Water Quality Modeling in Estuaries
Lessons Learned

Jim Fitzpatrick
Outline

- Evolution of models
  - State-variables and processes
  - Model grids
- Data issues
  - Inputs
  - Calibration
- Expect the unexpected
  - System perturbations
- Simple still has utility
  - Utility of “simple” models
Evolution of Models

Modern

Water Quality Model Phytoplankton Kinetics

Solar Radiation as Reduced by Cloud Cover and Water Column Light Attenuation (SS & CDOM)

Atmospheric Resorption

Hydrolysis/Mineralization

Grazing

Nitrification

Photosynthesis

Oxidation

Sediment Oxygen Demand (SOD)

Nutrient Fluxes (NH₄, NO₂, NO₃, PO₄)

Settling

Sediment Diagenesis of Organic Matter

SEDIMENT
Evolution of Models

Sediment oxygen demand and nutrient fluxes based on observed data.
Evolution of Models

Reduce calibrated fluxes in proportion to decrease in organic matter deposition.
Evolution of Models

Oxygen dependency of $PO_4$ flux from sediment cores

DiToro and Fitzpatrick (1993)

Mainstem Chesapeake Bay and some tributaries
Evolution of Models

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**Evolution of Models**

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**Oxygen dependency of PO₄ flux from sediment cores**

- **DiToro and Fitzpatrick (1993)**

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**Incubation of segmented Chesapeake Bay sediment cores to analyze decomposition of organic matter in the sediment**

- **Burdige (1991)**

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25-1 = 0-2 cm depth

25-2 = 5-7 cm depth

25-3 = 12-14 cm depth
Evolution of Models

One organic carbon pool
vs.
Split dissolved organic carbon into labile and refractory pools
Data Issues: Inputs Loadings

Importance of storm related sampling

Spatial variability in rainfall

Potomac River Median Annual Flow and Concentration
Total Phosphorous (TP): 1983-2006

Potomac R. fall-line P loading

Susquehanna R. fall-line P loading
Data Issues: Inputs
Boundary Conditions
Data Issues: Inputs

Boundary Conditions

![Image of a diagram showing nutrient fluxes and boundary conditions.](image)

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<th>TN</th>
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(All units are kg/day)
Data Issues: Calibration

Data Issues: Calibration

Chlorophyll-a to Carbon Ratio

October 1993

- Chl-a:C Ratio (mg Chl-a/mg C)
- Asterionellopsis Glacialis Cell Counts
Expect the Unexpected

but then

Causality?
Hypotheses:
- low flow caused the location of the null zone to move upstream of Suisun Bay (Arthur and Ball, 1979)
- more saline conditions allowed more salinity tolerant benthic species (*Mya arenaria*) to move into Suisun Bay and increased filtration of the water column (Nichols, 1985)
- present condition – dominance by *Cobula amurensis*
Expect the Unexpected
Despite reductions in total phosphorus from the Blue Plains WWTP from 24,000 lb/day in 1970 to 4,100 lb/day in 1980 to 2,100 lb/day by 1983 a large bloom of the blue-green algal *Microcystis aeruginosa* occurred late in the summer of 1983.
Expect the Unexpected

Interestingly, maximum total phosphorus levels were well downstream of the Blue Plains WWTP and in the vicinity of the peak chlorophyll-a concentrations.
Expect the Unexpected

Potomac estuary algal bloom - August, 1983
Evolution of Models Revisited

Modified from Thomann (1998)
Evolution of Models Revisited

Hydrodynamic grid (Rich Signell USGS)

Water quality grid

644 x 10 cells (6,440)

4624 x 12 cells (55,488)

Reduction in execution time ~ 20:1

Fine Grid

Aggregated Grid

\[ C_A \]

\[ V_A \]
Evolution of Models Revisited – Grid Aggregation

Comparison of Aggregated Grid Dissolved Oxygen vs. Unaggregated Grid

Bottom water dissolved oxygen – end of September
Gulf of Mexico Hypoxia Model
Streeter-Phelps framework (BOD-DO deficit)
Assumptions:
assume that sub-pycnocline water can be modeled as 1-D
hypoxic zone length characterizes hypoxic area ($r^2=0.79$)
river nitrogen load is a surrogate for sub-pycnocline biological oxygen demand
sub-pycnocline oxygen demand is 1$^{st}$ order
oxygen flux across pycnocline is 1$^{st}$ order proportional to oxygen deficit
Design the models to answer the question(s)

- Get managers, scientists and modelers working together early

Data quality important

- Collect the data appropriate for calibrating the model
- More data is (usually) good

Ecosystems change

- System perturbations/climate warming

Simple still has utility

- Build on existing understanding
Questions