Department of the Environment

Modeling to Support the Development of Nutrient TMDLs in Baltimore Harbor

Miao-Li Chang

Maryland Department of the Environment

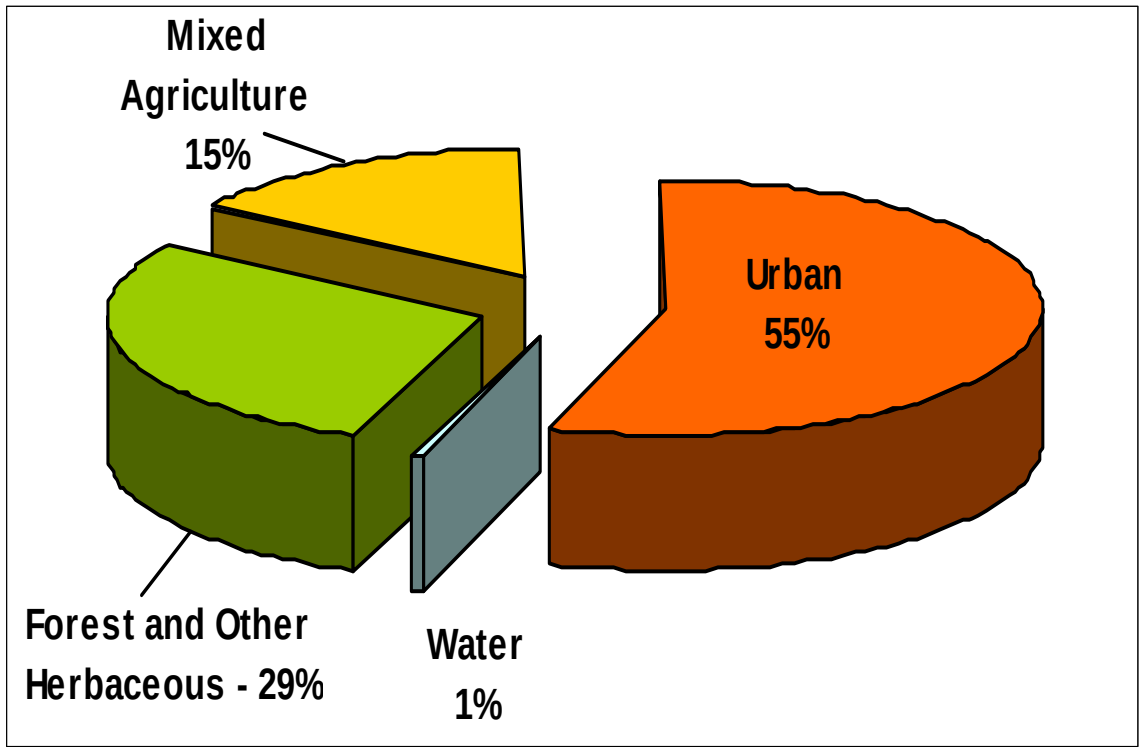
Acknowledgment

Special thanks to the following individuals for data compilation, model setup/simulations, and document reviews: Nauth Panday, Dinorah Damalsy, Hui Liu and Dr. Harry Wang (Virginia Institute of Marine Science).

Watershed Characteristics

The watershed is home to 1.5 million people

Landuse is predominantly industrial, commercial and residential (55 %)



General Information

There are more than 100 industrial facilities with wastewater or cooling water discharges to Baltimore Harbor

The Baltimore Harbor is a very complex system with a unique 3-layer hydrodynamic flow pattern. The upper and lower layers flow inward to the head of the Harbor, and the middle layer flows outward.

Spatially variable elevated levels of nutrients, metals and organics in water, sediments and bottom-feeding species of fish.

This complexity necessitates a comprehensive monitoring and modeling program.

Harbor Eutrophication Modeling Framework

- Watershed Model - HSPF
  - MDE Model used Patapsco/Back
  - CBP Model used for Upper Bay
- Hydrodynamic Model - CH3D
- Water Quality Model - CE-QUAL-ICM
- Sediment Fluxes - Chesapeake Bay Sediment Flux Model
- Consistent with CBP modeling framework for Tributary Strategy
- Finer resolution and more local data for calibration

Harbor Eutrophication Modeling Framework

Watershed Model
HSPF
Hydrology (flow, TSS)

→

Hydrodynamic Model
CH3D
Velocity, Diffusion, Surface Elevation, Salinity, Temperature

↓

Watershed Model
HSPF
nutrients, sediments

→

Water Quality Model
CE-QUAL-ICM
Temperature, Salinity, Total Suspended Solid, Cyanobacteria/Diatoms/Algae, Carbon, Nitrogen, Phosphorus, COD, DO, Silica

←

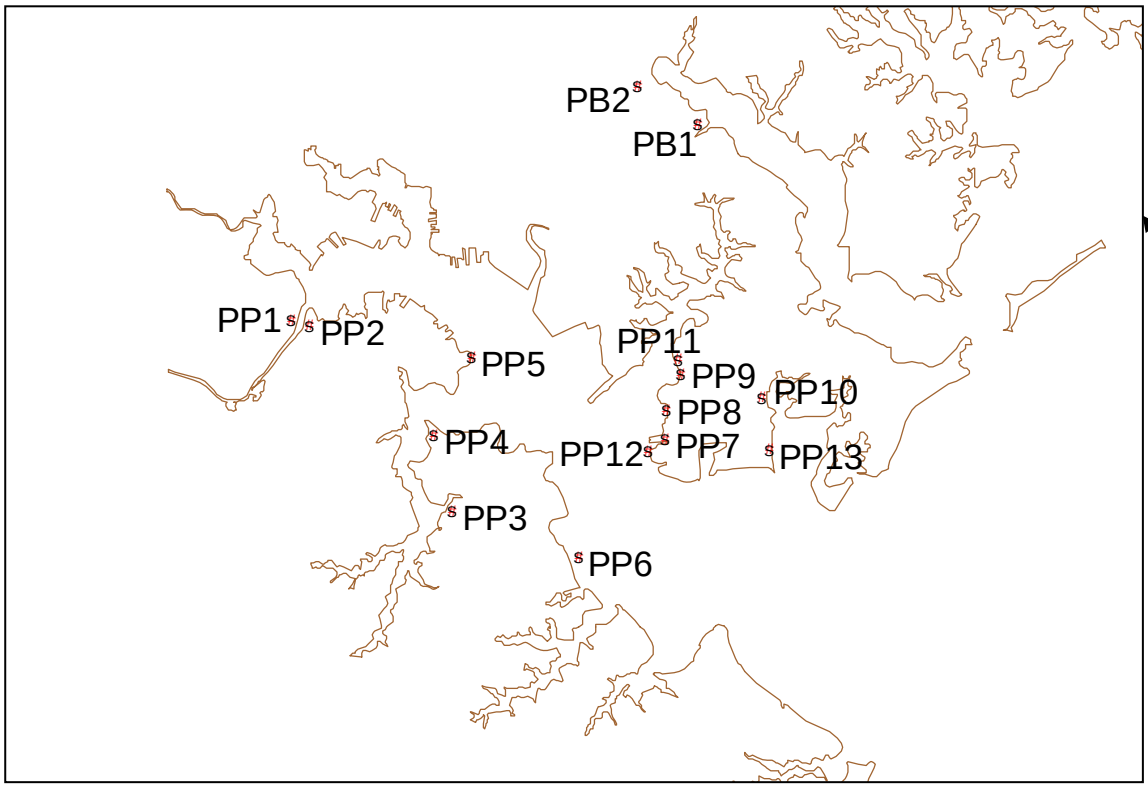
Sediment Diagenesis Model
Sediment initial condition, Sediment settling rate

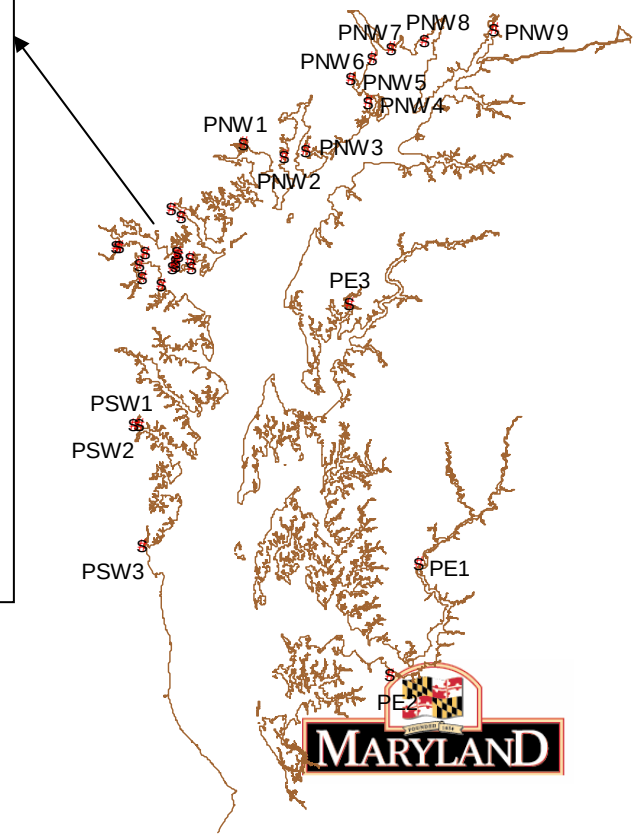
Point Source and other loads

↓

Water Quality Prediction

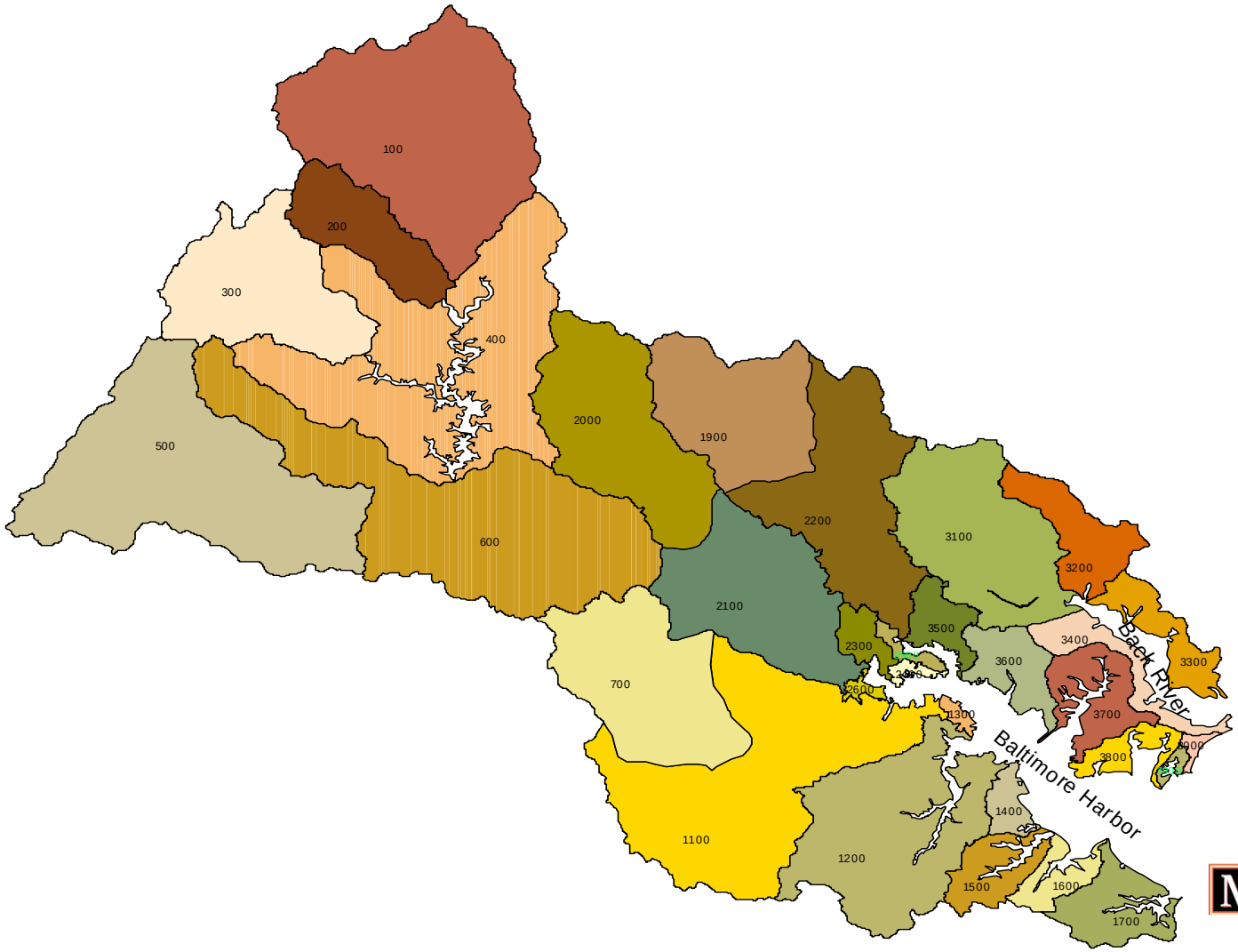
Point Source Locations





PB1 = Back RiverPB2 = Eastern Stainless
PP1 = CongoleumPP2 = Freedom District
PP3 = ChemetalsPP4 = W.R. Grace
PP5 = PatapscoPP6 = Cox Creek
PP7-PP13 = Bethelehem Steel

Nonpoint Source Load – Watershed Model - HSPF Segmentation

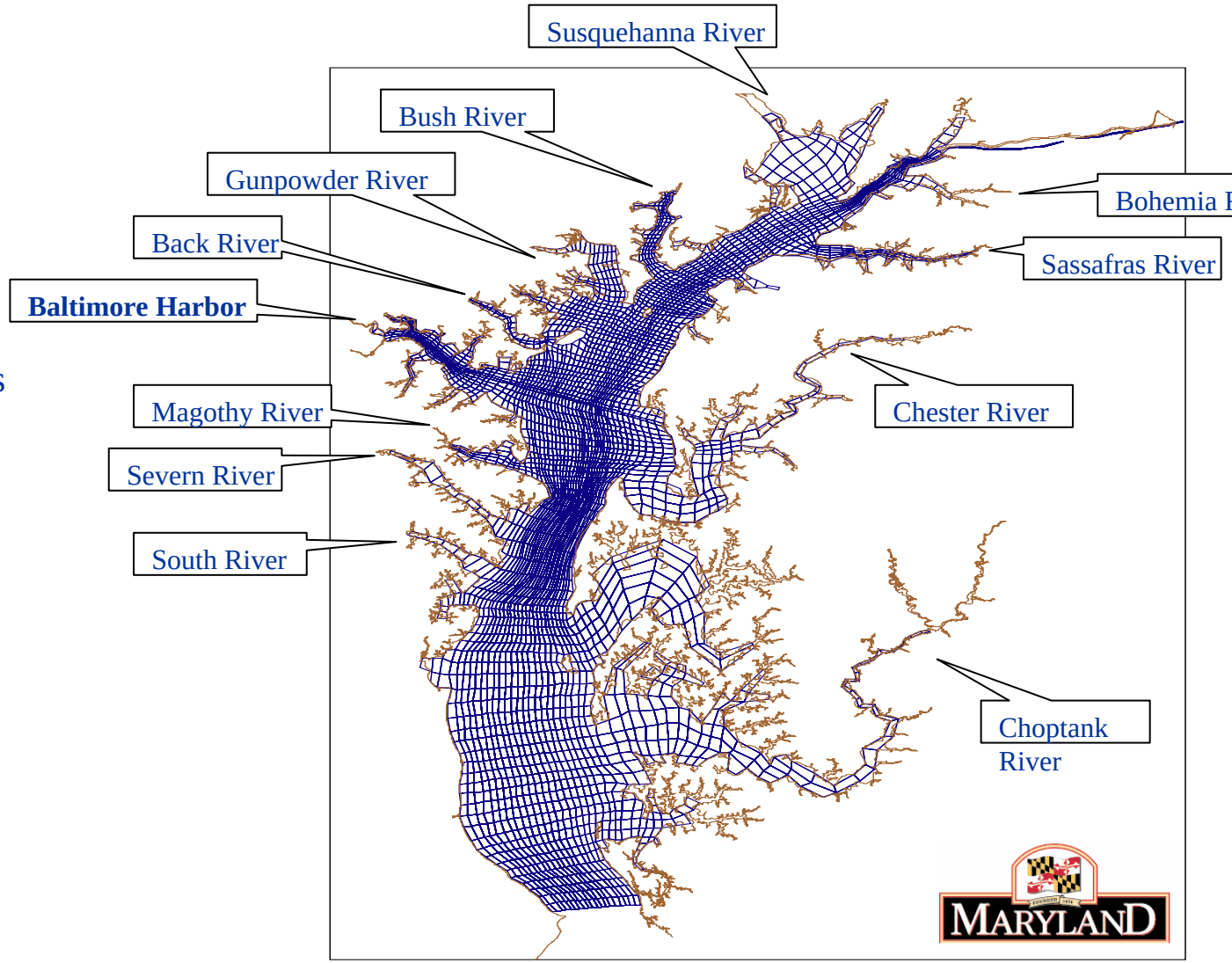


Hydrodynamic Model

CH3D - Curvilinear Hydrodynamic 3-dimension

Velocity, Diffusion, Surface elevation, Salinity, Temperature on an intratidal time scale.

Model physical processes impacting bay-wide circulation and vertical mixing



Water Quality Model

CE-QUAL-ICM

Integrated compartment box model

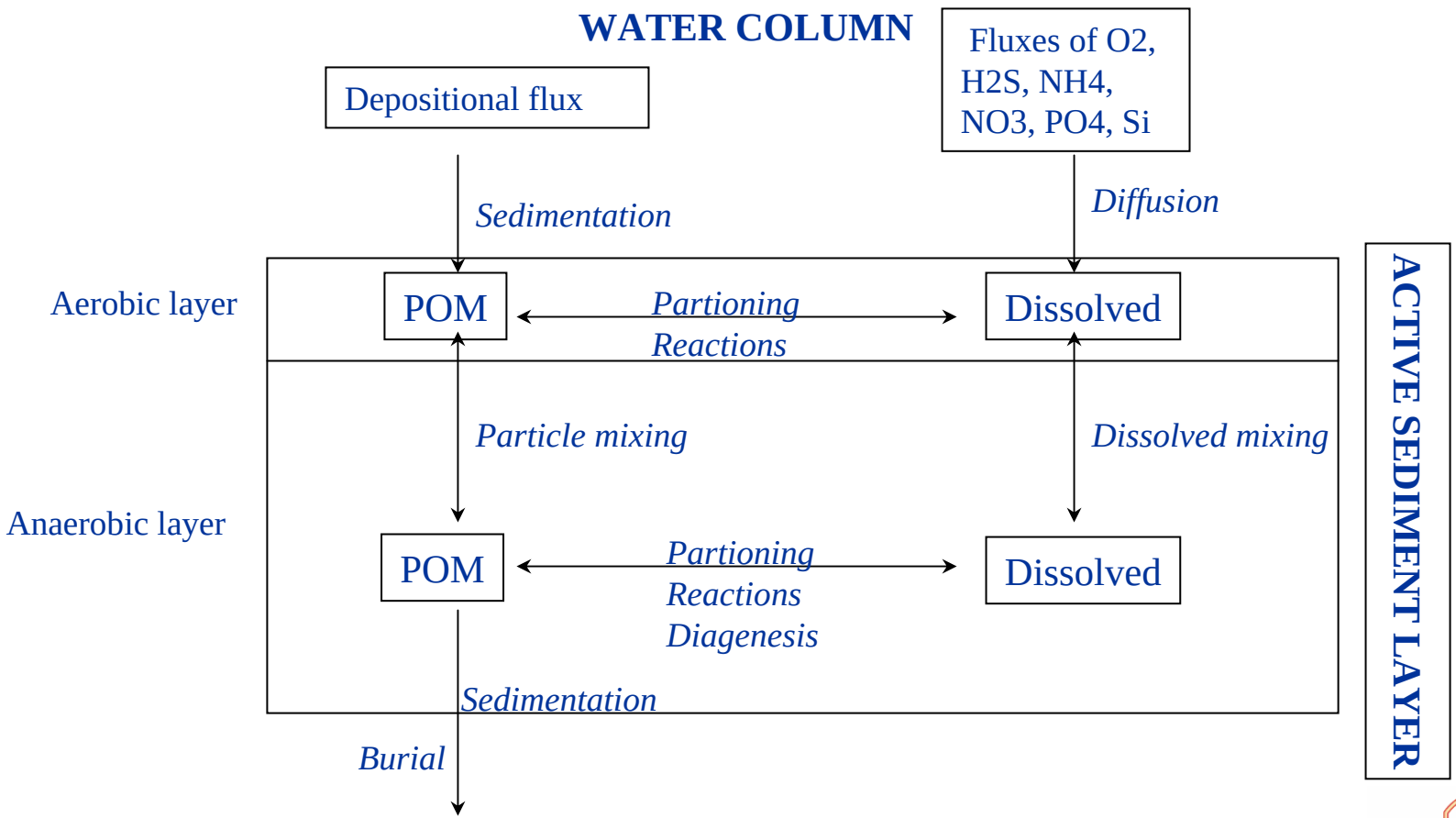
Boxes correspond to cells in x-y-z space on the CH3D grid (3029 cells - 2 km × 0.5 km × 1.7 m in the surface plane, 8970 cells – 2 to 15 cells in the vertical)

Finite difference method using QUICKEST algorithm (Leonard, 1979) in the horizontal directions and a Crank-Nicolson scheme in the vertical direction

Kinetics are computed using a temporal dimension of days

- **22 state variables, 140 parameters**
  - Temperature
  - Salinity
  - Total suspended solid
  - 3 algae groups : Dinoflagelete , Diatoms, Other (green) algae
  - Carbon cycle : DOC, LPOC, RPOC
  - Nitrogen cycle : Ammonium, Nitrate-nitrite, LPON, RPON
  - Phosphorus cycle : Total phosphate, DOP, LPOP, RPOP
  - Silica cycle : Available Silica, Particulate Biogenic Silica
  - COD
  - DO

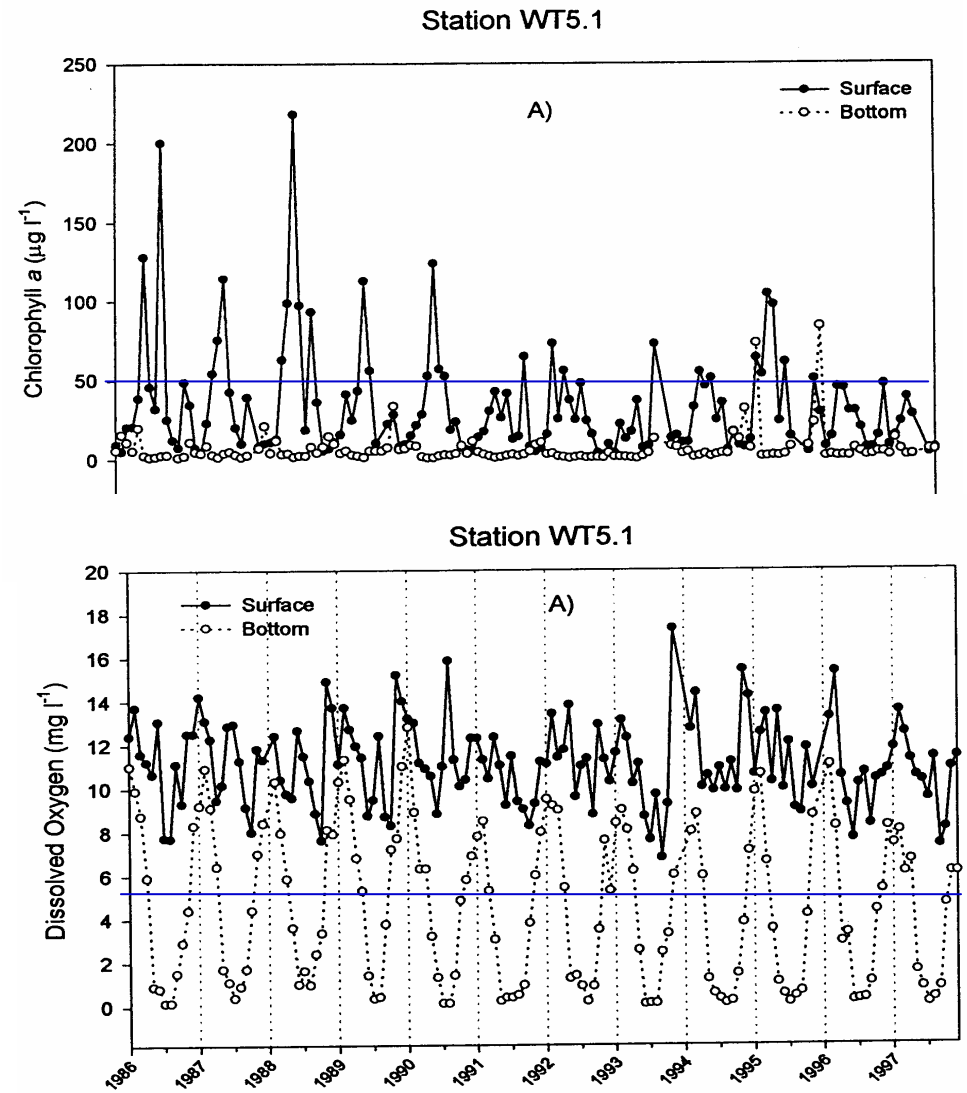
Sediment Flux Model



WQ Calibration

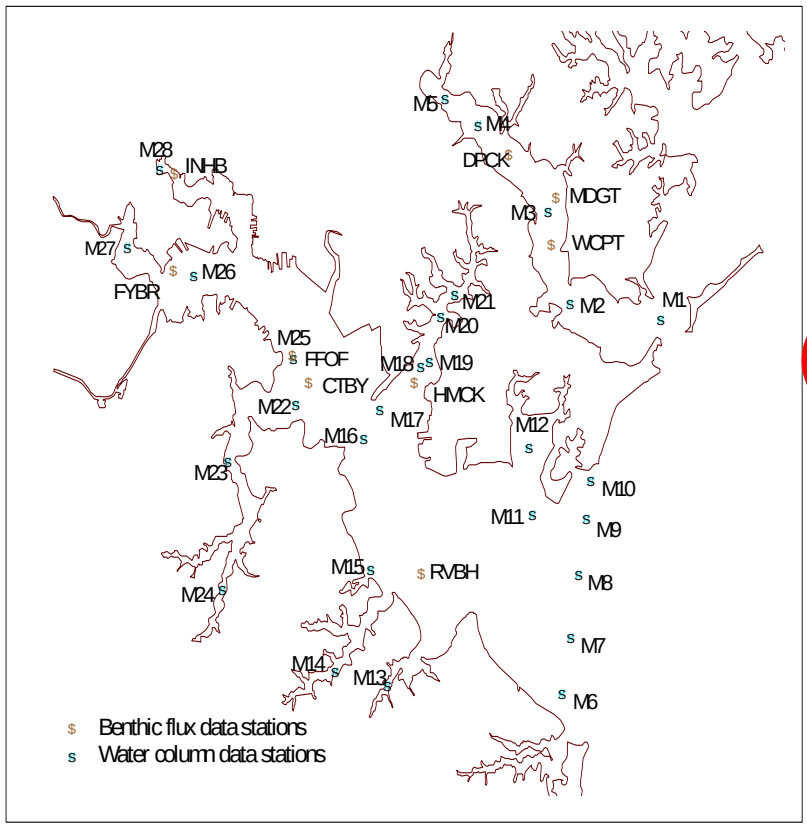
Baltimore Harbor

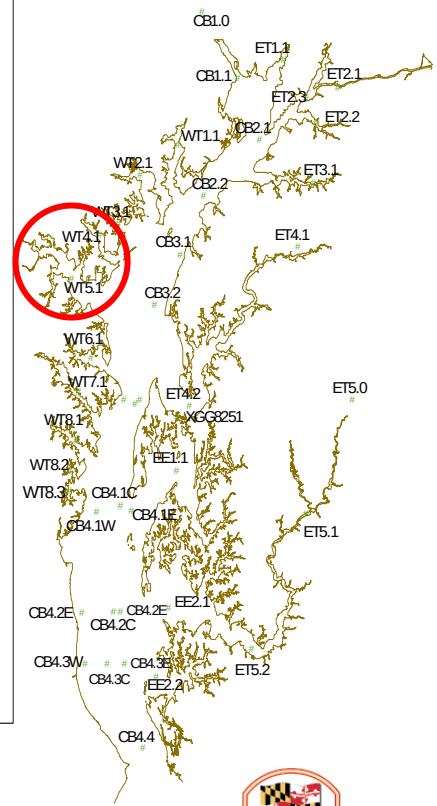
- Algal bloom
- Hypoxia/anoxia
- Very eutrophication



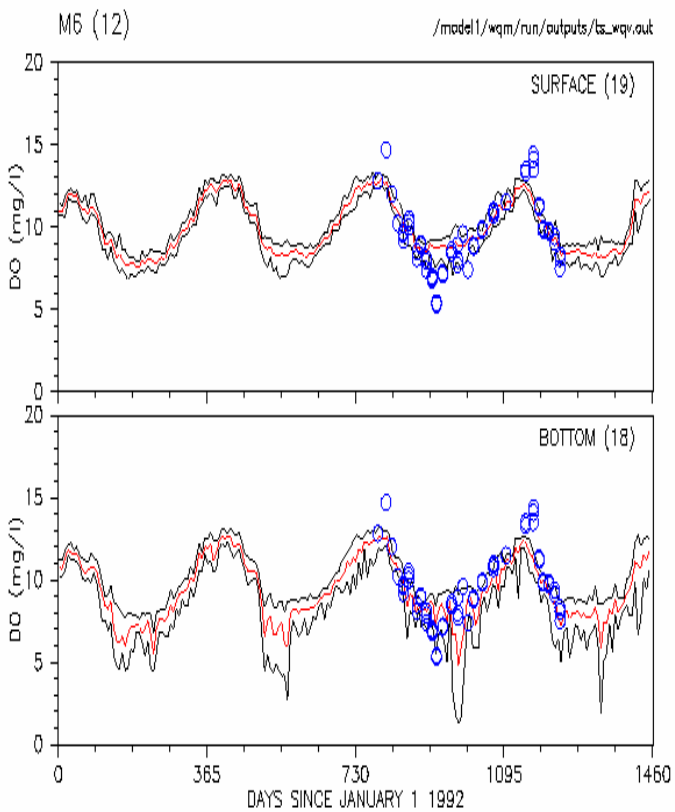
Water Quality Data

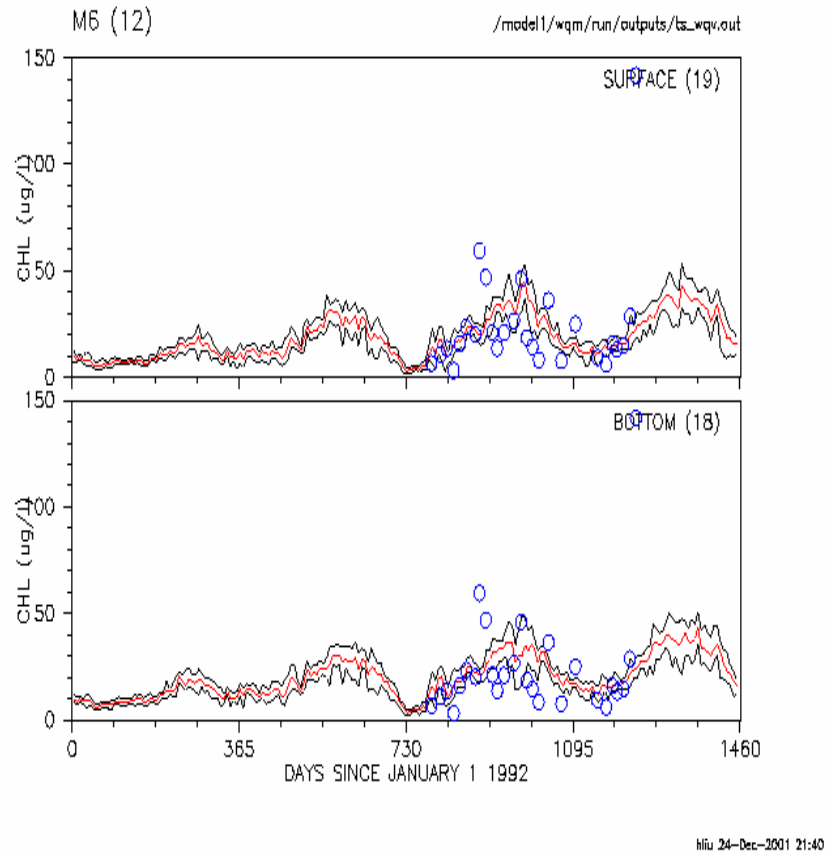
- Water column
  - MDE 94-95
  - Baltimore City Department of Public Work 97
- Benthic flux
  - University of Maryland 94, 95, 97
- Upper Bay
  - Chesapeake Bay Program 82~





WQ Calibration



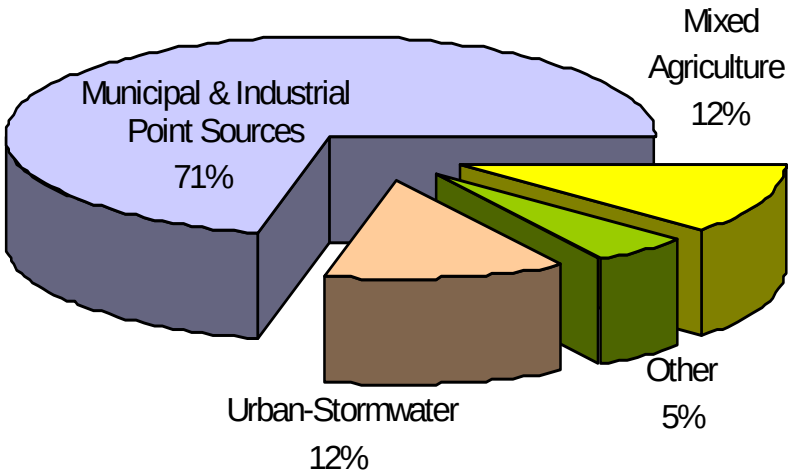


Technical Review Update

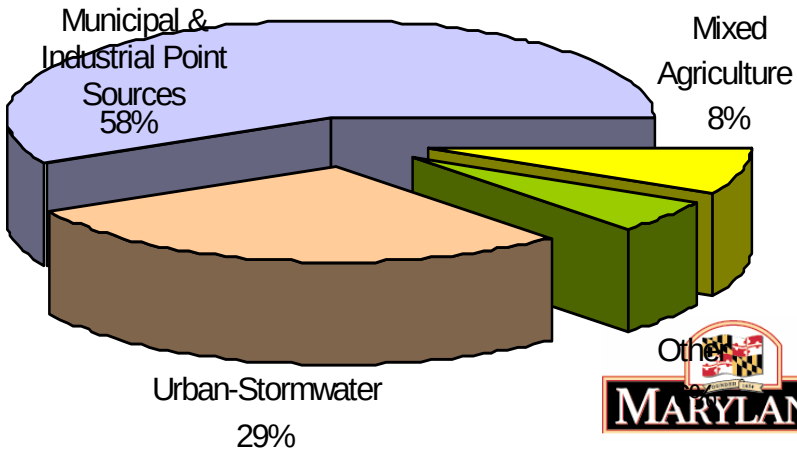
- Reviewed by State Agencies, Baltimore County and Baltimore City
- Reviewed by Chesapeake Bay Program Modeling Subcommittee
- Reviewed by SAG Modeling Technical Group

Percentages of Average Annual Loads in the Baltimore Harbor

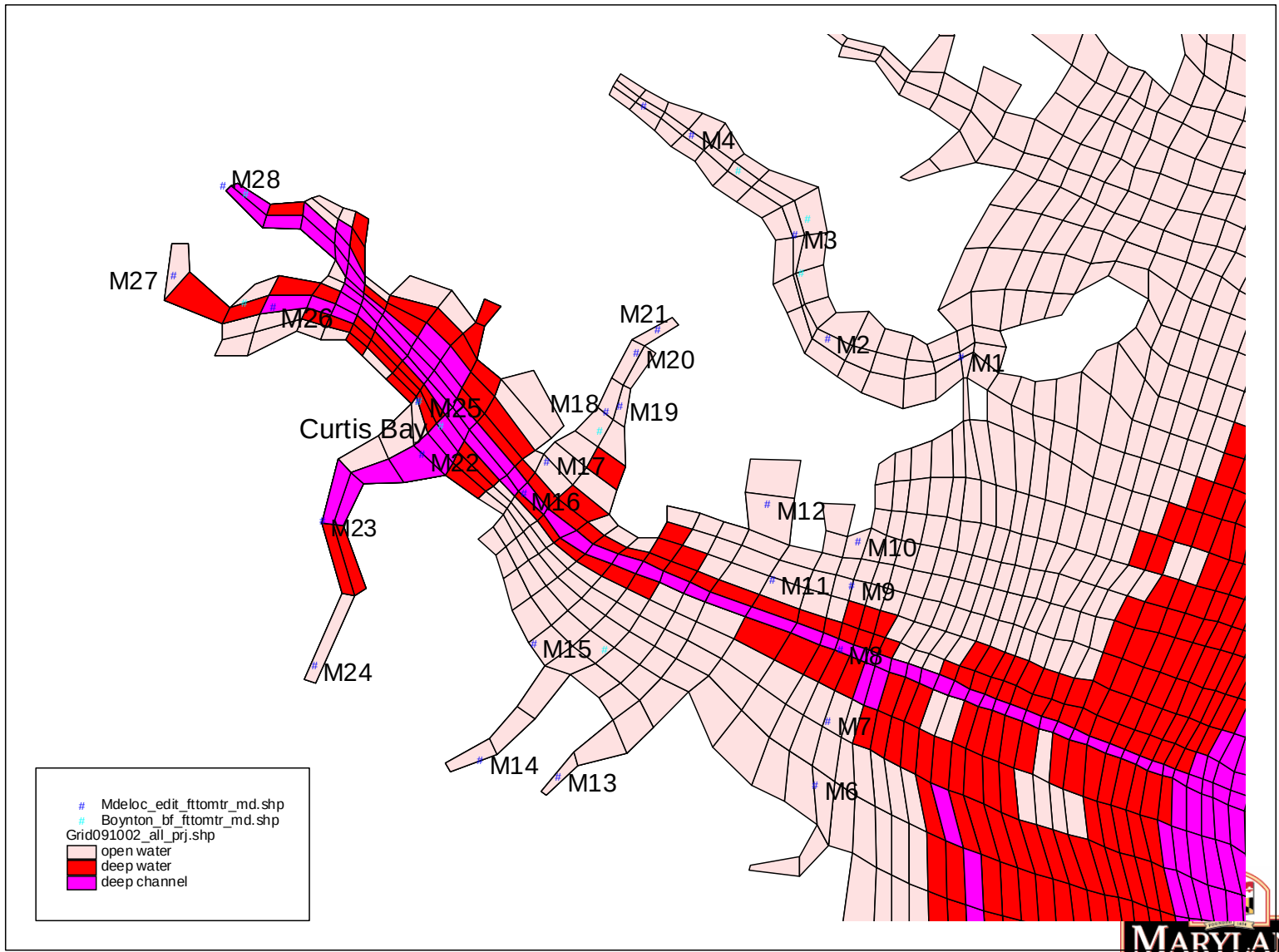
Total Nitrogen 1995-1997



Total Phosphorus 1995-1997



Harbor Designated Uses



Target TMDL water quality goals

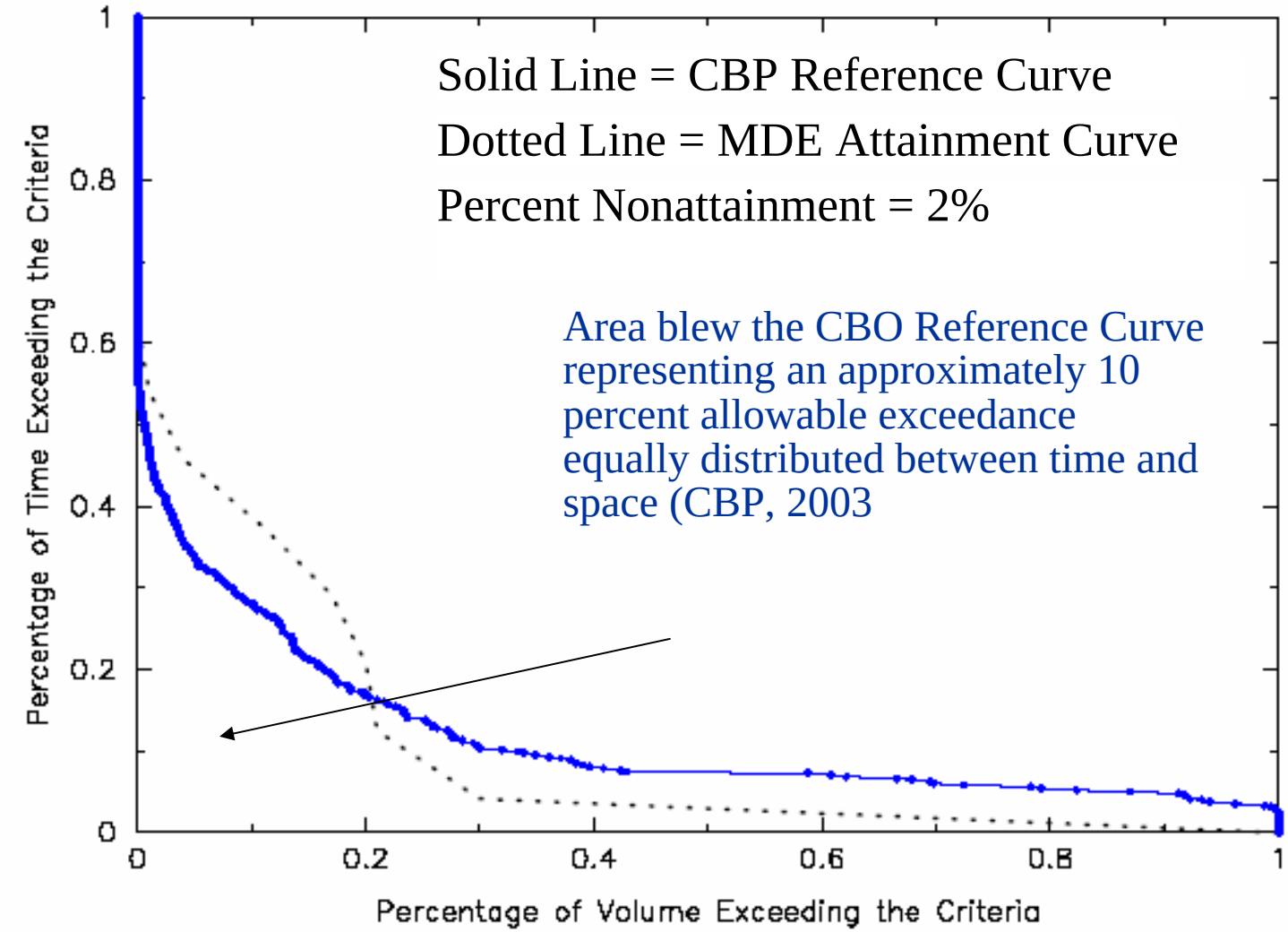
- Ensure that minimum DO concentrations specified for each designated use of the Baltimore Harbor are maintained;
- Resolve violations of narrative Chla criteria.
  - MDE has determined, per Thomann and Mueller, that it is acceptable to maintain Chla concentrations below a maximum of 100 µg/L, and to target, with some flexibility depending on waterbody characteristics, a 30-day rolling average of approximately 50 µg/L.

Baltimore Harbor
Designated Uses and DO criterion

	Feb 1 –May 31	June 1 –Sept 30	Oct 1 –Jan 30
0 – Upper Pycnocline	Migratory Fish (MF)	Open Water (OW)	Open Water (OW)
Upper – Lower pycnocline	Migratory Fish (MF)	Deep Water (DW)	Open Water (OW)
Lower Pycnocline - Bottom	Migratory Fish (MF)	Deep Channel (DC)	Open Water (OW)

Designated Use	30-day mean	7-day mean	1-day mean	Instantaneous minimum
MF				5.0
OW	5.0	4.0		3.0
DW	3.0		2.3	1.7
DC				1.0

DO Attainment Check



Sensitivity Scenarios

1. **No Point Sources** – 100% removal of point source loads in Harbor area: To test the impact of point sources.

2. **No Nonpoint Sources** -- 100% removal of nonpoint source loads in Harbor area: To test the impact of nonpoint sources.

3. **No Anthropogenic Loads** - 100% removal of point and nonpoint source loads: To test the impact of human activities (point + nonpoint source loads)

4. **Clean Sediment** -- Start model with clean sediment initially: To test the impact of internal source (pollutant loads from bottom sediments)

5. **Bay Influences** -- 100% removal of point and nonpoint source loads and start model with clean sediment initially: To test the impact of loads from Chesapeake Bay to Baltimore Harbor.

Sensitivity Model Scenarios

Sensitivity Scenarios	Baltimore Harbor DO Percent non-attainment				
	Deep Water June to September	Deep Channel June to September	Open Water June to September	Migratory Fish February to May	Open Water October to January
Calibration	**29**	**87**	**1**	**4**	**1**
Zero Point Source Loads	**14**	**60.9**	0	0	0
Zero Nonpoint Source Loads	**12**	**61**	0	0	0
Zero Point Source + Zero Nonpoint Source Loads	**9**	**57.8**	0	0	0
Zero Sediments Initial Conditions	**10**	**44.2**	0	0	0
Zero Point Source + Zero Nonpoint Source Loads + Zero Sediments Initial Conditions	**4**	**37.2**	0	0	0

BALTIMORE HARBOR OTHER SCENARIOS LOADINGS and DO Attainment Check

SCENARIO	% Violation MIGRATORY FISH	% Violation OPEN WATER (June-Sept)	% Violation OPEN WATER (Oct-Jan)	% Violation DEEP WATER	% Violation DEEP CHANNEL*
Calibration	4	1	1	29	87
CBP Allocation	0	0	0	16	63.5
MDE NPS, CBP Allocation PS	0	0	0	16	63.5
PS = permit limits MDE NPS Upper Bay = CBP	0	0	0	18	65.3
PS = E3 MDE NPS Upper Bay = CBP	0	0	0	14	60.7
PS = ENR MDE NPS Upper Bay = CBP	0	0	0	7.8	80

Baltimore Harbor Possible TMDL Scenario Run

Point Source :

- Flow: Maximum permit flow
- ENR to Municipal - TN: 4 mg/L annual average

(3 mg/L in May - October, 5 mg/L in November - April), TP: 0.3 mg/L

- Industrial PS – Best Possible Control loads

Nonpoint Source:

- 15 % reduction in controllable loads (urban storm water and agriculture loads)

Progress to Date

- Model developments – Completed
- Technical Review – Completed
- Draft TMDL numbers – Completed

- Plan: TMDL submittal in 2006