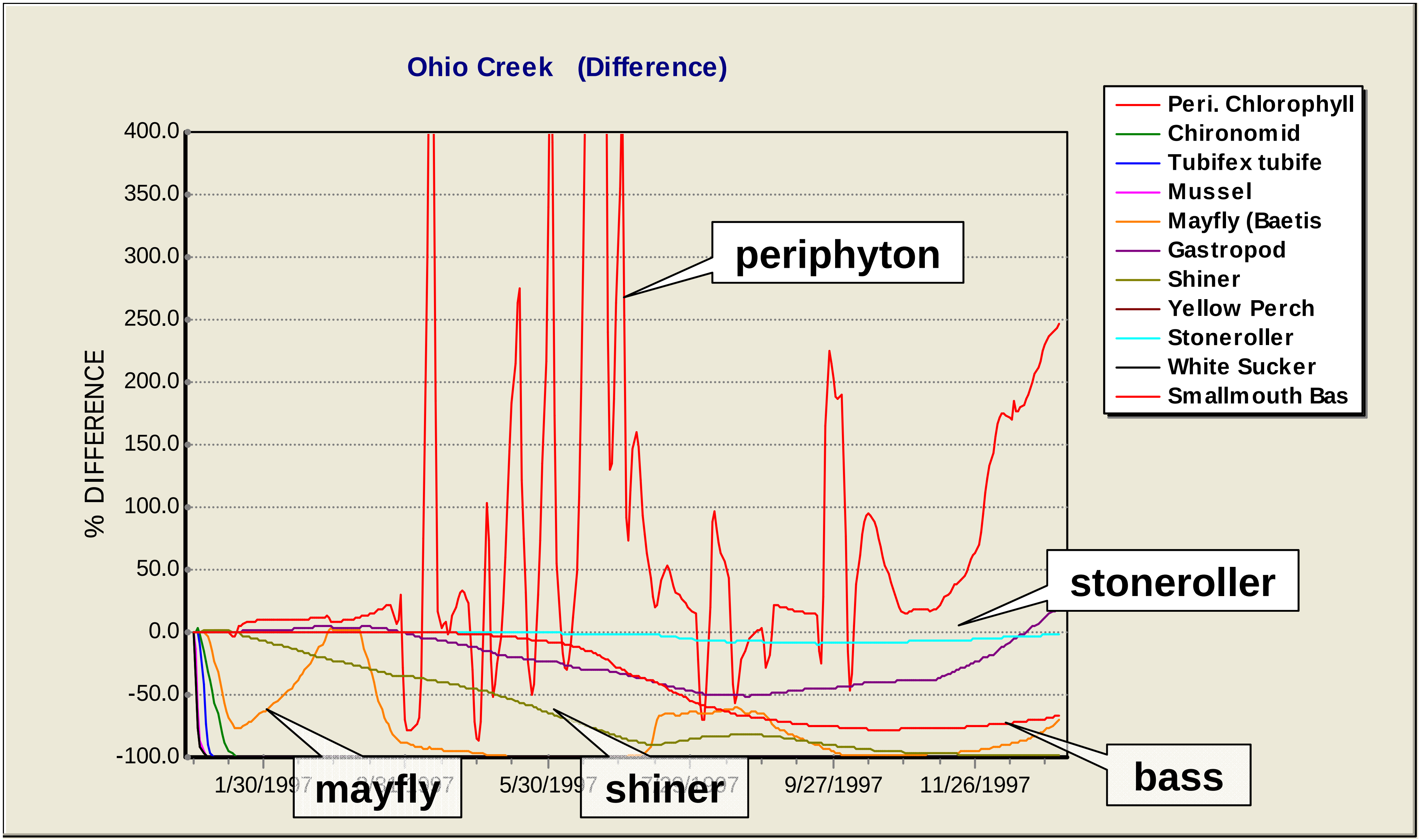
# Set exposure to a constant in Study Setup

## Set “Control Setup” to omit toxicants from “control” results

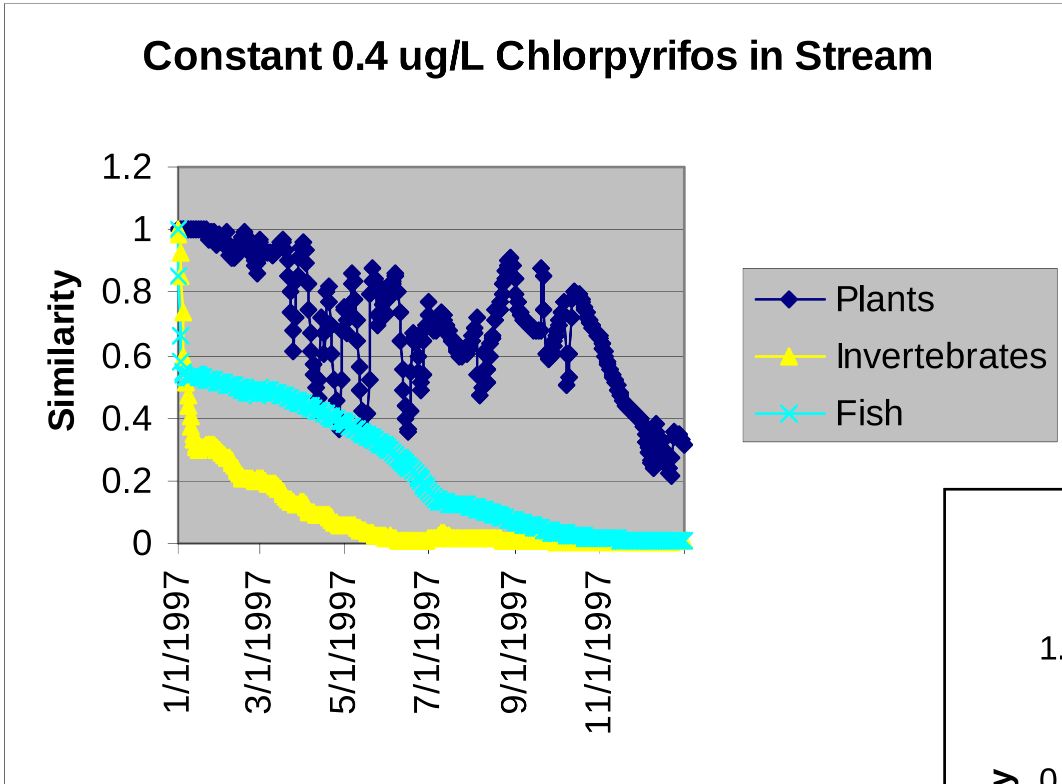
check box



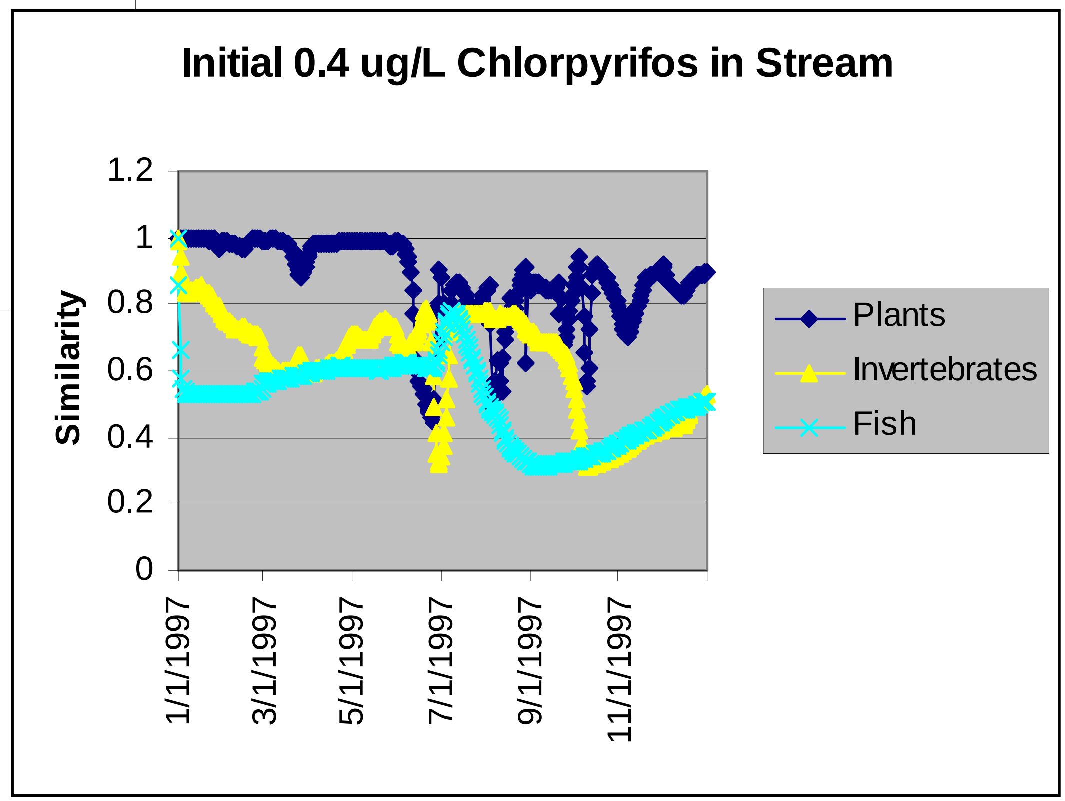
# Impacts of constant chlorpyrifos are dramatic: animals decline, algae increase (less herbivory)



# Plot of Steinhaus indices shows lasting impacts predicted by the model

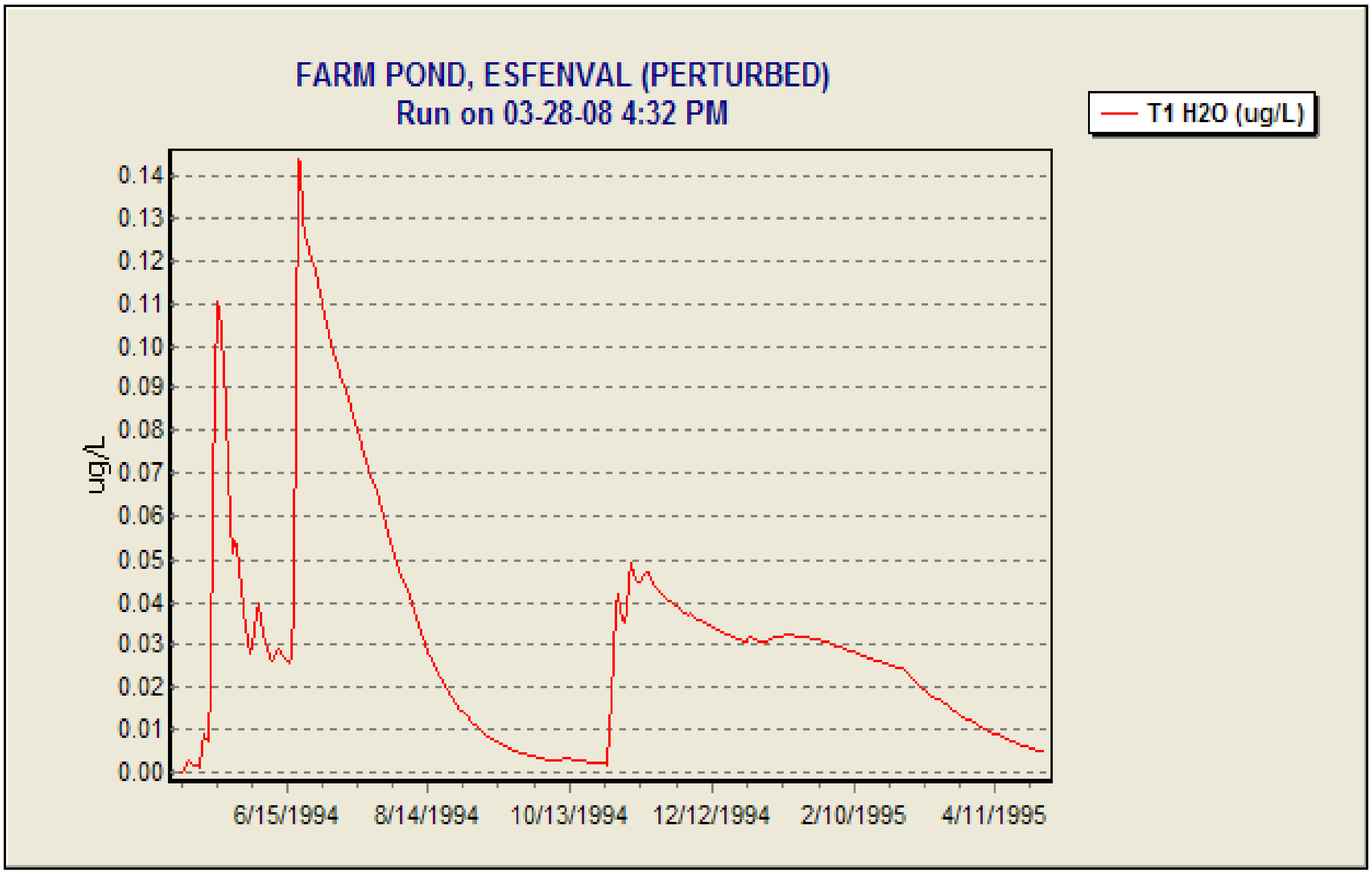



$$S = \frac{2 * \sum_{k=1}^{n} Min(a_{1,k}, a_{2,k})}{\sum_{k=1}^{n} a_{1,k} + \sum_{k=1}^{n} a_{2,k}}$$

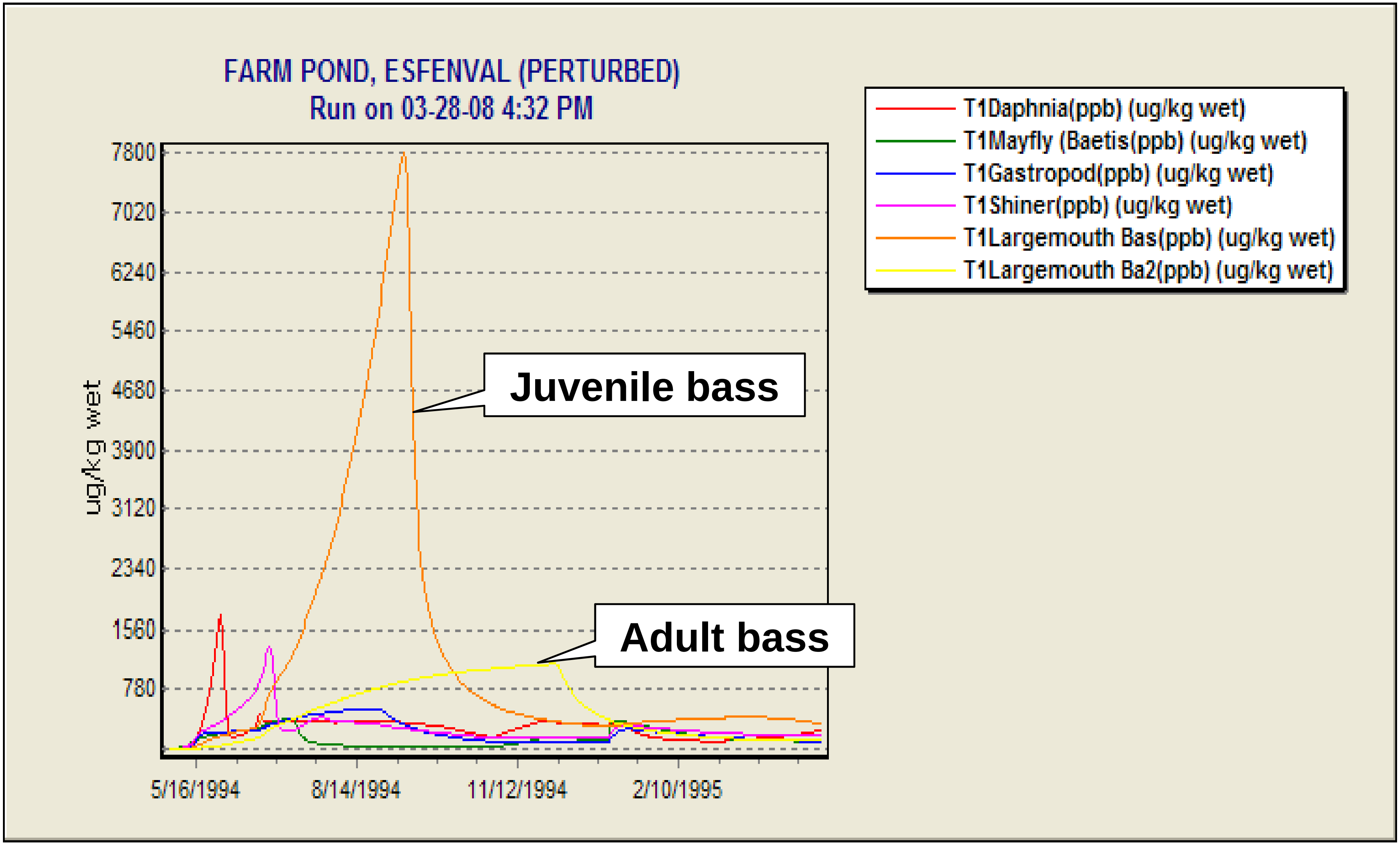


# Farm Pond MO, Esfenvalerate

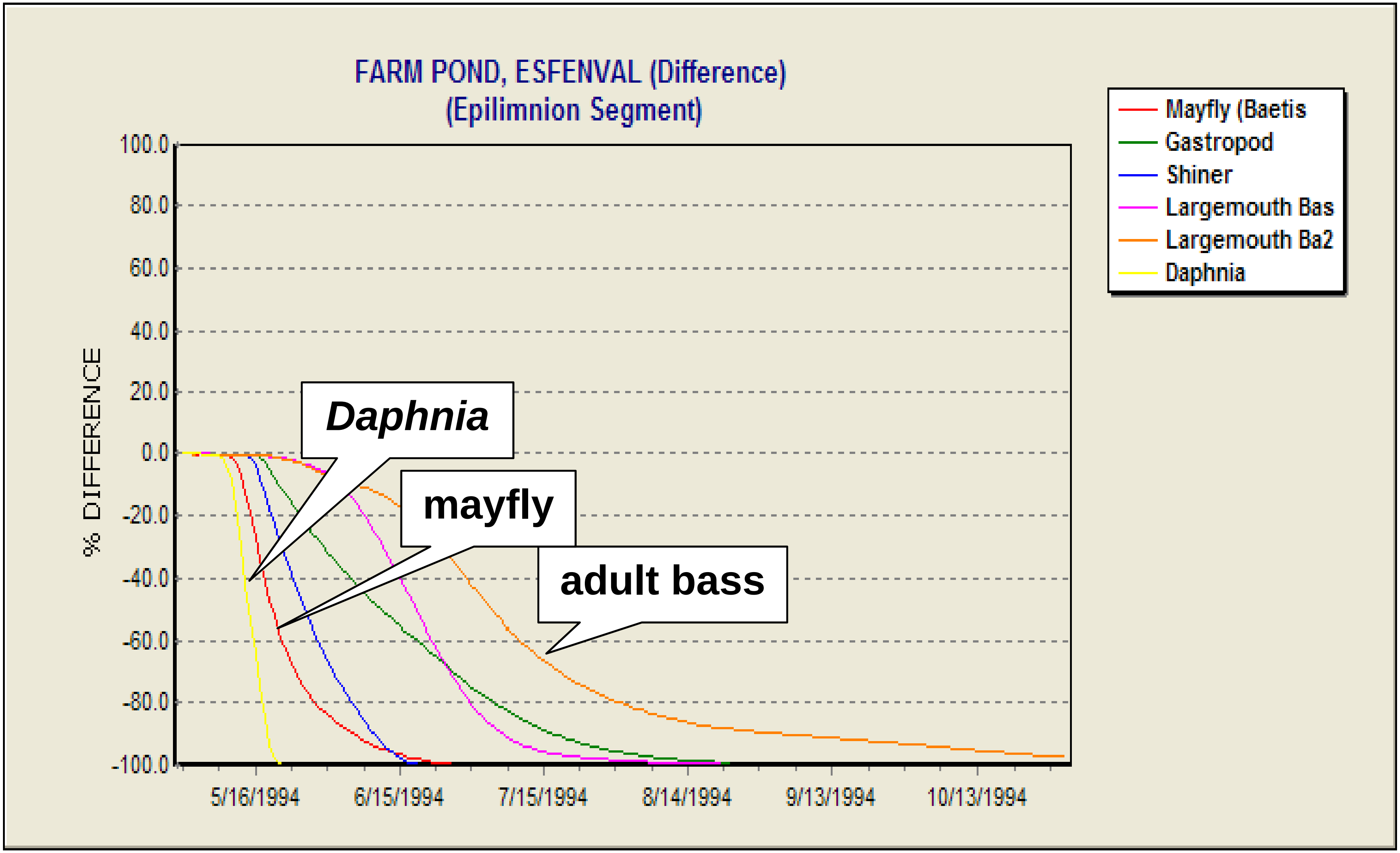
- Loadings from PRIZM for adjacent cornfield
- 20% of worst case scenario for runoff of pesticide predicted by PRZM



# Farm Pond, Esfenvalerate Chemical Uptake in animals

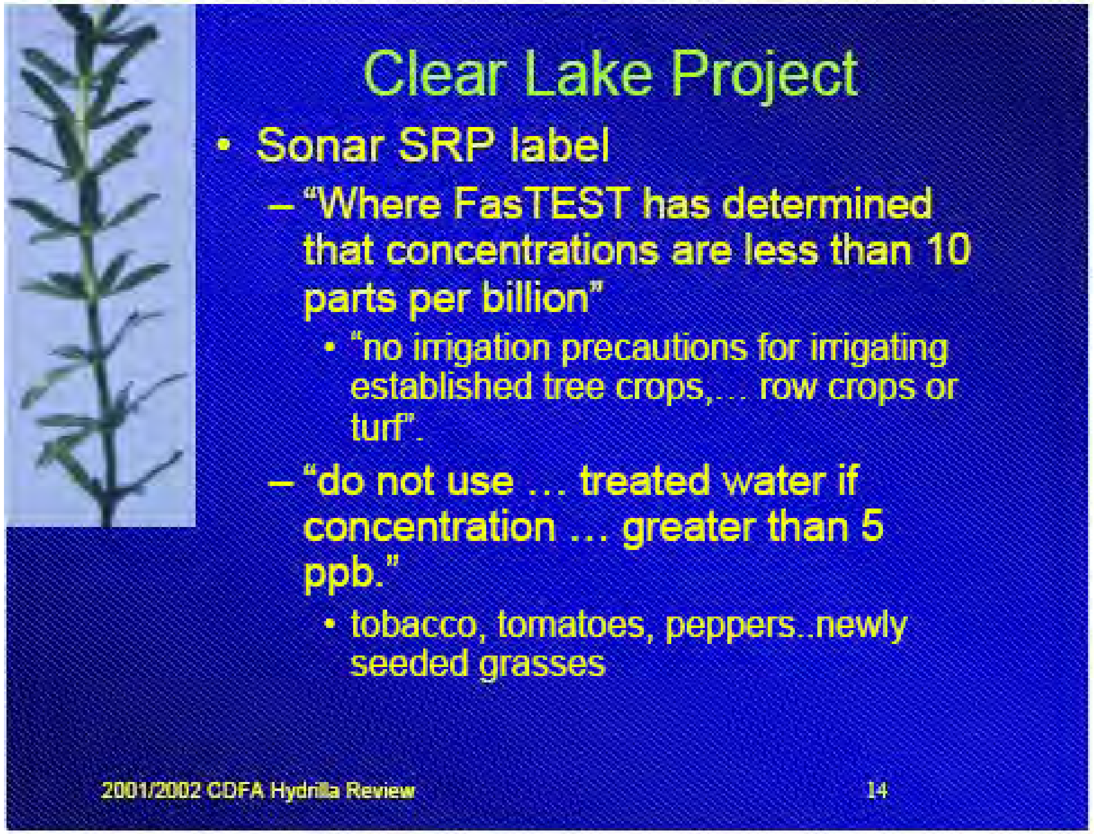


# Farm Pond, Esfenvalerate Difference Graph

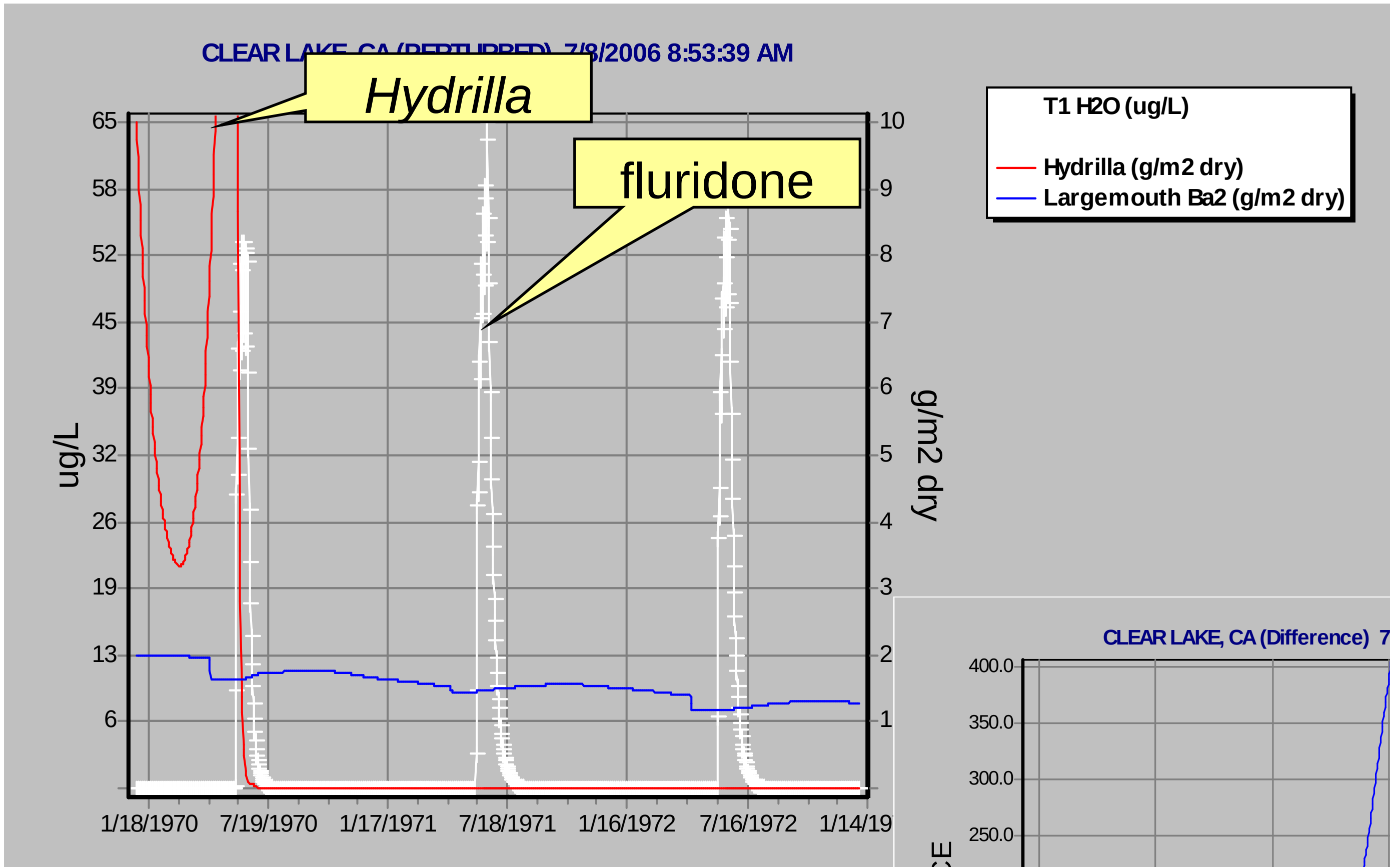


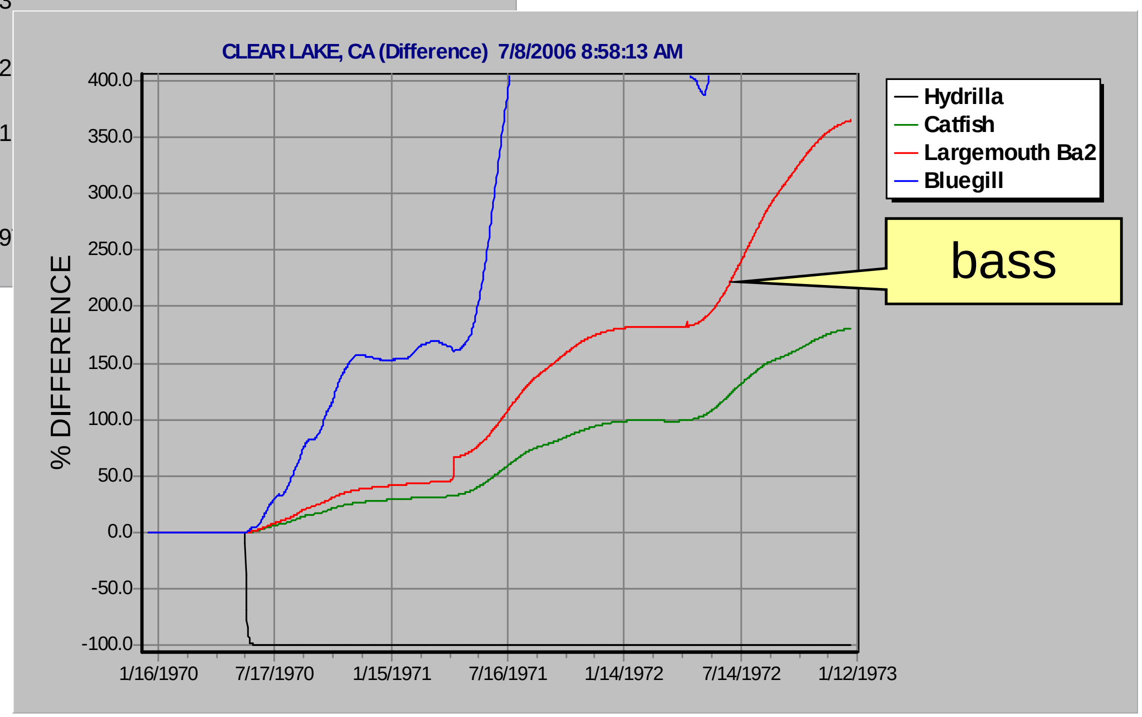
# Fluridone (Sonar) used to eradicate *Hydrilla* in Clear Lake CA

- Six doses
  - 20 ppb dose
- What is impact on non-target organisms?
- What is recovery of Clear Lake ecosystem?
- Impact on DO from death of large *Hydrilla* biomass?



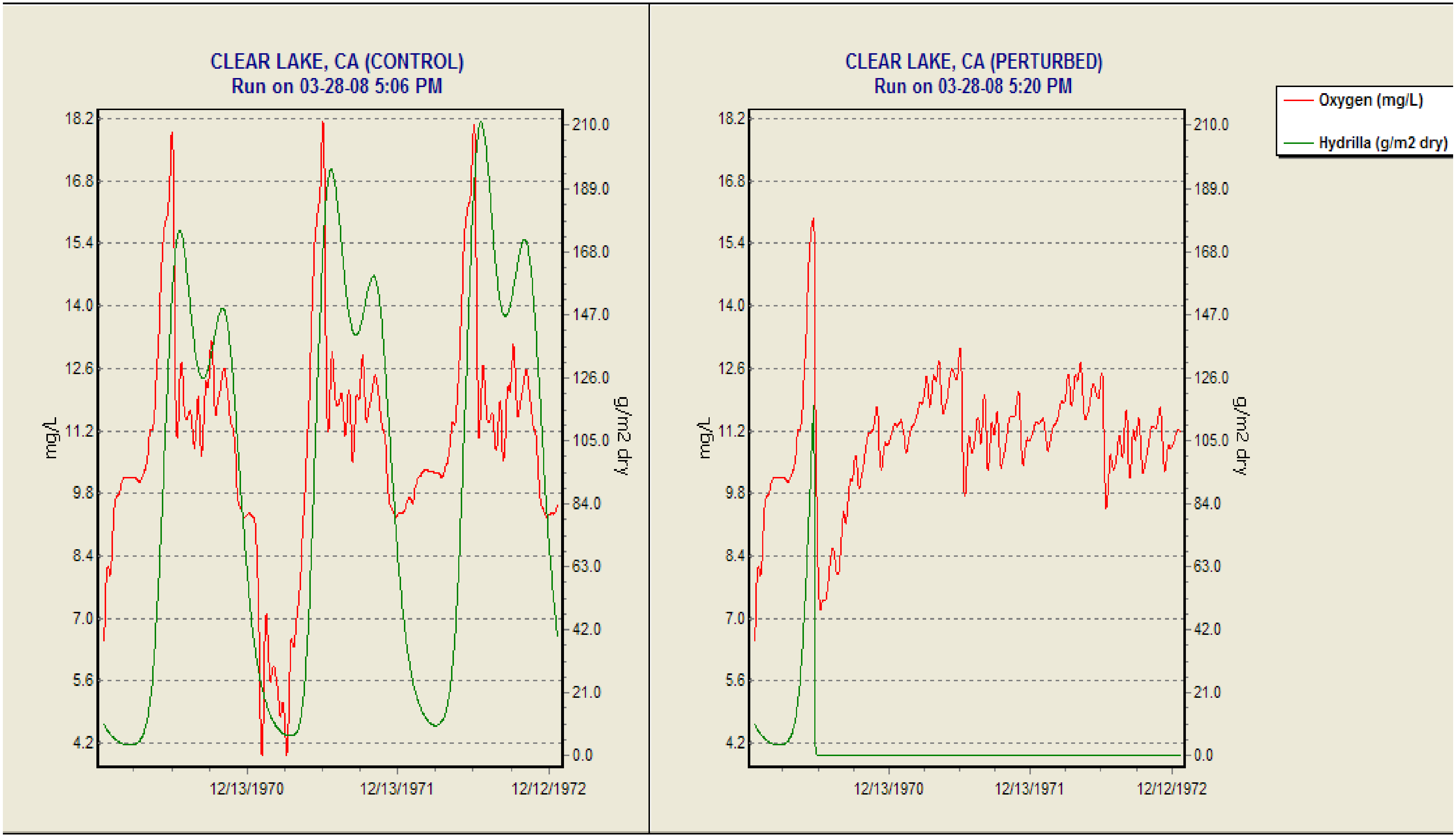
# Addition of Fluridone causes dramatic response of Clear Lake ecosystem



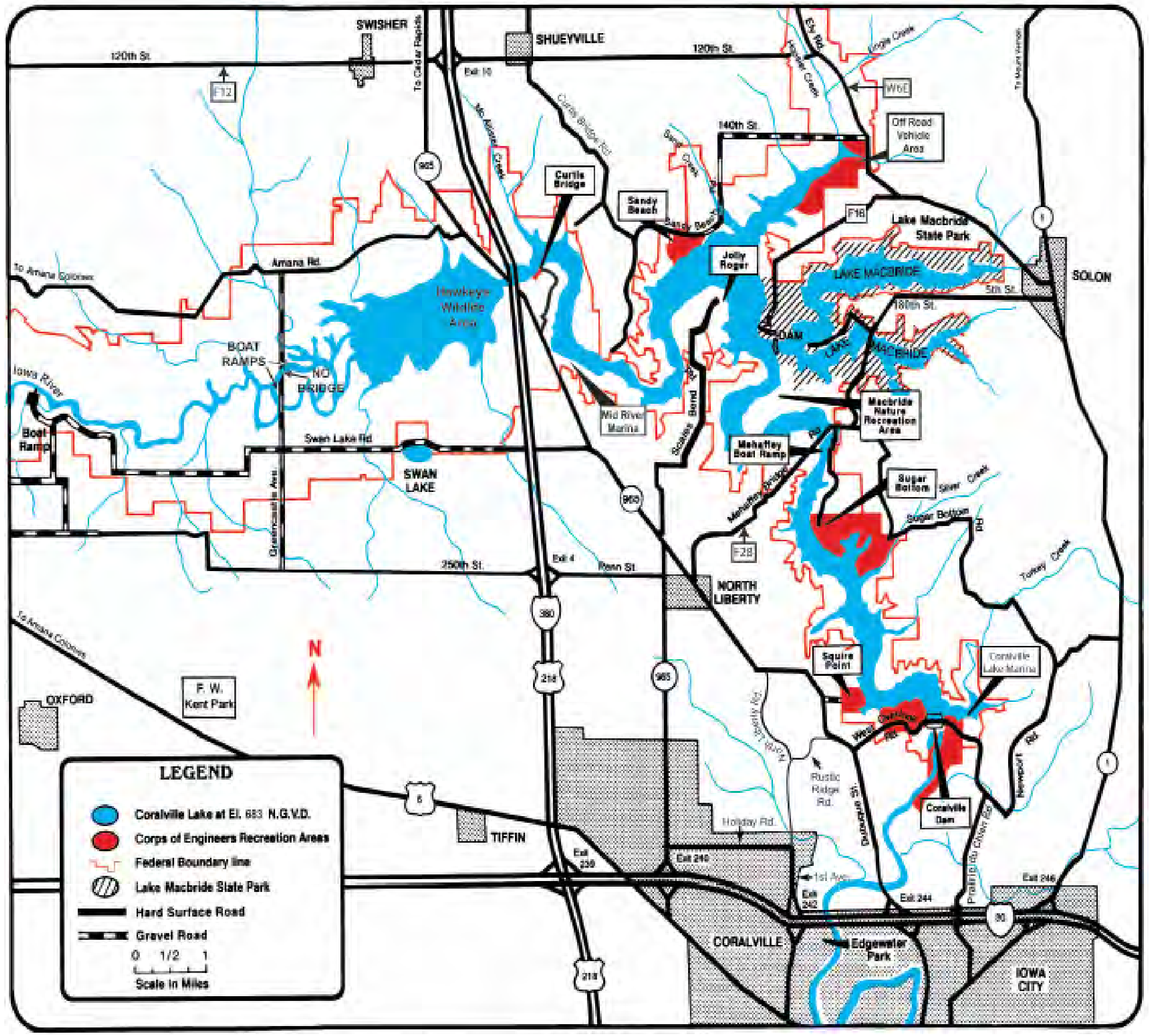
# Indirect Effects Captured

## e.g. Impact on DO levels is negligible

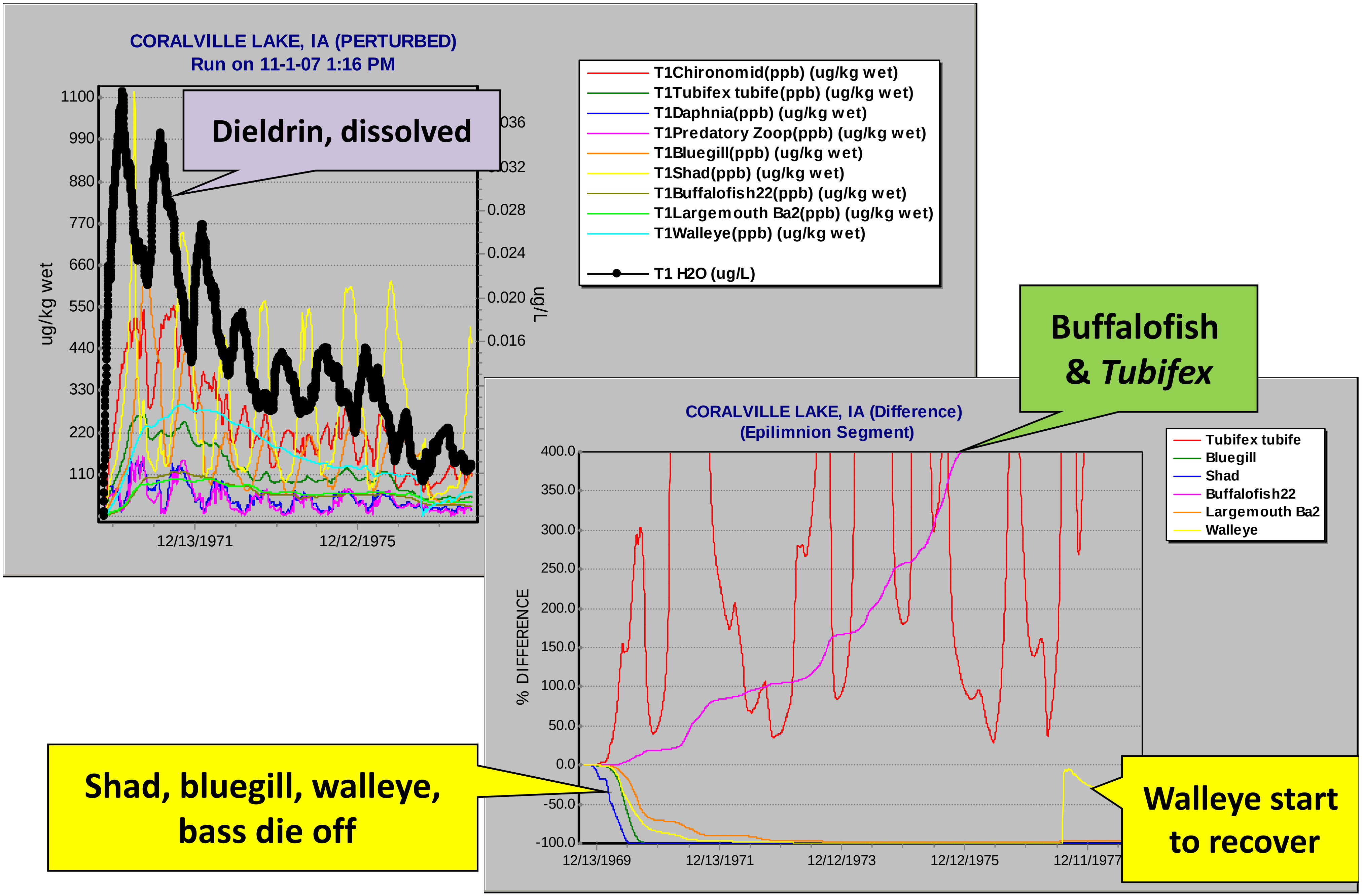


# Coralville Reservoir Iowa
# long-term contamination with dieldrin

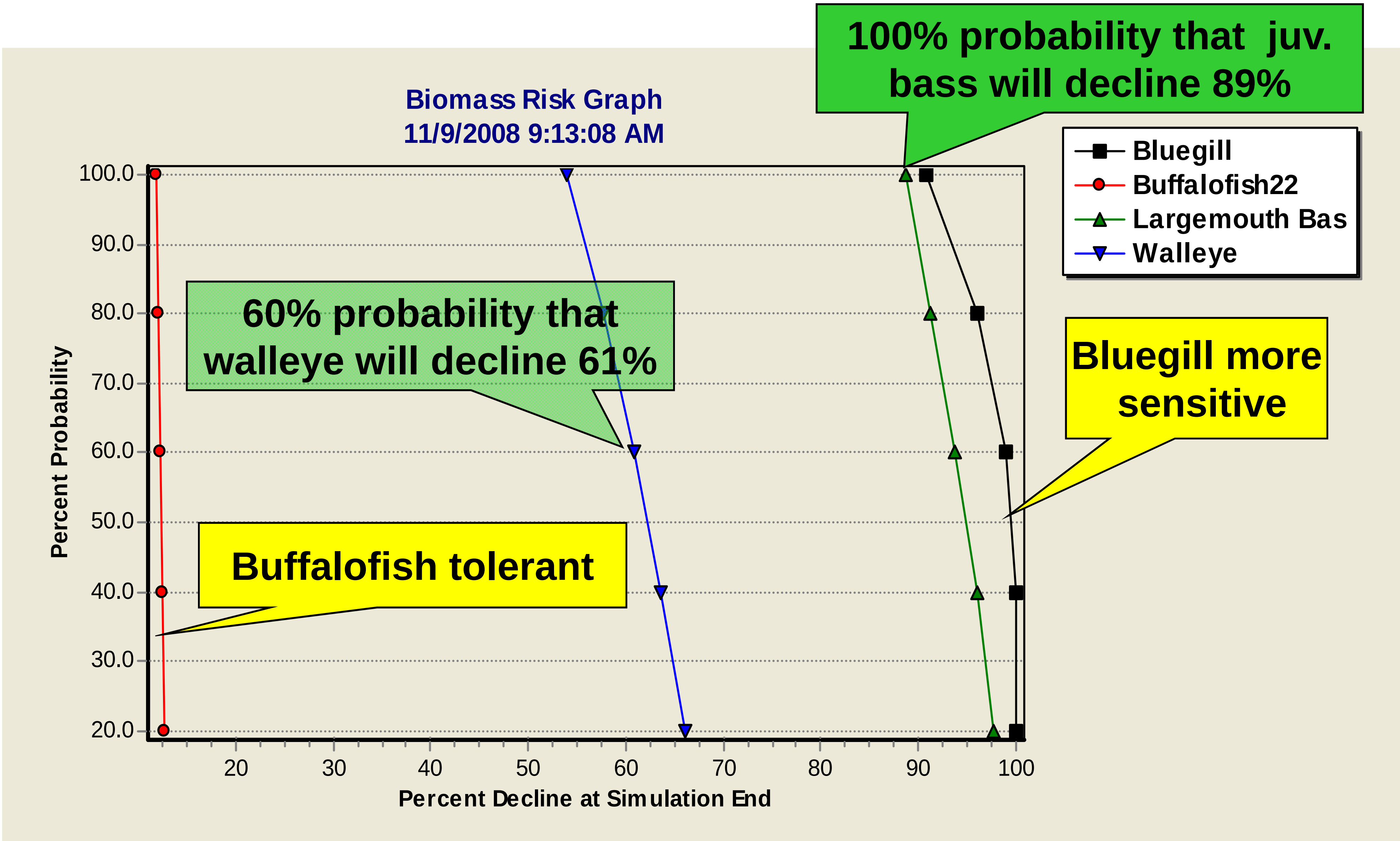
- Run-of-river
- Flood control
- 90% of basin in agriculture
  - Nutrients
  - Pesticides
  - Sediment



# Dieldrin bioaccumulates & declines over 20 years with fish mortality, but tolerant buffalofish, *Tubifex* prosper



# Probability of decline in biomass (end of 1st year) can be estimated based on uncertainty

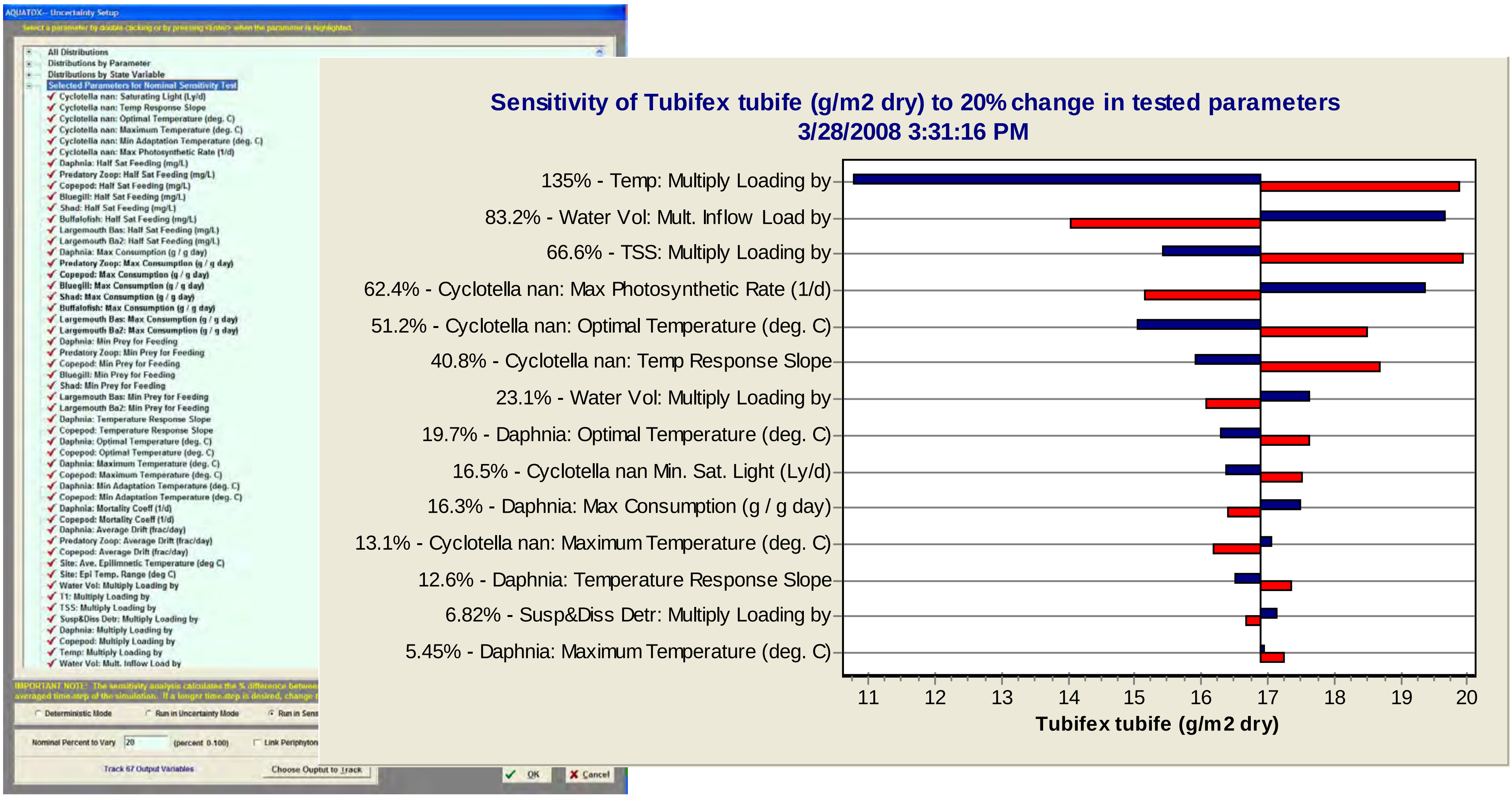


# Uncertainty and Sensitivity Analysis

- "Sensitivity" refers to the variation in output of a mathematical model with respect to changes in the values of the model inputs (Saltelli, 2001).
- Sensitivity analysis provides a ranking of the model input assumptions with respect to their relative contribution to model output variability or uncertainty (EPA, 1997).
- A comprehensive sensitivity analysis of AQUATOX is currently being performed for diverse sites.

# Coralville Sensitivity Analysis Demo

## Demonstration of inputs and outputs from Coralville analysis

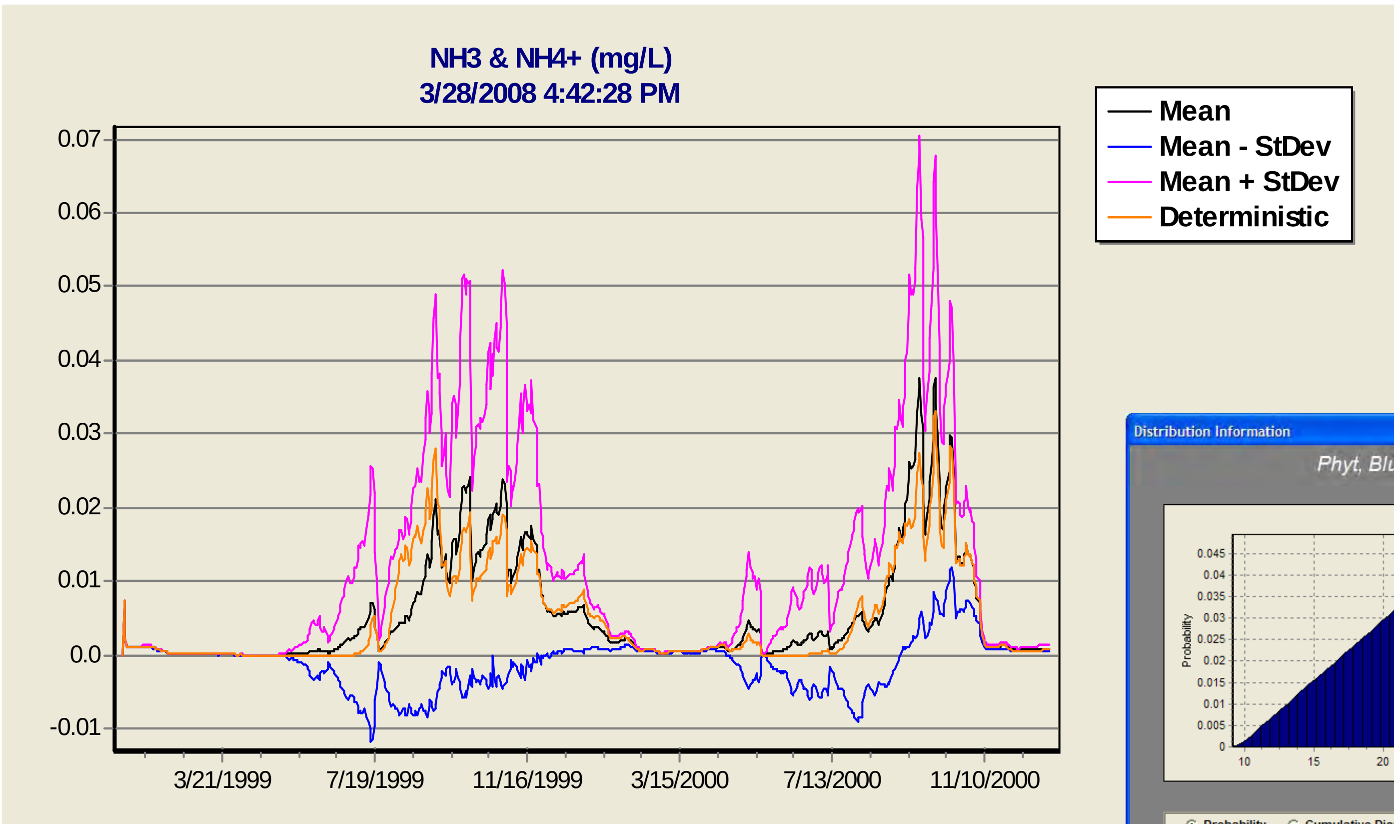


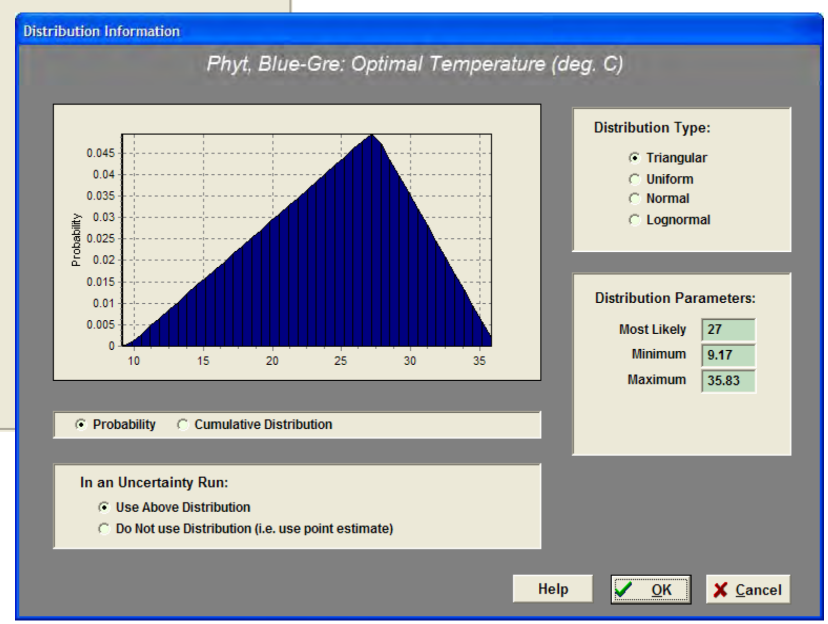
# Uncertainty Analysis

- Uncertainty analyses describe sources of incertitude and variability
- There are many sources of uncertainty e.g.
  - parameter uncertainty
  - model uncertainty due to necessary simplification of real-world processes
- Monte Carlo analysis is a statistical sampling technique that allows us to obtain a probabilistic approximation to the effects of parameter uncertainty
- AQUATOX Utilizes Monte Carlo analysis with efficient “Latin Hypercube Sampling” (reduces required iterations)

# Blue Earth Uncertainty Analysis Demo

## Demonstration of inputs and outputs from Blue Earth River, MN

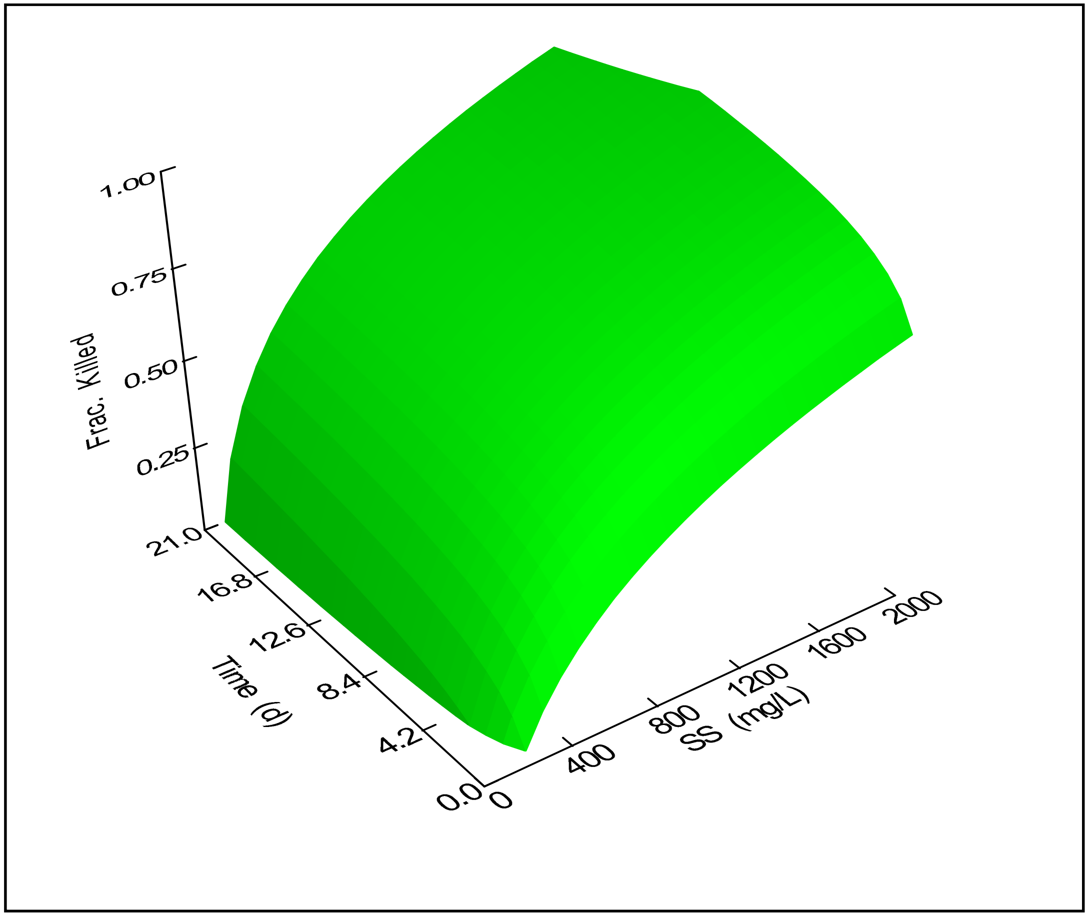


# Sediment Effects Overview

- Suspended and bedded sediment effects
  - Mortality

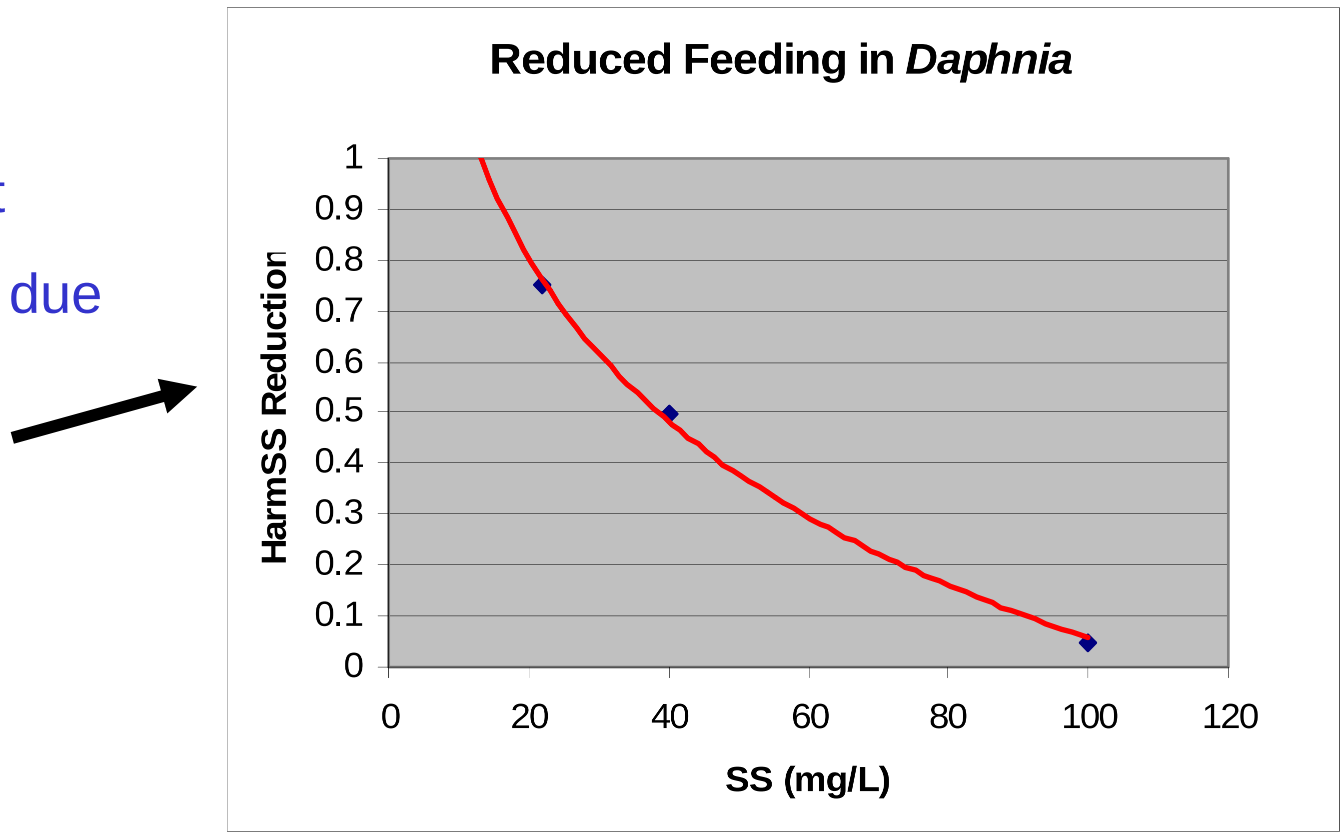
- Highly Sensitive
- Sensitive
- Tolerant
- Intolerant



# Sediment Effects Overview

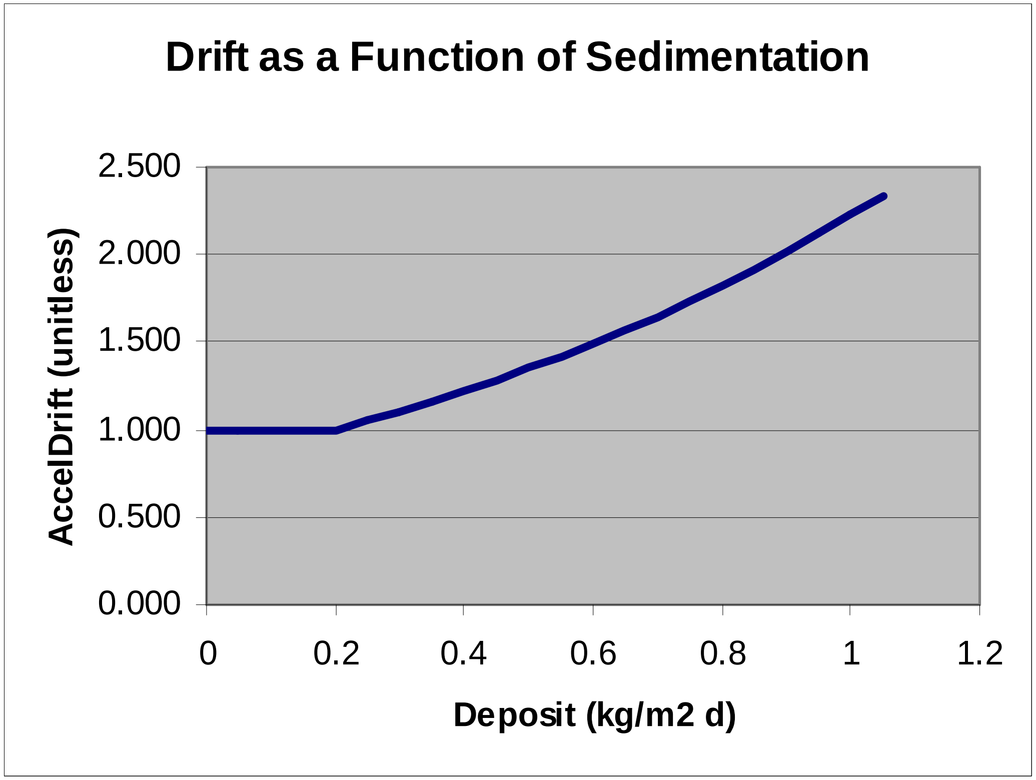
- Suspended and bedded sediment effects
  - Mortality
  - Reduced Feeding

- Dilution effect
- Direct effects due to clogging of filter feeding apparatus



# Sediment Effects Overview

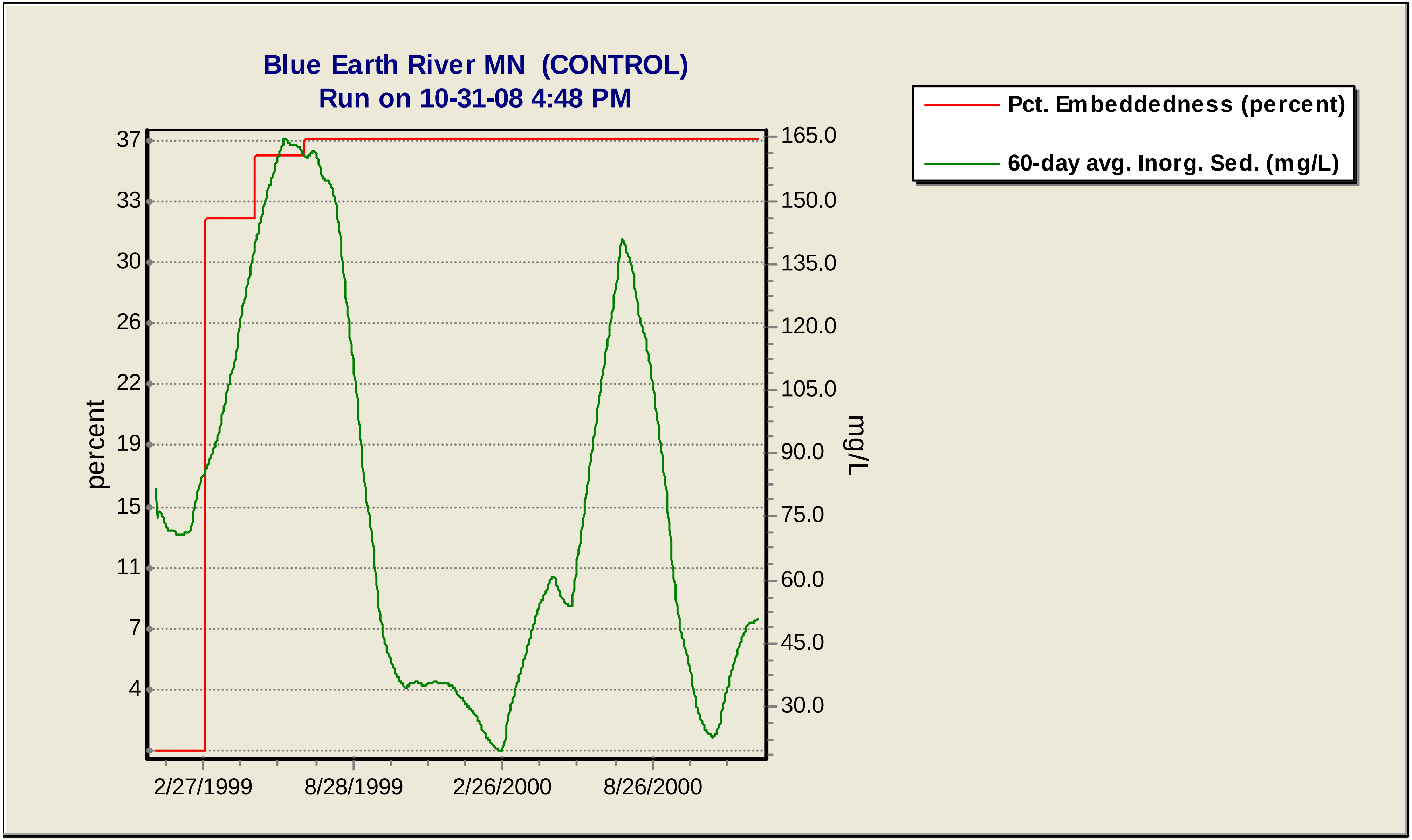
- Suspended and bedded sediment effects
  - Mortality
  - Reduced Feeding
  - Increased drift of grazers due to sedimentation



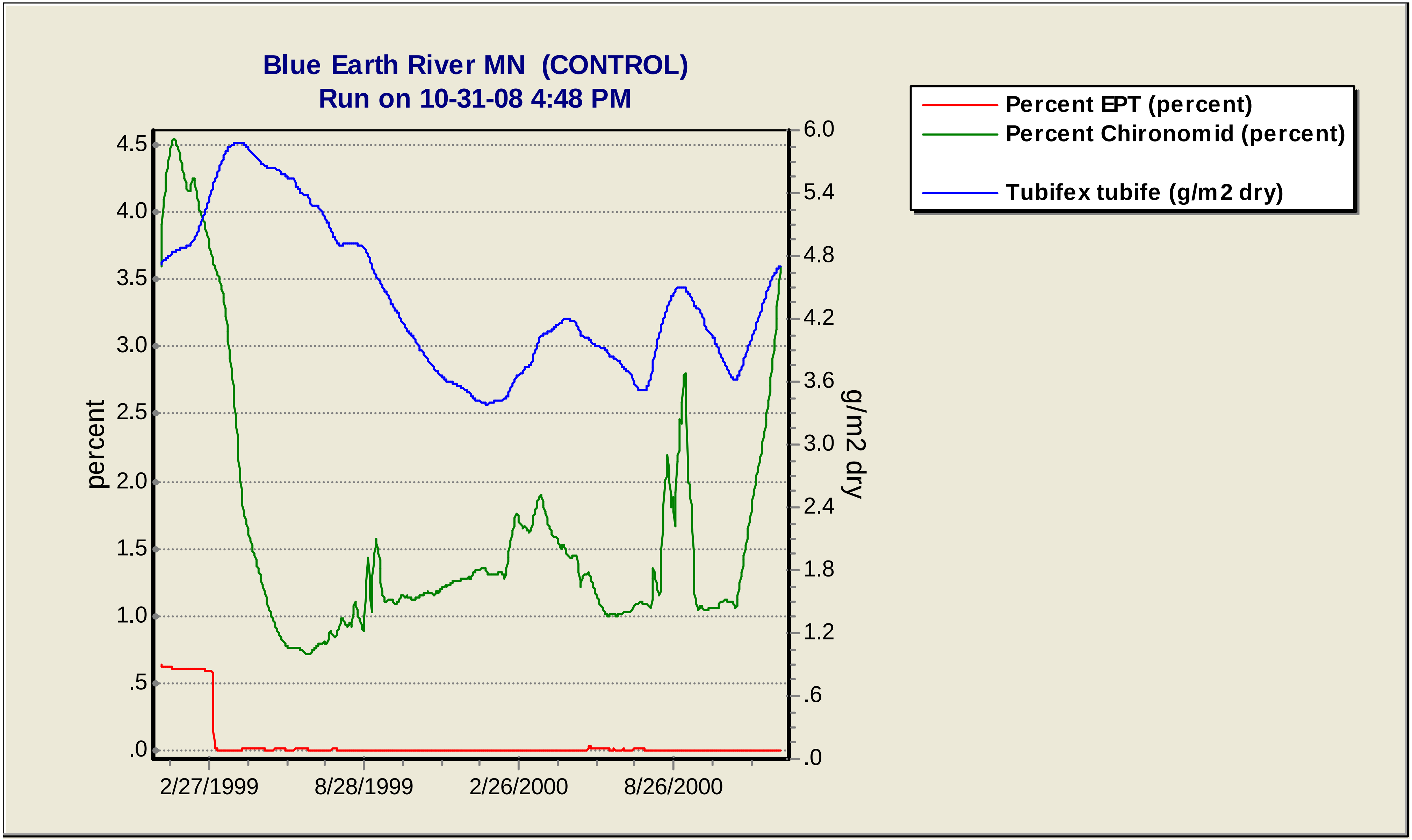
# Sediment Effects Overview

- Suspended and bedded sediment effects
  - Mortality
  - Reduced Feeding
  - Increased drifting of grazers due to sedimentation
  - Deposition of fines and affect on invertebrates and salmonid reproduction
    - Percent Embeddedness calculated as a function of 60-day average TSS

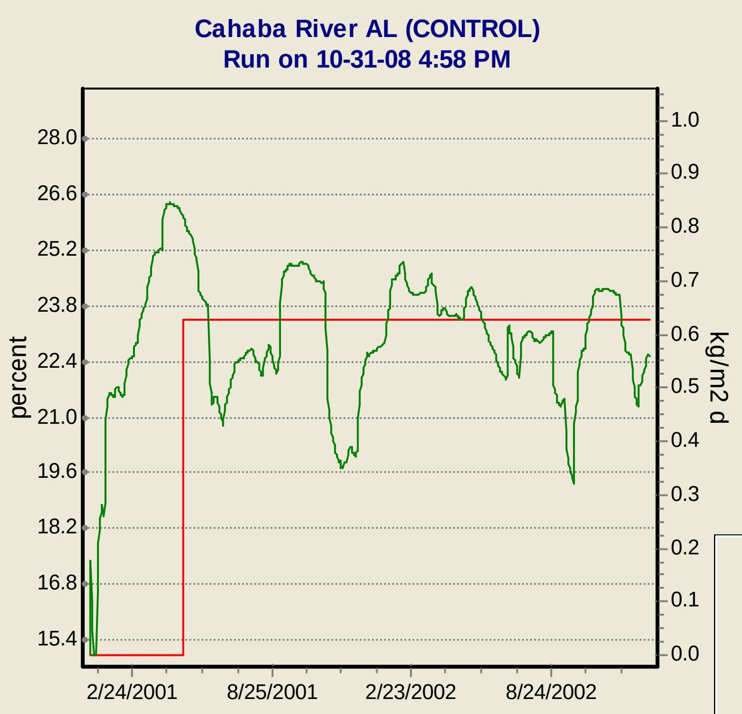
# Percent embeddedness is computed from 60-day deposition rate (a function of TSS)



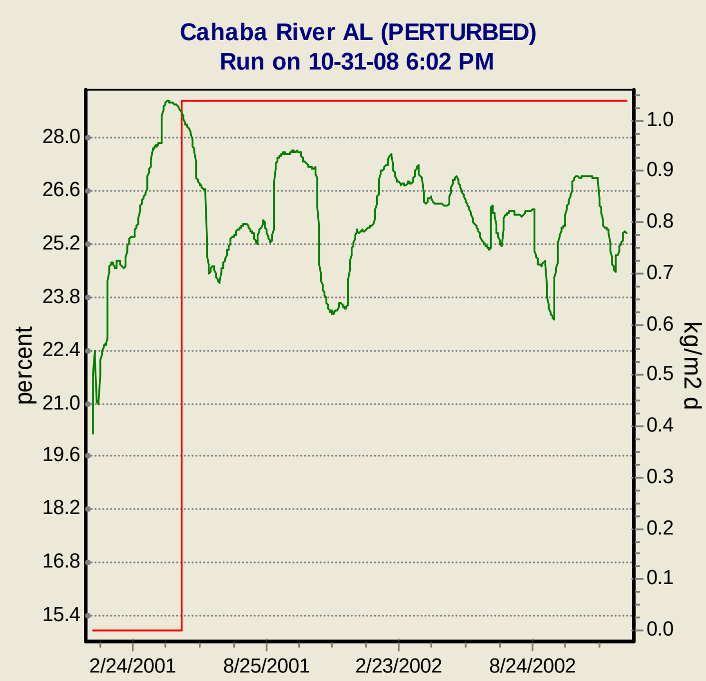
# Mayflies, stoneflies, & caddisflies (EPT) are sensitive to embeddedness, chironomids aren't



# Doubling TSS increases embeddedness in Cahaba River, AL

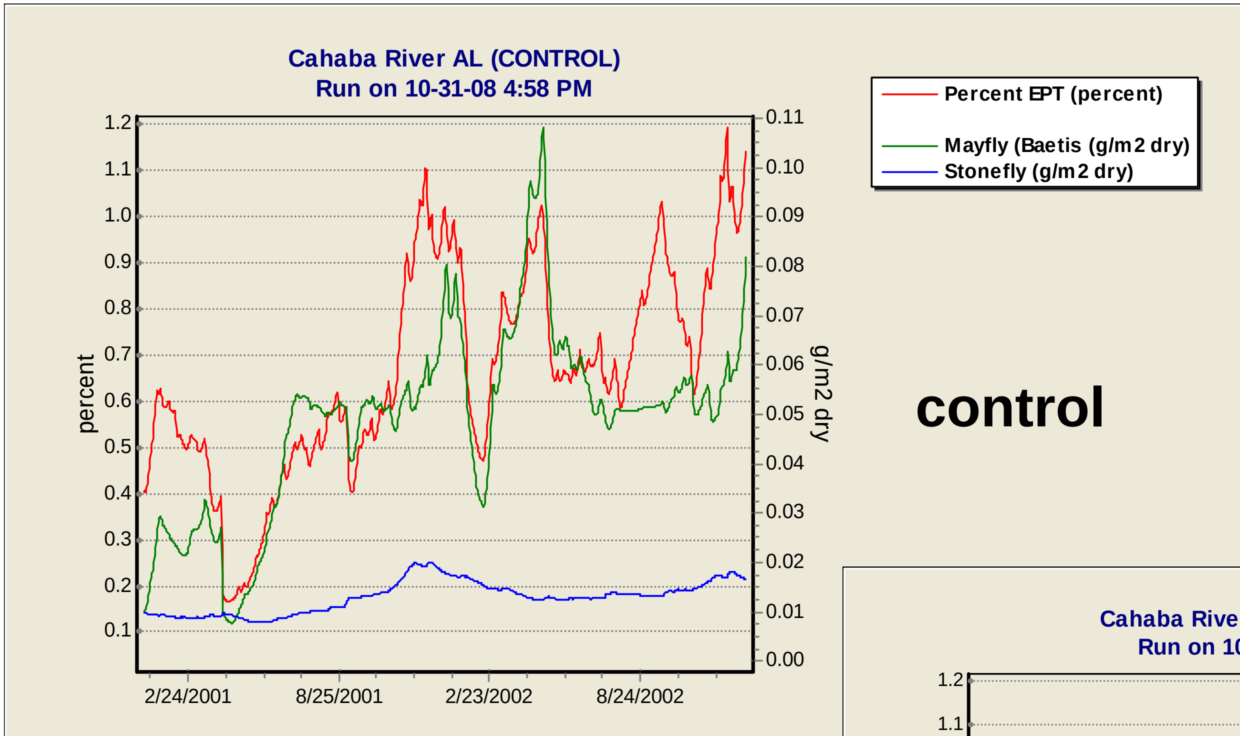



control

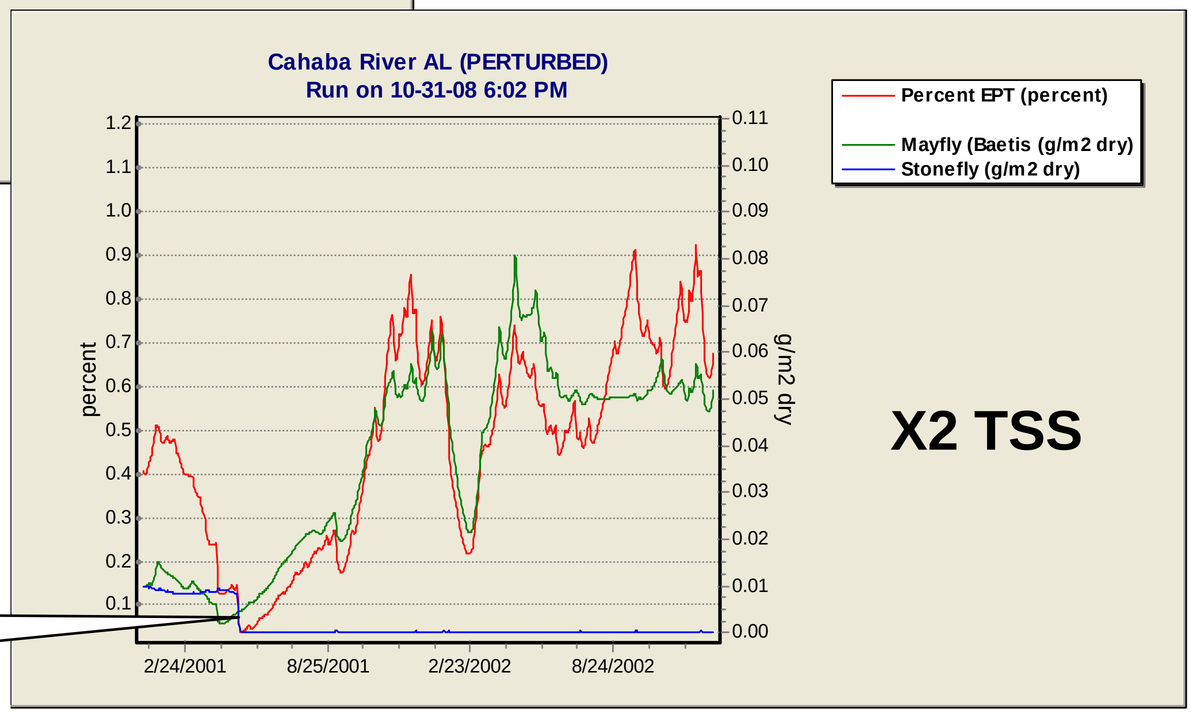



X2 TSS

# Doubling TSS loadings adversely impacts insect community in Cahaba River, AL




**control**




**X2 TSS**

**stoneflies crash**

# Closure

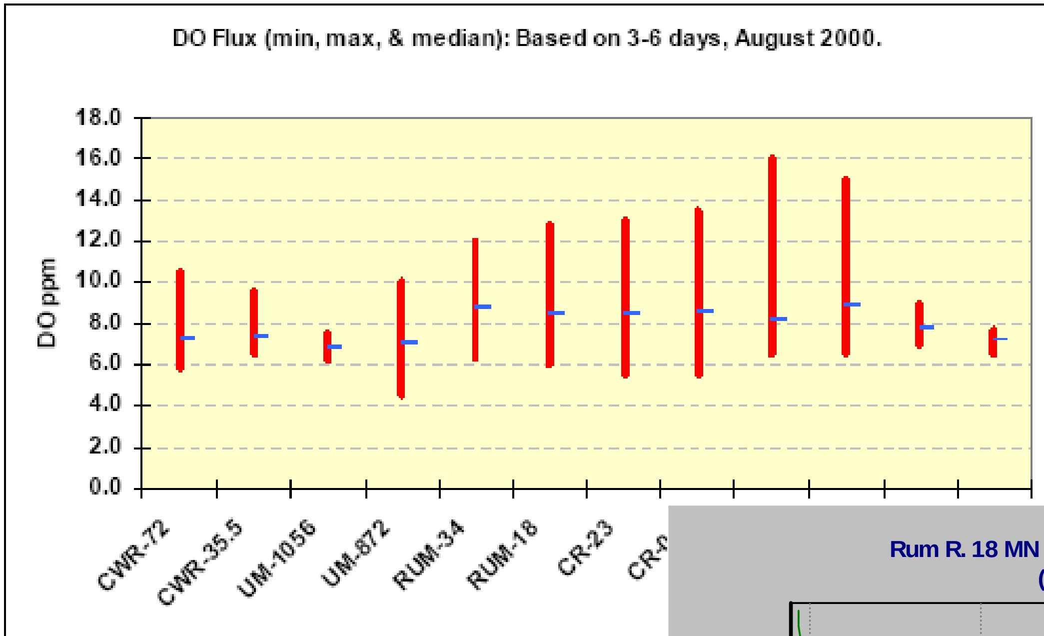
- Topics not yet covered (time-permitting)
  - Diel Oxygen
  - Sand-Silt-Clay model
  - Multi-layer sediment model
- Final Q&A

# Please Keep in Touch!

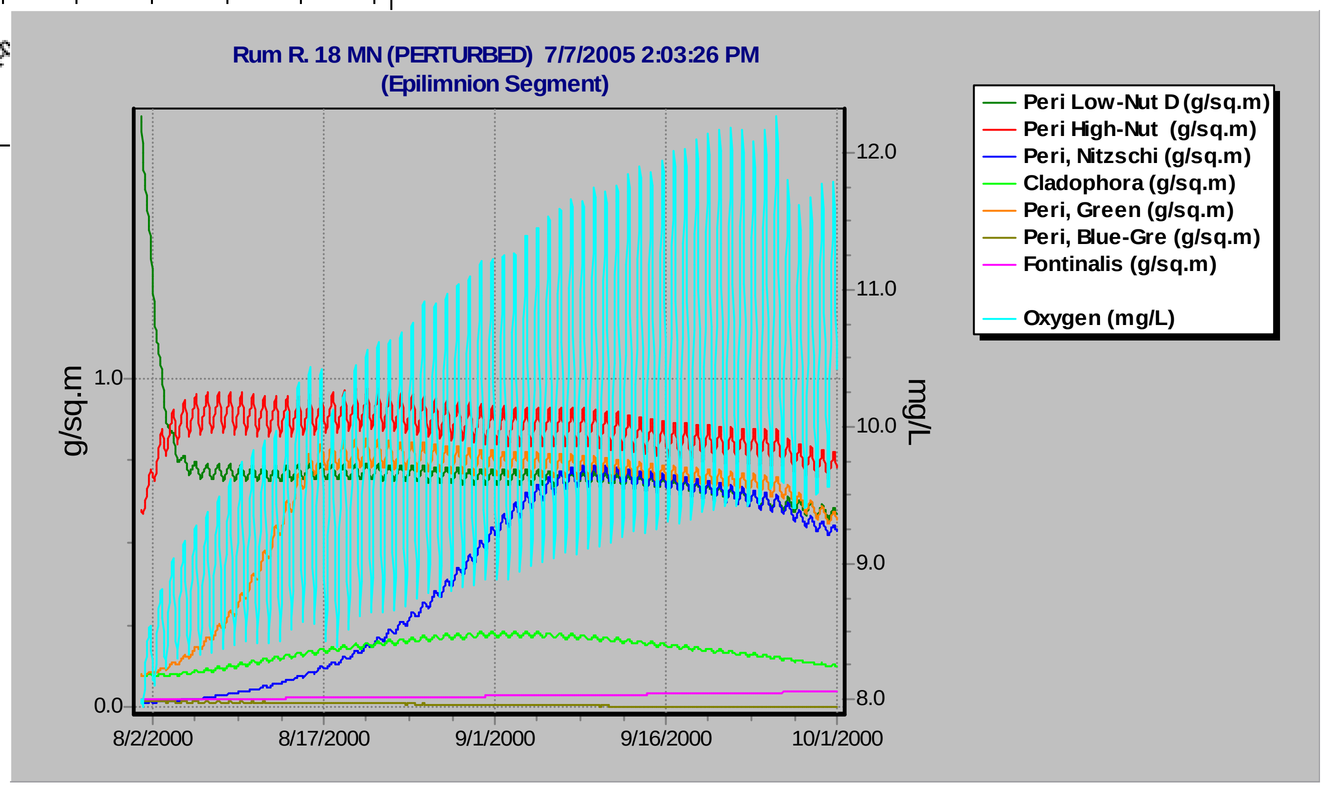
- Applications help drive enhancements, example studies and data libraries
- Growing user community builds robustness and confidence
- Continued model and user support
  - One-on-one technical support is available
  - AQUATOX listserver
- Visit the AQUATOX web site
  - http://epa.gov/ost/models/aquatox/

# Diel Oxygen, Light; Hourly time-step

Figure 4. Dissolved oxygen flux based on continuous measurement.

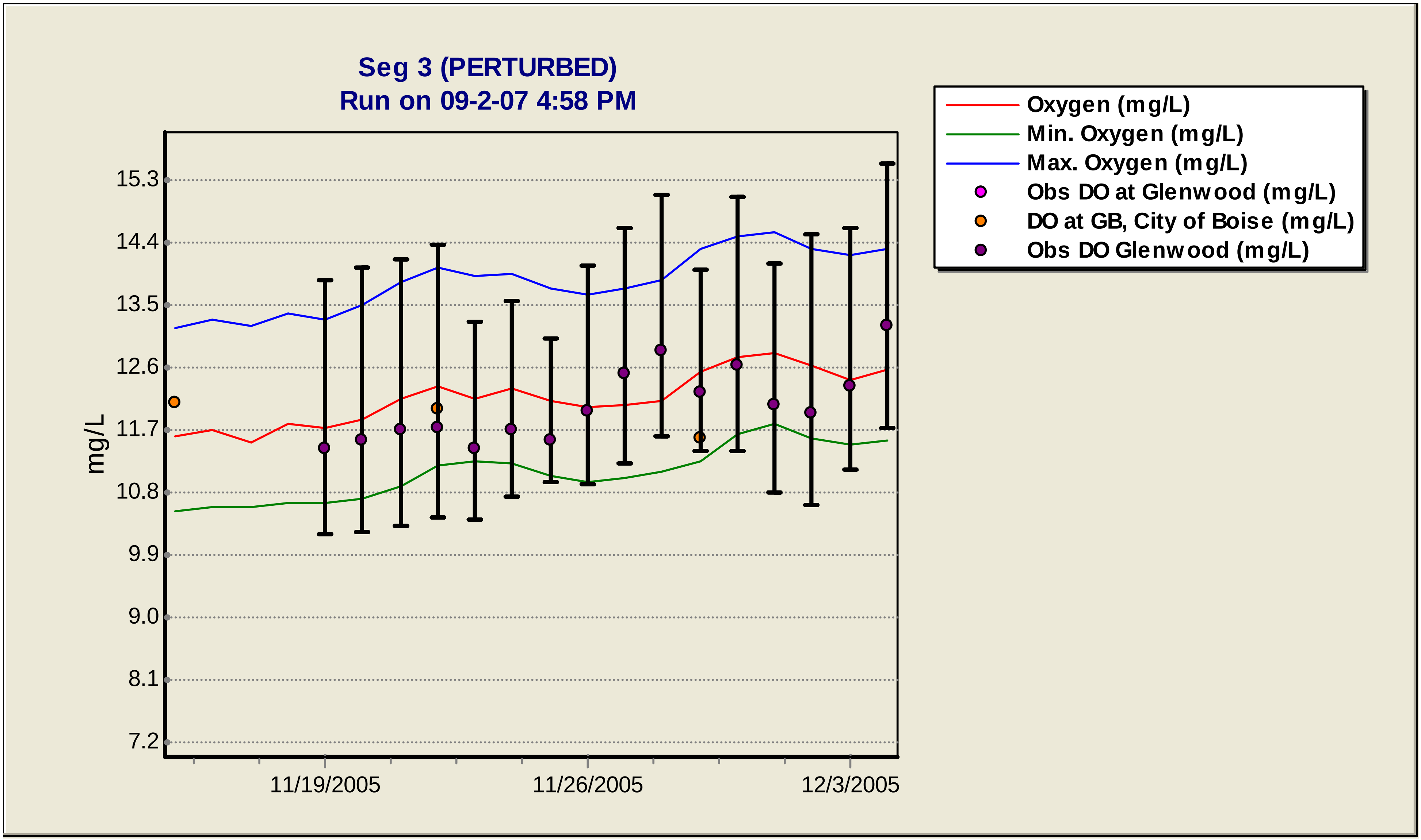



AQUATOX can now run with an hourly time-step including hourly light inputs. This results in a simulation of oxygen concentrations on an hourly basis




Monitoring data indicate that oxygen levels fluctuate daily

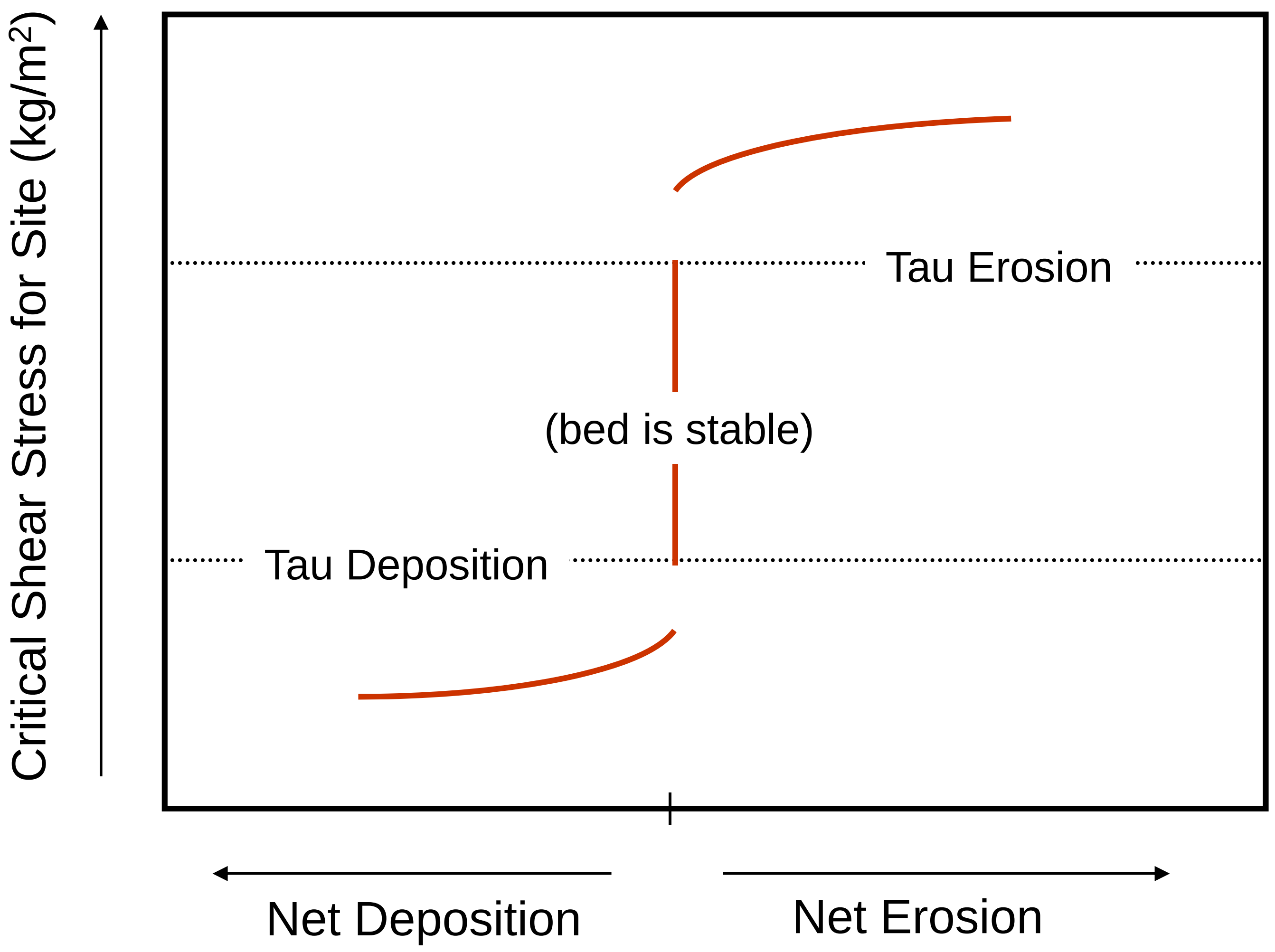
# Diel Oxygen, Light;  Hourly time-step



# Modeling Inorganic Sediments (sand, silt, and clay)

- Stream simulations only
- Scour, deposition and transport of sediments
- River reach assumed short and well mixed
- Daily average flow regime determines shear stresses
- Feedback to biota through light limitation, sequestration of chemicals

# Critical Shear Stress for Erosion and Deposition Key Parameters



# AQUATOX Multi-Layer Sediment Model based on the IPX module (Velleux et al. 2000)