Optimized Use of Conceptual and Mathematical Models in Sediment Assessment and Management

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Addressing Uncertainty and Managing Risk at Contaminated Sediment Sites
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Panel 2: Setting the Stage for Effective Management Decisions

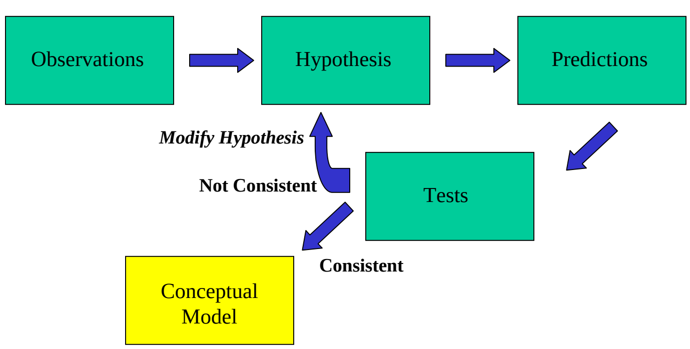
Conceptual and Mathematical Models

- **Both describe the processes that determine exposure and risk**
- **A conceptual model is an organized set of ideas**
  - Qualitative description of how the system works
  - A framework of interconnected "black boxes" with sense of relative importance
- **A mathematical model is an organized set of equations**
  - Quantitative, mechanistic descriptions of what is going on inside the "black boxes"
  - Conforms to the basic laws of physics and chemistry (conservation of mass, momentum and energy)
- **A mathematical model provides a strong test of the conceptual model by simulating the mechanisms driving the processes identified in the conceptual model**
- **A mathematical model provides a means to ask how will the system will respond to perturbation**
- **Both types of models provide a framework for data collection**

Optimized Use of a Conceptual Model

- **Framework for the remedial Investigation**
  - Develop initial model as a set of hypotheses derived from existing data and knowledge gained from other sites
    - Ensure consistency among the various hypotheses
  - Use the scientific method to design and conduct studies to test and refine the hypotheses and the model
  - Use scientific consensus or weight of evidence to judge adequacy of the model for decision making
- **Basis for a mathematical model**
  - Identifies important processes and their interconnections

Site Evaluation Using the Scientific Method



Evolution of the Conceptual Model for the Grasse River PCB Site

- **Version 1 – based on water column and sediment data collected from 1991 through 1995**
  - Sediments in the vicinity of the principal discharge point are the primary source of PCBs to the river
  - Basis for a removal action
  - Initial analysis of data pre- and post-removal suggested that remediation substantially reduced the PCB loading
- **Monitoring in 1996 to test the model**
  - 7 rounds of discrete water column monitoring June – October at 6-8 stations along the river
  - 5 rounds of time integrated water sampling (caged fish/SPMDs) at 4-10 locations
  - 2 high flow events
- **1996 monitoring indicated that conceptual model was incorrect**
  - Significant PCB sources to water column downstream of primary discharge point
- **Monitoring in 1997 to provide basis to correct conceptual model**
  - Broadscale sampling of surface sediments to define PCB distribution (141 locations)
  - Collection of high resolution sediment cores to evaluate burial and loading history
  - 14 rounds of discrete water column monitoring April – November at 5 stations along the river
  - 8 rounds of time integrated water sampling (SPMDs) at 6-7 locations
  - 2 high flow events
  - 1 intensive time-of-travel water column sampling study to locate sources

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Evolution of the Conceptual Model for the Grasse River PCB Site Cont'd.

- **Version 2 – Developed from 1996-97 Data**
  - Surface sediments are the primary PCB source
  - The sediment source is widely distributed
    - this is not a "hot spot" problem
  - There is little risk of expanding the problem by erosion
  - Natural recovery is occurring, but the rate is uncertain
  - Meaningful acceleration of the recovery requires addressing most of the sediment surface area

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Evolution of the Conceptual Model for the Grasse River PCB Site Cont'd.

- **1998-2002 Efforts**
  - Routine bi-weekly water column monitoring April-November 1998-2004
  - High flow event monitoring 1998 and 2002
  - Time-integrated water column monitoring (SPMDs) 1998-99
  - Sediment sampling in 2000; 2001
  - Capping Pilot Study to confirm stability of sediments and ability to install cap
- **Results**
  - Confirmed existing elements of model, but identified missing element: ice jam induced scour
- **2003 Efforts**
  - Extensive investigation of ice jam processes and frequency of occurrence
  - Identification of sediment vulnerable to scour during ice jams

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Evolution of the Conceptual Model for the Grasse River PCB Site Cont'd.

- **Version 3 – Developed from 1996-2003 Data**
  - Surface sediments are primary PCB source to biota
  - Surface sediment PCB source is diffuse and widespread
  - Deeper channel areas are the predominant source of PCBs to the water column and ultimately, biota
  - Sediments are stable under non-ice conditions
  - Ice jams can occur in the upper third of the river and cause localized scour at a frequency of about once per decade
  - Natural recovery through burial is occurring at a relatively fast rate in fine sediment areas

Use of hypothesis testing to focus data collection and interpretation produces stepwise refinement of, and increased confidence in, the conceptual model

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Optimized Use of a Mathematical Model

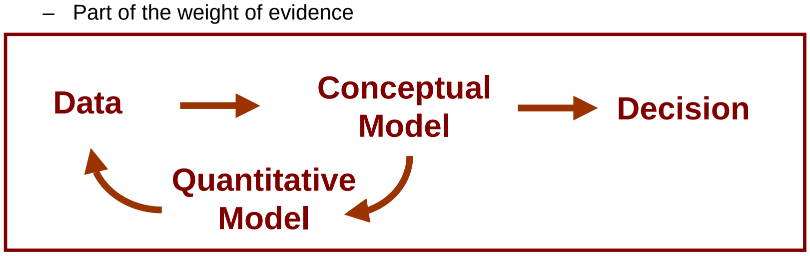
- **The goal of the mathematical model is to reduce the uncertainty of remedy effectiveness, by:**
  - Evaluating the validity of the conceptual model
    - Can the elements of the conceptual model explain the contaminant trends at the site?
  - Identifying the uncertainties that impact the assessment of remedy effectiveness and identifying data needs to reduce those uncertainties
  - Quantitative prediction of remedy effectiveness and associated uncertainty

> *Models can limit arbitrary action, achieve consistency, and unpack crude risk-assessment numbers and simple qualitative conclusions through comparisons that illuminate the nature of relevant uncertainties.*
>
> Stephen Breyer, Breaking the Vicious Circle: Toward Effective Risk Regulation, 1993

The Use of Mathematical Models in Decisions

- **Common conception:**

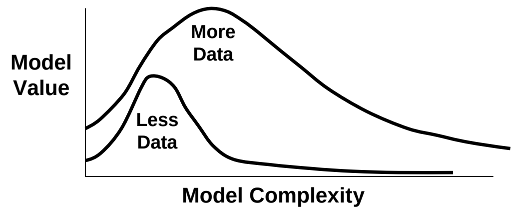
- **More realistic: a quantitative model is one way to interpret data**
  - Part of the weight of evidence



Conceptual model and mathematical model are linked elements in the development of an effective decision for a site

Optimal Mathematical Model Complexity Varies from Site to Site

- **Depends on the cost of being wrong**
- **Simple models provide insights about dominant processes and importance of various potential sources, but effectiveness of remedial options remains uncertain**
- **As model complexity is increased, effectiveness uncertainty *may* decrease**
  - Depends on available data and complexity of the problem
    - All components of the model must be constrained by data

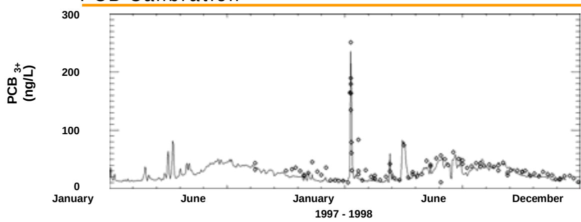


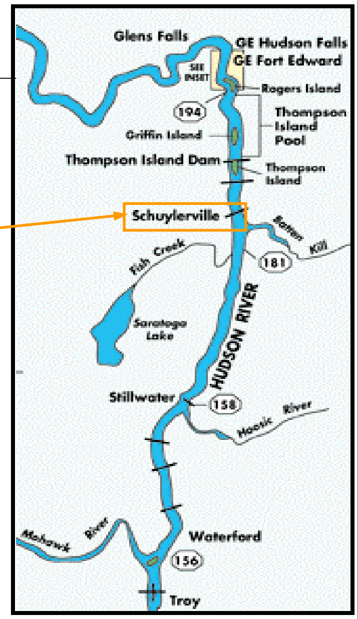
Use of Mathematical Modeling to Evaluate Remedy Effectiveness at the Hudson River Site

- **Used to validate conceptual model**
- **Used to predict remedy effectiveness**
- **Used to evaluate importance of uncertainties to remedy effectiveness**
  - Upstream source strength
  - PCB release by resuspension during dredging
  - Post-dredging residual PCB concentration
- **Used to assist in remedy design**
  - Velocities expected in dredge areas
  - Water depths expected in dredge area and navigational channel under different flow conditions
  - Effect of resuspension on ability to meet performance standards – necessity of controls

Example Model-Data Comparison

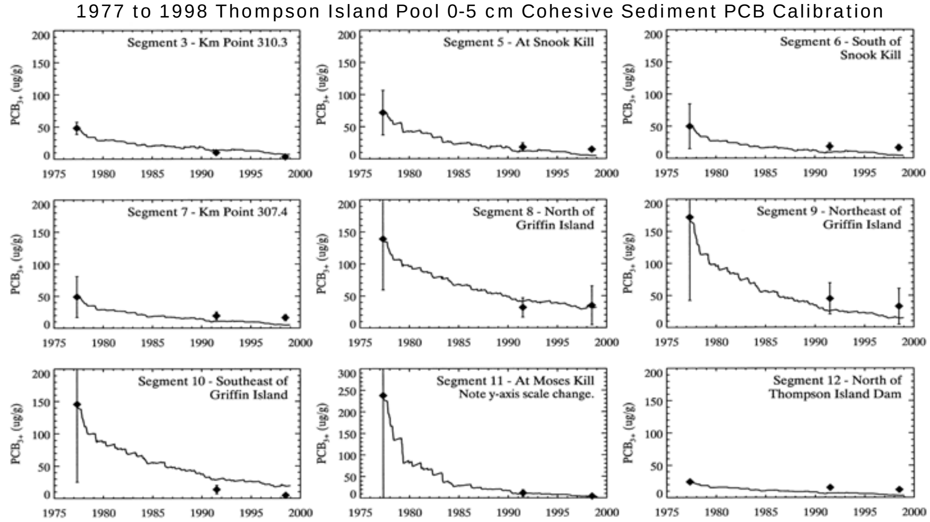
Schuylerville Water Column
PCB Calibration





Example Model-Data Comparison

1977 to 1998 Thompson Island Pool 0-5 cm Cohesive Sediment PCB Calibration



Conclusions

- Models form a central element of site evaluation
- Conceptual models explain the factors affecting exposure and risk
- Mathematical models provide a means to test the conceptual model, guide data collection and predict how the system will respond to proposed remediation
- Mathematical models can assist in remedy design
- Optimized use of models requires strict adherence to the scientific method and explicit recognition and accounting of uncertainty

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