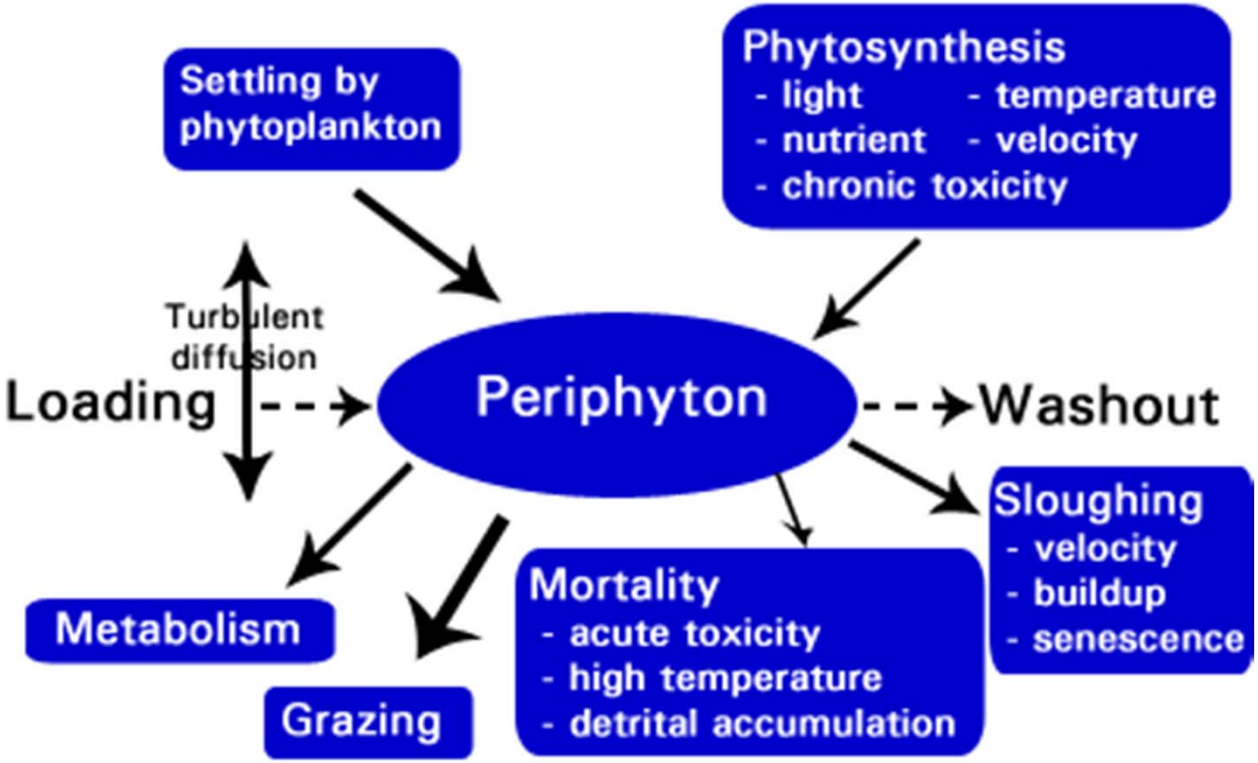
AQUATOX Modeling of Attached Algae

WERF Case Study and Lessons Learned

Brown AND Caldwell

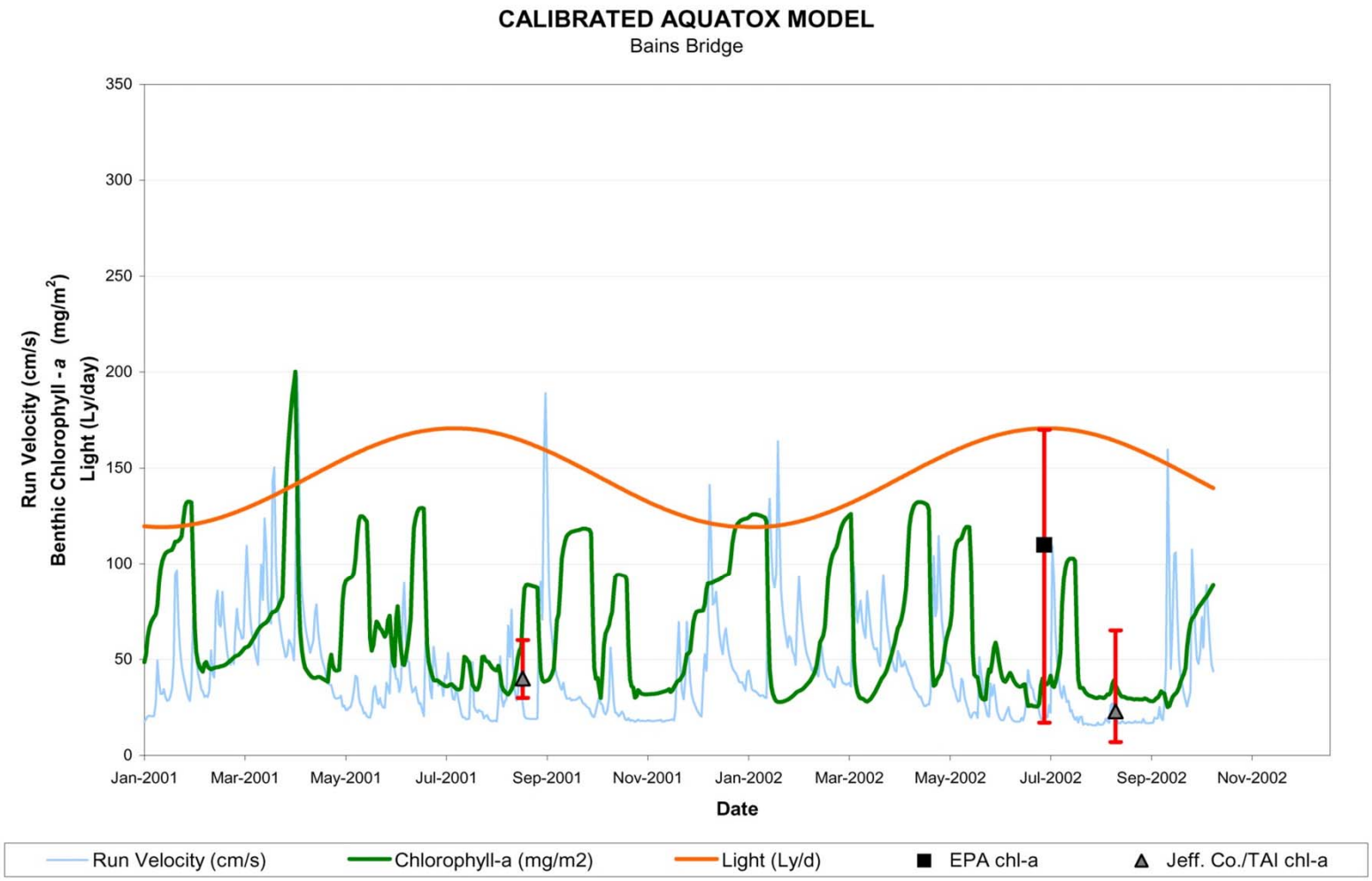
Periphyton simulation is at the edge of modeling science.



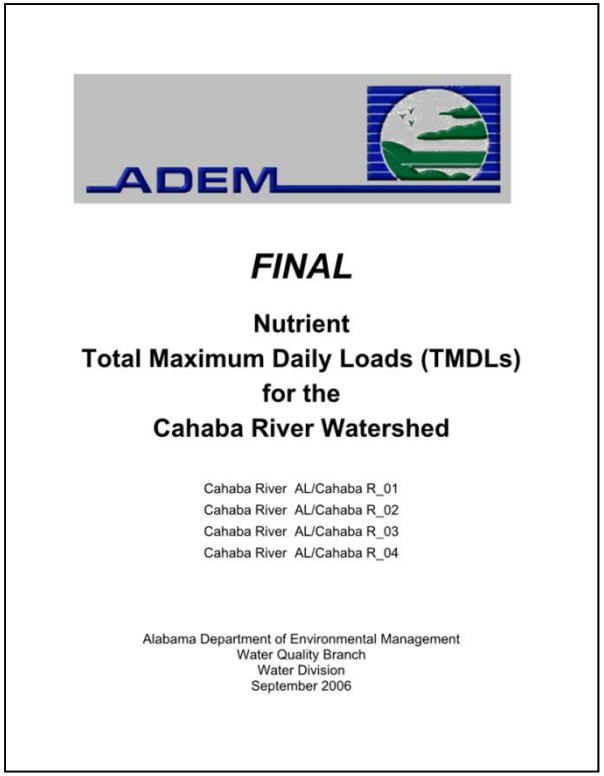
Phosphorus TMDL for Cahaba River, AL

- Downstream of Birmingham, AL
- *Cladophora* partially blamed for T&E species declines
- 1990s: 303(d)-listed for:
  - Nutrients
  - Siltation
  - Other habitat alteration

Stakeholder Recommendation: Model to a Periphyton Target



TMDL Used Reference Condition Approach



ADEM

FINAL

Nutrient
Total Maximum Daily Loads (TMDLs)
for the
Cahaba River Watershed

Cahaba River AL/Cahaba R_01
Cahaba River AL/Cahaba R_02
Cahaba River AL/Cahaba R_03
Cahaba River AL/Cahaba R_04

Alabama Department of Environmental Management
Water Quality Branch
Water Division
September 2006

- No direct attempt to predict periphyton response
- Instream P target (0.035 mg/L) derived from small, shaded watersheds.
- P limits more stringent than BAT
- Agency expressed hope for technological breakthroughs

WERF Case Study: Modeling Attached Algae in Virginia Streams

- Can models be used for TMDLs/NPDES permits to:
  - Predict algal biomass?
  - Predict algal type?

Is Screening Level Modeling Viable for Regulatory Applications?

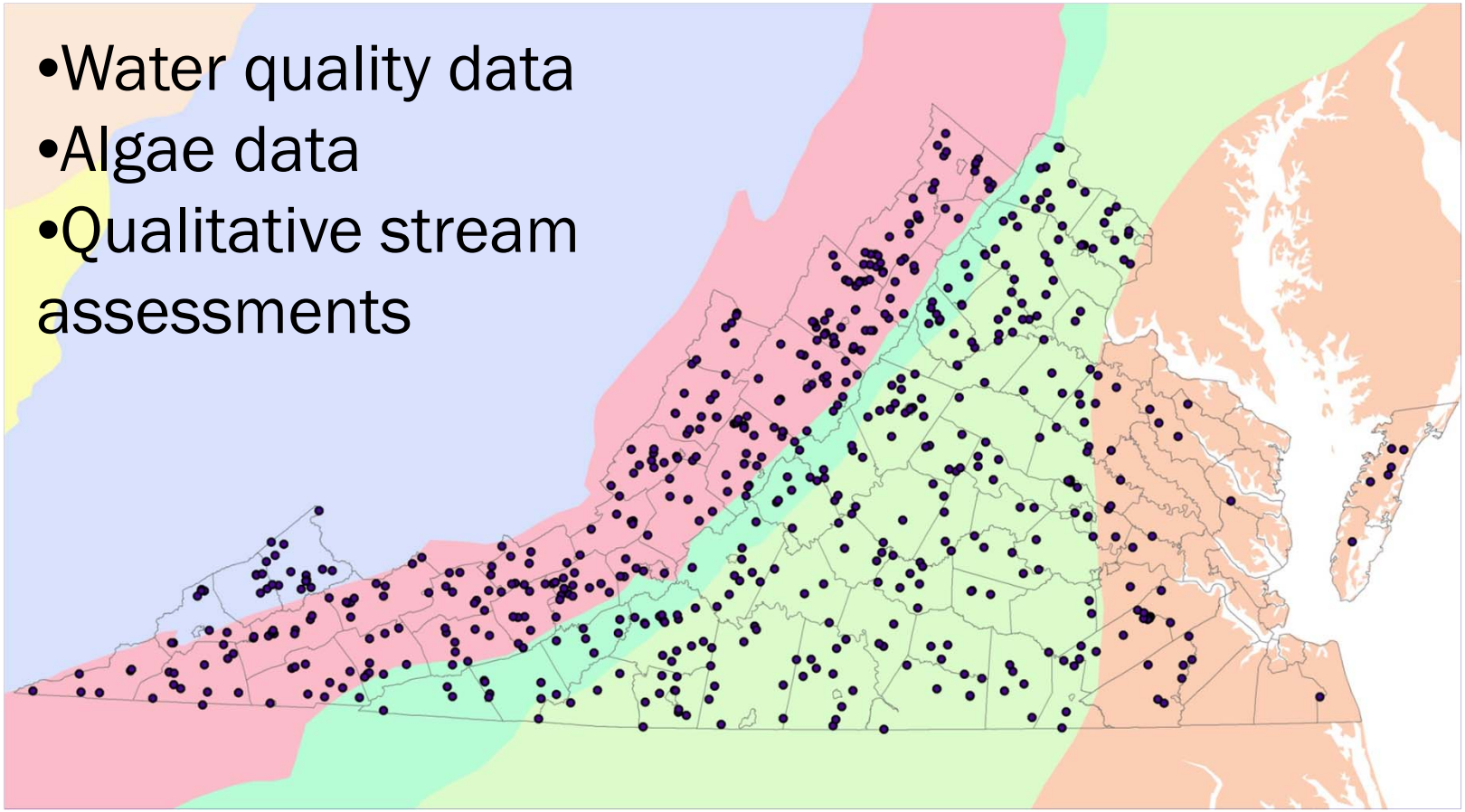
Water-Quality Based Approach

Technology-Based Approach

Hybrid Approach

Screening/Prioritization of Pre-Defined Management Tiers

Used data from Virginia's Pilot Program Database



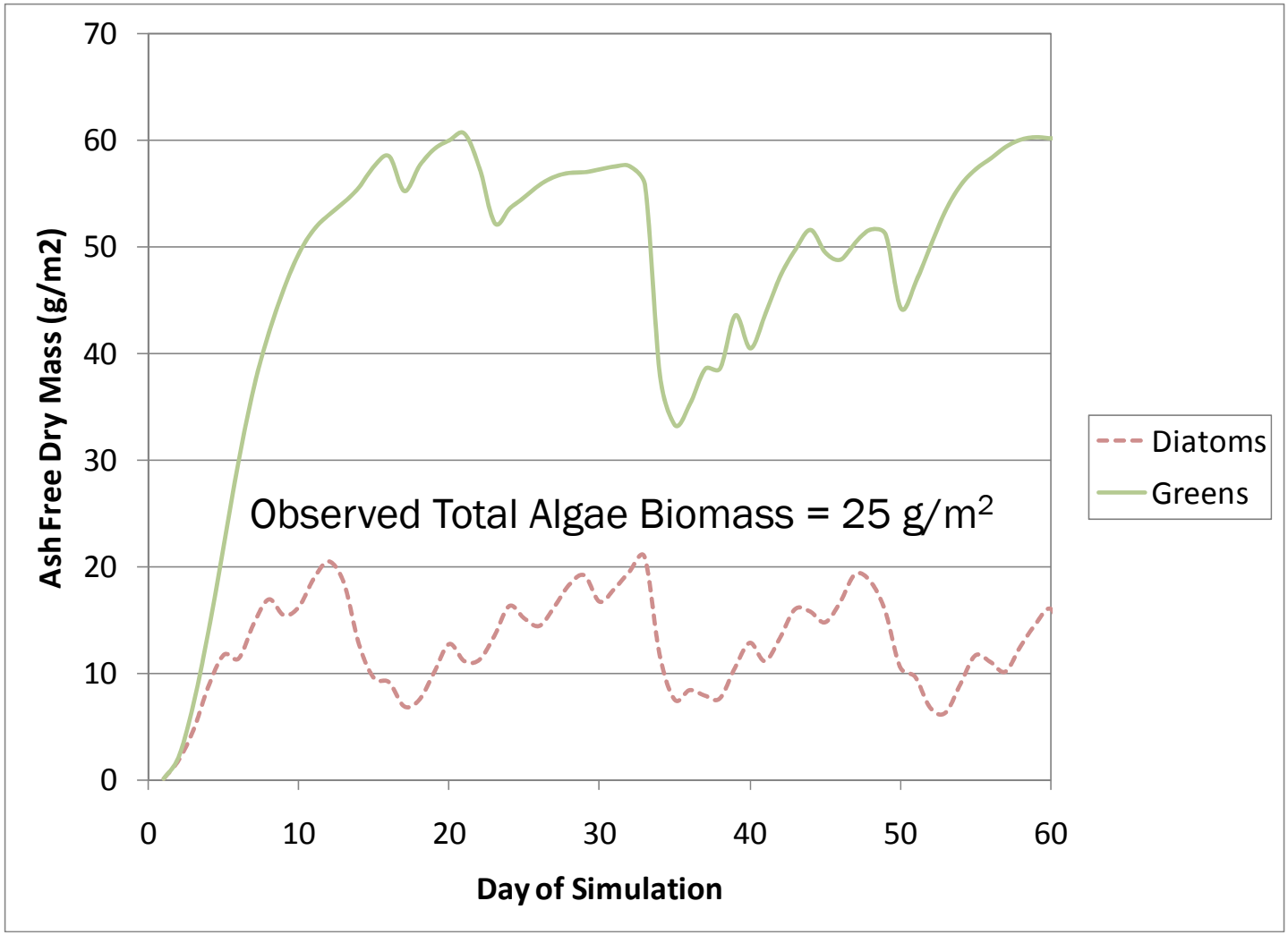
Several Stream Algae Models Considered

Simulation Capability	Model Code		
	QUAL2K	WASP7	AQUATOX
Attached stream algae	√	√	√
Substrate limitation	√	√	√
Dynamic hydraulics		√	√
Intracellular nutrient storage	√	√	
Grazers		√	√
Flow stimulation effects			√
Scour/sloughing			√
Multiple algal taxa			√
Self-shading			√

Focused on four sites with USGS stream gages

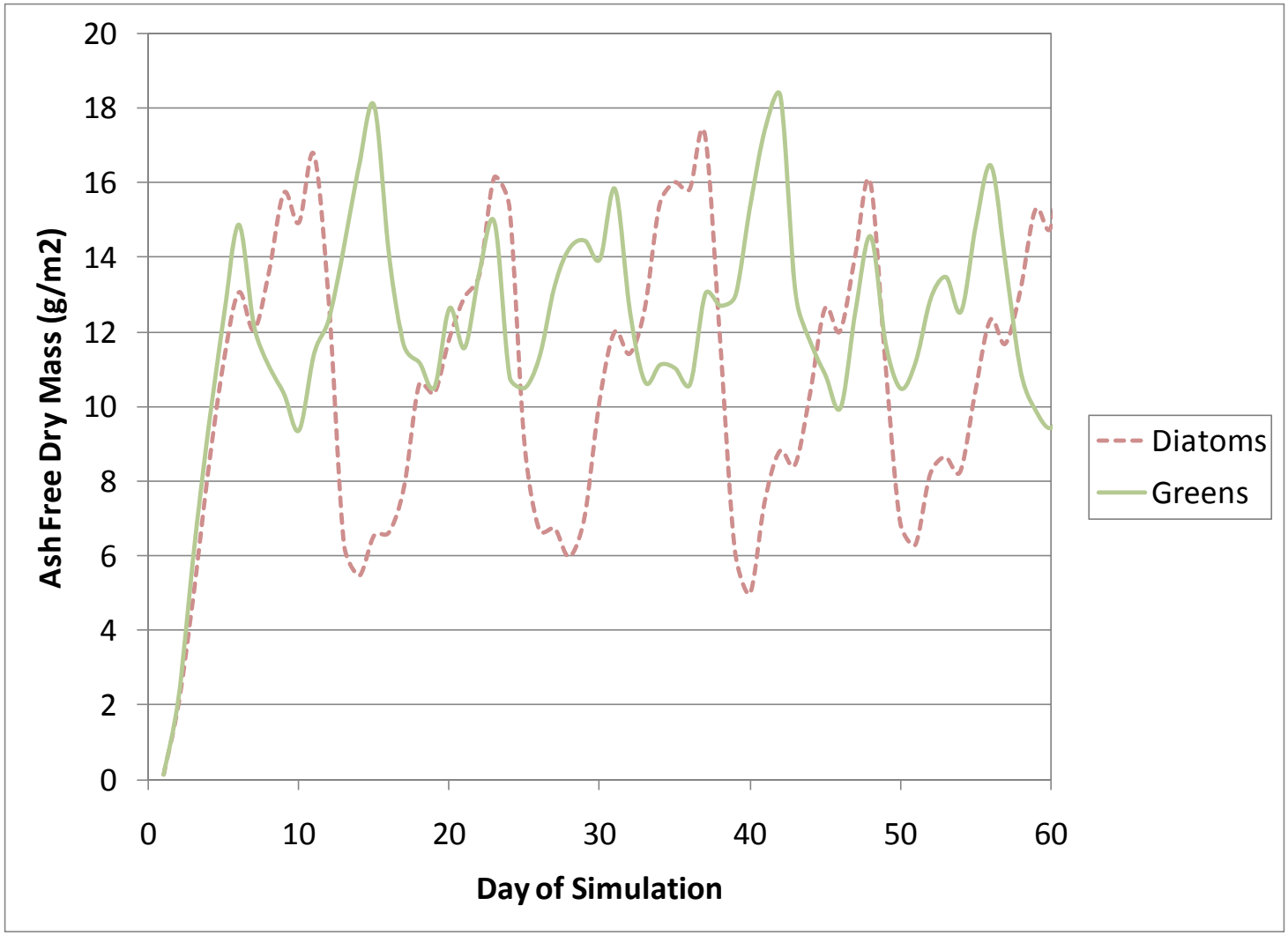
Site	Characteristics
A	Higher algal biomass (25 g/m^2) Green algae dominance
B	Higher algal biomass (31 g/m^2) Green algae dominance
C	Lower algal biomass (10 g/m^2) Diatom dominance
D	Lower algal biomass (3 g/m^2) Diatom dominance

Model Results for Site A – Green Algae Dominated



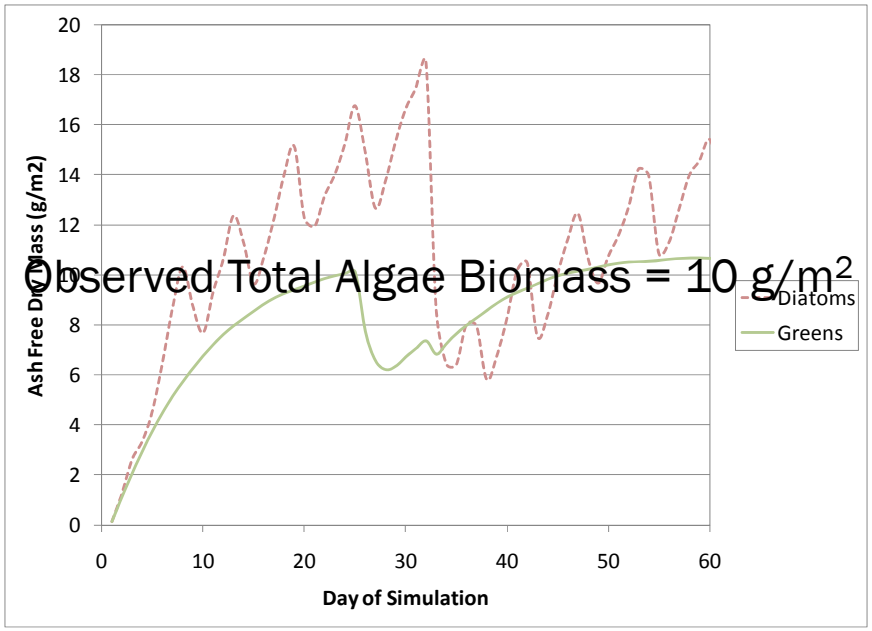
Model Results for Site B – Mixed Algae

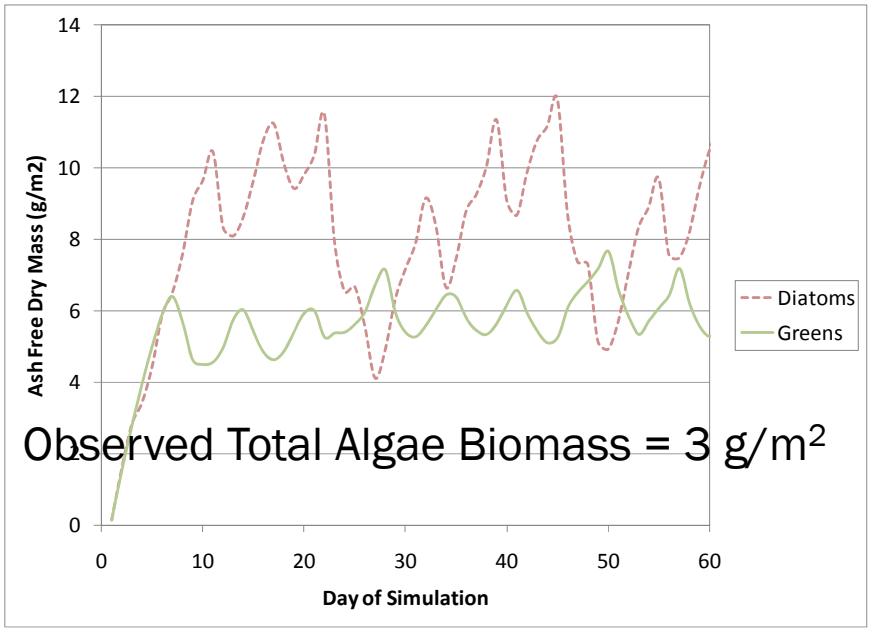
Observed Total Algae Biomass = 31 g/m^2



Site B

Sites C & D: Diatoms predicted to be more abundant.





Summary of Uncalibrated Results

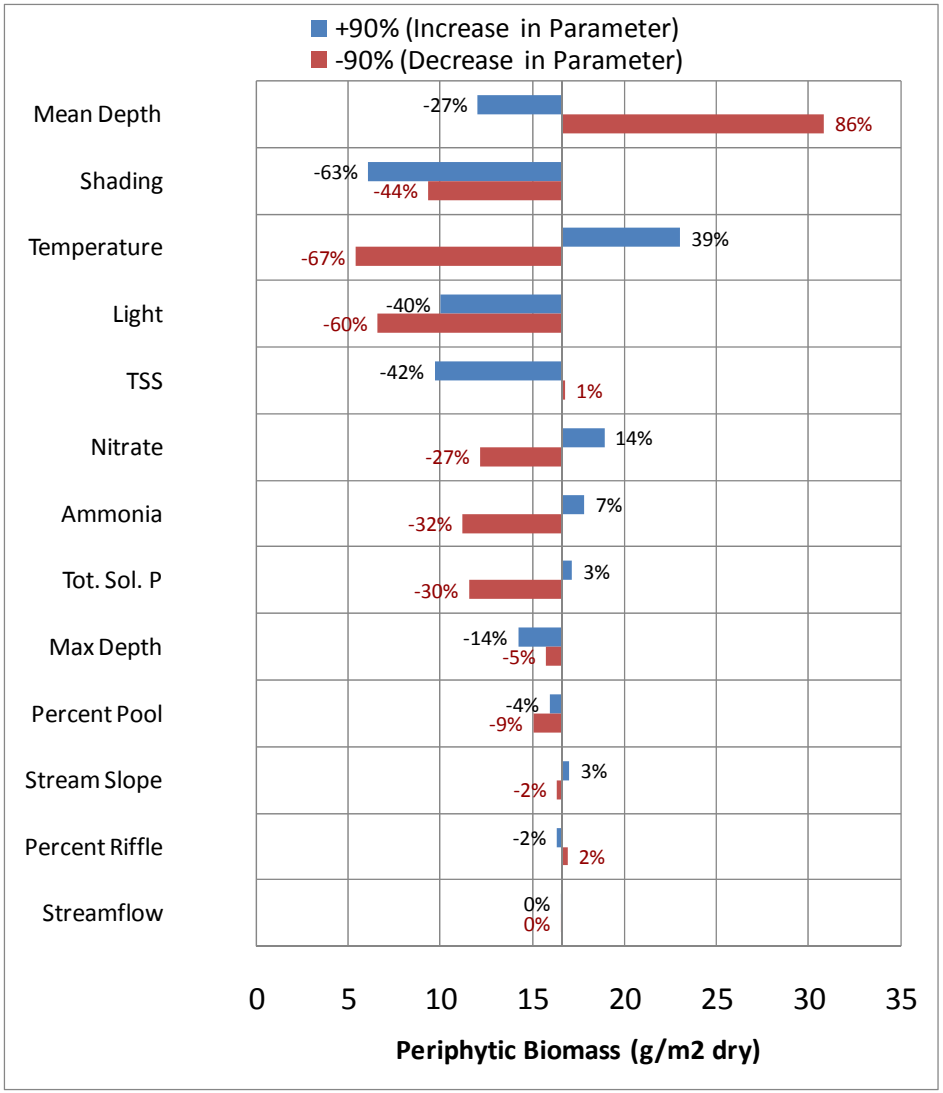
Site	Obs. Biomass (g m^{-2})	Predicted Biomass (g m^{-2})	Observed Biomass Rank (of four sites)	Predicted Biomass Rank (of four sites)	Observed Dominant Algae	Predicted Dominant Algae
A	25	75	2	1	Tall, filamentous, bright-green	Green
B	31	43	1	2	Green mat	Periods of green dominance
C	10	23	3	3	Thin brown mat	Mixed diatom/green
D	3	17	4	4	Thin brown film & brown mat	Mixed diatom/green

Observations on “Screening Level” Model

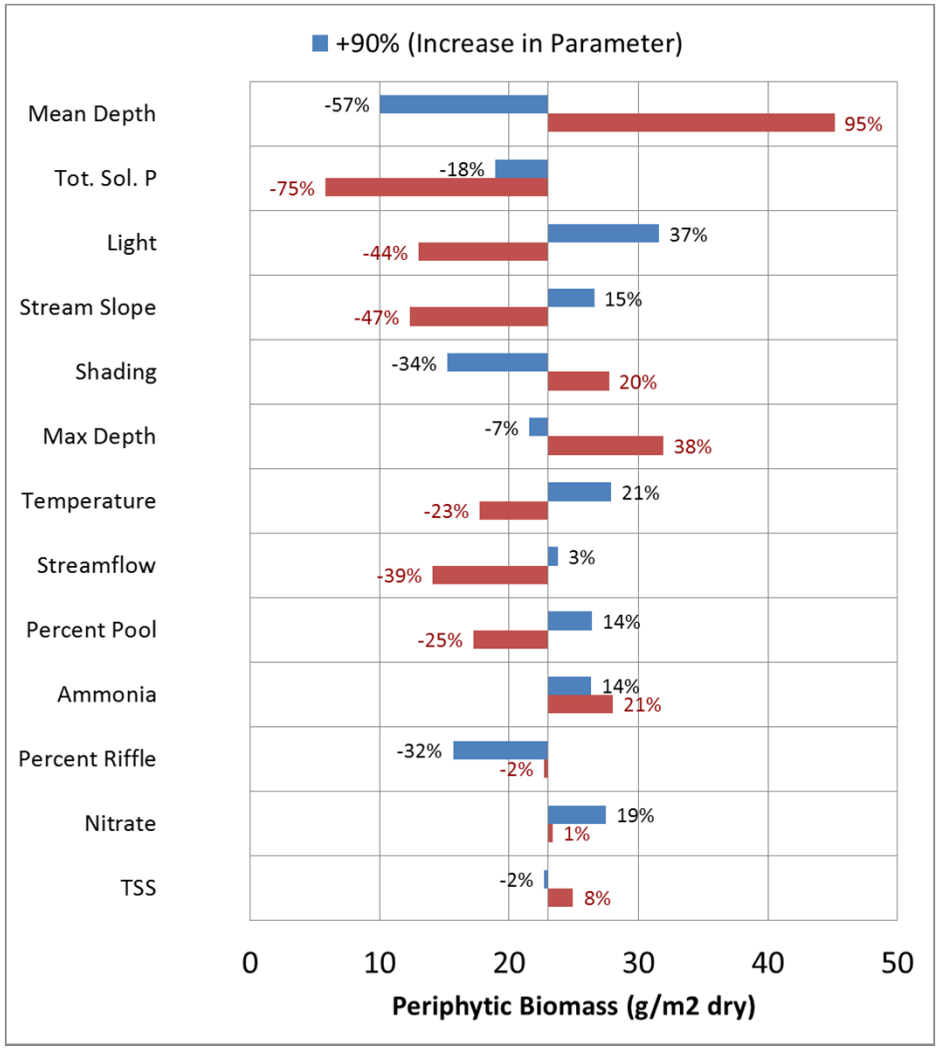
- Capable of distinguishing between “higher biomass” and “lower biomass” sites.
- Capable of predicting when filamentous greens would predominate
- Consistently overpredicted algal biomass

Sensitivity Analysis Provides Valuable Insights into Predictions

- Site A
  - Light conditions optimal
  - Not nutrient limited
  - Biomass sensitive to depth/velocity



Sensitivity Analysis Provides Valuable Insights into Predictions (cont.)



- Site C
  - Light limited
  - Not sensitive to nutrient additions
  - Sensitive to depth/velocity

Parameters to which algal predictions were sensitive

- Algal parameters
- Stream depth/velocity
- Light/shading
- Temperature
- Nutrient concentrations
- Grazers

90% reduction in nutrients to achieve 30% reduction in biomass

What phosphorus thresholds will “max out” growth rates?

- 15 ug /L (Stevenson and others, 1999)
- 7 ug /L (Seeley, 1976)
- 8 ug/L (Horner and others, 1990)
- 3—4 ug/L (Bothwell, 1985)
- 0.3—0.6 ug/L (Bothwell, 1988)

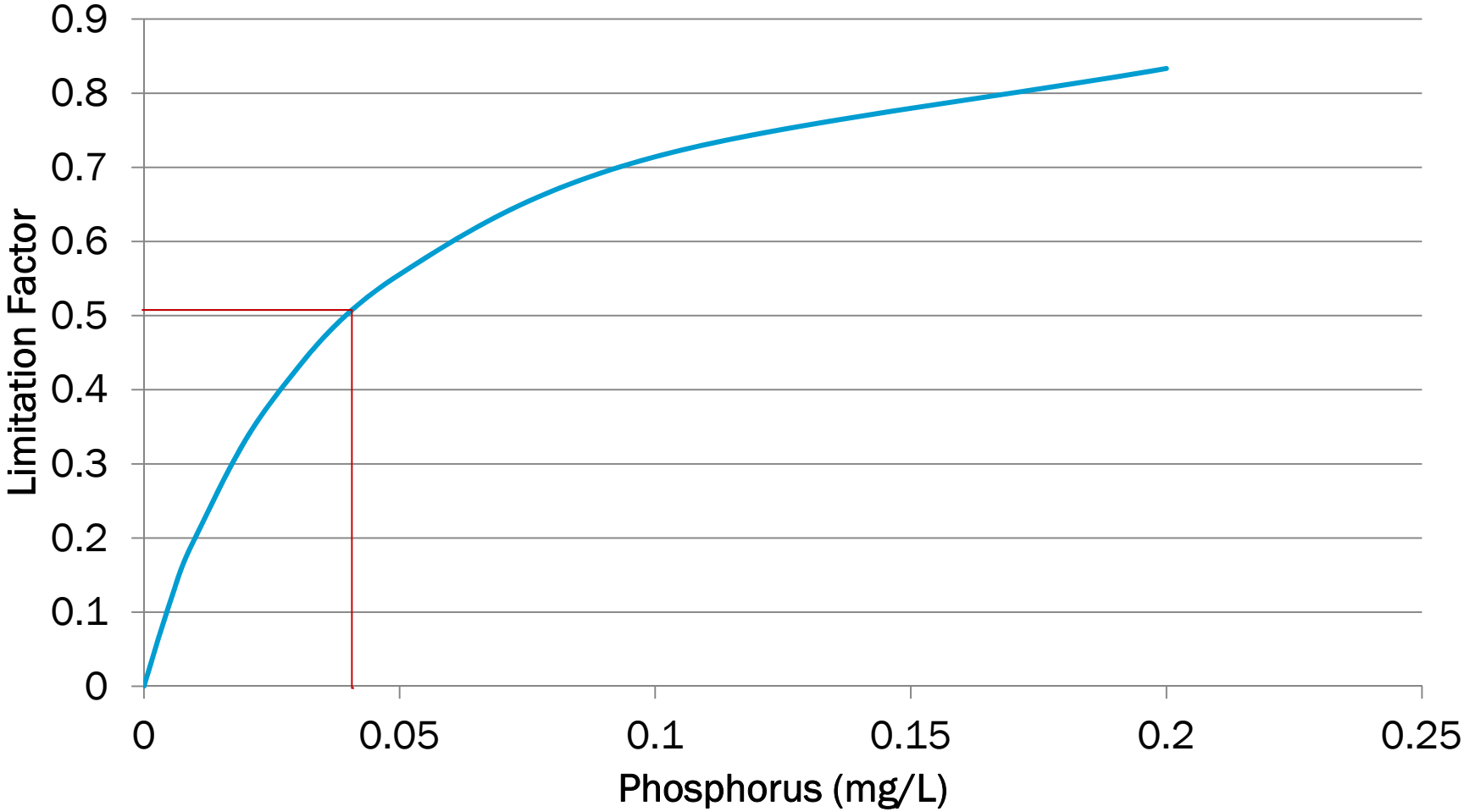
…but effectively higher in field (40-100 ug/L) due to mat diffusion effects

AQUATOX's golden table of algal parameters…

Table 2. Select algal parameters employed in AQUATOX simulations.

Periphyton	Topt	Tmax	Tresp	LightSat	Pmax	Lightex	P half-sat	N half-sat	C half-sat	ExpMoCo	Fcrit	%sl
Low-nutrient diatoms	20	39	2	64	0.65	0.03	0.006	0.07	0.054	0.01	**0.001** (0.003)	**75** (90)
High-nutrient diatoms	20	35	1.8	22.5	2.3	0.03	0.055	0.2	0.054	0.01	0.004	60
Greens	25	42	2	**70** (110)*	**1.7** (2)	0.03	0.1	0.8	0.054	0.01	**0.004** (0.003)	**20** (60)
Cladophora	30	42	2	135	**0.7** (1.4)	0.05	0.04	0.1	0.054	0.05	0.004	90
Blue-Greens	30	50	2	45	1.4	0.03	0.1	0.8	0.024	0.01	0.004	90
Nitzschia	25	39	2	82.5	**0.5** (1.75)	0.03	0.095	0.4	0.054	0.05	**0.001** (0.003)	**50** (90)
Phytoplankton												

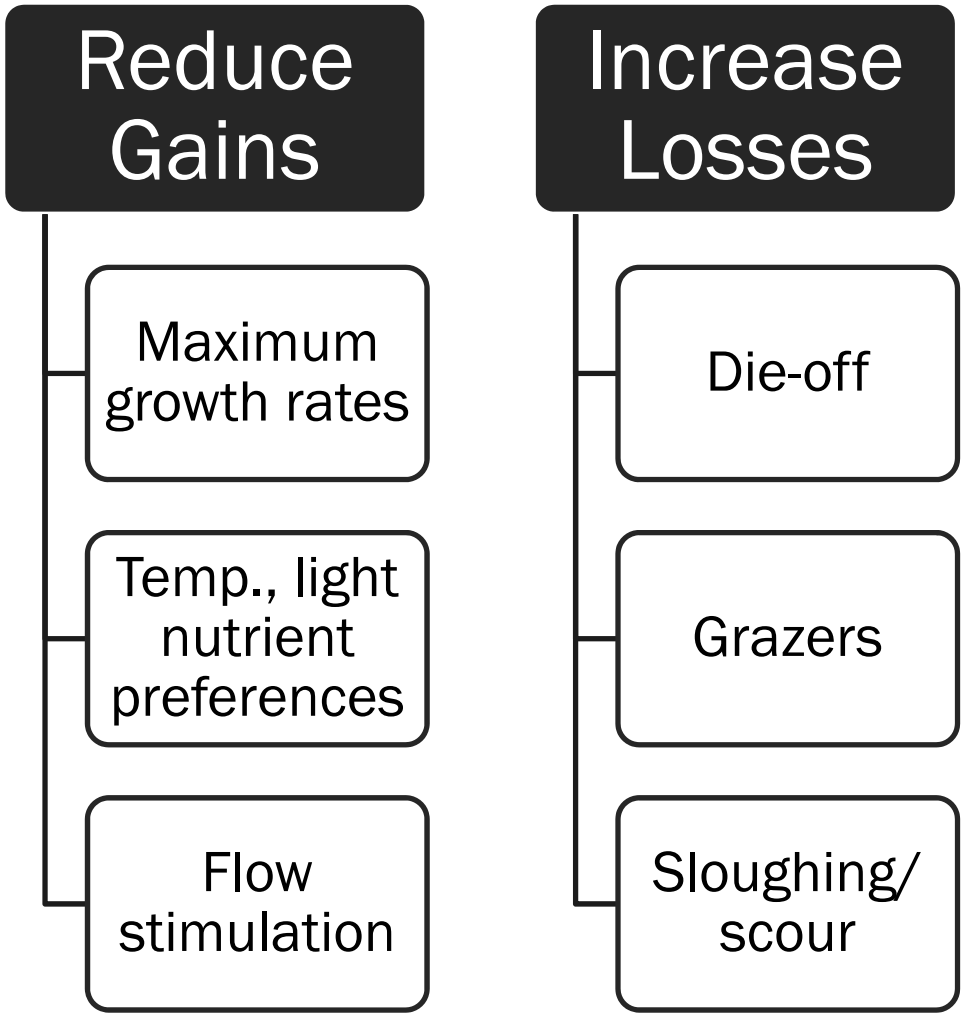
Growth rates can be 60-80% of maximum rates at background nutrient concentrations



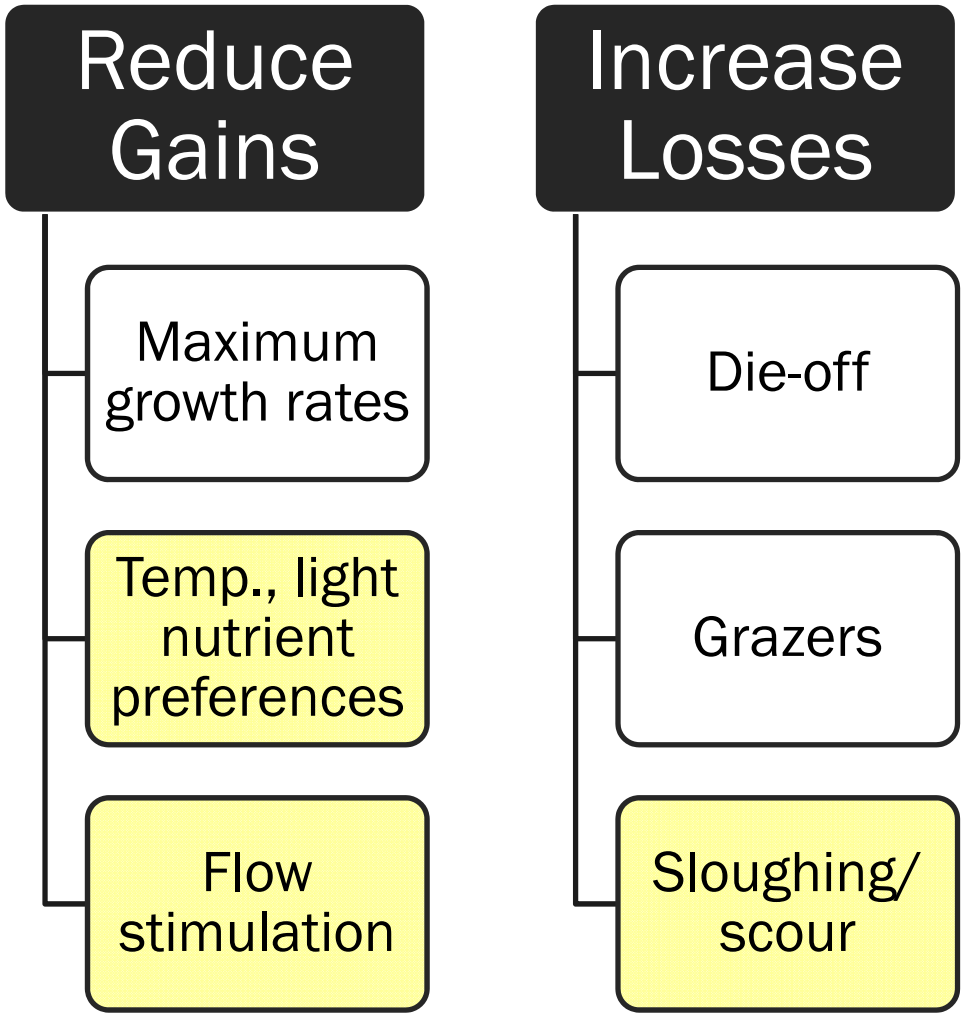
What does the model say will lead to filamentous green algae dominance?

- Higher growth rates of green algae taxa
- Higher light availability
- Higher temperatures

Calibration Strategies for Attached Algae



Calibration Strategies for Attached Algae



Management Interpretation of AQUATOX

Site	Primarily Limitation(s)	Nutrient Management Tier
A	Weak light and nutrient limitation	Tier 2
B	Strong nutrient limitation Ideal physical conditions	Tier 3 Consider dam releases
C	Strong light limitation	Tier 1
D	Moderate light and nutrient limitations	Tier 2

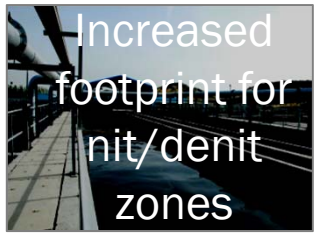
Major technology upgrades to remove last few mg/L

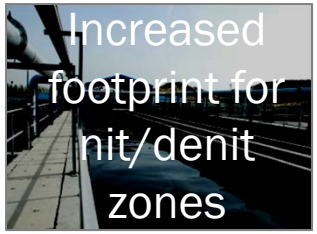
No nutrient removal (18 mg/L)

8 mg/L

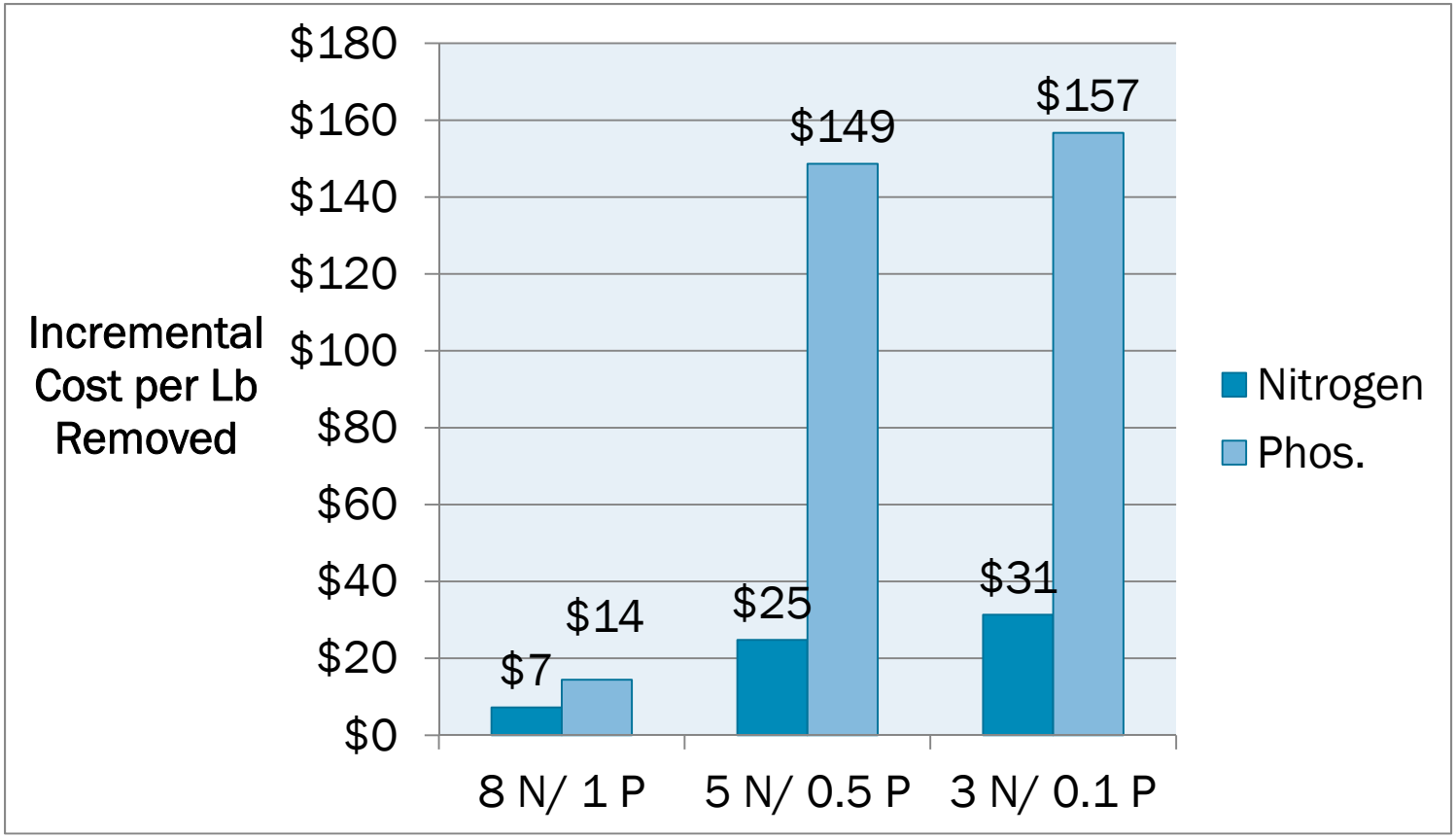
5 mg/L

3 mg/L





Incremental cost per pound escalates as treatment level increases



Data Sources: CBC (2012), EPA (2002), EPA (2008)

Observation #1: AQUATOX is useful for predicting where nuisance algal conditions will prevail

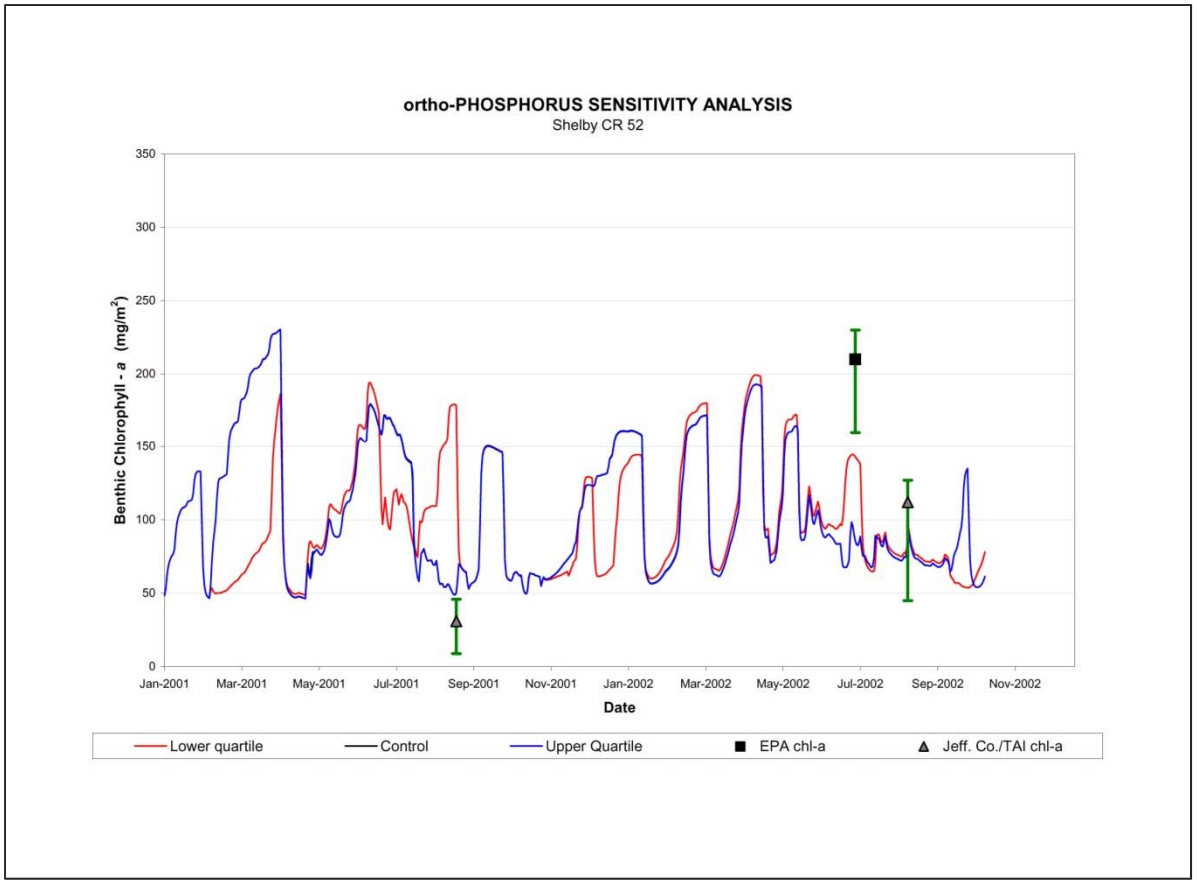
…but quantitative predictions require rigorous calibration.

Observation #2: The sensitivity analysis is as valuable as the calibration

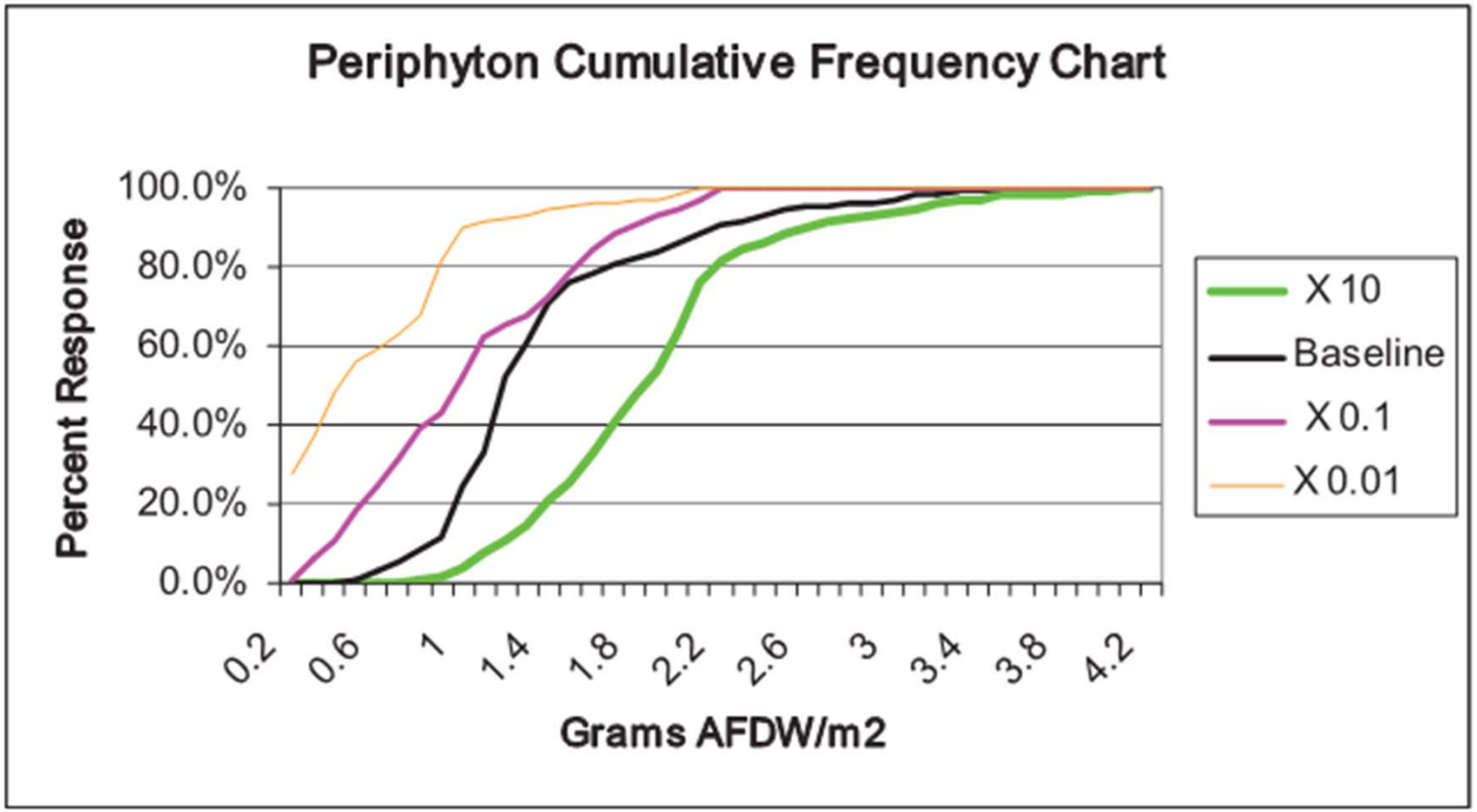
- Expect attached algae to be sensitive to many non-nutrient factors:
  - Light
  - Flow/velocity conditions
  - Grazers
- Bring perspective on what to expect from management controls.

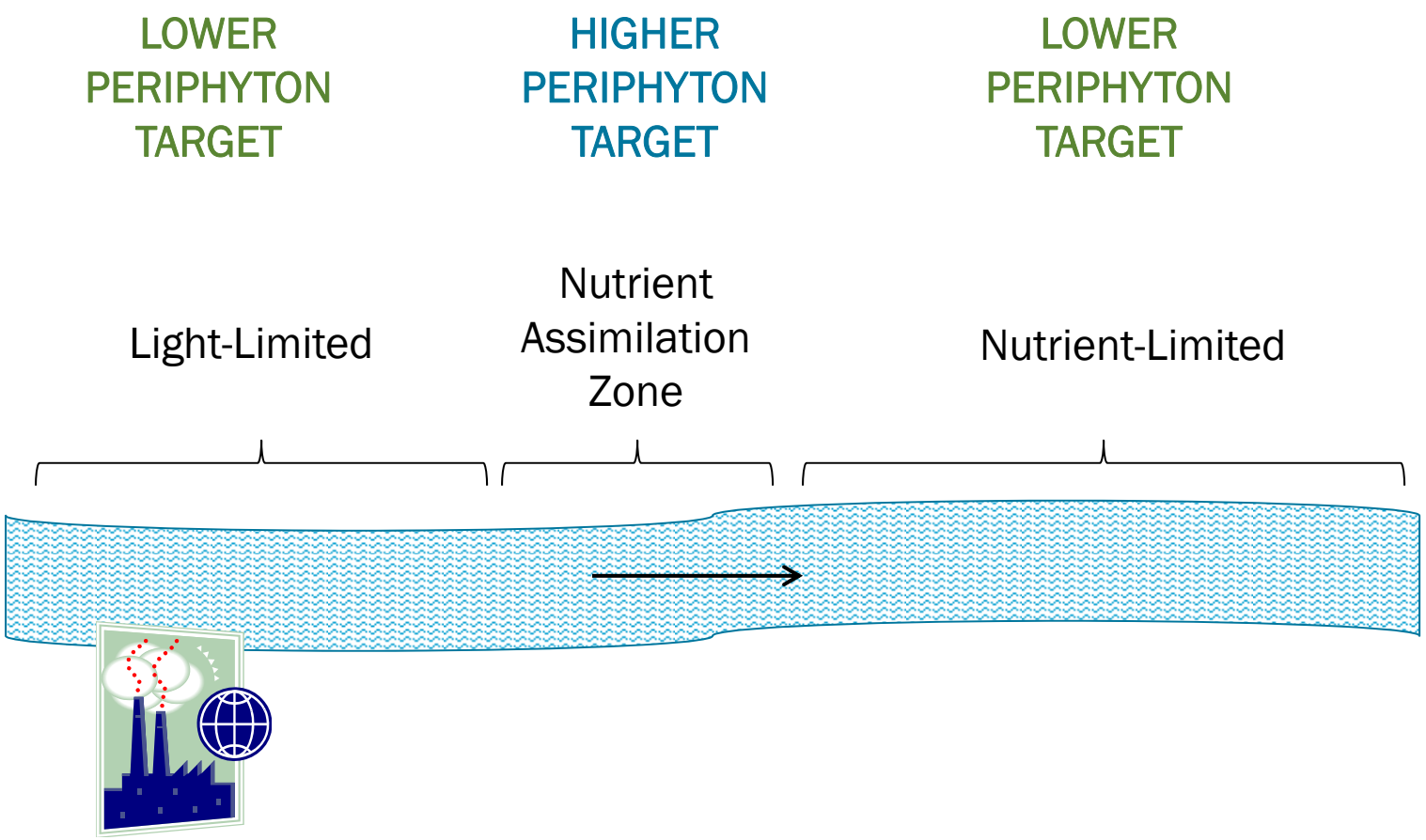
Observation #3: We're Slowing Algal Growth, Not Stopping It

- Algal growth rates can be ~60-80% of maximum rates at background nutrient concentrations.



Observation #4: Important to consider *frequency* and *duration* of attainment



Source: Blancher and others (2002)

Observation #5: Models can show where tiered aquatic life uses should be considered.