Chesapeake Bay Program Models

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Chesapeake Bay Program Modeling
3 presentations

• Chesapeake Bay Program Models and Management

• Current Working Watershed Model (phase4.3)

• Watershed Model in Development (phase5)
The Chesapeake Bay is one of North America’s largest and most biologically diverse estuaries, home to more than 3,600 species of plants, fish and animals.
Nutrient and Sediment Pollution

#1 Problem in the Bay

Chesapeake Bay Program Modeling
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.
Effects of Excess Sediment

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

Can damage habitats of some Plants and animals.
The Chesapeake Bay Program Partnership

Governor of MD

Governor of VA

Governor of PA

EPA Administrator

Executive Council

Mayor of DC

Chair of Chesapeake Bay Commission

Chesapeake Bay Program Modeling
Chesapeake Bay Agreements

1983 Agreement
- Established Executive Council, Chesapeake Bay Program

1987 Agreement
- Established Goal of **40% Reduction in Nutrient Loads**

1992 Amendments
- Established Approach for Tributary Specific Nutrient Load Reduction Strategies

1998 Directive
- Called for Assessment of Progress Toward Goals

2000 Agreement
- Reestablished and expanded restoration goals
- Established goal of “Delisting” Bay
Portions of the Chesapeake Bay and its tidal rivers are listed under the Clean Water Act as “impaired waters” largely because of low dissolved oxygen levels and other problems related to nutrient pollution.
De-Listing = TMDL avoidance

Establish Tidal Water-Quality Criteria
- Dissolved Oxygen
- Chlorophyll a
- Clarity

Apply Tidal Water-Quality Model to Set Allocations for Major Drainages

Apply Watershed Model to Set Allocations Within Major Drainages
Setting Load Allocations

Allocate Loading Caps to the 9 Major Basins

Further allocate cap load responsibilities to each state

Further allocate major tributary basin load caps to 37 state defined sub-basins
# NY goals

## Pollutant Loads and Goals

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>1985 Loads</th>
<th>2002 Loads</th>
<th>Healthy Bay Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (million lbs/yr)</td>
<td>21</td>
<td>18.23</td>
<td>12.58</td>
</tr>
<tr>
<td>Phosphorus (million lbs/yr)</td>
<td>1.14</td>
<td>1.02</td>
<td>0.59</td>
</tr>
<tr>
<td>Sediment (million tons/yr)</td>
<td>0.172</td>
<td>0.145</td>
<td>0.131</td>
</tr>
</tbody>
</table>

## Percentage of Total Load or Land Use in New York (2002)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Agriculture</th>
<th>Urban/Suburban</th>
<th>Point Source</th>
<th>Septic</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>44</td>
<td>15</td>
<td>10</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>54</td>
<td>15</td>
<td>27</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Sediment</td>
<td>56</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>% Land Cover</td>
<td>20</td>
<td>18</td>
<td>NA</td>
<td>NA</td>
<td>61</td>
</tr>
</tbody>
</table>

Chesapeake Bay Program Modeling
CBP Modeling Structure

Regional Acid Deposition Model

Sparrow

Watershed Model

Chesapeake Bay Estuary Model Package

Chesapeake Bay Program Modeling
CBP Modeling Structure

Watershed Model

Chesapeake Bay Program Modeling
Purposes of the Watershed Model

1. Accurately deliver loads to the Tidal Water Quality Model

2. Equitably account for all load sources

3. Assess changes due to management
Requirements for WSM

• Daily flow, nutrient, and sediment load
• Accurately simulate any major land use
• Responsive to Nutrient input to land
• Responsive to Structural BMPs
HSPF

- Hourly time step
- Complex
  - sensitive to many inputs
  - very flexible
- Open Source, Free
- Wide usage
Chesapeake Bay
Watershed
64,000 square miles
Simulated with HSPF
Chesapeake Bay Program Modeling

Loading Sources in Watershed Model

- Pasture
- Conv. Till
- Cons. Till
- Hay
- Manure

- Forest
- Mixed Open
- Perv Urb
- Imp Urb

- Septic
- Point Source

Chesapeake Bay Program Modeling
Loading Sources in Watershed Model
Land Simulation -- 1 Acre

Surface
Interflow
Lower Zone
Ground Water

Chesapeake Bay Program Modeling
Land Simulation – 4 soil layers

Surface

Interflow

Lower Zone

Ground Water

Chesapeake Bay Program Modeling
Each Soil Layer

Lower Zone

Chesapeake Bay Program Modeling
Chesapeake Bay Program Modeling

Nutrient and Sediment Simulation

Meteorology

Precipitation

Land Morphology

Runoff and Groundwater

Phosphorus Cycle

Sediment Export

Nitrogen Cycle

Nutrient Inputs

Chesapeake Bay Program Modeling
Nitrogen Cycle in Watershed Model Forest

- Trees
- Roots
- Leaves

- Nitrate
- Solution Ammonia
- Adsorbed Ammonia
- Particulate Labile Organic N
- Solution Labile Organic N
- Particulate Refractory Organic N
- Solution Refractory Organic N

- Atmospheric Deposition
- Denitrification

Exports and Reactions

- Solution Ammonia
- Particulate Labile Organic N
- Solution Labile Organic N
- Particulate Refractory Organic N
- Solution Refractory Organic N
Nutrient and Sediment Simulation

Chesapeake Bay Program Modeling
Nutrient and Sediment Simulation

Meteorology

Precipitation

Land Morphology

Runoff and Groundwater

Phosphorus Cycle

Sediment Export

Nitrogen Cycle

Nutrient Inputs

Chesapeake Bay Program Modeling
Each Soil Layer

Lower Zone

Chesapeake Bay Program Modeling
Chesapeake Bay Program Modeling

Land Simulation – 4 soil layers

- Surface
- Interflow
- Lower Zone
- Ground Water

Chesapeake Bay Program Modeling
Land Simulation --1 Acre
River Simulation

Chesapeake Bay Program Modeling
Land-River Connection

- X 4000 acres
- X 200 acres
- X 900 acres
Chesapeake Bay Program Modeling
Chesapeake Bay Watershed

64,000 square miles
CBP Modeling Structure

Regional Acid Deposition Model

Sparrow

Watershed Model

Chesapeake Bay Estuary Model Package

Chesapeake Bay Program Modeling
CBP Modeling Structure

Chesapeake Bay Estuary Model Package

Chesapeake Bay Program Modeling
Hydrodynamic and Estuarine Model

- Predict
  - Flows
  - Dissolved Oxygen
  - Clarity
  - Chlorophyll
CH3D Hydrodynamic Model

- 3-D primitive equations
- Curvilinear non-orthogonal x-y plane
- Z-grid vertical
- Two-equation turbulence closure
CE-QUAL-ICM Eutrophication Model

- Requires external specification of hydrodynamics
- Simulates C, N, P, Si, DO, Chl, etc.
- Living resources
- Sediment diagenesis model
Conservation of Mass Equation

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

\( V_j \) = volume of jth control volume (m\(^3\))
\( C_j \) = concentration in jth control volume (gm m\(^{-3}\))
\( Q_k \) = volumetric flow across flow face k of jth control volume (m\(^3\) sec\(^{-1}\))
\( C_k \) = concentration in flow across flow face k (gm m\(^{-3}\))
\( A_k \) = area of flow face k (m\(^2\))
\( D_k \) = diffusion coefficient at flow face k (m\(^2\) sec\(^{-1}\))
\( n \) = number of flow faces attached to jth control volume
\( S_j \) = external loads and kinetic sources and sinks in ith control volume (gm sec\(^{-1}\))
\( t, x \) = temporal and spatial coordinates
Chesapeake Bay Program Modeling

Three Algal Groups

Microzooplankton

Mesozooplankton

Dissolved Organic Carbon

Labile Particulate Organic Carbon

Refractory Particulate Organic Carbon

Sediments

External Loads

Inorganic Carbon

Respiration

Respiration
Hydrodynamic and Estuarine Model

- Current Version has
- 2961 surface cells
- 12920 total cells
New Version for 2007
11500 Surface Cells
50,000 Total Cells
Other improvements

• Sediment Transport
  - Submerged Aquatic Vegetation
  - Dissolved Oxygen
  - Toxins
• Oysters and other filter feeders
  - Top-down pressure on phytoplankton
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Chesapeake Bay Program Modeling
Nitrogen Pollution vs. Cost

- **1985 conditions**: TN delivered to Bay is significantly high, indicating substantial pollution. The cost is also high, reflecting the effort required to manage such pollution.
- **2000 progress**: The TN delivered to Bay shows a decrease compared to 1985, indicating progress in pollution control. The cost is also reduced, suggesting more efficient management.
- **Tier 1**: There is a noticeable decrease in TN delivered to Bay, showing effective pollution control strategies. The cost incurred is moderate, indicating a balanced approach.
- **Tier 2**: Further reduction in TN delivered to Bay is observed, indicating continued improvement in pollution control. The cost is higher compared to Tier 1, reflecting the increased effort and investment.
- **Tier 3**: The TN delivered to Bay is minimal, indicating effective pollution control. The cost is significantly high, highlighting the high investment required for advanced pollution control measures.
- **E3**: TN delivered to Bay is minimal, similar to Tier 3, indicating effective pollution control. The cost is moderate, suggesting a balance between effectiveness and efficiency.

The graph shows the progression from 1985 to 2000 and further into more advanced tiers, with a clear trend of decreasing TN delivered to Bay and increasing cost.
Judging Progress

Percent of Bay in non-attainment

- 1990 Observed
- 2000 Progress
- Tier1
- Tier2
- Tier3
- E3

- Observed: 80%
- Progress: 70%
- Tier1: 70%
- Tier2: 70%
- Tier3: 20%
- E3: 0%
Judging Progress

The graph shows the relationship between the percentage of the Bay in non-attainment and the amount spent per year in millions of dollars (M$). The graph indicates that as more money is spent per year, the percentage of the Bay in non-attainment decreases. The tiers are labeled as Tier 1, Tier 2, and Tier 3, with Tier 1 having the highest percentage and Tier 3 having the lowest percentage in non-attainment.
Chesapeake Bay Program Modeling

Lower Potomac Estuary - Dissolved Oxygen - Deep Water

Absolute Effect Normalized by load

Susquehanna
MD Western Shore
Patuxent
Potomac
Rappahannock
York
Potomac
MD Eastern Shore
VA Eastern Shore
Effect of Geographic Targeting

- Tier3
- Drastic Option
Effect of Geographic Targeting

Tier 3

Drastic Option

Efficient Option

Nitrogen Load

percent of Bay in non-attainment