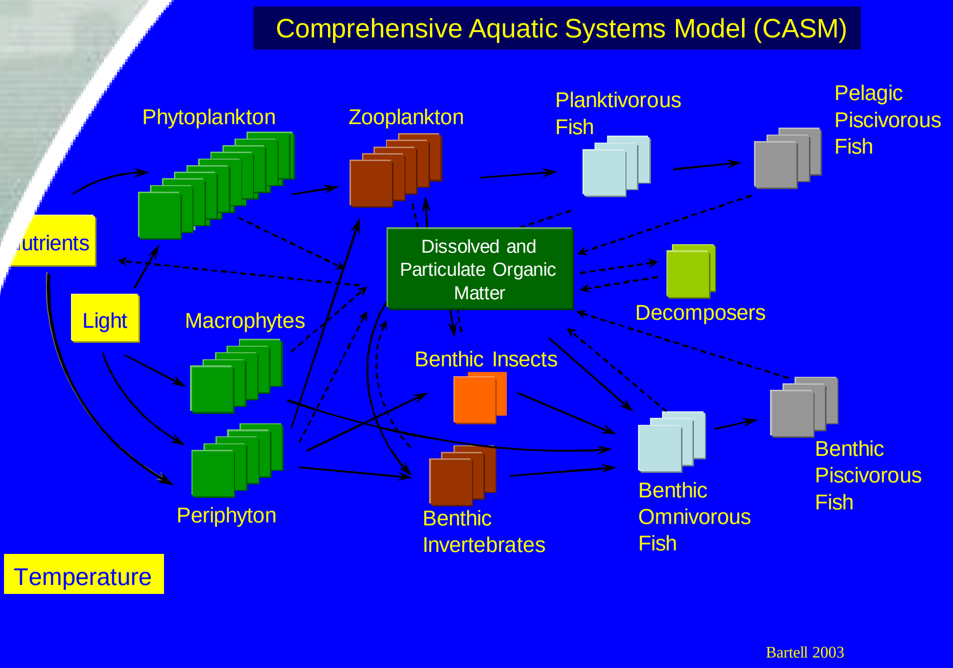
Application of the Comprehensive Aquatic Systems Model (CASM) to Lake Texoma, Oklahoma and Texas



Objectives

- CASM application to evaluate chloride management alternatives
  - Future with- and without-project
  - Relationship between TDS, light extinction, and primary productivity
  - Relationship between TDS and *Prymnesium parvum* (Golden Alga)
  - Relationship between long-term storage losses and chloride management alternatives
  - Evaluate water quality and modeled population responses to annual environmental variability under multiple chloride management alternatives

Comprehensive Aquatic Systems Model (CASM)

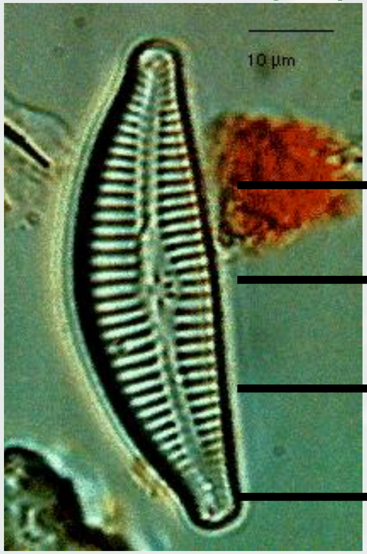
- Ecosystem model with water chemistry and food-web components
- Functions on spatial and temporal scales
- Simulates daily water quality parameter concentrations
  - Mass-balance approach
  - Includes external inputs, internal uptake, nutrient recycling
- Simulates producer and consumer biomass based upon the modeled community structure, population characteristics, and selected representative species for each population (bioenergetics based model)
  - Production output as grams of carbon (g-C)
- Literature derived and site specific constants utilized in model calibration
  - Temperature, light saturation, sinking rates, respiration, excretion, mortality, etc...

Producer Bioenergetics

Photosynthesis

$$\Delta B = P - (R + M + S) - G + (I - O)$$

Phytoplankton i



Macrophyte j

Inflow

Outflow, scour

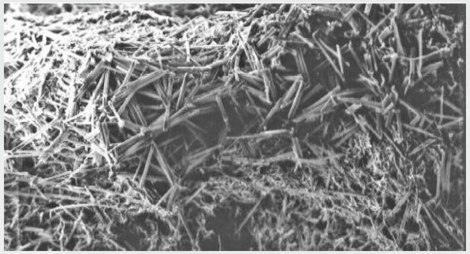
Respiration

Mortality

Grazing

Sinking

Periphyton k



Emergent l

Governing equation for primary producer populations

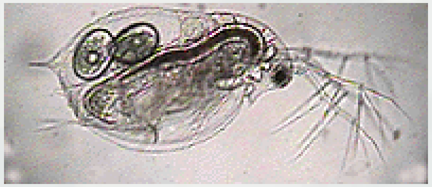
For population i,

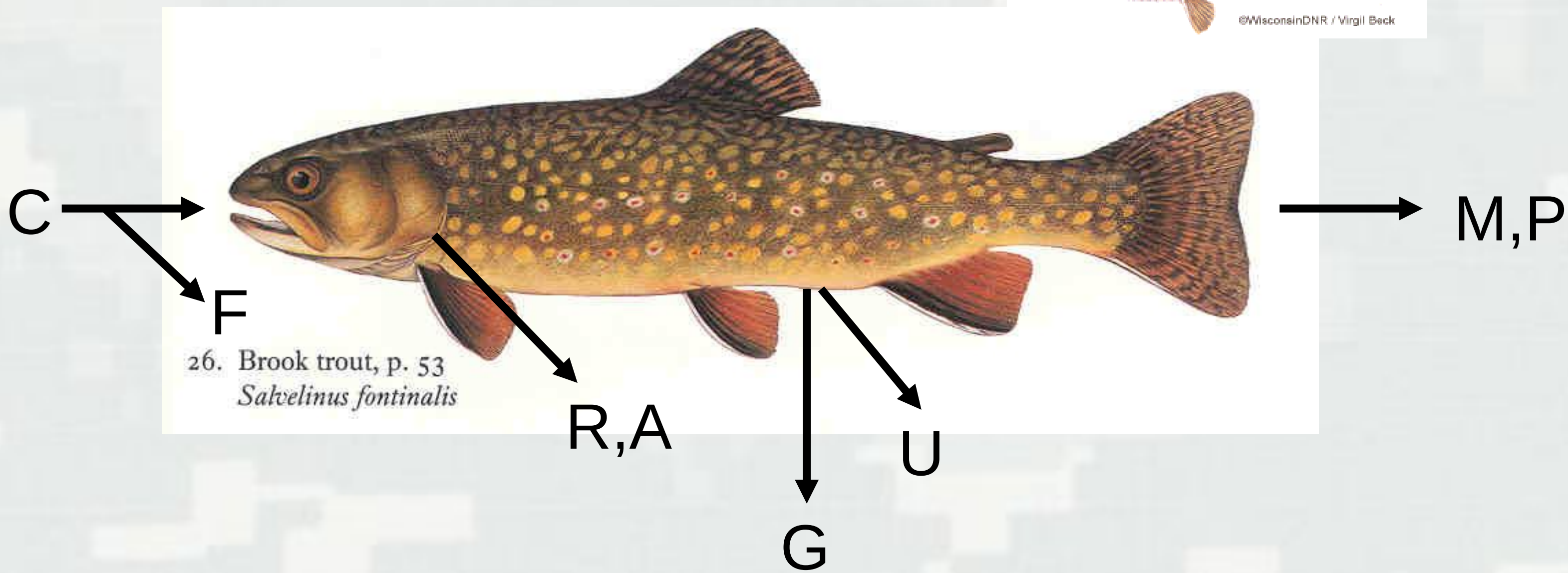
$dB_i/B_i dt = [Pm_i \{h(T)_i, f(I)_i, g(N)_i, hmod_i\} (1-Presp_i)] – Dresp_i – S_i – M_i – G_i - Sc_i$

where,

B_i	biomass of population i	gC/m^2
Pm_i	maximum photosynthesis rate	gC/gC/d
$h(T)_i$	temperature dependence	unitless
$f(I)_i$	light limitation	unitless
$g(N)_i$	nutrient limitation (N,P,Si)	unitless
$hmod_i$	habitat quality modifier	unitless
$Presp_i$	photorespiration	unitless
Drespi	dark respiration	gC/gC/d
S_i	sinking rate (phytoplankton)	$gC/m^2/d$
M_i	mortality rate	$gC/m^2/d$
G_i	loss to grazing	$gC/m^2/d$
Sc_i	physical scour (periphyton)	$gC/m^2/d$

Consumer Bioenergetics





$$\Delta B = C - F - (R + A) - U - G - M - P$$

Governing equation for consumer populations

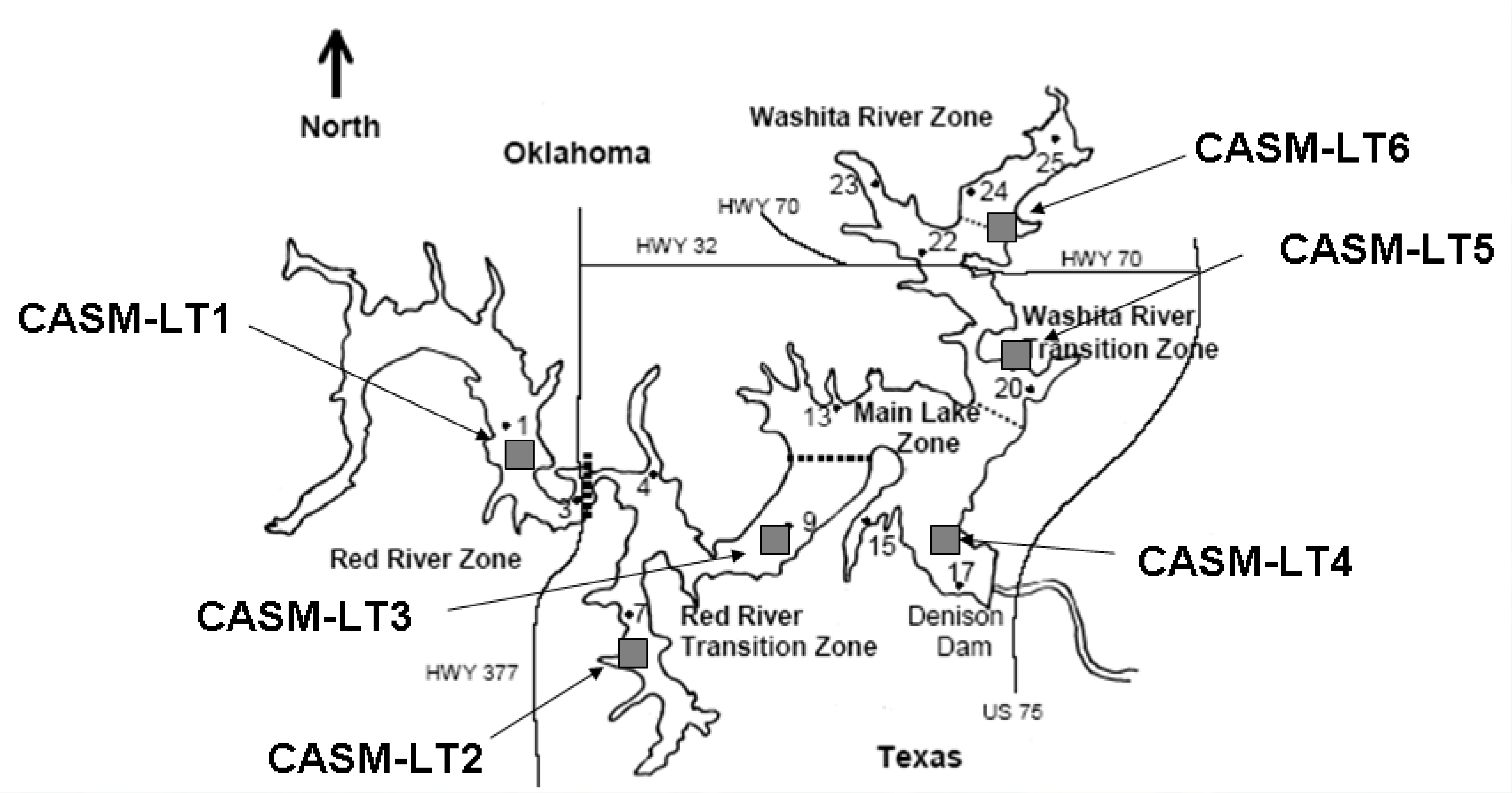
For population i,

$$dB_i/B_i dt = [Cm_i \{h(T)_i, hmod_i\} (1-F_i-A_i -U_i)] - Resp_i - M_i - G_i - P_i$$

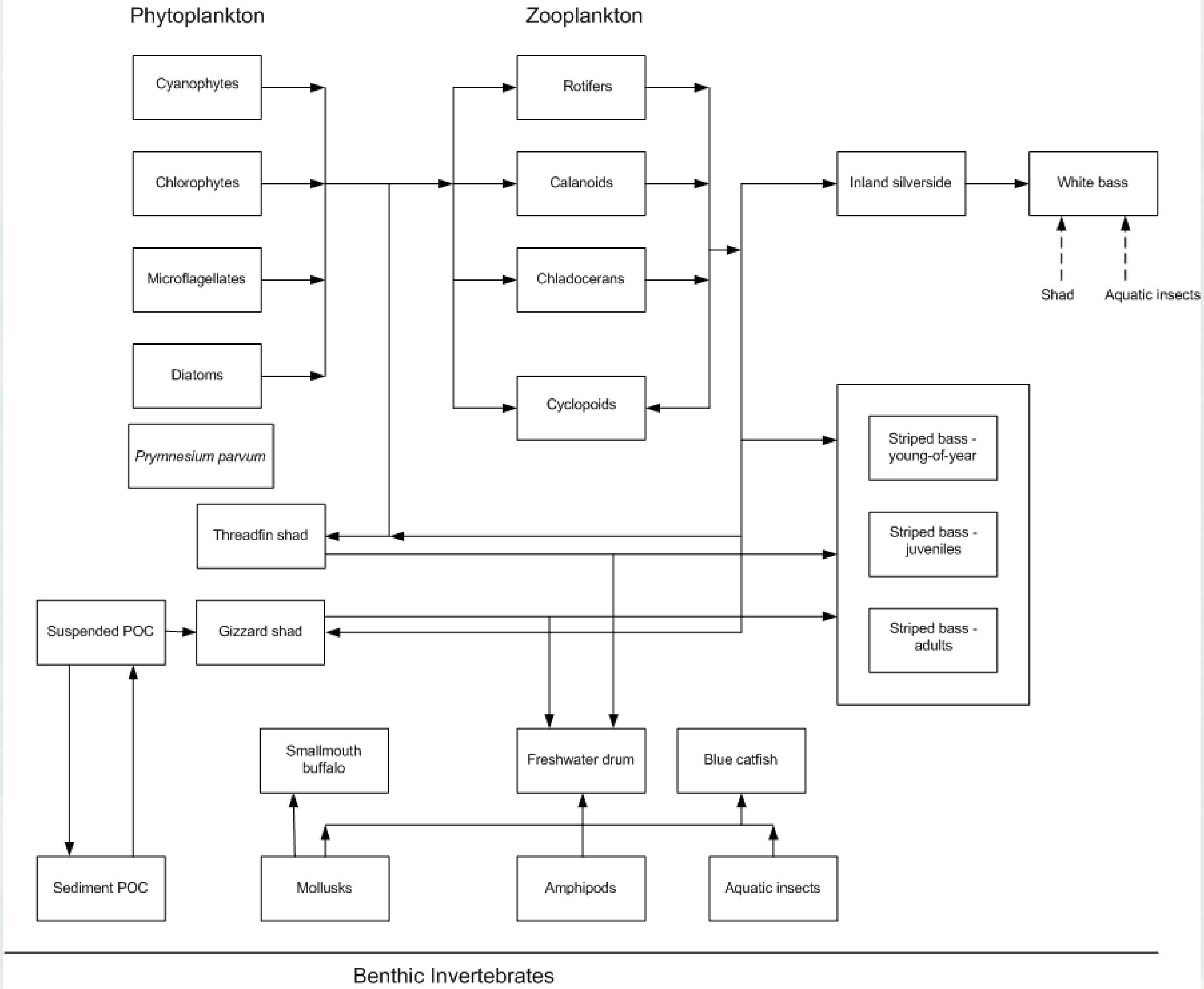
where,

B_i	biomass of population i	gC/m^2
Cm_i	maximum ingestion rate	gC/gC/d
$h(T)_i$	temperature dependence	unitless
$hmod_i$	habitat quality modifier	unitless
F_i	egestion	unitless
A_i	specific dynamic action	unitless
$Resp_i$	standard respiration	gC/gC/d
U_i	excretion rate	unitless
M_i	mortality rate	$gC/m^2/d$
G_i	gonad formation	$gC/m_2/d$
P_i	loss to predation	$gC/m^2/d$

Sampling locations and CASM stations used for model calibration



Lake Texoma food web structure for the Lake Texoma CASM



Comparison of modeled and measured light extinction, Secchi depth, and phytoplankton production

	Extinction coefficient (m^{-1})		
	Station 9	**Station 17**	**Station 24**
Clyde, 2004			
Mean	1.13	0.83	1.89
Minimum	0.82	0.54	1.11
Maximum	2.20	1.21	3.58
Lake Texoma CASM			
Mean	1.14	1.98	1.46
Minimum	0.49	0.48	0.40
Maximum	5.52	6.34	5.83

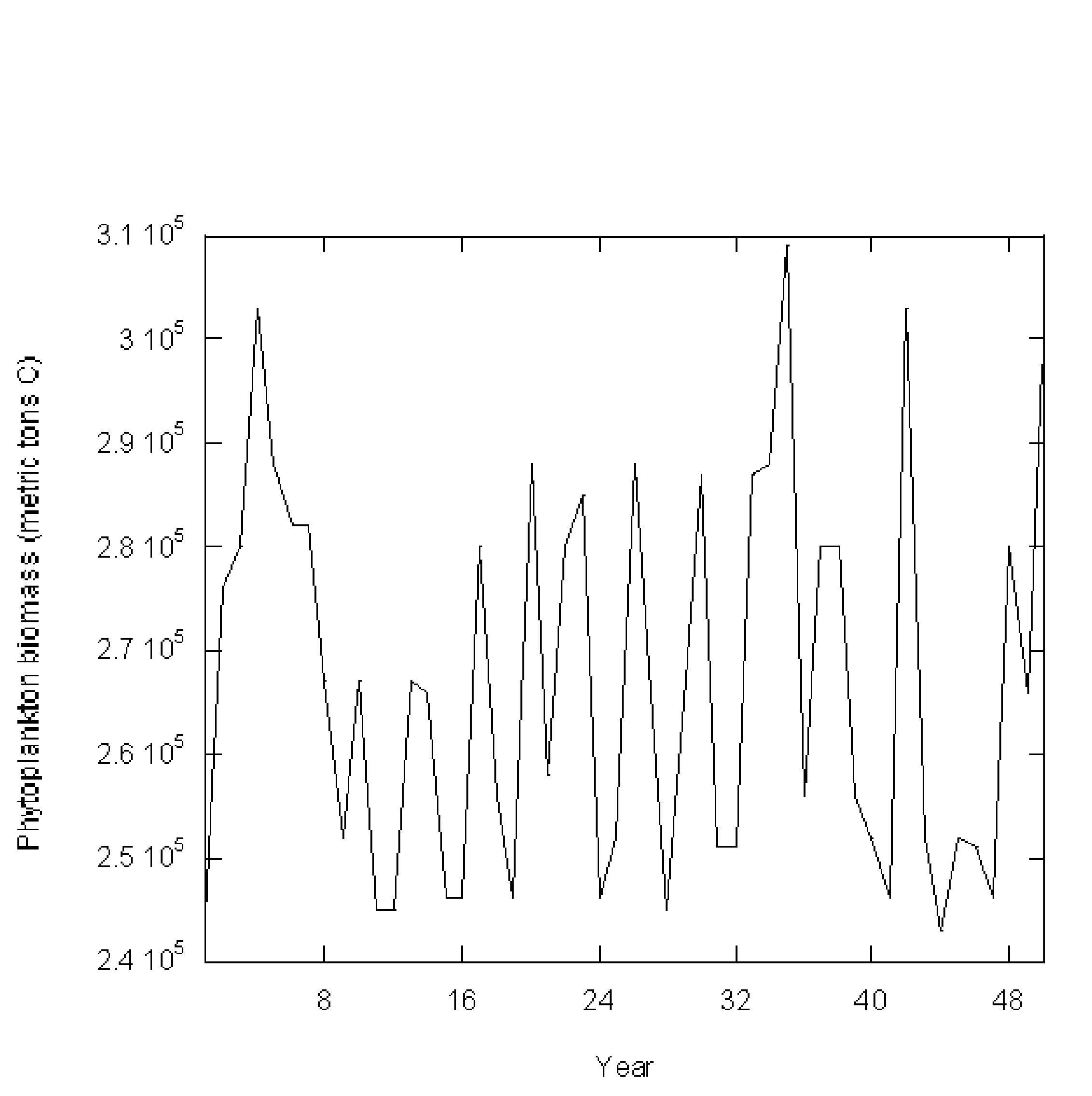
	Secchi depth (m)		
	Station 9	**Station 17**	**Station 24**
Clyde, 2004			
Mean	1.05	1.60	0.54
Minimum	0.45	0.65	0.15
Maximum	1.85	3.45	1.25
Lake Texoma CASM			
Mean	1.63	0.93	1.32
Minimum	0.30	0.26	0.28
Maximum	3.30	3.46	4.08

		Percent of total annual productivity[2]			
	Measured	82.9	6.7	2.6	4.4
	net annual				
Lake Texoma	**productivity[1]**	**cyanophytes**	**chlorophytes**	**diatoms**	**microflagellates**
Station	g-C/m²/y	g-C/m²/y	g-C/m²/y	g-C/m²/y	g-C/m²/y
3	326	270	22	8	14
1		296	21	6	9
9	285	236	19	7	13
9		1,125	11	4	30
17	267	221	18	7	12
17		424	35	5	21
22	308	255	21	8	14
24		317	6	4	8

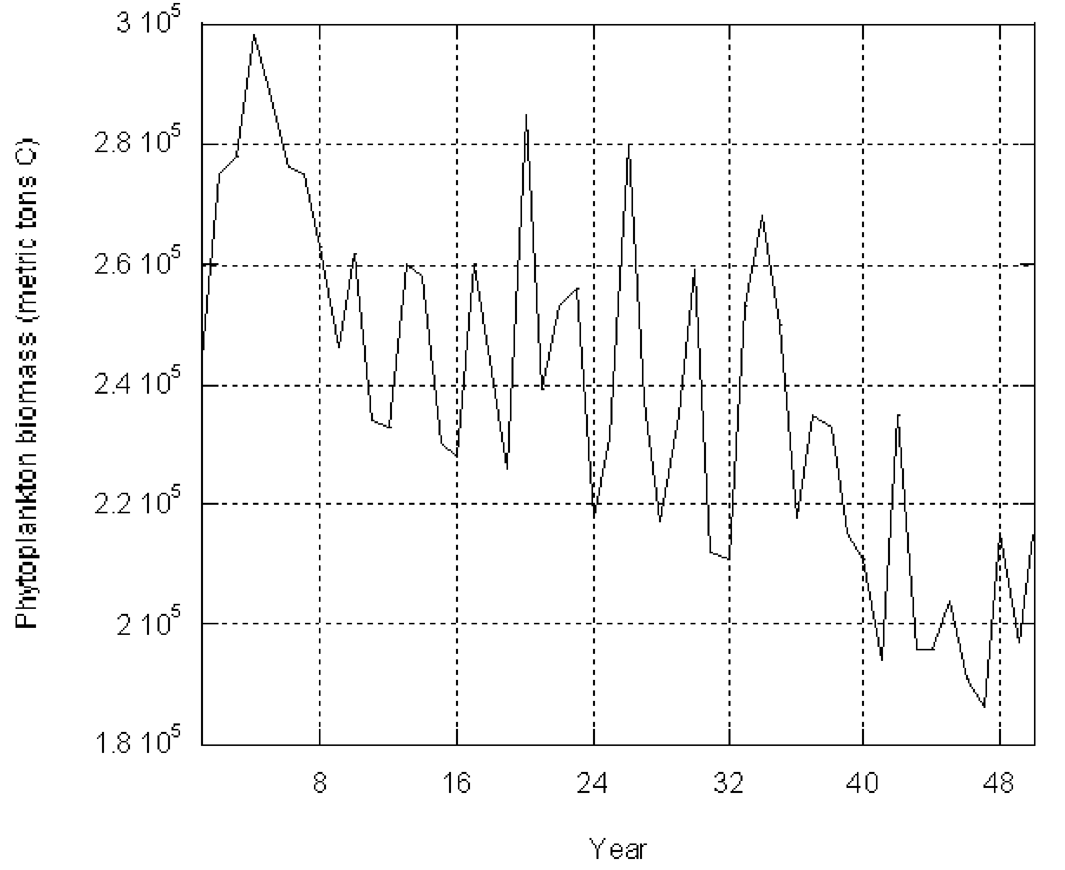
Future without-Project Results

- Annual environmental variability
- Annual environmental variability with sedimentation
  - 10,099 acre-feet/year (flood, conservation, inactive, and dead pools)
  - 6,885 acre-feet/year (conservation pool only)
- 50 year planning timeline
- Phytoplankton results
  - Biomass production range 186,000 to 298,000 metric tons C; mean 238,000 metric tons (12% variability)
- Striped Bass results
  - Biomass production range 13,200 to 21,600 metric tons C; mean 17,300 metric tons C (17.5% variability)

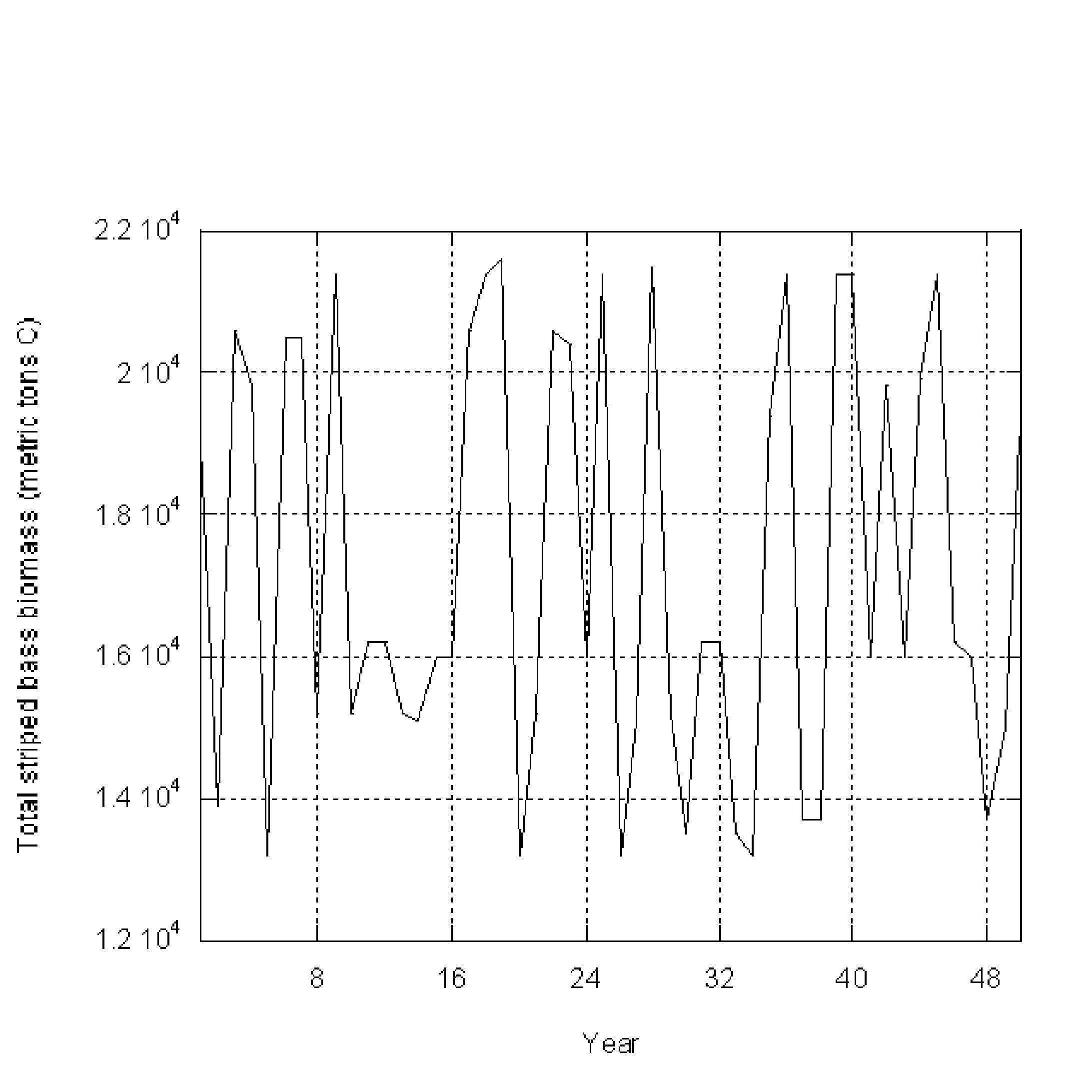
Effects of environmental variability on Lake Texoma phytoplankton population



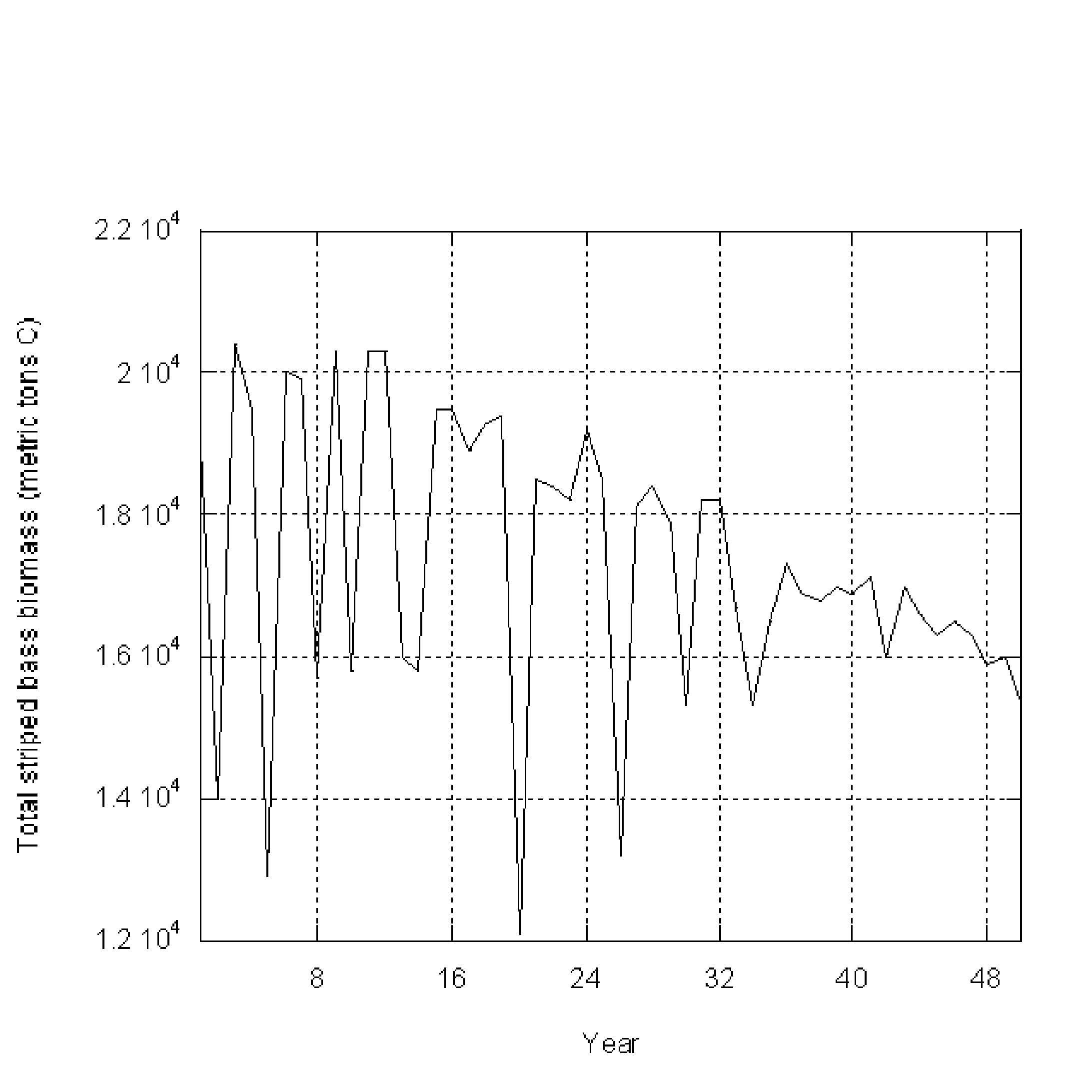
Effects of environmental variability and sedimentation on Lake Texoma phytoplankton population



Effects of environmental variability on Lake Texoma striped bass population



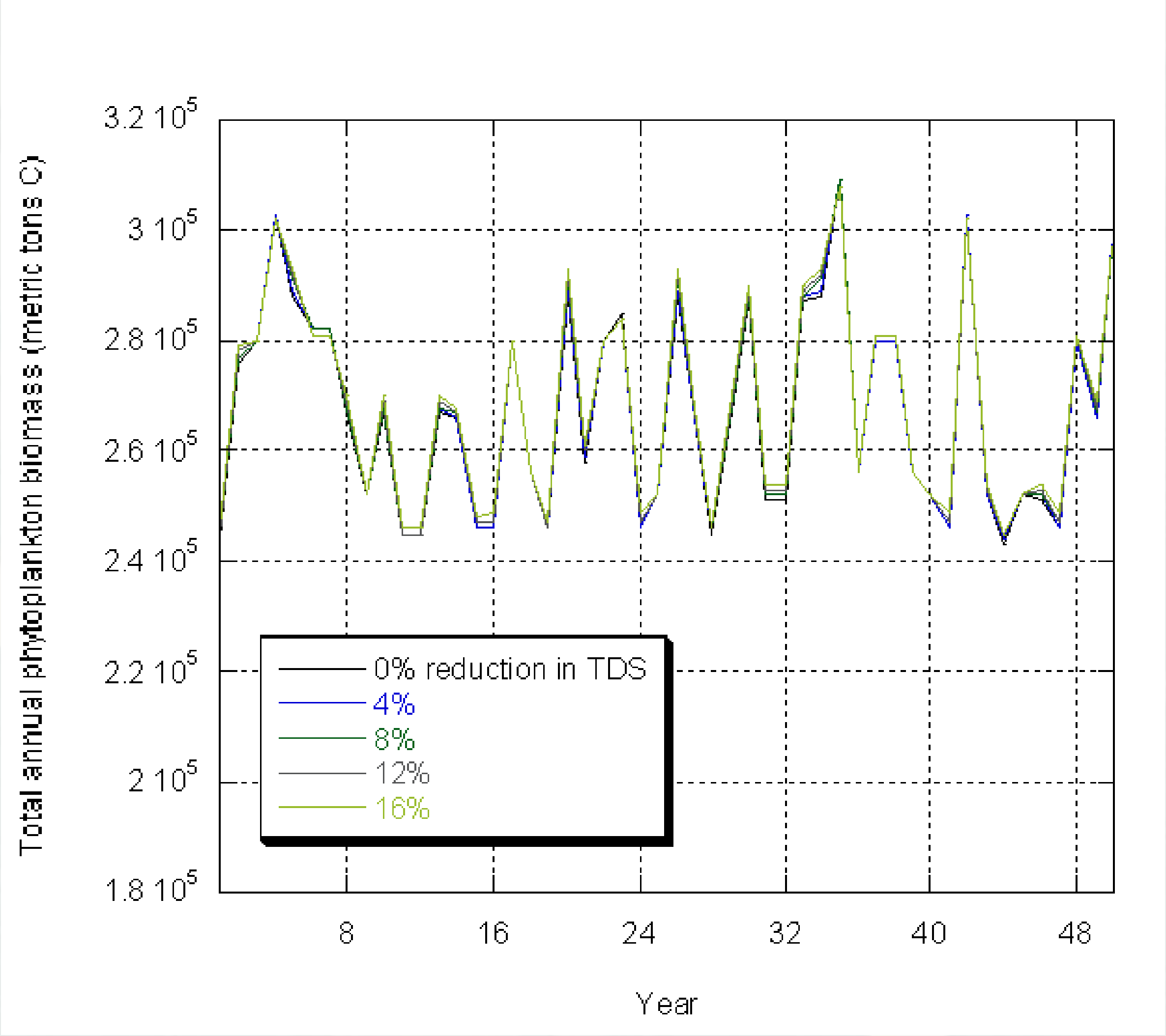
Effects of environmental variability and sedimentation on Lake Texoma striped bass population



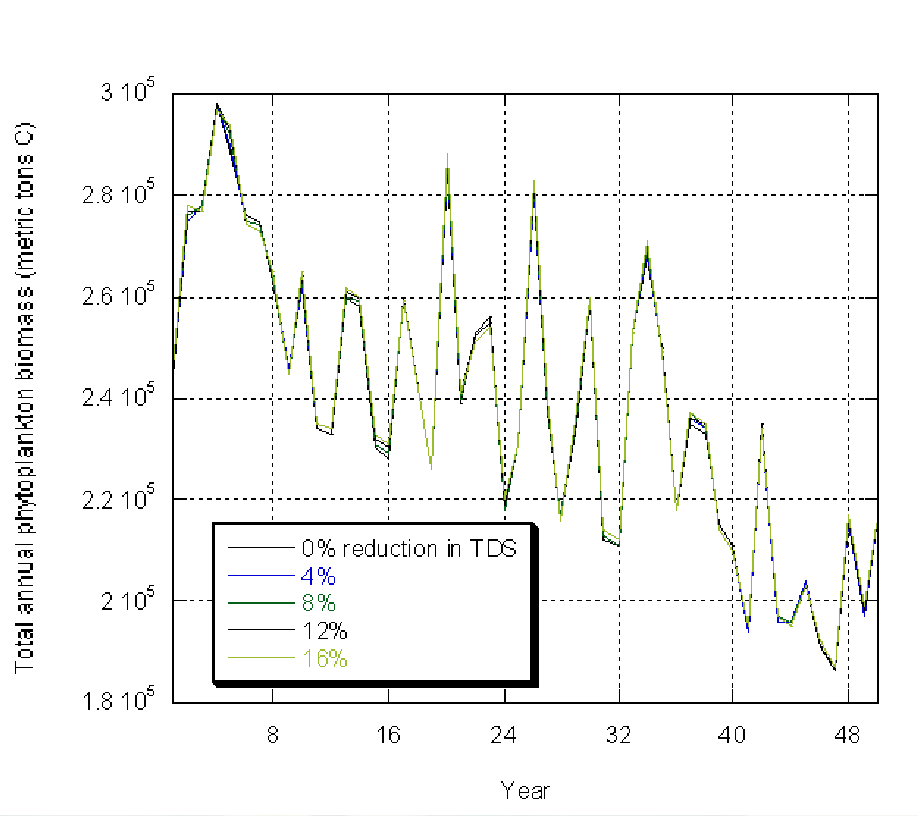
Future with-Project Results

- Primary project related potential impact is reduced settling rates of suspended solids
  - Decreased light penetration (water transparency)
  - Decreased primary productivity
  - Decreased sport fish biomass production
- Previous study by ERDC (Schroeder and Toro 1996)
  - ~85% of variance in sedimentation rate due to varying TDS concentrations; ~13% of variance due to initial turbidity
  - Initial turbidity values of 8 and 16 NTUs; settling rates were not significantly different between the two initial turbidity values
- Alternatives of 4%, 8%, 12%, and 16% TDS reductions simulated using CASM-LT
  - Target TDS reduction would be ~ 8%
- TDS exhibits strong spatial gradient in Lake Texoma
  - Dilution and advection

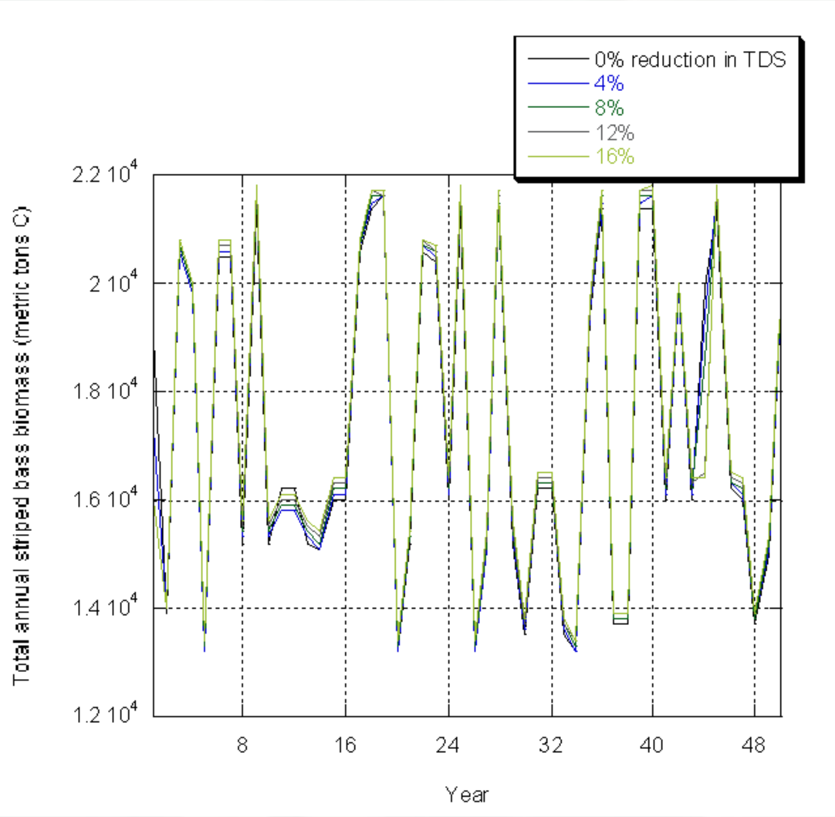
Effects of environmental variability and chloride alternatives on Lake Texoma phytoplankton population



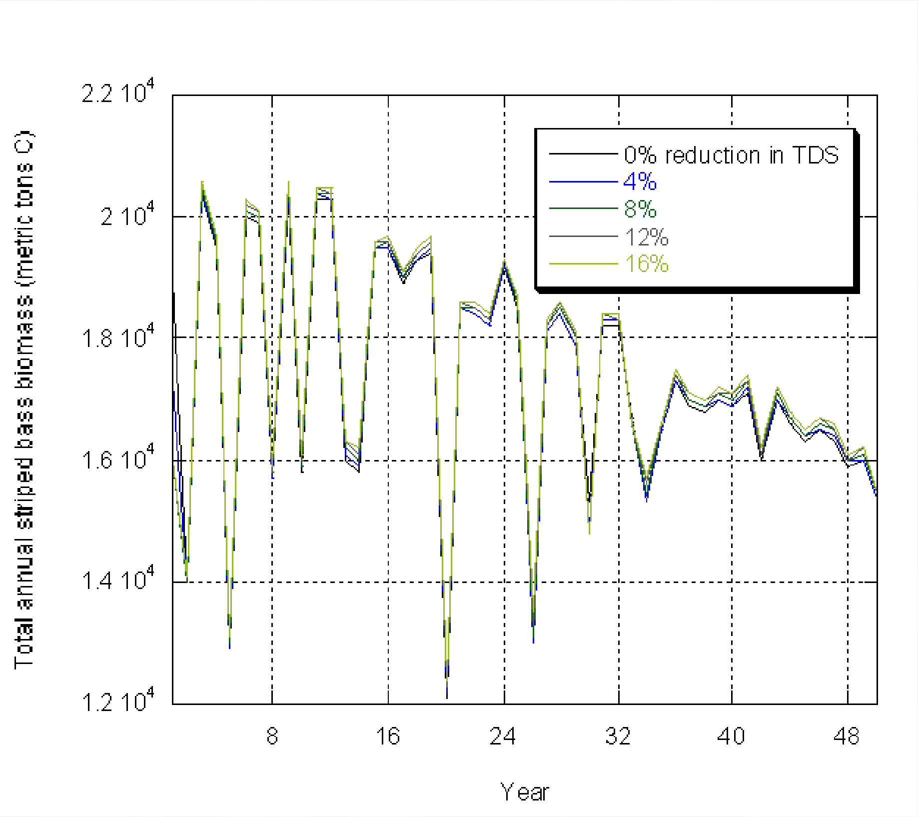
Effects of environmental variability, sedimentation, and chloride alternatives on Lake Texoma phytoplankton population



Effects of environmental variability and chloride alternatives on Lake Texoma striped bass population



Effects of environmental variability, sedimentation, and chloride alternatives on Lake Texoma striped bass population



Discussion – Future Direction

- Statistical vs. Ecological significance
  - What's the difference?
  - Does it matter?
- Continued development of *P. parvum* model parameters (completed 2011)
  - Currently qualitative requirements obtained from literature
  - Quantitative and toxicity data through collaboration with University of Oklahoma
- Zebra mussel populations in Lake Texoma (complete 2011)
  - Confirmed population in 2009
  - "New" existing condition not currently included in the CASM-LT
  - Requires site specific bioenergetic components
    - Will initially incorporate regional data
  - Filtering efficiencies could present a more serious impact than chloride management activities to primary productivity
    - Changes in light saturation relative to ambient light; impacts to primary productivity?
- How good is good enough?
  - Direct link of a physical model to Lake Texoma (ADH?)
  - Constant desire for more data
    - Needs versus wants
    - Costs versus benefits

Environmental Issues in the 21st Century

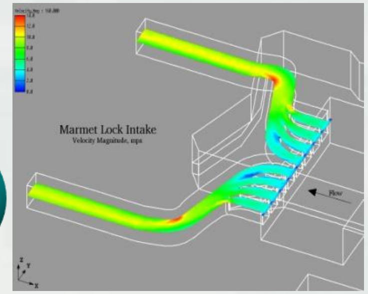
- Environmental/Water resource issues becoming more complex
- Require holistic approaches to understand system
- Coupled hydrodynamic-ecological models
  - Links fine scale hydrodynamics to ecological systems (e.g., food webs, fish behaviors, etc.)

Benefits of coupled Eco-Hydro approaches

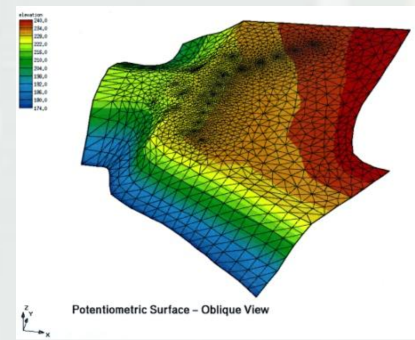
- Dynamic feedback between constituent transport and biota (uptake and nutrient cycling)
- Spatially-explicit
- Embraces temporal variability of flow, water quality and ecosystem dynamics

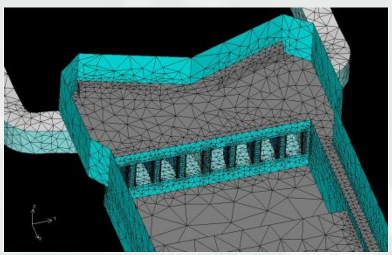
Adaptive Hydraulics Overview

Navier-Stokes Equations

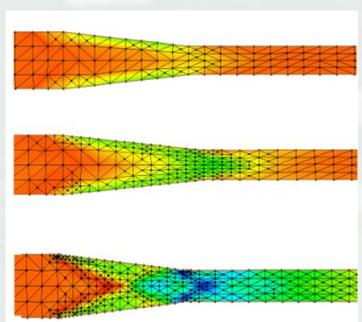


Unsaturated Groundwater Equations

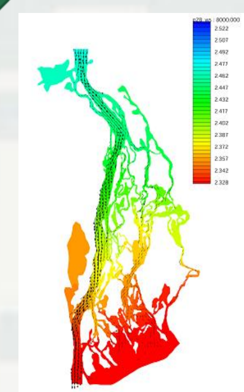




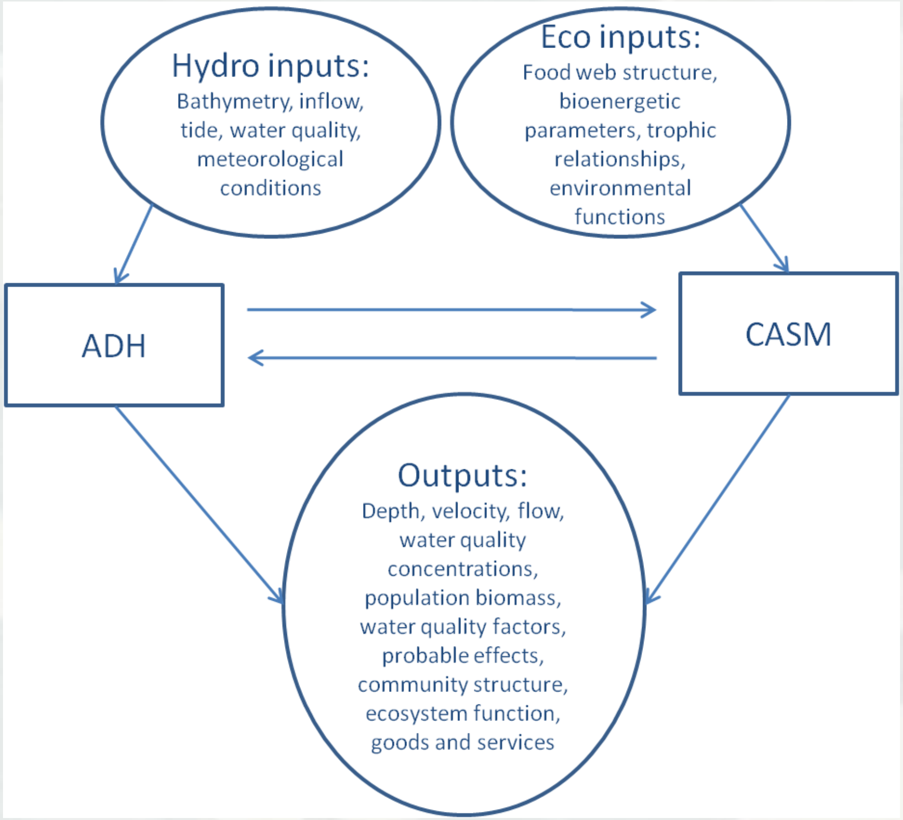
Computational Engine
(FE utilities, preconditioners, solvers, I/O to xMS GUIs)



Shallow Water Equations



ADH-CASM Linkage



ADH-CASM Outputs

Hydrology
- velocity
- depth, elevation
- salinity

Geomorphology
- sediment transport, deposition
- substrate variability
- channel structure

Biogeochemistry
- dissolved oxygen
- DIN, DIP, DOC
- particulate carbon, TSS
- water clarity

Habitat
- physical-chemical characteristics
- biological (e.g., SAV, emergents)

Biota
- phytoplankton
- periphyton
- SAV
- emergent aquatic plants
- zooplankton
- benthic invertebrates
- omnivorous fish
- piscivorous fish

Chesapeake Bay Oysters

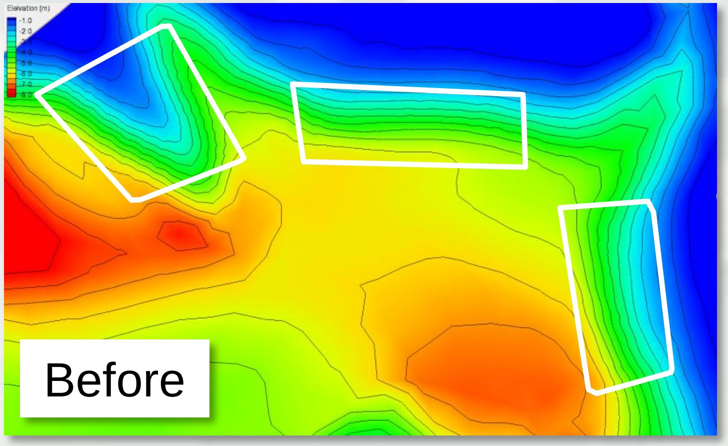
- Oyster populations at 1% of historic levels
- Oyster fishery is $100+ million/annually
- Oyster reefs provide tremendous environmental benefits (water quality, biodiversity, storm protection, etc)
- Different viewpoints on how to restore oysters and maintain fishery

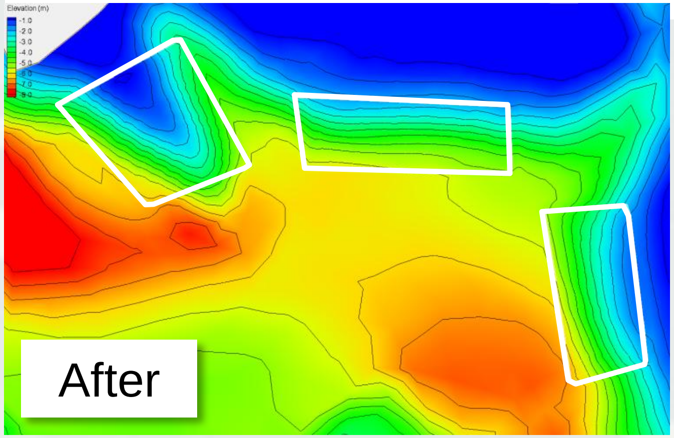
Brief History of the Great Wicomico River Oyster Restoration

- 2004: 9 reefs were restored with additions of shell and spat-on-shell
- Reefs were restored as low- and high-relief reefs
- Subtle changes in bathymetry, even with high-relief reefs (see below)
- Oysters density was ~5x greater on high-relief reefs

Susan Conner and Dave Schulte – USACE-Norfolk

Science Magazine 31 July 2009



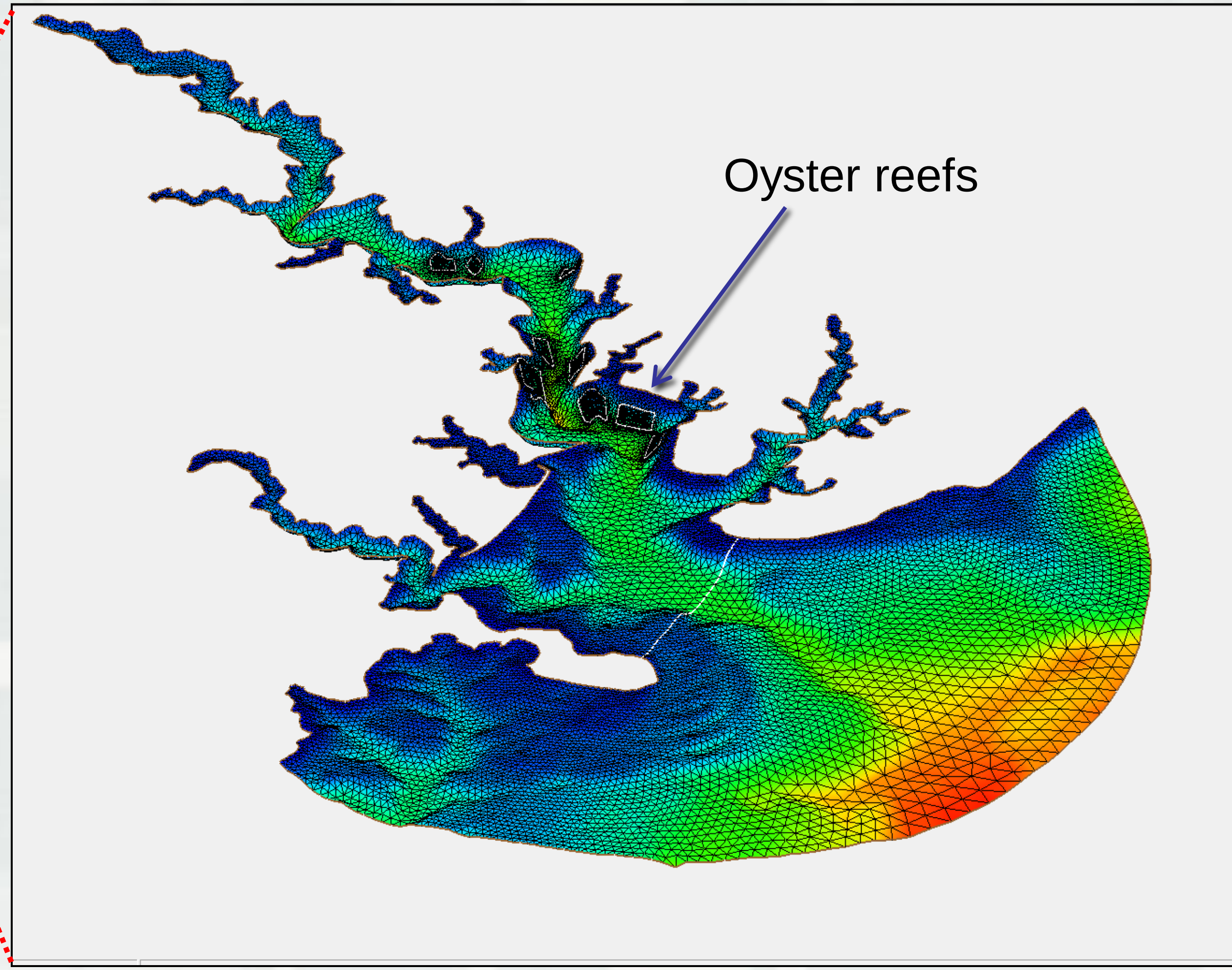


What effect do oysters have on the water quality in the vicinity of the reef?

- Modeling scenarios
  - pre-construction (no structure + no function)
  - reefs (structure + no function)
  - reefs + CASM (structure + function)

Bivalve and Flow

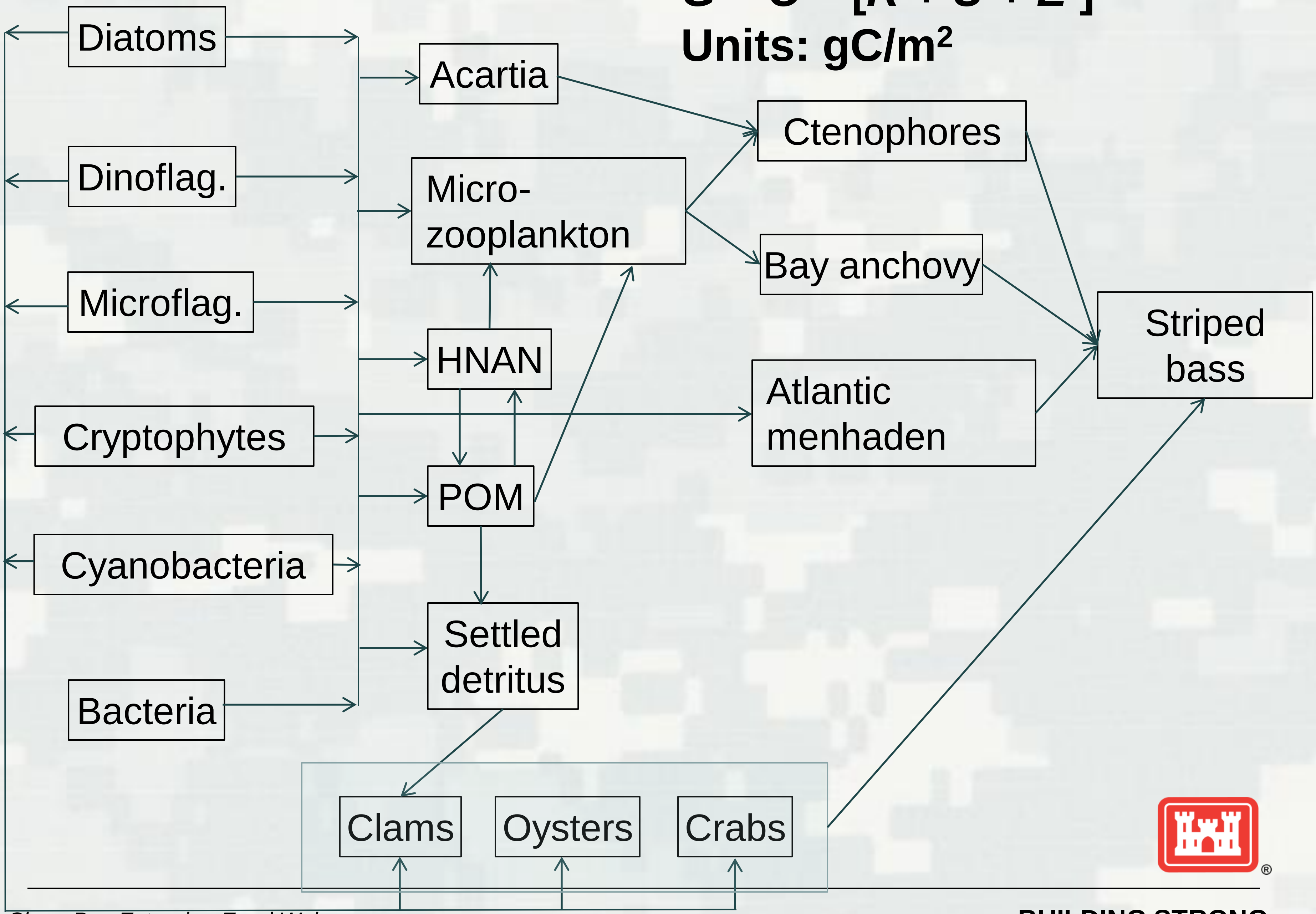
Great Wicomico River ADH mesh



BUILDING STRONG®

$G = C - [R + U + E]$

Units: gC/m²



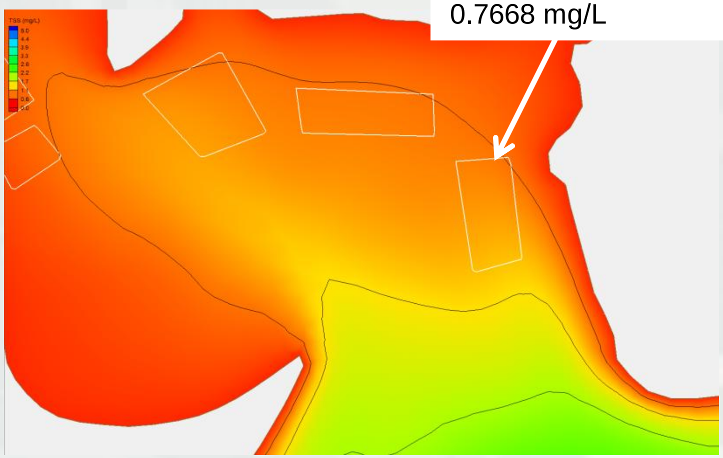
Ches. Bay Estuarine Food Web
Bartell et al 2003

Results

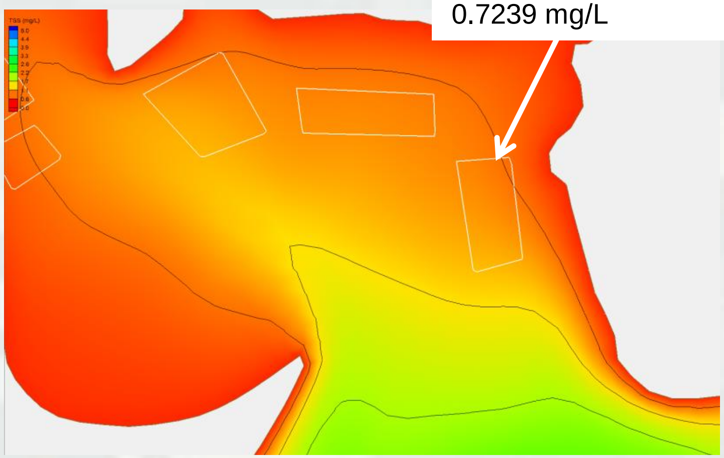
TSS Reduction - filtration

- No CASM
- With CASM

Avg. TSS day 160:
0.7668 mg/L



Avg. TSS day 160:
0.7239 mg/L



~5.6% reduction in TSS

Discussion

- Coupling models result in direct benefits out (e.g., TSS reductions and nutrient uptake)

- Captures critically system processes, such as feedback loops and interspecies dynamics

Other uses for coupled modeling

- Ecosystem services
- How management affects multiple levels of trophic structure (e.g., salmonids to plankton)
- Examine future conditions (SLC, ocean acidification)
- Addresses issues across scales

Benefits

- Holistic approach
  - ► System dynamics for ecosystem restoration, sea level change, water chemistry
- Food web can be developed for any system
  - ► Data intensive, but can use surrogates to identify future research needs

Management implications

- Scenario analysis for multiple management strategies (rotational harvest, sanctuary, etc), hydrologic scenarios and/or climatic regimes
- Can develop system-level risk assessments
- Provides mechanism for visualizing dynamic feedback loops

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