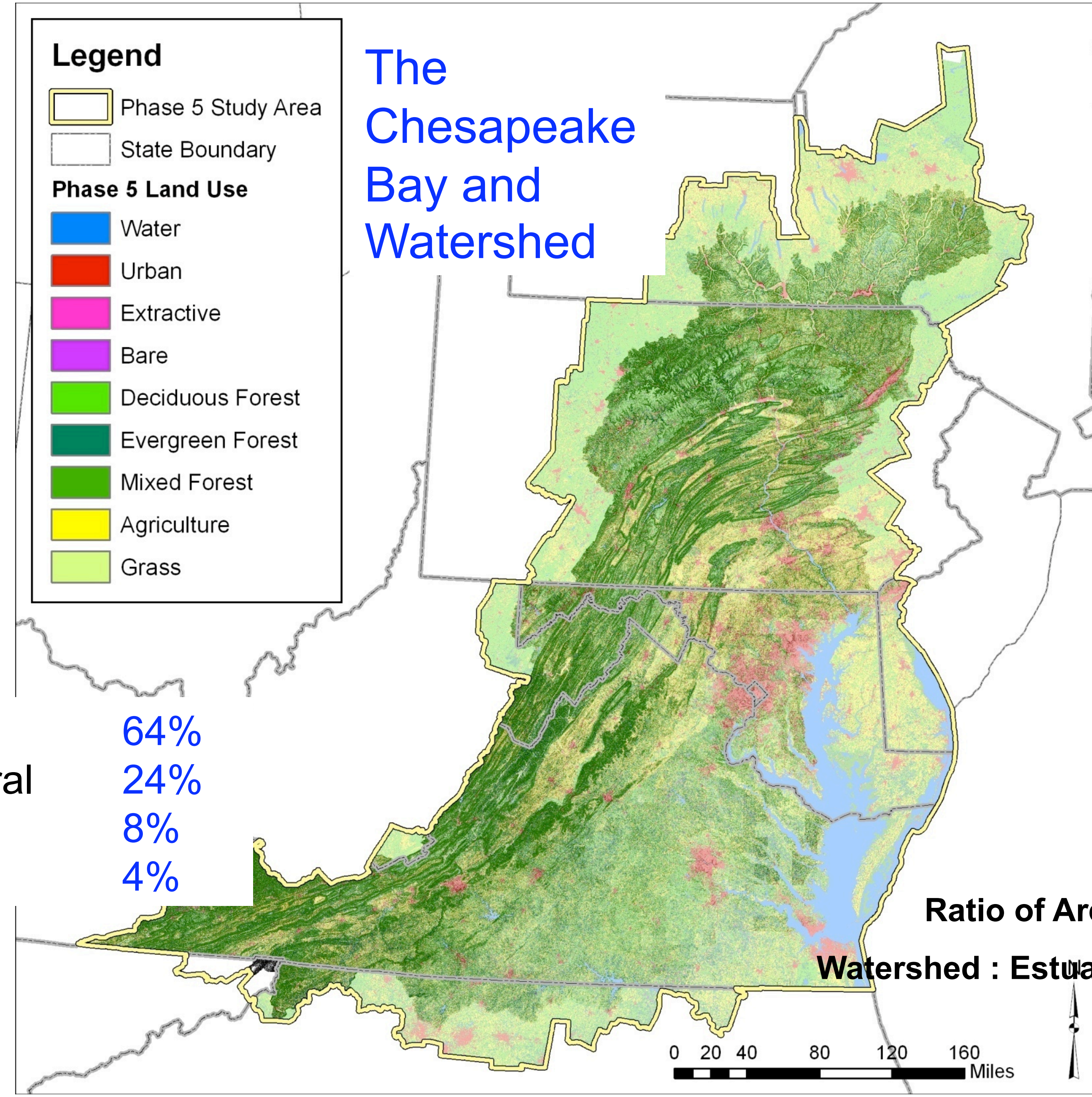
Chesapeake Bay Program Modeling Past, Present, and Future

Chesapeake Bay Program Office

The Chesapeake Bay and Watershed

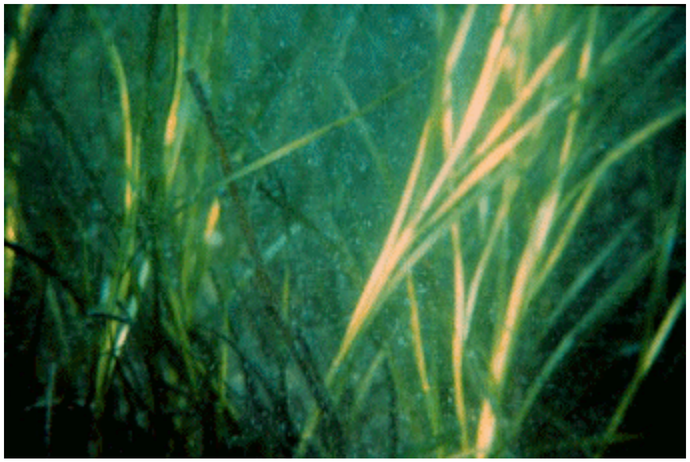


Forest	64%
Agricultural	24%
Urban	8%
Other	4%

Ratio of Areas

Watershed : Estuary ~ 15:1

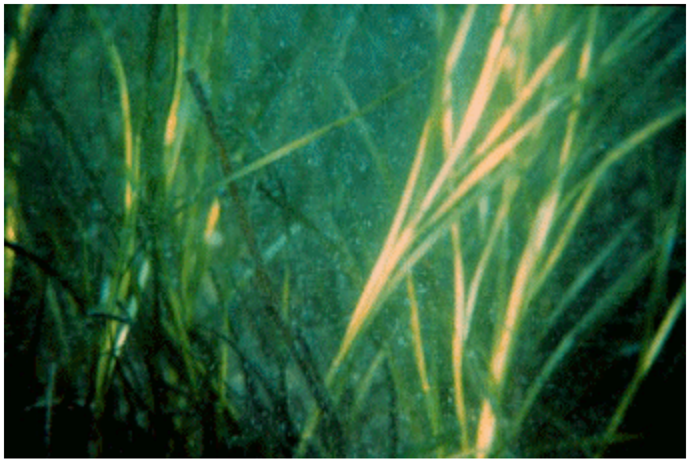
Effects of Excess Sediment



Excess sediment can cloud water, block sunlight, and cause SAV to die.

Can damage habitats of some Plants and animals.

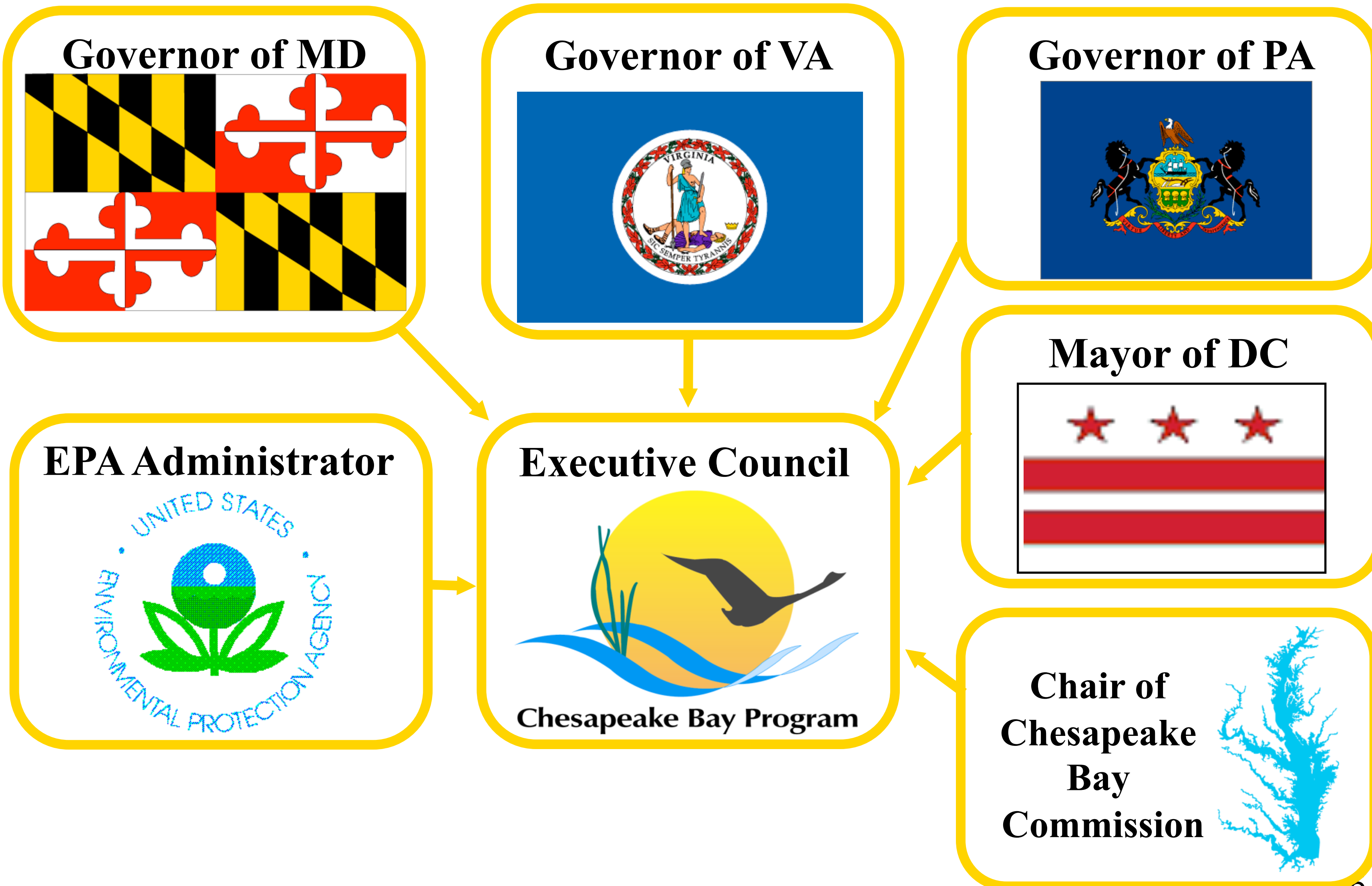
Effects of Excess Nutrients



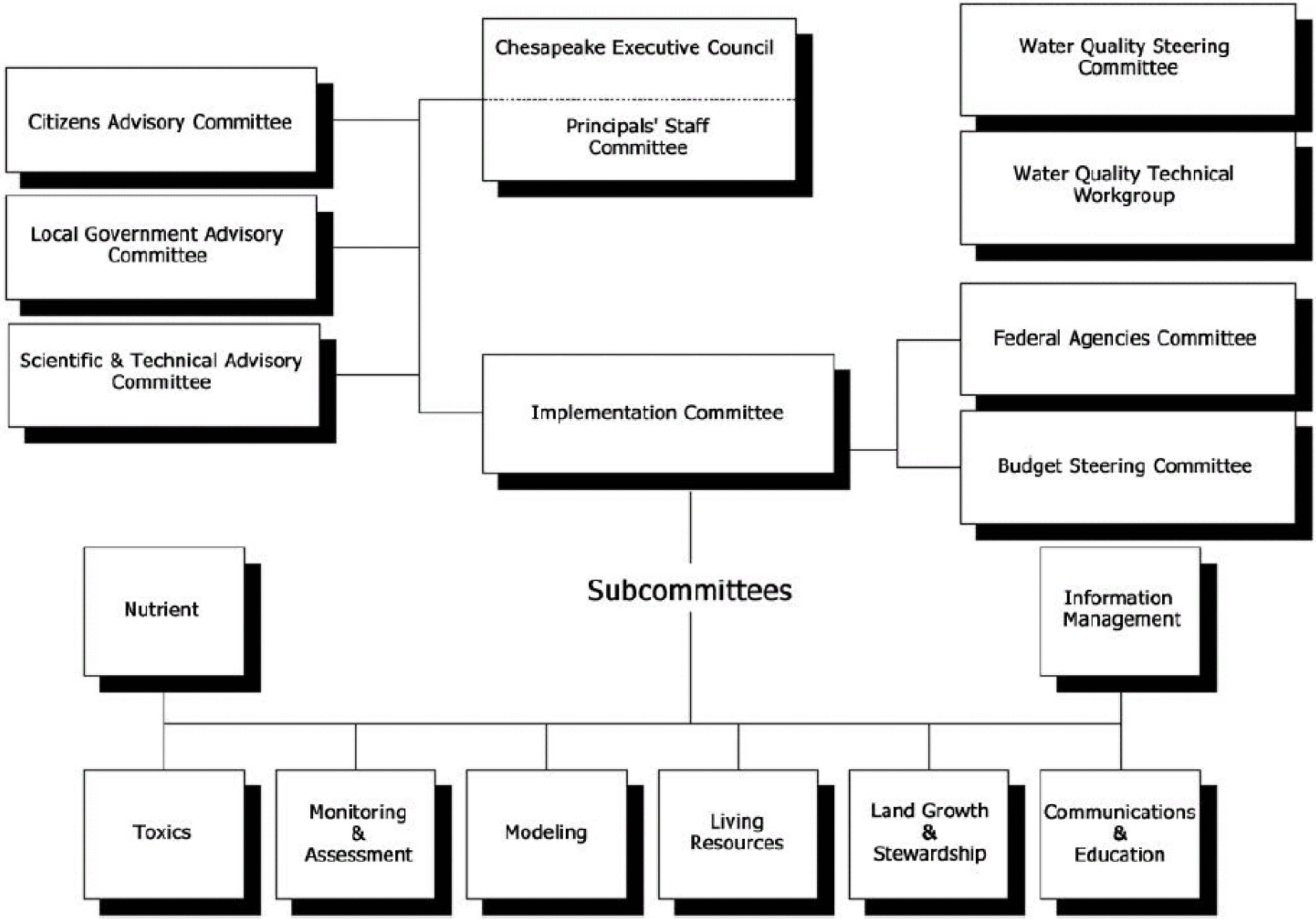
Excess algae cloud water, block sunlight, and cause SAV to die.

When excess algae die and decompose, they use up oxygen in the water that plants and animals need to survive.

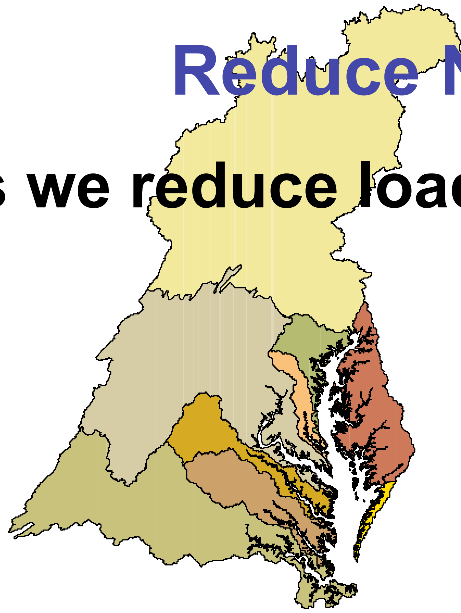
The Chesapeake Bay Program Partnership



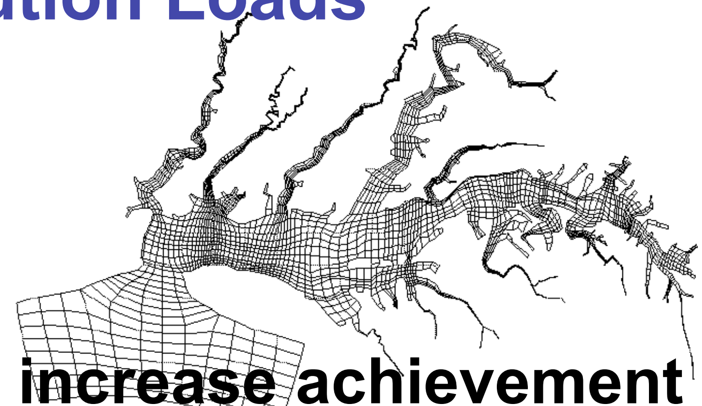
Chesapeake Bay Program Organizational Chart



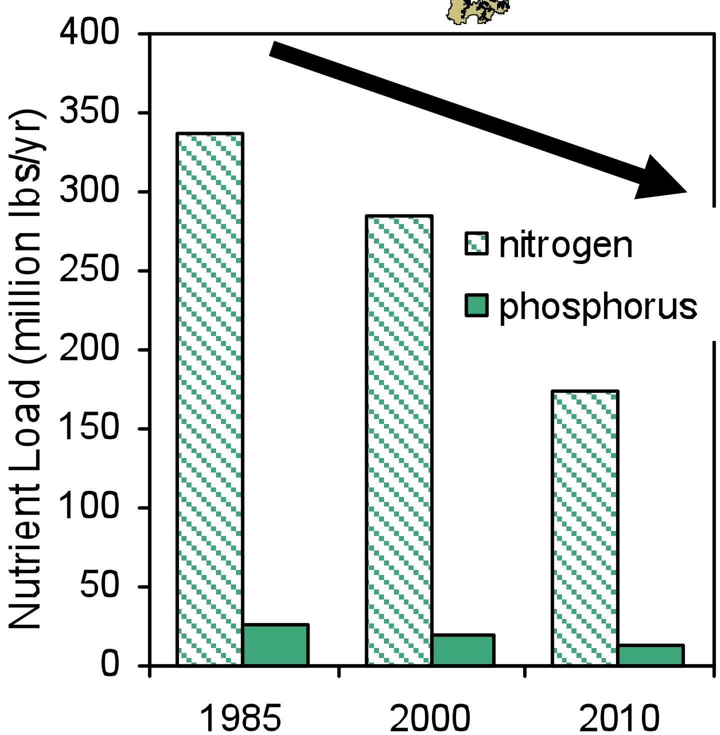
Reduce Nutrient Pollution Loads

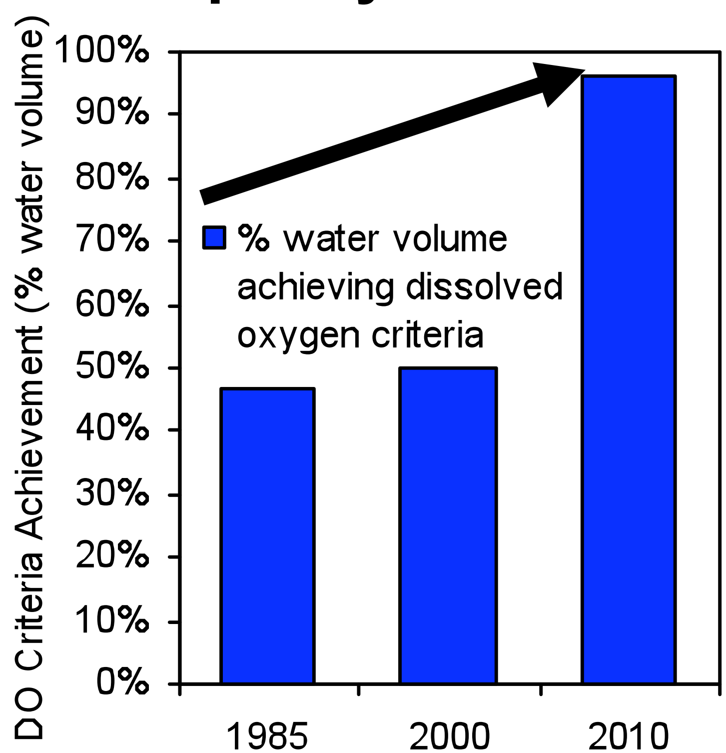


As we reduce loads...



…we increase achievement of water quality conditions.

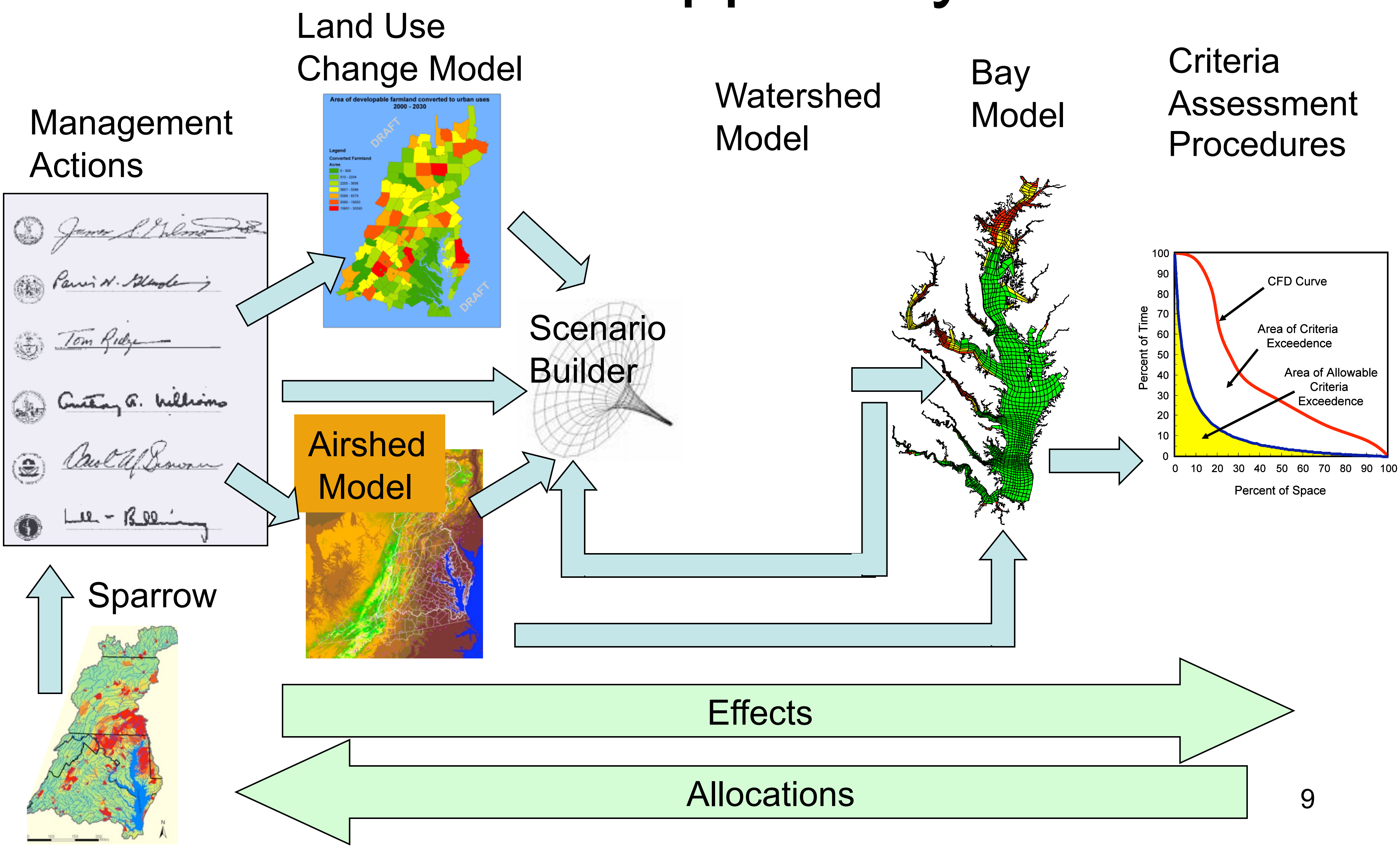




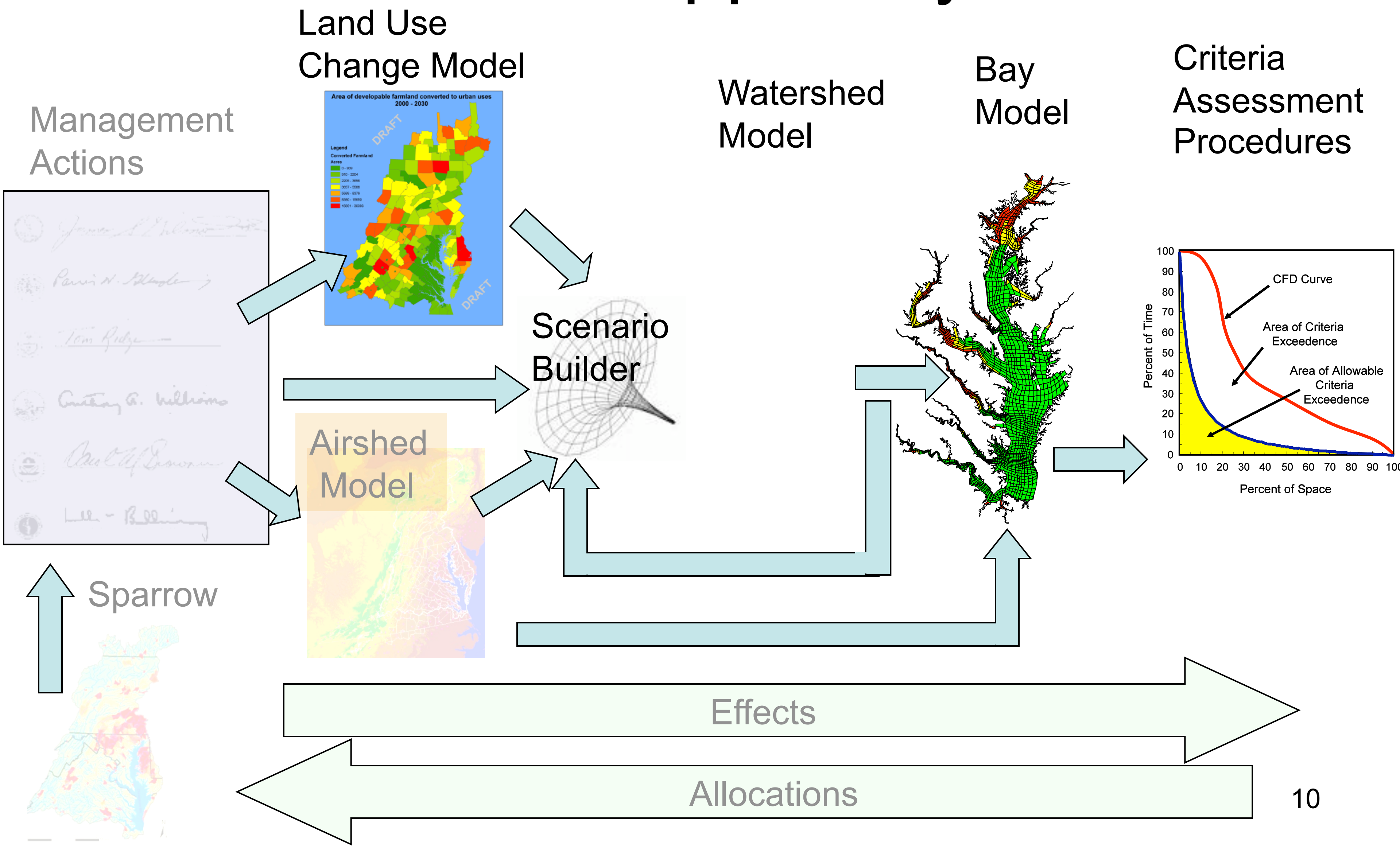
Chesapeake Bay Program Management Questions

- What is the estuarine response to reductions of nutrients and sediment?
  - Water quality (dissolved oxygen)
  - Living resources (crabs and fish)
- What reductions are achievable?
  - What to do
  - Where to do it
  - Changes in loads from management actions
  - What are the local effects on riverine water quality?

Chesapeake Bay Program Decision Support System



Chesapeake Bay Program Decision Support System



Watershed Model

Quick Overview of Watershed Model **Scenarios**

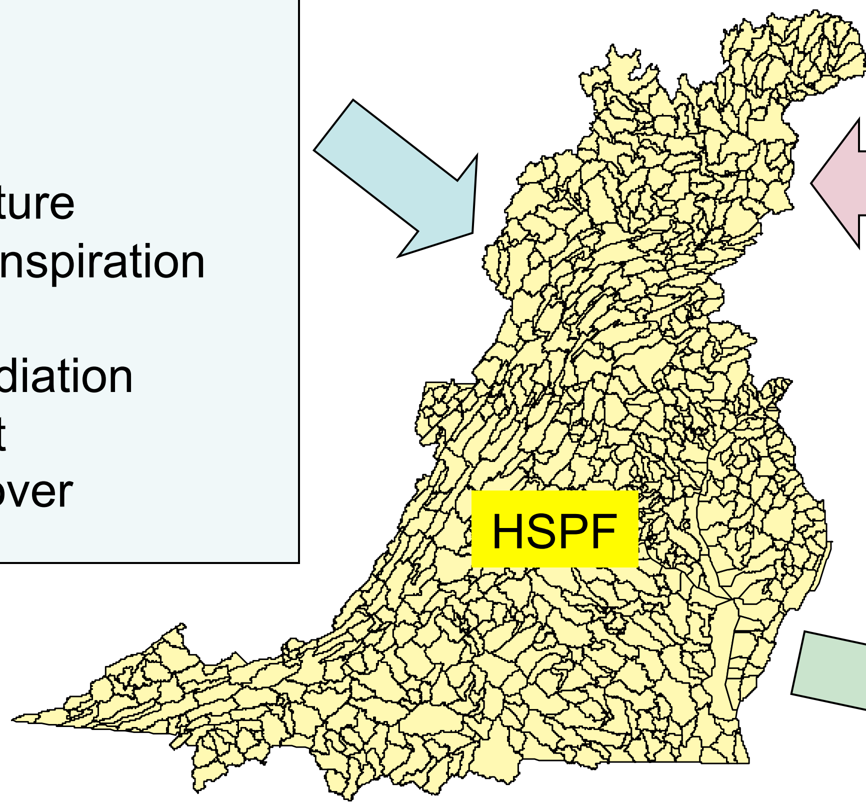
Hourly output is summed over 10 years of hydrology to compare against other management scenarios

Snapshot:

Land Use Acreage
BMPs
Fertilizer
Manure
Atmospheric Deposition
Point Sources
Septic Loads

Hourly Values:

Rainfall
Snowfall
Temperature
Evapotranspiration
Wind
Solar Radiation
Dewpoint
Cloud Cover



1991-2000

"Average Annual Flow-Adjusted Loads"

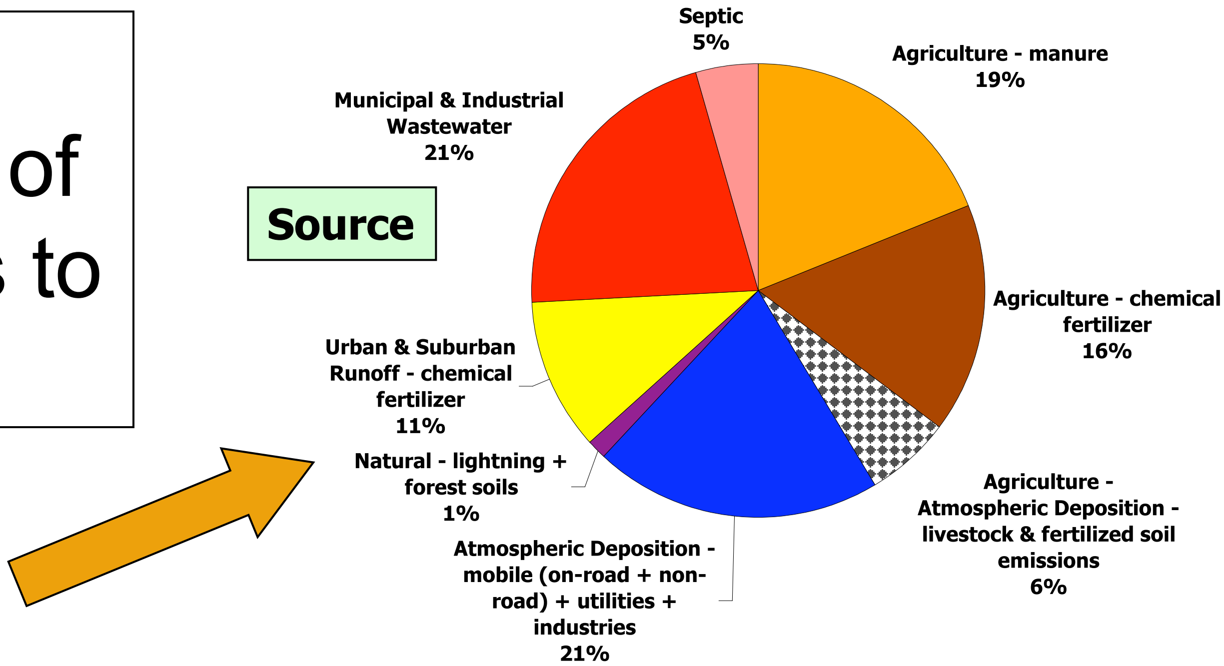
Each segment consists of separately-modeled land uses

- High Density Pervious Urban
- High Density Impervious Urban
- Low Density Pervious Urban
- Low Density Impervious Urban
- Construction
- Extractive
- Wooded
- Disturbed Forest

- Corn/Soy/Wheat rotation (high till)
- Corn/Soy/Wheat rotation (low till)
- Other Crops
- Alfalfa
- Nursery
- Pasture
- Degraded Riparian Pasture
- Animal Feeding Operations
- Fertilized Hay
- Unfertilized Hay
  - Nutrient management versions of the above

Plus Point Source and Septic

Different Types of Load Allocations to Sources



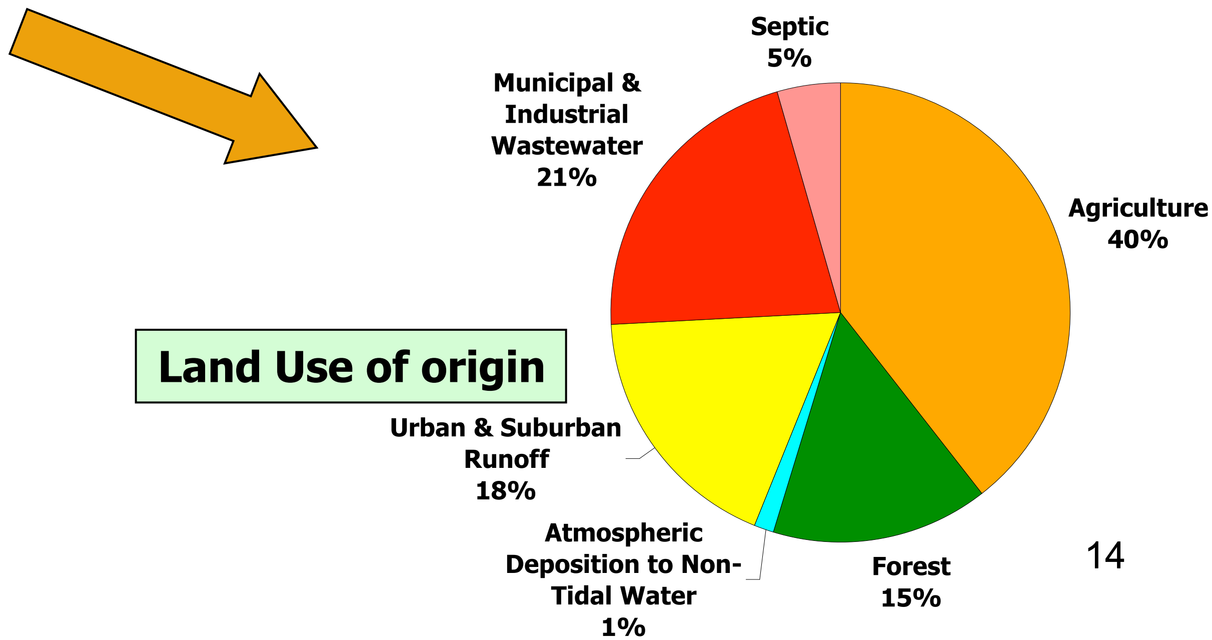
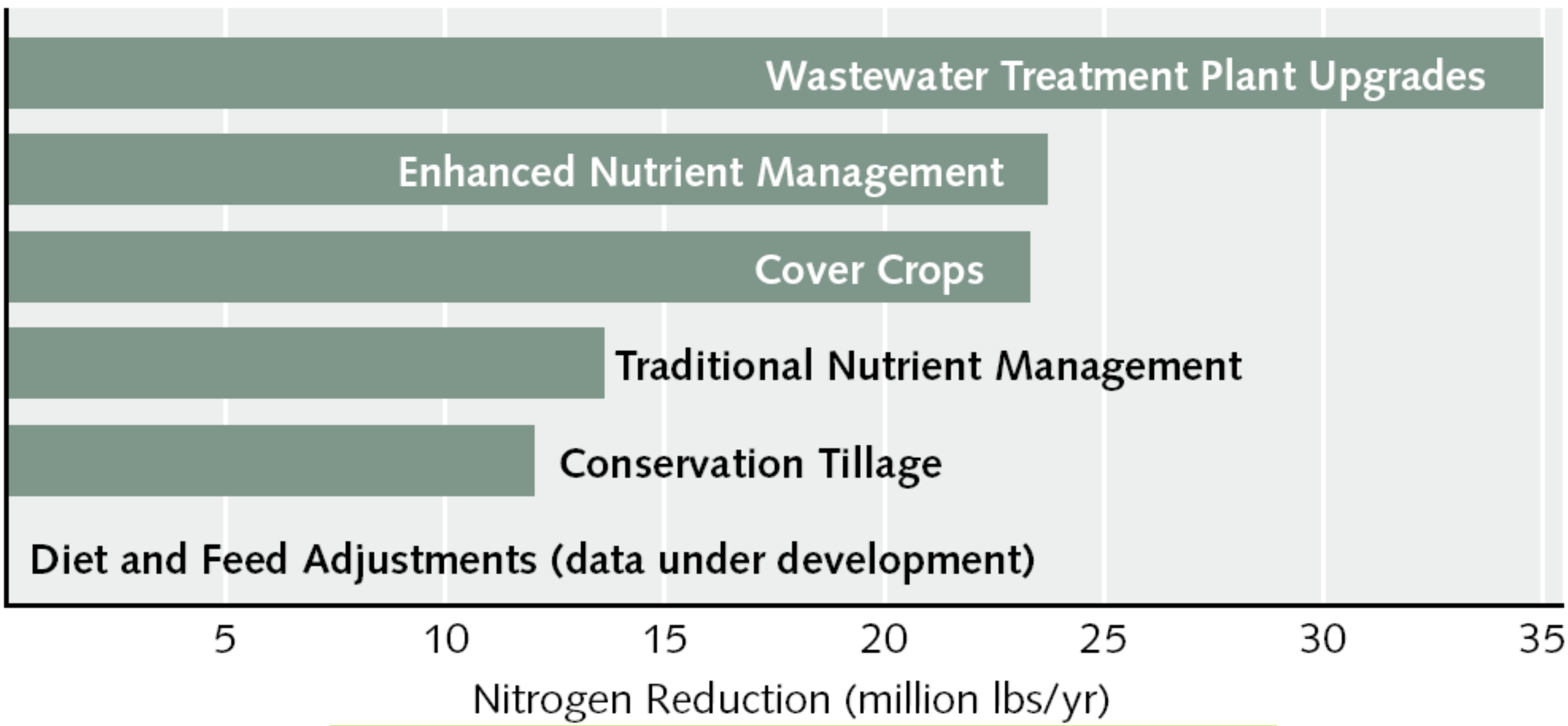
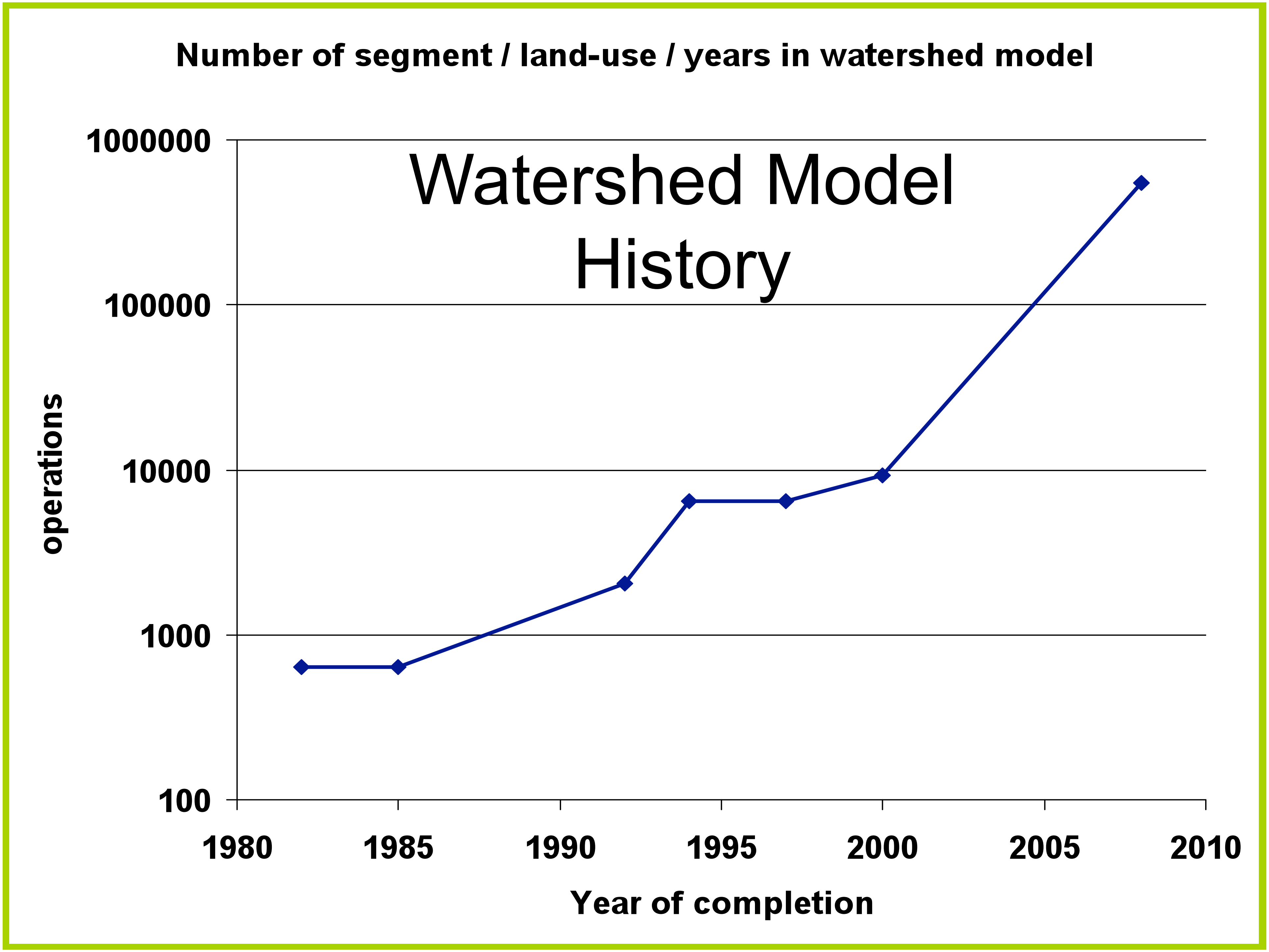


FIGURE 3

MAXIMUM POTENTIAL NITROGEN REDUCTION BAYWIDE*
FOR INDIVIDUAL BEST MANAGEMENT PRACTICES (2002 BASELINE)

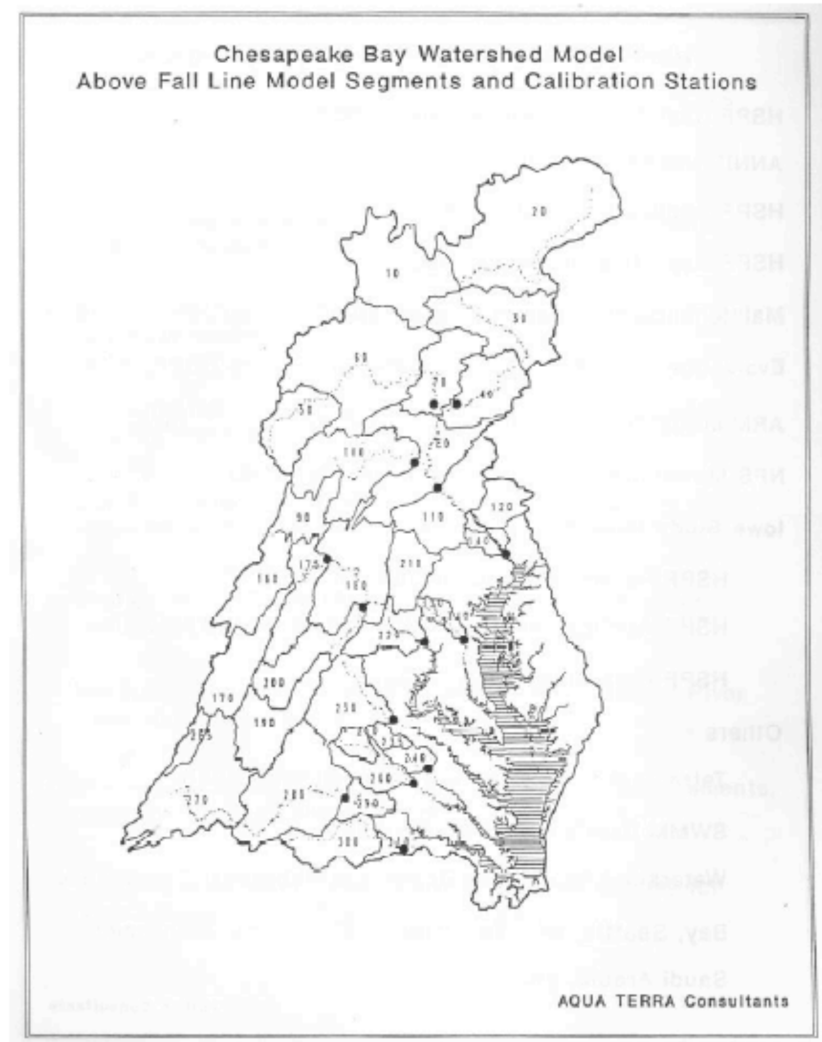


From the Chesapeake Bay Commission Report:
Cost-Effective Strategies for the Bay
December, 2004


Number of segment / land-use / years in watershed model
Watershed Model History
1000000
100000
10000
1000
100
operations
1980
1985
1990
1995
2000
2005
2010
Year of completion

First Version of the Watershed Model:

- Completed in 1982.
- 63 model segments.
- 2 year calibration period (Mar.- Oct.).
- 5 land uses.
- IBM mainframe platform.



Primary Products of the First Version of the Watershed Model:

First estimate of relative point source and NPS loads for each major basin.

Demonstration of the importance of controlling NPS loads in the Chesapeake.

"Framework for Action" report, the first basin by basin assessment of Chesapeake nutrient loads.

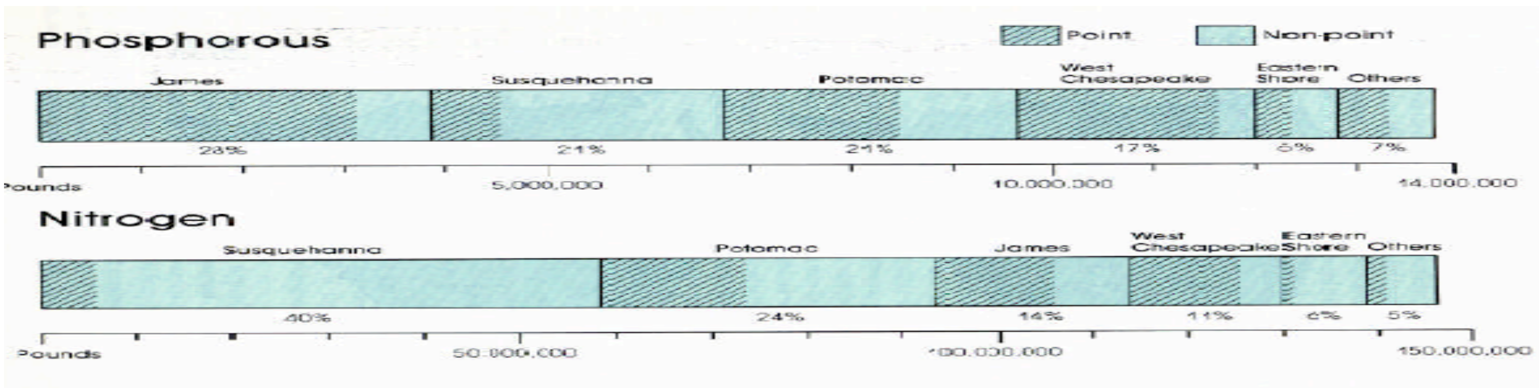


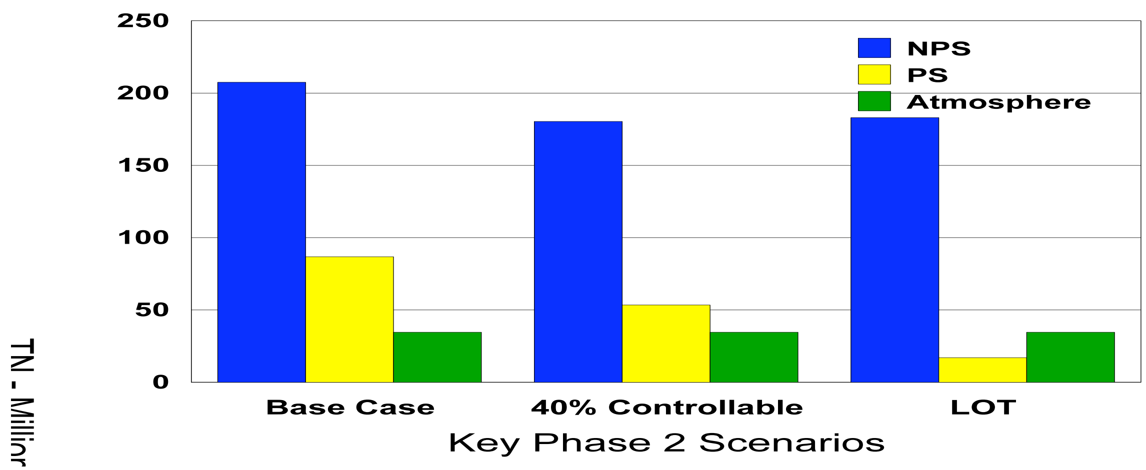
FIGURE 20. Nutrient loadings (March to October) by major basin under average rainfall conditions.

Second Version of the Watershed Model - Phase 2:

- Completed in 1992.
- 63 model segments.
- 4 year calibration period (1984-87).
- 9 land uses.
- DEC VAX mainframe platform.

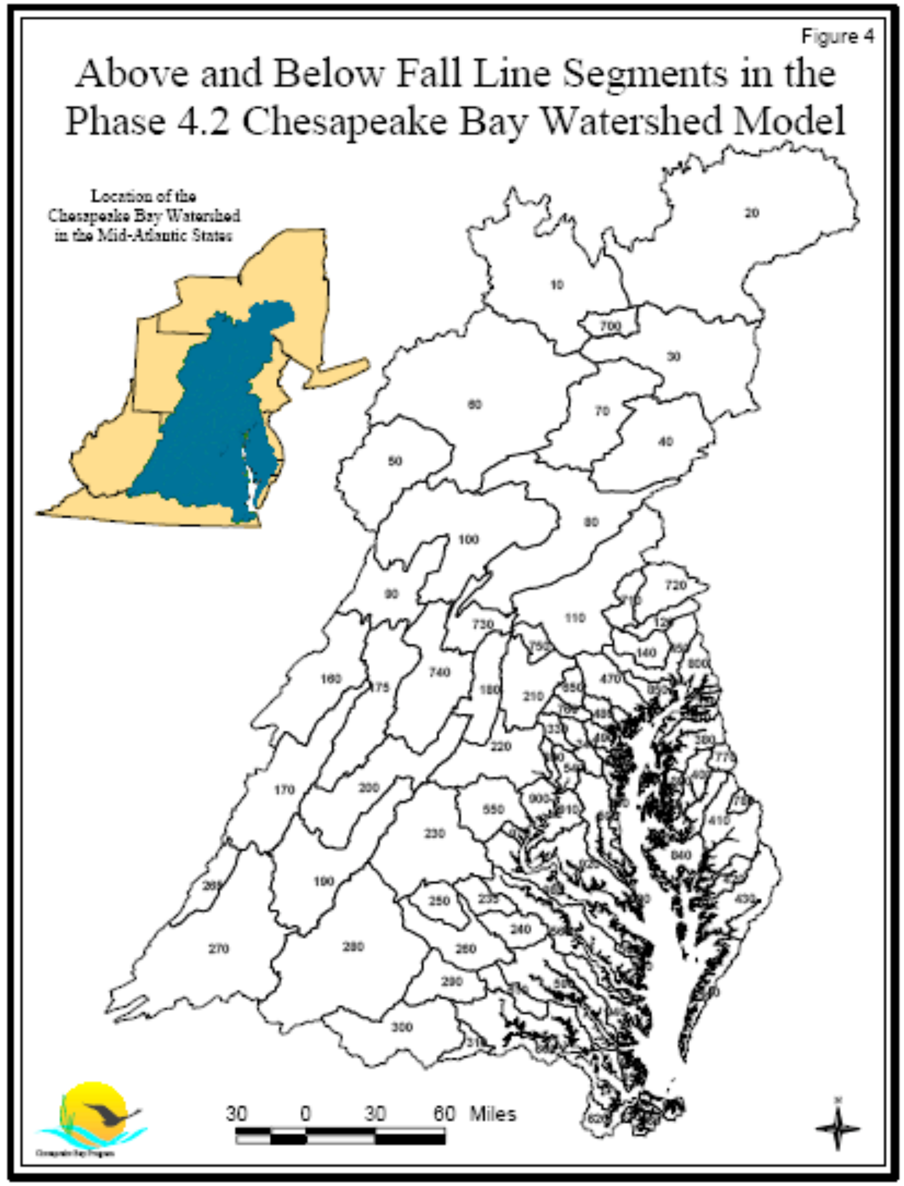
Primary Products of Phase 2:

- First nitrogen and phosphorous allocations for each major basin.
- First linkage to water quality model of the estuary.
- First linkage to the airshed model (RADM) and estimates of atmospheric loads for each major basin.



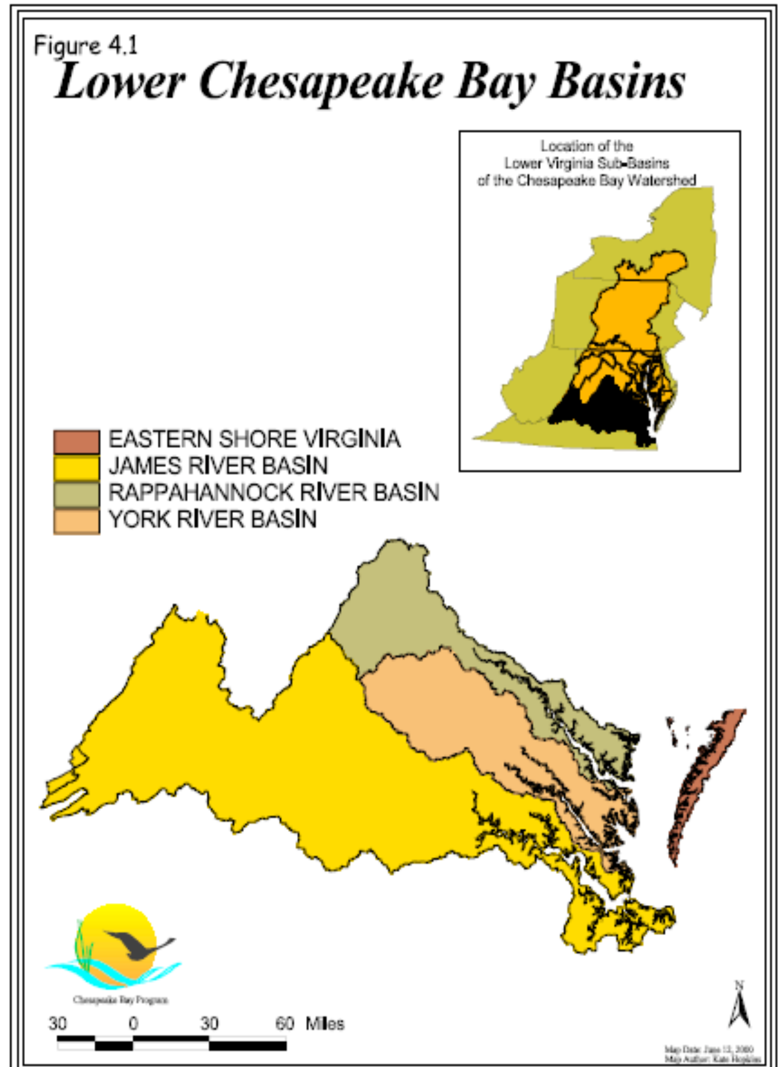
Third Version of the Watershed Model - Phase 4:

- Completed in 1998.
- 94 model segments.
- 9 land uses.
- 14 year calibration period (1984-97) using automated input and output model processors.
- Cray, DOS, Solaris, and linux platforms.



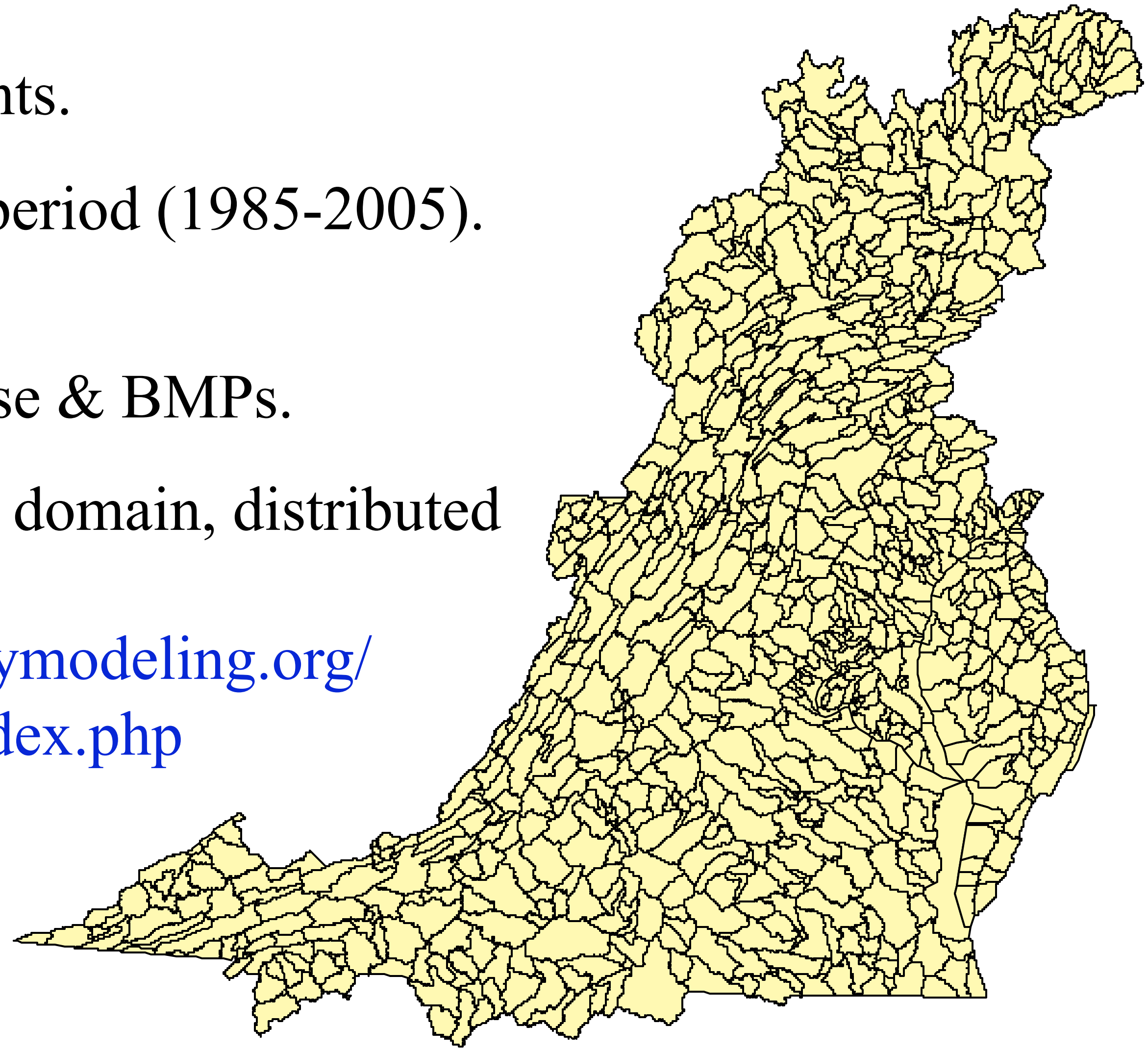
Primary Products of Phase 4:

- Nutrient Allocations in 2000 (p4.1)
- Nutrient Allocations in 2003 (p4.3)
- Began open source, public domain, web distribution of preprocessors, post processors, and open source code. First download and use by non-CBP.

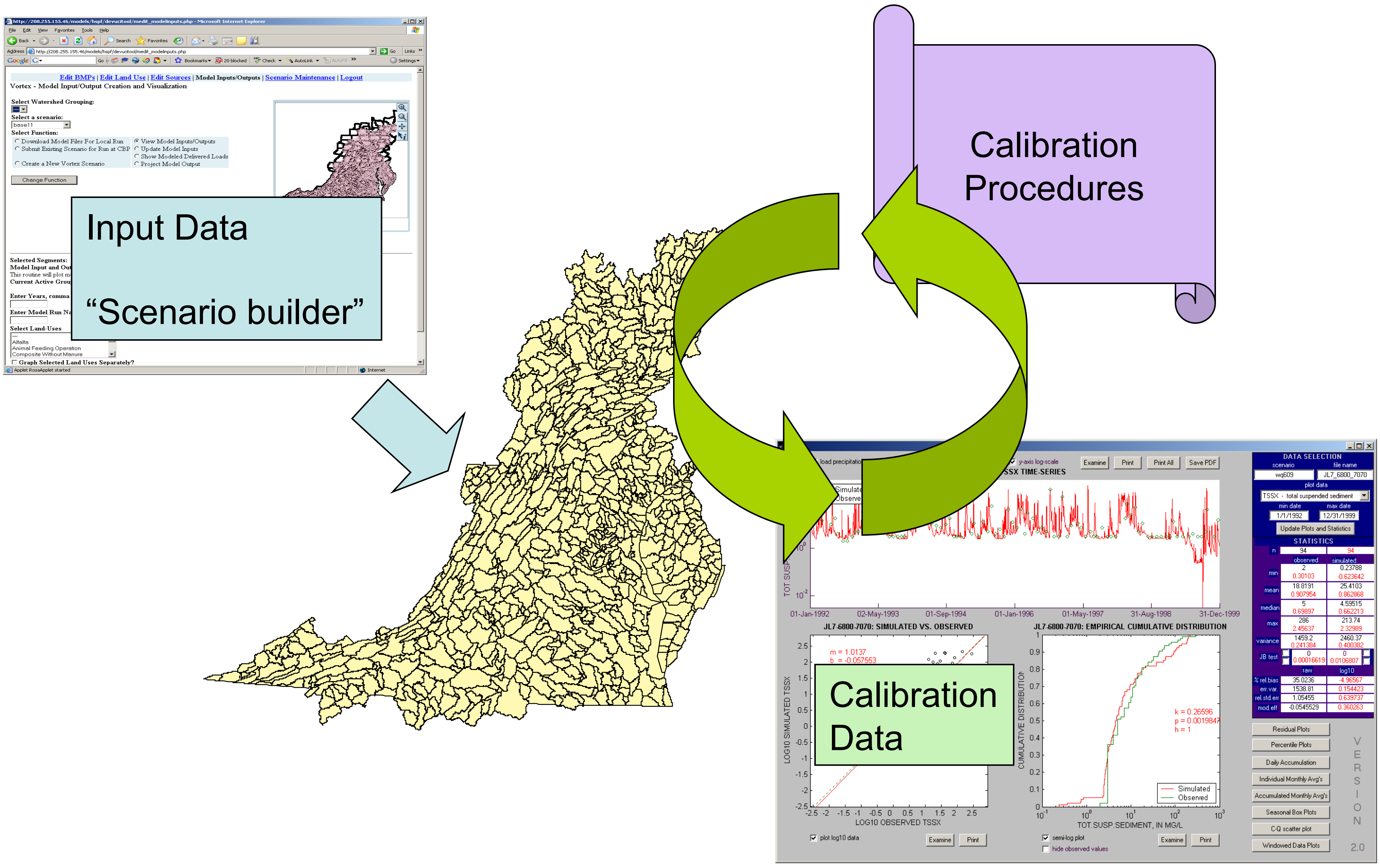


Fourth Version of the Watershed Model - Phase 5:

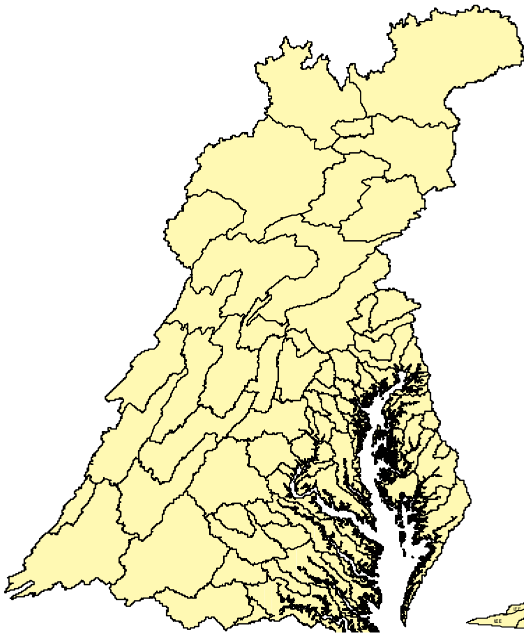
- 1,063 model segments.
- 21 year calibration period (1985-2005).
- 24 land uses using
- time-varying land use & BMPs.
- Open source, public domain, distributed over the web: http://ches.communitymodeling.org/models/CBPhase5/index.php
- Purpose: TMDL



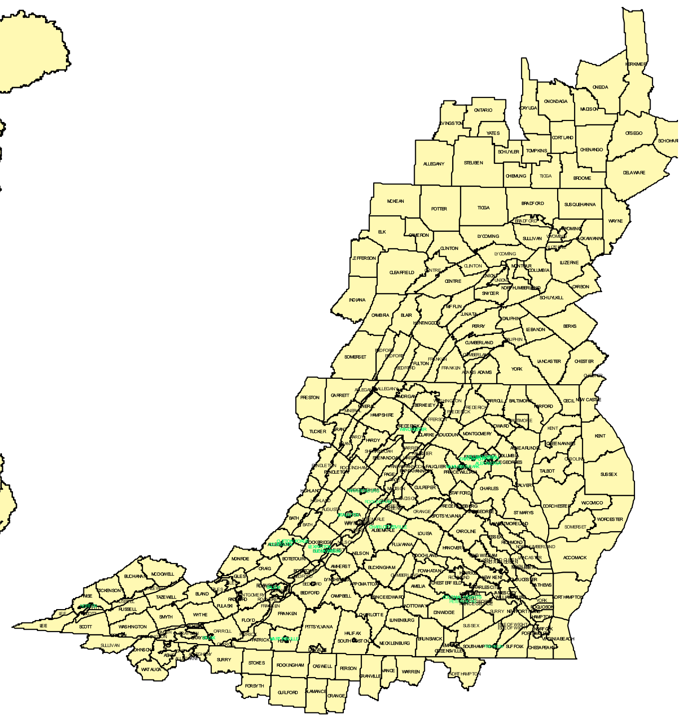
Automated Calibration



Phase 5 – A Ten Fold Increase in Segmentation Over Previous Phase 4.3 Model



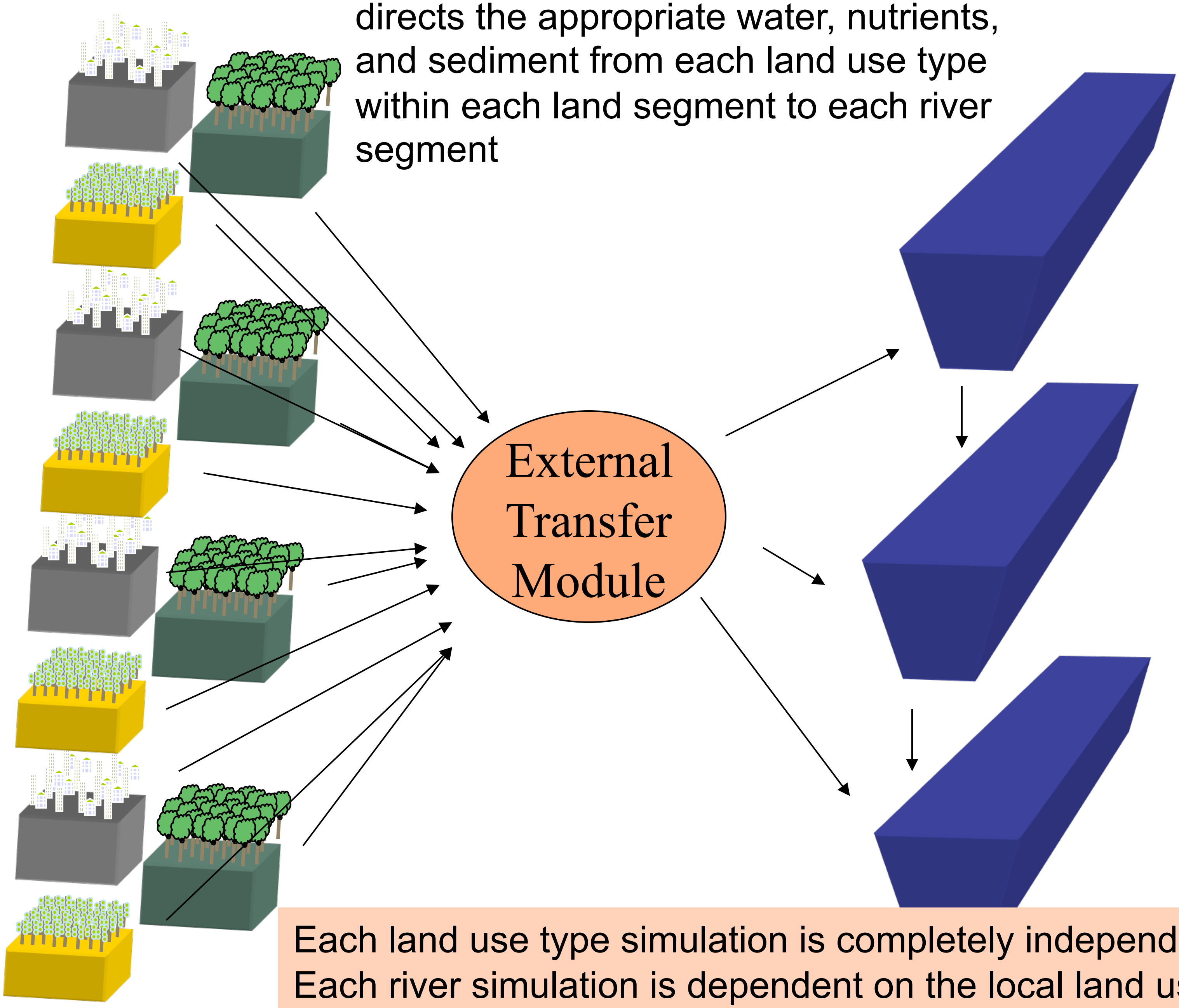
Phase 4.3 land and river segments



Phase 5 land segments

Phase 5 river segments

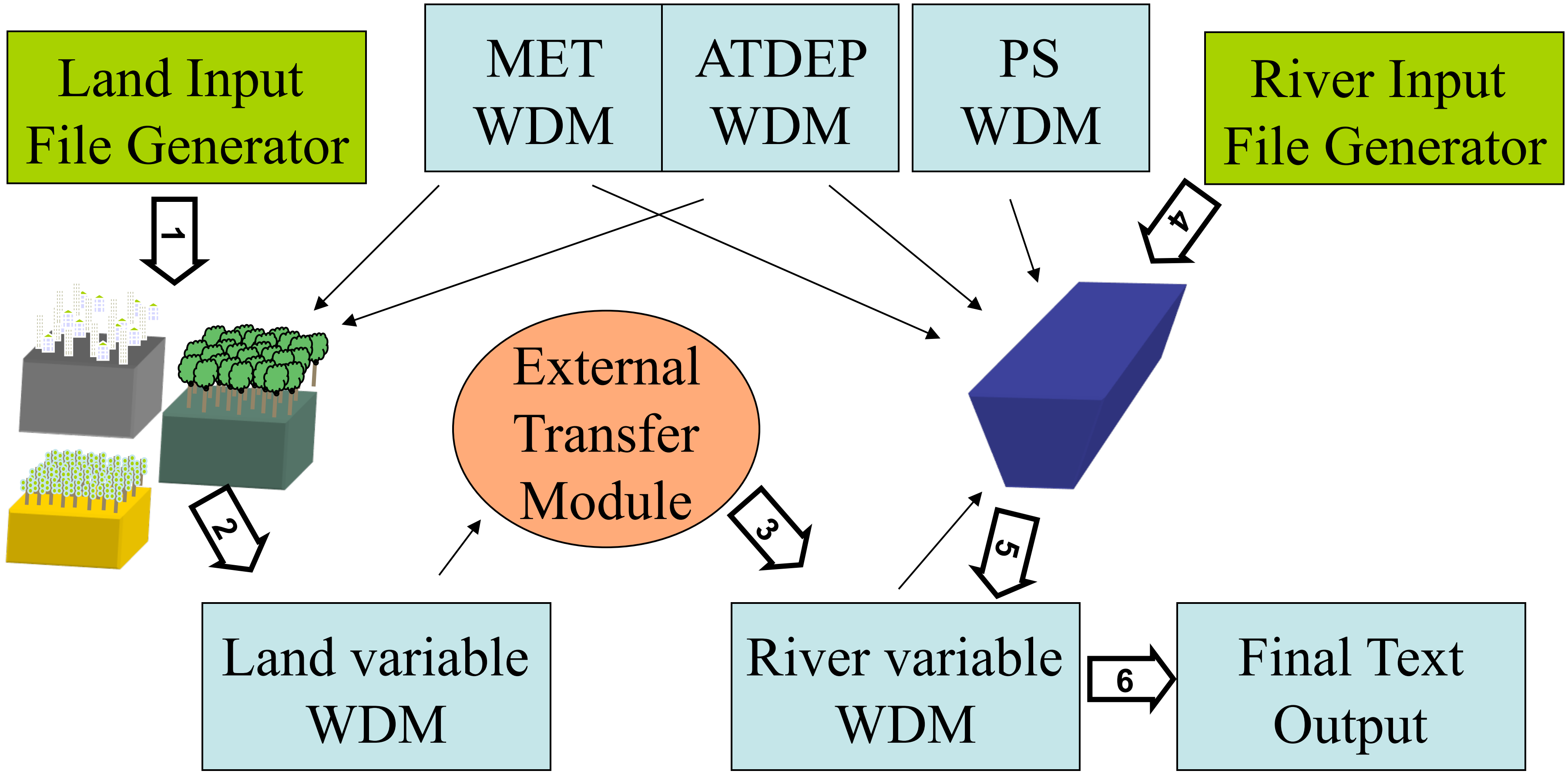
A software solution was devised that directs the appropriate water, nutrients, and sediment from each land use type within each land segment to each river segment



Each land use type simulation is completely independent.
Each river simulation is dependent on the local land use type simulations and the upstream river simulations.

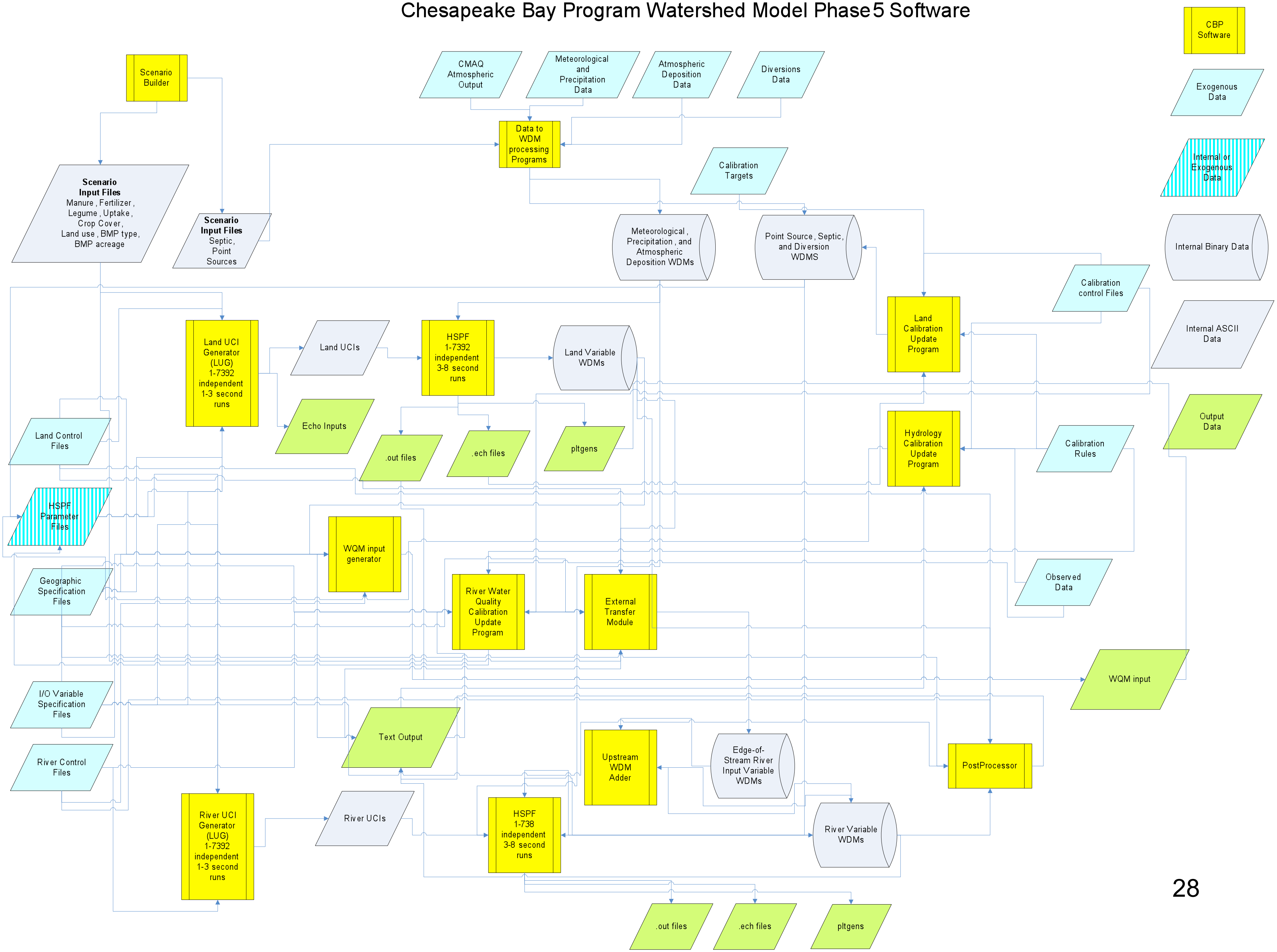
Flexible Functionality

WDM = HSPF-specific binary file type
UCI = User Controlled Input (input file)



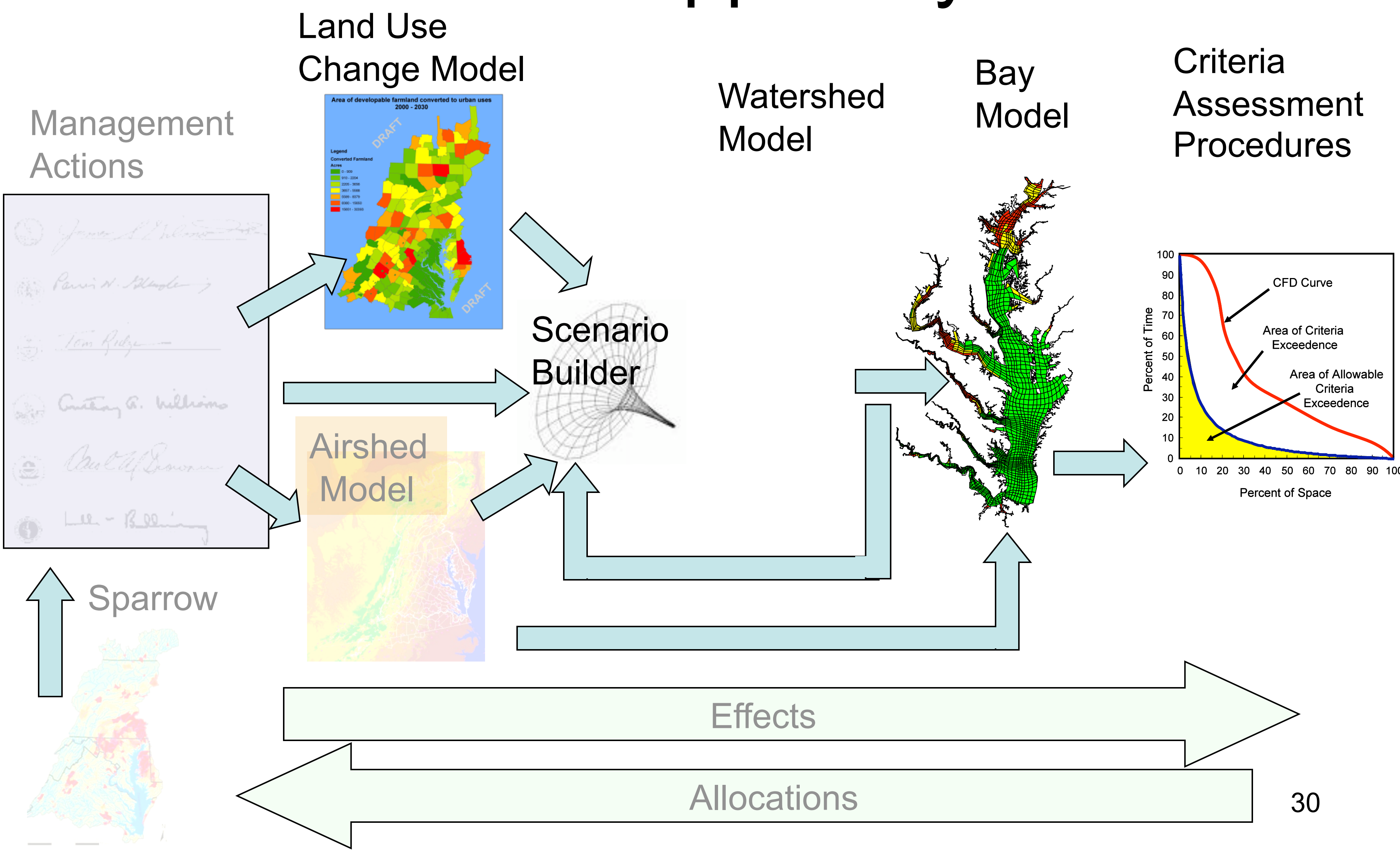
1. Land UCIs are generated
2. HPSF is run on the land UCIs and output is stored in individual WDMs
3. The ETM is run converting land output to river input, incorporating land use, BMPs, and land-to-water delivery factors. Output is stored in river-formatted WDMs
4. River UCIs are generated
5. HSPF is run on the river UCIs and output is written back to WDMs
6. Postprocessor reads river WDMs and writes ASCII output

Chesapeake Bay Program Watershed Model Phase 5 Software



Scenario Builder

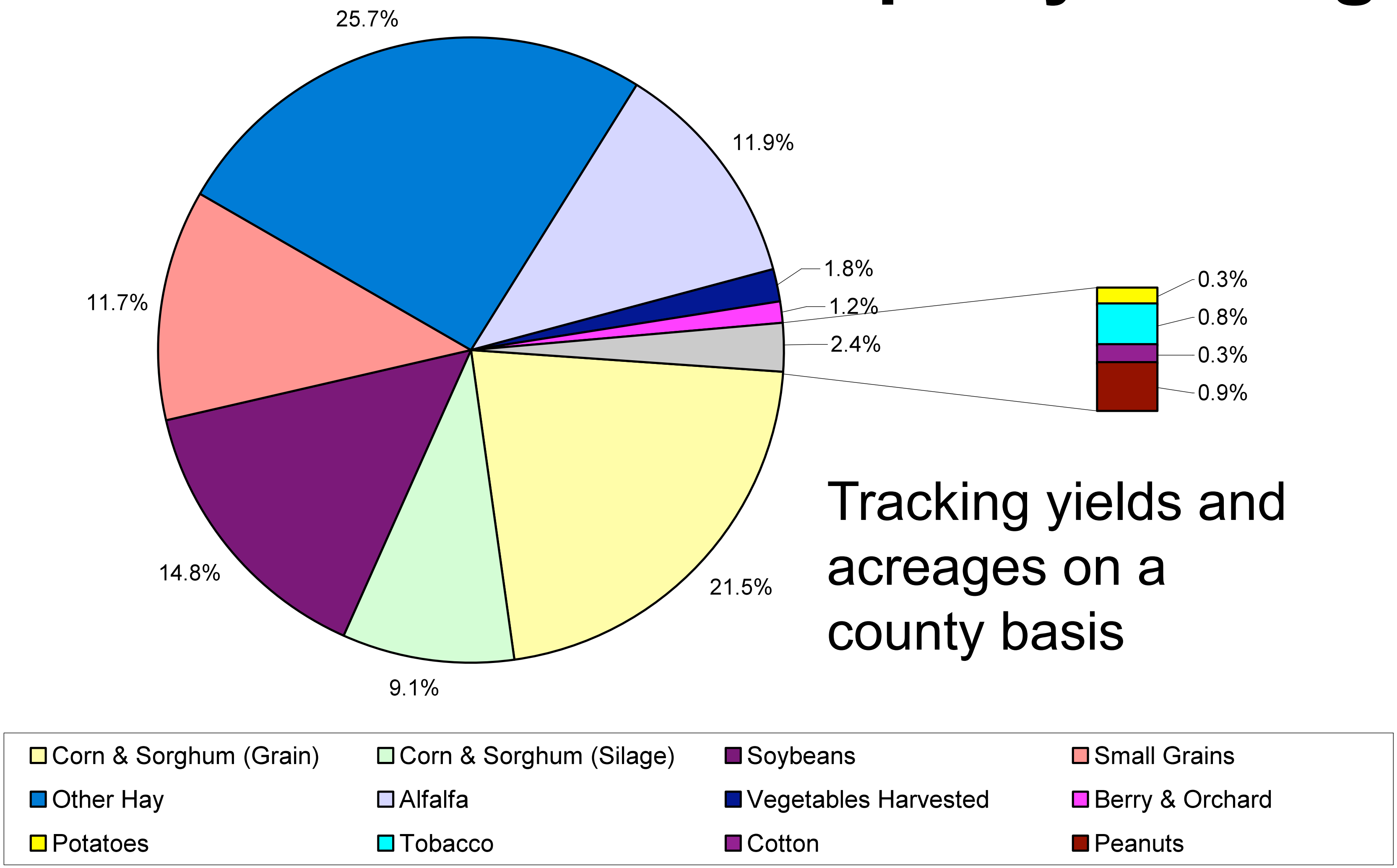
Chesapeake Bay Program Decision Support System



Number of Scenarios

- Phase 1 – 0
- Phase 2 – fewer than 10
- Phase 3 – never used
- Phase 4.1 – 37
- Phase 4.3 – 400-500
- Phase 5 – about 30 pre-finalization
  - Lauren Hay plans to run 600
  - 1000s? For management

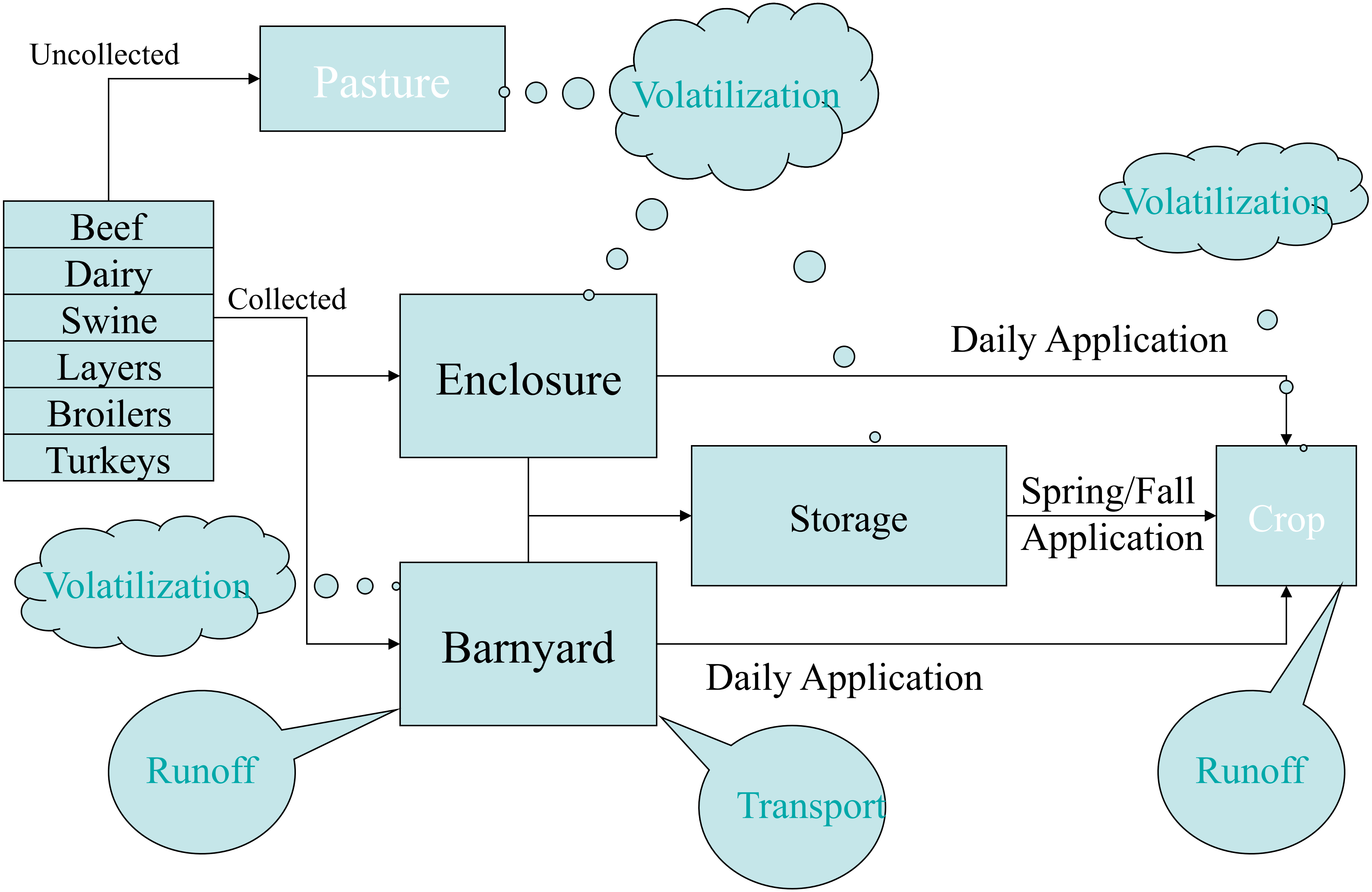
Watershed Wide Crops by Acreage

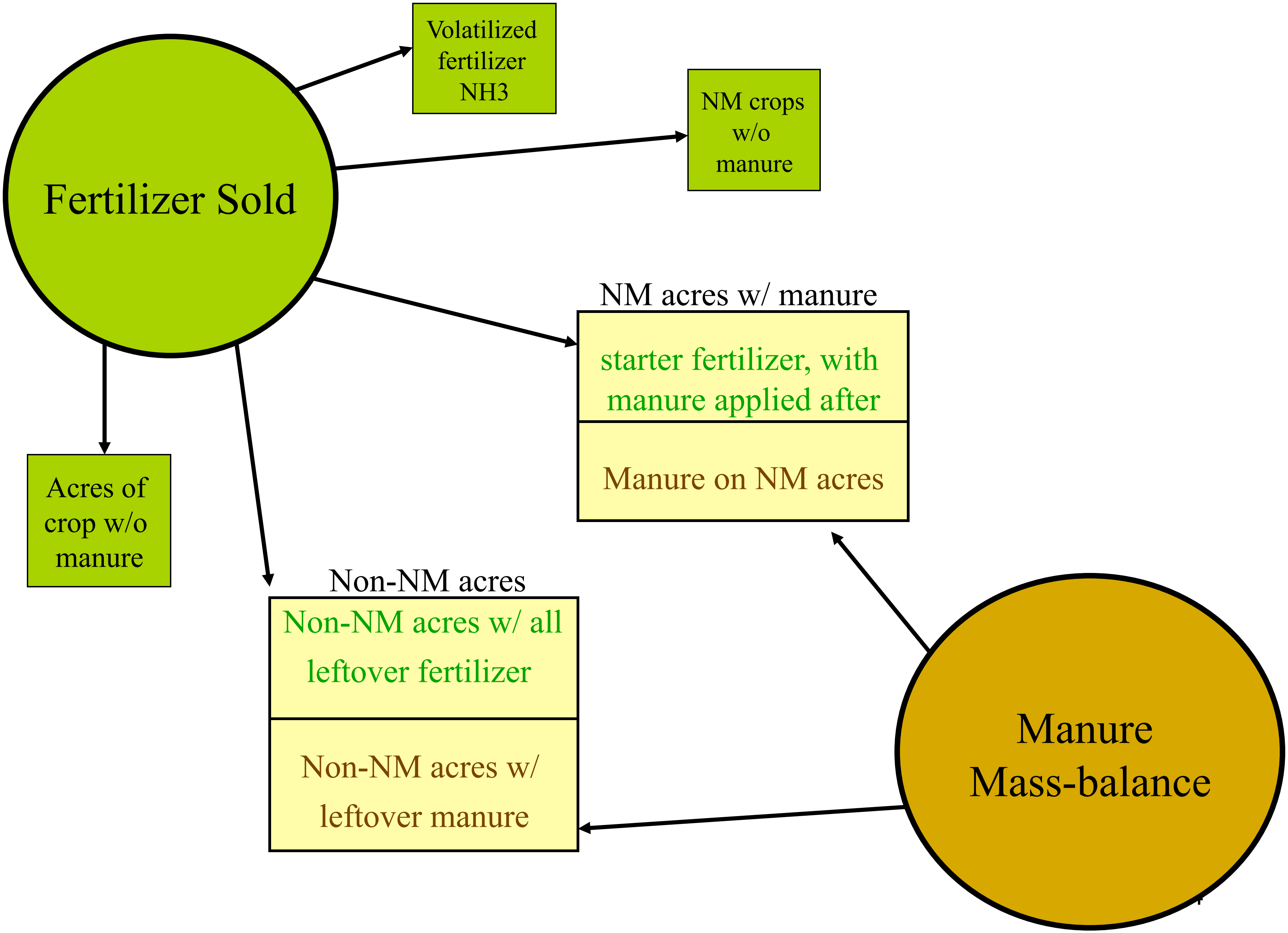


Tracking yields and acreages on a county basis

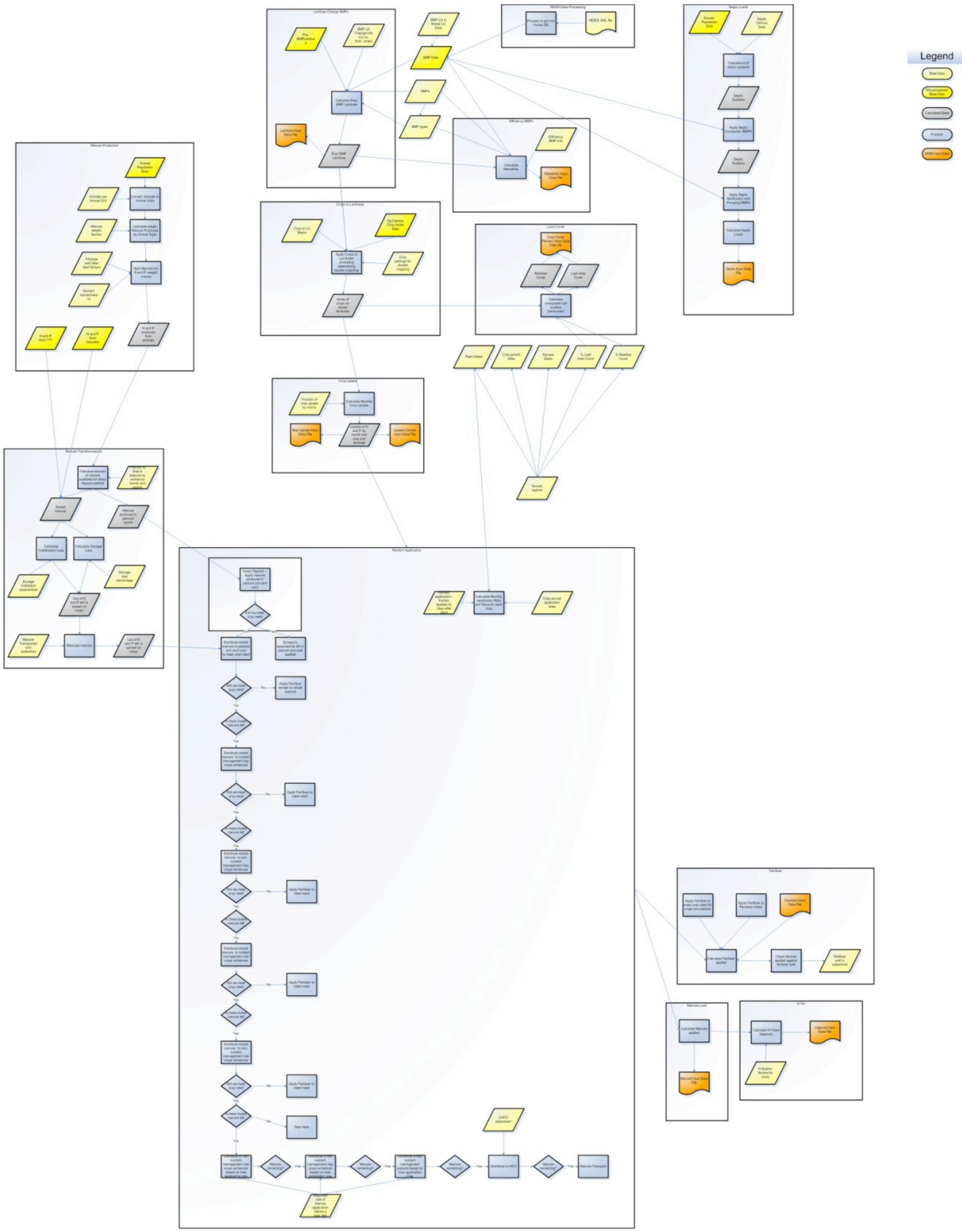
Approximately 100 crop types and 10 growing regions with different parameters for each

Manure Data Model





Fertilizer Sold
Volatilized fertilizer NH3
NM crops w/o manure
NM acres w/ manure
starter fertilizer, with manure applied after
Manure on NM acres
Acres of crop w/o manure
Non-NM acres
Non-NM acres w/ all leftover fertilizer
Non-NM acres w/ leftover manure
Manure Mass-balance

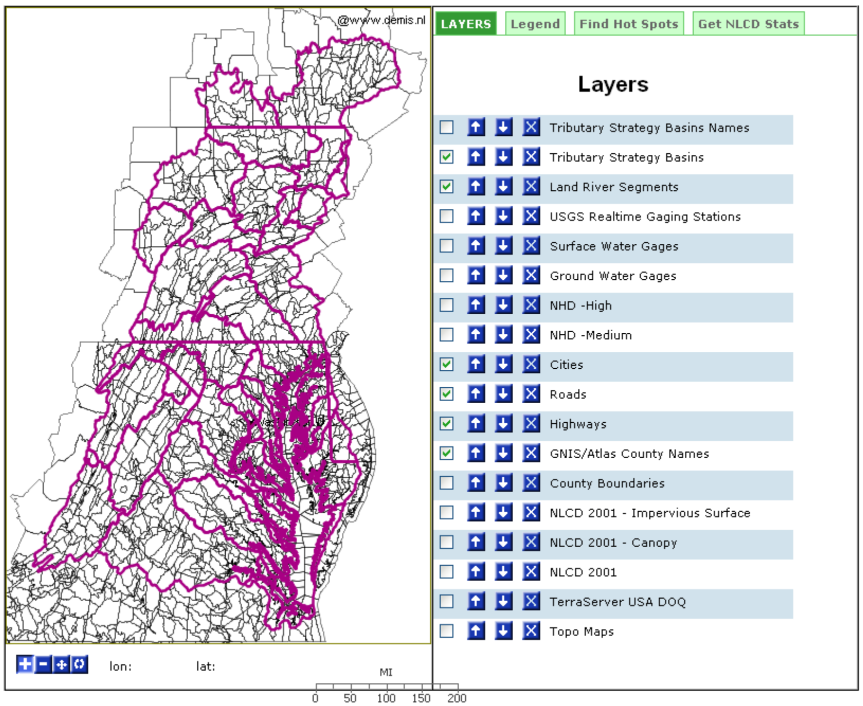


Scenario Builder

AKA COAST
AKA Vortex

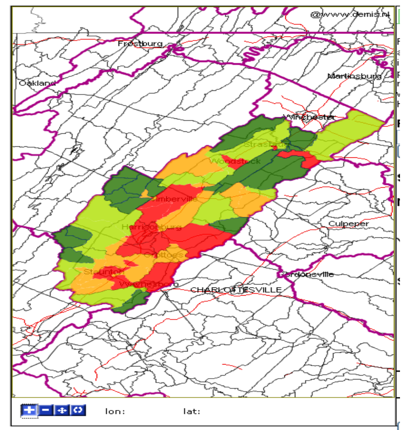
Chesapeake Online Assessment Support Tool

Select Your Watershed



Product of USGS and CBPO

Choose your task

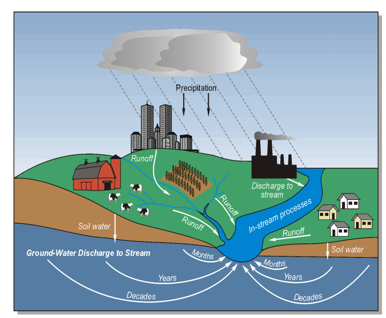


View loads spatially

Scenario Builder

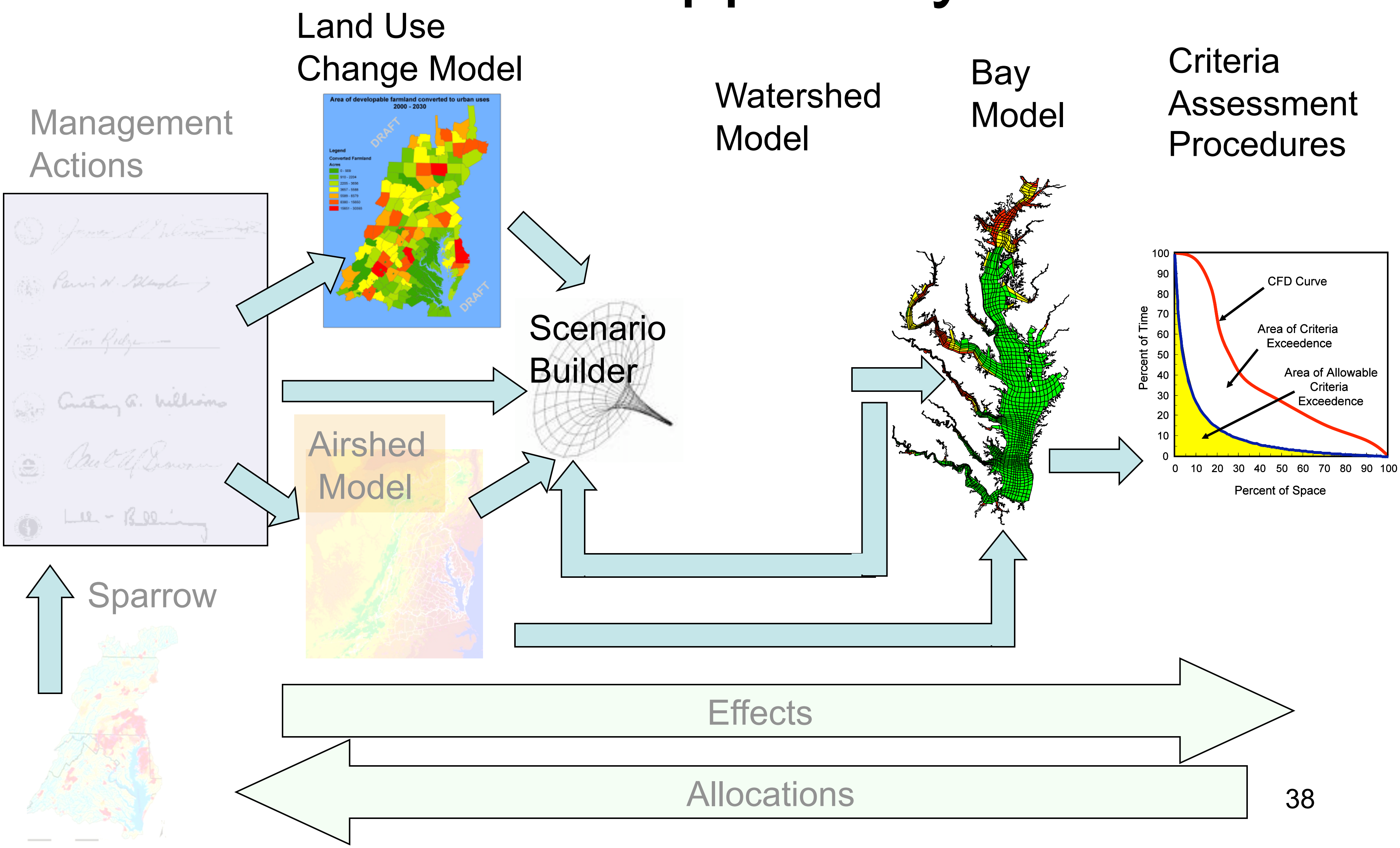
Observed Data and Calculated Trends

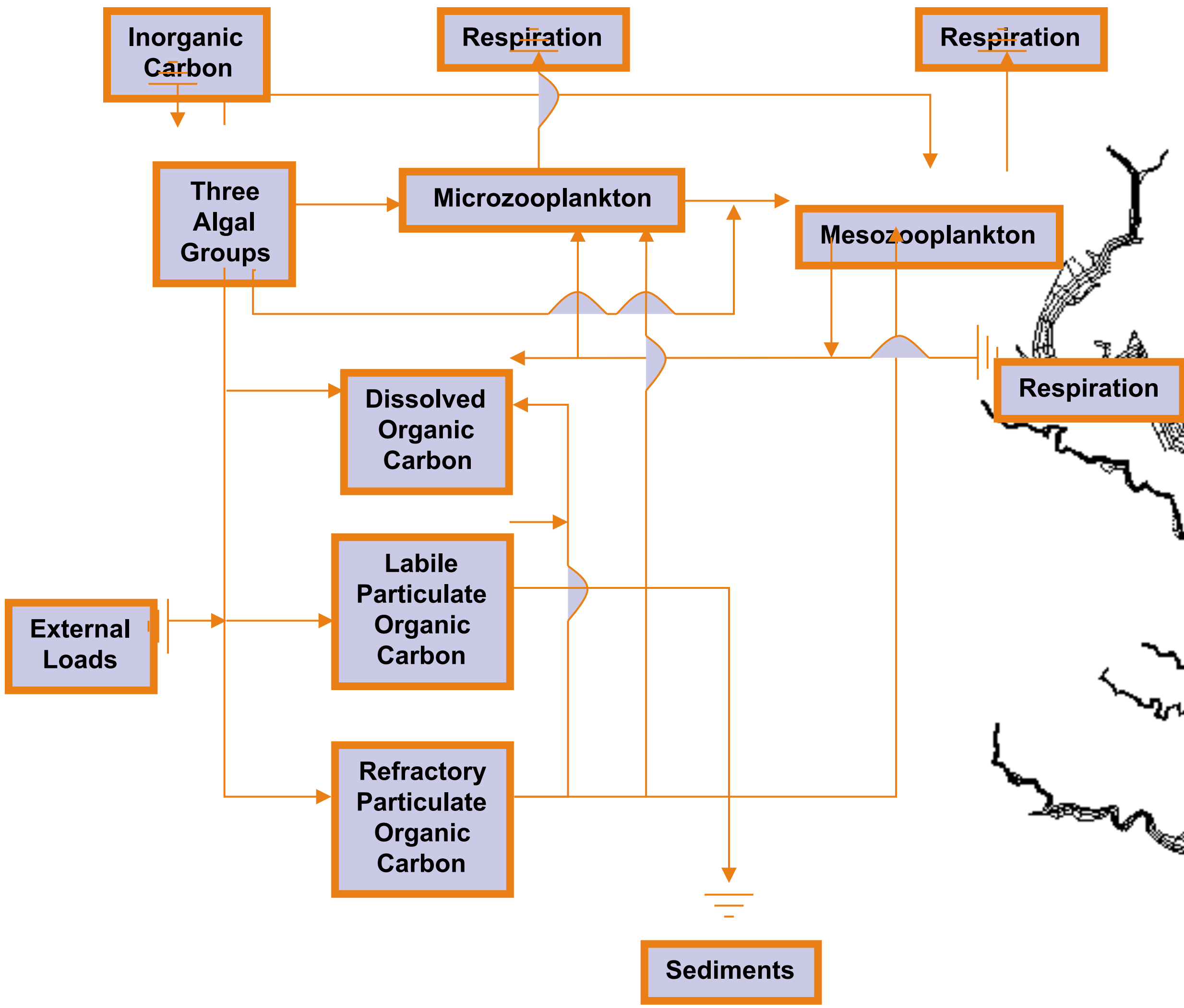
View Factors Affecting Trends



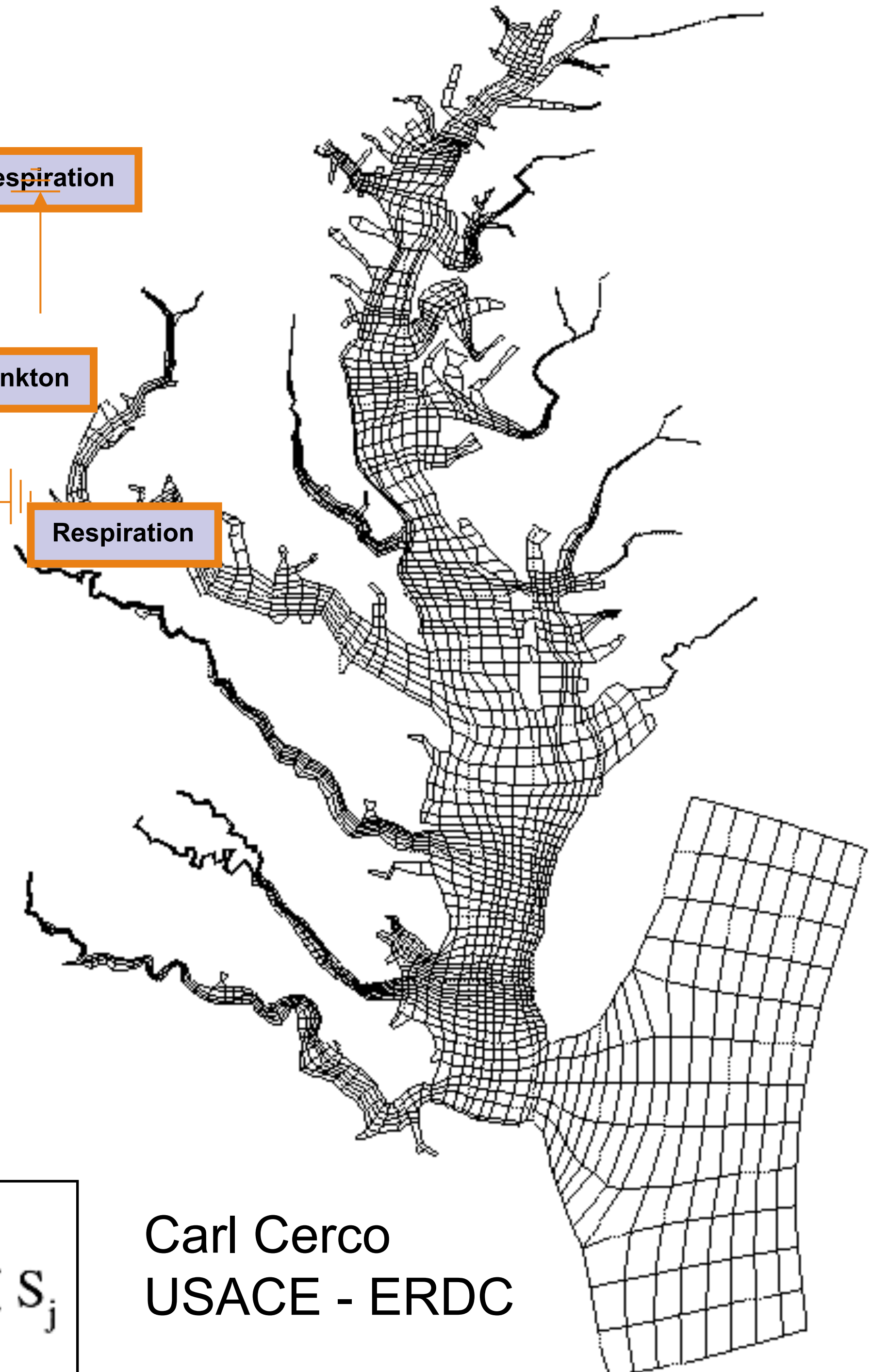
Estuarine Model

Chesapeake Bay Program Decision Support System



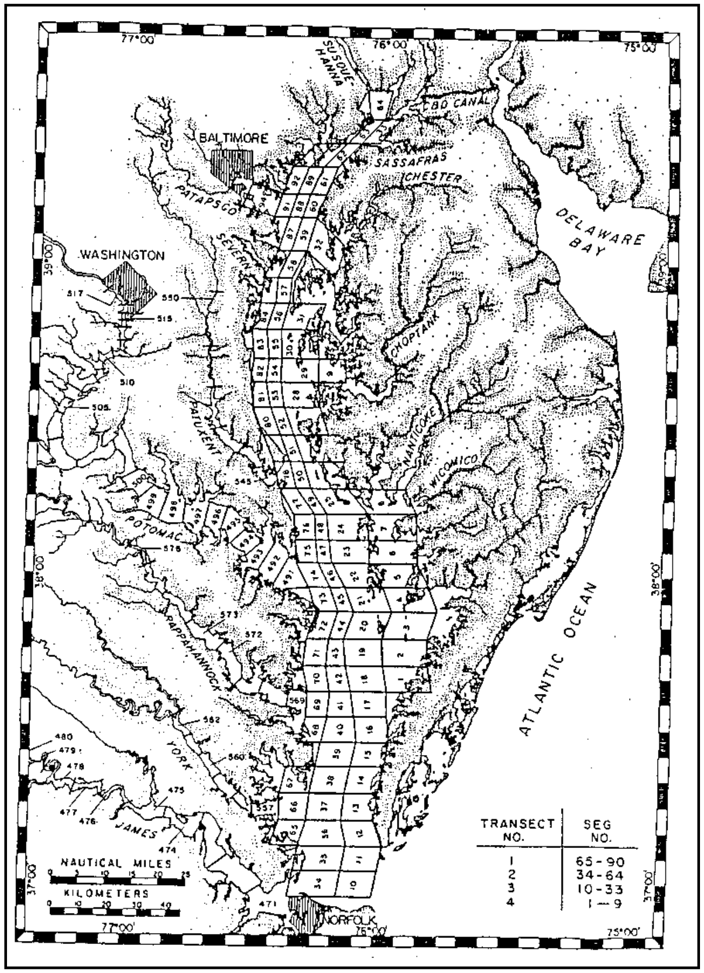


$$\frac{\delta V_j C_j}{\delta t} = \sum_{k=1}^{n} Q_k C_k + \sum_{k=1}^{n} A_k D_k \frac{\delta C}{\delta x_k} + \sum S_j$$



Carl Cerco
USACE - ERDC

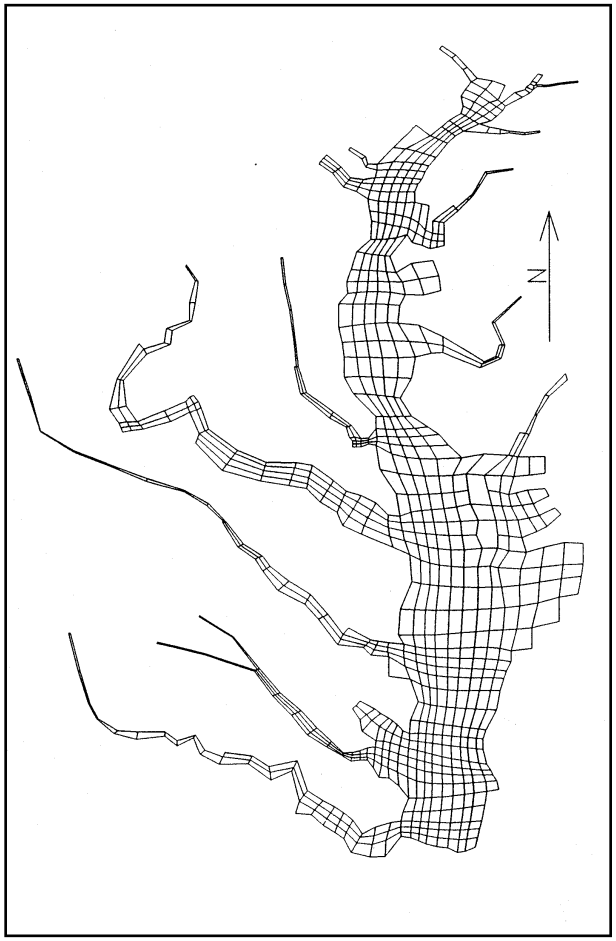
The 1987 Model



1985 grid, 585 cells

- 3-D hydrodynamics and water quality.
- Summer, steady-state.
- Indicated the importance of sediment-water interactions.
- One part of decision process that concluded a 40% nutrient load reduction would eliminate anoxia.

Three-D Time Varying Model (1992)

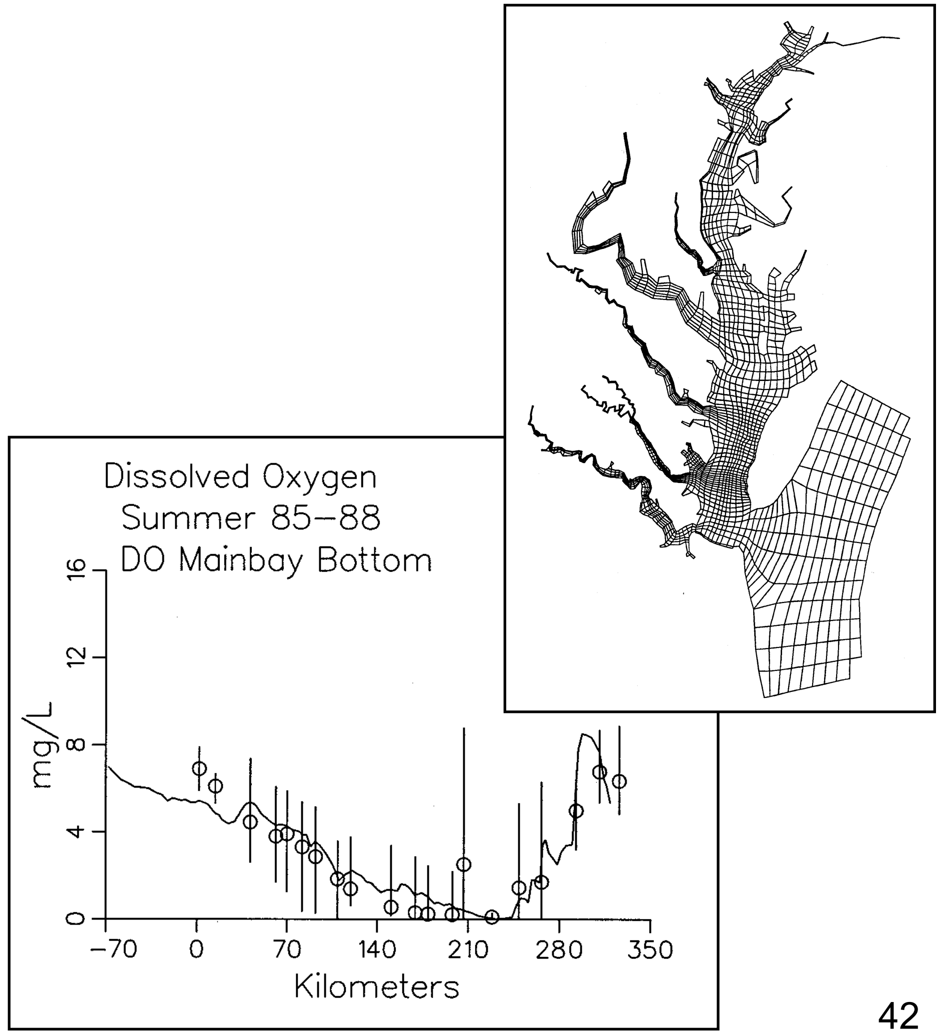


1992 grid, 5000 cells

- Linked watershed, hydrodynamic, and eutrophication models.
- Dynamic benthic sediment diagenesis component.
- Continuous application 1984-1986 and 1959-1988.
- Guided 1991 re-evaluation of 1987 Chesapeake Bay Agreement.

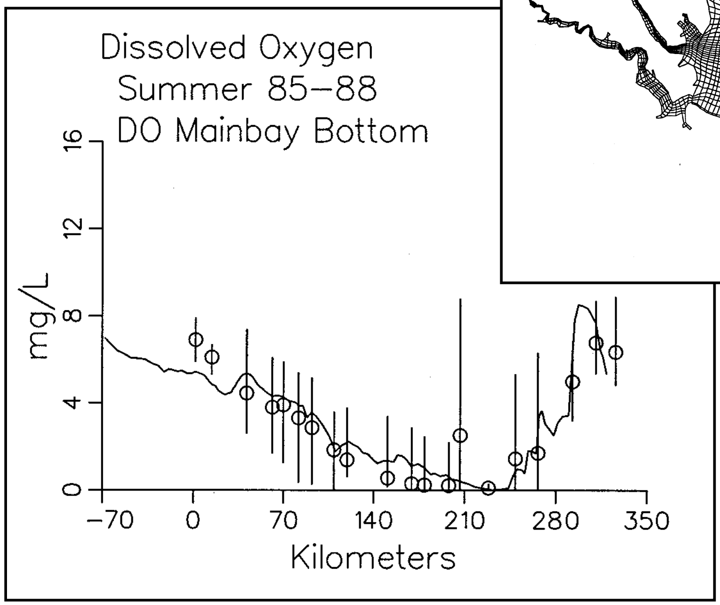
Tributary Refinements 1997

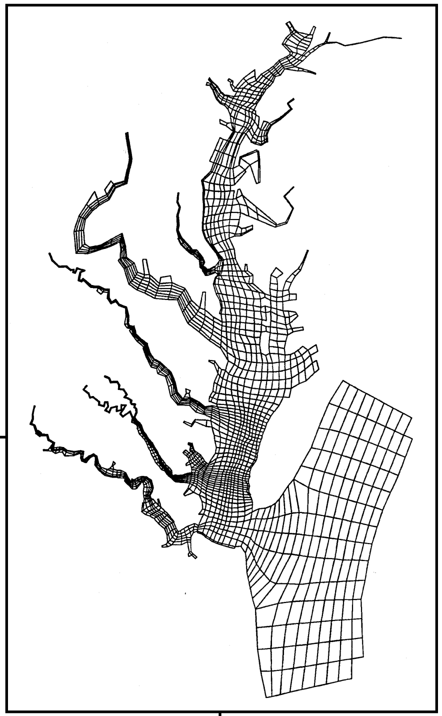
- 10,000 cell grid.
- Intertidal hydrodynamics.
- Ten-year simulation 1985-1994.
- Direct simulation of living resources.



Tributary Refinements 1997

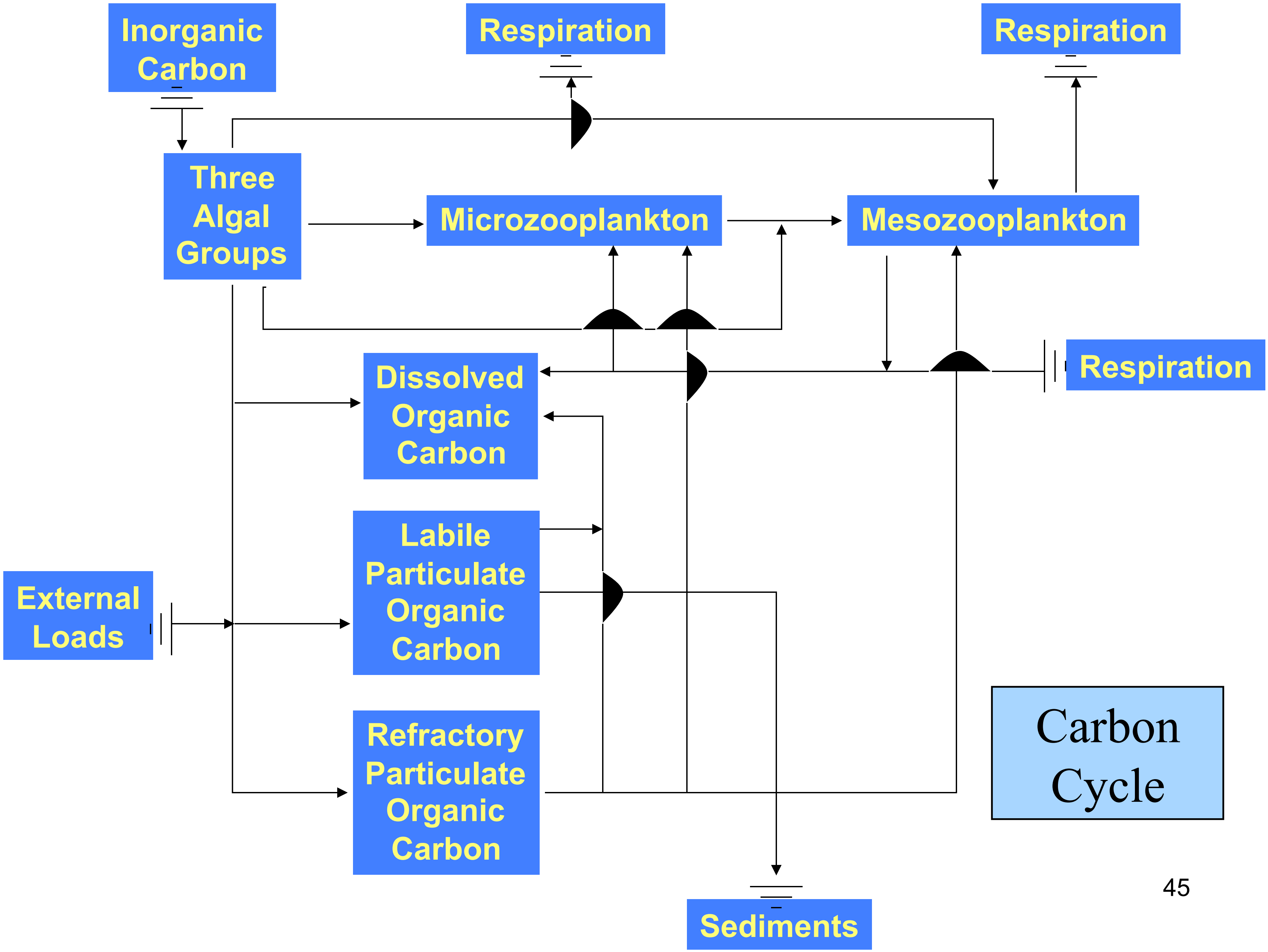
- Move boundary out to continental shelf.
- Introduce suspended solids.
- Relate light attenuation to suspended solids.

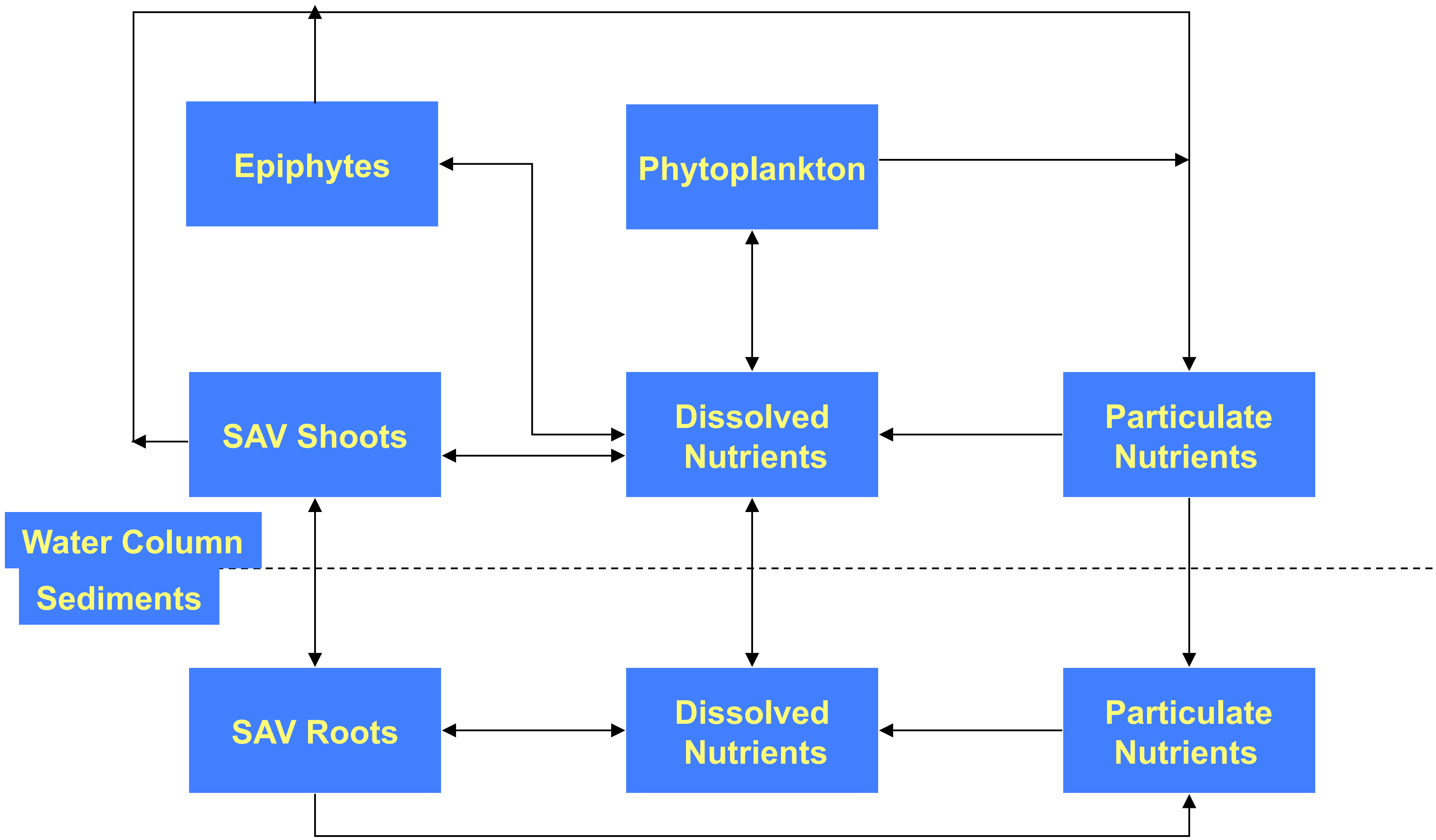




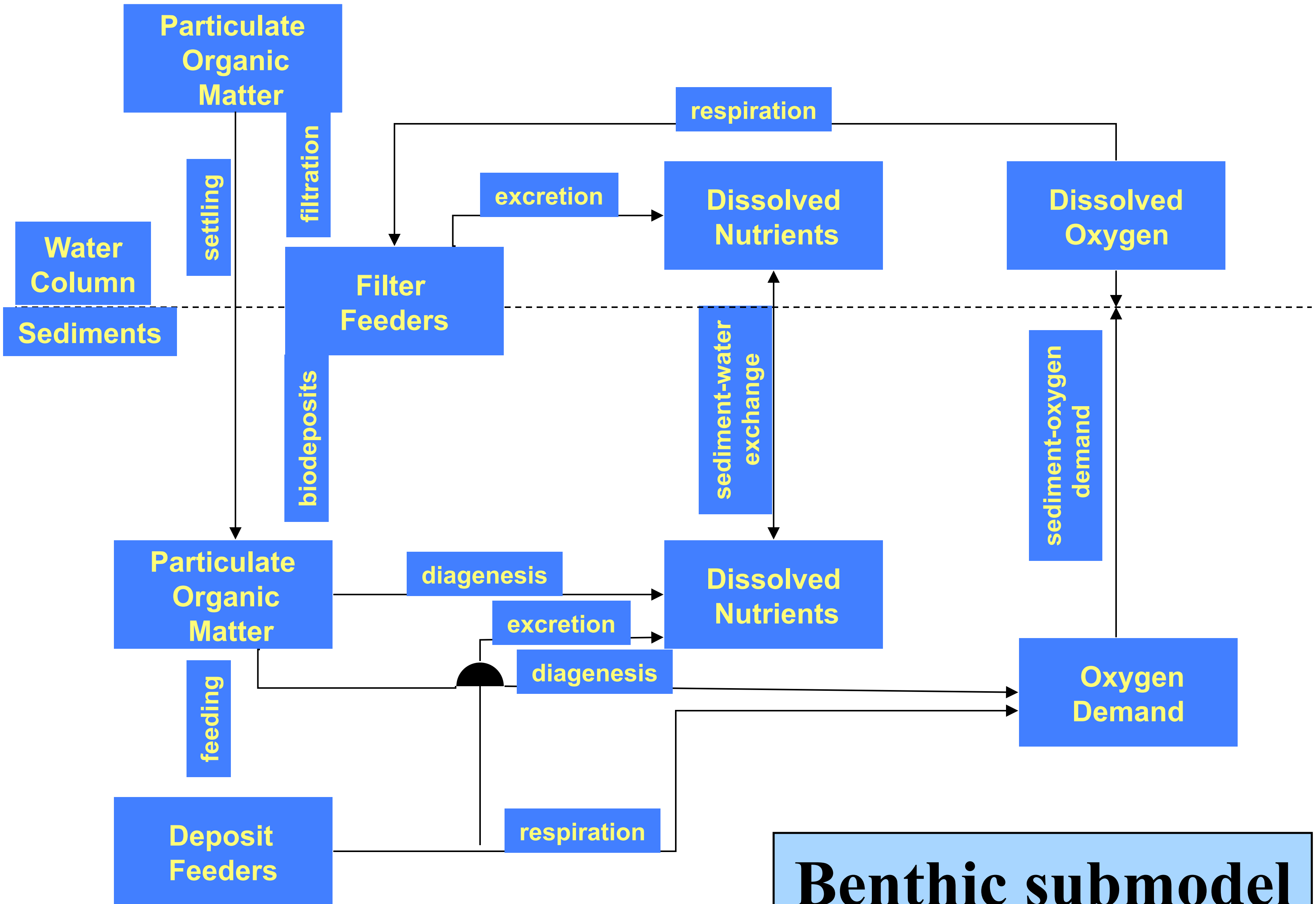
Added Living Resources 2003

- 13,000 cells
- Mesozooplankton
- Microzooplankton
- Submerged Aquatic Vegetation
- Filter Feeding Benthos (three species)
- Deposit-Feeding Benthos


Inorganic Carbon
Respiration
Respiration
Three Algal Groups
Microzooplankton
Mesozooplankton
Respiration
Dissolved Organic Carbon
Labile Particulate Organic Carbon
External Loads
Refractory Particulate Organic Carbon
Carbon Cycle
Sediments

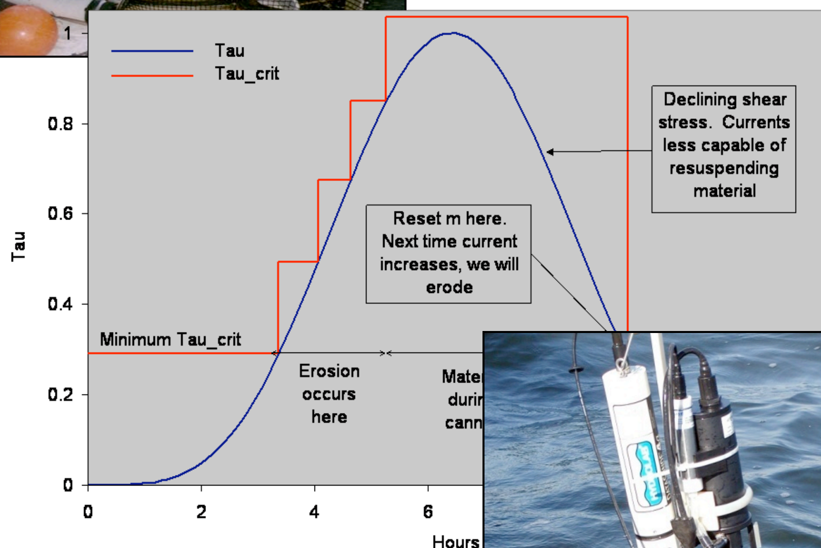


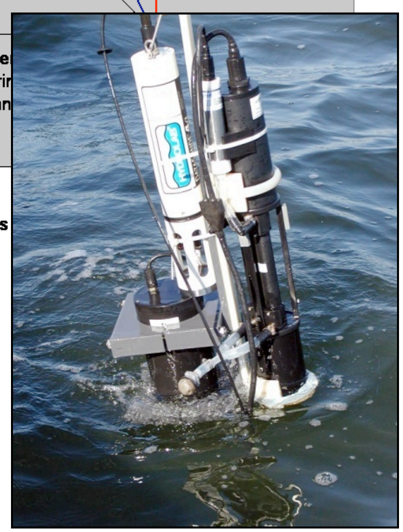
Submerged Aquatic Vegetation Model



Benthic submodel

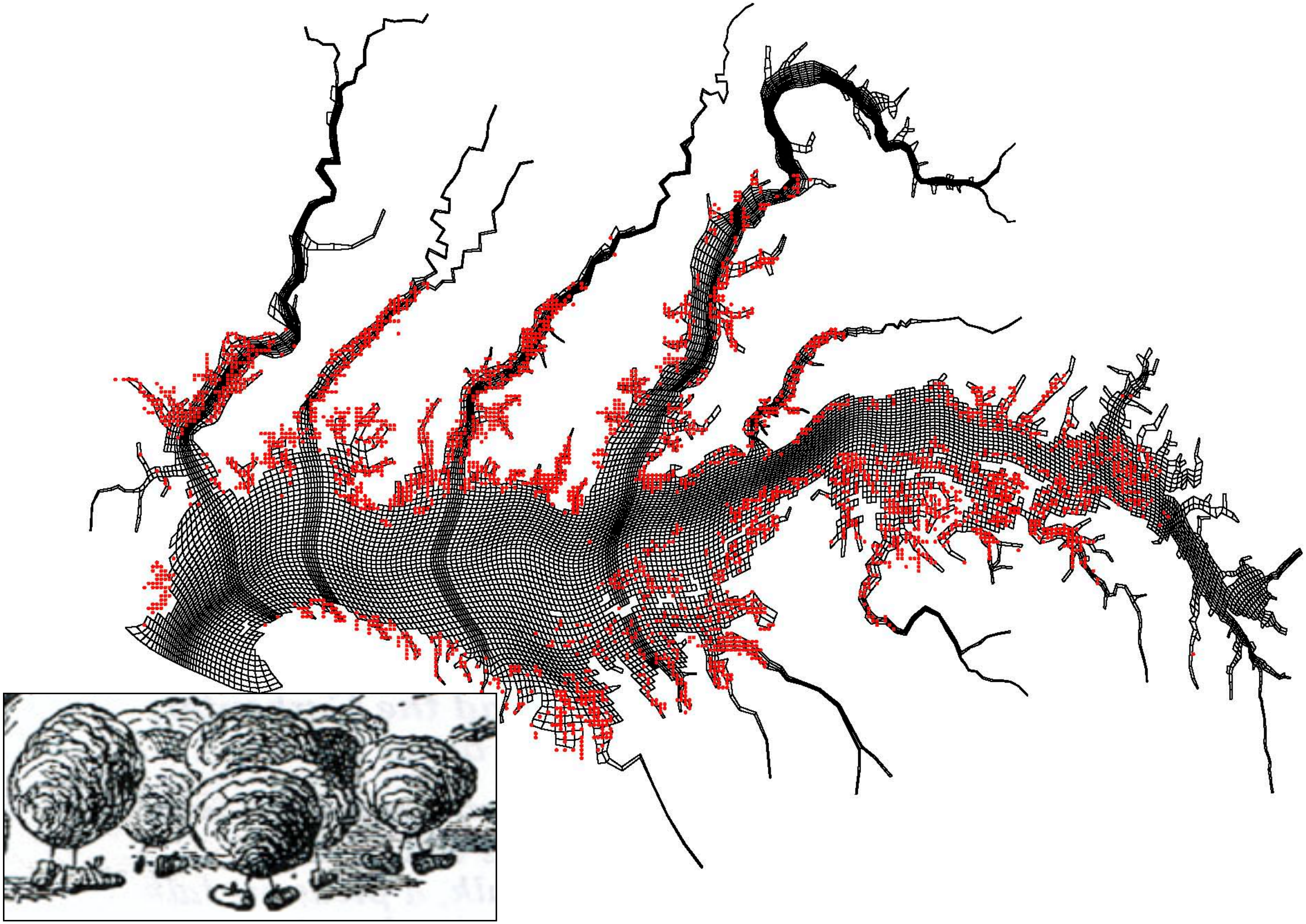
The 2008 Model





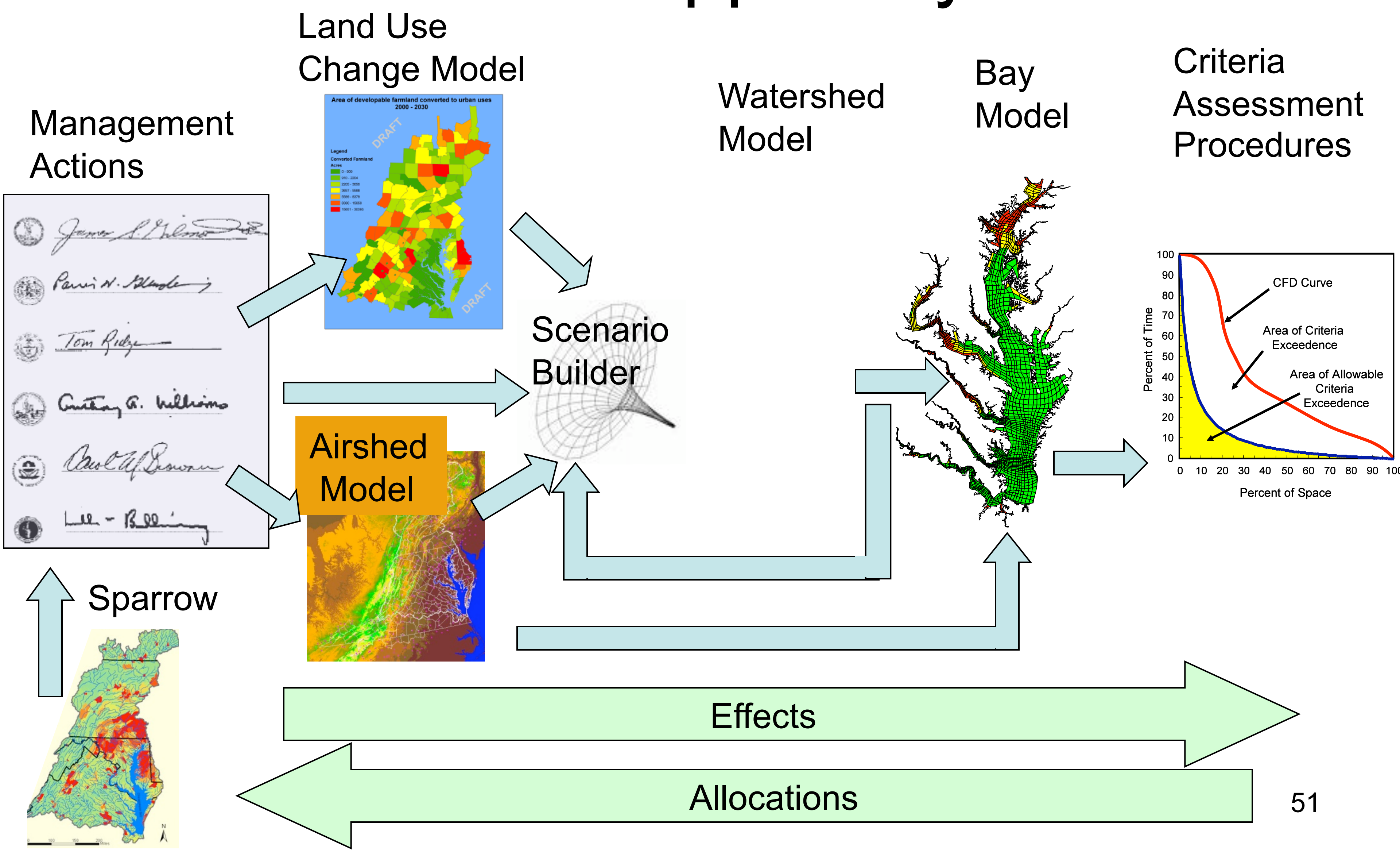
- 57,000 total cells.
- Process-oriented suspended solids model with ROMS bed.
- Advanced optical model.
- oyster model.
- Menhaden model

8400 Oyster Bars



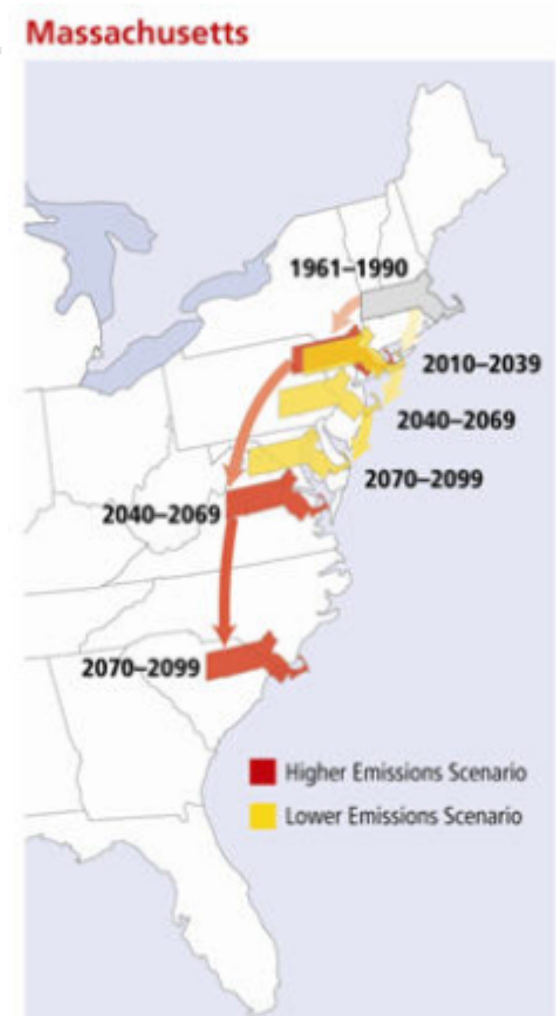
Linkages to outside models

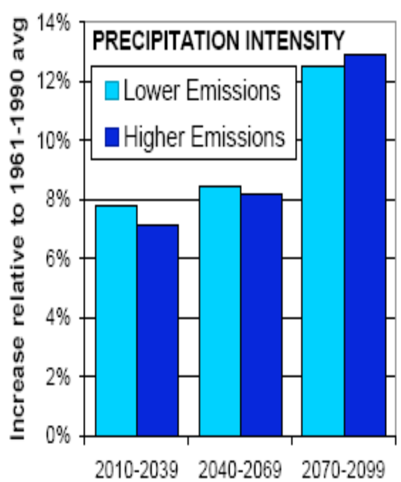
Chesapeake Bay Program Decision Support System

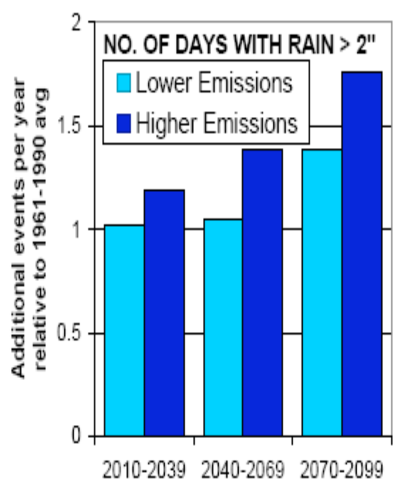


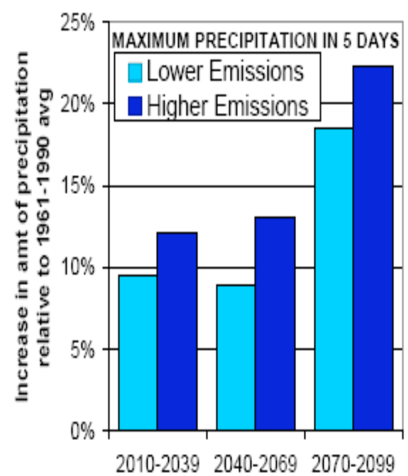
Climate Change Model

- EPA office of climate change supplied down-scaled climate change output
- Linked to rainfall model and watershed model.

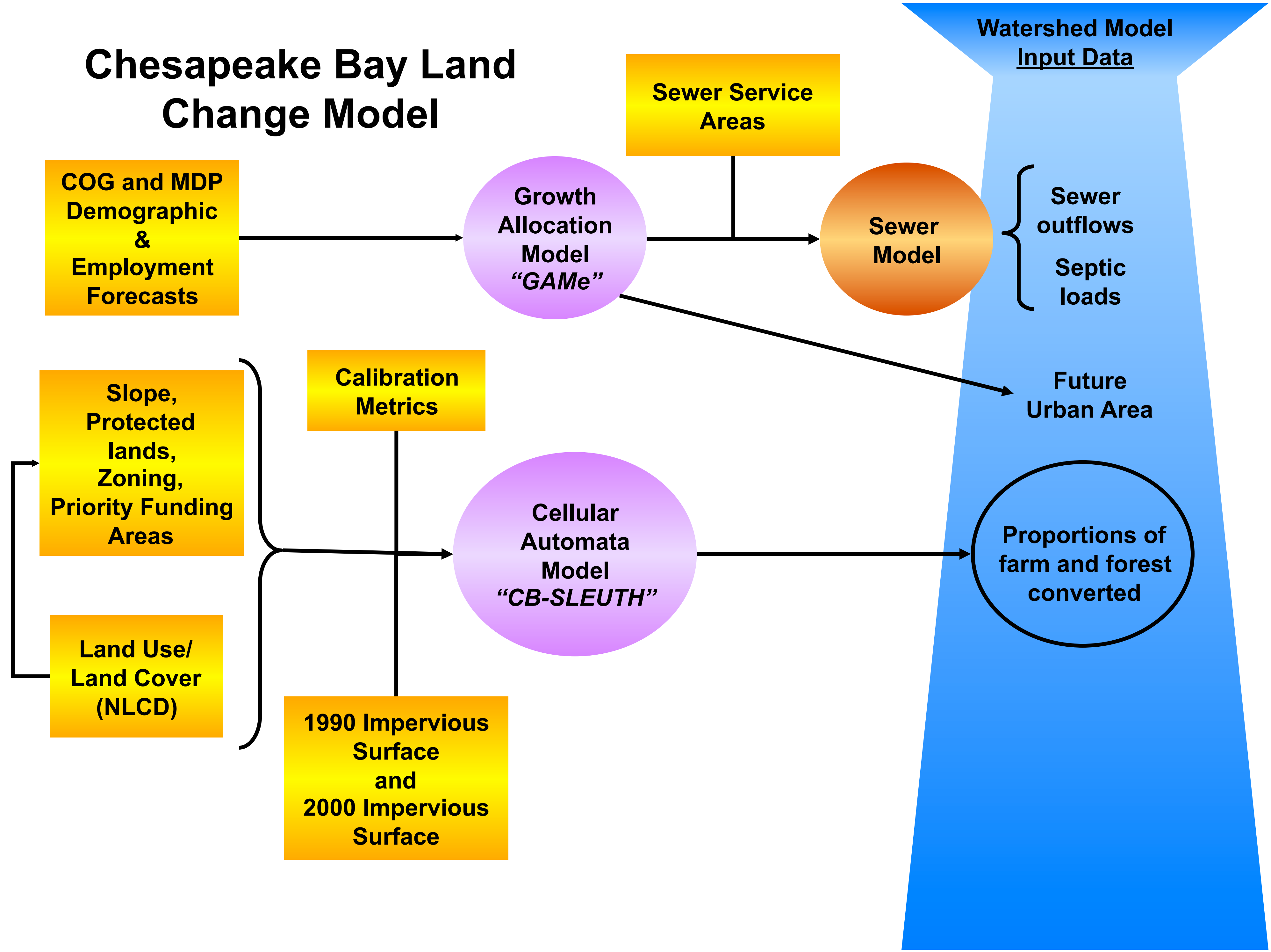


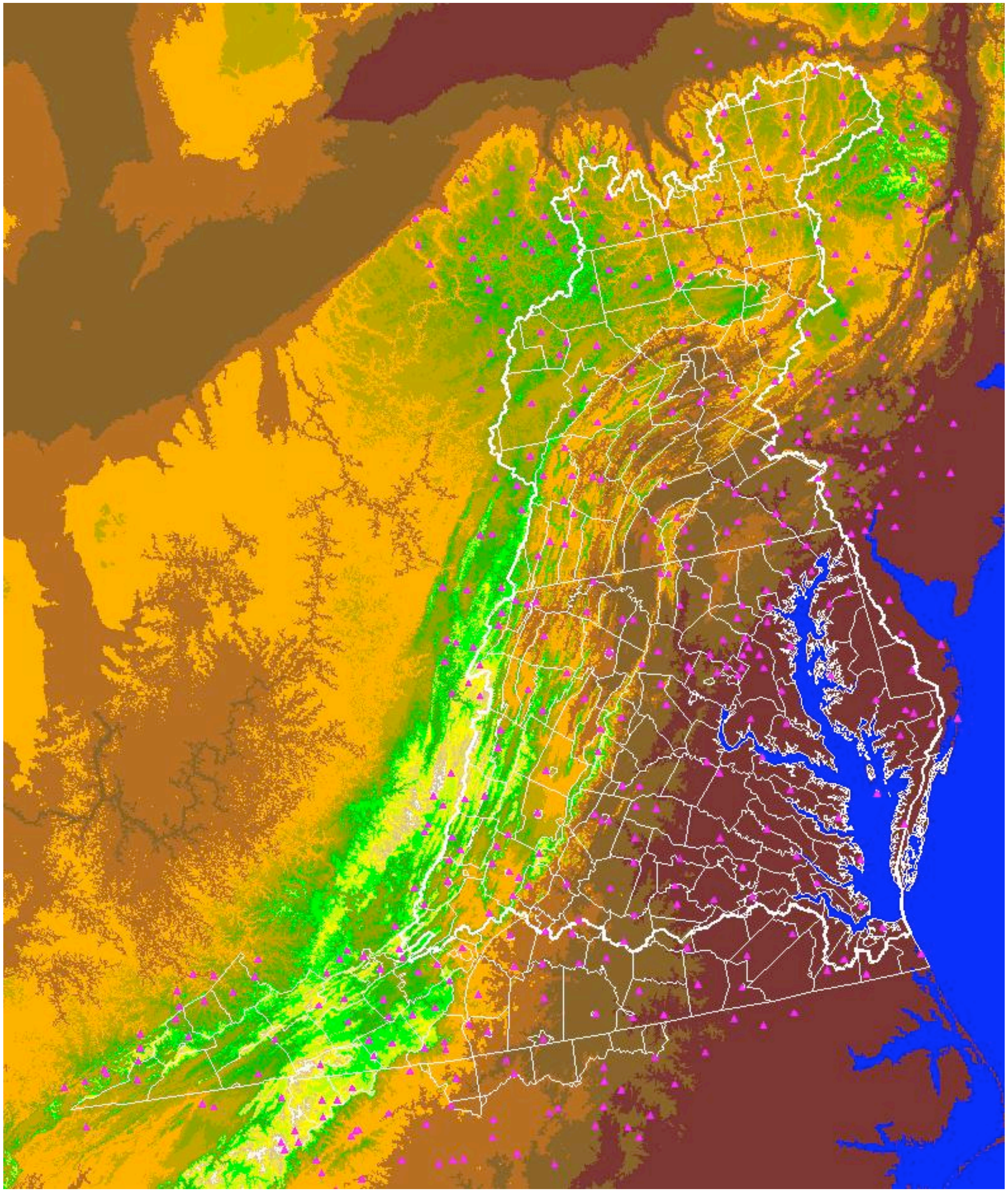






Source: Frumhoff et al. 2006 Climate change in the NE United States


Chesapeake Bay Land Change Model
COG and MDP Demographic & Employment Forecasts
Growth Allocation Model "GAMe"
Sewer Service Areas
Sewer Model
Watershed Model Input Data
Sewer outflows
Septic loads
Future Urban Area
Slope, Protected lands, Zoning, Priority Funding Areas
Calibration Metrics
Cellular Automata Model "CB-SLEUTH"
Proportions of farm and forest converted
Land Use/ Land Cover (NLCD)
1990 Impervious Surface and 2000 Impervious Surface



Rainfall

487 daily stations
192 hourly stations

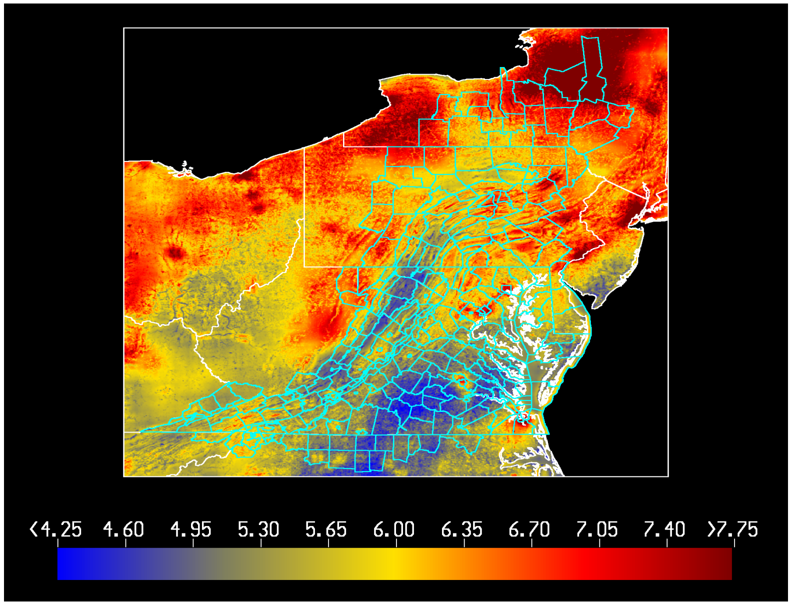
Monthly Regression of
- Latitude
- Longitude
- Altitude

Daily Intercept

1984-2005

Lauren Hay – USGS NRP

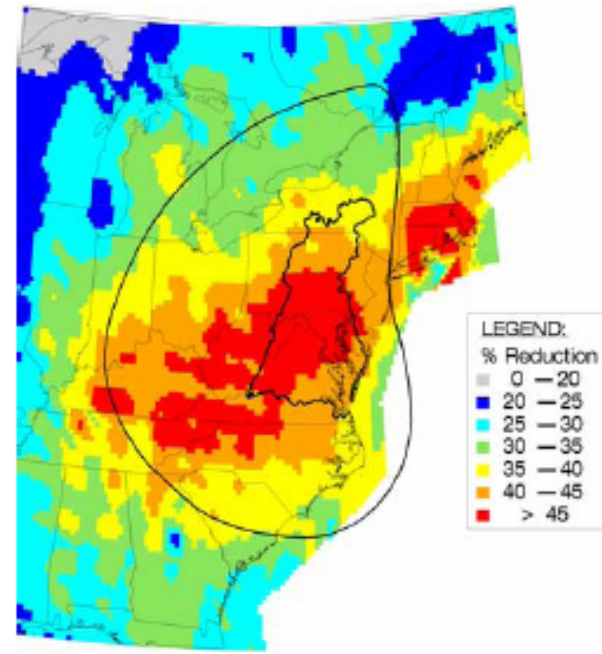
Atmospheric Deposition Estimates



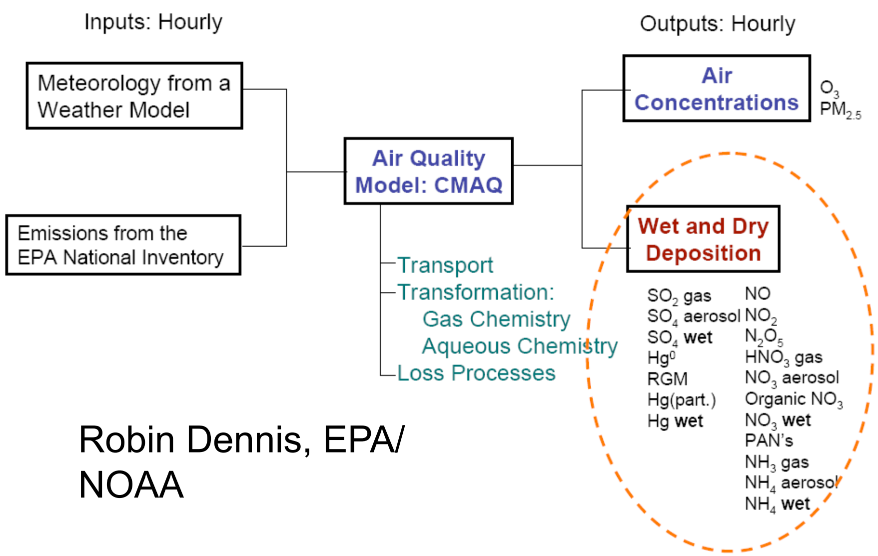
Combining a regression model of wetfall deposition...

Jim Lynch, Jeff Grimm
Penn State

NOx SIP Reg +
Tier II Mobile +
Heavy Duty Diesel Regs
2020
ox-N Dep % Change from 1990



…with CMAQ estimates of dry deposition for the base…

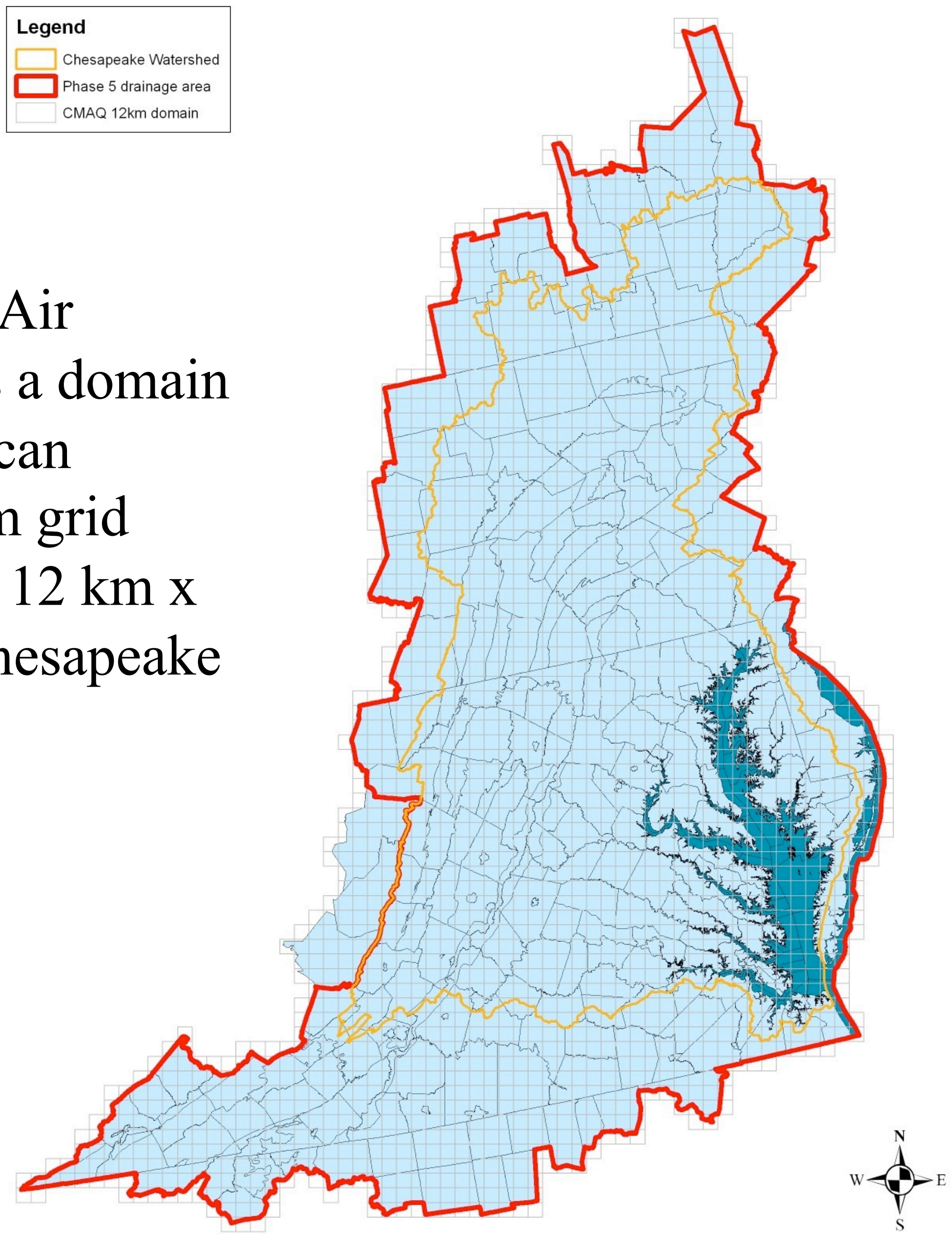


Robin Dennis, EPA/
NOAA

…and using the power of the CMAQ model for scenarios.

CMAQ Model

The Community Multiscale Air Quality Model (CMAQ) has a domain that covers the North American continent at a 36 km x 36 km grid scale and is nested at a finer 12 km x 12 km grid scale over the Chesapeake watershed and Bay.



Mostly ad hoc, hard coded

- CMAQ → watershed model
- Rainfall → watershed model
- Land change models → scenario builder
- Estuarine model outputs
- Scenario Builder → watershed model
  - But could easily be fit to a standard

Watershed – Estuarine coupling

- Not a particular standard, but very flexible.
- Geography file
- Transcription of Variables file
- Uses so far
  - 13k estuarine model
  - 57k estuarine model
  - 4k estuarine model (CBEO)
  - Potomac TMDL
  - York TMDL
  - SERC Study
  - UMD study

Watershed model is actually a coupled system of models

- 24 X 308 land models
- 700 river models
- Translation models
- Examples of modularity
  - Mass-balance and coefficient-based land nutrient models running simultaneously
  - Some urban models swapped for CSO data
  - Reservoir operations models inserted

Crystal Ball

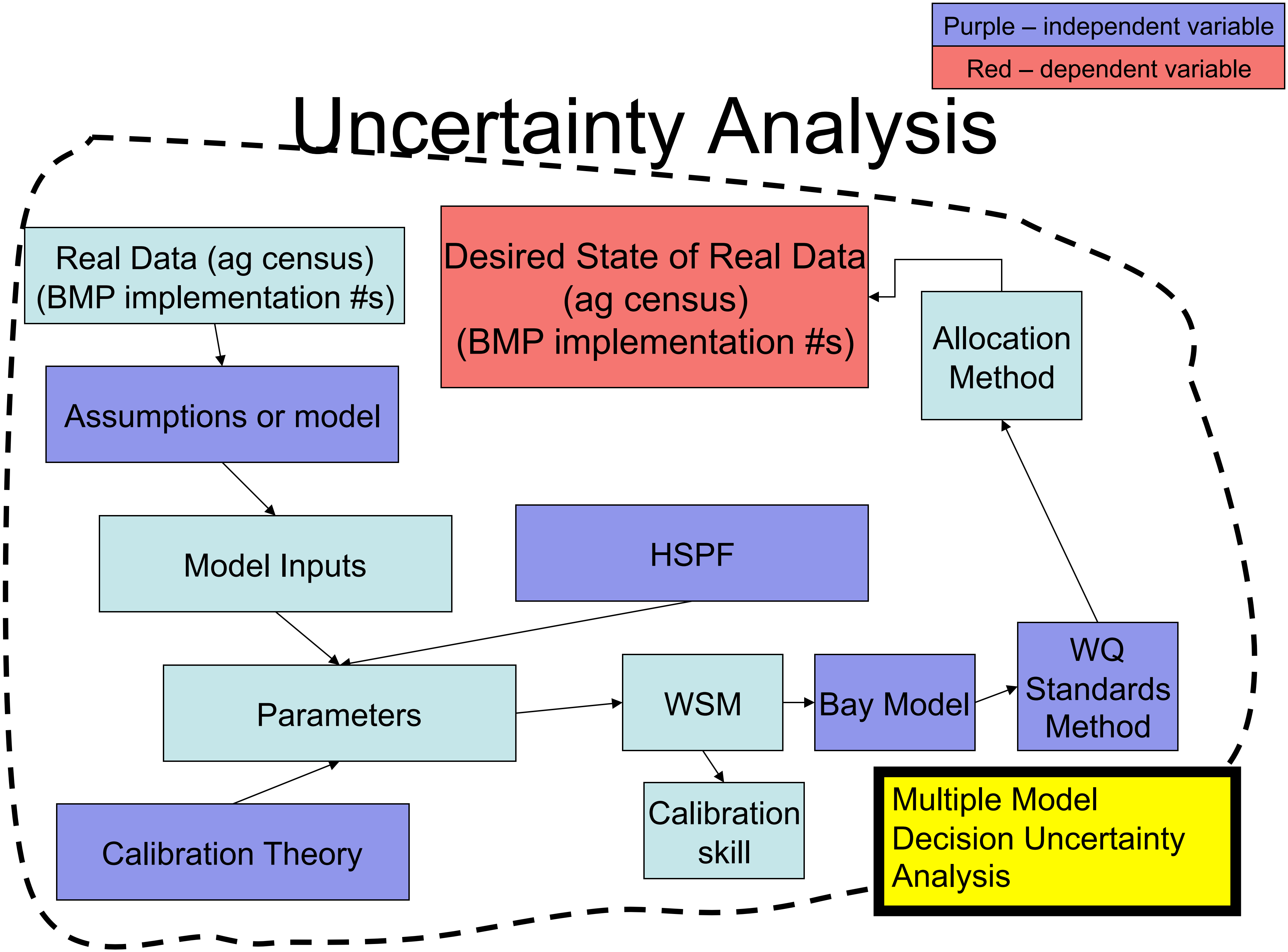
Scenario Builder Future

- Within the next year
  - Finish building
  - Create web-based GUI
  - Port to grid
- Longer Term
  - Interface with other models?
  - Automated data gathering?
  - Integrate with EPA's BASINS?
  - Use for a different study area?

Watershed Model future

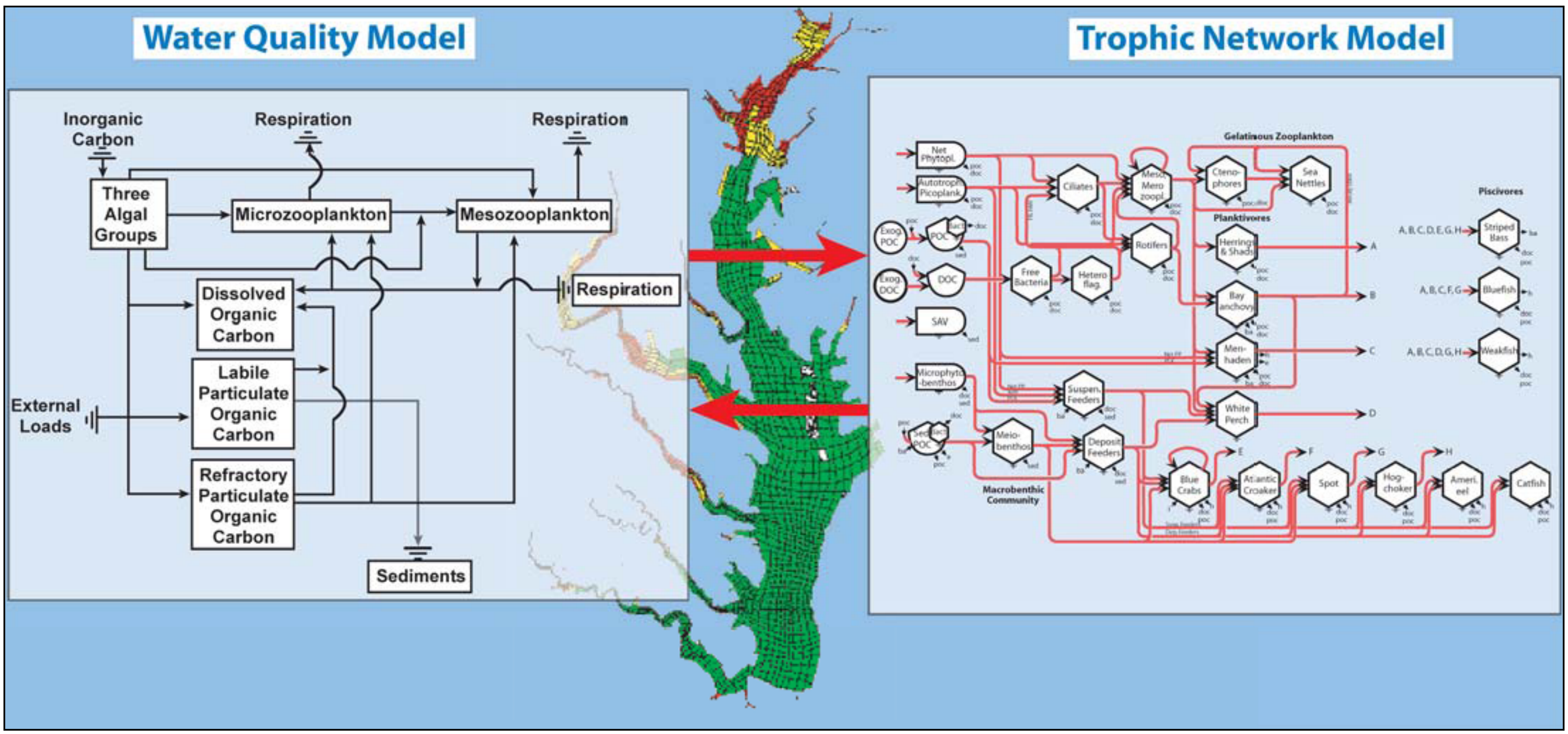
- Near Future
  - Port to grid
  - Uncertainty analysis
  - Substitute models
    - Different river simulation?
    - Small-scale agricultural models?
  - Expand geographic area?
- Longer Term
  - Evolve on phase 5 framework
    - or
  - Move to distributed

Uncertainty Analysis



Water Quality Model

Coupling the Ecopath with Ecosim ecological model to the Water Quality Model will examine the interaction between habitat and living resources.



Current questions

- Has the assimilation capacity changed (Hagy hypothesis)
- What is the interaction between water quality and living resources
- Refine factors that predict nutrient and sediment runoff from land sources including management practices.

Questions requiring short-term modeling

- Are the fish safe to eat?
- Can we swim?
- What will the current be tomorrow?
- Are the fish biting?
- Will there be jellyfish tomorrow?
- Will my city flood when the hurricane comes?