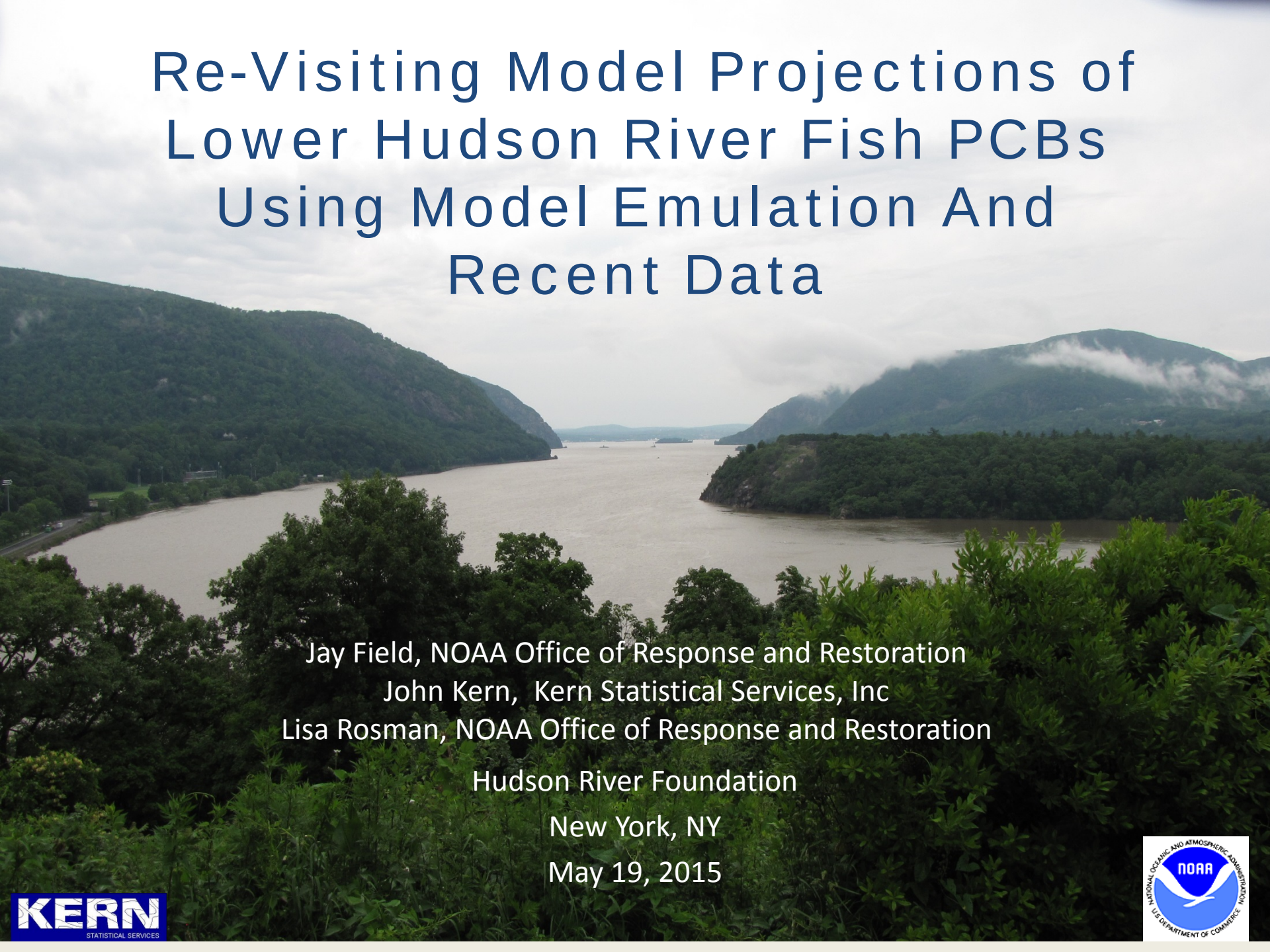
Re-Visiting Model Projections of Lower Hudson River Fish PCBs Using Model Emulation And Recent Data



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Introduction

- Model projections of PCBs in fish played an important role in the comparison of remedial alternatives in the 2002 Record of Decision (ROD) for the Hudson River PCBs Superfund Site
- Post-ROD findings showed that the models overestimated the rate of natural recovery in surface sediment
- Model emulation provides a way to update the original mechanistic models with new information

Why Are We Doing This?

- Need models to predict the future impact of decisions
- Similar models used to inform decision-making at other large Superfund sites
- Rare opportunity to re-visit model predictions

Important Questions

- What is the impact of new information on mechanistic model projections for recovery of fish concentrations in the Lower Hudson River (LHR)?
- What are the implications for the use of similar models in comparing remedial alternatives?

Overview

- Background (Hudson River, Remedy)
- Post-ROD findings
- EPA Mechanistic Modeling for the Upper Hudson River (UHR) and Lower Hudson River (LHR)
- Emulation of Mechanistic Model
- Impact of Post-ROD findings on model projections of recovery of LHR Fish

Hudson River PCBs Superfund Site

Hudson Falls/Ft Edward GE Plant Sites

Former Ft Edward Dam

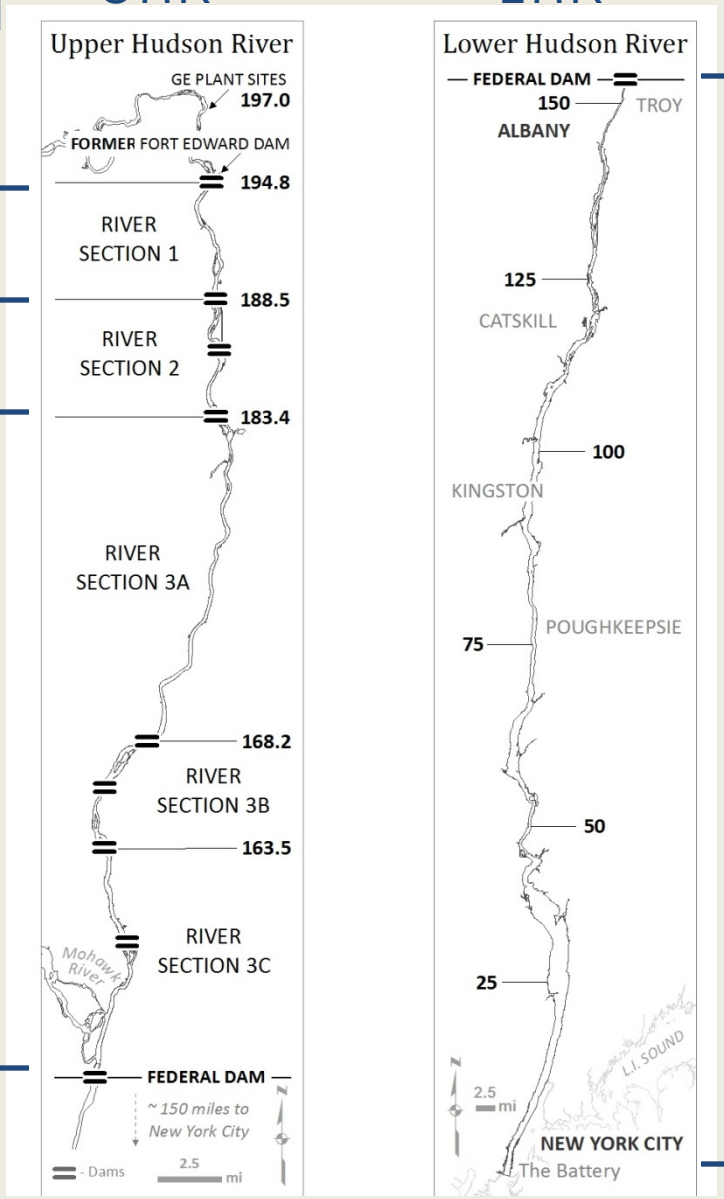
River Section 1

River Section 2

EPA Remedy

River Section 3

Federal Dam



Federal Dam

~ 150 miles

The Battery/NYC

Selected Remedy for the Upper Hudson River (UHR)

- REM3/10/Select: Dredging and Monitored Natural Recovery
  - Upstream source control (NY State remedial process)
  - Target Cleanup Levels
    - River Section 1 (Thompson Island Pool) ~ 6 miles
      - **3 g/m^2 Tri+ PCBs mass per unit area (MPA)**
      - **10 mg/kg Tri+ PCBs in surface sediment** (~ 25-30 mg/kg total PCBs in top 12 inches)
    - River Sections 2 & 3 (multiple reaches/pools) ~ 35 miles
      - **10 g/m^2 Tri+ PCBs MPA**
      - **30 mg/kg Tri+ PCBs in surface sediment** (~ 60-90 mg/kg total PCBs in top 12 inches)

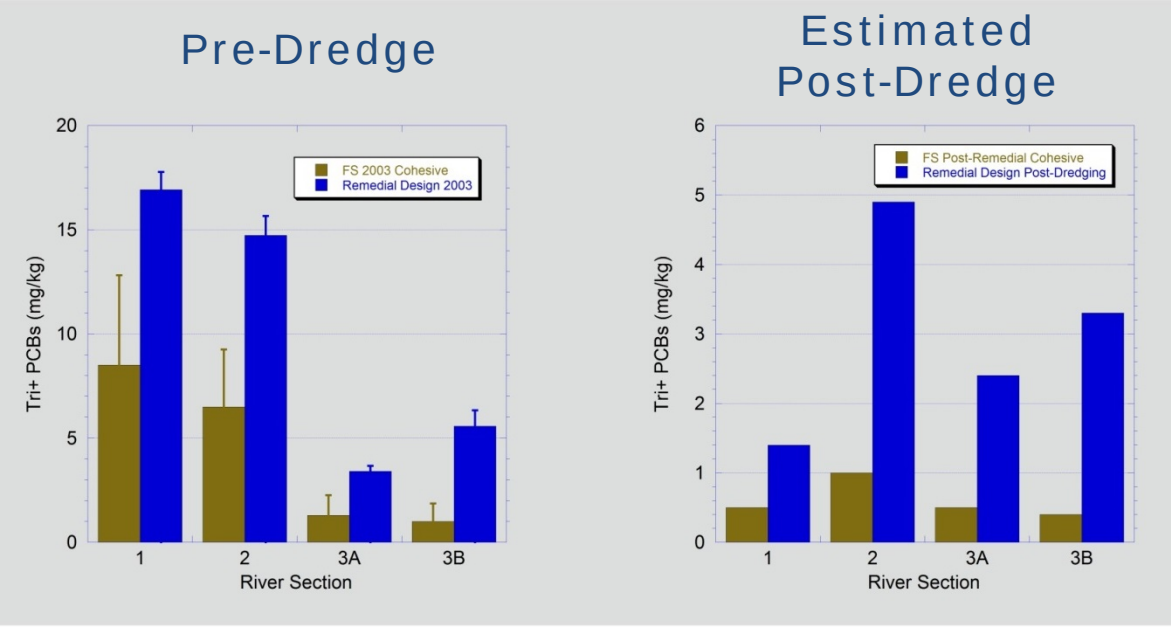
Tri+ PCBs: Trichloro-biphenyl and higher chlorinated PCBs

- Consistent with historical analytical data
- PCBs in HR fish 98-100% Tri+ (USEPA 2002)

Post-ROD Data

- Sediment Data collected for Remedial Design
  - Systematic (unbiased) sampling for UHR (2002-5)
    - RS1: all sediment (cohesive and non-cohesive)
    - RS2 & RS3: cohesive sediment only
  - >8000 cores collected from UHR with PCBs measured in the top 2 inches (5 cm)
  - Mean PCBs assumed to represent 2003 and comparable to 4 cm surface PCBs in model output

Surface Sediment PCBs: Mechanistic Model Predicted vs Measured Post-ROD



Tri+ PCBs in surface sediments exceeded the mean by a factor of 2-3 and the upper bound of model predictions

Estimated post-remediation PCBs for the selected remedy were 3-5X higher than model predictions

Surface sediment represents top 4 cm for model and top 2 inches (5 cm) for remedial design data

Empirical Estimate of Natural Recovery Rate

	Average Tri+PCB (mg/kg) in Surface Sediment		
Model Subsection	GE 1991 UHR Survey[1] (Cohesive Sediment)	Remedial Design Data 2002-2005[2]	Exponential Decay Rate
1	20	16.9 (3414)	1.4%
2	18	14.7 (1540)	1.7%
3A	4.3	3.4 (2129)	2.0%
3B	5.7	5.6 (685)	0.1%
Mean			1.3%
95% CI			-0.1% - 2.6%

< 3%

[1] O'Brien & Gere Engineers, Inc. 1991 Data Summary Report, Hudson River Project

[2] Includes cohesive and non-cohesive sediments from top 2 inches in River Section 1 and cohesive only in Sections 2 and 3. Data collected 2002-2005, considered to represent concentrations in 2003.

Summary of Post-ROD Findings

- Surface sediment PCBs higher than predicted by the mechanistic model throughout UHR
- Rate of sediment recovery slower than models predicted
- PCB loads from the UHR to the LHR prior to 2009 greater than predicted by EPA's mechanistic models and showed little evidence of decline[1]

[1] USEPA 2010. Hudson River PCBs Site EPA Phase 1 Evaluation Report

Importance of Incorporating New Data into Model Framework

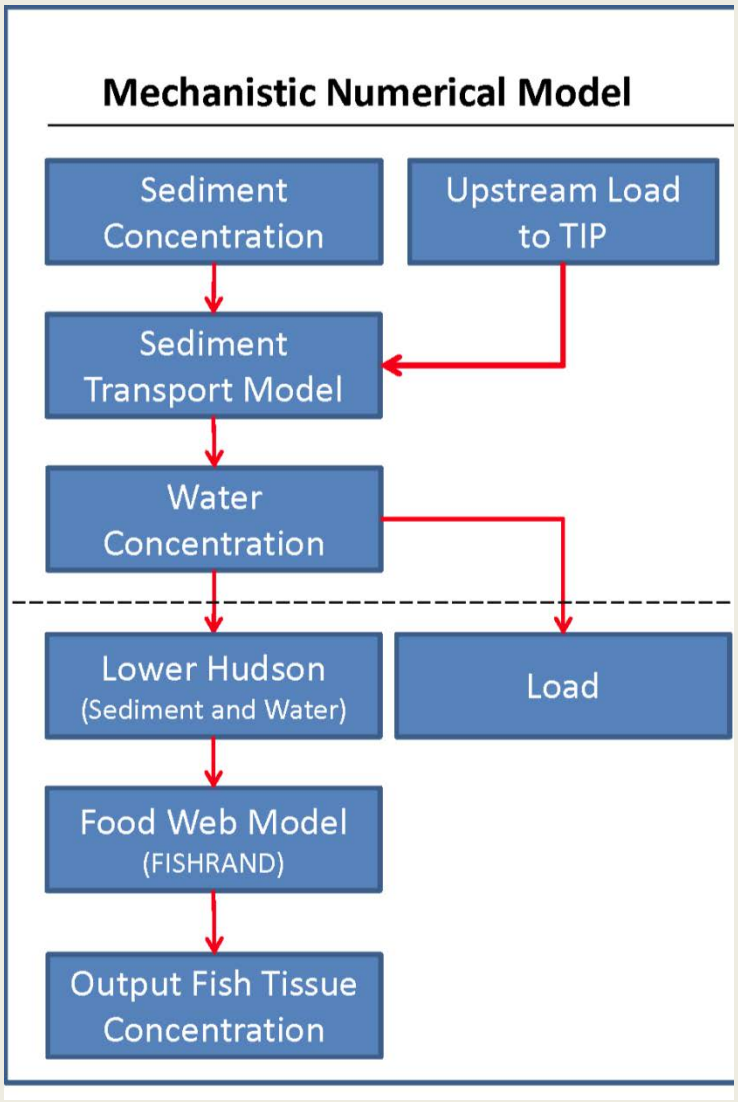
- Post-ROD findings in UHR sediment and estimates of load to LHR likely impact projected declines in LHR fish PCBs

- Re-running the original mechanistic models with new data was not an option because of the cost and effort involved

Why Use Model Emulation?

- Provides alternative approach to efficiently condense complex integrated models into a simple, easy-to-use model
- Maintains the underlying relationships within the mechanistic model
- Consider alternative scenarios
- Used effectively for large numerical ocean and climate change models

Mechanistic Model Schematic



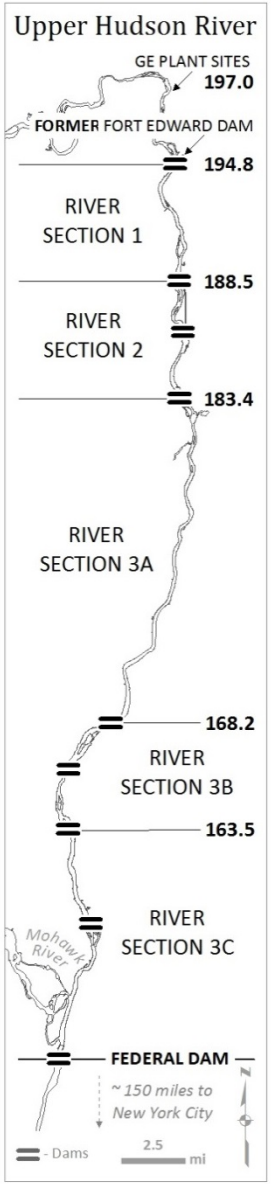
Model boundary conditions: Upstream PCB input into RS1 (Thompson Island Pool)

Surface sediment PCBs projected for UHR model subsections

PCBs in water projected for UHR model subsections

Output from UHR models used to predict fish PCBs at 4 LHR locations between RM152 and RM50 for 4 species of fish

Upper Hudson River (UHR)



Boundary Condition

RS1

RS2

RS3A

RS3B

RS3C

Surface sediment & water PCBs projected for UHR

PCB Load from Waterford (RS3B) used as input to LHR models

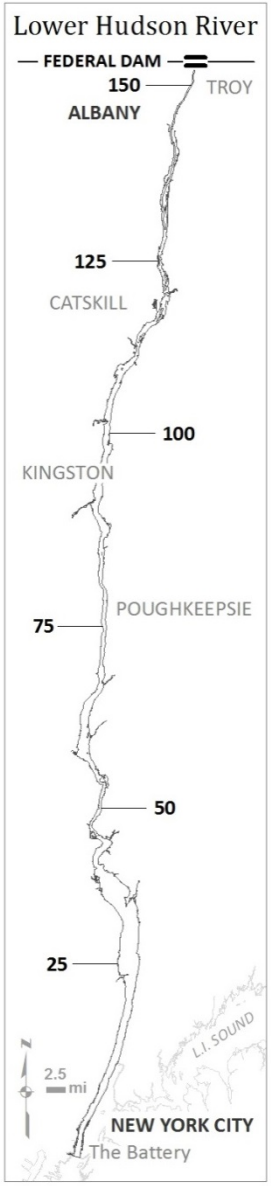
Lower Hudson River (LHR)

Output from mechanistic model PCB Load from Waterford (RS3B) used as input to LHR models

Farley[1] model used to project LHR water and sediment PCBs

FISHRAND Food Web model used Farley model output to project PCBs in 4 species of fish at 4 LHR locations

- White Perch
- Largemouth Bass
- Brown Bullhead
- Yellow Perch



RM152

RM113

RM90

RM50

[1]Farley KJ 1999. An integrated model of organic chemical fate and bioaccumulation in the Hudson River Estuary

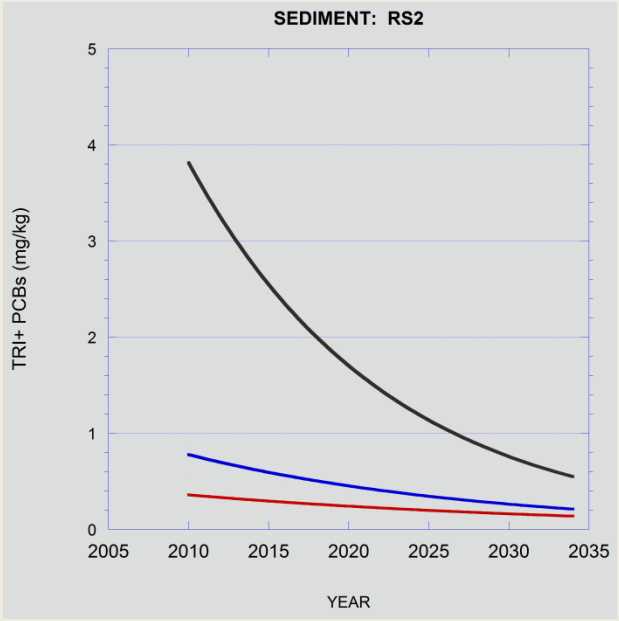
Mechanistic Model Remedial Scenarios

- MNA: Monitored Natural Attenuation with source control (assumes upstream boundary conditions of 2 ng/L PCBs by 2005)
- REM-3/10/Select: Selected Remedy
- REM 0/0/3: Full section removal in RS1 & RS2

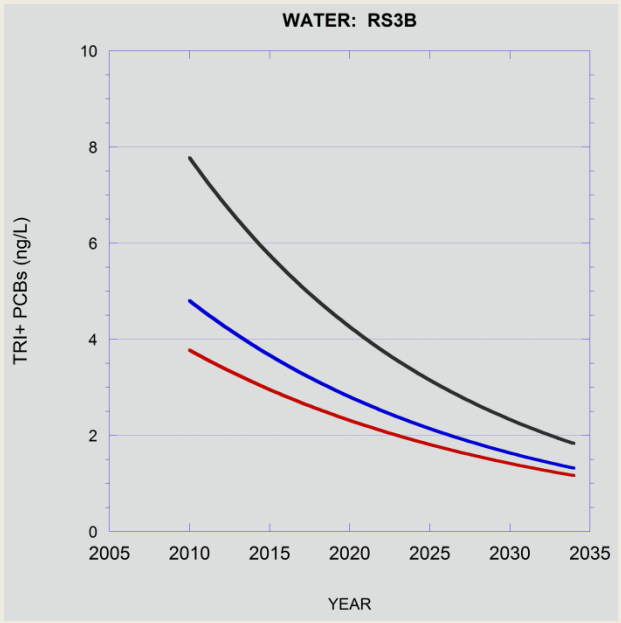
Models assumed active remediation began in 2003 and completed by 2010

EPA Mechanistic Model Projections for 3 Remedial Alternatives

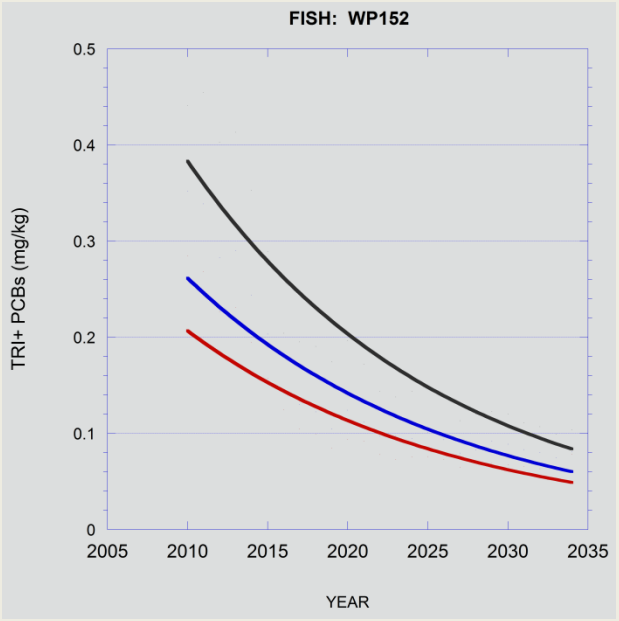
SEDIMENT (RS2) [1]

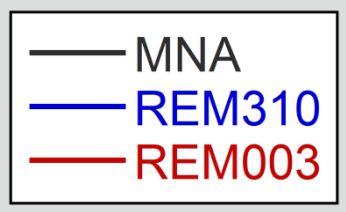


WATER (RS3B) [1]



FISH (LHR) [2]





[1] USEPA 2000. Hudson River PCBs Reassessment RI/FS Phase 3 Report. Feasibility Study.

[2] USEPA. 2002. Hudson River PCBs Site Record of Decision and Responsiveness Summary.

Model Emulation Approach

- Develop statistical models to reproduce mechanistic model projections for PCBs in UHR surface sediment and water and LHR fish for Monitored Natural Attenuation (MNA) and the selected remedy (REM)

- Use updated surface sediment PCBs and rate of decrease in sediment PCBs to assess the impact of the post-ROD findings on predictions of LHR fish PCBs

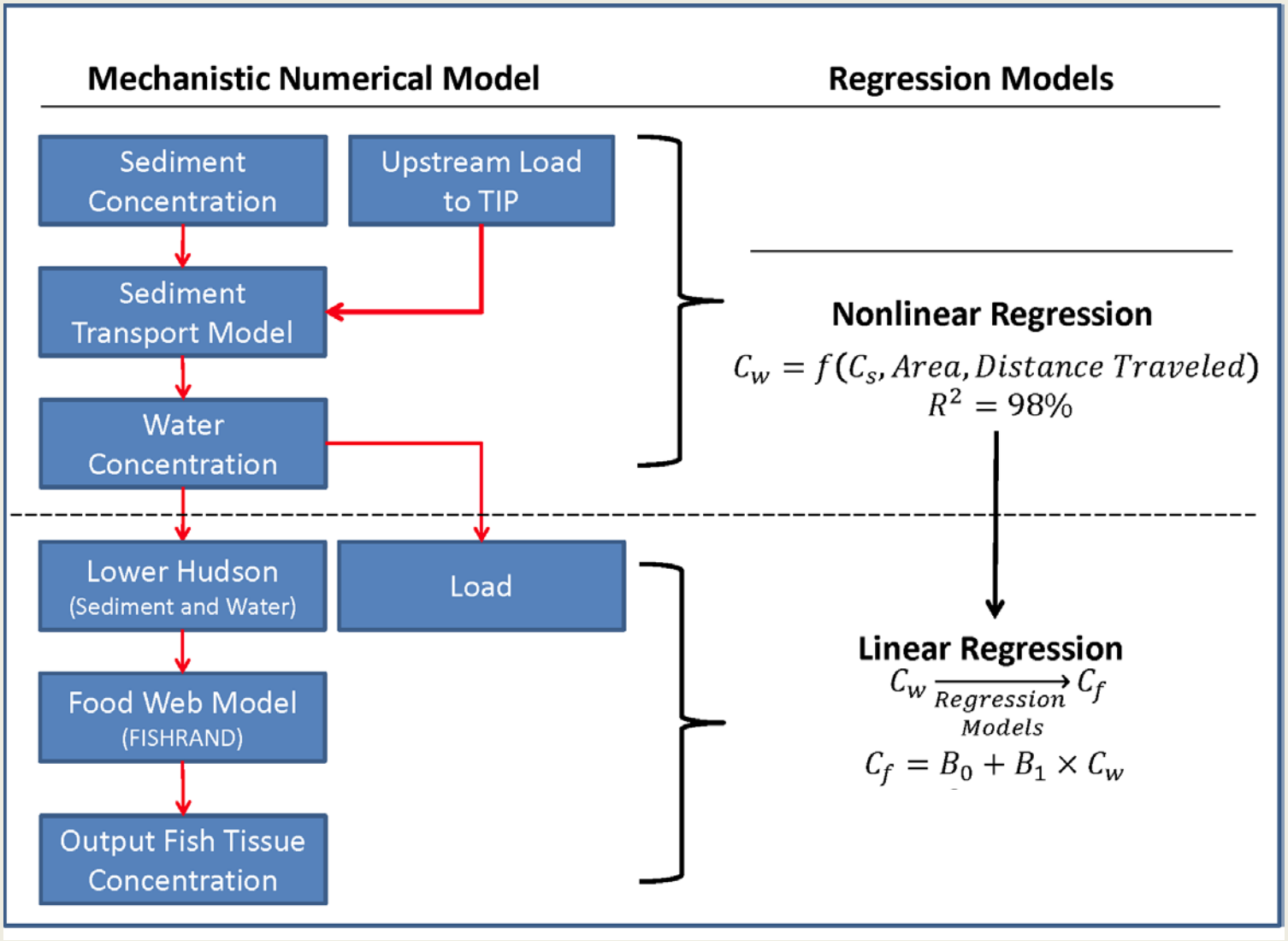
Overview of Model Emulation

- UHR Sediment: Reproduce mechanistic model projections for cohesive sediment PCBs in 4 UHR subsections

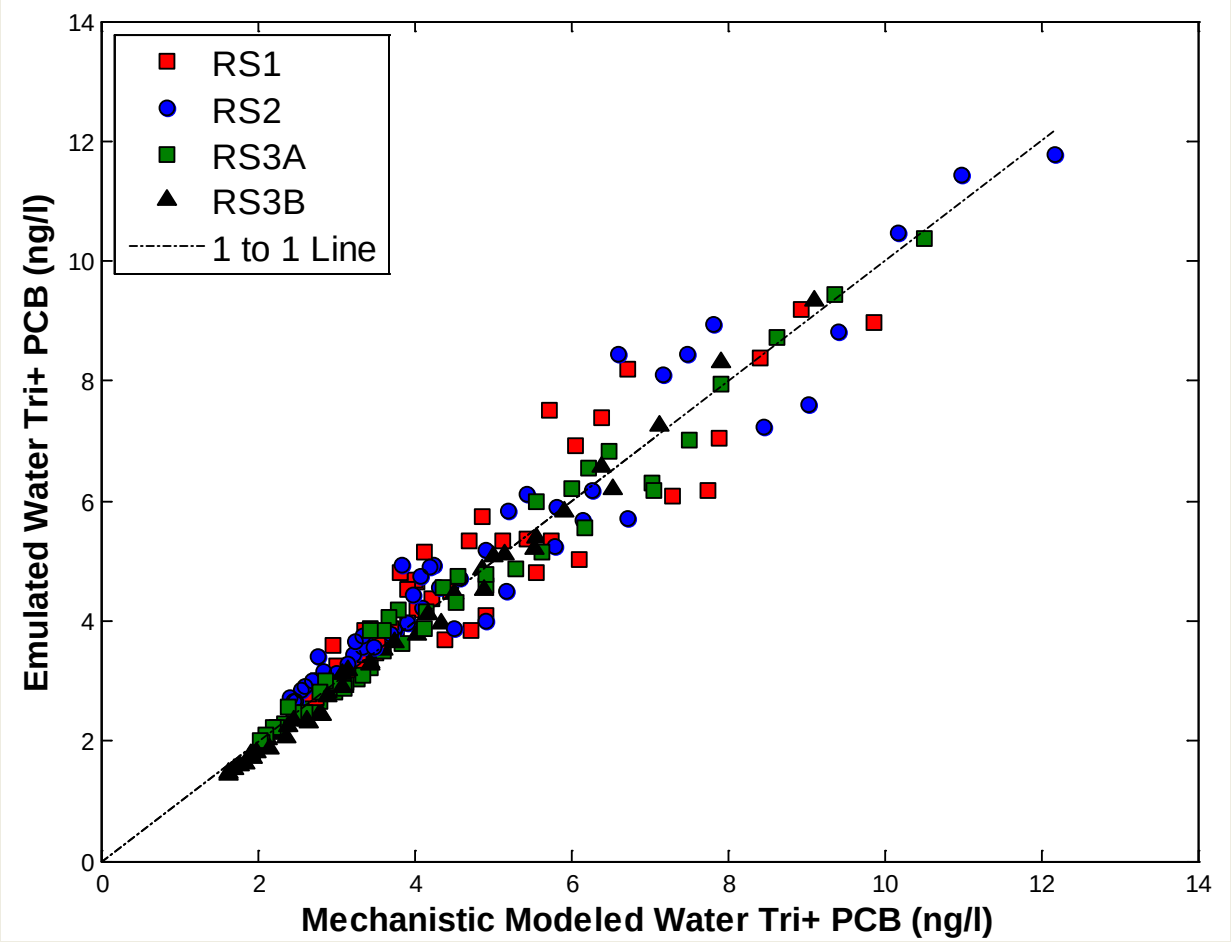
- UHR Water: Use non-linear regression to predict water PCBs in 4 UHR subsections from sediment PCBs

- LHR Fish: Use linear regression to predict fish PCBs in 4 species of fish at 4 locations in the LHR from water PCBs at Waterford (RS3B)

Model Emulation Schematic



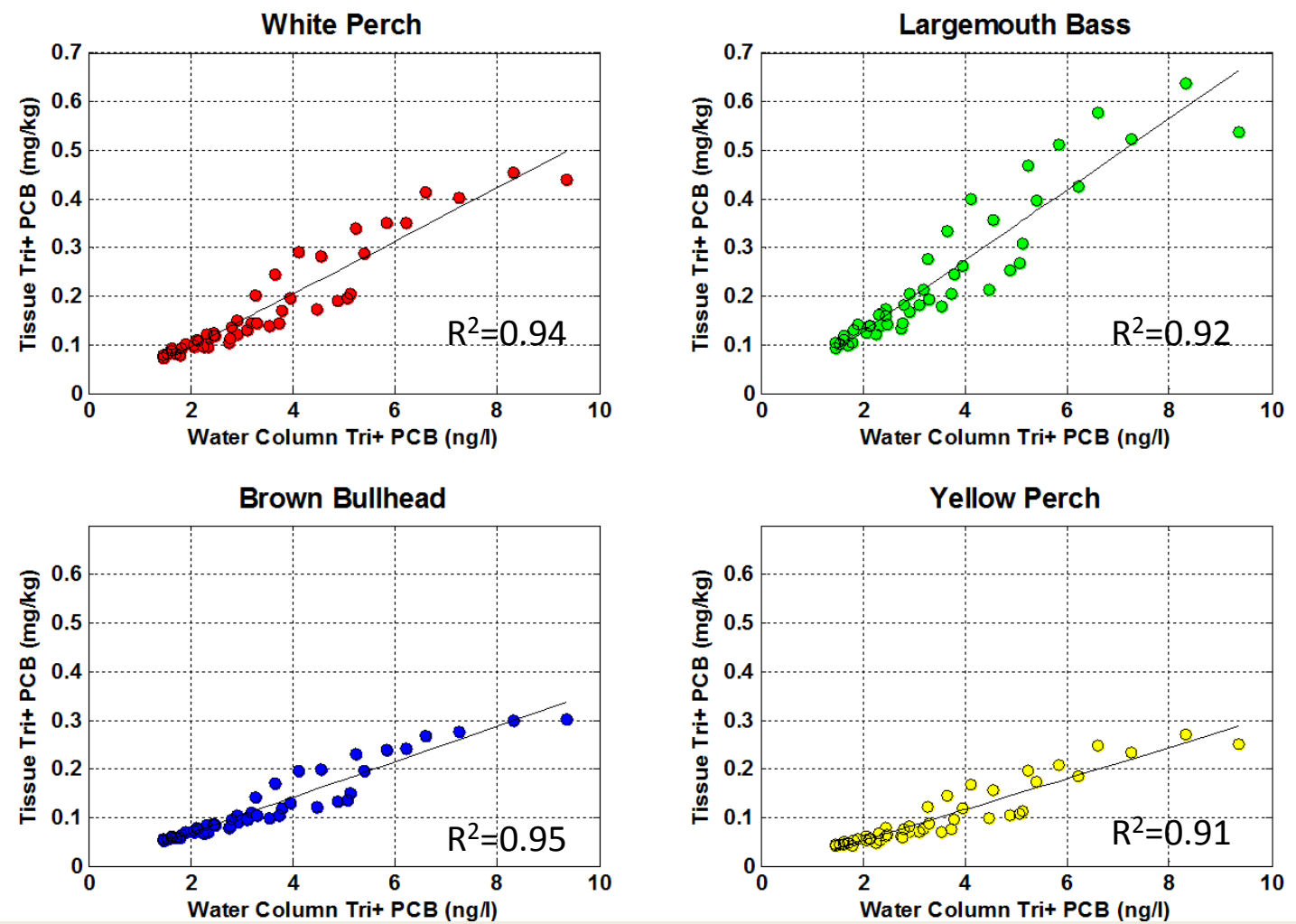
Emulated vs Mechanistic Model Water Concentrations (Tri+ PCB, ng/L)



Data Source: USEPA. 2002. Hudson River PCBs Site Record of Decision and Responsiveness Summary.

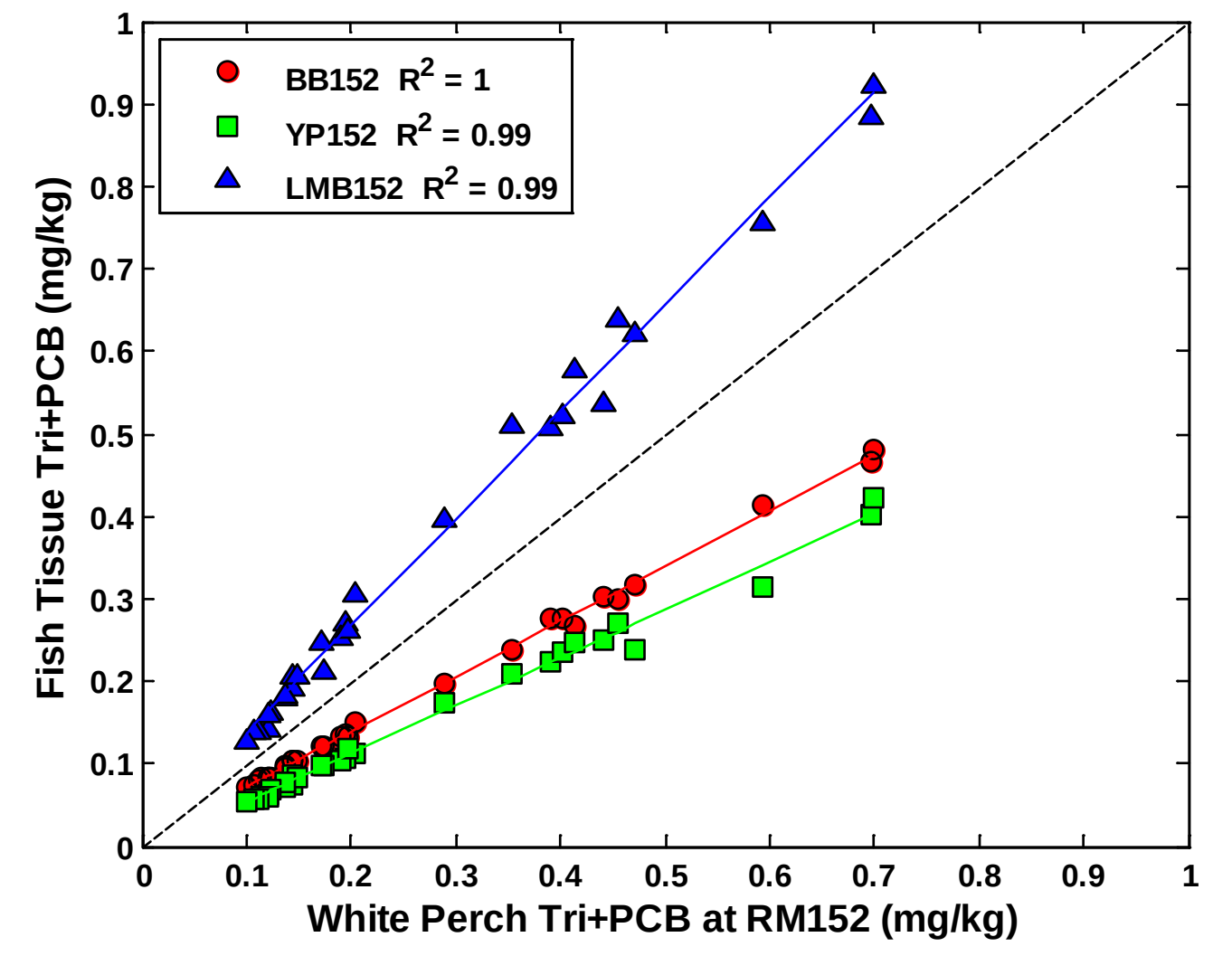
Emulation of LHR Fish PCBs Mechanistic Model Output

Water (RS3B) vs Fish PCBs at RM152



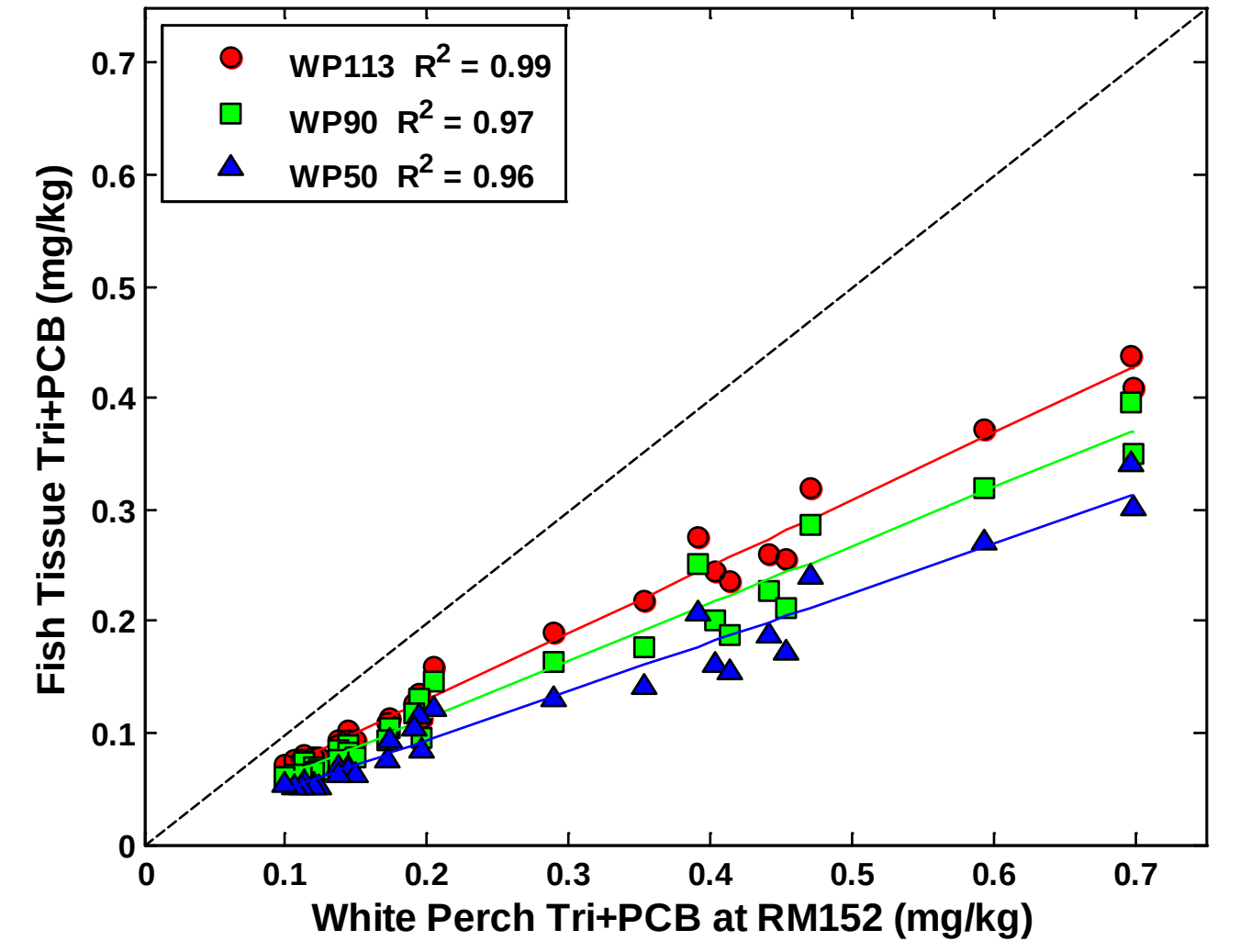
Data Source: USEPA. 2002. Hudson River PCBs Site Record of Decision and Responsiveness Summary.

Mechanistic Model Output
Fish Species Comparison



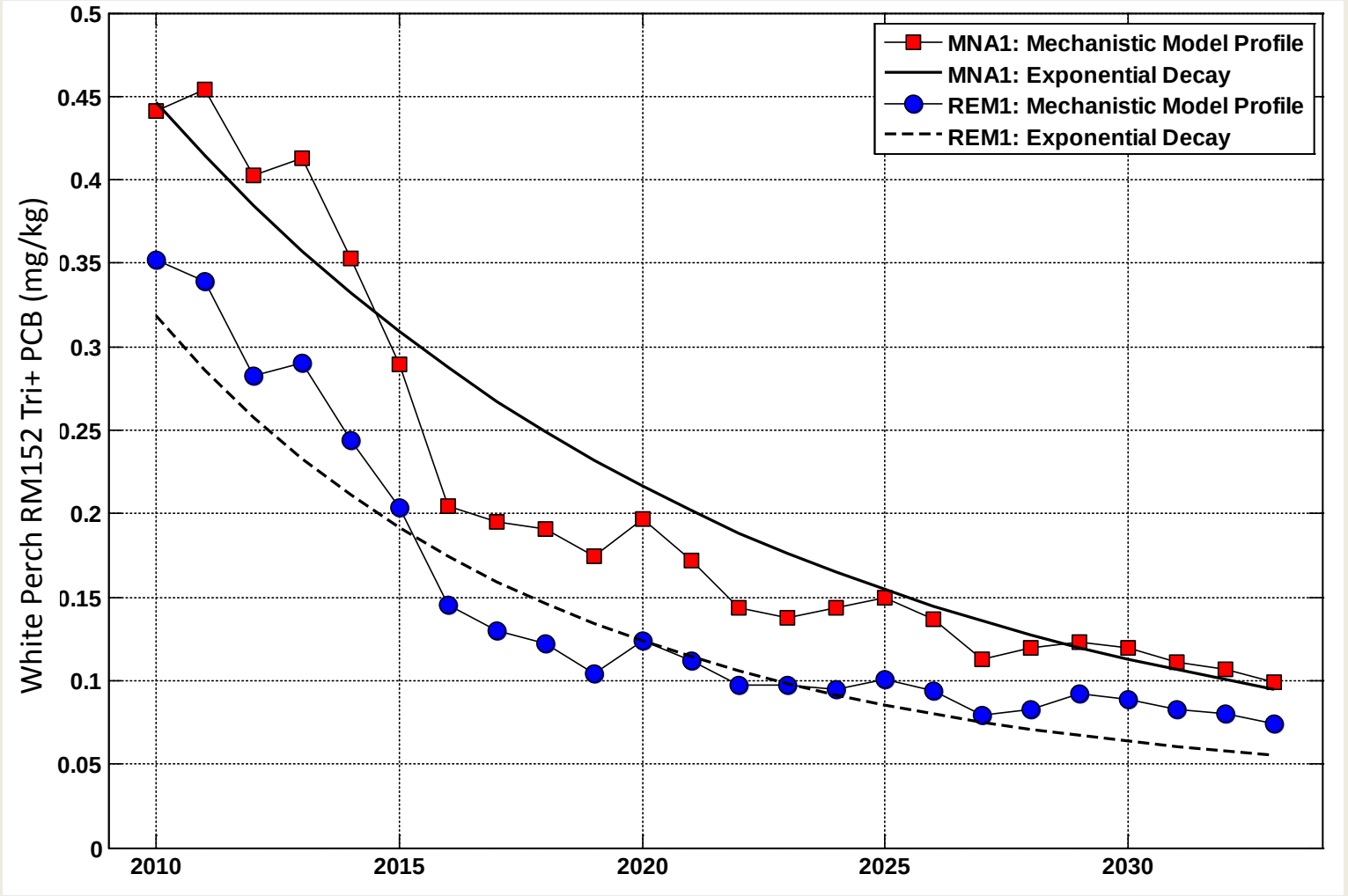
Data Source: USEPA. 2002. Hudson River PCBs Site Record of Decision and Responsiveness Summary.

Mechanistic Model Output
Fish Location Comparison



Data Source: USEPA. 2002. Hudson River PCBs Site Record of Decision and Responsiveness Summary.

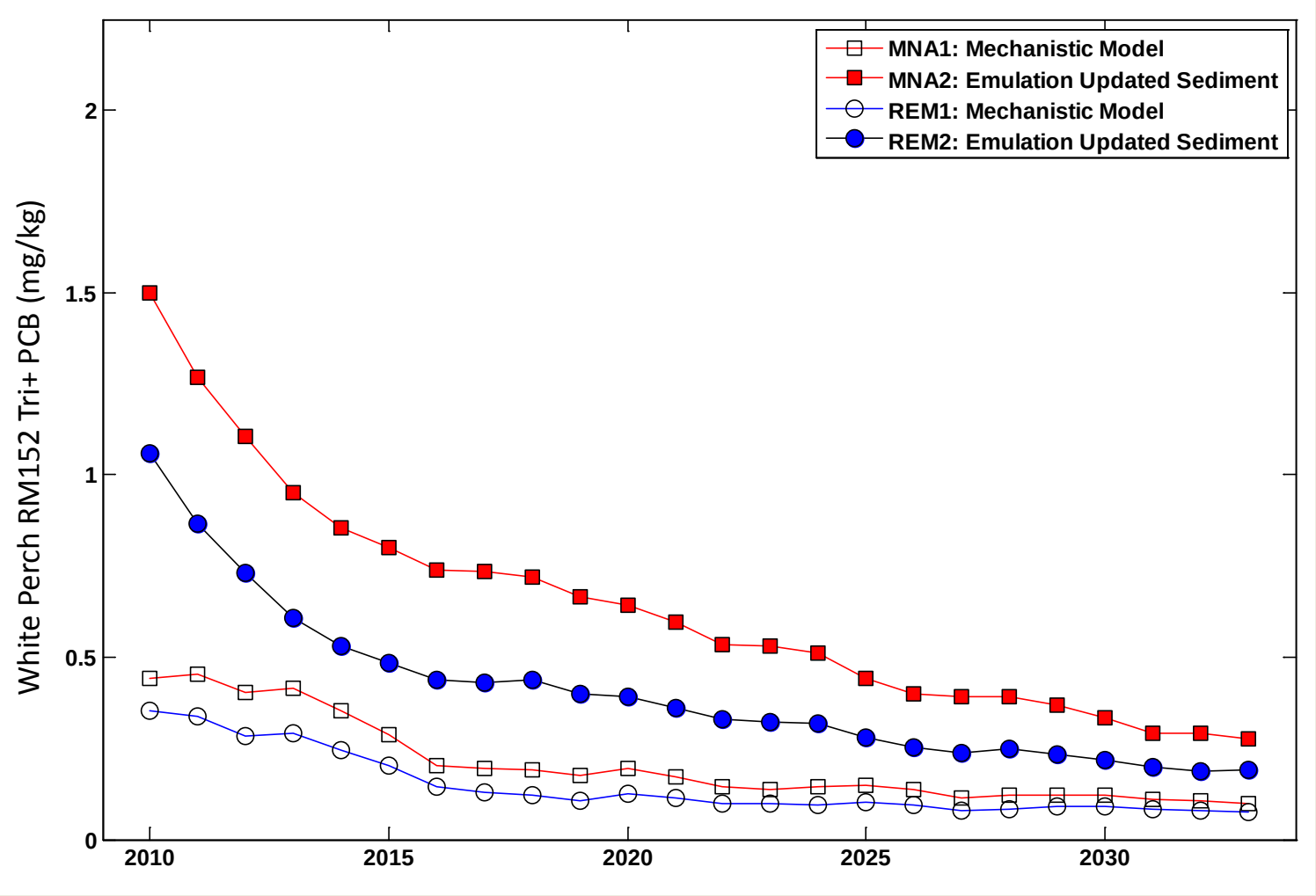
Mechanistic Model Projections vs Exponential Decay (8%) Model



Emulated Model Scenarios

Scenario	Emulated Model Projections
MNA1/REM1	Original model projections for Monitored Natural Attenuation (**MNA1**) and the selected remedy (**REM1**)
MNA2/REM2	MNA (**MNA2**) and the selected remedy (**REM2**) with updated sediment PCBs
REM3	Alternative scenario applying RS1 criteria for MPA and surface PCBs to RS2 and RS3 (**REM3**) with updated sediment PCBs
Exponential decrease	Original (8%) and updated (3%) exponential decrease in sediment PCBs applied to all scenarios

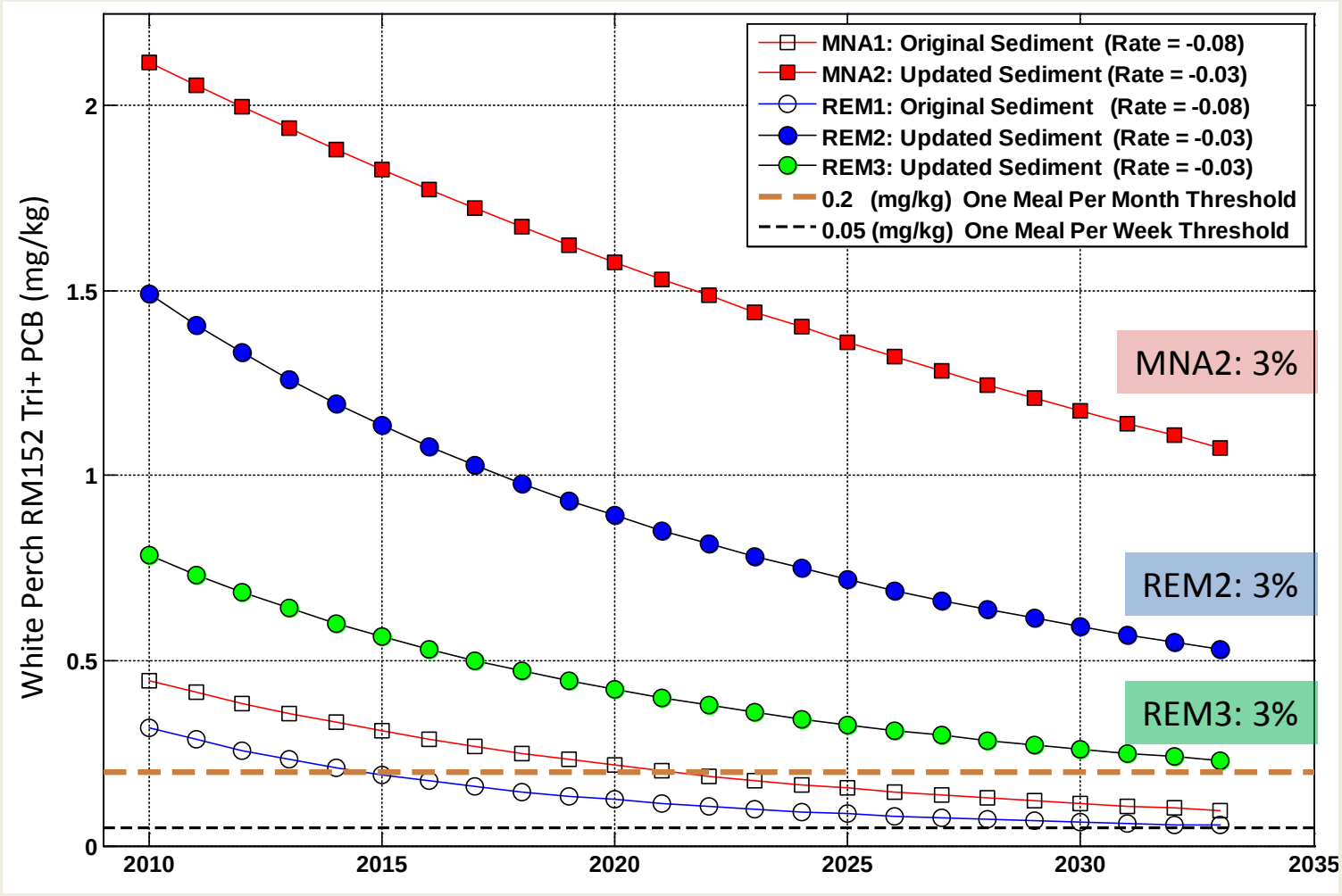
Emulated Model Projections of Fish PCBs with Original (MNA1, REM1) and Updated (MNA2, REM2) Sediment PCBs



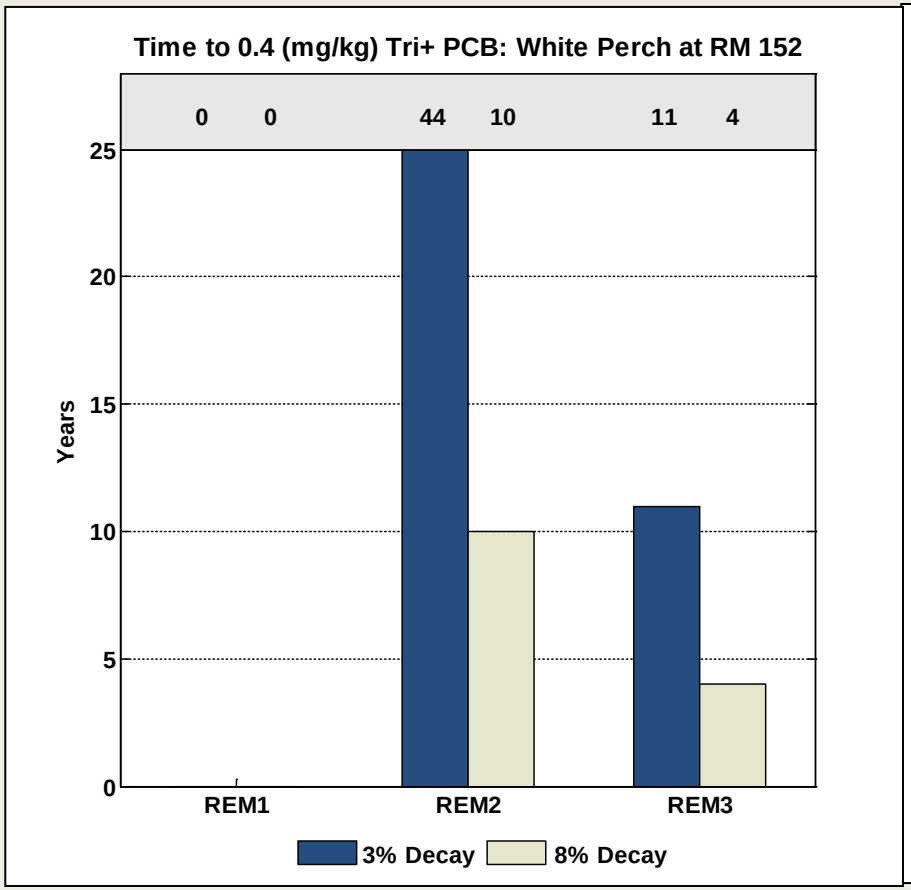
Remedial Action Objectives
Human Health

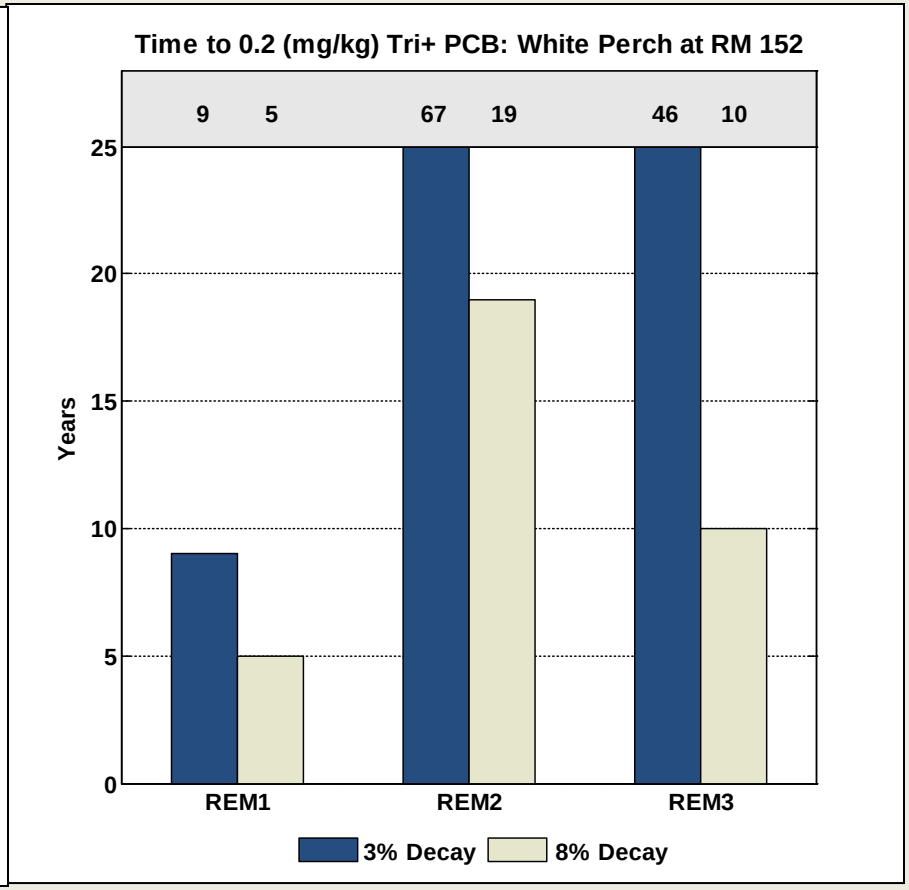
- ***Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish.***
  - 0.05 mg/kg PCBs in fish fillet, one half-pound meal per week
  - 0.2 mg/kg PCBs in fish fillet, one half-pound meal per month
  - 0.4 mg/kg PCBs in fish fillet, one half-pound meal every 2 months

Emulated Model Projections for MNA and Remedial Scenarios



Model Emulation: Post Remediation Years to 0.4 and 0.2 ppm PCB Thresholds





- REM1: Original model initial projected sediment concentrations for selected remedy in 2010
  REM2: Emulated model for selected remedy with updated sediment concentrations
- REM3: Emulated model for revised remedial scenario with updated sediment concentrations

Summary: Model Emulation

- **Application to Hudson River**
  - Reproduced mechanistic model projections of sediment, water and fish PCBs under MNA and the selected remedy
  - Enabled application of updated sediment concentrations and estimated rate of exponential decrease to re-visit temporal projections of LHR fish tissue concentrations
  - Evaluated alternative scenario
- **Other Advantages**
  - Statistical uncertainty evaluations
  - More accurate model calibration and validation

Summary: Hudson River Sediment and Fish

- Recovery of UHR sediment surface much slower than predicted
- Recovery of LHR fish much slower than original projections
- Applying REM3 would reduce time to achieve PCB thresholds in fish, but longer than predicted for the selected remedy

Use of Models in Decision-Making

- Overestimation of the rate of natural recovery in sediment minimizes difference among remedial alternatives
- Accurate estimation of the rate of natural recovery is essential for comparisons of alternatives
- Without baseline sediment data, relative comparisons of remedial alternatives may be misleading
- Model emulation can be a useful tool in reducing and understanding uncertainty

Conclusions

- Original models used were overly optimistic about the rate of recovery of surface sediment under MNA and the selected remedy
- Attainment of EPA's Remedial Action Objectives for fish in the LHR will take longer than predicted
- Additional removal of PCB-contaminated sediment in the UHR needed to achieve reductions in LHR fish PCBs anticipated in the ROD


Questions?