Evaluation of Natural Recovery Models for Sediment in the Upper Hudson River

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Abstract

Prior to 2002, EPA and GE developed models for the Upper Hudson that predicted temporal changes in surface sediment concentrations under different remedial alternatives. Following EPA's Record of Decision in 2002, over 9000 core samples were collected from the Upper Hudson during remedial design. The comparison of predicted and observed surface sediment PCB concentrations suggests that both models underestimated future PCB concentrations under natural recovery scenarios, with measured concentrations from 2002-2007 exceeding the upper bound of model predictions for 2003. In addition, PCB concentrations following the selected remedial alternative estimated from the recent data are approximately five times higher than EPA model estimates for River Sections 2 and 3.

Introduction

Natural recovery models frequently play an important role in the evaluation of remedial alternatives at large sites. These models are intended to forecast changes in surface sediment contaminant concentrations that can be linked to exposure models for predicting recovery rates under different remedial scenarios. If, as often stated "all models are wrong, some are useful", how does a project manager know if models relied on to provide insight into the relative difference between alternatives are useful? In this paper, we consider model predictions of surface sediment concentrations for the Upper Hudson River in light of an extensive remedial design dataset.

The Hudson River PCBs Superfund Site extends approximately 200 miles from Hudson Falls to the Battery in New York Harbor. EPA's Record of Decision in 2002 addressed PCB contaminated sediments in the Upper Hudson River, the 40 miles between Ft. Edward and the Federal Dam at Troy. The Upper Hudson was divided into three sections: River Section 1 (Thompson Island Pool) is 6 miles long; River Section 2 is 5 miles long and includes two reaches (pools separated by dams); and, River Section 3 is 29 miles long and includes five reaches (Figure 1). The selected remedy includes dredging an estimated 1.8 million cubic yards of sediment and monitored natural attenuation (MNA) of PCB contamination remaining in the river after dredging.

	Number of Surface Samples (Top 2 inches)				
River Subsection	**2002**	**2003**	**2004**	**2005**	**Total**
1	822	1264	946	382	3414
2	140	749	483	169	1541
3A		1550	550	91	2191
3B		447	203	35	685
3C		220	95	21	336
TOTAL	962	4230	2277	698	8167

Methods

Remedial design data collected by GE between 2002 and 2007 (GE 2008) are assumed to represent year 2003. Data used also available in NOAA 2008.

Most data were collected from systematic grid sampling. River section and subsection average sediment Tri+ PCB concentrations were calculated as the arithmetic average of surface sediment samples using samples collected from sediment depths of less than or equal to 2 inches (n=8167).

Calculation of post-remedial Tri+ PCB concentrations: Samples within the remedial design dredge footprints (GE 2005, GE 2007) were assigned a surface sediment Tri+ PCB concentration of 0.25 ppm and averages for each river subsection were recalculated.

EPA and GE model predictions of surface sediment concentrations were taken from figures in EPA 2002 and GE 1999.

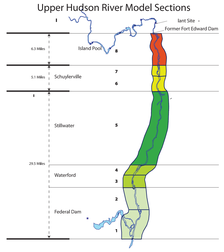


Figure 1. The Upper Hudson River (UHR) section, subsection and reach designations.

Table 1. Target cleanup levels for the Upper Hudson River (EPA 2002).

River Section 1 (Reach 8: Thompson Island Pool):

3 g/m² Tri+ PCBs[1] Mass per unit area (MPA)

10 mg/kg Tri+ PCBs in surface sediment (in top 12 inches) (~ 25-30 ppm total PCBs)

River Sections 2 & 3 (Reaches 1-7)

10 g/m² Tri+ PCBs MPA

30 mg/kg Tri+ PCBs in surface sediment (~ 60-90 ppm total PCBs)

[1]Tri+ PCBs: sum of trichloro- through decachlorobiphenyl PCBs

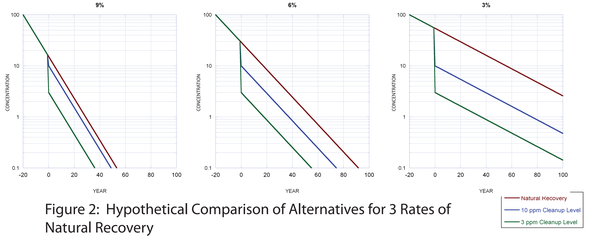


Figure 2: Hypothetical Comparison of Alternatives for 3 Rates of Natural Recovery

- Assumes an initial contaminant concentration of 100 ppm and completion of two removal alternatives of 10 ppm and 3 ppm after 20 years of natural recovery, using three rates of exponential decline in surface sediment concentrations of 3, 6, and 9%.
- Illustrates the importance of accurately estimating the rate of natural recovery.
  1) Difference in length of time to reach sediment target (eg., 1 ppm) for individual alternatives.
  2) Difference in number of years to reach sediment target among remedial alternatives

Approximate Number of Years until Target Sediment Concentration of 1 ppm Reached Depends on Rate of Decline

	Number of Years to Reach 1 ppm Target		
Rate of Decline	Natural Recovery	10 ppm Alternative	3 ppm Alternative
9%	29	25	12
6%	55	38	18
3%	>100	76	37

Consequences of Overestimating Rate of Decline

- Ability to discriminate between benefits of natural recovery and active remedies and between different active remedies is reduced
- Relative differences in time to recovery are compressed
- Remedies appear more similar

Example: The difference between the 10 ppm and 3 ppm alternatives attaining the 1 ppm target is approximately 13 years at a 9% rate of decline, compared to ~ 40 years at a 3% rate of decline.

Hudson River Model Predictions

EPA (2000a) and GE models both predicted exponential decline in surface (top 4-5 cm) sediment Tri+ PCBs of approximately 7-9% per year

Sediment Data Used in Model Development and Calibration

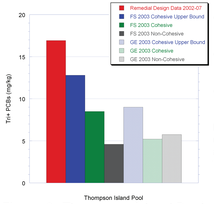
Initial conditions
NY State 1976-78 survey (260 cores, 700 grabs)

Primary model calibration data
GE 1991 composite samples at 1-2 mile intervals of UHR (160 cores, 46 grabs)
GE 1998 composite samples, mostly Thompson Island Pool (TIP) (70 cores, 3 grabs)

Supplemental data
NY State 1984 survey (550 locations, TIP, top 10-30 cm)
EPA 1992 High resolution cores (limited locations in UHR)
EPA 1994 Low resolution cores (mostly TIP and selected hot spots)

Remedial Design Sediment Data

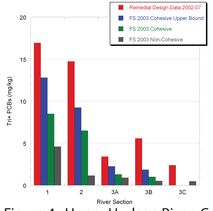
- Over 9000 sediment cores/grabs from 3 river sections between 2002 – 2007 (GE 2008) -
- Top core segments <2 inches (8167 surface samples)
- Cores in TIP and fine-grain sediment areas in other river sections sampled (mostly 80-ft or 160-ft grid spacing)
- All sediment types were sampled in RS1 and fine-grained sediments in RS2 and RS3.
- Data evaluated as concentration of Tri+ PCBs (Trichlorobiphenyl homologues and higher for consistency with historical analysis)



- The red bar on the left represents the average Tri+ PCB concentration of all remedial design (RD) top core segments with a lower depth of <=2 inches collected by GE between 2002 and 2007.
- The solid blue bar (EPA 2002) and the cross-hatched blue bar (GE 1999) represent upper bound model predictions of Tri+ PCB concentrations in cohesive sediments for the top 4 or 5 cm
- The green bars and the grey bars represent average predicted Tri+ PCBs in cohesive and non-cohesive sediment, respectively.

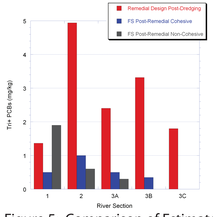
RD measured Tri+ PCB concentrations exceed both EPA and GE models upper bound predictions for natural recovery by 2003 and are more than a factor of 2 higher than the average predicted concentrations for the Thompson Island Pool.

Figure 3: Thompson Island Pool: Comparison of Remedial Design Data to EPA and GE Model Predictions for 2003



EPA model predictions for 2003 underestimated Tri+ PCB concentrations throughout the Upper Hudson. In all river sections/subsections, the RD Tri+ PCB concentrations are higher than the predicted upper bound of cohesive sediment concentrations and more than 2X the average predicted cohesive sediment concentrations.

Figure 4: Upper Hudson River: Comparison of Remedial Design Data to EPA Model Predictions for 2003



A comparison of the estimated post-dredging Tri+ PCB concentrations from the RD data (red bar) with the FS model predictions (blue and grey bars for cohesive and non-cohesive sediments) shows that estimated post-dredging surface concentrations will be at least a factor of 5 higher than the FS/Responsiveness Summary predictions for the selected remedy in River Sections 2 and 3.

Figure 5: Comparison of Estimates of Post-Dredging Concentrations from Remedial Design Data to EPA Model Predictions for the Selected Remedy

EPA models predicted post-remedial surficial Tri+ PCB concentrations of <1 ppm in cohesive sediments throughout the Upper Hudson River (EPA 2002). The percent reduction in River Sections 2 and 3 is much less than predicted.
If percent reduction in surface sediment concentrations is directly related to fish concentrations (as implied by BSAF-type models), then reduction in fish concentrations following remediation will be much less than expected.

		Model Predicted Cohesive Sediment Tri+ PCBs (ppm)		Remedial Design (RD) Estimated Tri+ PCBs (ppm)		Percent Reduction After Removal	
River Section	Model Section	Pre-Removal	Post-Removal	Pre-Removal	Post-Removal	Model	RD
1	Thompson Island Pool	8.5	0.9	16.9	1.4	94.1	91.9
2	Schuylerville	6.5	1.0	14.7	4.9	84.6	66.4
3A	Stillwater	1.3	0.5	3.4	2.4	61.5	29.4
3B	Waterford	1.0	0.4	5.6	3.3	65.0	40.4
3C	Federal Dam	NA	NA	2.4	1.8	NA	24.5

Hudson River Summary

- Remedial Design Tri+ PCB concentrations in surface sediment exceeded upper bound model predictions for 2003 and average concentrations by at least a factor of 2 throughout the Upper Hudson River.
- Remedial Design Tri+ PCB concentrations in surface sediment exceeded surface concentrations in 1998 GE data for TIP and EPA model estimates for other river sections (not shown)
- Estimated post-removal concentrations from RD data exceed model predictions by factor of 5 for River Sections 2 and 3.
- Percent reduction in surface concentrations following removal will be much less than predicted for River Sections 2 and 3.

Why Do These Models Overestimate Sediment Recovery?

- Model initial conditions?
  Data collected only 3-4 years after Ft. Edward dam removal. Processes involved in downstream redistribution of sediment following dam removal not well-captured by models.
- Limitations in data used for calibration?
  Spatial coverage: much more data for TIP than rest of UHR
  Sediment composites in 1991 and 1998 were used in model calibration, possibly not representative and biased low.
- Unaccounted for source?
  Remediation at plant sites
  Ongoing PCB DNAPL seeps from bedrock
  Models accounted for ongoing releases
- High flow events?
  Maximum flows post-1998 are within normal range considered by models
- Model parameterization?
  Mixing depth used in models may be too low: "Increasing the depth of mixing by 50% (i.e., 10 cm to 15 cm) decreases the rate of decline, resulting in predicted concentrations in 1991 and 1998 that are slightly closer to the mean observed values than in the calibration." GE 1999)

Implications of Overestimating Rate of Natural Recovery in Sediment in the Hudson River

- Surficial sediment concentrations will be higher than expected at initiation of remedial action
- Surficial sediment concentrations following remediation will be much higher (~5x) than expected in River Sections 2 and 3
- Higher surficial sediment concentrations outside of remediated areas greatly increase the potential for recontamination and extend time to recovery
- Model projections of time to recovery of surface sediment concentrations (and fish and piscivorous and other wildlife) likely underestimate the time to recovery in River Sections 2 and 3

Conclusions and Recommendations

All natural recovery models are wrong, some are useful: How do we know if relative comparisons of remedial alternatives based on these models are giving us useful information? Unless the model predictions of the rate of natural recovery can be clearly validated with surface sediment concentration data independent of model calibration, the relative comparison of alternatives may be misleading.

We recommend developing sediment sampling plans that are specifically designed to estimate temporal trends in surface sediment concentrations as part of the Remedial Investigation for any large site with the potential for sediment remediation.

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