GLRC PBS Strategy Team Working Meeting
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Value of Mass Balance Modeling in Formulating a PTS Reduction Strategy for the Great Lakes

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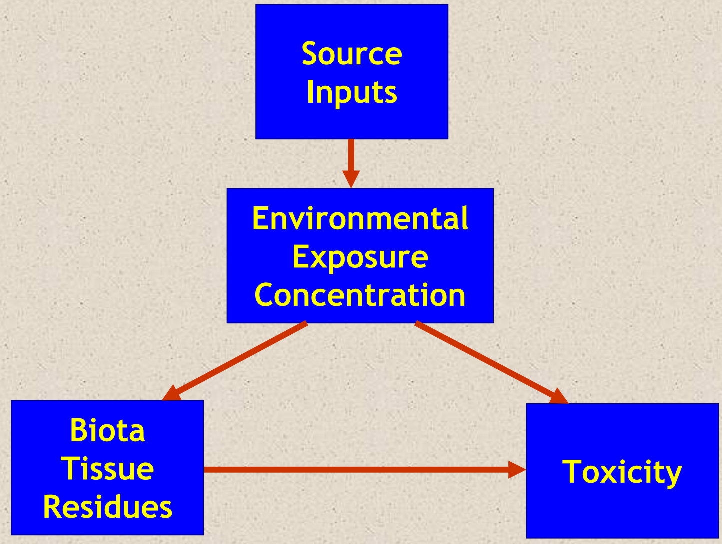
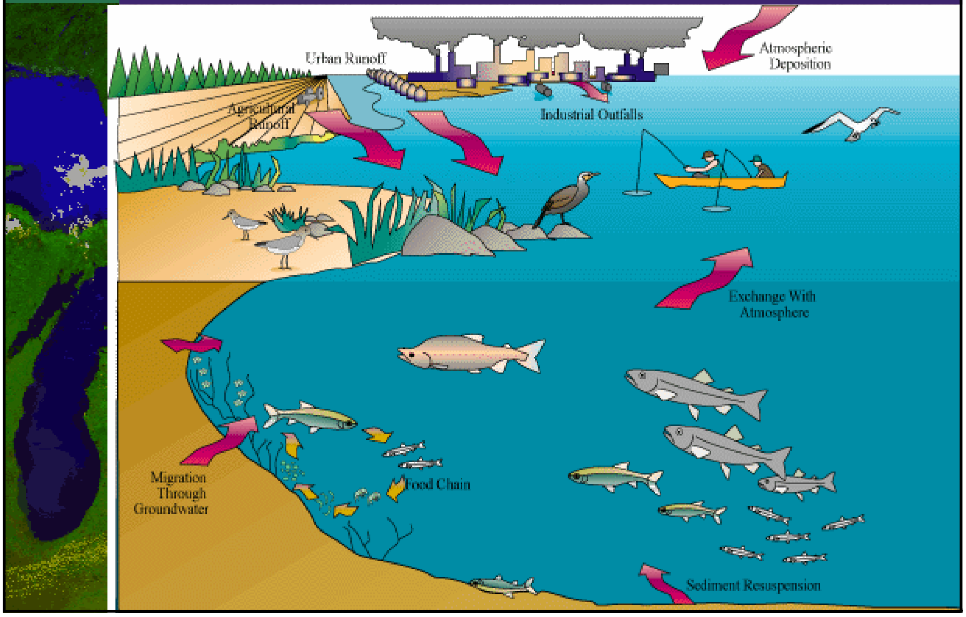
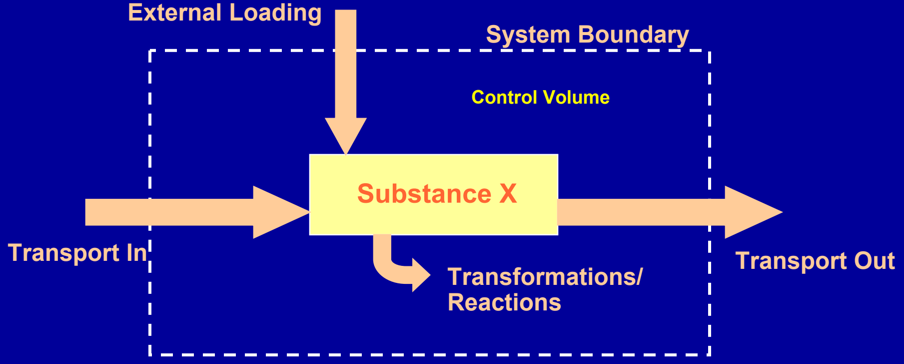
Conceptual Approach to Assessing Chemicals of Concern



MB Models Help Identify Significant Pathways of Exposure



Mass Balance Model Concept



External Loading

System Boundary

Control Volume

Substance X

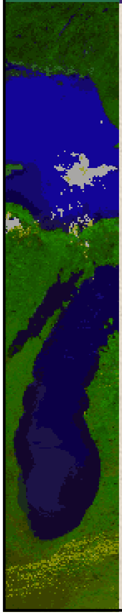
Transport In

Transport Out

Transformations/ Reactions

Rate of Change of [X] within System Boundary (dC_X/dt) = Δ(Loading) ± Δ(Transport) ± Δ(Transformations)

Mass Balance and Bioaccumulation Models developed to support toxics management



- First models in early 1980s
- First large lake feasibility study
  - (IJC “Battle of the Models” in Lake Ontario - 1987)
- Green Bay Mass Balance Study (1988 - 1993) is first coordinated large lakes study
- Concept expanded to full Lake Michigan via LMMB Study (1994 - 2004)
- ARCS program used mass balance modeling for assessing remedial actions in Great Lakes AOCs
- Lake Ontario Mass Balance Study (1997 - present)
- Mackay and MacLeod bringing multi-media modeling to Great Lakes basin

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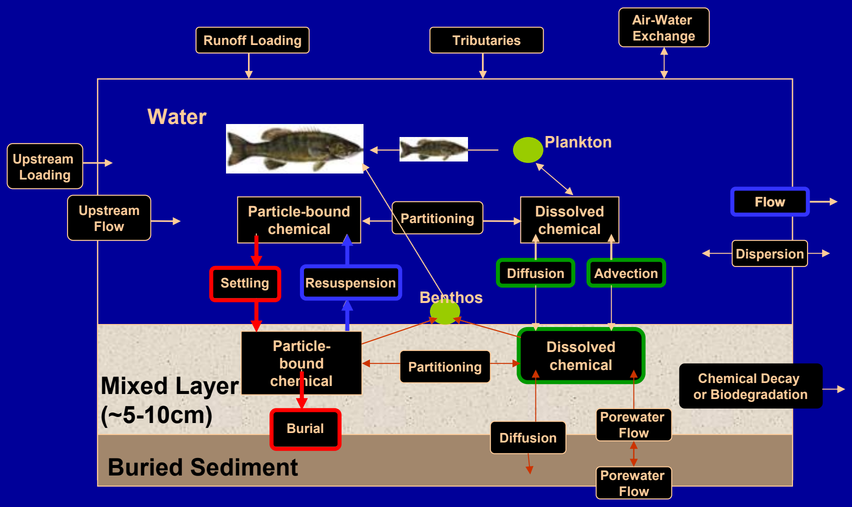
Example Exposure Model Framework



Runoff Loading

Tributaries

Air-Water Exchange

Water

Plankton

Upstream Loading

Upstream Flow

Particle-bound chemical

Partitioning

Dissolved chemical

Flow

Dispersion

Settling

Resuspension

Diffusion

Advection

Benthos

Particle-bound chemical

Partitioning

Dissolved chemical

Chemical Decay or Biodegradation

Mixed Layer (~5-10cm)

Burial

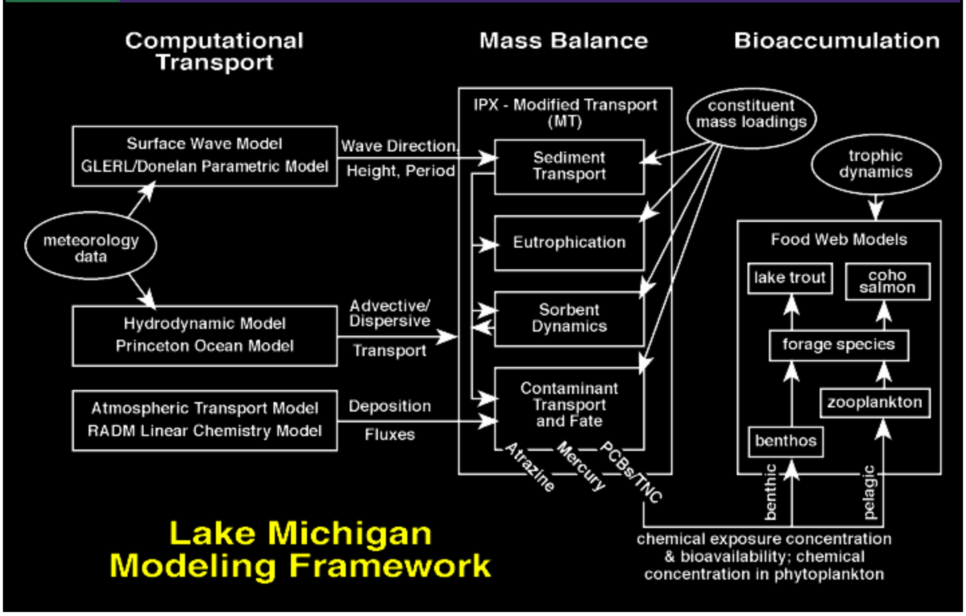
Diffusion

Porewater Flow

Porewater Flow

Buried Sediment

Lake Michigan Mass Balance Study Model



Computational Transport

Mass Balance

Bioaccumulation

Surface Wave Model
GLERL/Donelan Parametric Model

Wave Direction, Height, Period

meteorology data

Hydrodynamic Model
Princeton Ocean Model

Advective/ Dispersive Transport

Atmospheric Transport Model
RADM Linear Chemistry Model

Deposition Fluxes

IPX - Modified Transport (MT)

Sediment Transport

Eutrophication

Sorbent Dynamics

Contaminant Transport and Fate

Atrazine

Mercury

PCBs/TNC

constituent mass loadings

trophic dynamics

Food Web Models

lake trout

coho salmon

forage species

zooplankton

benthos

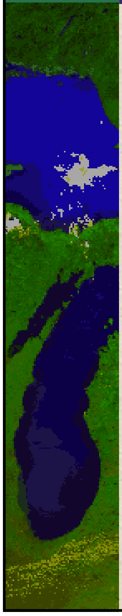
benthic

pelagic

chemical exposure concentration & bioavailability; chemical concentration in phytoplankton

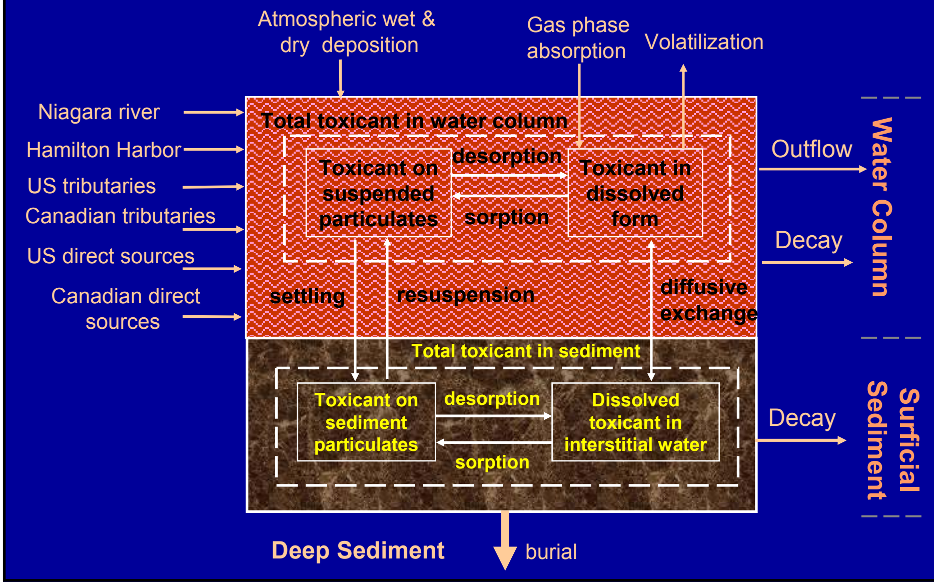
Lake Michigan Modeling Framework

Value of Models for PTS Policy and Management



- Quantify relationship between loads and *in situ* concentrations
  - Rational basis for regulatory and remedial actions
- Assist in design of more effective and efficient monitoring/surveillance programs
  - Documenting success of regulatory/remedial efforts
- Models can provide a reference point for ecosystem health/integrity
  - Restoration goals, sustainable development
- Models can aid *a priori* assessments
  - Relative risks of chemicals of emerging concern
  - Impact of exogenous stressors (e.g., zebra mussels, climate change
- Provide a reference state for management programs
  - By forecasting system trend under no action
  - By explaining small scale, stochastic variability in monitoring data

LOTOX2 Chemical Mass Balance Framework



Atmospheric wet & dry deposition

Gas phase absorption

Volatilization

Niagara river

Hamilton Harbor

US tributaries

Canadian tributaries

US direct sources

Canadian direct sources

Total toxicant in water column

Toxicant on suspended particulates

desorption

sorption

Toxicant in dissolved form

settling

resuspension

diffusive exchange

Outflow

Decay

Water Column

Total toxicant in sediment

Toxicant on sediment particulates

desorption

sorption

Dissolved toxicant in interstitial water

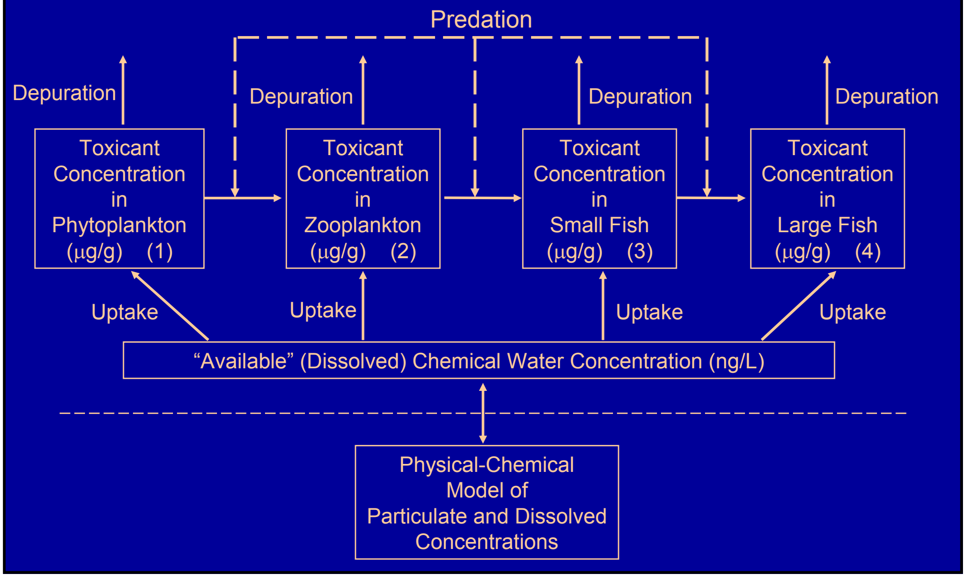
Decay

Surficial Sediment

Deep Sediment

burial

Bioaccumulation Model Framework



Predation

Depuration

Depuration

Depuration

Depuration

Toxicant Concentration in Phytoplankton (µg/g) (1)

Toxicant Concentration in Zooplankton (µg/g) (2)

Toxicant Concentration in Small Fish (µg/g) (3)

Toxicant Concentration in Large Fish (µg/g) (4)

Uptake

Uptake

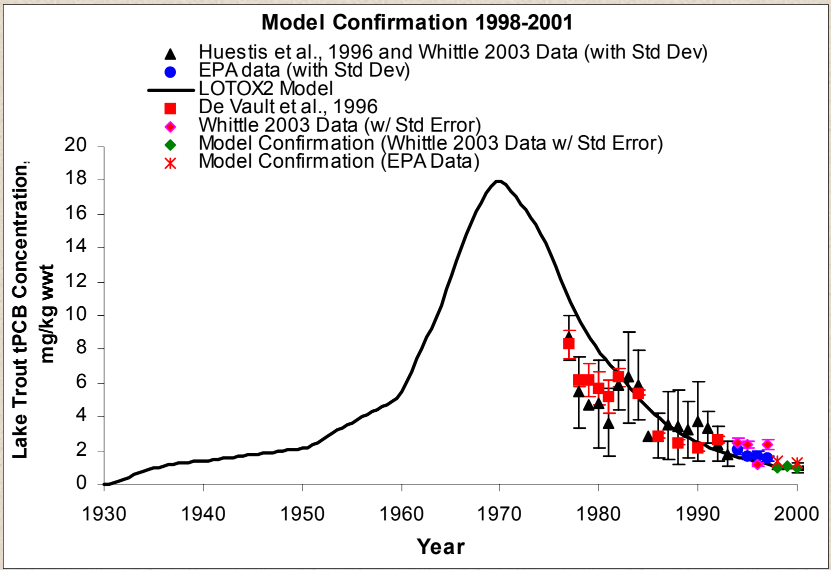
Uptake

Uptake

“Available” (Dissolved) Chemical Water Concentration (ng/L)

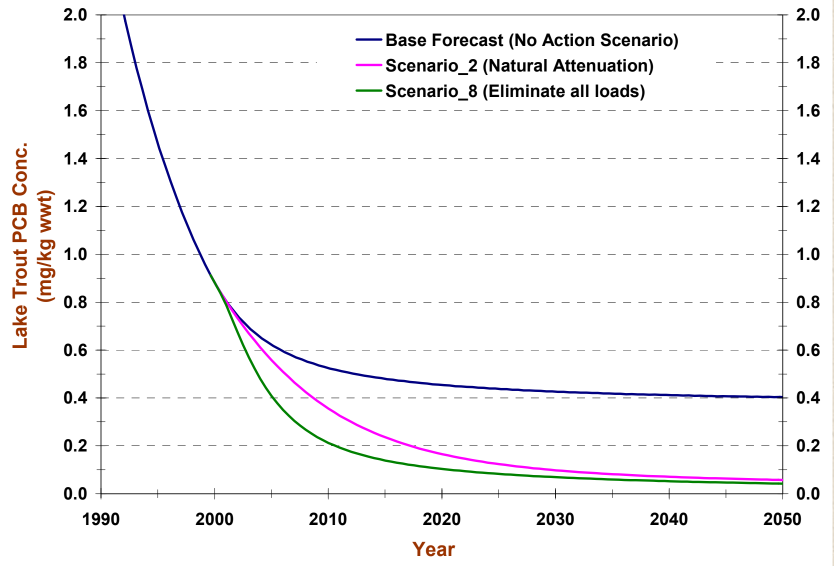
Physical-Chemical Model of Particulate and Dissolved Concentrations

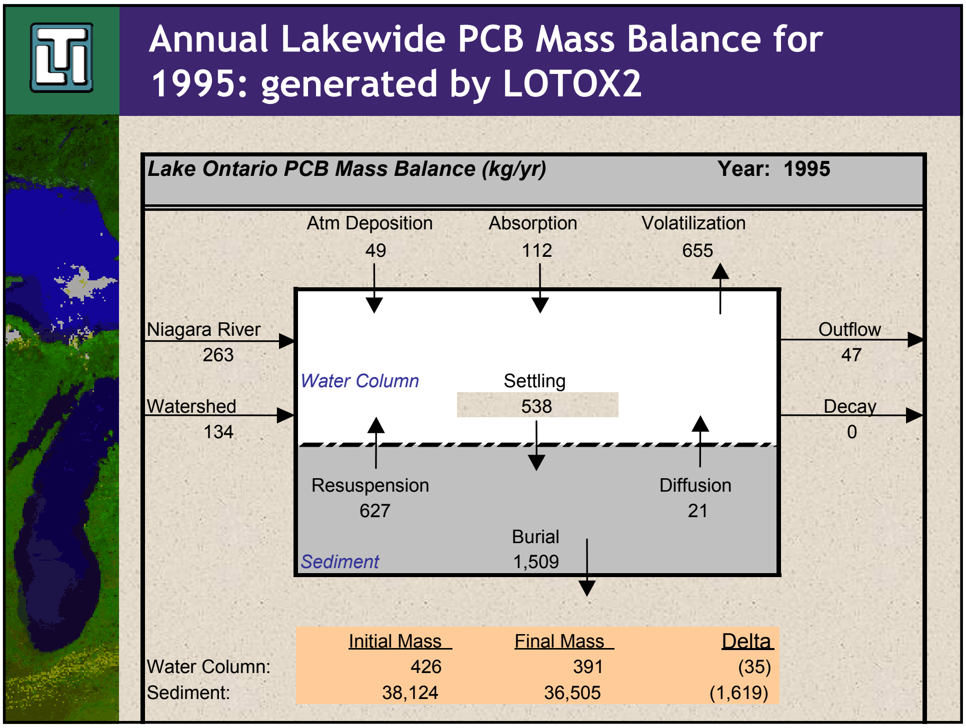
Model Calibration/Confirmation - Lake Trout PCB



Baseline and Categorical Scenarios

(all scenarios start at 2000 and run for 50 years)





Annual Lakewide PCB Mass Balance for 1995: generated by LOTOX2

Lake Ontario PCB Mass Balance (kg/yr) **Year: 1995**

Atm Deposition 49

Absorption 112

Volatilization 655

Niagara River 263

Watershed 134

Outflow 47

Decay 0

Water Column

Settling 538

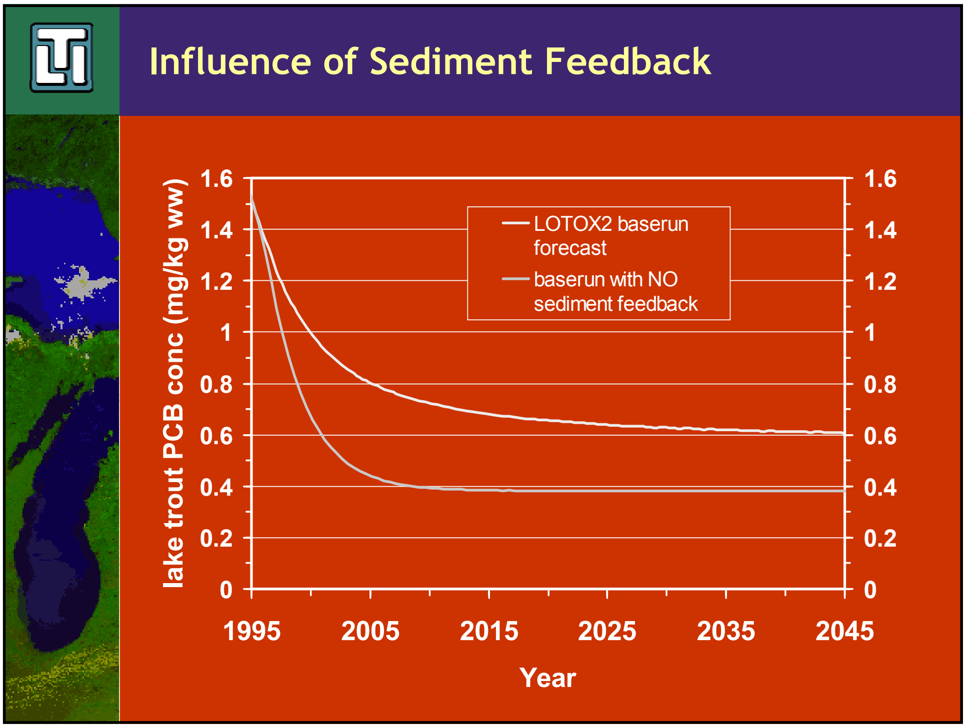
Resuspension 627

Diffusion 21

Burial 1,509

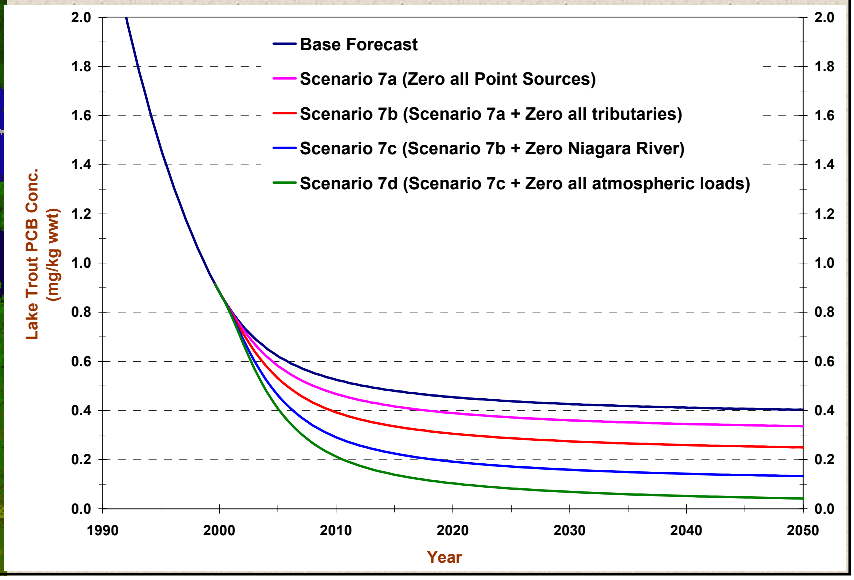
Sediment

	Initial Mass	Final Mass	Delta
Water Column:	426	391	(35)
Sediment:	38,124	36,505	(1,619)



Influence of Sediment Feedback

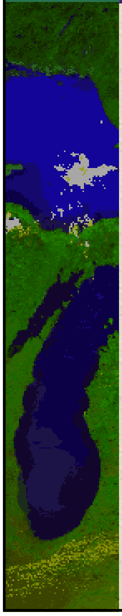
Baseline and Categorical Scenarios
(all scenarios start at 2000 and run for 50 years)



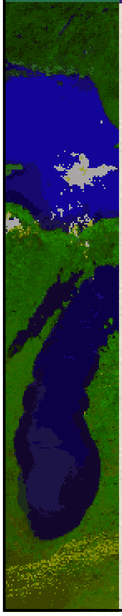
Process for Using MB Modeling to Evaluate Chemical Reduction Strategies

- Estimate loading of contaminant of concern to the lake
- Gather available concentration data in all media
- Obtain physical-chemical property data for chemical of concern
- Obtain lake-specific environmental/ limnological data
- Run steady-state model to reconcile ambient data against loads
- Run dynamic model to estimate time-variable response to recommended actions relative to targets

Using MB Modeling to Screen *Chemicals of Emerging Concern* Requires



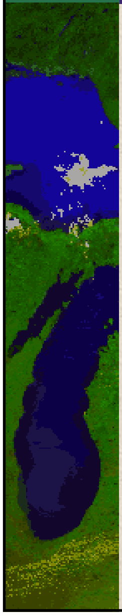
- A multi-media, basin-wide modeling framework
  - Assess exchange between air, land, and water media
  - Connect receptors to source emissions
  - Assess relative contributions from inside and outside the basin
  - Assess inter-lake transfer
- Calibrate the multi-media model
  - Water, solids, and PCB balances
- Chemical-specific data
  - Chemical properties (e.g., K_{oc}, H)
  - Estimate or projection of chemical emissions from PS and NPS
  - Basin boundary conditions



Baseline and Categorical Scenarios

(all scenarios start at 2000 and run for 50 years)

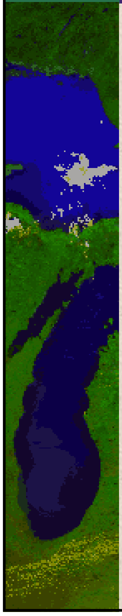
1. Baseline “No Action” scenario - **constant load from all sources after 2000**
2. Ongoing recovery scenario - **loads from all sources continue to decline at first-order rate based on previous 15 years**
3. Point source elimination - **zero all point sources with other loads held constant**
4. Tributary source elimination - **zero all tributary loads (including PS) while holding Niagara River and atmospheric sources constant**
5. Niagara River elimination - **zero load from Niagara River with all other sources held constant**
6. Atmospheric load elimination - **eliminate wet/dry deposition and zero atmospheric gas phase concentration with all other sources held constant**



Baseline and Categorical Scenarios

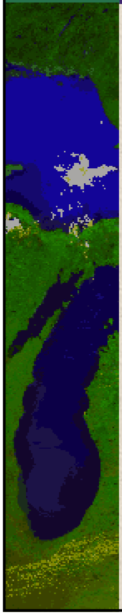
(all scenarios start at 2000 and run for 50 years)

7. Cumulative source category elimination scenario - **sequentially zero PS, tributaries, Niagara River, and atmospheric deposition**
   a. **Zero all point sources**
   b. **Zero all PS + tributaries**
   c. **Zero all PS + tributaries + Niagara River**
   d. **Zero all PS + tributaries + Niagara River + atmospheric deposition/boundary condition (equivalent to scenario no. 8)**
8. Eliminate all external loads and atmosphere boundary condition



LOTOX2 Findings for Management of PCBs in Lake Ontario

- Significant load reductions from mid-60s through 80s have had major impact on open water and lake trout rapidly declining trends through that period.
- Slower declines in open waters through '90s are largely result of sediment feedback as sediments respond much slower than water.
- Lake is not yet at steady-state with current loads. Time to approximate steady-state with 2000 loads is ~30 years.
- Ongoing load reductions after 2000 take 5-10 years before lake trout responses are distinguishable from no post-2000 load reductions.



LOTOX2 Findings for Management of PCBs in Lake Ontario (cont.)

- At current levels, atmospheric gas phase PCBs will begin controlling lake trout concentrations when watershed loads decrease to approximately 200 Kg/y.
- Point Sources of PCBs are relatively small fraction of current total loading; therefore, further PS reductions will provide small improvement in lakewide conditions.
  - At present model cannot address problems in localized areas (tributaries, bays, nearshore areas (AOCs)), where PS reductions will have greatest value.