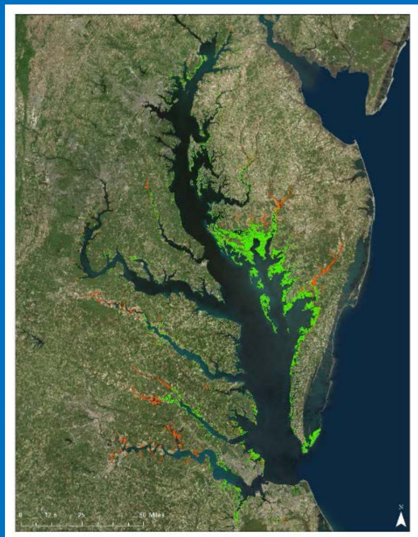
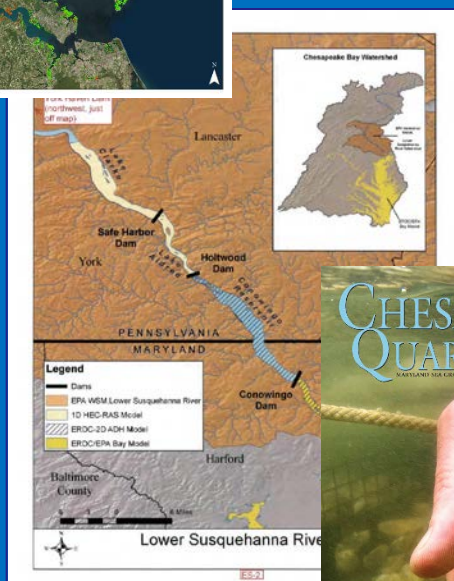
The 2017 Model





- The same grid and formulations as the 2010 model.
- Phase 6 Watershed Model.
- Extension of application to 2014.
- Emphasis on novel nutrient sources and sinks, shallow water processes.
- To be used in a 2017 Midpoint Assessment of progress towards the 2010 TMDL.

Extend Model Application Period to 2011

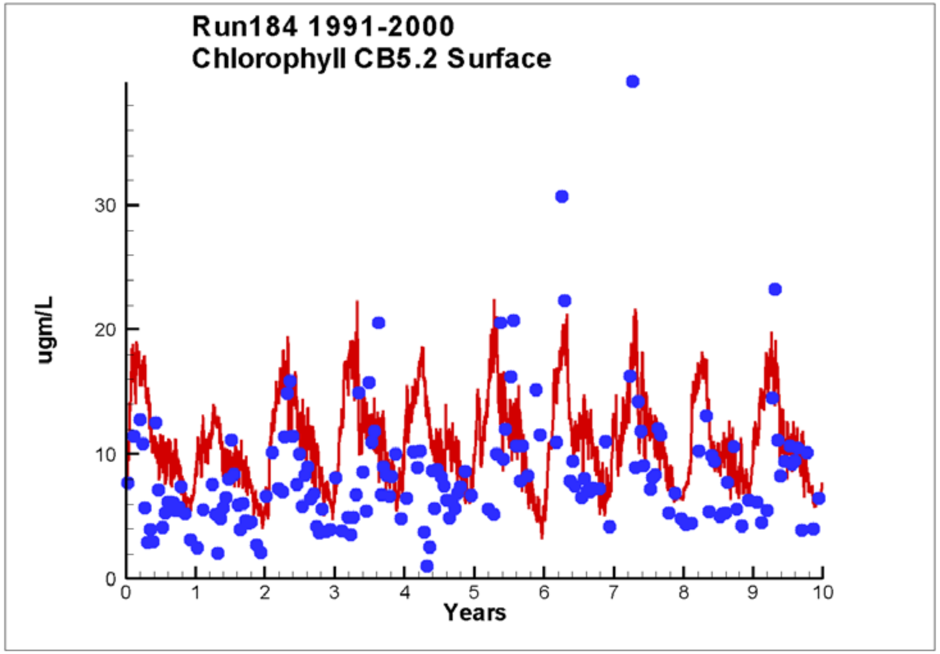
- We're extending the model application period to 2011 (maybe farther).
- Motivations:
  - Include Shallow-Water Monitoring program which started 2005.
  - Incorporate more recent observations and loads.
- Our previous application period ended at 2005 with focus period 1991-2000.
  - The TMDL emphasizes 1993-1995.
  - Many process-based observations in this period (e.g. SONE, primary production).

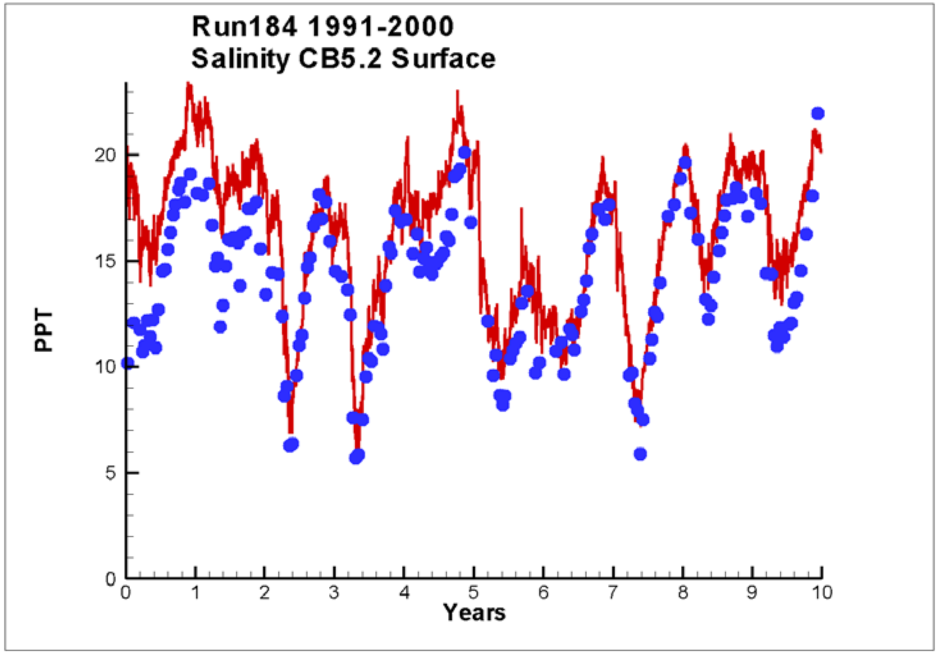
Extend Model Application Period to 2011

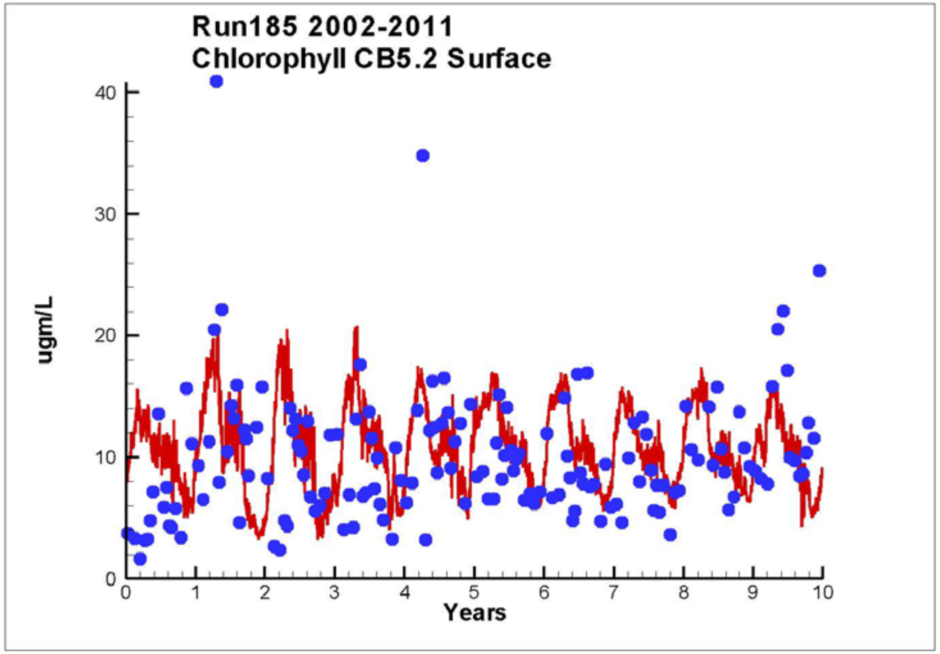
- Develop a second focus period, 2002-2011.
- At present, we are treating the two periods as a classic sequence of calibration, 1991-2000, and verification, 2002-2011.

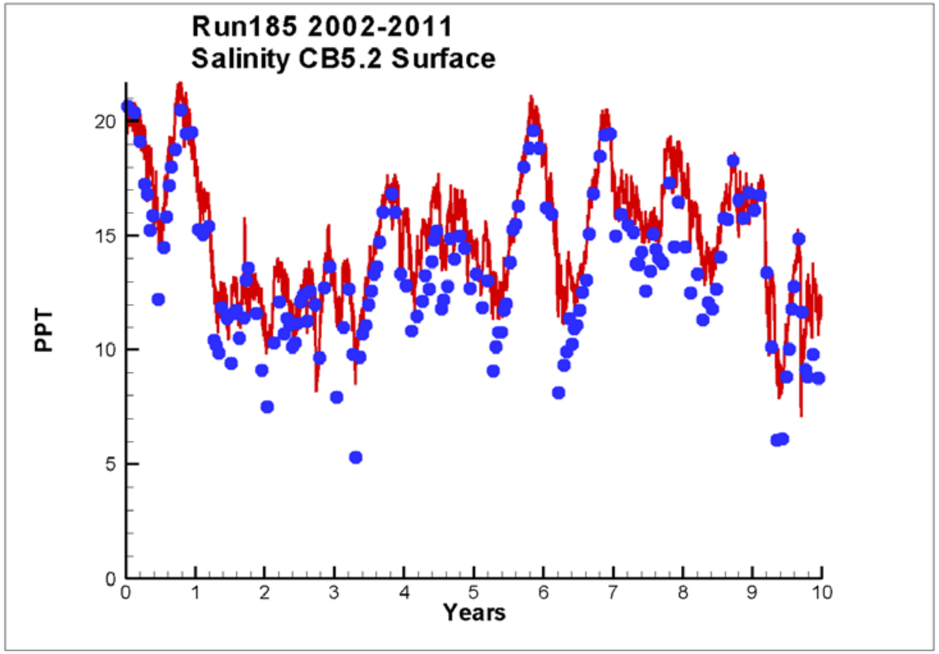
Link to Phase 6 Watershed Model

- The present model takes loads from Phase 6 Beta 4 version of the WSM.
- The 2010 model was driven by Phase 5.3.2 of the WSM.
- The present calibration is not optimal and will be revisited following delivery of final loads (June 1, 2017).
- We anticipate no significant changes in model formulation. Parameter values and calibration status will change.


Run184 1991-2000
Chlorophyll CB5.2 Surface
ugm/L
Years
0 10 20 30
0 1 2 3 4 5 6 7 8 9 10


Run184 1991-2000
Salinity CB5.2 Surface
PPT
Years
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10

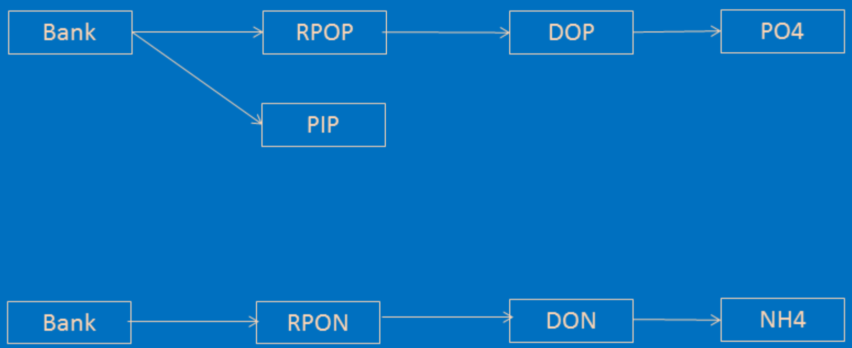

Run185 2002-2011
Chlorophyll CB5.2 Surface
ugm/L
Years
0 10 20 30 40
0 1 2 3 4 5 6 7 8 9 10


Run185 2002-2011
Salinity CB5.2 Surface
PPT
Years
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10

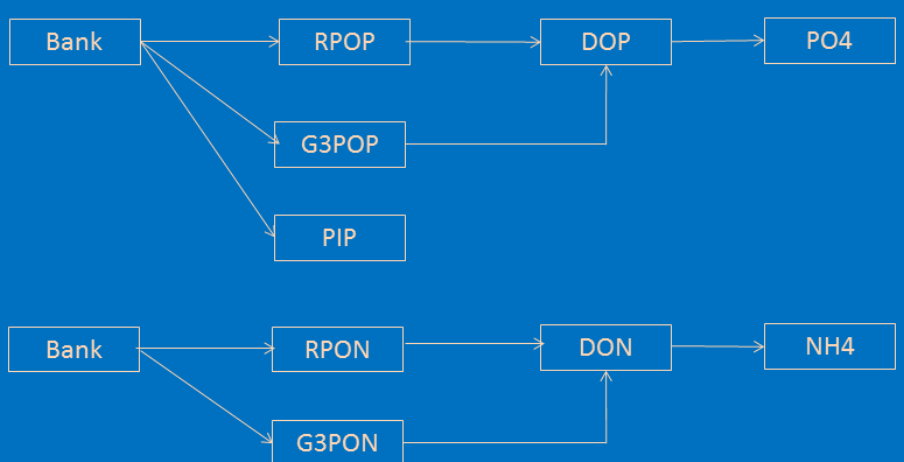
Explicit Representation of G3 Organic Matter in Water Column

- Since 1988, we have had two classes of reactive material in the water column, labile and refractory, but three classes of reactive material in the sediments, G1, G2, G3.
- Refractory material was split into G2 and G3 when deposited in the sediments.
- We had the ability to vary the splits by location e.g. near a fall-line vs. open water.
- Now we need to specify composition of various sources e.g. shoreline loads vs. phytoplankton.

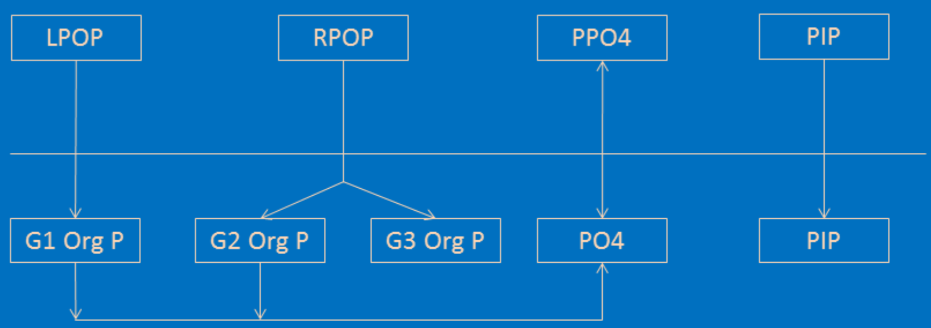
Initial Routing of Bank Nutrient Loads to Water Column



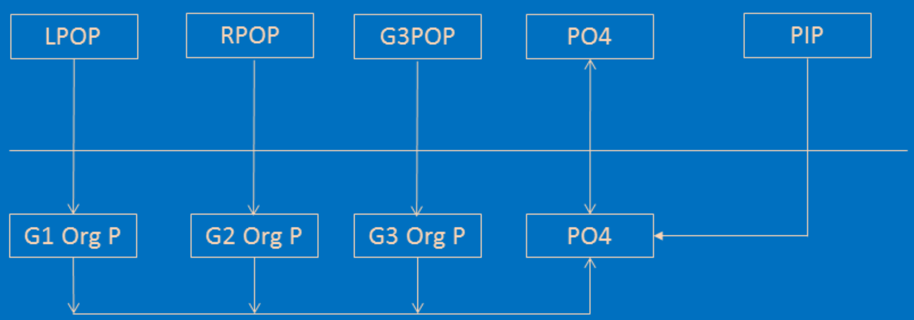
Revised Routing of Bank Nutrient Loads to Water Column



Former Routing of Water Column P to Sediments

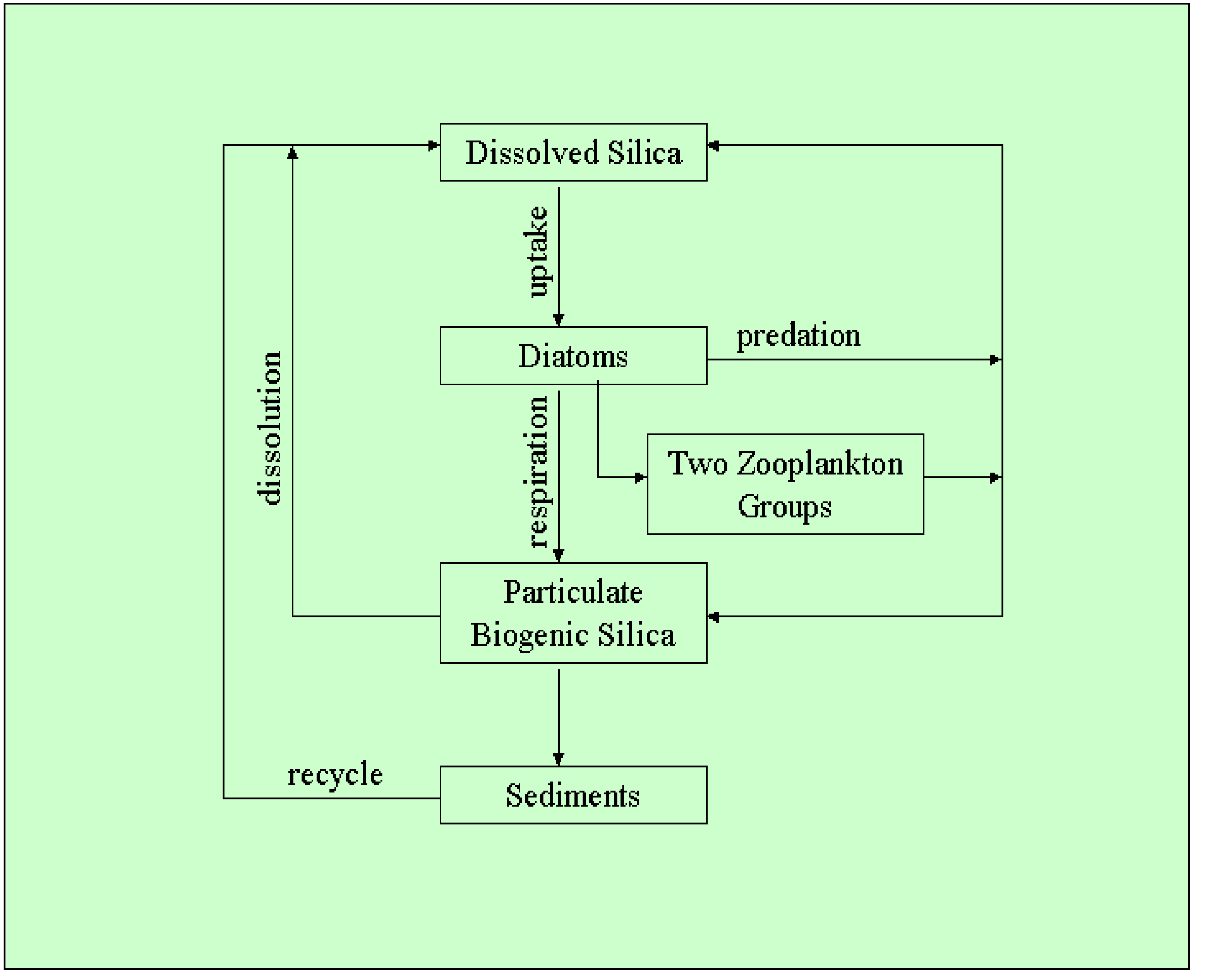


Revised Routing of Water Column P to Sediments



Deletion of State Variables

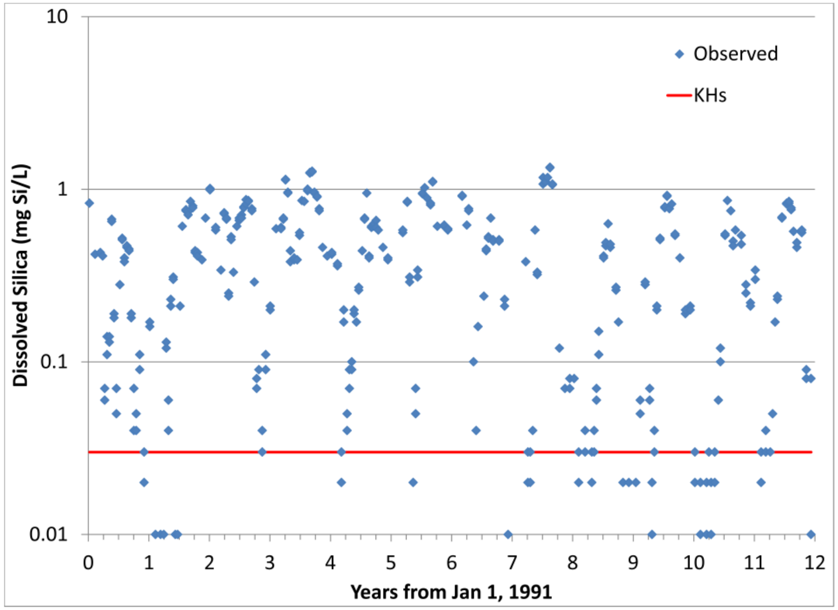
1. The model was framed in 1987-1988.
2. Since then numerous features have been added during multiple phases with various emphases.
3. Features that are no longer necessary or were unsuccessful tend to hang on.
4. There is potential danger when we operate with features we seldom or never examine.



Circa 1987 we were advised to include silica in the model as a potential limiting nutrient during the spring bloom. It was coded in the model of the water column and bed sediments.

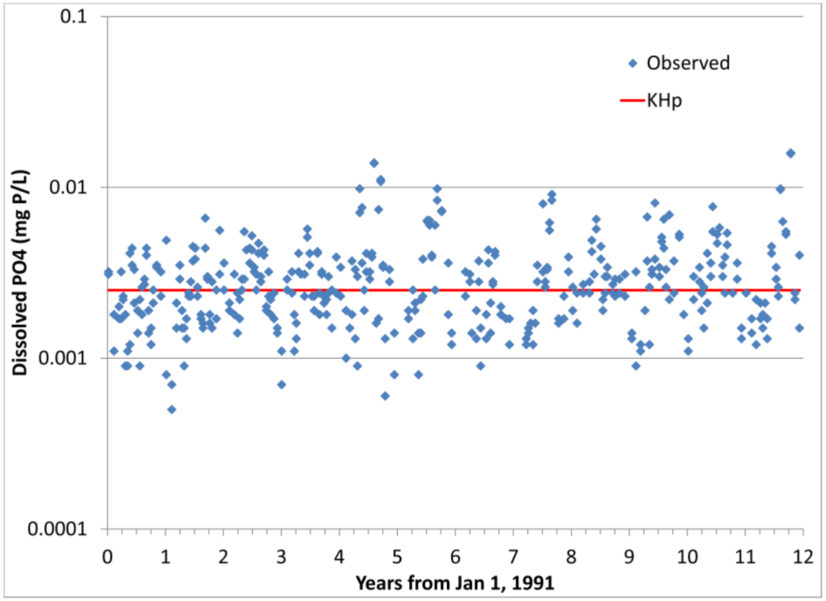
Problems with Silica

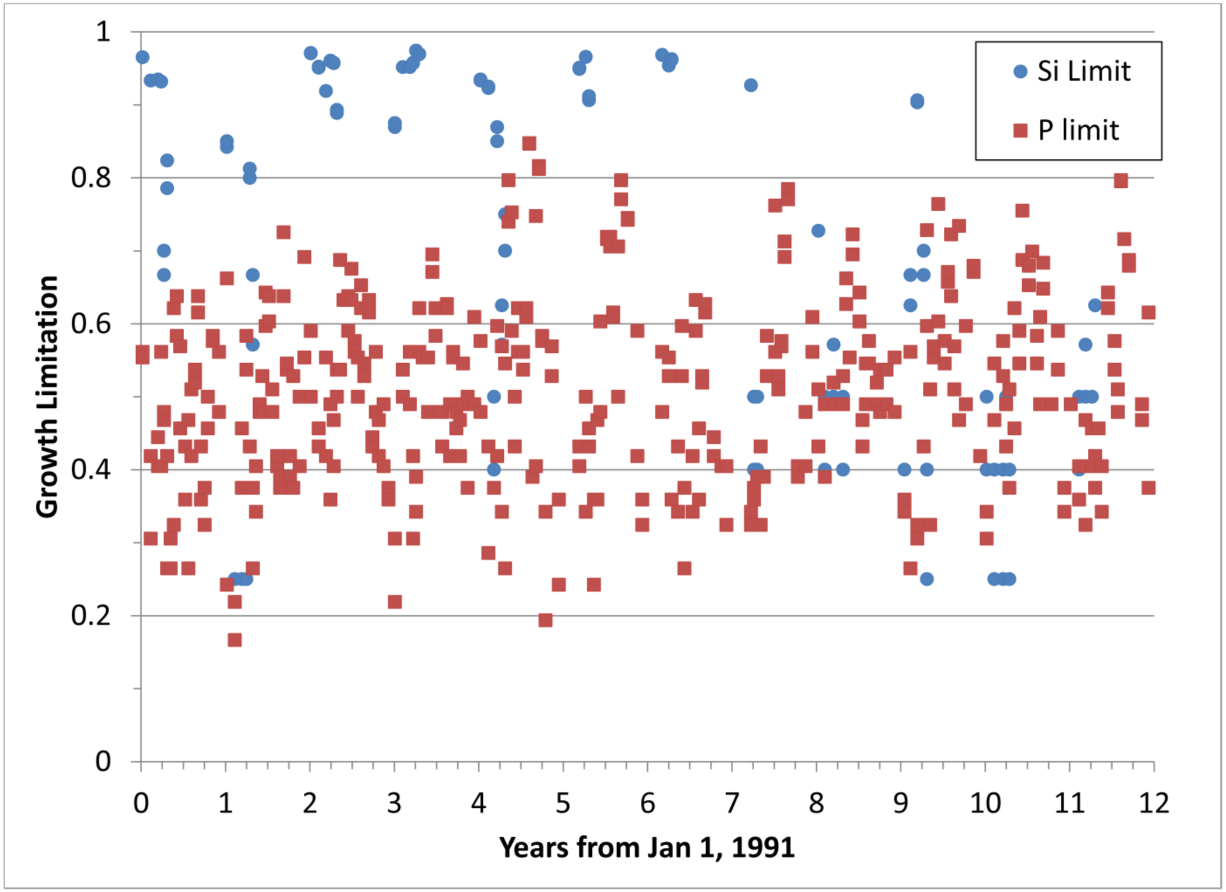
1. We have limited observations from which to calculate particulate biogenic silica load.
2. We have limited observations to calibrate and verify particulate biogenic silica in the water column.
3. For 2002-2011 dissolved silica observations for loads and boundary conditions are sporadic.
4. Only the spring diatom group utilizes silica. We have to incorporate model parameterizations to approximate silica for the rest of the year.
5. Is it worth it?



At station CB5.2, 31% of dissolved silica observations (Jan – Apr) are <= to model KHs.

At station CB5.2, 74% of dissolved PO4 observations (Jan – Apr) are <= to model KHs.

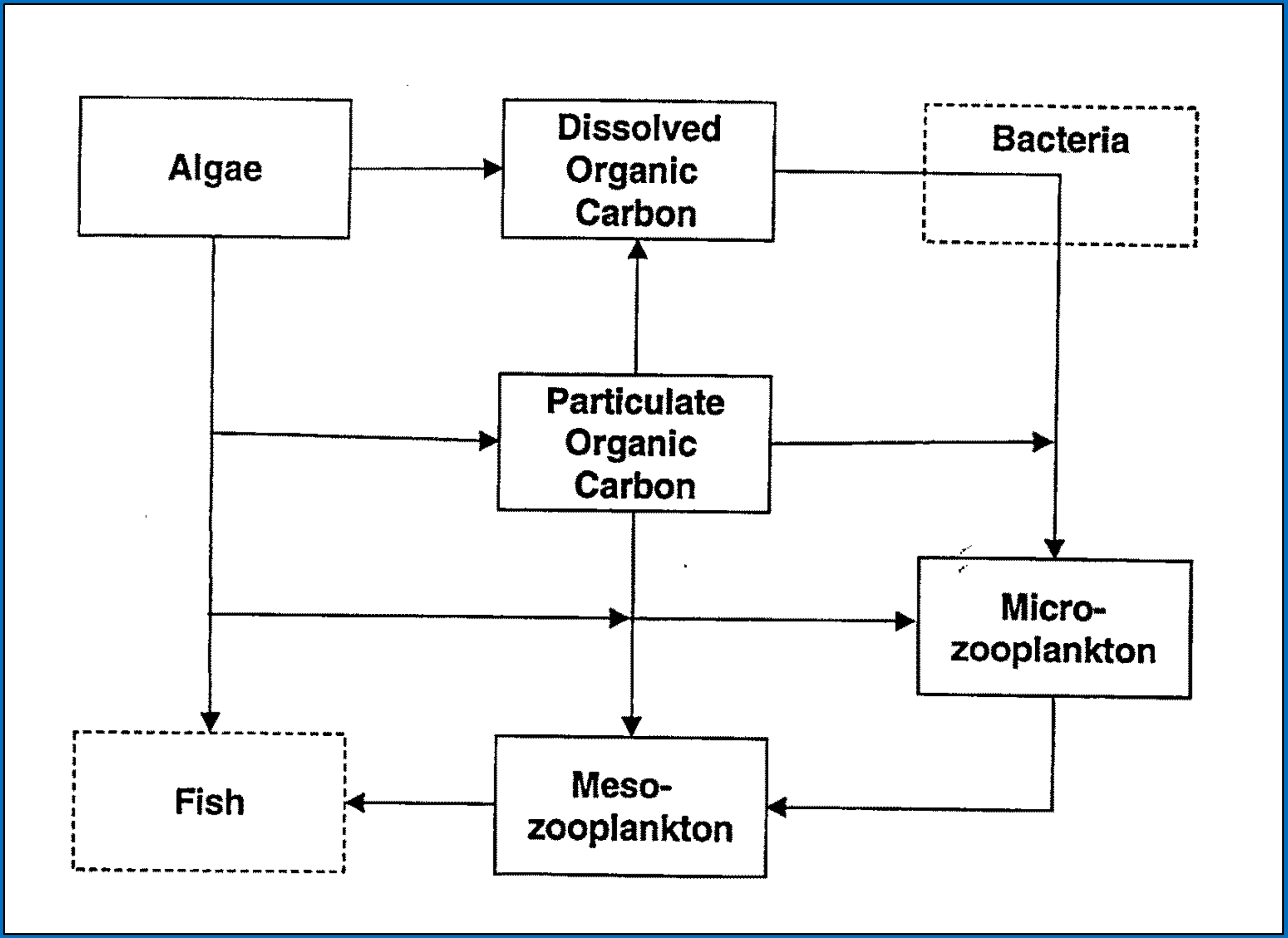




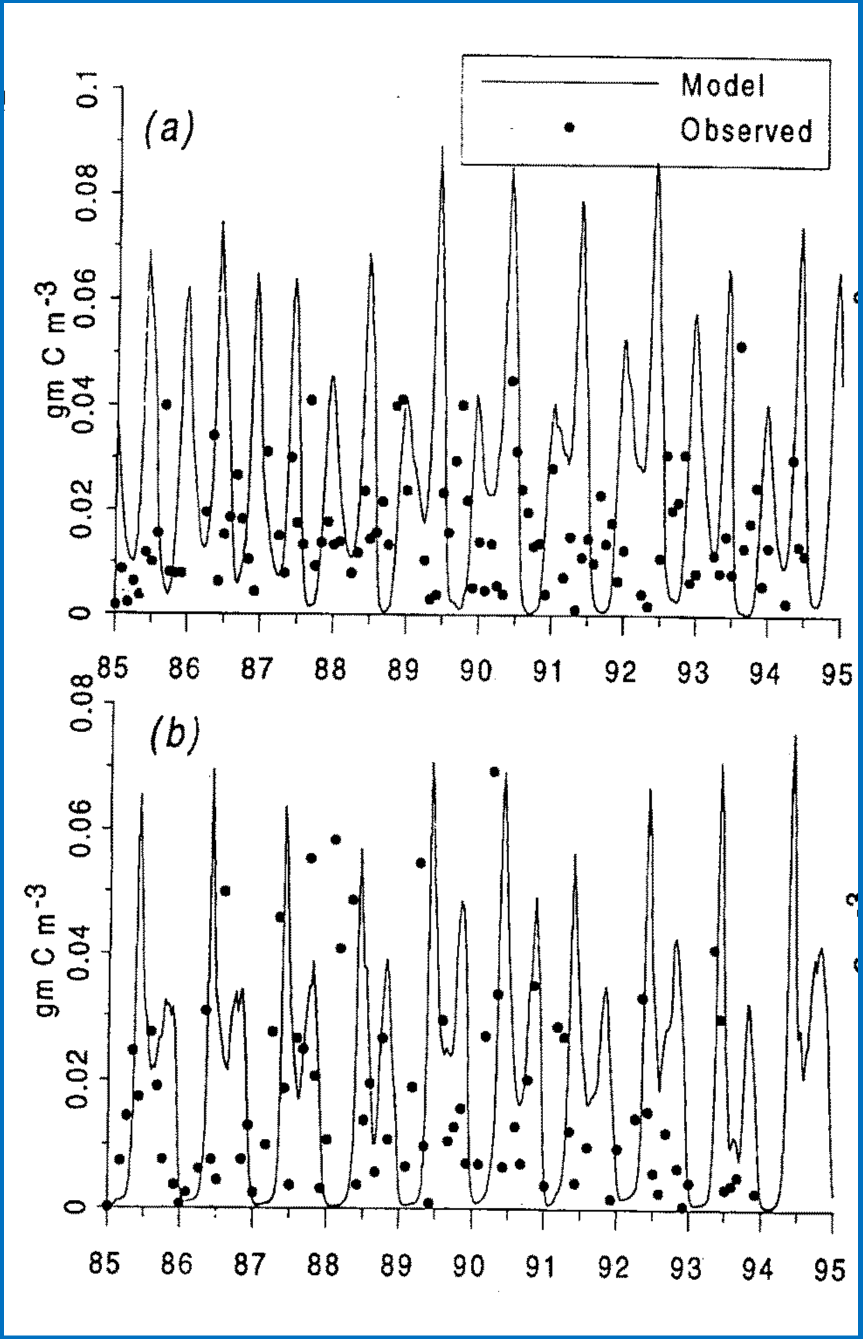
When silica is limiting, phosphorus tends to be more limiting or at least as limiting. Silica adds nothing to the model. Let's eliminate it.

Zooplankton

- Zooplankton were added circa 2000 during the Virginia Tributary Refinements phase.
- The zooplankton framework was determined during a series of workshops preceding this study phase.
- One motivation was an interest in direct computation of living resources e.g. SAV, zooplankton, benthos.
- A second motivation was to improve phytoplankton dynamics by improving predation terms.



- New state variables are microzooplankton and mesozooplankton.
- Problems are presented by the absence of bacteria and by the need to parameterize predation on mesozooplankton.



We get credible computations!

Time series of (a) predicted and observed microzooplankton biomass; (b) predicted and observed mesozooplankton biomass in segment CB5. Microzooplankton are from above the pycnocline; mesozooplankton are depth-averaged values.

Algal sources and sinks in the conservation equation include production, metabolism, predation, and settling. These are expressed

$$\frac{\delta}{\delta t} B = \left(G - BM - Wa \cdot \frac{\delta}{\delta z} \right) B - PR \qquad (2)$$

B = algal biomass, expressed as carbon (g C m^{-3})
G = growth (d^{-1})
BM = basal metabolism (d^{-1})
Wa = algal settling velocity (m d^{-1})
PR = predation (g C m^{-3} d^{-1})
z = vertical coordinate

The final representation of predation, including zooplankton, is:

$$PR = \frac{B}{KHsz + B} \times RMsz \times SZ + \frac{B}{KHlz + B} \times RMlz \times LZ + Phtl \times B^2 \qquad (14)$$

RMsz = microzooplankton maximum ration (g algal C g^{-1} zoo C d^{-1})
SZ = microzooplankton biomass (g C m^{-3})
KHsz = half saturation concentration for carbon uptake by microzooplankton (g C m^{-3})
RMlz = mesozooplankton maximum ration (g algal C g^{-1} zoo C d^{-1})
LZ = mesozooplankton biomass (g C m^{-3})
KHlz = half saturation concentration for carbon uptake by mesozooplankton (g C m^{-3})
Phtl = rate of predation by other planktivores (m^3 g^{-1} C d^{-1})

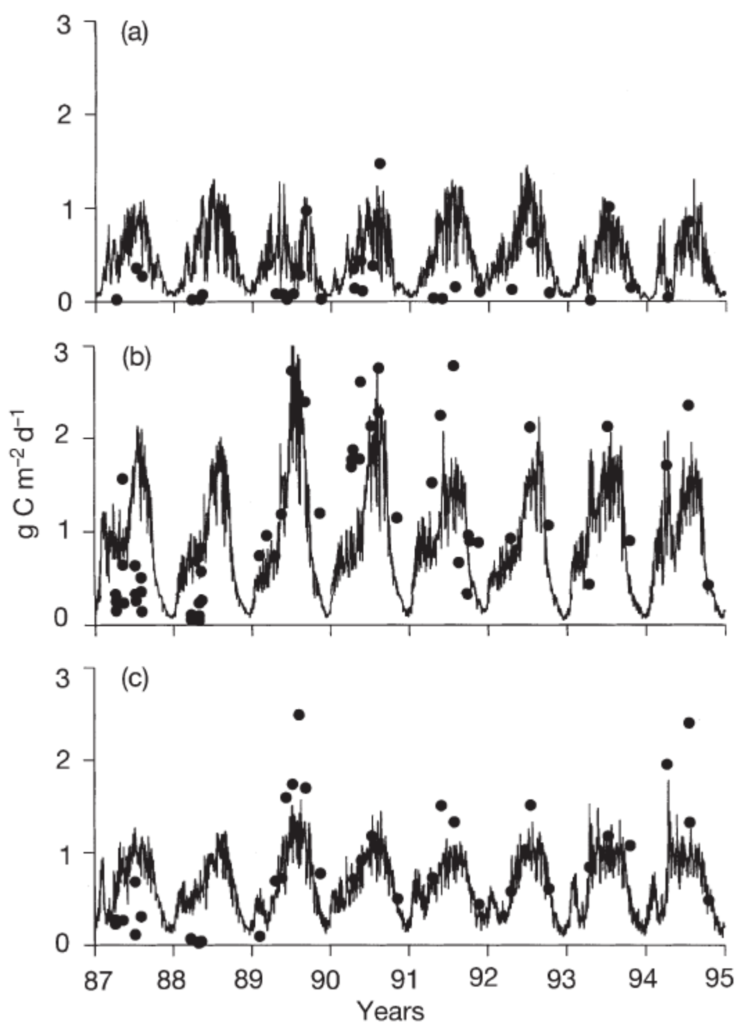


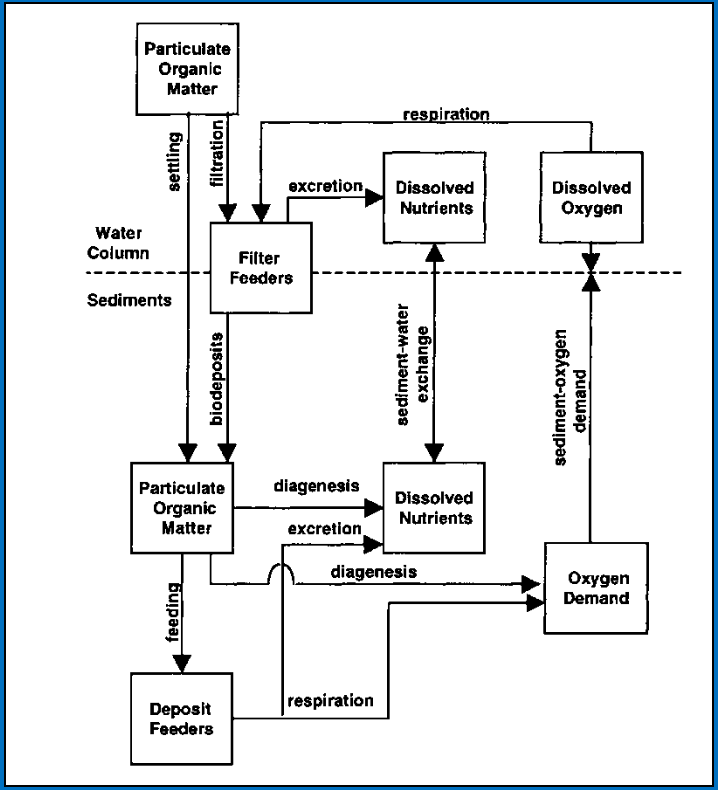
Fig. 5. Observed and computed NPP for (a) upper, (b) mid- and (c) lower Chesapeake Bay

Table 4. Computed annual net algal production and consumption by predators

Location	NPP ($g\,C\,m^{-2}\,d^{-1}$)	Consumption ($g\,C\,m^{-2}\,d^{-1}$) by: higher trophic levels	microzooplankton	mesozooplankton
NB	0.48	0.36	0.03	0.01
MB	0.87	0.67	0.11	0.14
SB	0.64	0.38	0.10	0.13

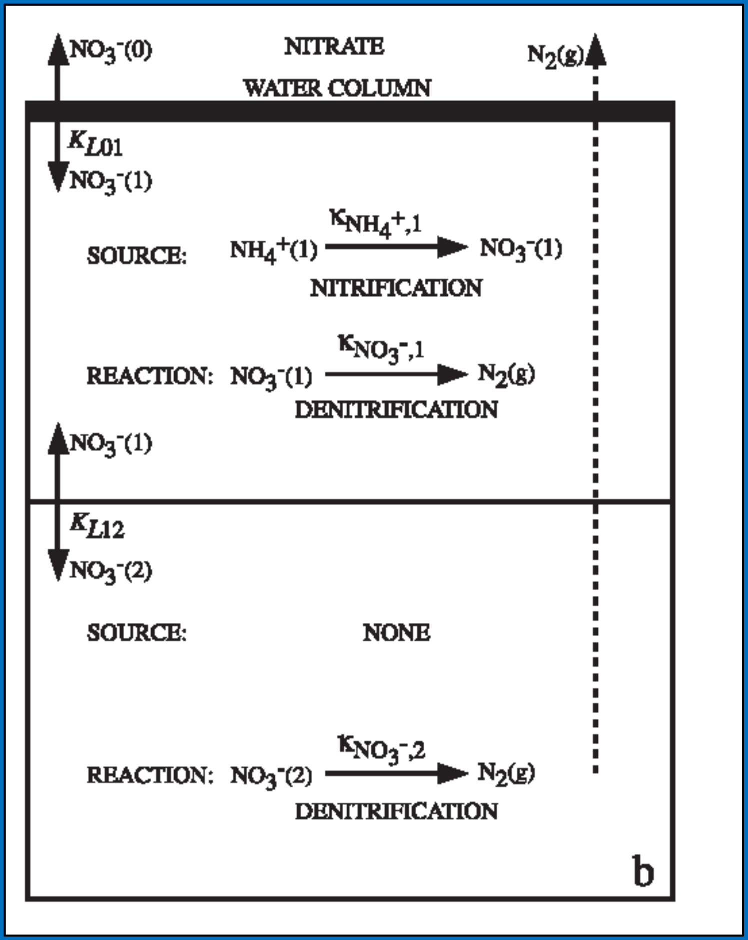
- We get credible computations of phytoplankton biomass and production with zooplankton playing a minor role.
- It’s maddening to try to calibrate phytoplankton by manipulating zooplankton parameters.
- We’ve been carrying zooplankton along for ten years without looking at it. Time to eliminate zooplankton.

Deposit-Feeding Benthos



- Deposit feeders were added at the same time as other living resources.
- The purpose was as indicator organisms. They are fish food and react to dissolved oxygen concentration.
- They serve little or no functional role in the model. We haven't looked at them in years. Contemporary data is sparse.
- Eliminate them.

Revised Sediment Denitrification Formulation



$$\frac{d(H\cdot C_{T1})}{dt} = \frac{-K_1^2}{K_{L01}} \cdot C_{T1} + \cdots . + \cdots . + \cdots . \quad (1)$$

H = layer thickness (L)
C_{T1} = concentration (M/L3)
K_1 = reaction velocity (L/T)
K_{L01} = mass-transfer coefficient (L/T)

Substitute K_{L01} = D/H and $K_1 = (D\cdot k)^{1/2}$ results in

$$\frac{d(H\cdot C_T)}{dt} = -k \cdot H \cdot C_{T1} + \cdots . + \cdots . + \cdots . \quad (2)$$

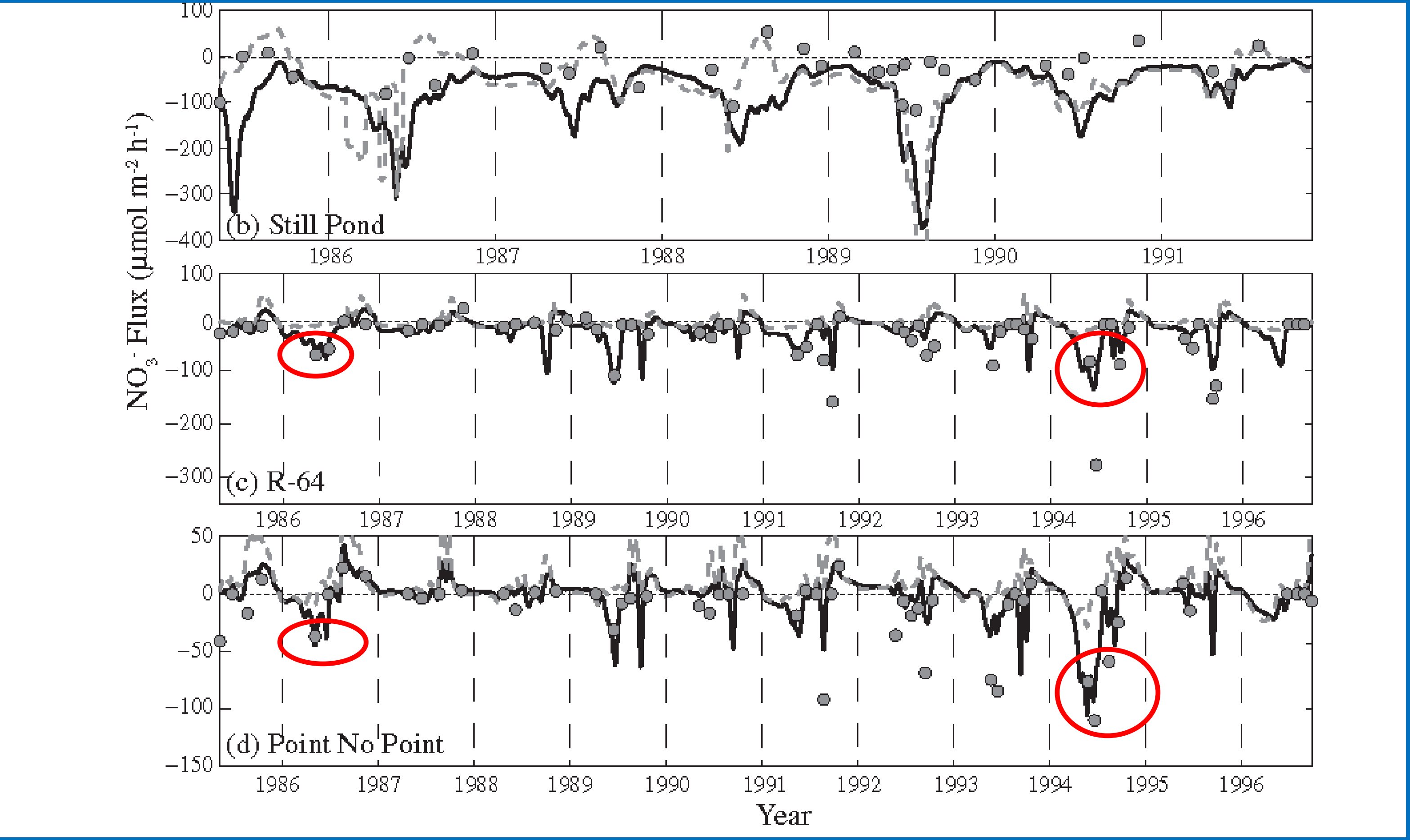
Note that H appears on both sides of the equation. This is effectively a first-order reaction.

Testa et al. propose

$$\frac{d(H\cdot C_{T1})}{dt} = -k \cdot C_{T1} + \cdots . + \cdots . + \cdots . \quad (3)$$

The reaction rate is independent of layer thickness. Relative to Equation 2, we would expect Equation 3 to produce more denitrification when H is small (thin aerobic layer) and less denitrification when H is large (thick aerobic layer).

Revised Sediment Denitrification Formulation



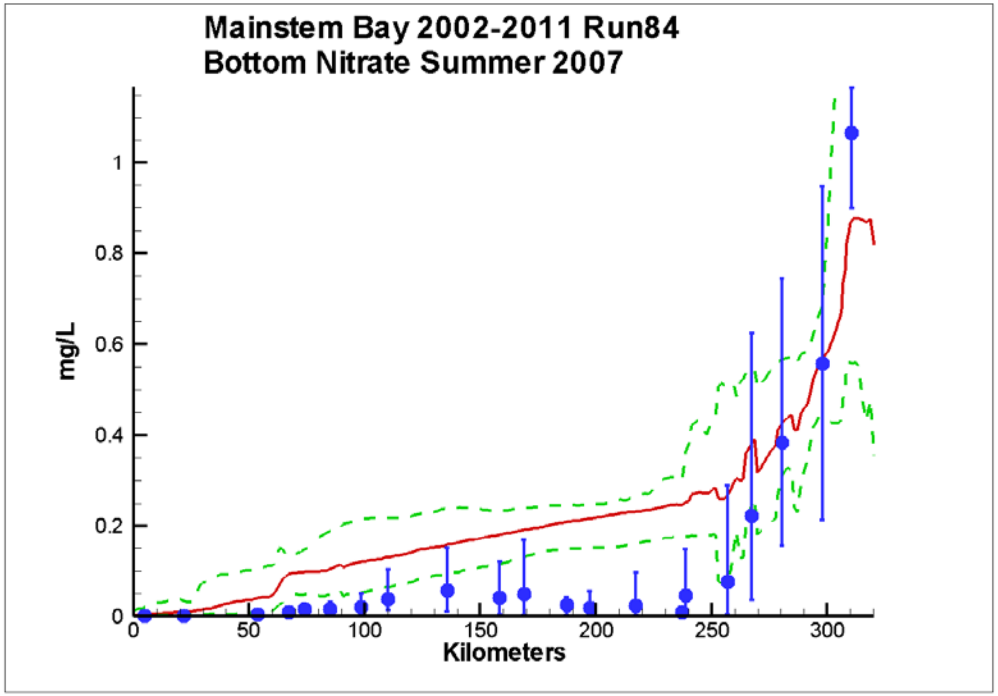
Original Formulation

New Formulation

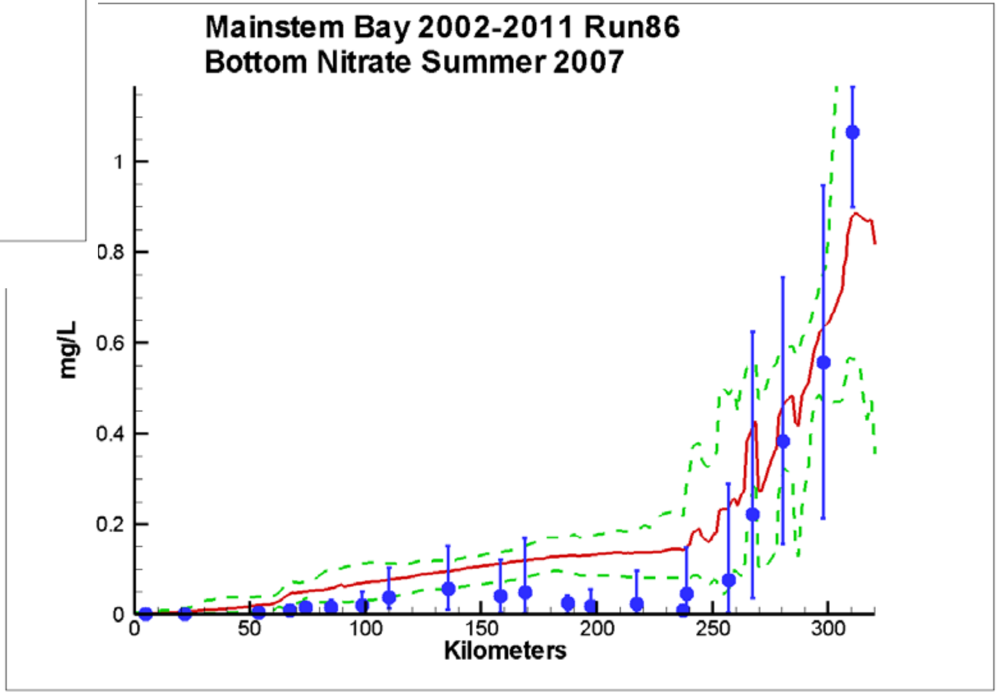
R-64 and Point No Point are hypoxic in summer. Thin aerobic layer, more denitrification.

Revised Sediment Denitrification Formulation

Old Formula

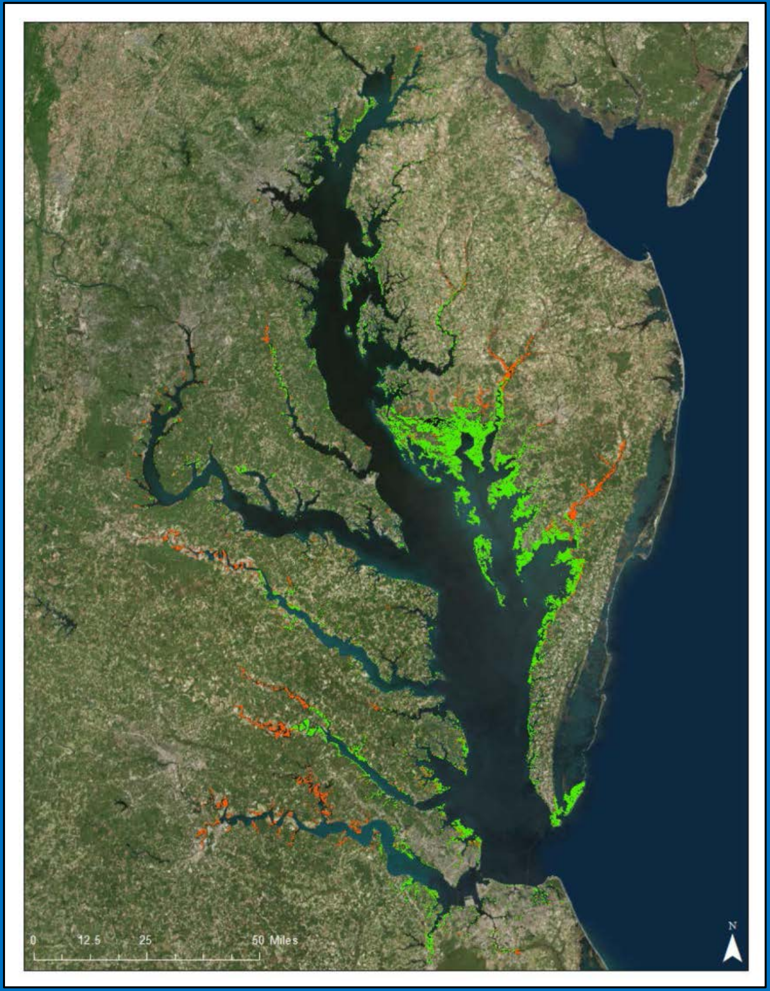


New Formula



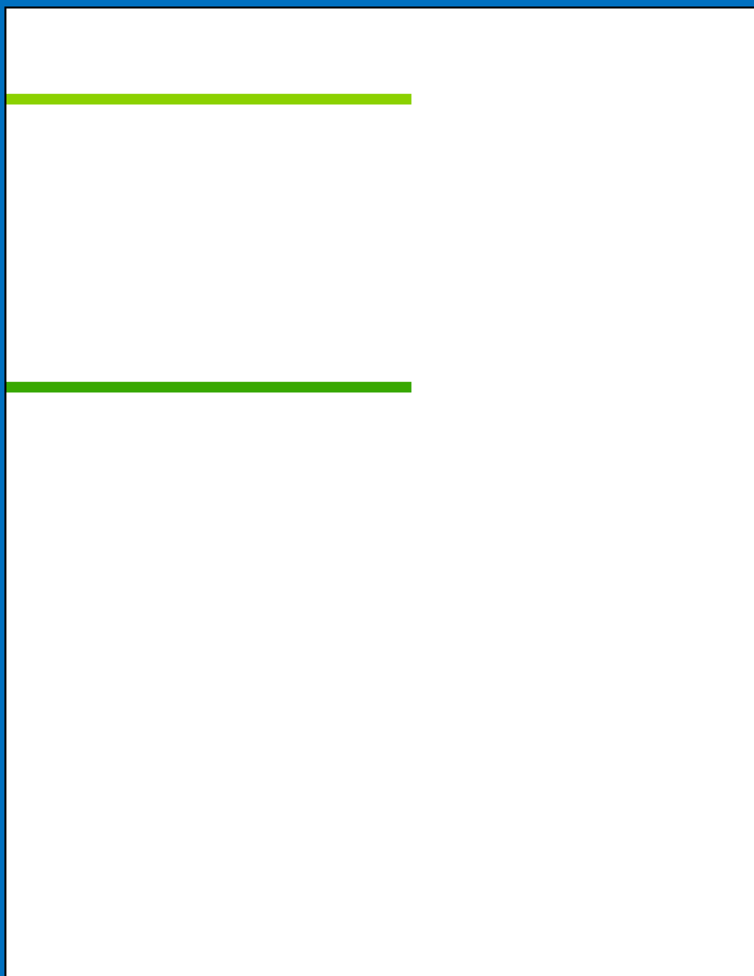
The new formulation helps remove excess nitrate at the bottom of the Bay. Not a cure-all.

Wetlands Module



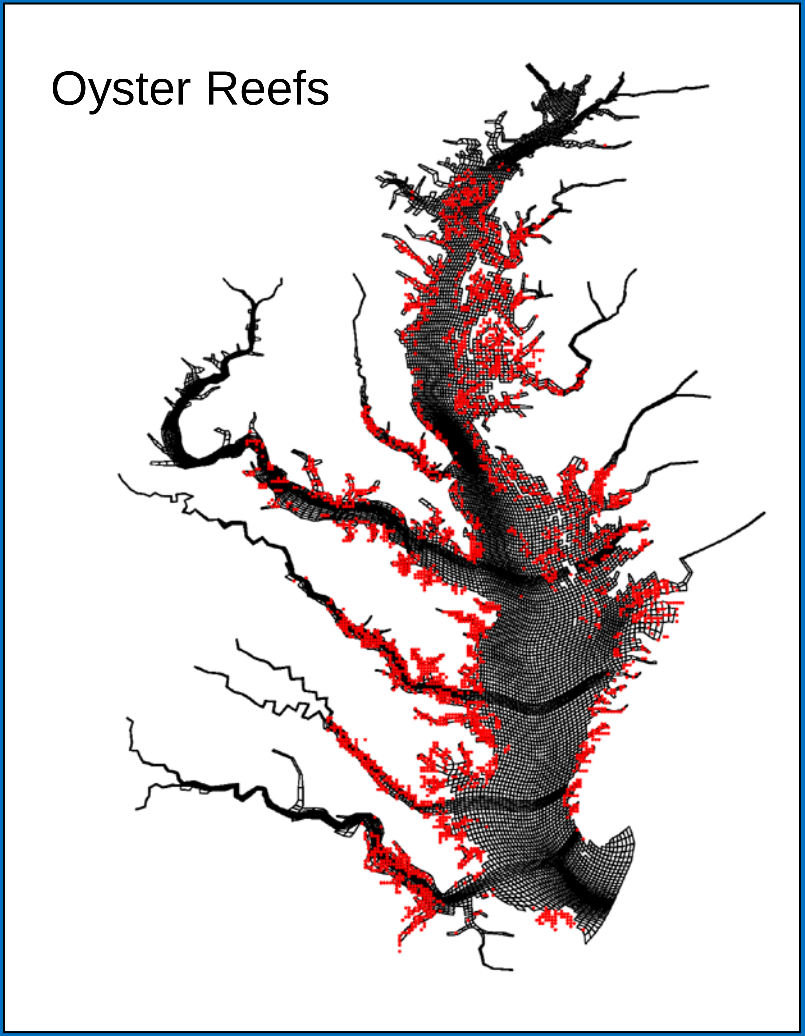
- Protocols have been developed to provide nutrient and sediment mass reduction credits for shoreline management projects that include restoration of vegetation.
- Wetlands respiration has been represented in the Chesapeake Bay model since the 2002 version.
- We new have a new "wetlands module." The module provides basic representations of relevant wetlands processes including burial of organic and inorganic particles, denitrification, and respiration.
- Wetlands area from the National Wetlands Inventory and the "Sea Level Affecting Marshes Model."

Nutrients from Shoreline Erosion



- Nutrients associated with shoreline erosion have been included in various model versions.
- The loads were omitted from the 2010 TMDL version because no guidance existed as to how to incorporate them in the TMDL.
- A recent report recognizes the potential for nutrient reduction associated with erosion management practices but withholds recommendations pending more information.
- In view of the pending consideration of these nutrients in TMDL development, nutrient loads from shoreline erosion are restored to this model version.

Oysters



- Bivalve filter feeders were added to the model as part of the 2002 Tributary Refinements phase.
- The bivalve model was subsequently parameterized for oysters to investigate the effect of a ten-fold increase in population.
- Oysters are receiving increased attention because of the rapid rise in aquaculture and the potential associated beneficial effects.
- The oyster module has been updated to reflect contemporary populations on reefs and current aquaculture operations.

Light Attenuation

- Light attenuation is computed with a "partial attenuation model."
- Light attenuation is the linear sum of the contribution from individual components.
- The components include water itself, colored organic matter, and suspended particles.

The Approach

- Download 18,000 observations of Ke from the Monitoring Data and Shallow-Water Monitoring Program.
- Download observations which are representative of the three contributors:
  - Particulate and Dissolved Organic Carbon
  - Total and Volatile Suspended Solids
  - Chlorophyll
  - Salinity

The Approach

- Use stepwise regression to evaluate various combinations of contributing factors.
- Superior results ($R^2 = 0.62$) are obtained from a simple model which includes TSS and salinity.
- Chlorophyll is a significant ($p < 0.0001$) but marginal contributor ($R^2 = 0.012$). Neglect it.

Additional Considerations

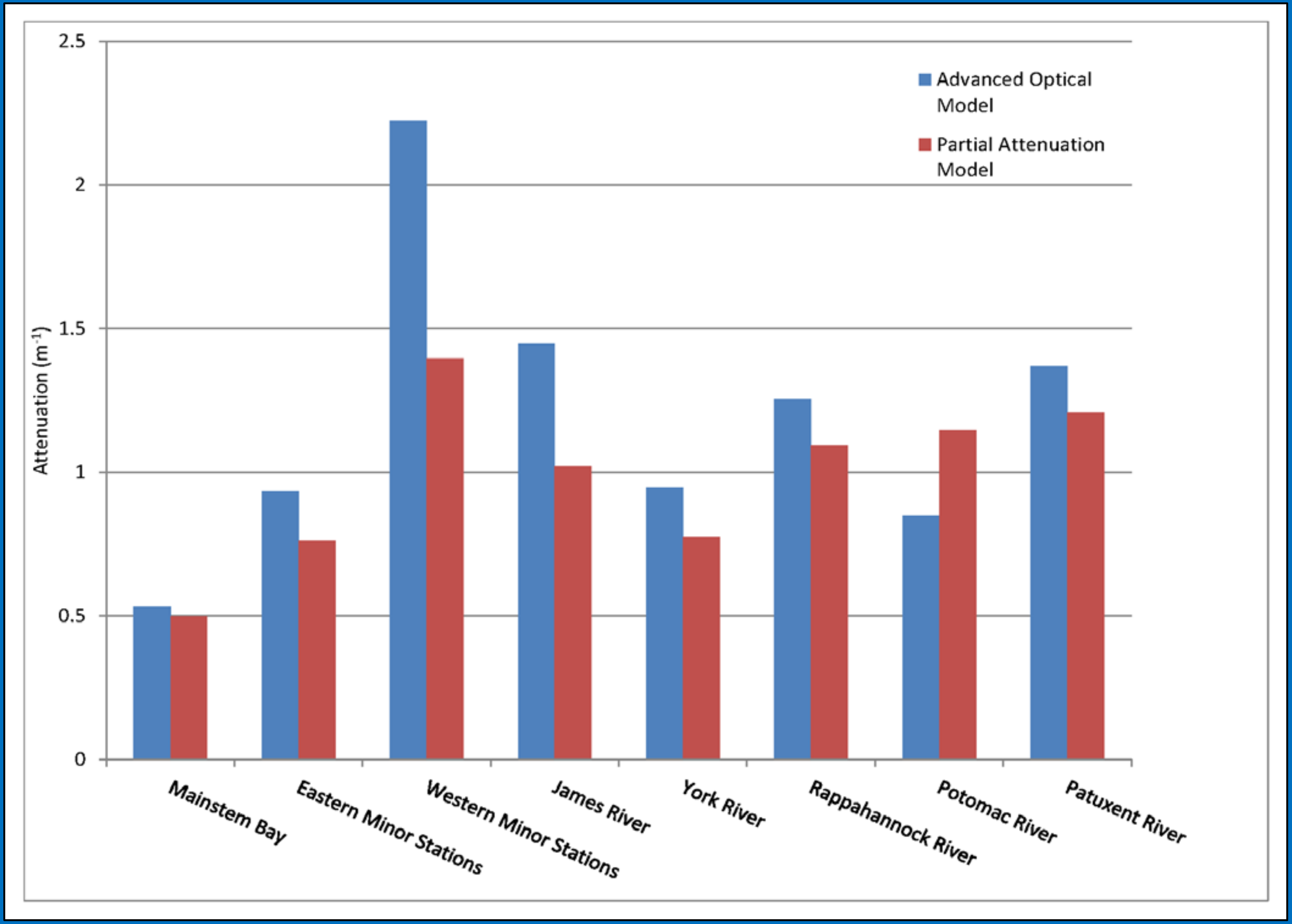
$$Ke = a1 + a2 \cdot TSS + a3 \cdot SALT$$

- a1 = 1.65 m^{-1}, a2=0.056 $m^2\ g^{-1}$, a3=-0.062 $m^2\ kg^{-1}$
- Examine residuals. Adjust background attenuation in regions with significant deviations from the model.
- Specify a minimum Ke (0.15 m^{-1}) to avoid negative results when salinity is high and TSS are low.

Advanced Optical Model

- The 2010 TMDL model employed an "advanced optical model" in which attenuation was a non-linear function of scattering and absorption.
- The AOM is superior from a theoretical standpoint. However:
  - The AOM is demanding in terms of data requirements.
  - The AOM is difficult to "tune" to improve agreement between computations and observations.

Comparison of Two Optical Models



absolute mean difference statistic for the partial attenuation model vs. the advanced optical model