



**U.S. Army
Corps of Engineers**

New England District
Concord, Massachusetts



**U.S. Environmental
Protection Agency**

New England Region
Boston, Massachusetts

RESPONSIVENESS SUMMARY TO THE PEER REVIEW OF MODEL VALIDATION: MODELING STUDY OF PCB CONTAMINATION IN THE HOUSATONIC RIVER

DCN: GE-111006-ADII

November 2006

**Environmental Remediation Contract
GE/Housatonic River Project
Pittsfield, Massachusetts**

Contract No. DACW33-00-D-0006

Task Order 0003

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OF MODEL VALIDATION:
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in the Housatonic River**

**ENVIRONMENTAL REMEDIATION CONTRACT
GENERAL ELECTRIC (GE)/HOUSATONIC RIVER PROJECT
PITTSFIELD, MASSACHUSETTS**

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Prepared for

U.S. ARMY CORPS OF ENGINEERS
New England District
Concord, Massachusetts

and

U.S. ENVIRONMENTAL PROTECTION AGENCY
New England Region
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APPENDIX A.4 COMMENTS OF MARCELO H. GARCIA

APPENDIX A.5 COMMENTS OF FRANK GOBAS

APPENDIX A.6 COMMENTS OF WILBERT LICK

APPENDIX A.7 COMMENTS OF E. JOHN LIST

LIST OF ACRONYMS

CFD	computational fluid dynamics
cm/s	centimeters per second
CMS	Corrective Measures Study
DRM	Document Review Meeting
EDS	energy-dispersive system
EFDC	Environmental Fluid Dynamics Code
EPA	U.S. Environmental Protection Agency
EqP	equilibrium partitioning
FCM	food chain model
FMD	Final Model Documentation
FN	Floodplain Number
GE	General Electric Company
HOCs	hydrophobic organic chemicals
HSPF	Hydrologic Simulation Program - FORTRAN
kg/year	kilograms per year
KS	Kolmogorov-Smirnov
MB	Model Bias
MCR	Model Calibration Report
MFD	Modeling Framework Design
mm/year	millimeters per year
MVR	Model Validation Report
NRCSE	National Research Center for Statistics and the Environment
PCB	polychlorinated biphenyl
PRC	Peer Review Committee
PSA	Primary Study Area
QAPP	Quality Assurance Project Plan
RFI	RCRA Facility Investigation
ROR	Rest of River
RSM	Response Surface Modeling
SEM	scanning electron microscopy
SNL	Sandia National Laboratories
SPI	sediment profile imaging
SRA	SRA International, Inc.

LIST OF ACRONYMS (CONTINUED)

TSS	total suspended solids
UV-B	ultraviolet
XRD	x-ray diffraction

1

INTRODUCTION

2 This document presents the response from the U.S. Environmental Protection Agency (EPA) to
3 comments and questions raised by an independent Peer Review Panel following their review of
4 the Model Validation Report for the GE/Housatonic River Site Rest of River released in March
5 2006. The review was conducted by seven professionals in disciplines related to numerical
6 modeling of aquatic and riverine systems. This document, referred to herein as the Model
7 Validation Responsiveness Summary, has been prepared as part of EPA's obligations under
8 Appendix J of the comprehensive agreement relating to the cleanup of the General Electric
9 Company (GE) Pittsfield, MA facility, certain off-facility properties, and the Housatonic River
10 (referred to as the "Consent Decree"). The Consent Decree was entered on October 27, 2000, by
11 the United States District Court of Massachusetts - Western Division, located in Springfield,
12 MA.

13 Under the terms of the Consent Decree, EPA was required to conduct modeling of the fate,
14 transport, and bioaccumulation of polychlorinated biphenyls (PCBs) in the area referred to as the
15 "Rest of the River," defined as the area of river and adjacent floodplain downstream from the
16 confluence of the East and West Branches of the Housatonic River in Pittsfield, MA. The
17 Consent Decree further stipulates that the model will include a hydrodynamic component, a
18 sediment transport component, a PCB fate and transport component, and a bioaccumulation
19 component. Following completion of the Validation Report Peer Review, the model will be used
20 by GE as a tool in comparing the relative effectiveness of proposed remedial alternatives,
21 including baseline conditions.

22 Prior to the Peer Review, a 45-day public comment period provided the opportunity for the
23 public and GE to submit written comments on the Model Validation Report for consideration by
24 the Peer Review Panel, within the context of the Peer Review Charge. On June 28 and 29, 2006,
25 the Model Validation Peer Review Panel ("Reviewers") met at a public forum in Lenox, MA, to
26 review and discuss the Model Validation Report within the framework of the Charge. During
27 this meeting, members of the public and GE were provided the opportunity to present oral
28 comments to the Panel, and the Panel was able to engage in a question/answer session with the
29 public presenters. The Reviewers subsequently submitted final written comments to EPA's
30 Managing Contractor for the Peer Review, SRA International, Inc. (SRA), of Arlington, VA.

31 APPROACH AND ORGANIZATION OF THIS DOCUMENT

32 As stipulated in Appendix J to the Consent Decree, Peer Reviewers were discouraged from
33 discussing their individual comments with each other outside the public Peer Review Meeting, to
34 allow the full discussion to take place in public. In addition, the Reviewers were not required to
35 reach consensus; therefore, the comments were prepared independently by each Reviewer.
36 During the Peer Review meeting, many of the Reviewers provided some of the same comments
37 on the Model Validation Report; therefore, they submitted similar written comments on these
38 topics. Conversely, at many times Reviewers had differing views on topics; this is also reflected
39 in the written comments.

1 As a result of these considerations, and to avoid unnecessary repetition and to increase clarity in
 2 the Model Validation Responsiveness Summary, EPA organized this document so that responses
 3 to general topics are grouped together, followed by responses to other (miscellaneous)
 4 comments.

5 The responses to the General Topics address subjects that were raised by a number of Reviewers
 6 and/or had broad implications for the model validation and for the modeling study in general.
 7 EPA has identified 12 General Topics and one Other (Miscellaneous) Topic and has provided a
 8 Summary of Topic for each to frame the technical basis for the issue and to provide an indication
 9 of how often the topic was noted by the Reviewers. Typically, each Summary of Topic is
 10 followed by EPA's response to the General Topic. Most of the responses to the General Topics
 11 reference the Final Model Documentation (FMD) Report to avoid unnecessary repetition.

12 Appendix A presents the Peer Reviewer Comments and indicates the classification of these
 13 comments in relation to the General Topics.

14 **RELATIONSHIP OF THE MODEL VALIDATION RESPONSIVENESS SUMMARY TO**
 15 **THE MODELING STUDY FOR REST OF RIVER**

16 This Responsiveness Summary provides EPA's formal response to the final written Peer Review
 17 comments and, together with the issuance of the FMD Report and meetings/discussions of the
 18 Model Working Group transferring the model code and input files, constitutes EPA's declaration
 19 of completion of the Model Validation Report Peer Review and fulfillment of the requirements
 20 of Paragraph 22.j of the Consent Decree.

21 The purpose of the FMD is to summarize the enormous effort resulting from 8 years of
 22 interpretation, analysis, and evaluation that occurred in support of the modeling study for the
 23 Housatonic River, incorporating input from GE and its consultants as part of the Model Working
 24 Group established under the Consent Decree, and in response to the Peer Reviews. The FMD
 25 finalizes the outcome of the modeling study and draws upon the information contained in the
 26 following documents:

- 27 ▪ Draft Model Framework Design (MFD) document and Quality Assurance Project
 28 Plan (QAPP) (October 2000).
- 29 ▪ Responsiveness Summary to the Peer Review of the MFD and QAPP (June 2002).
- 30 ▪ Final MFD (April 2004).
- 31 ▪ Model Calibration Report (MCR) (December 2004).
- 32 ▪ Responsiveness Summary to the Peer Review of the MCR (January 2006).
- 33 ▪ Model Validation Report (MVR) (March 2006).
- 34 ▪ Responsiveness Summary to the Peer Review of the MVR (November 2006).

1 ▪ Other materials prepared in response to the Peer Reviews that are included in the Peer
2 Review record.

3 ▪ The RCRA Facility Investigation (RFI) Report prepared by GE (September 2003).

4 The FMD is organized in roughly parallel construction to both the Model Calibration and
5 Validation Reports to assist the reader in going back to the source document to obtain more
6 detail regarding the subject being presented, if desired.

7 The comments received from Reviewers on the Model Validation Report were used by EPA in
8 preparing this Responsiveness Summary and the FMD. In many cases the modeling team
9 performed further evaluations of the data or model formulations based upon suggestions by the
10 Reviewers. In some cases, these resulted in changes in the model framework. These efforts and
11 resulting changes are discussed in this Responsiveness Summary and documented in the FMD.

12 EPA recognizes the hard work and thought that the Reviewers contributed in conducting the Peer
13 Review. Although EPA agrees with many of the comments provided by the Reviewers, EPA
14 does not agree with some of the comments. These are documented in the responses and in the
15 FMD; in such cases, the technical basis for EPA's position is provided.

1 **RESPONSE TO GENERAL TOPICS AND SPECIFIC COMMENTS**

2 **1. GENERAL TOPIC 1: REPRESENTATION (PARAMETERIZATION) OF**
 3 **MODEL PROCESSES**

4 **1.1 BALANCE OF FATE PROCESSES**

5 **1.1.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Bohlen	Page 4, lines 23 to 33
	Page 8, line 38 to page 9, line 7
	Page 9, lines 8 to 23
	Page 14, lines 26 to 31
Endicott	Page 2, lines 20 to 21
Garcia	Page 1, lines 25 to 37
	Page 5, line 39 to page 6, line 2
Gobas	Page 2, lines 28 to 42
	Page 3, lines 34 to 37
	Page 5, lines 4 to 17
	Page 13, lines 9 to 25
Lick	Page 1, lines 19 to 28
	Page 3, line 16 to page 4, line 10
	Page 9, lines 14 to 43
List	Page 5, lines 31 to 34
	Page 5, lines 39 to 40

6 **1.1.2 General Topic Summary**

7 The model framework for the Housatonic River includes HSPF, EFDC, and FCM. To achieve
 8 the goals of the modeling study, the model framework must reasonably account for the relevant
 9 processes that control PCB fate, transport, and bioaccumulation in the Housatonic River. In the
 10 framework, EFDC is used to simulate hydrodynamics, sediment transport, and PCB fate. Within
 11 EFDC, multiple processes are represented and interact to influence the transport and fate of
 12 sediment and contaminants and occur across different spatial and temporal scales. The

1 representation of the interactions between processes and the relative importance of the relevant
2 processes (i.e., the balance of fate processes), at the relevant scales, is central to determining the
3 ability of the framework to simulate future conditions.

4 The majority of Reviewers expressed opinions that processes were either not well understood or
5 incorrectly (or not accurately) represented in the model. Reviewers often recommended that
6 additional information and/or data be collected to address their concerns. In some cases specific
7 examples were provided and are summarized, with EPA's response, in the following subsections
8 of the discussion of this General Topic.

9 **1.1.3 General Topic Response**

10 EPA strongly disagrees with Reviewer opinion that relevant sediment transport and/or
11 PCB fate processes are not reasonably represented in the model framework. The
12 balance of fate processes refers to the relative importance of processes for phase
13 distribution, erosion, deposition, and sediment-water mass transfer that give rise to PCB
14 exposure concentrations in water and sediment.

15 It is important to recognize that the overwhelming majority of Reviewer comments
16 regarding the relative balance of fate processes described in the model framework are
17 founded on erroneous interpretations of the rate at which PCB concentrations in river
18 sediment have changed over time and how individual transport processes affect that
19 rate. The change in sediment PCB concentrations over time was initially described in
20 the RFI (BBL and QEA, 2003), and EPA documents such as Responses to Questions
21 from the Reviewers, and is now more fully quantified in Appendix A.1 of the Final Model
22 Documentation (FMD) Report. Specifically, these analyses indicate that the trend (or
23 decline) in sediment PCB concentrations in Reaches 5 and 6 is not statistically different
24 from zero (i.e., slow to no change over time).

25 Accurate quantification of spatial and temporal PCB concentration trends in river
26 sediments is complex. Sediment sampling efforts for the Housatonic River were not
27 designed to estimate PCB concentration trends over time. Differences in sediment PCB
28 concentrations resulting from spatial heterogeneity, temporal variability, and analytical

1 bias confound analysis and make clear identification of trends challenging (see FMD
2 Appendix A.1 and General Topic 2).

3 The trend (or decline) in surface sediment PCB concentrations in Reaches 5 and 6
4 shows slow to no change over time. Model results are consistent with this observation.
5 Specifically, the simulated rate of surface sediment PCB concentration decline in EFDC
6 is slow and within the uncertainty envelope of the data. The analysis of spatial and
7 temporal trends in PCB concentrations in fish tissue shows a slight decline over time in
8 whole-body fish tissue PCB concentrations in Reaches 5 and 6. The decline in fish
9 tissue concentrations was statistically significant for some of the species and/or
10 subreaches and not for others. The magnitude of the decline was generally small in
11 most cases, with a half-life on the order of decades. This is consistent with the results
12 of the analysis of trends in sediment PCB concentrations. PCB exposure
13 concentrations simulated in the water column and sediment and passed from EFDC to
14 FCM result in the accurate simulation of the concentrations of PCBs in fish tissue, with a
15 simulated rate of decline which is slow and within the uncertainty envelope of the data.

16 In contrast, the Reviewers assumed that there was a more rapid decline in sediment
17 PCB concentrations over time and then incorrectly concluded that the rate of decline in
18 PCB concentrations simulated by the model (which is in agreement with the data) was
19 too slow. The Reviewers did not have a sound basis for their assumption, which led to
20 their erroneous conclusions that the balance of fate processes was not correctly
21 represented in the model framework. Therefore, many of the ensuing Reviewer
22 comments regarding individual fate processes, the balance of fate processes, and the
23 ability of the model to simulate future conditions, are logically flawed.

24 Implementation of an independent calibration strategy helped ensure that errors were
25 minimized and that the balance of fate processes in the model framework is correctly
26 represented. All models in the framework were calibrated independently. Information
27 was passed forward from one model to the next in sequence, as presented in FMD
28 Figure 1-11. Outputs from HSPF were used as inputs to EFDC and FCM. Further
29 outputs from EFDC were used as inputs to FCM. Information was never passed

1 backwards from FCM to EFDC or HSPF. No compensation was made in one model for
2 a performance issue in another model. For example, FCM was not recalibrated to
3 achieve acceptable model-data comparisons in fish tissue to compensate for any
4 potential bias in flow, TSS, or PCB outputs from EFDC or HSPF.

5 In addition, a priori model performance measures were proposed in the Quality
6 Assurance Project Plan, which was the subject of the first of the three Peer Reviews
7 along with the Modeling Framework Design (MFD). These measures were
8 subsequently adopted following Review comment. All three models, including EFDC,
9 and more importantly, the linked FCM, produce results that are, in virtually all cases,
10 within these performance measures. Achieving these performance measures, in
11 combination with the successful implementation of this independent calibration strategy,
12 demonstrates that model framework performance is adequate to meet the goal of the
13 modeling study.

14 Many comments nonetheless focused on the balance of fate processes in EFDC. The
15 Reviewers did not recognize that a fundamental attribute of the EFDC calibration
16 strategy was that each transport and fate process in the model was independently
17 examined. Specifically, the site data were reviewed to isolate conditions where
18 sediment or PCB transport was controlled by a single, predominant process. To the
19 greatest extent possible, values for each model process were determined using site-
20 specific information. This calibration approach is particularly important to the overall
21 model development effort because it ensured that: (1) each individual transport and fate
22 process was correctly parameterized; and (2) the relative importance of each process is
23 appropriately represented. In addition, calibration of the food chain model was
24 performed independently of the calibration of EFDC. PCB exposure concentrations
25 simulated in the water column and sediment and passed to FCM result in an accurate
26 simulation of the concentrations of PCBs in fish tissue, which provides a further test of
27 the adequacy and accuracy of the representation of the balance of fate processes in
28 EFDC.

1 In other instances, the Reviewers have made recommendations for data collection
2 efforts that fall well outside the spatial scales of intended model use or the timeframe for
3 model development efforts. EPA has taken seriously Reviewer suggestions for data
4 collection to improve model development. In fact, EPA undertook several data
5 collection efforts in response to recommendations. However, it must be recognized that
6 over the past 6 years, three Peer Reviews of the Model Framework, Calibration, and
7 Validation have now been completed. While the Peer Review Charge for the Modeling
8 Framework Design (2000) included specific questions asking Reviewers to recommend
9 supporting data collection efforts, the Model Validation Peer Review Charge did not.
10 EPA nonetheless collected additional information in response to Reviewer comments
11 where practicable. After 8 years of model development, EPA believes that appropriate
12 and adequate data collection activities have been conducted, and combined with
13 changes to model parameterization following input from the Reviewers, model
14 development has been sufficient to achieve the goal of the modeling study.

15 EPA responses to assertions regarding specific processes are provided in the
16 subsections below and in other General Topics, and supporting analyses and
17 discussion are provided in the FMD.

18 **1.1.4 Responses to Specific Comments on General Topic 1**

19 **W. Frank Bohlen**

20 The global list of processes and governing factors incorporated in the linked three (3) model
21 system is comprehensive and includes all those necessary for a detailed evaluation of PCB
22 transport, fate and bioaccumulation (see Table 2-1 pp.2-3 Vol.1). In addition, the model, as
23 structured provides an excellent framework for the systematic evaluation of each of the factors
24 governing PCB transport and its ultimate bioavailability in the Housatonic River. This
25 framework directly complements quantitative study of transport and subsequent investigation
26 and ranking of remedial alternatives.

27 **Response 1-FB-1:**

28 EPA agrees with the Reviewer's comments that the model framework is
29 comprehensive and includes all processes necessary to investigate potential
30 remedial alternatives.

1 Despite the completeness of the global list, however, realization of the full potential of the
2 models is governed by the extent to which model formulation provides accurate process
3 simulation. Review indicates that model utility would benefit from improvements/modifications
4 in a number of areas.

5 **Response 1-FB-2:**

6 EPA disagrees with the Reviewer's assertion that further study would necessarily
7 result in a demonstrably superior model framework. See General Response
8 above.

9 Moving to the areas of standing water in the main channel, the backwaters and Woods Pond, I
10 remain concerned about the accuracy of the sediment transport formulations. This concern is not
11 entirely alleviated by the sensitivity analyses presented in the previous calibration report
12 (Weston, 2004) and those included in the MVR. The response to a 50% variation in a variety of
13 parameters overall seems reasonable and makes clear that all of the model results are sensitive to
14 upstream boundary conditions. This, of course, is not surprising given the role of streamflow
15 across this boundary in model dynamics and the limited number of areas within the PSA
16 sufficient to serve as a sediment supply. What's demonstrated is in fact why one worries about
17 the accuracy of the sediment transport formulation.

18 **Response 1-FB-3:**

19 The model's ability to simulate floodplain interactions is well documented. The
20 model reproduces the extent of flooding documented during extreme events
21 (Hurricane Bertha). Further evaluations of model performance based on
22 conservation of mass (continuity) demonstrate that the model correctly simulates
23 the storage (and release) of water from flooded areas during out-of-bank events.
24 The hydrodynamics of floodplain interactions controls the movement of sediment
25 and PCBs between the river channel and floodplain. The theory for describing
26 sediment transport and the formulations application are identical (and equally as
27 accurate) regardless of whether the material in transport is in the channel or the
28 floodplain. The mass flux ("process-based flux" and "tracer runs") summaries of
29 the model results illustrate the connection between the channel and floodplain
30 areas in the model. See FMD Appendix B.7 and FMD Section 4.2.

31 Nor are concerns alleviated by model runs requiring what appear to be inordinately high
32 diffusive fluxes to explain the simulated increase in PCBs at New Lenox road relative to those at
33 Holmes Road (see pp.6-72 and Fig.6.2-42 MVR) during low flow conditions. This response
34 suggests that the calibration of the sediment transport formulation might, because the majority of
35 the available data were obtained during high flow events, have produced a function that is overly
36 specific to higher flow conditions. This calls to mind the comments of Dr. Lick regarding the
37 need to reduce the number of adjustable parameters in the transport formulation and more
38 accurately specify those that remain (comments that I second) so as to have confidence that the
39 algorithm is an accurate representation of governing physics and not simply some curve fitting
40 routine.

Response 1-FB-4:

At the outset, it is worth noting that this Reviewer opined that the PCB sediment-water mass transfer (“diffusive”) flux was inordinately high, while, in contrast, other Reviewers commented that the mass transfer flux was “too low.” Further discussion of the mass transfer flux is provided in the response to General Topic 1B and in FMD Appendix B.10.

The number of adjustable parameters in EFDC was limited to the fewest number possible. Most sediment transport parameters depend on the measurable physical properties of the sediment (grain size, density, etc.) and are not adjustable. In fact, only parameters for cohesive sediment transport were even potentially adjustable. Even in these few instances, the parameters were derived from site-specific measurements. The model results are a reflection of the proper representation of the physics of sediment (and PCB) transport and are not a simple curve fit of data. This is illustrated in Figure 3.3-1 of the FMD, and further discussion is presented in FMD Section 3.3.2, Section 4.3, and Appendix B.8.

I would recommend that increased focus be placed on the sediment transport formulation and that model runs be conducted in which the sediment supply across the upstream boundary is set to zero. Minimal “tuning” and reasonable results under these conditions would increase confidence in the formulation and directly benefit future evaluations in the CMS that very likely will be dealing with transport in specific areas within the PSA and require accurate estimates of local mass movements.

Response 1-FB-5:

EPA believes that it is unrealistic to assume that solids loadings at the upstream boundary would be zero under any circumstance, or that any model results generated using such an assumption could be considered reasonable. However, a sensitivity analysis was performed where the upstream solids loads were increased and decreased by 50% and the resulting model output was presented (see Section B.3.4 of the Model Calibration Report [MCR], Section 5 of the Model Validation Report [MVR], and Section 3.7 of the FMD). EPA believes that the Reviewer was inquiring if the spatial erosion and deposition patterns simulated by the model appear reasonable. Such analyses were presented in Figure 4.2-51 of the MVR for a range of flow conditions. These results were judged reasonable by the modeling team.

Next, additional work is required to develop an accurate formulation of sediment transport. The suggestions of Dr. Lick in terms of both equation parameters and the structure of the sediment bed should be carefully evaluated. There seems to be an abundance of data and experience to suggest that δ_{in} is an overestimate of the active bed thickness. There is also concern that the model as it exists may be biased to high flow conditions. Add to these questions regarding side bank erosion and floodplain dynamics.

1 **Response 1-FB-6:**

2 EPA disagrees that further work is needed to develop accurate sediment
 3 transport formulations. For non-cohesive sediments, the transport formulas used
 4 are well described in the peer-reviewed literature. For cohesive sediment, the
 5 transport formulas used are those recommended by Dr. Lick. Further, cohesive
 6 sediment erosion parameters were derived from site-specific measurements
 7 made with the Sedflume. These data have been evaluated in accordance with
 8 suggestions made by Dr. Lick.

9 It should be noted that the active thickness used in the model was determined
 10 based on an extensive set of physical measurements, literature review, and site-
 11 specific sediment profile images. See FMD Appendices A.3, B.4, and B.5.

12 **Douglas Endicott**

13 There appear to be parameterization errors in specific sediment transport and PCB fate and
 14 transport processes.

15 **Response 1-DE-1:**

16 See General Response above. EPA believes that the processes in the models
 17 were correctly parameterized and all relevant processes accurately represented.
 18 This is clearly documented in the FMD.

19 **Marcelo H. Garcia**

20 While a substantial effort has gone into improving the capabilities of the Housatonic River
 21 Model since its calibration, it is clear that there is still a long way to go before the model can
 22 truly be used as a “predictive tool” to quantify future spatial and temporal distributions of PCBs
 23 (both dissolved and particulate forms) within the water column and the bed sediment.

24 This reviewer is of the opinion that the Housatonic River Model will need to be continuously
 25 improved until all the processes (biological and physical bed sediment mixing, streambank
 26 erosion, floodplain deposition, etc.) relevant to the transport and fate of PCBs are not only
 27 accounted for in the model but are also well represented and based on sound knowledge of
 28 sediment transport mechanics, stream biology, ecology and morphodynamics.

29 **Response 1-MG-1:**

30 EPA disagrees that the model cannot be used as a “predictive tool” and must
 31 undergo continuous improvement. Eight years of model development have
 32 resulted in a model framework, as calibrated and validated, that is adequate to
 33 achieve the modeling study goal to simulate future conditions and the relative
 34 performance of potential remedial alternatives. The Reviewer’s comment is
 35 based on a false premise that the balance of fate processes is not correctly
 36 represented. See the General Response above.

1 Given the facts that several processes are yet to be fully characterized in the model and that a
 2 coarse computational grid has been used for the model calibration, I do not think that a full
 3 sensitivity analysis can be conducted at this time.

4 **Response 1-MG-2:**

5 EPA disagrees with the Reviewer’s assertion that several processes have yet to
 6 be characterized. All relevant processes needed to simulate PCB fate, transport,
 7 and bioaccumulation have been adequately characterized. Further, the model
 8 sensitivity to parameter perturbation has been evaluated and was presented in
 9 the MCR as well as MVR Section 5. The sensitivities of the model parameters
 10 are further described in FMD Section 3.7.

11 **Frank Gobas**

12 The temporal response of the model is based (i) on the parameterization of the sediment-water
 13 exchange rate of PCBs (which is the rate determining step in the depuration of the River) and (ii)
 14 on model calibration. With regards to the parameterization of the sediment-water exchange of
 15 PCBs, there are several model parameters including the depth(s) of “accessible” and “non-
 16 accessible” bottom sediments, diffusion rates, bioturbation rates and subduction velocities that
 17 are currently difficult to measure or assess. The best strategy for parameterization is to use the
 18 best empirical data and best expert judgment possible. I am not convinced that this was achieved
 19 in this study. Dr. Lick has provided several papers to demonstrate that the current
 20 parameterization of the sediment-water exchange process in the model is not consistent with
 21 some key studies and observations. Also, I place considerable weight on Dr. Lick’s expert
 22 judgment and his lack of confidence in the selection of parameter values. However, that said, it is
 23 unknown at this time whether an alternative parameterization of the sediment-water exchange
 24 processes will produce a significantly different and better characterization of the temporal
 25 response of the PCB concentration in the River.

26 **Response 1-FG-1:**

27 EPA agrees with the Reviewer’s conclusion that an alternative parameterization
 28 of the processes may not result in a significantly different or better
 29 characterization of the temporal response of PCB concentrations in the
 30 Housatonic River. This is demonstrated by the extensive exploratory analyses
 31 conducted in response to the Reviewers’ comments, many of which were
 32 discussed in prior documents and all of which are provided in the FMD and/or
 33 discussed in this Responsiveness Summary. Throughout the model
 34 development process, great care was exercised to ensure that each model
 35 process was parameterized in an independent manner to achieve the proper
 36 balance of fate processes. See FMD Section 3.3.2, Section 4.3, and supporting
 37 appendices.

38 The modelers should explore alternate parameterization schemes (possibly with the help of Dr.
 39 Lick) of the sediment-water exchange processes with the goal to select model parameterization
 40 schemes that are defensible based on available laboratory and field observations.

Response 1-FG-2:

Sediment-water mass transfer was parameterized from site-specific measurements. See FMD Appendix B.10.

With regards to achieving model objective #2, i.e. ability to quantify the historical and current relative contributions of various PCB sources to PCB concentrations in water and bed sediment, I do not think that the model reasonably accounts for the relevant fate processes. The reason is that the model has difficulty assessing the amount of historical PCB mass that is “accessible” by the River. Difficulties in the selection or determination of an “accessible” sediment layer and decisions regarding the inclusion or exclusion of flood plains as accessible sources of PCBs to the Housatonic River contribute to the overall difficulty in assessing the current mass of PCBs in the River. As a result it is difficult to assess the relative contribution of any current inputs of PCBs into the River. The lack of any significant change in the PCB concentrations in the River over time over the period that significant removal of PCB sources in the immediate vicinity of the GE facility remediation took place may be an indication that historical sources of PCBs throughout the PSA are likely the main contributor to current PCB concentrations in the River.

Response 1-FG-3:

As described throughout this General Response, the FMD, and all other supporting documents, EPA believes that the model reasonably accounts for all relevant fate processes, that each individual transport and fate process was correctly parameterized, and that the relative importance (balance) of each process is appropriately represented. The Reviewer’s comment regarding an “accessible” sediment layer was unclear and interpreted to mean the bioavailable sediment depth for estimating food chain exposures. The bioavailable depth was determined based on an extensive set of physical measurements and literature review, and was verified using site-specific sediment profile images (see FMD Appendices A.3, B.4, and B.5). The river floodplain is an important reservoir of PCBs in the Housatonic River. Risks to both human and ecological receptors were identified from exposure to PCBs in the floodplain. Therefore, EPA believes that no simulation of PCB transport and fate in this system is complete without explicit consideration of the floodplain and its interactions with the main river channel. As part of his final point, the Reviewer is correct that there has not been a significant change in sediment PCB concentrations within the PSA over time. However, in making this point, the Reviewer incorrectly assumed that the period over which no statistically significant change in PCB concentrations in sediment was observed corresponds to the timeframe during which sediment and bank soil remediation was performed upstream in the vicinity of the GE facility. Nonetheless, EPA agrees with the Reviewer’s conclusion that sources of PCBs within the PSA are likely a main contributor to PCB concentrations in the river, as shown in the tracer analyses (see Section 4.2.5 of the FMD).

The model is the only available tool to simulate the future response of PCB concentrations in response to remediation efforts. The model framework represents a suitable approach to estimating the future time response of PCB concentrations in the River and the calibration and

1 validation of the model have involved significant efforts. The most valuable information for the
 2 calibration and validation of the model is a change in PCB concentrations in the River in
 3 response to a known reduction in PCB loading. This kind of information was not obtained in the
 4 current study as concentrations of PCBs in the River showed little or no significant variation
 5 with time. The current model therefore has to rely on the characterization of a number of key
 6 state variables for the estimation of the long term temporal response of PCB concentrations to
 7 remedial scenarios. The key parameters include the amount of “available” River and floodplains
 8 sediments and rates of resuspension, diffusion, bioturbation and subduction. All of these model
 9 state variables are either currently unmeasurable or very difficult to measure or estimate. As a
 10 result the model’s outcome with regards to the long term time response of PCB concentrations in
 11 the River is uncertain. The model uncertainty translates in considerable uncertainty about future
 12 PCB concentrations in the River resulting from remediation efforts or the absence of
 13 remediation.

14 **Response 1-FG-4:**

15 EPA agrees with the Reviewer’s comment that little change in PCB
 16 concentrations (no statistically significant trend) was observed during the period
 17 of data record, thus making the assessment of model performance more
 18 challenging and introducing uncertainty into the model simulations. However,
 19 even without changes in PCB concentrations, there is already uncertainty
 20 associated with model predictions, given that the data demonstrate orders of
 21 magnitude variability in PCB concentrations over the same period in space and
 22 time. EPA also agrees with the Reviewer that many of the variables in the model
 23 are either currently unmeasurable or very difficult to measure in a way that would
 24 result in a decrease in uncertainty. Where possible, EPA did undertake such
 25 measurements, and where not possible, EPA did extensive literature reviews to
 26 derive the best possible estimates for such values.

27 **Wilbert Lick**

28 1. In the present model, the processes of sediment erosion, sediment deposition, the finite
 29 sorption rate of PCBs by the sediments, and the sediment-water flux due to “diffusion” are
 30 described incorrectly and inaccurately. This is exacerbated by a very coarse numerical grid used
 31 to define the bathymetry of the river and an unnecessarily fine grid to define the
 32 bathymetry/topography of the floodplain. More specific reasons for these comments as well as
 33 specific suggestions for improvement of the model are presented in the complete response which
 34 is attached. I do not believe that the present model can reasonably account for the relevant
 35 processes affecting PCB fate, transport, and bioaccumulation in the Housatonic River to a degree
 36 consistent with achieving the goal of the modeling study.

37 **Response 1-WL-1:**

38 See General Response above. In this comment, the Reviewer made a series of
 39 flawed assumptions that resulted in erroneous conclusions regarding the model
 40 representation of processes. The majority of processes in the model were
 41 parameterized from site-specific measurements.

1 For example, the model representation of PCB partitioning is entirely consistent
2 with site data. However, the Reviewer asserted that it was necessary to include
3 time-dependent sorption in the model because use of the equilibrium partitioning
4 approach would necessarily result in an improper representation of PCB phase
5 distributions, particularly during high-flow events. EPA evaluated the Reviewer's
6 proposed methods, conducted simulations, and documented that: (1) use of
7 equilibrium partitioning yields PCB concentrations that are within 5 to 10% of
8 results obtained using time-dependent ("frozen reaction rate") sorption; and (2)
9 PCB fluxes computed using equilibrium partitioning during an event are nearly
10 identical to those computed using "frozen reaction rates." This small difference in
11 model results is less than the uncertainty associated with reported PCB sorption
12 rates. These analyses are further described in FMD Appendix B.9.

13 Responses to assertions that other processes were incorrectly parameterized are
14 provided in the remaining sections of this Responsiveness Summary. Complete
15 documentation of the parameterization of these processes is provided in the
16 FMD and appendices.

17 In the long term, the main source of contaminants in the Housatonic River is the bottom
18 sediments (both those in the river and in the floodplain). In this long term, environmental
19 conditions will change with time and will be different than they are at present, especially because
20 of and after remediation. For purposes of predicting water quality, it is therefore essential to
21 accurately determine not only the flux of contaminants between the bottom sediments and the
22 overlying water but also the parameters on which this flux depends. Otherwise, long-term
23 predictions of water quality will not be accurate or believable. Because of this, my comments
24 will emphasize processes which govern the sediment-water flux of contaminants, i.e., sediment
25 erosion, sediment deposition, the sediment-water flux due to "diffusion", and equilibrium
26 partitioning.

27 **Response 1-WL-2:**

28 EPA agrees. Model simulations indicate that river sediment is likely to be a
29 major source of PCBs.

30 In my last review (Model Calibration, May 13, 2005), I commented extensively on the proposed
31 calibration of both sediment erosion and deposition by means of the measured suspended solids
32 concentration, C. A simple example was given whereby it was easy to see that a numerical
33 model can "predict" the observed values for C with an almost arbitrary value of erosion rate as
34 long as the deposition rate was changed accordingly, i.e., such that the two were equal and gave
35 the observed C. I stated "For a predictive model, the values of erosion rate and deposition rate
36 can not both be determined from calibration of the model by use of the suspended solids
37 concentration alone." I later stated that "models with many unconstrained parameters and
38 especially models which include processes that are not described correctly as far as their
39 functional behavior is concerned can lead to non-unique solutions; these can lead to the incorrect
40 predictions of long-term behavior."

1 EPA responded by more-or-less agreeing with the above statements but then stating “This
2 concern does not recognize that there is a constraint imposed by PCB transport that results from
3 resuspension and deposition processes.” Although this argument has some validity, it is not
4 sufficient or correct as I will argue below. This problem of non-unique solutions is important, is
5 more general than that indicated above, and is related to the necessity for accurately determining
6 the basic processes that govern the sediment-water flux of PCBs and other hydrophobic organic
7 chemicals (HOCs). Because of this, I will return to this problem of non-unique solutions after
8 discussing the flux processes mentioned above. Accurate descriptions of the basic processes also
9 depend on an adequate resolution of the bathymetry/topography of the Housatonic. Because of
10 this, comments and suggestions on the problem of numerical gridding in the model will be made.
11 Some discussion on unexplained results of the present model will then be given. A summary and
12 specific suggestions for improvements to the model will conclude my comments.

13 **Response 1-WL-3:**

14 EPA disagrees with the Reviewer’s comment that the model parameterizations
15 are “unconstrained.” The calibration of sediment transport included consideration
16 of suspended solids concentrations as well as the net deposition flux to the
17 sediment bed. The net deposition flux was estimated from cesium-137 data as
18 described in MVR. Although more qualitative than the analysis of cesium-137
19 data, computed bed shear stresses provide another “constraint” on cohesive
20 solids deposition because solids will not be incorporated into the sediment bed if
21 the shear stress exceeds the critical shear for deposition. As the Reviewer
22 acknowledges, the final constraint on the parameterization of erosion and
23 deposition is successful simulation of PCB concentrations. This includes PCB
24 concentrations in both the water column and the sediment bed. The model
25 parameterization is appropriate because suspended solids, net deposition fluxes,
26 water column PCBs, and the rate of change of PCBs in the sediment bed are all
27 correctly simulated over time as demonstrated by the evaluation of model results
28 presented in FMD Section 3.5 and Section 4.

29 However, the Reviewer’s comments regarding the “uniqueness” of model
30 solutions are unrealistic. These comments are based on the assumption that a
31 so-called “unique” solution must be the goal of a modeling study and that without
32 a “unique” solution the results obtained will necessarily be incorrect or
33 inaccurate. In an “algebraic” sense, a unique solution can only occur when there
34 is a unique set on inputs such that there is a one-to-one correspondence
35 between model inputs and outputs. For practical applications of environmental
36 models, the Reviewer’s position is unrealistic because naturally variability in
37 model inputs such as upstream solids and PCB loads, sediment bed PCB
38 concentrations, and partition coefficients preclude development of a unique set of
39 inputs.

40 In this light it is more realistic to consider whether model results are sufficiently
41 definitive to provide a meaningful solution. In this context, model results can be
42 considered “sufficiently definitive” if they describe the essential characteristics of
43 the natural system with an accuracy and resolution that is adequate to achieve

1 the goals of the modeling study. Pre-determined (a priori) model performance
2 measures were used to assess if model results provide a sufficiently definitive
3 description of the Housatonic River. As documented in FMD Section 3.5 and
4 elsewhere in the FMD, model results are, in virtually all cases, well within the
5 established performance measures. For this reason, EPA believes the model
6 framework is adequate to achieve the goal of the modeling study to simulate
7 future conditions and the relative performance of potential remedial alternatives.

8 As discussed above, the processes which govern the sediment-water flux of HOCs (sediment
9 erosion, sediment deposition, the sediment-water flux due to “diffusion”, and equilibrium
10 partitioning) are described incorrectly and inaccurately. Each of these processes can modify the
11 flux by factors of two to ten. Nevertheless, EPA documents indicate that there is good
12 agreement between the calculated and measured suspended solids concentrations as well as
13 contaminant concentrations. At the same time, sensitivity and uncertainty analyses also seem to
14 say that the model is doing a good job. **How can this be? Are accurate models of sediment
15 and contaminant transport and fate really unnecessary?**

16 The answers to these questions are in the non-uniqueness of calibrated solutions and the nature
17 of sensitivity and uncertainty analyses. More specifically, it seems that a modeler can assume a
18 wide range of parameters to describe a particular process and still “calibrate” the model so as to
19 determine a mathematical solution which agrees with observations over some time interval. As
20 discussed above, examples of parameters which significantly affect flux processes are (1)
21 different values of the power n in erosion formulas (this gives greatly different erosion rates at
22 high shear stresses depending on the value of n), (2) different parameterizations for settling
23 speeds, (3) different process models and parameters for the sediment-water flux due to
24 “diffusion”, and (4) equilibrium partitioning (equivalent to high reaction rates), frozen reaction
25 rates, or anything in between. Calibration of a model does not guarantee that the processes in the
26 model are described properly. At the risk of being repetitive, a water quality modeler can always
27 get good agreement between calculated and observed quantities for a limited time interval and
28 limited conditions, whether the fundamental processes are described properly or not. Another
29 modeler, with quite different descriptions of processes and/or different parameters in his/her
30 model, can get equally good agreement between the calculated and observed quantities.
31 However, future predictions by the different models and modelers will be quite different. This
32 has been demonstrated repeatedly (e.g., see comments on Fox River modeling (Tracy and Keane
33 2000) in my comments of May 2005). In other words, **calibration is necessary but not
34 sufficient.**

35 **Response 1-WL-4:**

36 See Response 1-WL-3 and responses to the remainder of General Topics 1A
37 through 1D.

38 **E. John List**

39 My opinion is that the underlying processes involved with the PCB fate and transport do not
40 appear well enough understood for a meaningful model to be developed. If the processes that

1 seem to define the PCB fate and transport are not included in the model then their sensitivity
2 cannot be assessed.

3 **Response 1-JL-1:**

4 EPA believes that the underlying processes controlling PCB fate and transport
5 have been adequately characterized to construct a credible model framework.
6 These processes are also understood in sufficient detail at the spatial and
7 temporal scales of interest for the intended use of the model. While mechanistic
8 representation of factors controlling the variability of PCB concentrations or other
9 constituents across small spatial scales may be of interest from a research
10 perspective, the model framework does not need to explicitly represent such
11 small variability to achieve the goal of the modeling study (see Sections 2, 3, and
12 4 of the FMD).

13 Since the basic processes for the fate and transport of PCB are clearly not properly included in
14 the model their uncertainty cannot be assessed.

15 **Response 1-JL-2:**

16 See General Response above.

17

1 **1.2 GENERAL TOPIC 1A: EROSION AND DEPOSITION**

2 **1.2.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 5, lines 1 to 12
Bohlen	Page 10, lines 3 to 14
	Page 10, lines 33 to 34
	Page 12, lines 6 to 13
Endicott	Page 3, line 28 to page 4, line 3
Lick	Page 4, line 12 to page 5, line 43
	Page 6, lines 1 to 7
	Page 12, lines 21 to 26
	Page 12, lines 28 to 32
List	Page 1, lines 34 to 39

3 **1.2.2 General Topic Summary**

4 Erosion of non-cohesive and cohesive sediment occurs through different mechanisms. Non-
 5 cohesive particles behave independently and act as individual particles. Cohesive particles
 6 interact with other particles and act as aggregates. Different formulations for these processes are
 7 used in EFDC. Garcia and Parker (1991) and Wu et al. (2000) are used to describe non-cohesive
 8 sediment erosion. Lick et al. (1994) is used to describe cohesive sediment erosion.

9 Deposition of non-cohesive solids is described by the formulations in van Rijn (1984), which are
 10 well established and have been used in numerous sediment transport models. Deposition of
 11 cohesive solids is a complicated process that can be represented at different levels of complexity,
 12 ranging from constant settling velocity to complex flocculation models. The settling velocity
 13 used in EFDC is a function of the weighted average of the settling velocities for washload and
 14 suspended load.

15 Many of the Reviewers concurred with the opinion expressed by a particular Reviewer that n
 16 (the cohesive sediment erosion exponent) should be greater than the value used in the modeling
 17 study, most agreed with the particular Reviewer that it should equal 2 or more.

1 Two Reviewers commented on the use of the deposition rate as a calibration parameter, and one
2 Reviewer recommended the use of his flocculation theory for deposition.

3 **1.2.3 General Topic Response**

4 For the EFDC application to the Housatonic River, the erosion of non-cohesive
5 sediments is represented by relationships for suspended load and bedload as described
6 by Garcia and Parker (1991) and Wu et al. (2000). These relationships were chosen
7 because they are applicable to sediment mixtures, include terms to describe the hiding
8 and exposure of particles within the bed, and have been validated by comparisons to
9 experimental measurements and field data.

10 In contrast, the erosion of cohesive sediment is highly variable and often requires site-
11 specific information regarding the characteristics of the bed. For the EFDC application
12 to the Housatonic River, the parameterization of cohesive sediment erosion was based
13 on site-specific data.

14 Experiments were conducted to characterize the erosion properties of the sediment of
15 the Housatonic River (Gailani et al., 2000). Two types of experimental devices were
16 used. The Sedflume (McNeil et al., 1996; Jepsen et al., 1997) was used to measure
17 erosion rates as a function of shear stress and depth in the sediment. Gailani et al.
18 (2000) presents a detailed description of the experimental procedures and data.

19 The Sedflume experiments quantify erosion rates at imposed shear stresses, but the
20 data also provide a description of how the shear stress required for erosion changes
21 with depth in the sediment bed. The absence or occurrence of erosion through a range
22 of imposed shear stresses can be summarized by two values: the maximum shear
23 stress imposed without initiating erosion, and the minimum imposed shear stress that
24 caused erosion. The shear stress required to initiate erosion, referred to as the critical
25 shear stress for erosion, lies between these two values.

26 In response to Peer Review comments, the cohesive sediment erosion exponent (n) for
27 the EFDC application to the Housatonic River was set to a value of 2.

1 A complete discussion of the analyses and evaluation of the critical shear stress for
2 erosion is provided in Appendix B.8 to the FMD.

3 **1.2.4 Responses to Specific Comments on General Topic 1A**

4 **Eric Adams**

5 The erosion formulation and parameters come from analysis of SedFlume data. W. Lick argues
6 that the exponent n (denoting dependency of erosion on shear stress) should be significantly
7 greater than the chosen value, which would produce proportionally more erosion during high
8 flow conditions. I agree with him, but am also leery of the fact that shear stresses in the model
9 are computed based on a grid width that is essentially equal to the river width. Thus the
10 computed hydrodynamics will yield cross-sectional average velocities, which ignores regions
11 within a cross-section with relatively high velocity and erosion (refer to later discussion under
12 Question 7). Unlike conditions in SedFlow, the real river is non-uniform. Thus the formulation
13 of erosion can not be divorced from the question of grid resolution. Indeed, it would seem
14 incorrect to simply import an erosion calculation from SedFlume.

15 **Response 1A-EA-1:**

16 As described in FMD Appendix B.8, the parameterization of cohesive sediment
17 erosion in EFDC was developed from the site-specific Sedflume measurements
18 for the river. As demonstrated in Appendix B.8, the model results are not
19 particularly sensitive to the erosion exponent value for the range of shear
20 stresses encountered. For the final model simulations, EPA used a value of $n =$
21 2 for cohesive sediment erosion as recommended by the Reviewers.

22 As noted by the Reviewer, there can be a connection between model grid scale
23 and the parameterization of model processes. In the case of cohesive sediment
24 erosion, the variability of Sedflume measurements from individual core locations
25 was large. Given this variability, the most reliable approach to using Sedflume
26 measurements in the model framework was to compute erosion parameters on a
27 reach-wide average basis. This approach is appropriate in consideration of the
28 intended spatial scale of use for the model framework.

29 Also as noted by the Reviewer, it is difficult to simply import erosion parameters
30 from Sedflume measurements without consideration of grid scale. To account for
31 possible grid scale dependencies, the critical shear stress for cohesive sediment
32 erosion in EFDC was calibrated within the range of the Sedflume measurements.
33 Further, model sensitivity to the erosion rate coefficient was evaluated as
34 presented in the MVR. This sensitivity analysis was subsequently expanded to
35 include both the erosion exponent and the erosion rate coefficient as
36 documented in FMD Section 3.

1 W. Frank Bohlen

2 The TSS data set appears to be moderately robust although I worry that too much emphasis
3 might have been placed on storm conditions. The data also appear to be primarily point
4 measurements with some representing integrated measurements over the vertical. The absence of
5 time series data prevents detailing of processes such as the time scales of resuspension and
6 deposition during rising or falling stage with particular emphasis on the onset of resuspension
7 during relatively low flow conditions. The influence of such low level but persistent
8 resuspension and transport on PCB fluxes is largely ignored in the present study which places
9 primary emphasis on storm events. Absent the low flow details it's difficult to assess the role of
10 these processes in the long term. Such assessments will be a subject of study in the upcoming
11 CMS. As noted above I'd recommend immediate initiation of a monitoring program designed to
12 provide time series observations of TSS concentrations at a number of selected stations
13 throughout the PSA.

14 Response 1A-FB-1:

15 Time series data for TSS (including data collected on both the rising and falling
16 limb of the hydrograph) were collected during the storm events, and when
17 possible, data were also collected at the time of low flow preceding the rise of the
18 hydrograph. EPA disagrees that the influence of low level but persistent
19 resuspension and transport on PCB fluxes was largely ignored and that the
20 primary emphasis was placed on the storm events. Both storm flow and low flow
21 conditions were evaluated during the calibration process, and both must be
22 considered in modeling potential remedial alternatives in the CMS. It should be
23 noted that GE is expected to continue monthly monitoring for PCBs and TSS at
24 many locations in the study area.

25 An additional check on model results that should be considered includes the use of time series
26 bathymetric data to check on the accuracy of sediment erosion/deposition estimates.

27 Response 1A-FB-2:

28 The time series bathymetric data were evaluated for use in evaluating model
29 performance. The obstacle preventing this type of analysis was that bathymetric
30 data do not exist at enough locations along the stream and at an appropriate
31 temporal frequency to permit accurate estimation of erosion and deposition
32 volumes in a manner that could be appropriate compared to model results to
33 provide a quantitative measure of model performance.

34 As noted on several occasions above, visual examination of the figures suggests that the model
35 overpredicts TSS concentrations at low flows and underpredicts them at high flows. The
36 distribution of residuals provides clear indication of the overprediction at low flows for most
37 stations (see Table 6.2-6). Although a number of reasons for these differences (both high and low
38 flow) are presented there is no mention of the possibility that they are the result of less than
39 accurate formulation of the sediment transport process, in particular bed erosion/deposition, in

1 the model. As discussed above, this seems more than possible and should be carefully evaluated
2 since it will be of increasing concern during the CMS.

3 **Response 1A-FB-3:**

4 Sediment erosion in the model framework considers both non-cohesive and
5 cohesive sediment. In EFDC, the erosion of non-cohesive sediment is computed
6 using peer-reviewed transport formulations by Garcia and Parker (1991) and Wu
7 et al. (2000). Cohesive sediment erosion in EFDC is computed using the
8 formulation recommended by Dr. Lick (and other Reviewers) and is
9 parameterized with site-specific data. While there is uncertainty associated with
10 their predictive abilities, these formulations represent the best available tools to
11 drive erosion calculations in the model. Further, it is worth noting that sensitivity
12 analyses were performed for the parameters used in these sediment transport
13 formulations.

14 **Douglas Endicott**

15 Sediment transport parameterization: Cohesive sediment resuspension is parameterized based on
16 the analysis of data from SEDFLUME experiments conducted on a number of sediment cores.
17 Results of this analysis produced shear stress exponents of 1.59 for sediments in Reaches 5A and
18 5B and 0.95 in Reaches 5C and 6¹. These values are considerably lower than shear stress
19 exponents reported in the literature. For example, Lick, Ziegler and coworkers have reported that
20 for cohesive sediments tested at a significant number of sites, the shear stress exponent is
21 generally constrained within a fairly narrow range ($n=2.6\pm0.3$). Based upon this, it appears that
22 parameterization of cohesive sediment resuspension in the model is erroneous, and should be
23 corrected consistent with the guidance offered by Dr. Lick. As a consequence, it will also be
24 necessary to recalibrate deposition rates.

25 **Response 1A-DE-1:**

26 In response to Reviewer comments, cohesive sediment erosion in EFDC has
27 been changed to a value of $n = 2$. However, it is worth noting that the erosion
28 exponent values presented by the Reviewer ($n = 2.6\pm0.3$) were derived from the
29 shaker (Particle Entrainment Simulator, PES) and not the Sedflume. Erosion
30 exponents derived from the PES are not believed to be applicable to the
31 Sedflume as has been noted by Dr. Lick. Furthermore, as documented in FMD
32 Section 3, increasing the cohesive sediment erosion exponent in the model did
33 not require recalibration of deposition rates. This assessment was based on
34 comparisons of water column TSS values and comparisons to net sedimentation
35 measurements in Woods Pond (see FMD Appendix B.6).

¹ Model Calibration Report, Volume 3 - Appendix B Hydrodynamic and Sediment/PCB Fate and Transport Model Calibration, Attachment B.5 Analysis of Sediment Erosion Data

1 **Wilbert Lick**

2 In the previous review on Model Calibration (May 13, 2005), I commented extensively on
3 sediment erosion. Although those comments are still valid, I won't repeat all of them here.
4 However, I would like to repeat the following from those comments.

5 "In a paper by Lick et al. (2005), approximate equations for sediment erosion rates are examined.
6 It is shown that, for fine-grained, cohesive sediments, a valid formula is

$$7 \quad E = 10^{-4} \left(\frac{\tau}{\tau_c} \right)^n \quad (3)$$

8 where E is the erosion rate, τ is the shear stress, and τ_c is a critical shear stress defined as the
9 shear stress at which an erosion rate of 10^{-4} cm/s occurs; τ_c depends on the particular sediment
10 being tested and generally is a measured quantity. This equation is valid for fine-grained,
11 cohesive sediments but **not** for coarse-grained, non-cohesive sediments.

12 "For coarse-grained, non-cohesive sediments, the appropriate formula is

$$13 \quad E = A(\tau - \tau_c)^n \quad (4)$$

14 where A, τ_c , and n are functions of particle diameter but not a function of density. This equation
15 is shown to be valid for coarse-grained, non-cohesive sediments but **not** for fine-grained,
16 cohesive sediments.

17 "To approximate erosion rates for all size sediments with a single, uniformly valid equation, the
18 appropriate equation is

$$19 \quad E = 10^{-4} \left(\frac{\tau - \tau_{cn}}{\tau_c - \tau_{cn}} \right)^n \quad (5)$$

20 where $\tau_{cn}(d)$ is the critical shear stress for non-cohesive particles and is given by

$$21 \quad \tau_{cn} = 0.414 \times 10^3 d \quad (6)$$

22 where d is the particle diameter. Eq. (5) is uniformly valid for both cohesive and non-cohesive
23 sediments. It reduces to Eq. (3) as $d \rightarrow 0$ and to Eq. (4) for large d.

24 "In all the work we've done with Sedflume on the determination of erosion rates as a function of
25 shear stress (the number of cores is on the order of 100), n in Eq. (5) is typically about 2 or more
26 (see Lick et al., 2005 and Chapter 3 of Notes). Because of this, I suspect that the parameters $n =$
27 1.59 and $n = 0.95$ used in the Housatonic modeling (p. 4 of Attachment B.5) are incorrect."

28 One reason for the low values of n determined for the Housatonic is that the above equations are
29 only applicable to sediments which have the same bulk properties. In order to use these
30 equations properly, sediments with similar bulk properties must be grouped together. Properties

1 of sediments in a single sediment core generally vary with depth due to consolidation but also
2 because of layering due to deposition after big events. Because of consolidation with depth,
3 sequential Sedflume measurements on one core will bias the value of n since cores at depth will
4 be more consolidated, more difficult to erode, and will be measured later in the measurement
5 cycle. I suggested an interpolation procedure that we had used before and which gave us
6 reasonable results. EPA did not seem to have good results with this procedure. Attached is a
7 description of a modified procedure which I have applied to several randomly selected cores on
8 each of the Kalamazoo, Housatonic, and Passaic Rivers. This procedure is more fundamental
9 and correct. In all cases, it produces an n that is equal to two or greater in Eq. (5) above, just as
10 has been demonstrated by all Sedflume laboratory measurements that we have made. With this
11 procedure, the coefficient modifying $(\tau - \tau_{cn})^n$ and n are functions of depth for each
12 representative area core and are obtained from the Sedflume data. The fact that n is two or
13 greater is important in determining erosion rates at high shear stresses, i.e., during big events,
14 and can lead to shear stresses higher by an order of magnitude than the n 's chosen by EPA for
15 the Housatonic.

16 **Response 1A-WL-1:**

17 As understood by EPA, the central topic of this comment is that the cohesive
18 sediment erosion exponent n should have a value of 2 (or more). In response to
19 Reviewer recommendations, cohesive sediment erosion in EFDC is now
20 parameterized using $n = 2$. See the General Response above. For further detail
21 regarding the formulations and parameterizations for erosion that are used in
22 EFDC, see FMD Section 2 and Appendix B.8.

23 In that previous report, I also stated the following. "Bed armoring is an important process and
24 causes large changes in bed shear stresses and hence large changes in erosion/deposition. This
25 occurs, for example, when a layer of coarse sediments (as little as a few particle diameters thick)
26 is deposited on a layer of finer, non-cohesive sediments. As the EPA model is presently
27 configured, any deposited sediments are immediately mixed with the 6-inch surficial layer.
28 Because of this, effective coarsening takes place very slowly (a small amount of added sediment
29 has little effect on the average properties of the 6-inch layer). In reality, this mixing only occurs
30 in a layer a few particle diameters thick, and this thin layer must be present in the model for
31 realistic coarsening to occur (see SEDZLJ)."

32 EPA stated that the surficial layer was assumed to be 7 cm thick, not 6 inches as I stated. Since
33 bed coarsening occurs in a layer only a few particle diameters thick, the assumption of a 7 cm
34 mixed layer is also incorrect. **The above comments are still valid.**

35 **Response 1A-WL-2:**

36 For clarification, it should be noted that surface sediment layer thicknesses in
37 EFDC range from 4 to 7 cm.

38 Bed armoring and the development of armor layers is a complex topic. Armoring
39 depends on many factors including the grain size distribution of particles in the
40 bed at the sediment surface. In EFDC, some of the effects of armoring are

1 addressed through the hiding and exposure factors for the erosion of individual
2 sediment grains in a non-uniform sediment mixture. In addition, the fraction of
3 cohesive sediment in the sediment bed is also used to modify non-cohesive
4 erosion, as described in FMD Section 2.3.2.

5 As noted by the Reviewer, an armor layer in the bed can form in a thickness of
6 only a few (2 to 3) grain diameters. Given typical grain size distributions in the
7 Housatonic River, the potential exists for armor layers to form over a depth of 1
8 to 1.5 cm, based on the average diameter of the NC3 solids class ($d = 0.516$ cm).
9 However, this represents a minimum. A further limitation on the development on
10 an effective armor layer is the extent and frequency of bed disturbance by
11 turbulent shear and burst or other factors that contribute to sediment mixing. Bed
12 load transport processes can also impact armor development.

13 Sediment profile images and bedform observations for the Housatonic River
14 suggest that frequent sediment disturbances likely prevent the development of
15 significant or persistent armor within the first few centimeters of the bed surface
16 (see photographs in FMD Appendix A.3 and Appendix B.5). Based on these
17 factors, EPA believes that the model representation of bed armoring is adequate
18 to meet the goal of the modeling study.

19 I suggested the use of a dynamic flocculation theory that was recently developed and was
20 relatively simple. EPA seems to have had problems implementing the theory. I presume from
21 what they said that this was due to numerical stability problems. That's too bad because it would
22 have given reviewers more confidence in the modeling of deposition rates.

23 **Response 1A-WL-3:**

24 In response to Peer Review comments, a mechanistic flocculation model was
25 tested for use in EFDC. Specifically, the approach described by Lick et al. (2005)
26 was tested. This flocculation model includes a non-linear iterative solver for floc
27 diameter, which controls the effective settling velocity. While tests conducted for
28 steady flow and steady concentration conditions without erosion appeared
29 promising, the approach of Lick et al. (2005) could not be used to simulate
30 flocculation for normal river conditions. Normal river conditions are unsteady
31 because flow and concentration can change rapidly over short periods of time.
32 When tested for the unsteady conditions routinely expected to occur in the
33 Housatonic River, when there is erosion and rapidly changing flow and
34 suspended solids concentrations, the flocculation approach described by Lick et
35 al. (2005) failed because it computed unrealistically large settling velocities that
36 caused all cohesive sediment to settle almost instantaneously, causing
37 subsequent computations of zero floc diameters. Such failure under unsteady
38 conditions is not entirely unexpected because it is more difficult to obtain
39 solutions to many non-linear equations when conditions change rapidly. Further
40 description and details of the evaluation of the Lick et al. (2005) flocculation
41 model are presented in Section 4.1.2 of the MVR.

1 As a clarification, it is worth noting that the failure of the flocculation model was
2 not the result of numerical stability (or instability) in EFDC.

3 In the present model, erosion rates are too low (n is too small). During big events, erosion rates
4 may be as large as, or greater than, 10 times that predicted at present. The major effect of this
5 will be on the maximum depth of erosion during big events. A better analysis of Sedflume
6 results as suggested in the attached report will determine a higher and more reasonable value for
7 n. The coefficients in Eqs. (3), (4), and (5) should vary throughout the river as required by the
8 data.

9 **Response 1A-WL-4:**

10 See General Response above.

11 In the present model, deposition rates are also too low. Deposition rates are essentially a
12 calibrated parameter and are determined such that the suspended solids concentration is
13 calculated properly. If erosion rates are increased, deposition rates must also be increased in
14 order to maintain good agreement between calculated and observed suspended solids
15 concentrations.

16 **Response 1A-WL-5:**

17 As documented in FMD Section 3, increasing the cohesive sediment erosion
18 exponent in the model did not require recalibration of deposition rates. This
19 assessment was based on comparisons of water column TSS concentrations
20 and comparisons to net sedimentation measurements in Woods Pond. See
21 Response 1A-DE-1 and FMD Appendix B.6. It should also be noted that PCB
22 concentrations in the sediment bed and water column provide an additional
23 check on the appropriateness of gross erosion and gross deposition rates in the
24 model. See General Response above.

25 **E. John List**

26 On the other hand, models to simulate the movement of sediment in a fluvial stream are
27 significantly more problematic. The basic difficulty lies in the erodible stream bed. Bed erosion
28 is uniform neither transversally nor longitudinally in the stream. In addition, the bed erosion and
29 the consequent bed form changes result in a change in the stream friction factor, which feeds
30 back into a modification of the hydrodynamics of the flow.

31 **Response 1A-JL-1:**

32 The Reviewer correctly describes the feedback between hydrodynamics and
33 sediment transport. See General Response above.

1 **1.3 GENERAL TOPIC 1B: SEDIMENT-WATER MASS TRANSFER**

2 **1.3.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 3, line 25 to page 4, line 43
Endicott	Page 4, lines 4 to 10
Garcia	Page 5, lines 27 to 31
	Page 6, lines 4 to 7
Gobas	Page 15, lines 29 to 38
Lick	Page 12, line 44 to page 13, line 14

3 **1.3.2 General Topic Summary**

4 In a general sense, the sediment-water mass transfer of contaminants is often described as a (non-
 5 hydrodynamic) diffusive flux and can be the primary mechanism for contaminant exchange
 6 between sediment and surface water during low-flow conditions when sediment from the bed is
 7 not expected to erode.

8 This sediment-water mass transfer occurs via the exchange of dissolved and bound phase PCBs
 9 in the sediment bed pore water with PCBs in the water column. This occurs by a number of
 10 processes, including pore water advection (i.e., groundwater exfiltration), diffusion, and
 11 bioturbation. All of these sediment-water exchange processes can be summed and collectively
 12 expressed in the form of a gradient-driven mass transfer.

13 Some Reviewers commented that the mass transfer coefficient was too small (or low), while
 14 others felt it was too large (or high).

15 **1.3.3 General Topic Response**

16 For the Housatonic River, PCB sediment-water mass transfer was determined from site-
 17 specific data. Specifically, mass transfer coefficients were determined from the spatial
 18 profile of PCB concentrations in the water column when flows are low and no sediment
 19 erosion is expected. For conditions when the diffusive flux of PCBs from the sediment
 20 bed is most important, river flows would be low to moderate and TSS concentrations

1 would be expected to remain steady or decline while PCB concentrations would
2 appreciably increase. Under these conditions, the mass transfer of PCBs from the
3 sediment bed is expected to be the predominant fate process between Holmes Road
4 and New Lenox Road because: (1) mass erosion of particles from the sediment bed is
5 negligible (shear stresses are less than critical shear stresses for erosion); and (2) PCB
6 loss from the water column via deposition is small because solids concentrations are
7 relatively consistent. No specific temporal trend in mass transfer coefficients was
8 identified. See the Responsiveness Summary to the Peer Review of Model Calibration
9 and Appendix B.10 to the FMD.

10 Considerable effort was also devoted to analyzing the spatial patterns of TSS and PCB
11 transport throughout the PSA. Longitudinal concentration profiles for composite and
12 individual surveys at low, moderate, and high flow were assessed. Although spatial
13 gradients in TSS concentrations are typically small, PCB concentration gradients
14 measured between the confluence and New Lenox Road are large and identifiable. In
15 contrast, TSS and PCB gradients farther downstream are smaller and more variable.
16 Relative to other reaches, spatial patterns of TSS and PCB concentrations across
17 Woods Pond are even more variable, reflecting the differences in the physical setting
18 and corresponding hydrodynamics of the backwater effect of Woods Pond Dam. The
19 assessment of spatial patterns was based on composite and individual concentration
20 profiles for a wide range of river flows. See FMD Section 2.3.3 and Appendix B.10.

21 Based on consideration of measurements for 41 individual spatial surveys, geometric
22 mean and mean values for the sediment mass transfer coefficient range from 1.04 to
23 1.72 cm/day. The calibrated mass transfer coefficient (K_f) value in EFDC is 1.5 cm/day
24 and well within the range of values determined strictly from measured spatial gradients
25 of TSS and PCB concentrations.

26 **1.3.4 Response to Specific Comments on General Topic 1B**

27 **Eric Adams**

28 The calibrated mass exchange coefficient is $K_f = 1.5$ cm/d, which actually seems to be on the
29 small side, since it incorporates a number of processes in addition to strictly pore-water

1 diffusion. The coefficient for pore-water diffusion by itself should reflect the rate at which
 2 bioturbation brings PCB-sorbed sediment to the interface, the rate at which PCBs are desorbed to
 3 the porewaters, and the rate at which diffusion transports the dissolved PCBs into the overlying
 4 water column. These processes work like resistors in series. Chen (1993) showed that the
 5 sediment-water flux can be expressed as

$$6 \quad J = \frac{C_{sL} / K_p}{\frac{\delta}{D_m} + \frac{2.2R}{(1-\phi)[(D_b + D')D_m\rho_s K_p]^{1/2}} + \frac{L}{(1-\phi)\rho_s K_p D_b}} \quad (6)$$

7 where C_{sL} is the sorbed phase PCB concentration at the depth of the mixed layer L , δ is the water
 8 side boundary layer thickness, and D' is the effective diffusivity of PCBs within the sediment
 9 (molecular diffusion as affected by tortuosity).

10 Jorgensen and des Marais (1990) suggest $\delta = 0.02$ to 0.1 cm, and Shaw and Hanratty (1977)
 11 suggest

$$12 \quad \delta = \frac{12D_m^{0.3} \nu^{0.7}}{u^*} \quad (7)$$

13 where ν is the kinematic viscosity of water ($\sim 10^{-2}$ cm²/s) and u^* is the friction velocity. Using
 14 $u^* = 0.25$ cm/s gives $\delta \sim 0.05$ cm. Assuming $L = 5$ cm, $K_p = 10^5$ cm³/g, $D_m = 0.5 \times 10^{-5}$ cm²/s, D'
 15 $= 0.3 \times 10^{-5}$ cm²/s, $D_b = 5 \times 10^{-7}$ cm²/s (EPA's surface value), $\rho_s = 2.5$ g/cm³, $\phi = 0.6$, and $R = 0.01$
 16 cm, gives values for the three terms in the denominator of Eqn 6 of roughly 10^4 , 3×10^1 and 10^2
 17 s/cm respectively. This suggests that the flux is indeed water-side controlled (i.e, biomixing
 18 supplies contaminant to the interface sufficiently fast, and the contaminant desorbs sufficiently
 19 fast, that diffusion on the water side limits the transport) and that the last two terms can be
 20 ignored. Even if D_b were smaller by an order of magnitude ($D_b = 5 \times 10^{-8}$ cm²/s), the three terms
 21 in the denominator would be 10^4 , 3×10^1 and 10^3 s/cm, leading to similar conclusions, albeit by a
 22 smaller margin. The second term represents the "resistance" due to desorption, and the fact that
 23 it is small suggests that equilibrium partitioning can indeed be assumed in computing the flux.
 24 The reciprocal of δ/D_m is K_f which, with the above numbers, is $\sim 10^{-4}$ cm/s (8.6 cm/d). This is in
 25 the range of the values computed directly from EPA's flux analysis (e.g., Figure B.4-30 of the
 26 MCR, which includes values between 0.8 and 250 cm/d, with the majority between 3 and 10
 27 cm/d). However, it is significantly above the value of 1.5 cm/d identified in the Phase 1 model
 28 calibration. One possible reason for the calibrated value being significantly lower is that the
 29 PCB concentrations used for the upstream model boundary conditions are generally higher than
 30 the data, at low flow, which may cause the calibration to underestimate the sediment-water
 31 exchange flux downstream.

32 **Response 1B-EA-1:**

33 EPA disagrees with many aspects of the Reviewer's analysis, particularly the
 34 comment that the "low" mass transfer coefficient in the EFDC is the result of an
 35 error in assigning the model upstream boundary conditions. See General

1 Response above, FMD Appendix B.10, and the General Response for the
2 balance of fate processes in General Topic 1.

3 As noted by the Reviewer, the sediment-water mass transfer process is used to
4 represent the composite effect of individual processes that cannot be readily
5 measured or otherwise quantified in a practical manner on an individual basis.
6 As a practical consideration, the value of the sediment-water mass transfer
7 coefficient (K_f) used in EFDC was determined by calibration. However, this
8 calibrated model value is well within the range of values that can be determined
9 strictly from measured spatial gradients of TSS and PCB concentrations using
10 site-specific data for the Housatonic River from 41 surveys.

11 Based on these site-specific measurements alone, average K_f values for the
12 Housatonic River range from 1.04 to 1.72 cm/day. The measured average K_f
13 values do not depend on any simulation results or on the upstream boundary
14 condition assigned in the model. Consistent with model development and
15 evaluation procedures, EPA has relied extensively on site-specific data. These
16 data all demonstrate that the model framework accurately describes the
17 sediment-water mass transfer process for PCBs. On this basis, EPA believes
18 the Reviewer's comments that the calibrated K_f value in the model is low and is
19 impacted by upstream boundary conditions are incorrect.

20 Although the flux analysis indicated significant temporal variability in K_f that seems like it is
21 correlated with stream flow rate, EPA's values of K_f based on complete model calibration
22 appeared to be independent of flow rate. There seemingly should be some dependence,
23 since increased flow would increase stream turbulence, decreasing δ and increasing K_f . As EPA
24 acknowledges, as flow rate increases, it dilutes the water column concentration of PCBs, making
25 it difficult to test for flow dependent fluxes. But observations do show that the model over-
26 predicts water column PCB concentrations during low flow (when diffusive fluxes would
27 dominate) which could reflect, at least in part, the lack of flow-dependence.

28 **Response 1B-EA-2:**

29 The extent to which the mass transfer coefficient depends on flow was explored
30 through regression analyses. As a function of flow, the diffusive flux could range
31 from 0.4 to 2.5 cm/day over the range of flow from 15 to 500 cfs, based on the
32 spatial surveys between Holmes Road and Woods Pond Headwaters. However,
33 it should be noted that the regression with flow explained only 22% of the
34 variability in the measured K_f values (i.e., $r^2 = 0.22$) and that the range of K_f
35 values (0.4 to 2.5 cm/day) is within one standard deviation of the average values
36 determined from the spatial surveys. This range of K_f values is expected to be
37 within the measurement error of the spatial survey data. Given these factors,
38 EPA believes that the mass transfer coefficient in EFDC is properly defined
39 without further representation of potential flow dependencies.

40 In addition, it must be noted that the Reviewer's comment regarding over-
41 prediction of water column PCB concentrations due to the potential lack of flow

1 dependency is not correct. The difference between simulated and measured
2 PCB concentrations at low flow is the result of the variability of the TSS data on
3 which the model upstream boundary condition, including the PCB boundary
4 condition, is based. See FMD Appendix B.2 and General Topic 3.

5 The time scale for natural recovery is the mass inventory per unit area, $C_s(1-\phi)\rho_sL$, divided by
6 the flux, $J = C_{sL}K_f/K_p$, or $\tau = (1-\phi)\rho_sLK_p/K_f$. For $K_f = 10^{-4}$ cm/s (my value), and using other
7 parameter values from above, the time scale is 160 years. Thus diffusive exchange may not be
8 very important for contaminated sediments that are buried at or below the assumed level of bio-
9 mixing (i.e., most existing sediments). However, for recently transported sediments with smaller
10 L (e.g., following remediation), the time scale could be much smaller, especially if K_f were even
11 larger. For example, if L were only 1 and K_f were simply twice the above value (2×10^{-4} cm/s),
12 the time scale would be reduced to 16 years. However, the model would not be able to resolve
13 the resulting sharp gradients with the current, relatively coarse, vertical grid scheme.

14 **Response 1B-EA-3:**

15 The concept of the time scale for natural recovery by PCB sediment-water mass
16 transfer described in this Reviewer's comment is important. However, EPA
17 disagrees with the Reviewer's conclusion. It should be noted that the K_f value
18 used by the Reviewer was 10^{-4} cm/s (8.64 cm/day). This value is 5.76 times
19 greater than the K_f value used in EFDC (based upon site-specific data).
20 Consequently, when $K_f = 1.5$ cm/day is used in the Reviewer's calculations, the
21 estimated response of 160 years becomes 900 years. Using a K_f value that is
22 twice as large as the value currently in EFDC (i.e., 3 cm/day rather than 1.5
23 cm/day) would still result in a response time of 90 years, rather than 16 years as
24 projected by the Reviewer. Under these conditions, the model grid has the
25 resolution needed to represent any gradients in the sediment bed that could
26 reasonably develop over time.

27 **Douglas Endicott**

28 The diffusive flux (i.e. sediment-water exchange) of PCBs from sediment pore water to the
29 overlying water column was parameterized as a constant mass transfer coefficient during Phase 1
30 calibration. Phase 2 calibration has altered the spatial profiles of PCB water column
31 concentrations at low flow conditions, suggesting that sediment-water exchange should be
32 recalibrated. In all likelihood, the mass transfer coefficient should be increased, and made a
33 reach-specific parameter via a relationship between the mass transfer coefficient and the benthos
34 density.

35 **Response 1B-DE-1:**

36 See General Response above.

37 **Marcelo H. Garcia**

38 Model predictions in Figures 6.2-45 and 6.2-46, show that during low flow conditions the model
39 does not capture observed longitudinal gradients in the water column. This results in the model

1 underpredicting PCB fluxes from the sediments along Reach 5A, which in turn could lead to an
 2 under estimate of the bed sediments PCB contributions to fish in the Food Chain Model.

3 **Response 1B-MG-1:**

4 EPA disagrees with the Reviewer’s comment regarding the ability of the model to
 5 simulate spatial trends. MVR Figures 6.2-45 and 6.2-46 show that the model
 6 appropriately represents the observed spatial gradients in the water column for
 7 low-flow conditions. To properly interpret these figures, it must be realized that
 8 the model performance envelope (shown in gray) and the data range (shown as
 9 the bars for the measurements) overlap. The overlap of the model and data
 10 ranges indicates that model performance is adequate.

11 It is important to recognize that the balance of fate processes in the model is
 12 properly represented (see FMD Section 3.3 and the General Response to
 13 General Topic 1). Further, the bounding analysis demonstrates that FCM results
 14 are not impacted by potential bias in PCB exposure concentrations at low flow.
 15 See FMD Section 4.3.3 for bounding analysis results and discussion.

16 In the case of low flow conditions, the model predictions seem to be very sensitive to diffusion
 17 parameters, suggesting the representation of pore water diffusion as well as the thickness of the
 18 so-called “mixed layer” need to be carefully analyzed.

19 **Response 1B-MG-2:**

20 EPA agrees with the Reviewer that the mass transfer flux needs to be carefully
 21 analyzed. The mass transfer coefficient used in EFDC is consistent with site-
 22 specific data. See the General Response above.

23 **Frank Gobas**

24 The importance of a diffusive flux of PCBs from sediments to the water between Holmes Road
 25 and New Lennox Road during low flow periods is surprising (p.6-72 Model Validation Report)
 26 given the otherwise dominant roles of erosion and deposition (Fig 6.2-62 Model Validation
 27 Report). I have never seen a system, especially a riverine system, in which diffusion played such
 28 an important role. I think that it was necessary to invoke a high diffusion rate to explain the
 29 concentration data. I am not sure if there is any precedent for such a high diffusion rate though.
 30 This may be perhaps point to another parameterization problem in the model. I recommend the
 31 authors investigate this process in more detail and explore other options for calibrating the
 32 model.

33 **Response 1B-FG-1:**

34 The Reviewer comments that the PCB “diffusive flux” is too high. Given the
 35 context of the use by the Reviewer of the term diffusive flux, the comment is
 36 unclear to EPA.

1 It should be noted that the sediment-water mass transfer flux is often described
2 as a “diffusive flux” because the equation used to compute the mass transfer has
3 the same mathematical form as equations to describe diffusion. The usage of
4 the term “diffusive flux” is unclear in the comment because the mass transfer
5 process for PCBs represents the composite effect of several processes such as
6 diffusion (i.e., molecular diffusion), groundwater advection, and bioirrigation.

7 As EPA understands this comment, it is possible that the Reviewer used the term
8 “diffusive flux” in the context of molecular diffusion rather than sediment-water
9 mass transfer. In that context, it is worth noting that sediment-water mass
10 transfer coefficients for PCBs are always expected to be orders of magnitude
11 larger than corresponding rates for molecular diffusion because the mass
12 transfer process is a composite that includes processes far larger in scale than
13 molecular diffusion.

14 If the Reviewer did not misunderstand the usage of the term and “diffusive flux”
15 was meant to indicate the sediment-water mass transfer process, then it should
16 be recognized that the mass transfer coefficient used in the model is well within
17 the bounds values determined from measurements as described in FMD
18 Appendix B.10.

19 Regardless of the Reviewer’s intended usage of the term “diffusive flux,” the pore
20 water PCB concentrations in Housatonic River sediments are very high,
21 particularly in areas where organic carbon concentrations in the bed are low.
22 These high pore water PCB concentrations are a major determinant of the
23 sediment-water mass transfer flux.

24 **Wilbert Lick**

25 The sediment-water flux of PCBs due to “diffusion” as calculated by the present model is too
26 low. The formulation of this flux and its parameters are also incorrect. The mass transfer
27 coefficient, k , was given a value of 1.5 cm/day, constant throughout the river; this value was
28 chosen on the basis of calibration, not on the basis of any field or laboratory measurements.

29 **Response 1B-WL-1:**

30 EPA disagrees with the Reviewer’s comment that the formulation of the mass
31 transfer coefficient and its parameters is incorrect, and that the value is too low.
32 EPA also disagrees with the characterization that the value was chosen based
33 solely on calibration and not on the basis of field or laboratory measurements.
34 Values for the mass transfer coefficient are well within the range determined
35 strictly from measurements. See the General Response above and Appendix
36 B.10 to the FMD.

37 Since the PCB flux due to resuspension/deposition should be smaller than that predicted by the
38 present model, the PCB flux due to “diffusion” must increase, strictly on a calibration basis, to
39 compensate for this; it must also increase on the basis of a more fundamental investigation of
40 molecular diffusion and bioturbation (Deane et al. 1999, Lick et al. 2006, Luo et al. 2006). In

1 these articles, it is shown that k due to “diffusion” of HOCs has a lower limit of 1.2 cm/day (no
2 organisms) and increases to 10 cm/day (10^4 oligochaetes/m²) and even greater for larger numbers
3 of organisms, i.e., the sediment-water flux due to “diffusion” may be significantly greater than
4 that predicted by the present model. A realistic value for k should be determined on the basis of
5 the concentrations and types of benthic organisms. When this is done, k will be significantly
6 larger on the average than it is now and will be relatively low upstream but will increase in the
7 downstream direction.

8 **Response 1B-WL-2:**

9 EPA disagrees with the Reviewer’s characterization of the nature of the PCB
10 sediment-water mass transfer process. As demonstrated in FMD Appendix B.10,
11 the mass transfer coefficient for the Housatonic River can be determined from
12 measurements, entirely independent of the model. The mass transfer coefficient
13 value obtained by calibration, $K_f = 1.5$ cm/day, is well within the range defined by
14 measurements, 1.04 cm/day (geometric mean) to 1.72 cm/day (arithmetic mean).
15 Further, the Reviewer’s comment is based on the unfounded assumption that
16 “diffusion” is largely driven by benthic organisms. As discussed in the MCR and
17 MVR and as demonstrated by the sediment profiles images presented in FMD
18 Appendix A.3, physical mixing of river sediment also occurs. See the General
19 Response above.

1 **1.4 GENERAL TOPIC 1C: EQUILIBRIUM PARTITIONING**

2 **1.4.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 1, line 10 to page 2, line 27
Endicott	Page 4, lines 11 to 20
	Page 4, lines 21 to 30
Gobas	Page 15, lines 1 to 28
Lick	Page 8, line 1 to page 9, line 10
	Page 10, lines 7 to 12
	Page 11, lines 5 to 18
	Page 12, lines 34 to 42
List	Page 1, line 41 to page 2, line 3

3 **1.4.2 General Topic Summary**

4 PCBs are hydrophobic and readily partition between dissolved, bound, and particle-associated
 5 (particulate) phases. Partitioning to bound and particulate phases is a function of affinity for
 6 surfaces and organic carbon (Karichoff et al., 1979; Schwarzenbach et al., 1993; Chapra, 1997).
 7 Mechanistically, partitioning is a function of equilibrium rates at which chemicals sorb (move
 8 out of the dissolved phase) and desorb (move back into the dissolved phase). The PCB fate and
 9 transport computations in the EFDC model application to the Housatonic River are based on the
 10 concept of three-phase equilibrium partitioning (EqP), which assumes that the concentration of
 11 freely dissolved PCBs is always in equilibrium with the DOC-bound (complexed) and particulate
 12 (sorbed) fractions.

13 Three Reviewers commented that a time-dependent desorption approach should be applied in the
 14 model. One of these three Reviewers commented that it needs to be applied only to the water
 15 column and was not necessary for sediment. One Reviewer commented that the EqP approach
 16 was appropriate for both water and sediment.

17 Two Reviewers questioned EPA's interpretation of the assumption made regarding the
 18 relationship between K_{DOC} and K_{POC} and the interpretation of the work performed by Burkhard
 19 (2000).

1 1.4.3 General Topic Response

2 The use of EqP was reviewed and compared to time-dependent sorption to ensure EqP
3 is appropriate for use in the Housatonic River PCB fate and transport model. Careful
4 consideration was given to the details of how PCB partitioning was implemented in
5 EFDC. In addition to the information summarized in Appendix B.9 of the FMD, PCB
6 partitioning for the modeling study has been described in several other documents,
7 including Attachment B.9 of the Model Calibration Report (WESTON, 2004b), and
8 General Topic 5 of the EPA Response to Questions from the Model Validation
9 Document Overview Meeting (EPA, 2006).

10 Numerous PCB transport models are described in peer-reviewed literature as well as in
11 project reports, including applications for the Hudson River (Thomann et al., 1991; QEA,
12 1999; EPA, 2000), the Scheldt River in the Netherlands (Vuksanovic et al., 1996), and
13 the Lower Fox River (Velleux and Endicott, 1994; Steuer et al., 1995; WDNR, 2001).
14 Each of these models (as well as other model applications for sites including Green
15 Bay, Lake Michigan, Saginaw Bay, Milwaukee River, Sheboygan River, etc.) assumes
16 EqP for PCBs. This body of literature demonstrates that EqP is well established as the
17 state of the practice for large-scale PCB transport model applications. The EFDC
18 application for the Housatonic River PSA is fully consistent with this established state of
19 the practice. Further, no example of a large-scale PCB transport model that uses a
20 kinetic (non-equilibrium) approach was found in the peer-reviewed literature. While this
21 does not mean such kinetic applications do not exist, it does demonstrate that all
22 practical models in the literature utilize the EqP approach.

23 The EFDC application to the Housatonic River uses EqP for PCB transport and fate
24 calculations. This approach is consistent with the state of the practice for large-scale
25 PCB model applications. For most circumstances, the conditions for use of EqP are
26 satisfied. During high-flow events that resuspend sediment from the riverbed, it is
27 possible non-equilibrium conditions may exist. However, even for such high-flow
28 events, the maximum expected difference between water column phase distributions
29 computed using EqP or kinetic approaches will be approximately 5 to 10%. Therefore,

1 EqP provides a reasonable basis for modeling PCB fate and transport within the
2 Housatonic River.

3 **1.4.4 Response to Specific Comments on General Topic 1C**

4 **Eric Adams**

5 The model assumes that three chemical phases of PCBs are in equilibrium. As EPA points out,
6 this is a common modeling assumption, but I believe it is only reasonable within a stationary
7 sediment bed, and not within the water column during sediment resuspension.

8 Following Wu and Gschwend (1986), and focusing only on sorption and desorption among two
9 phases (sorbed PCB with concentration C_s and dissolved PCB with concentration C_d)

$$10 \quad \frac{dC_s}{dt} = k_1 K_p C_d - k_1 C_s \quad (1)$$

$$\frac{dC_d}{dt} = k_2 C_s / K_p - k_2 C_d$$

11 where k_1 and k_2 are rate constants constrained by

$$12 \quad k_1 = k_2 / \rho K_p \quad (2)$$

13 where ρ is the solid-water phase ratio $\rho = (1 - \phi)\rho_s / \phi$, ρ_s is the solid density, ϕ is porosity and
14 K_p is the partition coefficient. For a stationary sediment bed, ρ is about 1, so for hydrophobic
15 contaminants (large K_p), most of the contaminant is sorbed; hence the processes of sorption and
16 desorption cause C_d to vary in the range $0 \leq C_d \leq C_s / K_p$, whereas C_s remains nearly constant.
17 The characteristic time for sorption/desorption for highly particle-reactive species in a stationary
18 sediment bed ($\rho K_p \gg 1$) is thus k_2^{-1} .

19 Wu and Gschwend (1986) describe the sorption/desorption process as one of molecular diffusion
20 through particles (or particle aggregates). For large K_p and an assumed intra-aggregate porosity,
21 their effective (retarded) diffusion coefficient is given by

$$22 \quad D_{eff} \cong \frac{0.2D_m}{K_p \rho_s} \quad (3)$$

23 where D_m is the molecular diffusivity of PCBs. Wu and Gschwend (1988) fit a first-order
24 sorption kinetics model to the radial diffusion model over the (initial) time during which half of
25 the sorption/desorption takes place. Comparing the two models, and for $\rho K_p \gg 1$

$$26 \quad k_2^{-1} \sim \frac{(R / \rho K_p)^2}{D_{eff}} \quad (4)$$

1 where R is a characteristic aggregate radius. It can be seen that the time scale (k_2^{-1}) is
2 proportional to K_p^{-1} . In other words, for highly particle reactive species, little of the initially
3 sorbed mass is exchanged during desorption and that which is, is lost from the outside of the
4 particle (over an effective length of order $R/\rho K_p$). Even for a large R (0.01 cm) and $K_p = 10^5$
5 cm^3/g , the time scale (k_2^{-1}) is less than one second, suggesting that desorption is very fast, and
6 that the assumption of *equilibrium partitioning is probably acceptable within the sediment bed*.
7 See also following discussion under diffusive exchange.

8 **Response 1C-EA-1:**

9 EPA appreciates the detailed analyses provided by the Reviewer. As noted by
10 the Reviewer, average contact times in the sediment bed are typically so long
11 that the use of EqP is appropriate. See General Response above.

12 During resuspension, where the sediment concentration in the water column (TSS) is small,
13 equilibrium partitioning would require that most contamination become desorbed. Hence
14 diffusion must take place through the entire particle, giving a time scale (k_1^{-1})

$$15 \quad k_1^{-1} \sim \frac{R^2}{D_{eff}} \quad (5)$$

16 Even for a small R (0.001 cm), the time scale is over a day, which exceeds the duration during
17 which most suspended particles remain in the water column. Hence the assumption of
18 *equilibrium partitioning is not really valid for resuspended particles*. Because much of the
19 contamination on resuspended particles will not have time to de-sorb, assuming equilibrium
20 partitioning overestimates the PCB flux from bottom sediments due to resuspension. Of course,
21 during calibration, this could have been compensated for, in part, by assuming less sediment
22 resuspension.

23 **Response 1C-EA-2:**

24 EPA disagrees with the Reviewer's comment regarding the use of EqP for
25 resuspended particles on the basis of numerical tests of the Housatonic River
26 model conducted with EFDC. Those tests are presented in FMD Appendix B.9
27 and document that the expected difference in PCB phase distributions (i.e., the
28 fraction of the total PCB that is dissolved or particulate) computed for a short
29 resuspension event using EqP or kinetic approaches will be approximately 5 to
30 10%. This difference is minor given the large uncertainty associated with PCB
31 adsorption and desorption rate measurements. Based on this analysis, EPA
32 believes that EqP is an appropriate representation of the PCB phase distribution
33 in the water column as well as the sediment bed. See General Response above.

34 **Douglas Endicott**

35 EFDC uses the same equilibrium partitioning (EP) model as every other fate and transport model
36 in use today. EP generally works quite well, and simplifies the model computation by requiring
37 only a single state variable for each chemical. It has been suggested that desorption kinetics

1 should be incorporated into the Housatonic River model, because PCBs desorbing from
2 resuspended sediment might not reach equilibrium within the timeframe they remain in
3 suspension. This disequilibrium may help explain the pattern of PCBs moving in “ribbons” of
4 sediment downstream, and the high surficial PCB concentrations in Woods Pond sediment. I
5 think this is mostly speculation and, although I am curious to see if it is true, it is well and
6 beyond the objectives and goals of this modeling study.

7 **Response 1C-DE-1:**

8 EPA agrees with the Reviewer’s comment that EqP is the state of the practice for
9 fate and transport models in use today. EPA investigated the use of time-
10 dependent desorption in the model and corresponding model sensitivity. Further,
11 the difference between EqP and kinetic partitioning approaches is expected to be
12 approximately 5 to 10%, as documented in FMD Appendix B.9.

13 I have already commented on the misattribution of the assumption made regarding PCB
14 partitioning to non-filterable organic carbon in the water column ($K_{doc} = K_{poc}/100$), and EPA has
15 responded (less than satisfactorily) to this issue. Regarding the parameterization of the 3-phase
16 equilibrium partitioning model for PCBs, a useful citation (i.e., the Burkhard references) is:
17 USEPA, 2003. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of*
18 *Human Health (2000), Technical Support Document Volume 2: Development of National*
19 *Bioaccumulation Factors*. United States Environmental Protection Agency, Office of Water,
20 Office of Science and Technology. EPA-822-R-03-03
21 (www.epa.gov/waterscience/criteria/humanhealth/method/tsdvol2.pdf)

22 **Response 1C-DE-2:**

23 The modeling team has again considered this comment at length. The modeling
24 team still remains unsure as to the exact technical details and scope of the
25 Reviewer’s comment. As noted by the Reviewer, this topic was first raised at an
26 earlier stage of this Peer Review. At that time, the modeling team believed it had
27 fully responded to the Reviewer’s comment. Specifically, the Reviewer repeated
28 this comment and noted that he found the modeling team’s response “less than
29 satisfactory”. However, it must be noted the EPA had made every effort to fully
30 address the Reviewer’s comment as it was understood.

31 Nonetheless, in an effort to again resolve this comment, further descriptions of
32 EPA’s technical basis for selecting PCB partitioning parameters for the
33 Housatonic River model framework are provided below.

34 As part of model development, the modeling team assumed that $K_{POC} \approx K_{OW}$ as
35 described by DiToro (1985). From this assumption of the approximate equality of
36 K_{POC} and K_{OW} , it is concluded that $K_{DOC} = \alpha_{DOC} K_{POC} \approx \alpha_{DOC} K_{OW}$, as noted by
37 Burkhard (2000). With respect to the DOC binding efficiency (α_{DOC}), it is worth
38 noting that for sediment $\alpha_{DOC} = 0.1$, while for the water column $\alpha_{DOC} = 0.01$. Both
39 the values for α_{DOC} for sediment and α_{DOC} for the water column were determined
40 from site-specific data for the Housatonic River (see FMD Appendix B.9).

1 DOC binding effectiveness in the water column will typically be less than in the
2 sediment bed, as described by Eadie et al. (1990, 1992). One explanation for
3 the decreased binding efficiency in surface waters is photobleaching of DOC by
4 ultraviolet (UV-B) radiation (Kashian et al., 2004). On the basis of these
5 references and site-specific partitioning data, EPA believes that the relationship
6 between K_{POC} and K_{DOC} is appropriately defined for the Housatonic River.

7 Frank Gobas

8 The model assumption that the sorptive capacity of DOC is two orders of magnitude less than
9 that of POC (1.27-28, p.6-67 Model Validation Report) seems out of touch with the literature.
10 The lowest value I have seen to characterize the sorptive capacity of DOC compared to octanol
11 was 0.08, i.e. DOC has 8% of the sorptive capacity of octanol (Burkhard, L.P. Estimating
12 dissolved organic carbon partition coefficients for nonionic organic chemicals. *Environ. Sci.*
13 *Technol.* 2000, 34 (22), 4663-4668. – Note that in response to p. 2-72 of EPA response,
14 Burkhard states that $K_{\text{DOC}} = 0.08.K_{\text{OW}}$, not $K_{\text{DOC}} = 0.08.K_{\text{POC}}$). In comparison, the sorptive
15 capacity of POC is approximately 35% of that of octanol (Seth, R.; Mackay, D.; Muncke, J.
16 Estimating the organic carbon partition coefficient and its variability for hydrophobic chemicals.
17 *Environ. Sci. Technol.* 1999, 33 (14), 2390-2394.). Following these papers, the difference in sorptive
18 capacities between DOC and POC is approximately a factor of 35/8 or 4.38. Burkhard et al. did
19 report 95% uncertainty limits of a factor of 20 for the 0.08 value, hence the 0.01 value used in
20 the model is plausible, but it is very low.

21 Much higher values of the sorptive capacities of DOC in relation to octanol have also been
22 measured. For example, Macintosh et al. report 1.16 (± 0.49) for spiked and 61 (± 47) for native
23 PCBs and phthalates. This compared to 35 (± 19) for POC (Sorption of Phthalate Esters and
24 PCBs in a Marine Ecosystem, Mackintosh et al. *Environ. Sci. Technol.*; 2006; 40(11); 3481-
25 3488.). The latter results indicate no significant differences between sorptive capacities of DOC
26 and POC and also evidence of DOC-water disequilibria.

27 The assumed two orders of magnitude difference in sorptive capacities of POC and DOC in the
28 model is, albeit plausible, a very low value. Given the variation in literature data, I recommend
29 that empirical data are used to calibrate this model input requirement. The recent EPA response
30 document suggests that the latter has indeed been done.

31 Response 1C-FG-1:

32 As noted by the Reviewer, the sorptive capacity of POC relative to that of octanol
33 is variable. However, DiToro et al. (1985) found that $K_{\text{POC}} \approx K_{\text{OW}}$. Based on the
34 assumption of approximate equality of K_{POC} and K_{OW} , it is concluded that $K_{\text{DOC}} =$
35 $\alpha_{\text{DOC}} K_{\text{POC}} \approx \alpha_{\text{DOC}} K_{\text{OW}}$, as noted by Burkhard (2000). With respect to the DOC
36 binding efficiency (α_{DOC}), it is worth noting that for sediment $\alpha_{\text{DOC}} = 0.1$, while for
37 the water column $\alpha_{\text{DOC}} = 0.01$. Both the values for α_{DOC} for sediment and α_{DOC} for
38 the water column were determined from site-specific data for the Housatonic
39 River (see FMD Appendix B.9).

1 However, it should be noted that DOC binding effectiveness in the water column
 2 will typically be less than found in the sediment bed, as described by Eadie et al.
 3 (1990, 1992). One explanation for the decreased binding efficiency in surface
 4 waters is photobleaching of DOC by ultraviolet (UV-B) radiation (Kashian et al.,
 5 2004). On the basis on these references and site-specific partitioning data, EPA
 6 believes that the relationship between K_{POC} and K_{DOC} is appropriately defined for
 7 the Housatonic River.

8 **Wilbert Lick**

9 After sediment particles are resuspended, they will be transported downstream by the current and
 10 eventually settle out of the water column. During this time, the contaminant sorbed to the
 11 particle will desorb at some finite rate. The time for a particle to settle out of the water column
 12 depends on the settling speed and water depth, while the distance traveled by the particle before
 13 depositing depends on the settling time and current speed. For a reasonable range of settling
 14 speeds, w , for fine-grained particles/flocs (2×10^{-3} to 1×10^{-1} cm/s) and water depths, h , typical
 15 of the Housatonic (1 to 3 m), the settling times ($t = h/w$) are in the range (see table) from 10^3 s
 16 (15 min) to 1.5×10^5 s (1.5 days). For medium and coarse grained particles, the settling times
 17 are less.

18 Settling Times (Seconds) for Fine-Grained Particles in the Housatonic

19

h(cm)	w(cm/s)	
	2×10^{-3}	1×10^{-1}
1×10^2	0.5×10^5 (0.5 days)	1×10^3 (15 min)
3×10^2	1.5×10^5 (1.5 days)	3×10^3 (45 min)

20
 21 Some experimental results for the adsorption and desorption of HOCs are shown in the appended
 22 figures. These sorption times depend on the sediment concentration, particle and floc sizes,
 23 conditions of the experiment, and the value of the partition coefficient. The first three figures are
 24 for hexachlorobenzene ($K_p = 10^4$ L/kg), while the fourth figure is for the adsorption of HOCs
 25 with K_p 's from 10^3 to 6.6×10^4 L/kg. The last figure is for the desorption of a PCB with one
 26 chlorine (MCB, $K_p = 10^3$ L/kg), hexachlorobenzene (HCB, $K_p = 10^4$ L/kg), and a PCB with six
 27 chlorines (HPCB, $K_p = 6.6 \times 10^4$ L/kg, a K_p which is smaller than, but comparable to, the
 28 average K_p of about 10^5 L/kg for PCBs in the Housatonic). In 10 days, only about 25% of the
 29 HPCB has desorbed; in 50 days, only about 55% has desorbed. As the partition coefficient
 30 increases, the amount of desorption in these time intervals will be even less. For PCBs with $K_p =$
 31 10^5 L/kg, the desorption times would be approximately 1.5 times greater than those for HPCB
 32 shown here.

33 Since desorption times are much greater than settling times, it follows that contaminants on
 34 resuspended particles will not desorb completely, or even close to completely, in the water

1 column before the particles settle out of the water column. The chemical sorbed to the
2 suspended particles will therefore not reach chemical equilibrium with the chemical dissolved in
3 the water column. It follows that the assumption of equilibrium partitioning is not valid, nor
4 even a good approximation, for the sediments in suspension or in the surficial layers of the
5 bottom sediments.

6 Incidentally, finite rates of adsorption/desorption (1) will assist in explaining the high observed
7 values of PCBs in the surficial sediments of Woods Pond, (2) the high variability in observed
8 PCB concentrations in the sediments, and (3) probably will force a higher n in erosion formulas
9 (consistent with all other data) since non-equilibrium sorption will not be consistent with EPA's
10 imposed constraint due to equilibrium partitioning.

11 The conclusion is that finite rates of PCB adsorption and desorption have a major effect on the
12 sediment-water flux due to resuspension/deposition and must therefore be considered in the
13 modeling.

14 **Response 1C-WL-1:**

15 See General Response above and Appendix B.9 to the FMD. PCB phase
16 distributions computed using EqP and kinetic approaches as suggested by the
17 Reviewer are expected to differ by just 5 to 10% in the Housatonic River. This
18 difference is minor given the large uncertainty associated with PCB adsorption
19 and desorption rate measurements. It should be noted that the issue is whether
20 EqP is an adequate approximation for the model and not whether PCB
21 adsorption or desorption processes have reached full thermodynamic
22 equilibrium. Based on this analysis, EPA believes that EqP is an appropriate
23 representation of the PCB phase distribution in the water column.

24 EPA strongly disagrees with the Reviewer's conclusion that the difference in PCB
25 phase distributions as computed using EqP and kinetic approaches is "major."
26 For the Housatonic River, this difference is expected to be approximately 5 to
27 10%.

28 Since equilibrium partitioning is not valid, a new parameter (the sorption rate) is introduced into
29 the problem. Among other things, this invalidates EPA's statement (when speaking of non-
30 unique solutions) that "there is a constraint imposed by PCB transport that results from
31 resuspension and deposition processes." This constraint, if it exists, is incorrect because non-
32 equilibrium sorption would impose an entirely different constraint than that imposed by
33 equilibrium partitioning.

34 **Response 1C-WL-2:**

35 As noted in the General Response and Response 1C-WL-1, EqP is an
36 appropriate representation of PCB partitioning in the Housatonic River.

37 In my comments above, I emphasized that PCB sorption times are slow relative to particle
38 settling times and that, because of this, equilibrium partitioning (as assumed in the model) was
39 not a good assumption. Consider the effects of this on PCB transport to Woods Pond. The

1 upstream region of the Housatonic is erosional (on the average), and PCB concentrations near
2 the sediment surface are relatively high (because they were deposited at an earlier time before
3 remediation). As these sediments are eroded, PCBs tend to desorb from the suspended sediments
4 but do not reach anywhere near chemical equilibrium before the sediments are deposited, i.e., the
5 PCB concentrations of depositing sediments are much higher than if they had equilibrated in the
6 overlying water. This erosion/deposition may occur several times before the sediments and their
7 sorbed PCBs reach Woods Pond, or it may only occur once, depending on the flow rate and
8 turbulence. Either way, the sediments deposited in Woods Pond will have higher PCB
9 concentrations than if equilibrium partitioning was assumed, as is observed in field
10 measurements but is not predicted by the present model.

11 **Response 1C-WL-3:**

12 The reviewer's assumption that EqP is not appropriate for the Housatonic River
13 is incorrect. See FMD Appendix B.9. EqP adequately simulates the expected
14 phase distribution for PCBs.

15 Equilibrium partitioning is not a valid assumption. Desorption rates are relatively slow such that,
16 when bottom sediments are resuspended, the sorbed PCBs do not desorb sufficiently rapidly for
17 equilibrium partitioning to be approached before particle deposition occurs. The result is that
18 PCBs sorbed to the suspended solids are not in equilibrium with the PCBs dissolved in the water.
19 The sediment-water flux of PCBs due to resuspension/deposition is therefore much lower than
20 that predicted by equilibrium partitioning, as is assumed in the present model. A finite sorption
21 rate between the PCBs sorbed to the solids and the dissolved PCBs needs to be added to the
22 model and will replace the equilibrium assumption.

23 **Response 1C-WL-4:**

24 EPA disagrees with the Reviewer's assertion that EqP is not valid. See General
25 Response above and FMD Appendix B.9. The difference in phase distributions
26 computed using EqP and kinetic approaches is approximately 5 to 10%.

27 **E. John List**

28 Because the PCBs are an integral part of the stream sediments the difficulties of TSS mass
29 balances carry through to the PCBs. To compound the difficulty, the PCB mass flux has two
30 components: one associated with the sediments and the other with the dissolved phase in the
31 water. A further complication is the kinetics of the partitioning process of the PCB between the
32 water and the sediment, which was a matter of some discussion at the Peer Review meeting and
33 may need addressing.

34 **Response 1C-JL-1:**

35 EPA has evaluated the kinetics of the partitioning process (see General
36 Response above).

1 **1.5 GENERAL TOPIC 1D: BANK EROSION**

2 **1.5.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Bohlen	Page 8, lines 16 to 23
Garcia	Page 1, line 39 to page 2, line 18
	Page 2, line 37 to page 3, line 6
List	Page 1, lines 39 to 41

3 **1.5.2 General Topic Summary**

4 The model framework includes bank erosion because of its importance to longer-term
 5 simulations as identified in the MFD and Reviewers’ comments from the previous two Peer
 6 Reviews.

7 Two Reviewers commented on the adequacy of the formulation used to represent bank erosion in
 8 EFDC. One Reviewer noted that bank erosion can influence channel morphology.

9 **1.5.3 General Topic Response**

10 Bank erosion has two main components (Knighton, 1998): toe erosion by hydraulic
 11 action (fluvial erosion) and mass failure. The total bank erosion rate is the sum of these
 12 two components and can be estimated from field data using a range of approaches.
 13 Separating total erosion rates into toe erosion and mass failure components is difficult
 14 without direct time series observations and is still an area of active research. Site-
 15 specific data for Reaches 5 and 6 define short-term and long-term average rates of
 16 bank erosion but do not define the time history of erosion.

17 For the Housatonic River EFDC model application, an empirical approach was used to
 18 estimate bank erosion rates. Long- and short-term bank erosion solids loads were
 19 determined from field investigations, including the differences between geo-referenced
 20 aerial photographs and survey data (Woodlot, 2002, which is included as Appendix A.4
 21 to the FMD).

1 Although the exact time history of bank erosion cannot be determined directly from
2 these surveys, the overall bank erosion loads used in the model are constrained by the
3 bank erosion solids mass entering the river as determined from site-specific data for
4 long-term (1972–2001) and short-term (2001-2002) periods.

5 To approximate the time history of bank erosion, two types of solids loads were input to
6 EFDC: (1) continuous loads that represent erosion of the bank toe below the water line;
7 and (2) periodic loads that represent mass failure for an event. Both loads were
8 computed as empirical functions of flow, with the total bank erosion defined as the sum
9 of toe erosion and mass failure components.

10 The empirical functions developed to estimate bank erosion loads for EFDC model
11 application to the Housatonic River are consistent with long-term and short-term bank
12 erosion rates determined from field data and site-specific analyses. As parameterized,
13 the empirical equations yield bank erosion loads that match the long-term and short-
14 term erosion rates with a very small residual error. While there is uncertainty
15 associated with the time history of these loads, use of a mechanistic model to generate
16 an alternative time history would not eliminate or reduce this uncertainty. Further, it
17 should be recognized that bank erosion represents an appreciable but nonetheless
18 small component (13%) of the annual average external solids budget for the river.
19 Given the limitations and variability associated with bank erosion measurements for the
20 site, and because it is a small component of the overall solids budget, further refinement
21 of the bank erosion time history is neither practical nor necessary to achieve the goal of
22 the modeling study. See Appendix B.7 to the FMD.

23 **1.5.4 Response to Specific Comments on General Topic 1D**

24 **W. Frank Bohlen**

25 Beyond this matter of flow, velocity and shear stress, I was pleased to see that the current model
26 includes direct calculation of side bank erosion. I'll leave the adequacy of this formulation to
27 those more qualified than I but must state my concern over the apparently simple partitioning of
28 the mass of sediment supplied by this process between surficial erosion (during the rising
29 hydrograph) and mass failure (during falling stage). It's hard for me to see why the masses
30 should in anyway be equivalent. This subject was also noted in GE's review of the Model

1 Validation Report (MVR). Justification for this approach should be carefully presented using the
2 field data and/or supplementary data from previous publications.

3 **Response 1D-FB-1:**

4 See the General Response above. Estimates of bank erosion for the Housatonic
5 River are fully consistent with site-specific bank erosion data.

6 **Marcelo H. Garcia**

7 It is not enough to state that a given process is accounted for when the representation of the
8 process is deficient and its implementation in the model is done with algorithms and assumptions
9 that are not based on the physics of the process and cannot be supported by field observations.
10 For instance, streambank erosion has been recognized as a very important process since large
11 amounts of PCB-laden sediments can enter the river during medium to high flows. However,
12 fluvial erosion and mass failure of the stream banks are currently modeled simply as functions of
13 flow discharge, a rather crude approximation, which severely limits the capabilities of the model
14 to assess the effect of this process.

15 **Response 1D-MG-1:**

16 EPA disagrees with the Reviewer's comment. Bank erosion estimates in the
17 model are based on empirical functions that accurately reproduce the mass of
18 solids eroded from the river banks over time. Bank erosion is a complex topic in
19 general and the exact mechanism driving bank erosion in the Housatonic River
20 system cannot be determined from the present data. However, the empirical
21 functions developed for the model are based on information describing river bank
22 erosion conditions for the past 3 to 5 decades. Although the reviewer may
23 regard the empirical approach as "crude," it should be recognized that it is
24 accurate. See General Response above and FMD Appendix B.7.

25 How can one determine what regions of the banks are more prone to erosion and, therefore, need
26 protection if the model does not compute the distribution of flow velocity and bed shear stress
27 along the banks? Could native vegetation or other bioengineering techniques be used to protect
28 the banks of the Housatonic River against erosion or more hard-core solutions such as rip-rap are
29 needed? Is it possible to use a combination of both? As it stands now, the model can not be used
30 to compare the merits of such remedial alternatives, which is one of the goals of the modeling
31 study as stated above.

32 **Response 1D-MG-2:**

33 As EPA has stated to the Reviewers, it is not the goal of the modeling study to
34 develop models that will be used to evaluate specific engineering applications on
35 a location-specific basis in the CMS. The goal of the model (in the situation
36 described by the Reviewer) is merely to assess if the contribution of PCBs from
37 the banks in given reaches warrants attention when evaluating remedial
38 alternatives, and the relative impact of the bank contributions on alternatives.
39 The level of detail of modeling needed to evaluate this contribution for a remedial

1 alternative would be to simply “control” bank erosion in the model by setting the
 2 bank source contribution to zero as was done by EPA in one of the
 3 demonstration runs.

4 The Reviewer, however, questions the capabilities of the model for just such an
 5 application. The model will not be used to evaluate the specific areas of bank
 6 that will be subject to a specific engineering control such as bioengineering or
 7 hard engineering. There are other tools specifically developed to assist in
 8 evaluating these engineering techniques. Such decisions would be made in the
 9 design phase of a remedy, if necessary.

10 At the same time, the use of a coarse grid hinders the ability of the model to resolve the flow
 11 velocity distribution inside the main channel as well as the associated boundary shear stresses
 12 throughout its wetted perimeter. Given that erosion and sediment transport vary non-linearly
 13 with increments in flow velocity and shear stress, it is rather imperative to find a way to increase
 14 the spatial resolution of the model so that at least three “streamtubes” are used to model flow and
 15 sediment transport in the main channel of the Housatonic River. This will in turn facilitate and
 16 make more meaningful the computation of streambank erosion as well bed sediment erosion and
 17 resuspension.

18 **Response 1D-MG-3:**

19 See General Response. The empirical functions used to estimate bank erosion
 20 are based on flow, not velocity, and very accurately represent measured long-
 21 term and short-term erosion rates in the Housatonic River. See FMD Appendix
 22 B.7.

23 **E. John List**

24 If, in addition, the stream bank erodes then long term changes in the direction and shape of the
 25 channel can result.

26 **Response 1D-JL-1:**

27 The Reviewer correctly notes the linkage between bank erosion and channel
 28 morphology. See General Response above.

1 **2. GENERAL TOPIC 2: SPATIAL TRENDS AND MODEL-DATA**
 2 **COMPARISONS**

3 **2.1 GENERAL TOPIC 2A: PREDICTED SEDIMENT/WATER COLUMN PCB**
 4 **CONCENTRATIONS**

5 **2.1.1 Comment Summary**

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Adams	Page 7, line 25 to page 8, line 10
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6 **2.1.2 General Topic Summary**

7 The identification of trends in environmental media is important in assessing model performance
 8 because one of the most common ways of evaluating model performance is to compare the
 9 simulated concentrations in sediment and fish tissue with those measured. However, accurate

1 quantification of spatial and temporal PCB concentration trends is complex. The majority of the
2 sampling programs for the Housatonic River were not designed to estimate PCB concentration
3 trends over time. Differences in sediment PCB concentrations resulting from spatial
4 heterogeneity, temporal variability, sample size, and analytical bias confound analysis and make
5 clear identification of trends challenging. It is important to carefully evaluate the occurrence of
6 significant trends in contaminant concentrations using rigorous statistical methods that take into
7 account these potentially confounding factors. Often an apparent trend (one presumed by
8 viewing the data) is in fact not significant (does not exist in a statistically meaningful way).

9 Changes in surface water, sediment, and fish tissue PCB concentrations over time were initially
10 described in the RFI (BBL and QEA, 2003), and EPA documents such as Responses to
11 Questions from the Reviewers. Statistically significant changes in concentrations are now more
12 fully quantified in FMD Appendix A.1.

13 All Reviewers commented on the ability of the model to simulate concentrations of PCBs in
14 surface water and sediment, including indications in the data of real or apparent spatial patterns
15 and/or temporal trends in PCB concentrations in the PSA. Four of the Reviewers combined their
16 comments on these model-data comparisons with additional comments about small-scale spatial
17 variability in PCB concentrations, which is addressed in General Topic 2B.

18 All Reviewers commented that they believed there is, or should be, a trend of decreasing PCB
19 concentrations in Woods Pond sediment, yet the model did not reproduce the magnitude of this
20 trend and was thereby biased high with respect to the amount of time necessary for natural
21 remediation to reduce sediment PCB concentrations in Woods Pond. One Reviewer commented
22 further that even if the model was biased in this regard, it was apparent that any such natural
23 remediation would require “decades”; therefore, the question of bias may be moot.

24 Most Reviewers recommended additional study to better understand the behavior of the model
25 regarding spatial and temporal trends. One Reviewer recommended a more refined statistical
26 study of the data to better characterize the perceived temporal trend in Woods Pond sediment
27 PCB concentrations.

1 **2.1.3 General Topic Response**

2 In response to Reviewer comments, EPA performed further data analyses of trends in
3 surface water, surface sediment, and fish tissue PCB concentrations for Reaches 5 and
4 6 beyond those presented previously in the RFI and other documents. These analyses
5 are summarized in Appendix A.1 of the FMD.

6 Analyses indicate that the trend (or decline) in surface sediment PCB concentrations in
7 Reaches 5 and 6 is not statistically different from zero (i.e., slow to no change over
8 time). Model results are consistent with this observation. Specifically, the simulated
9 rate of surface sediment PCB concentration decline in EFDC is slow and within the
10 uncertainty envelope of the data. There is no statistically significant trend in PCB
11 concentrations in Woods Pond surficial sediment. In contrast, the Reviewers assumed
12 that there was a more rapid decline in sediment PCB concentrations over time and then
13 incorrectly concluded that the rate of decline in PCB concentrations simulated by the
14 model (which is in agreement with the data) was too slow. The Reviewers may have
15 based their assumption on what could appear visually to be a decline in Woods Pond
16 sediment. However, this decline is not statistically significant because of the limitation
17 of sample size available for certain time periods, and an analytical bias (low) in much of
18 the sediment data collected in the later portion of the time period. This analytical bias
19 was discussed in Attachment 4 to the MCR, and in Appendices A.1 and A.2 to the FMD.

20 Statistical analyses of trends in surface water concentrations for the validation period
21 were conducted and are documented in Appendix A.1 of the FMD. These analyses
22 indicate a statistically significant decline in PCB concentrations ranging from 5.8 to
23 13.8% per year in Reaches 5 and 6 for the period from 1979 to 2004. It is not
24 meaningful to estimate a trend in PCB concentrations in surface water from EFDC
25 results because the EFDC-simulated surface water concentrations are sensitive to the
26 boundary condition function, which was essentially constant over the 26-year period.
27 Within that time, EFDC boundary conditions would be influenced solely by the
28 hydrograph, and would not necessarily reflect the historical concentrations in loads that
29 predate the data set used to develop the upstream boundary flux function.

1 The analysis of spatial and temporal trends in PCB concentrations in fish tissue shows a
2 slight decline over time in whole-body fish tissue PCB concentrations in Reaches 5 and
3 6. The decline in fish tissue concentrations was statistically significant for some of the
4 species and/or subreaches and not for others. The magnitude of the decline was
5 generally small in most cases, with a half-life on the order of decades. This is
6 consistent with the results of the analysis of trends in sediment PCB concentrations.
7 FCM accurately simulates the concentrations of PCBs in fish tissue, with a simulated
8 rate of decline that is slow and within the uncertainty envelope of the data.

9 **2.1.4 Responses to Specific Comments on General Topic 2A**

10 **Eric Adams**

11 The spatial plots at low Q (Figure 4.2-69) and moderate Q (Figure 4.2-70) show that upstream
12 concentrations of both TSS and PCB are too low (a consequence of the BC) and that there is
13 more local variability (indicated by shading) than variability between reaches. There is no way
14 to verify the local variability. It is hard to say whether the overall spatial trend is correct or not,
15 because of variability in the data. The temporal trends look OK.

16 **Response 2A-EA-1:**

17 The Reviewer is correct in noting that the variability in the data complicates
18 evaluation of spatial and temporal trends. The figures identified by the Reviewer
19 in his comments regarding spatial patterns present model-data comparisons for
20 low-flow conditions (flows at Coltsville between 16 and 25 cfs) and conditions
21 slightly above average flow conditions (flows at Coltsville between 109 and 275
22 cfs). These figures highlight the effect of the spatial transient in PCB
23 concentrations due to PCB mass transfer from the sediment under low- to
24 moderate-flow conditions. An additional and perhaps more important
25 demonstration of model performance is the ability of the model to reproduce the
26 roughly one order of magnitude decline in water-column PCB concentrations and
27 also the decline in TSS concentrations between New Lenox Road and Woods
28 Pond Outlet under high-flow conditions (Figures 3.5-6 and 3.5-15 in the FMD,
29 previously presented as Figures 4.2-75 and 4.2-76 in the MVR).

30 The temporal changes in sediment PCB (top 6 inches) show that the model does not reproduce
31 the significant decline in Woods Pond over time (Figure 6.2-50). This is one of GE's main
32 points and suggests that the model might also underpredict the response to remedial actions,
33 including natural attenuation. *I see this as a major concern.*

34 The model misses the decline in PCBs across Woods Pond that is both observed and intuitively
35 suspected. This would mean the model overpredicts loading downstream (downstream model).

1 **Response 2A-EA-2:**

2 The statistical analysis of Woods Pond sediment PCB data, described in
 3 Appendix A.1 of the FMD, indicates that there is no statistically significant change
 4 in surface sediment concentrations in Woods Pond over time as the Reviewer
 5 incorrectly assumes. The simulated rate of sediment PCB concentration decline
 6 in EFDC is slow and is well within the uncertainty envelope of the data. This
 7 more rigorous statistical analysis supports the characterization of model-data
 8 comparison of PCB concentrations discussed in Section 6.2.5.1 of the MVR and
 9 in previous documents, including the RFI.

10 Like TSS, the equivalence plots for PCBs (Figure 4.2-85) shows less variability than the data.
 11 However, there is little indication of (overall) bias.

12 And also like TSS, it would also be nice to have had more data on PCBs. Again, there is better
 13 model-data agreement at relatively high (presumably more biologically relevant) concentrations.
 14 As with other variables, the model shows less variability than the data (i.e., it underpredicts the
 15 highs and overpredicts the lows).

16 **Response 2A-EA-3:**

17 EPA has consistently acknowledged in the MCR and MVR that the model results
 18 have less variability than the data, and discussed reasons why this is expected.
 19 EPA also agrees with the Reviewer that there is better model-data agreement at
 20 relatively high PCB concentrations, and that these conditions are more
 21 biologically relevant. A bounding analysis (MVR Section 6.2.3.4 and the EPA
 22 Response to Questions from the Model Validation Document Overview Meeting)
 23 demonstrated that the overpredictions of low PCB concentrations had less than a
 24 5% effect on fish tissue concentrations, averaged across all species.

25 Except for the transducers which record flow (through a stage discharge relationship), better data
 26 seem to be available for the calibration (especially the original calibration) period, than for the
 27 validation period. However, I am less concerned with traditional model validation (the model's
 28 ability to predict absolute concentrations under different hydrologic conditions) than I am with
 29 the model's ability to distinguish among different remedial alternatives that would presumably
 30 be evaluated under the same hydrologic conditions. See comments under Question 6.

31 **Response 2A-EA-4:**

32 The example simulations, which were recommended by this Reviewer, were
 33 viewed by the modeling team as an effective way to demonstrate the behavior of
 34 the model under very different conditions than those simulated during the
 35 calibration and validation periods. Although not intended to be viewed as an
 36 evaluation of any remedial alternative, the results of the example simulations
 37 provided the modeling team and several Reviewers with additional confidence in
 38 the ability of the model to describe (1) the response of the system to changes
 39 associated with potential remedial alternatives, and (2) the relative difference
 40 simulated in the two alternatives. The "tracer," or source-specific simulations,

1 provide additional insight into the relative contributions of different processes in
 2 different locations to the overall response of the system.

3 **W. Frank Bohlen**

4 In terms of PCBs, the model appears to overpredict concentrations in Woods Pond (see Fig.6.2-
 5 50). This is likely the result of inaccurate specification of suspended sediment flux associated
 6 with the above TSS predictions. Alternatively it may be associated with the specification of
 7 boundary conditions and/or the model treatment of PCB sequestering in Woods Pond. The model
 8 decline within the Pond appears to be approximately linear with time while the data suggest an
 9 exponential distribution. The latter might be the result of progressive source control (both natural
 10 due to burial and anthropogenic) acting in combination with sedimentation of cleaner materials.
 11 The model might easily obscure this process since it assumes a well mixed sediment column to
 12 6in. With sedimentation rates in Woods Pond averaging approximately 2-3 mm/yr the above
 13 depositional processes might be expected to influence the upper 3in over 25 years. This might
 14 very well result in a reduction in actual PCB concentrations that would not be well simulated by
 15 the model.

16 **Response 2A-FB-1:**

17 The Reviewer's interpretation of the comparison of trends in sediment PCBs in
 18 Woods Pond is erroneous, and contradicted by the results of the rigorous
 19 statistical analysis (FMD, Appendix A.1), which supports the interpretation
 20 provided by the modeling team in the MVR and Document Overview Meeting
 21 presentations. Because the Reviewer's premise is incorrect, no response can be
 22 provided for the hypotheses offered by the Reviewer to explain the supposed
 23 inconsistency.

24 It is noted, however, that the Reviewer's description of a 6-inch, well-mixed layer
 25 is inconsistent with the model's parameterization of the bed (see FMD Appendix
 26 B.5, Tables B.5-2 and B.5-3), which includes a 1.6-inch (4-cm) mixed layer in
 27 Reach 5A and a 2.8-inch (7-cm) mixed layer in the remainder of Reach 5 and all
 28 of Reaches 6 through 8.

29 **Douglas Endicott**

30 Model predictions of total PCB concentrations in the Housatonic River water column were
 31 compared to data using time series plots and longitudinal profiles. The time series plots (Figures
 32 4.2-65 thru 4.2-68 and 6.2-41 thru 6.2-44) indicate that, for PCB concentrations, there are
 33 significant gaps in data collection over the Phase 2 calibration and validation periods. As was the
 34 case for TSS, the model tends to overpredict low PCB concentrations, and the overprediction of
 35 these two state variables appear to coincide. This is most apparent at the Holmes Road station.
 36 Again, this is primarily due to significant bias in the specification of the East Branch boundary
 37 condition on days when PCB concentrations were not measured. Inspection of the timeseries of
 38 East River PCB boundary conditions (Figure 4.2-64) reveals that the only time East River PCB
 39 boundary concentrations are lower than 60 ug/L is when data have been measured below this

1 value, yet probably more than half of the data fall below this concentration. There are sufficient
 2 PCB data to evaluate the storm event predictions on only one occasion (May 19-21, 1999 at New
 3 Lenox Road; Figure 4-2.76); the model prediction timeseries agrees well with this data. The
 4 spatial profiles for PCB water column predictions appear to be quite variable.

5 **Response 2A-DE-1:**

6 Solids and PCB concentrations measured at the upstream boundary are highly
 7 variable. Across narrow ranges of flow, these measured values can vary by
 8 more than two orders of magnitude. For all practical purposes, a many-to-one
 9 relationship exists between measured concentration and flow. The high degree
 10 of variability in measured East Branch boundary TSS and PCB concentrations
 11 within narrow flow ranges presented a significant challenge for the development
 12 of estimates of boundary concentrations for times when data were not available.
 13 The uncertainty associated with boundary loadings estimates of PCBs has been
 14 acknowledged. Appendix B.2 of the FMD provides a discussion of the
 15 approaches evaluated to develop boundary conditions, including those proposed
 16 by Reviewers. Although none of the techniques considered were able to
 17 reproduce the variability of the measured concentrations, the technique that was
 18 developed was judged to be acceptable because it yielded estimates that fit the
 19 data somewhat better than prior estimation methods did, and a bounding
 20 analysis (MVR Section 6.2.3.4, and the EPA Response to Questions from the
 21 Model Validation Document Overview Meeting) demonstrated that the
 22 overpredictions of the low PCB concentrations had less than a 5% effect on fish
 23 tissue concentrations, averaged across all species.

24 In the *EPA Response to Questions from Model Validation Document Overview Meeting*, a
 25 statistical test (overlapping 95% confidence limits) is offered to show that the apparent decrease
 26 in PCB concentrations across Woods Pond may reflect sampling variability. It may be useful to
 27 use a statistical test to evaluate the gradient in PCB concentration data between two river
 28 locations; however, wouldn't it be better (more powerful) to test whether the *difference* in PCB
 29 concentrations between locations is significantly different than zero?

30 Timeseries plots comparing the predictions of PCB concentrations in the top 6" of sediment in
 31 mile reaches to data are shown in Figure 4.2-77 for the Phase 2 calibration period, and Figures
 32 6.2-49 for the validation period. The predictions appear to exceed the majority of data at the end
 33 of both the calibration and validation periods, in some or most mile reaches. Although data prior
 34 to 1999 are not abundant, the model also appears to underpredict the rate of PCB sediment
 35 decline in many mile reaches, including Woods Pond (Figure 6.2-50) as suggested by the
 36 overprediction of the majority of 1999 data. The failure of the model to reproduce the rate of
 37 decline in sediment PCB concentrations is a major problem, since in the long-term, PCB
 38 concentrations in biota will respond to this rate of change. The MVR fails to address this
 39 discrepancy and it's possible explanations, even though this error is evident in both calibration
 40 and validation periods. It would also be useful to compare sediment PCB concentration
 41 predictions to data for deeper, sub-surficial layers. Slower changes in PCB concentrations would
 42 be expected in deeper intervals, reflecting slower transport in deeper sediments.

1 **Response 2A-DE-2:**

2 As discussed above in the response to this General Topic, EPA conducted
3 further statistical analyses of potential temporal/spatial trends in water column,
4 sediment, and fish tissue PCB concentrations; these analyses are reported in
5 detail in Appendix A.1 of the FMD. Based on these more in-depth statistical
6 analyses, which incorporate a correction for known bias in some of the PCB
7 laboratory analyses, the decline in measured sediment PCB concentrations
8 throughout Reaches 5 and 6 during the 26-year validation period was shown to
9 be slow and not significantly different from zero. The model simulation is
10 consistent with the results of these analyses.

11 A number of significant model biases have been identified and discussed above (Question 2).
12 The most significant are:

- 13 o The predicted changes in sediment PCB concentrations are slower than observed,

14 **Response 2A-DE-3:**

15 The statistical analysis of sediment PCB concentrations (Appendix A.1 of the
16 FMD) indicates that there is no statistically significant change in sediment
17 concentrations with time. The rate of sediment PCB concentration decline
18 predicted by EFDC is slow and is well within the uncertainty envelope of the data.
19 The Reviewer's interpretation of an apparent trend in the data, leading to a
20 conclusion of a significant bias in the model, is incorrect and inconsistent with the
21 statistical analysis results and the interpretation of the data presented in the MVR
22 (Section 6.2.3.4).

- 23 o Spatial gradients in water column PCB concentrations do not match data under
24 low flow conditions, and

25 **Response 2A-DE-4:**

26 PCB mass transfer between the bed and water column is proportional to the PCB
27 concentration gradient between the water column and sediment pore water. This
28 concentration gradient does not substantially change in response to the
29 upstream PCB boundary condition because pore water PCB concentrations (on
30 the order of 10 µg/L) are much larger than water column PCB concentrations
31 (approximately 0.05 to 0.10 µg/L). This means that the gradient (the pore water
32 value minus the water column value) is approximately equal to the pore water
33 PCB concentration. As a result, the PCB mass transfer from sediment is not
34 noticeably affected by the upstream boundary concentration.

35 The calculated incremental PCB concentration increase between the confluence
36 and New Lenox Road (over a flow range from 50 to 100 cfs) that results from the
37 sediment PCB mass transfer is comparable in magnitude to the concentration at
38 the upstream boundary during low-flow periods. Consequently, the uncertainty
39 associated with setting the boundary concentration does not markedly alter the

1 ability of the model to simulate the water-column PCB concentrations. For
2 example, if the upstream PCB boundary concentration were set to 0.01 µg/L, the
3 water column PCB concentration would be controlled by the PCB mass transfer
4 from the sediment and would produce a water column PCB concentration of
5 approximately 0.10 µg/L at the downstream end of Reach 5A. Alternatively, if the
6 boundary concentration were set to 0.10 µg/L, the water column PCB
7 concentration at the end of Reach 5A would be approximately 0.2 µg/L. As a
8 result, the sensitivity of the mass transfer flux to changes in the upstream
9 boundary condition is small.

- 10 ○ The treatment of the upstream boundary condition results in serious
11 overprediction of low TSS and PCB concentrations.

12 **Response 2A-DE-5:**

13 EPA disagrees with the Reviewer's assessment that the treatment of the
14 upstream boundary condition results in a serious overprediction of low TSS and
15 PCB concentrations for the reasons stated above.

16 **Marcelo H. Garcia**

17 Of particular relevance for this reviewer is the validation of flood plain deposition throughout the
18 river system as well as sediment erosion and deposition in Woods Pond, since the record shows
19 that this pond is a major deposit for PCB-contaminated sediments.

20 Regarding the sedimentation of Woods Pond, the calibration/validation exercise has produced
21 results showing rates of (*net*) sedimentation for the period going from 1979 to 2004 (Figure 6.2-
22 34). The results seem reasonable with predicted sedimentation rates (mm/year) that are within
23 an order of magnitude of sedimentation rates determined from Cesium data. The model also
24 reproduces fairly well the distribution of PCBs with depth as observed from sediment cores.
25 However, as stated below, the model shows some bias when predicting temporal variations of
26 surface PCB concentrations in Woods Pond.

27 Woods Pond is perhaps one of the few locations in the Housatonic River where the capabilities
28 of the model to predict the spatial and temporal distribution of sediment and PCB can be
29 extensively tested due to the large amount of observations available. This has been done to some
30 extent but more effort should go into this since the pond could become a major source of PCBs
31 to the downstream portion of the river during a major flood event.

32 **Response 2A-MG-1:**

33 Additional comparisons between simulated and measured sedimentation rates in
34 Woods Pond, which were not included in the MVR, have been included in the
35 FMD (Section 4 and Appendix B.6). A more detailed statistical analysis of
36 temporal distributions of PCBs in Woods Pond sediment has been completed,
37 and is presented in Appendix A.1 of the FMD. EPA agrees with the Reviewer's
38 comment that the comparisons between measured and simulated sedimentation

1 rates are reasonable, and points out that the agreement on a core-by-core
2 comparison is better than the order-of-magnitude characterization mentioned by
3 the Reviewer.

4 As shown in MVR Figure 6.2-50, the model predictions of variation with of surface PCBs
5 concentrations are not consistent with the field observations in Woods Pond. The model seems
6 to underpredict the observed values in the time period from 1979-1984 and to overpredict the
7 observations in the time period from 1995 to 2000.

8 **Response 2A-MG-2:**

9 As stated in response to comments from other Reviewers, a statistical analysis of
10 Woods Pond sediment PCB data, described in Appendix A.1 of the FMD,
11 indicates that there is no statistically significant change in sediment
12 concentrations with time, and that the slow simulated rate of sediment PCB
13 concentration decline is well within the uncertainty envelope of the data.

14 There is evidence that model predictions do not match well with observed surface sediment
15 concentrations of PCBs in reaches 5A, 5B, and 5C as displayed in Figure 6.2-49.

16 **Response 2A-MG-3:**

17 EPA disagrees with the Reviewer's comment that the model predictions are not
18 consistent with the data. The statistical analysis described in Appendix A.1 of the
19 FMD and previous characterizations of the trends (or lack thereof) in PCB
20 sediment concentrations indicate there are no trends in the data, and that there is
21 a great deal of variability in the data. The model simulates the central tendencies
22 of the data very well.

23 **Frank Gobas**

24 The model calibration has been complicated by the lack of a significant change in PCB
25 concentration data in the River during the calibration period. Hence, the model calibration sheds
26 little light on the issue of whether the model is able to account for changes in PCB
27 concentrations over time that may occur as a result of remediation. The main conclusion from the
28 calibration is that the temporal response of PCB concentrations in the River is likely slow, but it
29 cannot tell us accurately how slow.

30 **Response 2A-FG-1:**

31 EPA agrees that the data do not suggest a significant change in PCB
32 concentrations, and this is supported by the conclusions of a statistical analysis
33 of the data provided in Appendix A.1 of the FMD as well as previous
34 characterizations of the trends (or lack thereof) in PCB concentrations in
35 sediment. EPA agrees with the conclusion that the Reviewer drew from the
36 Calibration that the temporal response of the system is slow, and acknowledges
37 that there is uncertainty in quantifying how slow the rate is.

1 Evidence to indicate that the current temporal response of the model may be flawed was
 2 presented by Dr. Connolly, who suggested that the half-life time of PCBs in the River is likely is
 3 closer to 36.5 yr (i.e. 0.693/0.019) than the current model prediction of 110 yr (i.e. 0.693/0.006).
 4 I think that Dr. Connolly is probably correct, but the uncertainty in the estimates of the half-lives
 5 is large and I have not been convinced that the current PCB concentration data in the River allow
 6 one to distinguish between these two estimates.

7 **Response 2A-FG-2:**

8 While there is uncertainty in the estimates of the rate of decline in sediment PCB
 9 concentrations, EPA disagrees with the Reviewer's opinion that Dr. Connolly's
 10 estimate of a half-life of 36 years is probably correct, rather than the simulation
 11 results of 110 years. As stated previously, a statistical analysis of Woods Pond
 12 sediment PCB data (described in FMD Appendix A.1) indicates that there is no
 13 statistically significant change in surficial sediment PCB concentrations with time,
 14 and that the slow simulated rate of sediment PCB concentration decline is well
 15 within the uncertainty envelope of the data.

16 Because the sediment PCB concentrations in the Housatonic River exhibit such
 17 a high degree of spatial variability, the number of data points available to
 18 calculate an annual average is important. The number of data points available to
 19 calculate each annual mean is included on the temporal plots of sediment
 20 concentrations (FMD Figure 3.5-20) to provide the reader with an indication of
 21 the number of samples used to estimate an annual average concentration in a
 22 particular reach of the river. The analysis presented by Dr. Connolly did not
 23 consider confidence bounds (which are a function of the number of samples and
 24 variability of the concentrations) around the annual mean concentrations used to
 25 assess trends over time. When the number of samples and the wide confidence
 26 bounds are considered, it is not surprising that the conclusions from the rigorous
 27 statistical analysis contradict those presented by Dr. Connolly. In fairness to Dr.
 28 Connolly, he characterized his analysis as "dumb and simple."

29 In conclusion, the current characterization of the key temporal aspects of the model is too
 30 uncertain to make reliable long term predictions of the concentrations of PCB in water,
 31 sediments and biota of the Housatonic River. This said, it is clear from the empirical data and the
 32 model calculations that the long term temporal response to changes in PCB loadings is slow.
 33 There appears to be very large standing mass of PCBs in the River sediments and its floodplains
 34 and the sediment removal rate from the PSA is relatively small. Natural recovery therefore can
 35 be expected to take a long time, with a system half-life time in the order of decades. Given this
 36 slow response time, the calculation of a more accurate natural recovery time may in some cases
 37 be inconsequential. Under certain conditions, the model, as it stands, may already be sufficient to
 38 address the long term temporal response of PCB concentrations in the water column and bed
 39 sediments (model objective #1).

40 The reason for the model's ability to convincingly assess the long term temporal response of the
 41 PCB concentrations in water, sediments and biota of the River are twofold. First, no significant
 42 long-term-changes in PCB concentrations over time were observed in water, sediment or biota

1 throughout the PSA during the calibration period. Secondly, the key parameters controlling the
2 temporal response of PCB concentrations are difficult to measure or estimate.

3 **Response 2A-FG-3:**

4 EPA agrees with the Reviewer's characterization that it is clear from the data and
5 the model results that the long-term temporal response to changes in PCB
6 loadings is slow, and that there is a large inventory of PCBs in the sediment and
7 its floodplain, and that the rate of sediment decline in the PSA is relatively small.
8 Statistical analyses and model simulations suggest that the system half-life time
9 is on the order of decades, as characterized by the Reviewer. EPA
10 acknowledges that given the uncertainty in the rate of decline (due to the lack of
11 ability to project this from the data), relative predictions by the model are likely
12 more reliable than absolute predictions. This is reflected in the statement of the
13 goal of the modeling study.

14 Although factors affecting the temporal response of the system are difficult to
15 measure or estimate, considerable effort has gone into parameterization of these
16 factors using site-specific data and information from literature (e.g., benthic biota,
17 coupled with literature values and SPI work for rates and depths of mixing;
18 sedimentation rates for net burial).

19 The modelers should revisit the calibration of the temporal response of the model based on a
20 more in-depth statistical analysis of the available model calibration data. I specifically refer to
21 the sediment concentration data as a function of time. Model calibration schemes should be
22 evaluated in terms of their ability to reproduce statistically validated temporal PCB concentration
23 data.

24 **Response 2A-FG-4:**

25 EPA agrees with the Reviewer's suggestion. The recommended statistical
26 analyses have been conducted (see Appendix A.1 to the FMD), and these
27 analyses indicated that the simulated rate of change in sediment PCB
28 concentrations by the model are consistent with the those observed in the data
29 for both sediment and fish tissue PCB concentrations.

30 The report indicates that the model reasonably accounts for the role of storm events. The model
31 appears to do a good job in describing the short term temporal response of river flow rates in
32 response to storm events. The comparison of simulated and observed river flows is more than
33 adequate. However, the excellent flow predictions do not translate in equally impressive TSS
34 concentrations. Figures 6.2-19 to 6.2-22 show considerable discrepancies between observed and
35 predicted short term TSS concentrations at Holmes Road, Lennox Road and Woods Pond Outlet.
36 On the other hand, Figures 6.2-39 to 6.2-41 show that the short term PCB concentration
37 variations in the water phase (assuming that the concentration data displayed are water column
38 tPCB concentrations) are reasonably well predicted. The reason for the poor predictability of
39 TSS concentrations, but good predictability of the PCB concentrations in the water column is
40 somewhat surprising and unclear. However, the data presented produce confidence in the

1 model's ability to make reasonable predictions of the effects of storm event(s) on the
2 redistribution of PCB-laden sediment in the study area (model objective #4).

3 Recommendation:

4 I recommend that the modelers investigate the source of error in the estimation of the TSS.

5 **Response 2A-FG-5:**

6 EPA agrees with the Reviewer's comment that the model's ability to make
7 reasonable predictions of the effects of storms has been demonstrated. The
8 modeling team has thoroughly investigated the source of the differences between
9 simulated and measured TSS, which are related to two major factors.

10 The first factor is that the model is designed to represent the typical (average)
11 response of the river to changes in flow and loadings. Because it represents the
12 average response, simulated TSS concentrations are less variable than those
13 measured. At low measured TSS concentrations (2 mg/L to 4 mg/L), simulated
14 concentrations are typically higher than those measured, but generally within 2 to
15 4 mg/L of the data. Closer agreement between simulation and measured
16 concentrations is generally achieved for higher TSS concentrations, which
17 typically occur at high flows. These periods are important for both solids and
18 PCB transport because these conditions result in the largest loadings.
19 Overprediction of low TSS concentrations that occur at low flow are less
20 important because loads for these conditions are far smaller (although on the
21 logarithmic scale, may appear large). Further, even though TSS concentrations
22 at low flow could also impact PCB concentrations at low flow, exposure
23 concentrations estimated by EFDC are not strongly influenced by differences
24 between simulated and measured TSS concentrations at low flow. As part of the
25 evaluation of the significance of the differences between simulated and
26 measured concentrations at the low range of measured concentrations, a
27 bounding analysis was performed using FCM, as discussed in further detail in
28 Section 4.3 of the FMD. The conclusions from the bounding analysis are that the
29 overpredictions of the low TSS and PCB concentrations have small effects on
30 solids mass transport, exposure concentrations, and resulting fish tissue PCB
31 concentrations.

32 The second factor that contributes to differences between simulated and
33 measured TSS concentrations is the effect of concentrations assigned to
34 upstream boundary conditions on the model simulations when data are not
35 available. This factor is most significant for Holmes Road, which is close to the
36 model upstream boundary. Agreement between simulated and measured TSS is
37 considerably better at New Lenox Road than at Holmes Road, especially in the
38 Phase 2 calibration period when data for New Lenox Road cover a wider range
39 of flow conditions and boundary condition estimation effects are less important.
40 The modeling team devoted considerable effort to developing methods to
41 estimate upstream boundary conditions for times when data were not available (a

1 full discussion of these efforts is provided in Appendix B.2 of the FMD). Large
2 variability in measured boundary condition concentrations at low flows resulted in
3 both positive and negative differences between measured and estimated
4 boundary concentrations, because the estimates from the regression equations
5 reproduce the central tendency of the data.

6 Based on the results of the bounding calculations, the differences between
7 simulated and measured TSS concentrations were judged to be acceptable
8 because of the small effect on TSS and PCB mass fluxes.

9 Thirdly, the analysis presented by Dr. Connolly during the June 28 Public Meeting indicates that
10 there may be a bias in the temporal response of the model, i.e. it appears that the rate of temporal
11 response of PCB concentrations in the River is underestimated by the model. However, there is
12 considerable uncertainty in the data on which the calculations are based and it is unclear whether
13 the uncertainty in the data is sufficiently small to distinguish between the temporal response rates
14 calculated by the model and Dr. Connolly's analysis. A bias in the temporal response of the
15 model could have large implications for model projections of remedial actions. More detailed
16 evaluations of the bias in temporal response need to be conducted. This should involve the
17 calculation of PCB concentration response times from observed data and the comparison of the
18 measured response times to the calculated response times to determine whether a bias exists.
19 Alternative model parameterization schemes may need to be explored to investigate whether the
20 model bias (if it exists) can be reduced.

21 **Response 2A-FG-6:**

22 EPA disagrees that there is a bias in the temporal response of the model for the
23 reasons stated in the responses above. The Reviewer is correct in recognizing
24 the effect of uncertainty in the data on estimation of temporal response. The
25 statistical analysis recommended by the Reviewer had been conducted, and
26 confirms that there is no temporal bias in model simulations.

27 The possible bias in the model's temporal response of the PCB concentrations in the River needs
28 to be investigated by comparing observed and predicted PCB concentration decline rates over
29 time. In case, significant bias exists, alternative model parameterization schemes need to be
30 explored to improve the long term temporal response of the model.

31 **Response 2A-FG-7:**

32 The results of the statistical analysis of surface sediment PCB data supports the
33 temporal response simulated by the model and indicates no temporal bias.

34 With regard to the temporal scale, the comparisons of model predictions with data are not
35 sufficient to evaluate the capability of the model to make accurate estimates of the temporal
36 response of PCB concentrations in the River. As discussed under charge question #1, this is
37 largely due to the considerable variability in observed PCB concentrations and the lack of a
38 significant decline in PCB concentrations over the calibration period. Hence, a temporal trend is
39 difficult to discern from the data and the lack of temporal trends makes it very difficult to
40 evaluate the temporal characteristics of the model.

1 **Response 2A-FG-8:**

2 The Reviewer is correct in commenting that the variability in observed PCB
3 concentrations and lack of a significant decline in concentrations make
4 evaluation of the temporal characteristics difficult. It is noted, however, that the
5 model results are consistent with both the slow change in sediment
6 concentrations (confirmed by statistical analysis – FMD Appendix A.1) and the
7 sedimentation rates derived from an analysis of cesium-137 data.

8 With regards to the spatial scale of the model, a similar conclusion can be reached at. The small-
9 scale spatial variability in the PCB concentration in the sediments is so great that spatial
10 differences in PCB concentrations among River sections are difficult to discern. The comparison
11 between observed and predicted concentrations therefore provides little information with regards
12 to the capability of the model to make accurate predictions of PCB concentrations as a function
13 of time or space.

14 Recommendations:

15 Dr. Connolly’s analysis suggests that with the application of suitable statistics it may be possible
16 to use the current data sets to better characterize temporal and spatial PCB concentration trends.
17 Spatial statistics and the application of geographical averaging methods may help to better
18 characterize spatial trends in the data that can be used to evaluate the applicability of the model.
19 Temporal trend analysis can be used to discern temporal trends. I recommend that this is done as
20 it may provide better data for a comparison of observed and predicted concentrations.

21 **Response 2A-FG-9:**

22 The statistical analyses recommended by the Reviewer have been conducted
23 (see FMD Appendix A.1) and support the simulated rate of change in surface
24 sediment PCB concentrations.

25 The model is the only available tool to simulate the future response of PCB concentrations in
26 response to remediation efforts. The model framework represents a suitable approach to
27 estimating the future time response of PCB concentrations in the River and the calibration and
28 validation of the model have involved significant efforts.

29 **Response 2A-FG-10:**

30 EPA agrees with the Reviewer’s comment.

31 The most valuable information for the calibration and validation of the model is a change in PCB
32 concentrations in the River in response to a known reduction in PCB loading. This kind of
33 information was not obtained in the current study as concentrations of PCBs in the River showed
34 little or no significant variation with time. The current model therefore has to rely on the
35 characterization of a number of key state variables for the estimation of the long term temporal
36 response of PCB concentrations to remedial scenarios. The key parameters include the amount of
37 “available” River and floodplains sediments and rates of resuspension, diffusion, bioturbation
38 and subduction. All of these model state variables are either currently unmeasurable or very

1 difficult to measure or estimate. As a result the model's outcome with regards to the long term
2 time response of PCB concentrations in the River is uncertain. The model uncertainty translates
3 in considerable uncertainty about future PCB concentrations in the River resulting from
4 remediation efforts or the absence of remediation.

5 **Response 2A-FG-11:**

6 EPA acknowledges that there will be uncertainty associated with future model
7 predictions. In any model framework, uncertainty arises from (1) the data and (2)
8 the degree of process aggregation (model formulations). Regardless of the
9 degree of process aggregation, no model can have less uncertainty with its
10 predictions than the uncertainty of the data.

11 However, it should be recognized that the response of the model to changes in
12 PCB loadings is quantified. As was shown in the RFI, other documents, and is
13 more fully explored in Appendix A.1 to the FMD, the rate of change in surface
14 sediment PCB concentrations in Reaches 5 and 6 (Woods Pond) is not
15 statistically different from zero (i.e., slow to no change over time). The example
16 and tracer simulations were performed explicitly to demonstrate the model
17 response.

18 **Wilbert Lick**

19 A good comparison of the model predictions with data is necessary, but not sufficient, to
20 evaluate the capability of the model. The low surficial PCB concentrations in Woods Pond and
21 the large variability in PCB concentrations throughout the river are unexplained by the present
22 model. See discussion in the complete response.

23 **Response 2A-WL-1:**

24 It is assumed that the Reviewer's statement that "low surficial PCB
25 Concentrations in Woods Pond ... are unexplained by the present model" refers
26 to the temporal comparison of simulated and measured concentrations. As
27 stated in responses above, the statistical analysis of Woods Pond surface
28 sediment PCB concentrations, described in Appendix A.1 of the FMD, indicates
29 that there is no statistically significant change in sediment concentrations with
30 time and that the rate of PCB concentration decline simulated by the model is
31 slow and is well within the uncertainty envelope of the data.

32 With respect to the Reviewer's comment regarding unexplained large variability
33 in PCB concentrations throughout the river, it is noted that this variability was
34 observed on a spatial scale of 1 m². Because of this variability, a decision was
35 made to develop average initial condition for spatial bins of approximately 400
36 meters in length (0.25 miles). Average concentrations were calculated for each
37 spatial bin and assigned to those grid cells (approximately 20 meters in length)
38 within the bin. Assigning a single average concentration to all grid cells in a
39 spatial bin, by definition, reduces the variance of the PCB concentrations

1 represented in the initial conditions. Although cell-to-cell variations in PCB
2 concentrations developed in the model over time due to cell-to-cell variations in
3 erosion and deposition (MVR Figure 4.2-79), it is completely expected that the
4 simulated concentrations have less variability than the original data used to
5 calculate the average initial conditions. This approach was adopted because the
6 goal of the modeling study is addressed at spatial scales greater than 1 m², or
7 20-meter grid cells.

8 During previous peer review meetings, John List as well as others including myself (but John
9 was most vocal) have emphasized (a) the large unexplained variance in the PCB concentrations
10 in the surficial (six inch) layer of the sediments and (b) the unexplained high concentrations of
11 PCBs in the surficial layers of the sediments in Woods Pond.

12 EPA had no explanations for these latter two problems, but also stated that an understanding of
13 these problems was not necessary. An understanding of these problems may not be necessary,
14 depending on your point of view, but the problems themselves are quite interesting, deserve
15 some discussion, and are related to the inaccurate modeling of the basic sediment and
16 contaminant flux processes mentioned above. Some discussion of these problems is given here.

17 **Response 2A-WL-2:**

18 EPA agrees that the issue of the variability in sediment PCB concentrations is
19 interesting and it has been discussed in each of the reports developed during the
20 modeling study (MFD, MCR, MVR) and each of the modeling Peer Reviews. The
21 EPA modeling team disagrees with the Reviewer's comment that the
22 unexplained variance in surface sediment PCB concentrations is related to
23 inaccurate modeling because the same variability is noted on a very small-scale
24 in the benthic sampling data set, in which variability of two orders of magnitude or
25 more was observed at each of 9 sampling locations where 12 samples were
26 collected within an area of 1 m². Attempting to model this system with a grid
27 resolution on the order of 0.1 m² (1 m²/9 samples) clearly is not feasible or
28 necessary to achieve the goal of the modeling study.

29 The higher than predicted PCB concentrations in Woods Pond as well as much of the variability
30 seen in the sediment PCB concentrations can be explained by finite PCB sorption rates as well as
31 by the variability in the PCB sources and the hydrodynamics. The improved model should be
32 able to predict some of this and at least suggest the reasons for the remaining variability if finite
33 sorption rates are assumed and a finer grid is adopted.

34 **Response 2A-WL-3:**

35 EPA disagrees with the Reviewer's comment. First, as discussed in previous
36 responses, the PCB concentrations simulated are not higher than those
37 "predicted" by the data. Second, finite PCB desorption rates would result in
38 minimal (<10%) change in concentrations of PCBs on deposited solids.

1 **E. John List**

2 A similar point arises in connection with the Validation Report, on Page 4-12 from line 23 et seq.
3 through page 4-13. The high concentrations of PCB in the surface layers of the sediment in
4 Woods Pond (apparent also in Figure 4.2-79) and the lack of an explanation thereof are
5 troubling. Again EPA has thrown up its hands and states that no explanation has been found (see
6 p. 4-13 of the Validation Report).

7 **Response 2A-JL-1:**

8 EPA disagrees with the characterization that “EPA has thrown up its hands” with
9 respect to evaluating the small-scale variability. Rather, EPA has determined
10 that explaining the source of the small-scale variability is not necessary for
11 achieving the goal of the modeling study, and is not worthy of a research effort
12 beyond the scope of the modeling study.

13 I recognize the fact that these a very difficult problems to address, but if the modeling is to
14 provide believable predictions of the future fate of the PCB in the sediments it seems to me that
15 the processes that have resulted in the existing PCB concentration distributions have to be
16 understood first.

17 **Response 2A-JL-2:**

18 See Response 2A-JL-1 above.

19 With respect to the PCB modeling the results are so tenuous (see Figure 6.2-49) that it is not
20 possible to draw any really solid conclusion with respect to bias. However, an important point is
21 demonstrated by Figure 6.2-50. This figure indicates that the sediment concentrations of PCB in
22 the lower reaches of the project study area have declined somewhat since 1990 (i.e., since
23 remediation activity started). Furthermore, there appears to be a similar decline in the water
24 column concentrations of PCB, as is somewhat evident in the lower panel of Figures 6.2-44. (It
25 is noted that there is no statistical measure of the significance of the decline in either the
26 sediment or the water column, but the data are very suggestive). However, the modeling does
27 not give any indication that any similar rate of decline has occurred (see Figure 6.2-50). In fact
28 the comparison between the data and the model in this figure is strongly suggestive that the
29 model does have a bias.

30 **Response 2A-JL-3:**

31 The Reviewer states that the data shown on Figures 6.2-49 and 6.2-50 are
32 suggestive of statistically significant declines in sediment PCB concentrations.
33 The data are presented as the mean \pm 2 standard errors, which approximates the
34 95% confidence interval of the mean. At that time, the wide range in the
35 confidence interval of the mean and the small number of samples in earlier years
36 were identified by the modeling team as factors that complicated characterization
37 of trends in the data and comparisons with trends computed by the model.

1 In response to the misconception of the Reviewers regarding the existence of a
2 trend in PCB concentrations in sediment, a more rigorous statistical analysis was
3 performed (see Appendix A.1 of the FMD). This analysis confirms previous
4 conclusions that there is no statistically significant decline in sediment PCB
5 concentrations. The results from this (and prior) analyses contradicts the basis
6 for the Reviewer's conclusion that these model-data comparisons indicate a bias
7 in the model.

8 In addition, it should be noted that the Reviewer is incorrect in his observation
9 that remediation began in 1990; no remediation was conducted in the river until
10 1997 (the Building 68 Removal Action), and significant continuous remediation
11 did not begin until October 1999.

12 The bias of the model is further reinforced by the results of the hypothetical remedial scenarios
13 plotted in the un-numbered figure on page 56 of the EPA Response to Questions from Model
14 Validation (Document DCN: GE-061406-ADFI), where, despite a reduction in the flux of PCB
15 from the sediments in the upper river reaches, there is no significant change in projected
16 sediment concentration of PCBs in the lower reaches. Thus the model does not match the
17 reduction in sediment concentration that has occurred subsequent to actual post-upstream
18 remediation, and projects no reduction as a result of an hypothetical reduction in the upstream
19 PCB flux, as in the hypothetical examples. This problem needs to be understood and/or fixed
20 before the model is used in real applications.

21 **Response 2A-JL-4:**

22 The results from the simulations of the example scenarios show a gradual
23 decline in PCB concentrations in sediment in downstream reaches for the base
24 case and Examples 1 and 2 (which include elimination of upstream sources).
25 The differences among the rates of decline in sediment PCB concentrations in
26 the base case and example simulations are small, which is consistent with the
27 statistical analysis that concludes that conditions in the river are changing slowly.

28 It must be noted that the Reviewer's statement that impacts of remediation
29 should have an appreciable influence on the model results is incorrect. With the
30 exception of limited activity associated with Building 68, the remediation in the ½-
31 Mile Reach began in October 1999, and remediation in the 1½-Mile Reach began
32 in 2002. While the model simulation used the 26-year validation hydrograph, the
33 initial conditions were derived using data that pre-dated remediation. The
34 Reviewer's evaluation of example scenario simulations is based on the incorrect
35 assumption that the data reflect 9 years of remediation activities.

36

1 **2.2 GENERAL TOPIC 2B: SMALL-SCALE SPATIAL VARIABILITY**

2 **2.2.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 5, lines 14 to 37
Endicott	Page 4, lines 11 to 20
	Page 8, lines 13 to 21
Garcia	Page 3, lines 8 to 13
Gobas	Page 4, lines 10 to 15
	Page 4, lines 35 to 36
	Page 10, lines 27 to 32
Lick	Page 1, lines 30 to 33
	Page 10, line 38 to page 11, line 3
List	Page 3, lines 10 to 21
	Page 3, line 22 to page 4, line 3
	Page 4, lines 18 to 21

3 **2.2.2 General Topic Summary**

4 A high degree of small-scale spatial variability in PCB concentrations in surface sediment was
 5 observed in data collected in the benthic sampling program, in which variability in
 6 concentrations of two orders of magnitude or more was observed at each of 9 sampling locations,
 7 where 12 samples were collected within an area of 1 m². Similar variability is observed in the
 8 remainder of the surface sediment data set, and is discussed in Appendix A.1 to the FMD and in
 9 previous model documents including the MFD, MCR, and MVR.

10 Six of the seven Reviewers commented on the variability in PCB concentrations over small
 11 spatial scales, particularly in regard to sediment PCB concentrations. In some cases, as noted in
 12 the summary of General Topic 2A, these comments were made in the context of the difficulty of
 13 understanding spatial patterns and temporal trends in the presence of such underlying variability.

14 Reviewers were divided on the implications of the acknowledged inability of the model to
 15 reproduce the observed small-scale variability in sediment PCB concentrations on achieving the
 16 goal of the modeling study. One Reviewer did not feel that the lack of such variability in model

1 predictions was an issue as long as it was acknowledged. Two Reviewers indicated that the issue
2 was of major importance and an indication that the model does not adequately reproduce the
3 underlying processes. The remaining Reviewers indicated the lack of small-scale variability in
4 model output to be problematical, but not sufficient to indicate major flaws in the underlying
5 structure or use of the model.

6 **2.2.3 General Topic Response**

7 EPA has spent considerable effort attempting to understand processes
8 responsible for the small-scale variability. Even though no mechanistic
9 explanation has been developed, EPA does not agree with the Reviewer's
10 comment that the lack of such an explanation compromises the ability of the
11 model to achieve the goal of the modeling study. In addition, EPA does not
12 agree that there is any inconsistency between the presence of pronounced small-
13 scale variability and the inability to resolve temporal variability in the data. In
14 addition, the sampling programs were not designed to assess short-term
15 temporal variability and any such short-term temporal variability that does exist
16 would be masked by the spatial variability.

17 EPA believes that it is not necessary to understand the processes that underlie
18 the small-scale variability or to include such processes or the resultant variability
19 in the framework to achieve the goal of the modeling study. As described in
20 previous documents and in the FMD, the spatial scale of interest is larger than a
21 grid cell and smaller than a reach. The variability occurs on a spatial scale that is
22 far smaller than the cells of the modeling grid; therefore, the model grid is unable
23 to resolve these differences or to make use of any process-oriented explanation
24 that might be developed, and it is not necessary to do so. Transport processes
25 are simulated on a scale that affects the bed sediment in each model cell equally,
26 so again it is not necessary to explicitly account for the small-scale variability.

27 The small-scale variability noted by Reviewers was identified as part of the
28 benthic community investigations, which involved collection of 12 replicate grab
29 samples of sediment from a small area, in some cases less than 1 m². Results of
30 PCB analyses of these samples indicated variability in some locations of over
31 two orders of magnitude in PCB concentrations, with no such differences
32 apparent in other factors known to be correlated with contaminant concentration
33 (e.g., sediment grain size, total organic carbon [TOC]). Although this high degree
34 of variability was observed in eight of the nine benthic community sampling
35 locations in the PSA, it is assumed to occur throughout the PSA because other
36 efforts were made to resample specific locations with the result being highly
37 variable PCB concentrations over small time scales as well.

38 In addition to the small-scale spatial variability in PCB concentrations, EPA also
39 noted that a subset of the samples in Reach 5A did not follow traditional

1 equilibrium partitioning (EqP) behavior. In these samples, PCB concentrations
2 were elevated well above concentrations that would be predicted based on
3 organic carbon content and, consequently, these samples appeared as outliers
4 when the data were carbon-normalized. As part of the investigation of this latter
5 phenomenon, microscopic examination of samples of Reach 5A sediment
6 indicated the presence of a film or coating on individual quartz grains. Samples
7 were sent to Sandia National Laboratories (SNL) and examined by scanning
8 electron microscopy (SEM), X-ray diffraction (XRD), and energy-dispersive
9 system (EDS) via microprobe. These studies indicated the presence of carbon
10 and chlorine in the coating, which was identified by the SNL scientists as
11 representing PCBs present in the film. This resulted in EPA's working hypothesis
12 that PCBs in these samples are present as a recalcitrant coating on individual
13 quartz particles, with a consequent reduction in bioavailability. This was
14 addressed in FCM for Reach 5A. This was analyzed and discussed at length in
15 the Model Calibration Report (Section C.3.1.2) and a procedure was developed
16 to arrive at adequate calibration.

17 **2.2.4 Responses to Specific Comments on General Topic 2B**

18 **Eric Adams**

19 Much has been said about the tremendous spatial variability in sediment PCB concentrations
20 over space scales of order one meter and the fact that the model can not reproduce this
21 variability. Whether or not this is a model failure, *per se*, or simply unresolved variability in
22 model input and output (sediment bed concentrations), depends on what has caused the
23 variability. I believe the variability was caused mainly by the stochastic method in which the
24 PCBs were introduced in the first place. In such case, we cannot expect the model to predict this
25 variability and the fact that the model averages concentration over relatively large grid cells is
26 not a problem (with the mean) unless sediment-water exchange of PCBs varies non-linearly with
27 concentration (and some non-linearity is inevitable, given the averaging associated with the
28 coarse grid).

29 **Response 2B-EA-1:**

30 EPA agrees with the Reviewer's comment that the model cannot be expected to
31 predict the variability observed in the data. In addition, the use of mean
32 concentrations does not pose a problem because sediment-water exchange of
33 PCBs is represented in the model by dissolved and particulate exchange that
34 varies linearly with concentration.

35 Of course, we can not expect the model to tell us anything about the future variance of sediment
36 bed concentrations and to the extent this is important, we should rely on the observed variability.
37 The PCBs have been in the sediments for several decades, and to a first approximation the
38 variability expected in the next decade or two (presumably our focus) will not be very much
39 different from the variability observed historically (at least for natural attenuation).

1 Response 2B-EA-2:

2 EPA agrees that the variability in the existing data could provide an estimation of
3 the variability in future concentrations (with some important caveats and the
4 recognition of significant uncertainty). It should be noted that the timeframe of
5 interest will likely be longer than that presumed by the Reviewer.

6 On the other hand, if the variability is due to active sediment transport processes that are sorting
7 the sediments and their contaminants, then the failure to pick this up could be a significant model
8 deficiency. For example, natural attenuation could conceivably increase local PCB
9 concentrations. The available time series data of PCB concentrations within surficial sediments
10 suggest a decrease in concentration (indeed more so than is being modeled), so I don't believe
11 this is a significant process.

12 Response 2B-EA-3:

13 EPA agrees with the Reviewer that analysis of the data shows no statistically
14 significant trend and that the model simulates a very slow decline; therefore, it is
15 not a significant process.

16 Douglas Endicott

17 EFDC uses the same equilibrium partitioning (EP) model as every other fate and transport model
18 in use today. EP generally works quite well, and simplifies the model computation by requiring
19 only a single state variable for each chemical. It has been suggested that desorption kinetics
20 should be incorporated into the Housatonic River model, because PCBs desorbing from
21 resuspended sediment might not reach equilibrium within the timeframe they remain in
22 suspension. This disequilibrium may help explain the pattern of PCBs moving in "ribbons" of
23 sediment downstream, and the high surficial PCB concentrations in Woods Pond sediment. I
24 think this is mostly speculation and, although I am curious to see if it is true, it is well and
25 beyond the objectives and goals of this modeling study.

26 Response 2B-DE-1:

27 EPA agrees with the Reviewer that non-equilibrium partitioning is beyond the
28 objectives and goals of the modeling study, and has presented calculations in
29 FMD Appendix B.9 to support the appropriateness of the use of equilibrium
30 partitioning. It is noted that there is no evidence of a pattern of PCBs moving in
31 "ribbons," but rather the data suggest that concentration patterns are random.

32 Figures 4.2-79 and 6.2-51 are intriguing plots of the change in spatial profiles of the grid cell
33 PCB sediment concentrations over the duration of the calibration and validation, respectively,
34 superimposed with the "shotgun pattern" of data for individual sediment PCB samples. Although
35 no interpretation of the model-to-data comparison is offered, it does suggest that the greater than
36 90% change in sediment PCB concentrations within many sediment grid cell is both plausible
37 and may help explain the spatial variability observed in sediment PCB data throughout the river
38 sediments. In other words, the model simulation suggests that sediment PCB variability arises

1 from contaminated sediments remaining in locations where erosion is not significant, and
2 (relatively) uncontaminated sediments replacing older contaminated sediments in locations
3 where erosion is significant.

4 **Response 2B-DE-2:**

5 The Reviewer correctly notes that spatial variability in simulated PCB
6 concentrations increases through the course of the simulation in response to
7 variability in erosion and deposition that is caused by local bathymetric features.
8 It is noted, however, that there is almost as much variability in the samples
9 collected within 1 m² where no variation in erosion and/or deposition patterns are
10 expected, as shown in MVR Figures 4.2-79 and 6.2-51. Therefore, EPA does
11 not believe that erosion and deposition patterns alone explain the small-scale
12 variability in PCB concentrations.

13 **Marcelo H. Garcia**

14 While the model capabilities have been improved since its calibration, my professional opinion is
15 that the validation of the model is not complete at this stage. In particular the model does not
16 capture the variability and spectrum of PCBs concentrations observed in river. There are several
17 aspects of the model that need to be improved as stated above before validation of the model can
18 be accomplished.

19 **Response 2B-MG-1:**

20 EPA recognizes that the output of the Housatonic River model does not
21 reproduce the range of variability in the data used to develop the model input.
22 Rather than a fault of the modeling framework or the models themselves, such a
23 result is an inevitable and expected consequence of any modeling activity.
24 Models are only representations of reality, and are not intended to include all of
25 the components of the system being modeled, or of all the relationships between
26 them. Indeed, if the model and the system being modeled are identical in all of
27 their characteristics, the concept of modeling loses its usefulness (Gold, 1977).
28 Therefore, it follows that models must be a simplification of the system being
29 modeled, and simplification necessarily results in the inability of any model to
30 completely simulate either the inputs to, or the outputs from, that system.

31 **Frank Gobas**

32 The model report reveals insufficient information to determine whether the capability of the
33 model to make accurate predictions of spatial differences in PCB concentrations is adequate. The
34 reason is that the calibration of the spatial characteristics of the model revealed that differences
35 in PCB concentrations (e.g. see Fig 6-2-45 and 6-2-46 Model Validation Report) among River
36 sections are small while variability in the PCB concentrations in the sediments at individual river
37 locations is high.

1 Response 2B-FG-1:

2 The Reviewer is correct in noting that the variability in the data complicates
3 evaluation of spatial and temporal trends. The figures identified by the Reviewer
4 in his comments regarding spatial patterns present model-data comparisons for
5 low-flow conditions (flows at Coltsville between 16 and 25 cfs) and conditions
6 slightly above average flow conditions (flows at Coltsville between 109 and 275
7 cfs). These figures highlight the effect of the spatial transient in PCB
8 concentrations due to PCB mass transfer from the sediment under low- to
9 moderate-flow conditions. An additional and perhaps more important
10 demonstration of model performance is the ability of the model to reproduce the
11 roughly one order of magnitude decline in water-column PCB concentrations and
12 also the decline in TSS concentrations between New Lenox Road and Woods
13 Pond Outlet under high-flow conditions (Figures 3.5-6 and 3.5-15 in the FMD,
14 previously presented as Figures 4.2-75 and 4.2-76 in the MVR).

15 Better spatial statistical methods should be used to explore the current spatial PCB concentration
16 data for spatial trends in the available PCB concentration data.

17 Response 2B-FG-2:

18 This analysis has been performed and is presented in Appendix A.1 of the FMD.

19 I agree with the EPA that it is not necessary to understand the processes causing small scale
20 variability in concentrations (1.3-4, p.15 Model Validation Report). This is normal in any
21 scientific observation. However, when interpreting the observation or the model calculation (in
22 this case), it is then important to recognize the uncertainty that is associated with the lack of
23 understanding, so that it can be taken into account in the decision analysis.

24 Response 2B-FG-3:

25 EPA agrees with the Reviewer's comment and the uncertainties associated with
26 the small-scale variability and the effect on the model simulations are recognized.
27 See FMD Sections 3 and 4, and Appendix A.1.

28 Wilbert Lick

29 A good comparison of the model predictions with data is necessary, **but not sufficient**, to
30 evaluate the capability of the model. The low surficial PCB concentrations in Woods Pond and
31 the large variability in PCB concentrations throughout the river are unexplained by the present
32 model. See discussion in the complete response.

1 **Response 2B-WL-1:**

2 As indicated in the General Response, EPA believes that it is not necessary to
 3 explain the large variability in PCB concentrations to achieve the goal of the
 4 modeling study.

5 During previous peer review meetings, John List as well as others including myself (but John
 6 was most vocal) have emphasized (a) the large unexplained variance in the PCB concentrations
 7 in the surficial (six inch) layer of the sediments and (b) the unexplained high concentrations of
 8 PCBs in the surficial layers of the sediments in Woods Pond.

9 EPA had no explanations for these latter two problems, but also stated that an understanding of
 10 these problems was not necessary. An understanding of these problems may not be necessary,
 11 depending on your point of view, but the problems themselves are quite interesting, deserve
 12 some discussion, and are related to the inaccurate modeling of the basic sediment and
 13 contaminant flux processes mentioned above. Some discussion of these problems is given here.

14 **Response 2B-WL-2:**

15 EPA agrees that the issue of the variability in sediment PCB concentrations is
 16 interesting, and it has been discussed in each of the reports developed during
 17 the modeling study (MFD, MCR, MVR) and each of the modeling Peer Reviews.
 18 The modeling team disagrees with the Reviewer’s comment that the unexplained
 19 variance in surface sediment PCB concentrations is related to inaccurate
 20 modeling because the same variability is noted on a very small scale in the
 21 benthic sampling data set, in which variability of two orders of magnitude or more
 22 was observed at each of 9 sampling locations, where 12 samples were collected
 23 within an area of 1 m². Attempting to model this system with a grid resolution on
 24 the order of 0.1 m² (1m²/9 samples) clearly is not feasible or necessary to
 25 achieve the goal of the modeling study.

26 **E. John List**

27 It is my professional opinion that the model does not “reasonably account for the relevant
 28 processes”, nor, *in its present state*, can it reliably “quantify future spatial and temporal
 29 distributions of PCBs”.

30 **Response 2B-JL-1:**

31 Many of the Reviewer’s comments focus on the need to explain the small-scale
 32 variability of sediment PCB concentrations and an erroneous interpretation that
 33 the sediment data describe a statistically significant decline in sediment
 34 concentrations. EPA has repeatedly stated that explaining the cause of the
 35 small-scale variability is not necessary to achieve the goal of the modeling study.
 36 In addition, EPA has also noted that there is no statistically significant trend in the
 37 surface sediment data in the MFD, MCR, and MVR, and this was discussed in
 38 the RFI. EPA has also conducted further rigorous statistical analysis that

1 definitely shows no statistically significant change in PCB concentrations in
2 surface sediment.

3 One of the reasons for this opinion is encompassed in Figure 4.2-79 of the validation report.
4 This figure indicates, from measured data, that 0-6 inch sediment PCB concentrations within the
5 river and flood plain are spread over three orders of magnitude (0.2-200 mg/kg) at locations that
6 are very close together along the river. Furthermore, for almost 12 miles along the river the
7 variance in the distribution of concentrations appears to be fairly uniform. From the fact that the
8 PCB concentrations appear this way after 30-40 years of river action involving sediment erosion
9 and deposition it is reasonable to conclude that the sediment transport processes are not
10 smoothing the sediment PCB concentration distributions.

11 **Response 2B-JL-2:**

12 EPA agrees that the sediment transport processes are not smoothing the
13 sediment PCB concentration distributions. In fact, Figure 4.2-79 of MVR
14 demonstrates that through the course of the model simulations, variability in
15 sediment concentrations increase relative to the initial conditions, which were
16 established as averages within spatial bins. The increase in spatial variability is
17 due to variability in erosion and deposition caused by spatial variations in
18 bathymetry.

19 A second reason for this opinion is that recent river bottom survey profiles indicate quite clearly
20 that sediment erosion and deposition is very definitely non-uniform across the river cross-
21 section. By contrast, and as discussed above, the modeling uses a single computational cell to
22 define the entire width of the normal river channel and the local erosion is defined by the fluid
23 shear stress that is averaged across the river cross-section. Because of the non-uniform nature of
24 the actual erosion, and the fact that the model uses an average shear stress to define the erosion,
25 it is highly probable that river bed erosion occurs long before the model predicts its occurrence.
26 Furthermore, the PCB concentration of the sediment that is eroded in the model is the average of
27 the local concentration over that cell. Thus the modeling uses cell averages that reduce the very
28 broad PCB concentration distributions to a local average, and then redeposits that PCB-laden
29 sediment at this average concentration. The net effect of the modeling therefore must be to
30 smooth out the distribution of PCBs, but in reality this has not occurred in the significant length
31 of time in which, according to the model, it should have occurred.

32 **Response 2B-JL-3:**

33 EPA disagrees with the Reviewer's assertion that cross-channel patterns in
34 erosion and deposition in the Housatonic River are always nonuniform. Although
35 there are exceptions, cross-channel differences in erosion and deposition are
36 frequently minimal (21 of 53 profiles examined), as described in Appendix B.6 of
37 the FMD. The Reviewer's conclusion that the net effect of modeling smoothes
38 out the distribution of PCBs is incorrect. In fact, through the course of the model
39 simulations, sediment PCB concentrations change relative to the initial
40 concentrations. These differences over time are caused by differences in the
41 spatial patterns of erosion and deposition and are themselves caused by spatial
42 variations in bathymetry and temporal variations in river flow.

1 Thus, given the fact that the very broad spectrum of PCB sediment concentrations has been
2 present in the river for more than 30-40 years despite continuous sediment erosion and
3 deposition over these years, it is clear that river erosion and deposition processes actually at work
4 do not smooth the PCB distributions. Absent any explanation of how these PCB concentration
5 distributions are developed and maintained over such a long period of time it seems very
6 unlikely that the modeling will provide any believable answers to remediation strategies. This
7 point has been made by me and others previously. Nevertheless, EPA and its contractors still say
8 they do not know what processes are involved with the PCB fate and transport that would give
9 rise to the very wide concentration spectrums observed. However, it is conceivable that the non-
10 uniform erosion and sediment sorting processes not included in the model are indeed responsible
11 for the non-uniform PCB distributions.

12 **Response 2B-JL-4:**

13 EPA would like to clarify the different spatial scales referenced by the Reviewer.
14 Variations in PCB concentrations of two orders of magnitude were observed
15 within areas of 1 m², with no variation in factors that influence erosion or
16 deposition (e.g., depth, velocity, bed composition). Despite significant efforts,
17 EPA was not able to identify the cause of this small-scale variability. EPA also
18 recognized that it was not necessary to identify the mechanistic explanation for
19 this small-scale variability to achieve the goal of the modeling study, where the
20 scale of interest is larger than a grid cell and smaller than a reach. The decision
21 was made to develop initial conditions taking this small-scale variability in the
22 data into account. Spatial bins of approximately 400 meters in length (0.25 mile)
23 were specified according to the procedures described in Appendix B.3 to the
24 FMD. Assigning a single average concentration to all grid cells in a spatial bin,
25 by definition, reduces the variability of the PCB concentrations represented in the
26 initial conditions. Although cell-to-cell variations in PCB concentrations
27 developed in the model over time due to cell-to-cell variations in erosion and
28 deposition (MVR Figure 4.2-79), it is completely expected that the simulated
29 concentrations have less variability than the original data used to calculate the
30 average initial conditions.

31 This approach is consistent with the Reviewer's comments from the MFD Peer
32 Review (April 24, 2001):

33 *The model that is proposed will attempt to describe the rates of erosion and*
34 *deposition on a 20-meter grid plan. As the field and laboratory data collected by*
35 *the Corps of Engineers would strongly suggest, predicting the rates of erosion on*
36 *a grid this small cannot avoid the substantial error that is associated with the*
37 *heterogeneity of the sediments. It is implausible to think that the riverbed*
38 *sediments can be characterized on a grid scale this small, so that attempting to*
39 *model the fate of the sediment on such a scale appears quite inappropriate. ...*

40 *For example, the description of resuspension and erosion of particles can be*
41 *described quite adequately by using the empirical data developed by the*
42 *SEDFLUME apparatus. The issue becomes how to use these data in the*

1 *modeling when it is known from the sediment sampling in the river channel and*
 2 *flood plains that the sediments are extremely variable with respect to the rate of*
 3 *erosion. It is not possible to describe completely the surface and depth*
 4 *distribution of the sediment properties that control erosion at the fine scale*
 5 *necessary to apply a two-dimensional model with a 20-meter (or less) grid scale.*
 6 *However, from the sediment flux data that have been developed in the field it*
 7 *should be possible to give average sediment properties that can be used to*
 8 *describe in a general way the resuspension of river bed sediments and flood*
 9 *plain sediments. This is not unusual in fluid mechanics; sometimes less is*
 10 *more...*

11 Although the specific details of PCB release are not well-characterized (in terms
 12 of the timing, sizes, and mechanisms of release), the fundamental processes
 13 impacting sediment transport processes (erosion and deposition) are well
 14 understood. This understanding was central to model development efforts and
 15 permits successful simulation of how PCB exposure concentrations respond to
 16 changes in inputs over time. See FMD Sections 3 and 4.

17 I recognize the fact that these a very difficult problems to address, but if the modeling is to
 18 provide believable predictions of the future fate of the PCB in the sediments it seems to me that
 19 the processes that have resulted in the existing PCB concentration distributions have to be
 20 understood first.

21 **Response 2B-JL-5:**

22 As discussed previously, the processes that produce two orders of magnitude
 23 variations in PCB concentrations on a spatial scale of 1 m² are not resolved by
 24 the model, but because this spatial scale is far smaller than the scale of interest
 25 for the CMS, that level of spatial resolution is not needed to meet the goal of the
 26 modeling study.

1 **2.3 GENERAL TOPIC 2C: SEDIMENTATION RATES**

2 **2.3.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Endicott	Page 6, line 17 to page 7, line 7
	Page 8, line 22 to page 9, line 3
Garcia	Page 3, line 35 to page 4, line 16

3 **2.3.2 General Topic Summary**

4 Net sedimentation is an indication of the difference between gross erosion and gross deposition
 5 over time. Because PCBs readily partition to solids, PCB concentrations in surface sediment are
 6 expected to respond to the net sedimentation over time. Consequently, the model response to
 7 changes in PCB inputs over time is strongly influenced by the ability of the model to accurately
 8 simulate net sedimentation rates.

9 One Reviewer noted that sedimentation rates in individual grid cells, particularly in Reach 5A,
 10 vary considerably and that there are no data that can be used to validate that result. Two
 11 Reviewers noted that the model-data comparisons of deposition in Woods Pond, where such data
 12 are available, suggest that the simulated sedimentation rates appear to agree well with the data.

13 **2.3.3 General Topic Response**

14 Although significant variations exist, EFDC is able to adequately simulate downstream
 15 trends in bed elevations over time on a subreach basis. Although cross-channel
 16 differences in erosion and deposition patterns are highly variable, these differences can
 17 be accommodated by aggregating the spatial and temporal scales of sediment transport
 18 processes. With process aggregation, a single model grid cell across the channel
 19 should be adequate to simulate sediment transport in the Housatonic River system.
 20 Other processes such as meander development and planform adjustment can be
 21 neglected as long as sediment inputs from bank erosion are explicitly included in the
 22 model.

1 The ability of the model to successfully simulate net sedimentation rates demonstrates
2 that the mass of solids entering the model from all sources is correctly routed though
3 the model domain. This is of particular importance for PCB transport simulations
4 because the slow rates of net sedimentation in Woods Pond suggest that system
5 response times to changes in PCB inputs will also be slow. The slow rate at which
6 surface sediment PCB concentrations in Woods Pond change over time (the rate of
7 PCB concentration change cannot be distinguished from zero) is further evidence that
8 this important model construct is correct (see Appendix B.6 to the FMD and Section 4.3
9 of the FMD).

10 **2.3.4 Responses to Specific Comments on General Topic 2C**

11 **Douglas Endicott**

12 Sedimentation rates predicted by EFDC for individual grid cells in the river channel over the 10-
13 year Phase 2 calibration period are plotted in Figure 4.2-58. This figure shows a highly variable
14 pattern of deposition and erosion, especially in Reach 5A, where deposition fluxes exceeding 5
15 cm/yr are predicted for cells in close proximity to others in which erosion fluxes of 1-2 cm/yr are
16 predicted. Predicted sedimentation rates are not tested by any data at this scale, however. On a
17 reach basis, relatively small deposition fluxes (0.2-0.5 cm/yr) are predicted throughout the ROR
18 for both the calibration and validation periods. Figure 4.2-60 graphs the sedimentation rate in
19 grid cells within Woods Pond, along with sedimentation rates measured in cores. There are many
20 EFDC grid cells in Woods Pond, and a significant number of dated sediment cores. I specifically
21 examined the 1995 sediment core data suggested to be most representative in terms of cesium-
22 137 profiles, and found that both measured and predicted sedimentation rates are in the range of
23 1 to 10 mm/y. On a pond-wide average basis, sedimentation rates predicted for the calibration
24 period agree fairly well with the sediment core data (Table 4.2-5). Over the 26-year validation
25 period, the predicted sedimentation rates appear to be somewhat low in comparison to data
26 (Table 6.2-7).

27 **Response 2C-DE-1:**

28 EPA agrees with the Reviewer's comments on the comparison of simulated
29 versus measured sedimentation rates in Woods Pond, with the exception of the
30 final statement that predicted sedimentation rates for the validation period (FMD
31 Table 4.3-7) appear somewhat low in comparison to the data. In that table, the
32 average sedimentation rate at the location of the core samples averaged 0.49
33 cm/yr. Sedimentation rates derived from the cesium data averaged 0.42 cm/yr
34 using the peak in the 1995 cores, and 0.57 cm/yr using the first occurrence in the
35 1995 cores.

1 Predicted sedimentation rates were also compared to measurements of bathymetric change made
2 between 2000 and 2006 at a series of transects in Reach 5A (Figure 6.2-33). The measurements
3 of bed elevation change (positive and negative) were consistently larger and more variable than
4 the corresponding model prediction although, since the predictions and data were both spatially
5 averaged, I have trouble interpreting the significance of this comparison. As with other EFDC
6 results for the sediment bed, grid cell predictions were aggregated to mile or sub-mile intervals.
7 At finer spatial scales, there appear to be problems with the fidelity of the model. For example,
8 the transect data from location XS153 show several feet of deposition while EFDC predicts
9 significant erosion at this location, both during calibration (erosion=1") and validation (4")
10 periods. The transect data themselves (presented at the Document Overview meeting: 09 -
11 *Erosion & Deposition - Garland.pdf*) show relative nonuniformity in sedimentation both
12 longitudinally (between transects) and laterally (within transects). To me, the data show that
13 lateral resolution is warranted for hydrodynamics (shear stresses) and sediment transport. Other
14 subgrid features (lateral variations in bathymetry, bends, trees in river) are also significant
15 physical features, which are not represented in the model.

16 **Response 2C-DE-2:**

17 To evaluate this aspect of model performance, EPA believes it is necessary to
18 recognize (1) the spatial scale of model resolution, and (2) downstream and
19 cross-channel differences in channel configuration over time. The minimum
20 spatial resolution of the model framework is the size of an individual EFDC grid
21 cell (20 to 70 m). In contrast, transects are composed of individual
22 measurements along a line.

23 From transect survey to survey, measured sediment bed elevation changes for
24 each subreach are variable. Differences between cross section average
25 elevations indicate that net erosion occurred at some locations while net
26 deposition occurred at others. When averaged over space and time, simulated
27 changes in bed elevation are often near zero.

28 Cross-channel profiles are of interest because the patterns of erosion and
29 deposition provide a means to assess the extent to which cross-channel
30 differences in sediment transport processes exist and require aggregation. In
31 many cases (21 of 53 profiles), sediment transport processes can be represented
32 with a single grid cell across the channel without aggregation or significant loss of
33 detail. However, in other cases (20 of 53 profiles), the profiles are so diverse that
34 process aggregation would still be required even if three grid cells across the
35 channel were used in EFDC. Given the need to integrate the floodplain and river
36 channel into a single, computationally feasible model grid, little benefit is gained
37 from adding model resolution to the river channel because aggregation of
38 processes would still be required. See Appendices B.1 and B.6 of the FMD.

1 I remain concerned that we may be falsely confident in the erosion/deposition predictions made
2 by this model, because the model is being applied and validated at relatively coarse spatial
3 scales. Due to practical constraints, the modeling team did not simulate sediment transport at the
4 resolution demonstrated in other successful sediment transport applications (Thompson Island
5 Pool: HydroQual, 1995; Watts Bar Reservoir: Ziegler and Nisbet, 1995; Fox River: Lick et al.,
6 1995; Saginaw River: Lick et al, 1995 and Cardenas and Lick, 1996; Buffalo River: Lick et al.,
7 1995 and Gailani et al., 1996).

8 **Response 2C-DE-3:**

9 The Reviewer acknowledges practical constraints that influenced the decision to
10 adopt a grid scheme with generally one cell across the river channel. The factor
11 that distinguishes the Housatonic River from the other systems is the need to
12 include the floodplain in the model domain because approximately 60% of the
13 PCB mass in the PSA resides in the floodplain. This presents a practical
14 constraint to the modeling analysis.

15 While features such as a meandering thalweg, sub-grid-scale undulations in
16 bathymetry, and large woody debris affect the ability of the model to reproduce
17 bathymetric changes at an individual transect, the performance of the model on
18 broader spatial scales (e.g., sedimentation rates in Woods Pond, slow temporal
19 changes in simulated PCB concentrations consistent with the results of a
20 rigorous statistical analysis, and deposition patterns on the floodplain consistent
21 with PCB concentration distributions) provides evidence of acceptable
22 performance at the spatial scales that are relevant for the intended use of the
23 model (see Appendices B.1 and B.6 of the FMD).

24 However, it is important to recognize that the literature cited by the Reviewer is
25 not directly applicable. None of the systems examined in these references
26 address contaminant transport in the floodplain. A particular aspect of PCB
27 transport and fate in the Housatonic River system is the ongoing, active (bi-
28 directional) transport of PCBs and solids between the river channel and
29 floodplain.

30 The unstated assumption is that applying a similar model on a cruder resolution will correctly
31 average the sub-grid scale phenomena, even though some of these phenomena are demonstrably
32 nonlinear. This assumption is not supported by either data comparisons or numerical
33 convergence testing using alternative grid resolutions. Predictions of net sediment accumulation
34 can only be tested for Woods Pond, because that is the only portion of the ROR where a reach-
35 wide average accumulation could be inferred from sediment data. Predictions of net sediment
36 accumulation are untested in other reaches. This is of more than academic interest, because we
37 are asked to believe in the model primarily on the basis of the water column predictions of TSS
38 and PCB concentrations. Yet these only indirectly measure erosion and deposition. Reach 5A,
39 for example, is described as a dynamic environment with rapid exchange of solids and associated
40 PCBs. Within this and other reaches, there are locations where both deposition and erosion are
41 taking place. If aggregated spatially (into either reaches or miles) much of this behavior is

1 “averaged out”. Aren’t there advantages to validating sediment transport predictions without this
2 spatial averaging? In fact, that is the only way it can be done.

3 **Response 2C-DE-4**

4 EPA has demonstrated that the model framework correctly simulates water
5 column TSS and PCB concentrations during storm events, long-term net
6 sedimentation rates, and surface sediment PCB concentration trends over time in
7 Woods Pond. This confirms that the balance of fate processes in the model is
8 correctly represented.

9 Model-data comparisons of TSS concentrations during storm events provide
10 more value than is recognized by the Reviewer. Because TSS data were
11 collected at a fine temporal frequency, the data provide a description of
12 conditions on the rising limb of the hydrograph, when little deposition is expected,
13 and on the falling limb, when deposition dominates the solids transport
14 processes. A sensitivity analysis presented in the Model Calibration
15 Responsiveness Summary (page 23) demonstrates that the balance between
16 erosion and deposition is constrained by the gradient between the water column
17 and bed PCB concentrations. The averaging of sub-grid scale variations in
18 bathymetry, shear stress, and PCB concentrations, therefore, has been
19 demonstrated to produce an adequate representation of the average response
20 on water column TSS and PCB concentrations.

21 The Reviewer correctly notes that Woods Pond is the only location where net
22 sedimentation can be adequately tested through comparisons with cesium-137
23 data. Simulated net sedimentation rates for Woods Pond are in close agreement
24 with measured values. This close correspondence is significant because it
25 demonstrates that on average the mass of solids entering the model from all
26 sources is correctly routed through the model domain (including deposition on the
27 floodplain and in the river channel upstream of Woods Pond). This means that
28 sediment input from each source (upstream, tributary, sediment bed, and river
29 banks) is correctly transported through the river and floodplain such that the
30 cumulative mass of solids deposited in Woods Pond over time matches the
31 independent estimates of net sedimentation. The slow rates of net sedimentation
32 in Woods Pond suggest that system response times to changes in PCB inputs
33 will also be slow. This is demonstrated by the fact that the rate at which surface
34 sediment PCB concentrations in Woods Pond change over time is slow (i.e., the
35 rate of PCB concentration change cannot be distinguished from zero) (see FMD
36 Appendix A.1). In essence, this is a straightforward application of a basic
37 engineering principle, conservation of mass (continuity).

38 Because the intended use of the model is at a resolution larger than a grid cell
39 but smaller than a reach, validation of the model at the grid scale and subreach
40 level is the appropriate scale for demonstrating model performance. Therefore,
41 EPA disagrees with the Reviewer’s premise that the only (implying the
42 appropriate) scale for model validation is at a subgrid scale.

1 Marcelo H. Garcia

2 Of particular relevance for this reviewer is the validation of flood plain deposition throughout the
3 river system as well as sediment erosion and deposition in Woods Pond, since the record shows
4 that this pond is a major deposit for PCB-contaminated sediments.

5 Regarding the sedimentation of Woods Pond, the calibration/validation exercise has produced
6 results showing rates of (*net*) sedimentation for the period going from 1979 to 2004 (Figure 6.2-
7 34). The results seem reasonable with predicted sedimentation rates (mm/year) that are within
8 an order of magnitude of sedimentation rates determined from Cesium data. The model also
9 reproduces fairly well the distribution of PCBs with depth as observed from sediment cores.
10 However, as stated below, the model shows some bias when predicting temporal variations of
11 surface PCB concentrations in Woods Pond.

12 Response 2C-MG-1:

13 EPA agrees with the Reviewer's comment that the comparisons between
14 measured and simulated sedimentation rates are reasonable, and points out that
15 the agreement on a core-by-core comparison is better than the order-of-
16 magnitude characterization mentioned by the Reviewer. A more detailed
17 statistical analysis of temporal distributions of PCBs in Woods Pond sediment
18 has been completed and is presented in Appendix A.1 to the FMD. The results
19 of this analysis indicate that the Reviewer's interpretation of a bias in the
20 prediction of temporal variations in surface PCB concentrations in Woods Pond is
21 incorrect.

22 Woods Pond is perhaps one of the few locations in the Housatonic River where the capabilities
23 of the model to predict the spatial and temporal distribution of sediment and PCB can be
24 extensively tested due to the large amount of observations available. This has been done to some
25 extent but more effort should go into this since the pond could become a major source of PCBs
26 to the downstream portion of the river during a major flood event.

27 Response 2C-MG-2:

28 Additional comparisons between simulated and measured sedimentation rates in
29 Woods Pond, which were not included in the MVR, have been included in the
30 FMD (Section 4.3 and Appendix B.6). A more detailed statistical analysis of
31 temporal distributions of PCBs in Woods Pond sediment has been completed,
32 and is presented in Appendix A.1 to the FMD.

1 **3. GENERAL TOPIC 3: VERTICAL AND HORIZONTAL SPATIAL**
 2 **RESOLUTION**

3 **3.1 GENERAL TOPIC 3A: NUMBER OF GRID CELLS ACROSS CHANNEL**

4 **3.1.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 12, lines 18 to 35
	Page 13, lines 1 to 18
Bohlen	Page 8, lines 1 to 15
	Page 10, lines 35 to 36
	Page 14, line 32 to page 15, line 15
Endicott	Page 2, lines 18 to 19
	Page 2, line 25 to page 3, line 5
Garcia	Page 2, lines 20 to 31
	Page 2, line 37 to page 3, line 6
	Page 5, lines 4 to 9
	Page 5, line 39 to page 6, line 2
Gobas	Page 4, lines 17 to 31
	Page 4, lines 38 to 45
Lick	Page 1, lines 19 to 28
	Page 11, line 20 to page 12, line 17
	Page 13, lines 16 to 17
List	Page 2, lines 4 to 42
	Page 3, lines 22 to 35

5 **3.1.2 General Topic Summary**

6 A grid must be specified for computer models of the environment to generate numerical
 7 solutions. A grid can be described as a collection of the points in space where model
 8 computations are performed in sequence over time. The process by which the physical region
 9 (domain) represented by a model is divided into points used for calculations is called grid
 10 discretization. Within each individual grid cell, the physical properties of the environment are

1 represented as averages. There is a tradeoff between the number of cells in the grid (grid
2 resolution) and the number of computations that must be performed (computational effort).

3 Six Reviewers questioned the representation of channel width by a single cell in the modeling
4 grid, with most suggesting that three or more cells should be used across the channel. Most
5 Reviewers noted that flow and velocity are variable across the channel and that erosion and
6 deposition processes are also variable. In particular, Reviewers noted that sediment transport
7 processes vary non-linearly with flow such that averaging across a single cell in the river channel
8 does not provide a good simulation of processes known to be important for sediment and
9 contaminant transport. Most Reviewers also recognized that additional grid cells would make
10 the model more computer-intensive which is a concern.

11 **3.1.3 General Topic Response**

12 Selection of an effective model grid was particularly important for the development of
13 the EFDC application to the Housatonic River because EFDC simulates PCB transport
14 and fate at the smallest spatial and temporal scales that occur in the model framework.
15 As described in FMD Appendix B.1, efforts to select a grid for EFDC focused on finding
16 a balance between grid resolution and computational effort based on six factors, four
17 that influence grid resolution at a conceptual level and two that reflect practical
18 constraints on grid resolution that are imposed by the existence (presence or absence)
19 of data and computational resources. These factors establish the balance between
20 what might be possible and what can be accomplished in the context of the modeling
21 study goal.

22 The model grid was chosen as a reflection of the nature of the Housatonic River system
23 (channel and floodplain) and the modeling study goal. Much of the PCB mass in the
24 system is in channel banks and floodplain areas. River flows periodically overtop
25 channel banks and inundate the floodplain. This connection between the river channel
26 and floodplain is important because risks to both human and ecological receptors were
27 identified from exposure to PCBs in the floodplain. Further, the goal was to develop a
28 modeling framework that can be used to adequately simulate baseline conditions and
29 the relative performance of potential remedial alternatives. The spatial scale needed to

1 adequately achieve this goal was defined by the Model Working Group as smaller than
2 a river reach but larger than a single grid cell (QEA, 2001; EPA, 2006). The temporal
3 scale of concern is on the order of decades, sufficiently long to evaluate the
4 effectiveness of remedial alternatives against baseline conditions. Collectively, these
5 considerations require that floodplain areas be explicitly represented in the model
6 framework and that model results be accurate when evaluated on a subreach scale.

7 A number of different model grid configurations were evaluated before the final grid for
8 EFDC was selected. Sensitivity analyses were conducted using detailed channel cross
9 sections, bathymetry and velocity information collected for a 1-km subsection of the
10 river during the Test Reach Investigation. Both in-bank and out-of-bank flow conditions
11 were examined. An overview of the Test Reach Investigation was presented in the
12 Section 5.4 of the Model Framework Design. A further summary is presented in FMD
13 Appendix B.1.

14 The need for explicit floodplain simulation imposes an important constraint on the type
15 of model grid that can be used. In an ideal simulation, the grid would allow high
16 resolution in the river channel to simulate differences in conditions across the channel
17 because such differences can influence the extent of bank and bed erosion. However,
18 even if this resolution was added to a model grid in the river channel, the model results
19 would not necessarily be more accurate. Moreover, this degree of detail in the channel
20 would be needed only if the model framework were going to be used to simulate
21 sediment and PCB transport at the scale of individual bars or individual grid cells. In the
22 application of the model framework for the Housatonic River, much larger spatial scales
23 are of concern, thereby reducing the need to simulate cross-channel variations. This
24 means that the effect of fine-scale processes can be adequately represented in a
25 simplified, aggregated fashion. Further, at the scale of fish movement (FCM reaches)
26 and risk assessment output, model results are not expected to be sensitive to use of a
27 more finely resolved model grid.

28 The evaluation of potential remedial alternatives is expected to focus on relatively large
29 spatial units (larger than a grid cell) and that fine-scale details, even at the scale of

1 individual grid cells, would always be aggregated and averaged regardless of the
2 resolution of the underlying model. In addition to information EPA provided to the
3 Reviewers, the need for process aggregation using a less detailed model grid was
4 presented by GE during their public comment to the Model Framework Design Peer
5 Review (see QEA, 2001). Moreover, even if the spatial scales of interest were ignored,
6 it is worth noting that cross-channel conditions are sometimes so variable that process
7 aggregation and averaging would still be needed even if the river were represented
8 using three grid cells across the channel. This type of cross-channel variability occurred
9 in 20 of 53 profiles examined in FMD Appendix B.6. Consequently, given the intended
10 use of the model framework and the potential for cross-channel variation even at
11 extremely fine spatial scales, some degree of process aggregation and averaging will
12 be needed regardless of how the river channel is represented in the model.

13 In consideration of all the factors that influenced selection of the model grid for EFDC, a
14 curvilinear grid that includes the 10-year river floodplain and represents the channel
15 width using a single grid cell was judged to provide the best balance between spatial
16 detail and computational efficiency as needed to meet the goals of the Housatonic River
17 modeling study.

18 **3.1.4 Response to Specific Comments on General Topic 3A**

19 **Eric Adams**

20 **Grid Resolution**

21 Like most other review panelists, I continue to be **concerned about the lack of lateral**
22 **resolution in the computational grid.** Having only about one grid cell over the river width
23 means that important processes must be parameterized. Because the existence and magnitude of
24 erosion and deposition depend non-linearly on stream velocity, a trapezoidal section with depth
25 varying linearly between 1 and 3 meters at the two banks will look to the model like a section
26 with uniform depth of 2 m, yet in practice the former may have regions of strong erosion and
27 deposition (as in re-surveyed cross-section XS061 shown in the DRM handouts), whereas the
28 latter might be marginal one way or the other.

Response 3A-EA-1:

Given the intended scale of use for the model framework, EPA believes that the net transport of solids and PCBs through the water column and average PCB exposure concentrations are the important features of the river system that must be accurately simulated on a subreach basis. As shown in FMD Section 3, the present model framework achieves this needed level of accuracy.

As noted in the General Response, some fine-scale detail is lost due to process aggregation. Specifically, cross-channel differences in erosion and deposition are aggregated such that the model response may seem less dynamic than the response that might be measured at any one point along or across the river. However, it should be recognized that the reduced precision in model results that arises from averaging does not mean that the results are less accurate.

First, process aggregation would be required in any model, regardless of scale, as a function of the intended scale of model use and point-to-point variability that occurs in the Housatonic River. Second, for any subreach, the flux of solids and PCBs moving through the water column is known from measurements. This means that the net flux solids and PCBs transported from any subreach can be determined with reasonable accuracy. It must also be recognized that the sediment bed of the Housatonic River is heavily contaminated with PCBs across the entire bed and that pockets of uncontaminated sediment do not exist. Consequently, it is not necessary to know the exact part of a model grid cell (or even exactly which cell) from which sediments and PCBs are eroded. Even if the model does not identify the precise location from which erosion occurs, the model still accurately simulates the average flux through the system because those fluxes are determinable from site-specific measurements and are accurately matched. Thus, the model is accurate even if some precision is lost through averaging.

As noted in the General Response above and in FMD Appendix B.6, there are many locations (20 of 53 profiles examined) where cross-channel differences in erosion and deposition are so extensive that processes would need to be averaged and aggregated even if the river were simulated as three cells across the channel. However, as shown in FMD Appendix B.1, the computational burden of using multiple cells across the channel is prohibitive. Given the computational burden and the need to aggregate processes at some level regardless of model resolution and inclusion of the floodplain, EPA believes that representation of channel processes with a single cell across the river is appropriate.

Process Aggregation Prevents Evaluation of Remediation

Even if the model gets the net erosion/deposition correct (doubtful due to the non-linearity), the failure to capture gross erosion/deposition is problematic, both for evaluating remedial measures (such as capping) and natural attenuation. Assume an entire channel cross-section is capped. If

1 half of the channel is erosional and the other half is depositional, the first half will require added
2 protection to keep the cap intact, while the second half will get covered with contaminated
3 sediments from upstream. Neither process would be forecast with a model that predicts marginal
4 net erosion/deposition. As for natural attenuation, contaminated sediments from an upstream
5 area with gross erosion can contaminate (or re-contaminate) downstream areas, but the model
6 would not predict this.

7 **Response 3A-EA-2:**

8 As noted in the previous response and as discussed in Sections 3 and 4 of the
9 FMD, the present model framework achieves the level of accuracy needed for
10 the modeling study. Further, it should be noted that the function of the model
11 framework in the next phase of the project will be to provide an estimate of the
12 relative difference between remedial alternatives.

13 The Reviewer's comment regarding the use of the model framework for
14 evaluating remedial alternatives does not accurately reflect the intended use of
15 the model. As noted, the model will be used to assess the relative difference
16 between simulations. Specifically, the impact of any given remedial option can
17 be successfully represented by altering model boundary conditions and initial
18 conditions to simulate the impact that the management of contaminants in
19 Housatonic River system will have on decadal time scales. The model is not
20 intended to be used a tool to engineer specific components of the selected
21 remedial alternative. Therefore, if capping were selected as a proposed remedy
22 for a portion of the site, guidance and procedures specific to cap design would be
23 used (e.g., USACE guidance for cap stability).

24 Therefore, the model framework must be considered a tool to evaluate the
25 relative impact that a given remedial strategy (such as a capping) is expected to
26 have on a level larger than a grid cell and smaller than a reach (e.g., the FCM
27 reaches). The model can serve this intended purpose by use of altered
28 boundary conditions and initial conditions to construct difference scenarios
29 representing different management strategies. The model framework will not be
30 used to address the engineering issues associated with the design and
31 implementation of a remedy.

32 **Scale-dependence of EFDC Calibration**

33 Too begin with, it must be recognized that the lateral grid size is a model parameter as well as a
34 numerical parameter. Ideally, when a set of equations are solved using a discretized numerical
35 model, one likes to reduce the grid size until results converge. ***But, we are no where near that***
36 ***here.*** Hence if the model grid size were to be reduced, this would affect other model processes
37 (notably erosion, which depends heavily on velocity, which would vary significantly across the
38 river width). Thus ***if the model grid were to be reduced, the entire calibration would need to be***
39 ***redone.***

1 It is not clear how much resolution would be needed to properly compute transport. Because of
 2 this uncertainty, and the time and effort involved, it may be too late in the game to make major
 3 changes to the model grid. However, at a minimum, some sensitivity tests could be conducted
 4 using a finer grid over a small portion of the (in-channel) domain and run over a short duration of
 5 the 26 year simulation period. The output from the more highly resolved model could be
 6 compared with that from the coarser model and then parameterized. For example, it might be
 7 determined that the net erosional flux with a resolved grid is X times that computed with the coarse
 8 grid, in which case predicted erosional fluxes with the coarse grid would be multiplied by X.

9 **Response 3A-EA-3:**

10 EPA recognizes the need for sensitivity analyses and the potential grid-scale
 11 dependencies that may exist in the model framework calibration. For EFDC,
 12 EPA presented a series of analyses in which model sensitivity to downstream
 13 and cross-channel grid resolution in the channel was examined. These
 14 sensitivity analyses were first presented in the Final MFD and are again
 15 summarized in FMD Appendix B.1. Stream velocity as calculated by the
 16 hydrodynamic model was the main parameter examined. EFDC results for
 17 Cartesian and curvilinear grids of different resolutions were compared. See
 18 Tables 1 and 2 of FMD Appendix B.1.

19 Further, it should be recognized that some degree of grid scale-dependency will
 20 exist in any practical model application. As model scale varies, processes that
 21 might have been negligible at one scale may become predominant at a different
 22 scale. This is why it is important to understand the intended spatial and temporal
 23 scales for which the model will be applied. Moreover, the difference between
 24 what happens at a single point can differ from what is observed over a broader
 25 area. This was well-documented throughout the modeling study as conditions in
 26 the Housatonic River system vary widely over very small spatial scales (just a
 27 few feet). Selection of any model spatial (or temporal) resolution requires that
 28 processes be aggregated and averaged. This is a fundamental concept in the
 29 difference between the integral and differential approaches in fluid mechanics.

30 The correct functioning of the model framework for the present grid scale, which
 31 was specifically selected to meet the goal of the modeling study, is well
 32 documented in Sections 3 and 4 of the FMD.

33 **W. Frank Bohlen**

34 **Model-Data Comparisons and Grid Scale**

35 Comparisons between measured and modeled velocities are complicated by the model use of a
 36 single grid cell across the main stem channel. If the single cell is to be retained measurements
 37 should be designed to yield cross-sectional averages as opposed to point measurements. The
 38 majority of available data do not appear to be suitable for this purpose.

1 **Response 3A-FB-1:**

2 Velocity measurements used for model-data comparisons are cross-section
 3 averages. Water quality samples are either depth-integrated (manual samples)
 4 or at a fixed depth (ISCO samples). As noted by the Reviewer, it might have
 5 been possible to facilitate model-data comparisons if all measurements were
 6 always cross-sectional averages.

7 **Need for More Grid Cells Across the River Channel**

8 While on the subject of model grid specification, I must repeat what has been stated before
 9 regarding the advisability of increasing the number of grid cells across the channel. My review of
 10 available data detailing bathymetry and sediment type indicates that accurate simulation of these
 11 characteristics and their proper incorporation within transport models requires a minimum of
 12 three grid cells rather than the present one. If this proves (or is known) to result in an
 13 unacceptable increase in computation time then consideration should be given a reduction in the
 14 lateral extent of the floodplain since there are a variety of data (see Example Model Simulations,
 15 e.g.) that suggest that there are substantial areas along the inshore limits of the floodplain that are
 16 only occasionally affected by flooding and where, as a result, minimal longterm changes are to
 17 be expected. Alternatively, a coarser grid might be used on the floodplain.

18 **Response 3A-FB-2:**

19 Use of a coarser model grid for the floodplain does not alter the computational
 20 burden because: (1) model time steps would still be controlled by downstream
 21 and cross-channel velocities in the river channel; and (2) model computations do
 22 not occur in floodplain cells when those cells are not flooded. See General
 23 Response above and Appendices B.1 and B.6 to the FMD.

24 Examination of these data might also be part the studies dealing with the recommended increase
 25 in the number of model grid cells across the river channel.

26 **Response 3A-FB-3:**

27 The choice of a single grid cell across the river channel was driven by the
 28 balance between the intended use of the model and the corresponding
 29 computational burden of added resolution. While data collection at a finer scale
 30 might prove to be necessary for design of a remedy, EPA believes that no further
 31 data collection is needed to meet the goal of the modeling study.

32 Even with these process questions resolved there remains the issue of run-time. It seems clear
 33 that the model as presently configured requires entirely too much time for the completion of a
 34 single run to be useful within timely evaluations of a significant number of remedial schemes.
 35 We probably knew this several years ago and should have been more sensitive to the need to
 36 develop alternative formulations. A number of these, including the separation of the
 37 hydrodynamics from the transport estimates and subsequent FCM evaluations were previously
 38 mentioned. It is now necessary and possible to go further. Using the experience gained from
 39 “whole model” runs it should now be possible to develop a number of synthetic hydrographs

1 detailing streamflow, stage, and TSS concentrations at the upstream boundary and each of the
 2 primary tributary streams. This would eliminate the need to run HSPF on a regular basis. EFDC
 3 is a ponderous model and can be streamlined now that we have a better idea of the relative
 4 importance of the governing variables. John Hamrick should be charged with this task (no more
 5 than 6 months) as soon as possible. As part of this streamlining the model grid characteristics
 6 should be carefully reviewed, again using what has been learned about the relative importance of
 7 each of the domain regions (sidebanks, backwaters, floodplains etc.). My sense of the present
 8 grid is that it underspecifies the channel region and overspecifies the floodplain. The latter could
 9 almost be treated as a box with fluxes simply proportional to stage which could be specified
 10 along its margin by EFDC. If in time more detail of the interior of the plain is needed for
 11 remedial purposes consideration might be given to replacing the high resolution grid on the plain
 12 while placing a box in some other area (channel sidebanks?). Finally, I'd consider eliminating
 13 the FCM in favor of a parametric (flow, TSS concentrations?) approximation of body burden
 14 uptake based on the results of the complete model runs.

15 **Response 3A-FB-4:**

16 Model framework run times are controlled by the time required to run EFDC. No
 17 meaningful reduction in run times can be accomplished by altering HSPF or FCM
 18 or the linkage between these tools and EFDC (see General Topic 4). As
 19 previously noted, coarsening of the EFDC grid for the floodplain will not
 20 significantly reduce run times because the model does not perform calculations
 21 on cells when they are dry and because model time steps for numerical
 22 integration are restricted by stream velocities in the channel.

23 Further, EPA has examined many approaches to reduce run times; over the
 24 course of the modeling study, the time required to complete EFDC simulations
 25 has decreased significantly. As of October 2006, the run time for a 1-year
 26 simulation is approximately 8 hours using a computer with two Intel Xeon 5160
 27 Dual-core CPUs running at 3.0 GHz with 4 GB of RAM running the Mandriva
 28 Linux 2007 operating system for X86-64. Even more recent computers may
 29 have the power to further reduce these run times. See responses in General
 30 Topic 4.

31 **Douglas Endicott**

32 EFDC fails to address lateral variation in hydrodynamics and sediment transport processes

33 **Response 3A-DE-1:**

34 Lateral variations in hydrodynamics do not need to be simulated at the intended
 35 scales of use for the model framework. See the General Response above.

36 On the first point, EFDC appears to fail to address lateral variation in hydrodynamics and
 37 sediment transport processes, because the model grid in the river channel is one-dimensional
 38 over most of the Rest-of-River (ROR). Prior applications of SEDZL (the model upon which the
 39 EFDC sediment transport code was apparently based) to river systems have used a 2-

1 dimensional, vertically-integrated grid, using 5 to 10 lateral grid cells to represent the channel
 2 cross section. The 2-dimensional sediment transport models have been demonstrated to predict
 3 scour and deposition in river channels with reasonable accuracy¹. These applications have
 4 demonstrated that lateral variation in current velocities and bottom shear stresses result in
 5 considerable variation in sediment scour depending upon location in the channel. This behavior
 6 is often observed in natural channels as a pattern of erosion from mid-channel/deposition
 7 nearshore, or erosion on the outside of a bend/deposition on the inside. Because the relationships
 8 between current velocity, shear stress and sediment erosion are nonlinear, it appears likely that
 9 sediment scour predicted by the 1-dimensional model of sediment transport in the Housatonic
 10 River will be different than the scour predicted by a 2-dimensional model. How much different is
 11 unknown, because the EPA modeling team have not tested the sensitivity of the EFDC sediment
 12 transport model to the number of lateral grid cells in the river channel. This is a significant issue,
 13 because release of PCBs from eroding sediments is a major source of the contaminant in the
 14 ROR.

15 **Response 3A-DE-2:**

16 See General Response above. In addition, at the intended scales of use for the
 17 model framework, cross-channel variation in sediment transport would be
 18 aggregated and averaged regardless of the resolution of the underlying model. It
 19 must be recognized that the sediment bed of the Housatonic River is heavily
 20 contaminated with PCBs across the entire bed and that pockets of
 21 uncontaminated sediment do not exist. Consequently, it is not necessary to
 22 know the exact part of a model grid cell (or even exactly which cell) from which
 23 sediments and PCBs are eroded.

24 The literature citing SEDZL applications to other sites is not appropriate to the
 25 Housatonic River system because none of those applications to other sites (such
 26 as the Lower Fox, Saginaw, or Buffalo Rivers, etc.) couple the river channel and
 27 floodplain into a single model domain or include any part of the floodplain. A
 28 distinguishing feature of the Housatonic River system is that 60% of the PCB
 29 mass inventory in Reaches 5 and 6 is present in the river banks and floodplain
 30 areas and that risks to human health and the environment are posed by
 31 exposure to PCBs in the floodplain. The overriding need to couple river channel
 32 and floodplain processes is a major constraint on the type of model framework
 33 that can be used for the Housatonic River system.

34 EPA presented a series of analyses for EFDC in which model sensitivity to
 35 downstream and cross-channel grid resolution in the channel was examined.
 36 These sensitivity analyses were first presented in the final MFD and are again
 37 summarized in FMD Appendix B.1. Stream velocity was the main parameter

¹ See: Gailani, J.Z., W. Lick, K. Ziegler, and D. Endicott. 1996. Development and Calibration of a Fine-Grained Sediment Transport Model for the Buffalo River. *J. Great Lakes Res.*, 22(3):765-778.

1 examined and EFDC results for Cartesian and curvilinear grids of different
 2 resolutions were compared. See Tables 1 and 2 of FMD Appendix B.1.

3 **Marcelo H. Garcia**

4 Arguably the main shortcoming of the model is not the Housatonic River model itself but rather
 5 its numerical implementation which, in my opinion, has rendered the model calibration and
 6 validation unreasonably difficult. Assuming that all the processes are eventually accounted for
 7 in the model and the right algorithms are used to simulate them, the most vexing issue will
 8 continue to be the characteristics of the computational grid used to simulate the river
 9 hydrodynamics, sediment transport and associated PCB transport and fate. The computational
 10 mesh (Figure 3-6) is “hard-wired” to water stages in the floodplain associated with a flood
 11 having a recurrence time of 10 years. This results in the main river channel being modeled with
 12 the same spatial resolution (i.e. a single computational cell) regardless of the flow discharge, not
 13 just the 10 year flood.

14 **Response 3A-MG-1:**

15 See General Response above. It should again be noted that the model grid
 16 resolution across the channel is appropriate because finer detail would be
 17 aggregated and averaged at the intended spatial and temporal scales of use for
 18 the model framework.

19 At the same time, the use of a course grid hinders the ability of the model to resolve the flow
 20 velocity distribution inside the main channel as well as the associated boundary shear stresses
 21 throughout its wetted perimeter. Given that erosion and sediment transport vary non-linearly
 22 with increments in flow velocity and shear stress, it is rather imperative to find a way to increase
 23 the spatial resolution of the model so that at least three “streamtubes” are used to model flow and
 24 sediment transport in the main channel of the Housatonic River. This will in turn facilitate and
 25 make more meaningful the computation of streambank erosion as well bed sediment erosion and
 26 resuspension.

27 **Response 3A-MG-2:**

28 It should be recognized that streambank erosion is parameterized as a load
 29 using site-specific empirical functions that accurately reproduce long-term and
 30 short-term erosion rates measurements for the Housatonic River as a function of
 31 cross-section average flow stream (see Appendix B.7 to the FMD). Use of these
 32 empirical functions eliminates the need to simulate cross-channel variations in
 33 velocity and shear stress along the channel banks with extreme detail.
 34 Furthermore, as demonstrated in Sections 3 and 4 of the FMD, the model is able
 35 to correctly resolve average sediment transport processes over the spatial scales
 36 of interest.

37 As mentioned in the response to question one, the size of the computational grid makes it
 38 difficult (and meaningless) to compare model predictions for processes that take place at
 39 hydraulic and sedimentation scales determined by the flow rate and the main channel width.

1 This is not the case for Woods Pond and the floodplains were the size of the computational grid
2 is appropriate for the scale of the flow field.

3 **Response 3A-MG-3:**

4 Woods Pond introduces a different flow regime than exists in Reach 5. Two-
5 dimensional representation of the river flow in Wood Pond is appropriate
6 because cross-pond differences in flow in this reach are significant for simulating
7 sediment and PCB transport at the spatial scale of interest to the modeling study.
8 However, in Reach 5 and free-flowing areas in Reaches 7 and 8, simulation of
9 the channel as a cross-section average is appropriate and justified given the
10 intended use of the model framework and the fact that downstream flow
11 velocities will always be much larger than cross-channel velocities in these
12 areas.

13 Given the facts that several processes are yet to be fully characterized in the model and that a
14 coarse computational grid has been used for the model calibration, I do not think that a full
15 sensitivity analysis can be conducted at this time.

16 **Response 3A-MG-4:**

17 Model sensitivities to grid resolution have been characterized. See Response
18 3A-EA-3 above.

19 **Frank Gobas**

20 The spatial resolution of the environmental fate and food-web model is unnecessarily complex.
21 A much simpler spatial model is consistent with the empirical data and the current model
22 calculations. The hydrodynamic model does not run on a low spatial resolution. However, it is
23 possible to run the hydrodynamic model on its optimal spatial resolution and aggregate the
24 hydrodynamic data for a much simpler PCB environmental fate model. The latter would also
25 reduce the model run-time from the current, unacceptable 30 to 50 d. This would also make the
26 model more transparent due to greater simplicity. The modelers could argue that in terms of
27 predicting spatially varying concentrations the current multi-compartment model is consistent
28 with a much simpler lower spatial resolution model, so there is no need to develop the simpler
29 model. This is true for the model's current application. However, the modelers should keep in
30 mind that when the current model is applied to make predictions of the impact of remedial
31 actions on PCB concentrations as a function of space (i.e. model objective #1), the model may
32 predict spatial differences in concentrations that have not been "validated" or "ground truthed".

33 **Response 3A-FG-1:**

34 EPA believes that the spatial and temporal resolution of the model framework,
35 particularly the grid for EFDC, is appropriate for the scales of interest for the
36 modeling study. However, as noted in Response 3A-FB-3, model run times are
37 not expected to be overwhelming because the run time for a 1-year simulation is

1 approximately 8 hours. This means 50-year long simulations can be completed
2 in 17 days.

3 The Model Working Group will continue discussions regarding various levels of
4 coupling/decoupling of model results as part of the Corrective Measures Study.
5 However, such decoupling was not needed for the development of the model
6 framework as conducted by EPA. See also the responses in General Topic 4.

7 The modelers should consider developing a simpler spatial representation of the environmental
8 fate and food-chain model by decoupling the hydrodynamic and sediment transport model from
9 the environmental fate and food-chain model. The current high spatial resolution of the model is
10 unnecessary for the environmental fate and food-chain model. Also, the time-step requirement
11 for the hydrodynamic model is too onerous and unnecessary for the environmental fate and food-
12 chain models. This change in model design will make it possible to make many model runs
13 within a reasonable computational time.

14 **Response 3A-FG-2:**

15 See Response 3A-FG-1 above.

16 **Wilbert Lick**

17 In the present model, the processes of sediment erosion, sediment deposition, the finite sorption
18 rate of PCBs by the sediments, and the sediment-water flux due to “diffusion” are described
19 incorrectly and inaccurately. This is exacerbated by a very coarse numerical grid used to define
20 the bathymetry of the river and an unnecessarily fine grid to define the bathymetry/topography of
21 the floodplain. More specific reasons for these comments as well as specific suggestions for
22 improvement of the model are presented in the complete response which is attached. I do not
23 believe that the present model can reasonably account for the relevant processes affecting PCB
24 fate, transport, and bioaccumulation in the Housatonic River to a degree consistent with
25 achieving the goal of the modeling study.

26 **Response 3A-WL-1:**

27 EPA believes the Reviewer comment is incorrect, particularly in regard to the
28 balance of fate processes in the model framework (see General Response in
29 General Topic 1). With respect to the model grid, explicit coupling between the
30 river channel and floodplain is required because roughly 60% of the PCB mass
31 inventory in Reaches 5 and 6 is in the floodplain (including channel banks). The
32 need to include floodplain areas constrains the model grid that can be used.
33 Furthermore, there will need to be some process aggregation and averaging of
34 model results regardless of whether the river is represented as 11, 5, 3 or just 1
35 cell(s) across the channel.

36 As far as the high PCB variance throughout the river is concerned, consider the following.
37 Sediment erosion/deposition depends on the hydrodynamics, e.g., high rates of erosion where the
38 flows are fastest and low rates of erosion (or deposition) where the flows are slow. Because of

1 this, large variations in erosion rates occur across the river (shallow, near-shore areas versus
2 deeper channels in the middle) as well as along the river. This is well illustrated in previous
3 calculations of sediment transport in rivers (Saginaw River (Cardenas et al. 1995), Fox River
4 (Jones et al. 2000)) when a reasonably fine grid was used, i.e., 5 to 11 grid points across the
5 river. Because of the coarse numerical grid, this is not described by the present model. i.e.,
6 everything in the model is averaged or smoothed. In some areas (e.g., upstream and/or in the
7 center of the channel where flows are high), mostly erosion occurs and PCB concentrations
8 reflect deposition at an earlier time and are relatively high. These sediments will be transported
9 downstream and will deposit in a non-uniform manner depending on the hydrodynamics. These
10 sediments will retain their high PCB concentrations. In other areas (e.g., sediments from above
11 the upstream boundary, near-shore depositional areas which have received clean sediments from
12 further upstream, or areas where deposition is slow such that surficial sediments can equilibrate
13 with the cleaner overlying water), the PCB concentrations of surficial sediments may be quite
14 low. Slow transport and multiple resuspension/deposition events can also cause low PCB
15 concentrations of surficial sediments.

16 Because of episodic events, the dependence of erosion/deposition of sediments on highly
17 variable hydrodynamics, the highly variable sources of PCBs (e.g., clean from far upstream,
18 contaminated from deep in the sediments, differences between near-shore, shallow areas and the
19 deeper channel in the center), and of course slow PCB desorption rates (which causes sediments
20 to retain their PCB sorbed concentrations, either high or low), it seems quite plausible that PCB
21 concentrations will be highly variable in space and time in the Housatonic. The present model
22 smooths this all out.

23 **Does this matter?** If the only purpose of the model is to duplicate known results, then accurate
24 models of sediment and contaminant transport and fate don't matter. However, if the model is to
25 be used for predictive purposes, then accurate process models do matter. In the predictive mode,
26 future conditions (such as sediment properties, contaminant concentrations in the sediments,
27 concentrations and types of benthic organisms, sediment-water fluxes, flow rates, etc.) will be
28 modified (for example by dredging, capping, or extreme environmental conditions), will change
29 with time, and will be different from those for which the model was calibrated. The basic
30 processes in the present and future are the same. However, their relative effects and
31 significances depend on the modified conditions and will change with time. If the models
32 describing the basic processes have incorrect functional behavior and/or inaccurate parameters,
33 then the model will not predict the long-term behavior properly. Because of this, for the long-
34 term prediction of sediment and contaminant fluxes, it is essential that the functional behavior
35 and parameters of the most significant processes in the model be described correctly.

36 **Response 3A-WL-2:**

37 The Reviewer comments intertwine the issue of model grid resolution with an
38 assessment of the balance of fate processes in the model framework (see
39 General Topic 1 for responses regarding the balance of processes). With
40 respect to the resolution of the grid, the Reviewer comment places a greater
41 emphasis on cross-channel differences rather than downstream gradients. To
42 achieve the goal of the modeling study, the model framework must be able to
43 describe PCB transport and fate over relatively large spatial units over decadal

1 time scales. As documented in Sections 3 and 4 of the FMD, the model
 2 framework successfully defines the relationships between PCB sources and
 3 resulting concentrations with appropriate accuracy.

4 The numerical gridding can be improved by increasing the number of grid cells across the river
 5 and decreasing the number of grid cells in the floosplain.

6 **Response 3A-WL-3:**

7 See the General Response above, and Appendices B.1 and B.6 to the FMD.

8 **E. John List**

9 EPA and its contractors decided to finesse the problems associated with the non-uniformity of
 10 stream bed sediment erosion by using a single computational cell to define the entire width of the
 11 river. This means that the bed erosion at any specific river station is defined by the mean bottom
 12 shear stress. However, because the actual shear stress on the bed at any location is proportional
 13 to the local *depth-averaged* velocity, and the rate of bed erosion (when the shear stress
 14 significantly exceeds the critical shear stress) is proportional to the shear stress squared (or an
 15 even higher power), it means that the rate of bed erosion in these circumstances is proportional to
 16 the fourth power (or even higher) of the mean velocity. Thus, if there is a transverse non-
 17 uniform depth-averaged velocity profile *across* the river the rate of bed erosion may vary quite
 18 substantially with location on the river cross section. At locations where the depth-averaged
 19 velocity is twice that at another location the rate of erosion can be 16 times as great (or even
 20 higher). The fact of the matter is that real streams do have widely varying flow velocities across
 21 the width of the river and this is the basic reason why the water depth is seldom uniform across
 22 the width of the river. It is my professional opinion that it is really inappropriate to attempt to
 23 describe the net result of the widely varying rates of erosion that occur in the Housatonic River
 24 by using a *cross-sectionally* averaged velocity. The probability that the mean erosion can be
 25 parameterized in the model on the basis of cross-sectionally averaged flow properties seems low
 26 to me. However, development of a sediment rating curve from the stream data may show that
 27 this is possible (see discussion below).

28 It is acknowledged that it is probably quite impracticable to model the sediment transport and at
 29 the same time compute the resulting changes in river bottom topography and their effects on the
 30 hydrodynamics. It would seem that a logical approach would be to use a quasi-steady approach
 31 in which the stream bed is divided transversally into three or more computational elements that
 32 enable at least a partial simulation of the bottom profile and the resulting velocity distribution
 33 and bed erosion. An alternative would be to take a longitudinal section of the stream and do a
 34 detailed three-dimensional computational fluid dynamics (CFD) analysis of the flow distribution
 35 and resulting erosion, then compare the results of this analysis to the one-dimensional approach
 36 to determine if a realistic one-dimensional parameterization is at all possible. Perhaps the single
 37 best alternative approach to this problem is simply to use empirical sediment and flow rating
 38 curves, which is the “old fashioned” empirical way these problems were solved before computers
 39 became involved (see, for example, <http://www.epa.gov/warsss/sedsorce/rivrelat.htm> and
 40 <http://water.usgs.gov/osw/techniques/TSS/Horowitz.pdf>, where it is shown that accuracies of

1 ±20% are possible for empirically-derived sediment concentration predictions). Incidentally, the
 2 hydraulic modeling could probably also benefit from a comparison of the predicted and actual
 3 stage-discharge curves, if this has not already been done.

4 **Response 3A-JL-1:**

5 As noted in the General Response above, some degree of process aggregation
 6 and averaging is necessary regardless of whether the river is represented as
 7 many cells across the channel or just one. Nonetheless, the model framework
 8 can simulate average sediment transport conditions, as demonstrated in
 9 Sections 3 and 4 of the FMD.

10 However, it should be noted that the alternative approaches suggested by the
 11 Reviewer would not be expected to materially improve model performance. The
 12 use of empirical rating curves is in many regards no different from the present
 13 model calibration approach. Further, the use of quasi-steady flow simulations to
 14 characterize hydrodynamics may be a less reasonable approach because river
 15 flow is known to be unsteady (vary over time). Temporal variations in flow cause
 16 variations in flow accelerations and corresponding sediment and PCB transport.
 17 EPA believes that accurate hydrodynamic simulation requires that the model
 18 accurately simulate these transient dynamics.

19 A second reason for this opinion is that recent river bottom survey profiles indicate quite clearly
 20 that sediment erosion and deposition is very definitely non-uniform across the river cross-
 21 section. By contrast, and as discussed above, the modeling uses a single computational cell to
 22 define the entire width of the normal river channel and the local erosion is defined by the fluid
 23 shear stress that is averaged across the river cross-section. Because of the non-uniform nature of
 24 the actual erosion, and the fact that the model uses an average shear stress to define the erosion,
 25 it is highly probable that river bed erosion occurs long before the model predicts its occurrence.
 26 Furthermore, the PCB concentration of the sediment that is eroded in the model is the average of
 27 the local concentration over that cell. Thus the modeling uses cell averages that reduce the very
 28 broad PCB concentration distributions to a local average, and then redeposits that PCB-laden
 29 sediment at this average concentration. The net effect of the modeling therefore must be to
 30 smooth out the distribution of PCBs, but in reality this has not occurred in the significant length
 31 of time in which, according to the model, it should have occurred.

32 **Response 3A-JL-2:**

33 See Appendices B.1 and B.6 to the FMD. In addition, cross-channel differences
 34 in erosion and deposition patterns were relatively consistent for 21 of 53 profiles
 35 examined. Where cross-channel differences do occur, in many cases (20 of 53
 36 profiles), these differences are so extensive that process aggregation and
 37 averaging would be required even if the river were represented as three (or
 38 more) grid cells across the channel.

39 The model framework does not act to “smooth out” PCB concentration gradients
 40 in river sediments (or floodplain soils) over time. As shown in the results of the

- 1 calibration, validation, and example simulations, cell by cell differences in surface
- 2 sediment PCB concentrations occur over the course of the simulations.

1 **3.2 GENERAL TOPIC 3B: FLOW/VELOCITY/SHEAR STRESS**

2 **3.2.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 6, lines 26 to 43
Bohlen	Page 5, lines 20 to 37
	Page 9, line 29 to page 10, line 2
	Page 14, lines 20 to 25
Garcia	Page 5, lines 4 to 9
List	Page 1, lines 29 to 34
	Page 4, lines 27 to 41

3 **3.2.2 General Topic Summary**

4 Water in a river channel or on the land surface moves (flows) by the action of gravity. In the
 5 Housatonic River, the flow of water through the river channel or across the floodplain can
 6 transport and redistribute bed sediment, floodplain soil, and associated PCBs. As water flows, it
 7 is subject to resistance (drag) along the boundaries (surfaces) of all material it passes. The
 8 balance between gravity and drag forces along the flow path determines the velocity and depth of
 9 the flow. The force that flowing water exerts on the river bed and bank, as well as on floodplain
 10 when the water depth exceeds the height of the river banks, is described in terms of the shear
 11 stress. The hydrodynamic model in EFDC is used to simulate flow, depth, velocity, and shear
 12 stress throughout the Housatonic River system and floodplain. The velocity and shear stress
 13 results are used in subsequent EFDC sediment transport and PCB transport and fate
 14 computations.

15 Four Reviewers commented on the ability of the model to accurately simulate flows and
 16 velocities, which in turn affect bed shear and the resuspension of bed sediment into the water
 17 column. The Reviewers, however, were divided on their evaluations of this aspect of the
 18 modeling study. Two Reviewers indicated that the flow simulations were either “good” or
 19 “excellent,” but a third Reviewer felt that flow was not properly simulated due to errors in the
 20 timing (vs. magnitude) of flows. One Reviewer who was satisfied with the flow simulation
 21 specifically noted the timing issue, but indicated that such discrepancies were “not important.”

1 The fourth Reviewer believed that the size of the model grid cells precluded evaluation of
 2 processes, such as flow, that vary on sub-grid scales.

3 Two Reviewers generally had less confidence in the resultant bed shear and, as a consequence,
 4 the ability of the model to accurately simulate suspended solids concentrations. Both of these
 5 Reviewers felt that there were insufficient TSS data to make a satisfactory evaluation, but one
 6 concluded as a result that the model was unlikely to provide adequate prediction of PCB fate and
 7 transport.

8 **3.2.3 General Topic Response**

9 The Reviewer comments on this topic are diverse; therefore, no general response is
 10 provided. Responses to specific comments are provided below.

11 **3.2.4 Response to Specific Comments on General Topic 3B**

12 **Eric Adams**

13 **Flows and Velocities**

14 Flows were simulated for the 10.5 year Phase 2 calibration period (Figures 4.2-4 through 4.2-14).
 15 Unfortunately there is not much data to compare with. The most data are for early 1999 when
 16 the model consistently under-predicts flow. (Yet it seems to do well in the later validation
 17 periods, based on the pressure transducer data.) Similar agreement with stage suggests that
 18 average velocities should be pretty good. (Figure 4.2-26 shows reasonable agreement between
 19 measured and predicted velocities, but the predictions are generally too low; EPA argues that
 20 discrepancies are due in part to coarse grid resolution.) During storms there was reasonable
 21 agreement, with moderate overprediction of flow at low flow. Agreement during storms shows
 22 times of over- and under-prediction, but they seem OK on average. The model seems to do
 23 reasonably well simulating the extent of overbank flow during August 1990 (Figure 4.2-25).
 24 Model statistics seem generally within ranges specified by the QAPP and there are few
 25 indications of bias.

26 In the validation period, flows and velocities look similar to or better than the calibration period.
 27 There are some errors in the timing of flows, but these are not important. No major bias is seen.

28 **Response 3B-EA-1:**

29 EPA agrees with the Reviewer that the model framework hydrodynamic results
 30 are quite good with little bias.

1 W. Frank Bohlen

2 This matter of flow phase and velocity and associated effects on transport could be better
3 evaluated if the report had provided a more complete discussion of measured vs. modeled
4 velocities when presenting the results of EFDC hydrodynamic calculations (see pp.6-31 e.g.).
5 Although the model uses HSPF generated flows at the upstream boundary, the resulting
6 simulations are to some extent independent of the HSPF generated flow/stage through PSA and
7 as a result may be less sensitive to this matter of stage timing. Speeds were measured using both
8 electromagnetic and acoustic doppler currents meters for short periods of time at several
9 locations within the PSA (see Figs 4.2-26 and 6.2-8 (attached)). These comparisons, while taken
10 to be generally acceptable, indicate to me that there is very likely a substantial difference in
11 measured versus modeled sediment transport associated with these differences in velocity. These
12 flow induced differences will require substantial "calibration" within the model to yield
13 reasonable estimates of sediment/contaminant flux. Given the non-linearity of both the
14 velocity/shear stress and the shear stress/transport relationships it will be unlikely that such
15 calibration will result in accurate simulations across a wide range of flows. This may be the
16 principal reason that the model, at least some locations, seems to over-predict TSS values at low
17 flows while under-predicting them at high flows. The significance of such variations will tend to
18 increase with the duration of the model run and may become more of a problem during the
19 extended runs planned for the Corrective Measures Study.

20 Response 3B-FB-1:

21 The small differences in the timing of simulated and measured flows are not
22 significant, as noted by other Reviewers (see comment above from Eric Adams).
23 Much of the difference is attributable to the timing of flow estimates computed
24 using HSPF and used to drive EFDC. EPA believes that the hydrodynamics are
25 appropriate for the goal of the modeling study. The differences in simulated and
26 measured TSS concentrations are largely attributable to uncertainty in model
27 upstream boundary conditions and tributary loads rather than small differences in
28 hydrograph timing.

29 This depends to some extent on the characteristic being studied. For stream flow and stage
30 model/data comparisons are based on a relatively long data set covering a wide range of
31 seasonal, annual and intra-annual conditions at a number of sites throughout the PSA. The
32 resulting comparisons are clearly sufficient to evaluate model capabilities over a relatively long
33 period of time.

34 Moving to velocities and ultimately shear stress involves a significantly shorter data set at a
35 limited number of locations. This does not necessarily mean that the data are inadequate since
36 these characteristics are not expected to significantly change with time. As discussed above,
37 however, it is the comparisons presented in the MVR that are less than sufficient. Better use of
38 the available data would be the place to start. Careful review of the results of these analyses may
39 then point to the need for additional data from differing locations and/or modified measurement
40 procedures.

1 **Response 3B-FB-2:**

2 EPA agrees with the Reviewer that the model-data comparisons presented are
 3 sufficient to evaluate model capabilities over a relatively long period of time. See
 4 FMD Sections 3 and 4 for presentation and discussion of model framework
 5 results.

6 This model system is not yet ready for use in the CMS. Several issues remain to be addressed.
 7 First, as discussed above, the hydrodynamics must be more thoroughly verified so as to insure
 8 accurate specification of boundary shear stresses. This factor will be central to future evaluations
 9 of selected remedial schemes such as capping and is presently essential within evaluations of
 10 sediment and PCB transport. The information and data provided in the validation report does
 11 little to build confidence in the present formulation.

12 **Response 3B-FB-3:**

13 EPA disagrees with this Reviewer comment. The model framework can be used
 14 to evaluate the relative performance of potential remedial alternatives for the
 15 system. It should be noted that there is a fundamental misunderstanding
 16 between the many Reviewers and EPA regarding the use of the model
 17 framework for evaluation of alternatives. The framework will be used to examine
 18 the impact that potential remedial alternatives have on the system using a set of
 19 evaluation criteria established in the Consent Decree and Reissued RCRA
 20 Permit. The framework will not be used to engineer specific components of a
 21 remedy. This means that the framework is intended to examine only the large-
 22 scale, long-term impacts of remediation strategies.

23 **Marcelo H. Garcia**

24 As mentioned in the response to question one, the size of the computational grid makes it
 25 difficult (and meaningless) to compare model predictions for processes that take place at
 26 hydraulic and sedimentation scales determined by the flow rate and the main channel width.
 27 This is not the case for Woods Pond and the floodplains were the size of the computational grid
 28 is appropriate for the scale of the flow field.

29 **Response 3B-MG-1:**

30 EPA disagrees with the Reviewer's comment. The model framework has been
 31 calibrated and validated for individual events and longer periods. These
 32 comparisons demonstrate that the model framework simulated PCB transport in
 33 the Housatonic River system with the accuracy needed to achieve the modeling
 34 study goal. See FMD Sections 3 and 4.

1 E. John List

2 In general terms, the modeling tends to show excellent agreement for water mass fluxes, which is
3 not at all surprising as models to simulate the flow of water in channels have been in use for a
4 long time and a failure on this score would be cause for real alarm. There is only one adjustable
5 parameter for such models and this is the friction factor for the stream, if this parameter is
6 correctly chosen, and the stream cross-sectional area is correct, then the water levels and flow
7 rates can be very accurately simulated.

8 Response 3B-JL-1:

9 EPA agrees with the Reviewer's comment. The results obtained demonstrate
10 the proper functioning of the model framework.

11 The EFDC comparisons between measured and simulated flow and stage offered in Figures 6.2-3
12 of the Model Validation Report for years 1979-1999 present essentially no measured data and
13 should not be offered up as part of the validation. The comparisons for years 2002-2004 are
14 convincing that EFDC does a good job of representing flow and stage. However, the equivalent
15 time series of Total Suspended Solids (TSS) concentrations for 2002-2004 (Figures 6.2-19
16 through 6.2-22) do not really provide an adequate basis to conclude that the sediment transport is
17 being properly modeled (which is not surprising considering the points made above). The field
18 data are simply too sparse to make any meaningful comparison between simulation and
19 measured data. Even the data for two specific flow events modeled (Figures 6.2-23 and 6.2-24)
20 offer only a few measured data points for comparison. The use of actual measured sediment
21 rating curves either for calibration or for analysis is urged. The PCB sediment data offered in
22 Figures 6.2-49, 6.2-50, and Figure 6.2-51 indicate just how difficult is the process of validating
23 the PCB fate and transport model and how unlikely it will be that the existing model will provide
24 any real hope of predicting the future fate and transport of the PCB.

25 Response 3B-JL-2:

26 Although the density of data for TSS and PCB concentrations in the water
27 column is less than for flow and stage measurements, comparisons of model
28 results to the site data demonstrate that the model successfully simulates
29 sediment and PCB transport in the Housatonic River over the 26-year validation
30 period.

31 Model performance is often driven by the solids and PCB loads entering the
32 system from the upstream boundary. These upstream boundary conditions are
33 rating curves where concentrations are parameterized as functions of flow, as
34 described in FMD Appendix B.2. However, the uncertainty associated with these
35 rating curves is large as a result of natural variations in solids and PCB
36 concentrations. For example, solids and PCB concentrations can vary by more
37 than a factor of 100 at any one flow rate. Even if rating curves for downstream
38 locations could be developed, they would have very large uncertainty due to
39 natural variability. Consequently, EPA believes that direct comparison of model

1 results to individual data (however sparse) is the most reliable means to evaluate
2 model performance.

3 Further, EPA believes the model framework can successfully simulate long-term
4 PCB transport and fate in the Housatonic River because the model calibration
5 approach helps ensure that all processes are properly parameterized and also
6 because the model meets the established performance targets. Evaluations of
7 model performance are documented in FMD Section 3.

1 **3.3 GENERAL TOPIC 3C: FLOODPLAIN INTERACTIONS**

2 **3.3.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Bohlen	Page 8, lines 24 to 37
	Page 14, lines 26 to 31
Endicott	Page 20, line 33 to page 21, line 3
Garcia	Page 1, lines 25 to 37
	Page 4, line 19 to page 5, line 2

3 **3.3.2 General Topic Summary**

4 In addition to aggradation and degradation of bed sediment, the banks of the Housatonic River
 5 are routinely modified by erosion, and interaction of the river channel with the floodplain occurs
 6 during periodic out-of-bank flood events. As riverbanks erode, solids and PCBs in the banks
 7 enter the river channel where they may be transported farther downstream. Similarly, periodic
 8 out-of-bank flow events transport solids and PCBs across the floodplain. Due to increased
 9 vegetative resistance relative to the river channel, flow velocities through inundated portions of
 10 the floodplain are expected to be smaller than velocities in the channel. Consequently, materials
 11 transported from the channel accumulate in the floodplain (Leopold et al., 1964; Knighton,
 12 1998). In addition to vegetative resistance, the magnitude of accumulation of solids and PCBs
 13 on the floodplain may also depend on other factors, such as the frequency and duration of out-of-
 14 bank events; upstream sediment, PCB, and overland solids inputs; floodplain topography; and
 15 the deposition characteristics of the materials in transport (see Appendix B.7 to the FMD).

16 With regard to sedimentation and related processes in the floodplain, one Reviewer noted that
 17 the model accounts for bank erosion and floodplain sedimentation/resuspension but does not
 18 consider transport of contaminated leaf litter or wash-off of material adhering to floodplain
 19 vegetation following flood events. The Reviewer questioned whether any thought had been
 20 given to including these processes in the model and suggested that phytoremediation might be
 21 considered in the floodplain.

1 Another Reviewer underscored the importance of processes in the floodplain and listed them
2 along with a wide variety of other processes that he felt needed to be better understood and
3 improved in the simulation. He further noted that the model had been validated over a long time
4 frame (i.e., 26 years), but the majority of transport occurs during relatively short storm events,
5 and he recommended that the model also be validated over shorter periods of high flow. Finally,
6 the Reviewer suggested that calculation of a “Floodplain Dimensionless Number” for specific
7 reaches could be used as a tool to evaluate the validation.

8 **3.3.3 General Topic Response**

9 The Reviewer comments on this topic are diverse; therefore, no general response is
10 provided. Responses to specific comments are provided below.

11 **3.3.4 Response to Specific Comments on General Topic 3C**

12 **W. Frank Bohlen**

13 The side bank issue affects both the margins of the river channel and the floodplain. All
14 indications suggest that this latter area is primarily a sink for sediment and PCBs. As I
15 understand it, the model treats each of the grids on the floodplain in a manner similar to those in
16 the river channel and seeks to erode the soil surface by flow induced shear during flooded
17 conditions. Given the presence of vegetation this very seldom occurs leading to continuing
18 deposition over most of the area. What sediment and PCB that is supplied by the floodplain
19 comes from aperiodic failure of the floodplain margin or sidebank.

20 **Response 3C-FB-1:**

21 Floodplain interactions are not exclusively limited to solids and PCB deposition.
22 The model framework can simulate both erosion and deposition in the floodplain.
23 Over the course of the simulations, some erosion may occur in the floodplain.
24 This is just one example of why it is so important to actively include the floodplain
25 in the model domain. Further, bank erosion is a significant source of both solids
26 and PCB. Over the course of the 26-year model validation period, bank erosion
27 amounts to approximately 13% of the solids mass budget and approximately
28 28% of the PCB mass budget. See FMD Section 4 for further detail.

29 If correct, this scheme seemingly neglects any transport associated with the movement of leaf
30 litter and/or the rainfall induced wash-off of materials adhering to the surfaces of vegetation
31 following flood inundation. Has consideration been given to the inclusion of these factors in the
32 model? If not, is there a solid basis for their neglect? It may be that this is a subject that could be

1 quantified in the revised monitoring program recommended above. It may also be that
2 phytoremediation should be included in this program (if it has not previously been investigated)
3 and/or included in the upcoming CMS.

4 **Response 3C-FB-2:**

5 EPA believes that the potential for PCB loading to the river via the mobilization of
6 leaf litter or particle wash-off from vegetation is an extremely small component of
7 the overall mass fate of PCBs in the Housatonic River system because the mass
8 of particles or leaf litter involved is expected to be orders of magnitude less than
9 the mass entering by bank erosion. The solids and PCB masses entering the
10 river by bank erosion is, however, quantified in the model framework.

11 Identification and analysis of potential remedial alternatives will be performed by
12 GE in the CMS. It should be noted, however, that phytoremediation is not a
13 remediation technique that has been found to be effective for PCBs.

14 Next, additional work is required to develop an accurate formulation of sediment transport. The
15 suggestions of Dr. Lick in terms of both equation parameters and the structure of the sediment
16 bed should be carefully evaluated. There seems to be an abundance of data and experience to
17 suggest that 6in is an overestimate of the active bed thickness. There is also concern that the
18 model as it exists may be biased to high flow conditions. Add to these questions regarding side
19 bank erosion and floodplain dynamics.

20 **Response 3C-FB-3:**

21 See Section 2.3.2 and Appendix B.8 of the FMD for a review of sediment
22 transport process formulations and bed representation. Active bed thickness in
23 EFDC is on the order of 4 to 7 cm (1.5 to 2.75 inches). Further, the thickness of
24 the active layer in the bed has been verified through using sediment profile
25 imagery as presented in Appendix A.3 to the FMD. Additional discussion of the
26 representation of the sediment bed is presented in FMD Appendix B.5.

27 **Douglas Endicott**

28 As pointed out by GE, predictions of PCB concentrations in flood plain soils are untested. There
29 appear to be substantial increases in PCB concentrations in the top 6" of much of the floodplain
30 soil in both example projections, which is somewhat surprising. However, since no data have
31 been shown to establish rates of PCB concentration change in floodplain soils, the
32 "reasonableness" of the flood plain projections cannot be determined. Really, this illustrates the
33 absurdity of devoting so many EFDC model grid cells to the flood plain, which it seems dictated
34 using a single footprint of tiles for the grid of the river.

35 **Response 3C-DE-1**

36 EPA disagrees with the Reviewer's opinion regarding the "absurdity of devoting
37 so many EFDC model grid cells to the floodplain..." Because 60% of the PCBs

1 within Reaches 5 and 6 (which contain an estimated 90% of the PCB mass) are
2 estimated to be in the floodplain, this portion of the domain deserves the
3 attention provided by the grid. This is required to obtain an understanding of the
4 response of the potential remedial alternatives with regard to the commensurate
5 reduction in risk.

6 In response to comments in General Topic 3 and General Topic 4, EPA indicated
7 that trading grid resolution on the floodplain for resolution in the channel would
8 not achieve substantial benefits in grid implementation because calculations are
9 performed in floodplain cells during a small portion of the simulation (when these
10 cells are wet). Conversely, decreasing the number of cells on the floodplain and
11 increasing the cells in the channel would dramatically increase run time.

12 In response to the Reviewer's assessment of "substantial increases in PCB
13 concentrations in the top 6" of much of the floodplain soil," it is noted that these
14 represent large percentage increases from initial concentrations (e.g., a 100%
15 change if concentrations increased from 0.5 to 1 mg/kg). Uncertainty in
16 establishing initial conditions is a major factor that contributed to increases in
17 floodplain soil concentrations simulated by the model. Both of these factors are
18 discussed in more detail in Appendix B.3 of the FMD.

19 **Marcelo H. Garcia**

20 While a substantial effort has gone into improving the capabilities of the Housatonic River
21 Model since its calibration, it is clear that there is still a long way to go before the model can
22 truly be used as a "predictive tool" to quantify future spatial and temporal distributions of PCBs
23 (both dissolved and particulate forms) within the water column and the bed sediment.

24 This Reviewer is of the opinion that the Housatonic River Model will need to be continuously
25 improved until all the processes (biological and physical bed sediment mixing, streambank
26 erosion, floodplain deposition, etc.) relevant to the transport and fate of PCBs are not only
27 accounted for in the model but are also well represented and based on sound knowledge of
28 sediment transport mechanics, stream biology, ecology and morphodynamics.

29 **Response 3C-MG-1:**

30 EPA disagrees with this comment because the ability of the model framework is
31 already well-established (as documented in Sections 3 and 4 of the FMD, which
32 summarize previous model performance). With regard to bank erosion and
33 floodplain interactions, these processes are included in the model, as described
34 in FMD Appendix B.7. All relevant processes are included, at the relevant
35 scales, and are based on the current understanding of these processes.

36 Regarding floodplain sedimentation, the model has been used to predict process-based
37 (advection, erosion, deposition, volatilization, etc) sediment and PCB fluxes (Kg/year) for the
38 main channel and the floodplain, over the validation period (Figures 6.2-62 and 6.2-63). The
39 analysis results in an estimate of yearly fluxes. However, it is well known that sediment erosion

1 and transport is most prominent during flood events, which can have duration of a few hours to
 2 several days. Thus it would seem that the model should be validated for time scales that are
 3 relevant to the processes involved.

4 Since a large percentage of the river system consists of floodplain, it is important to ensure that
 5 the model can indeed capture the process of floodplain sediment/PCB deposition. To this end, a
 6 simple one-dimensional approach was suggested that could be used to estimate a “Floodplain
 7 Dimensionless Number” for different reaches of the Housatonic River (Garcia, 2006-technical
 8 note on floodplain sedimentation). Once such number is calibrated for each reach, it will be
 9 possible to test if indeed the model can predict floodplain depositional rates that result in similar
 10 Floodplain numbers for different flooding conditions (hydrologic event scale), thus helping in
 11 the overall validation of the model. This approach will clearly show the capabilities of the
 12 model. If there is any hope of predicting PCBs fate in the floodplain, sedimentation has to be
 13 properly simulated by the model.

14 **Response 3C-MG-2:**

15 See Appendix B.7 to the FMD for specific discussion of the “Floodplain Number.”
 16 Although the duration of flood events is typically short, it should be noted that the
 17 storm event water column sampling program was specifically designed to provide
 18 measurements of solids and PCB concentrations during events. Focusing on
 19 Reaches 5 and 6, all inputs and outputs to the model domain during events can
 20 be reasonably determined from the event data in combination with other flow
 21 data. From this information, the mass of solids and PCBs accumulating in the
 22 sediment bed and floodplain areas can be successfully determined from the
 23 difference between inputs and outputs. This is a reasonable approach because it
 24 is based on a fundamental engineering principle, conservation of mass.

25 Furthermore, application of a dimensionless Floodplain Number (FN) is
 26 fundamentally flawed because the specific types of measurements needed to
 27 develop FN values do not exist for the Housatonic River system. In the absence
 28 of measurements, the only values that could be used to compute a FN would
 29 themselves be computed by averaging EFDC results. Consequently, a
 30 difference between an inferred FN value and full-scale EFDC results would
 31 indicate only a difference between the one-dimensional assumptions of the
 32 scaling analysis used to derive the FN and the two-dimensional conditions
 33 simulated by EFDC during out-of-bank events. More importantly, if values for
 34 parameters needed to compute a FN were known or could be determined from
 35 measurements, these values could be directly compared to values computed in
 36 EFDC without the need for an approximation using the FN. As a result, the FN
 37 approach is not informative for evaluating model performance.

1 **3.4 GENERAL TOPIC 3D: BED LAYERING AND BED MIXING**

2 **3.4.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 2, line 29 to page 3, line 23
Bohlen	Page 10, lines 25 to 32
	Page 13, lines 5 to 11
	Page 14, lines 26 to 31
Endicott	Page 3, lines 13 to 27
Garcia	Page 6, lines 4 to 7
Lick	Page 6, line 9 to page 7, line 43

3 **3.4.2 General Topic Summary**

4 The specification of vertical layers (compartments) in the sediment, and the extent to which
 5 material communicates between different layers, controls simulated sediment and water
 6 contaminant concentrations that drive food chain exposures. One element of sediment column
 7 compartmentalization of particular importance to PCB transport and bioaccumulation model
 8 development is the delineation of the active layer within the sediment bed. The depth (thickness)
 9 of the active layer can be a controlling factor when estimating food chain exposure
 10 concentrations.

11 The term “active layer” may be one of the most confusing phrases used in PCB transport and
 12 bioaccumulation studies because it has distinctly different meanings, depending on context. The
 13 commonality in all of these contexts is that the active layer is ultimately expressed as a depth
 14 into the sediment column over which mass transport processes or exposure can occur.
 15 Consequently, the compartmentalization and parameterization of layers in the sediment column
 16 is an important consideration.

17 Several Reviewers commented on the sediment bed layering in the model, particularly with
 18 regard to the specification of the thickness of the well-mixed surface layer and the rate of mixing
 19 between layers. In discussing this issue, all of these Reviewers focused on mixing attributable to
 20 benthic infauna and epifauna, and all agreed it is an important issue because it directly affects the

1 rate of change in sediment PCB concentrations as a result of simulated remedial alternatives.
2 Reviewers also agreed that the specified depth of the well-mixed layer was too thick, although
3 there was apparently some confusion about what depth(s) were used in the Validation.

4 **3.4.3 General Topic Response**

5 The mixing of particles and sorbed contaminants in surface layers of the sediment bed
6 is a complex, site-specific, time-dependent process. The extent and rate of particle
7 mixing in the sediment bed can vary widely. The causative agents of sediment mixing
8 also vary from site-to-site and time-to-time. For example, mixing can be caused by
9 benthic organisms and macrofauna (bioturbation), physical causes such as turbulent
10 burst and sweep, and chemical processes such as gas ebullition.

11 Throughout the Peer Review, numerous opinions were offered with respect to the extent
12 and rates of particle mixing. Most Reviewers focused on bioturbation attributable to
13 benthic organisms, largely neglecting mixing by other factors. Comments made on
14 behalf of GE furthered this discussion and also focused exclusively on bioturbation by
15 benthic organisms (QEA, 2006). In contrast, while the extent and rates of sediment
16 mixing in the model framework were based on literature review and site-specific
17 determinations based on measured benthic organism types and densities, this was
18 done with the explicit recognition and understanding that other factors may control
19 mixing at any site over time.

20 Further review of mixing by benthic bioturbation was performed and is summarized in
21 Appendix B.4 to the FMD. Sediment profile imaging (SPI) was also conducted and is
22 summarized in FMD Appendix A.3. In the SPI study, a high-resolution camera was
23 inserted into the sediment bed of the river to take detailed photographic images of
24 sediment profiles at 52 stations in Reaches 5 and 6. A total of 175 sediment profiles
25 were collected. Based on the interpretation of these profiles, average sediment mixed
26 layer depths were determined to range from 3 to 16 cm. Furthermore, in many locations
27 rapid physical processes were determined to be the primary agent for mixing. The
28 model formulation is consistent with these observations, specifically with respect to the

1 parameterization of surface layer thickness. Moreover, these results suggest that it
2 might be reasonable to specify faster rates of mixing in the model.

3 **3.4.4 Response to Specific Comments on General Topic 3D**

4 **Eric Adams**

5 **Biomixing and Bioavailable Depth**

6 Originally, the model used a bioavailable depth of 15 cm over which the biomixing coefficient
7 (bio-diffusivity) was $D_b=10^{-9}$ m²/s, or approximately 1 cm²/d. I commented that this seemed
8 quite large, and EPA agreed. They have changed their formulation to utilize a subduction
9 velocity, V_s , which they get from a literature review of the rates of sediment mass reworking per
10 organism per time, and site-specific data on organism abundances. Their chosen velocities are
11 approximately $V_s \sim 10^{-9}$ m/s over the top 4-7 cm, and $\sim 10^{-10}$ m/s over the next 6-8 cm. In the
12 absence of direct measurements of mixing, this may be the best approach, but it is noted from
13 figures presented at the May 10 Document Review Meeting (DRM) that there is tremendous
14 variability in organism reworking rates, suggesting much uncertainty.

15 Assuming a vertical distance of 5 cm between the top two sediment layers, their equivalent new
16 values of bio-diffusivity are $\sim(10^{-10}$ to 10^{-9} m/s)(0.05m) $\sim 5 \times 10^{-12}$ to 5×10^{-11} m²/s or ~ 20 to 200
17 times smaller than previous. These are probably more reasonable, but it is difficult to assess
18 whether or not they are right, because there is not much vertical variation in the existing
19 sediment PCB concentrations. However, following remediation, the vertical concentration
20 gradients could increase substantially, so this is an important process.

21 This also raises the issue of vertical resolution. If, following remediation, clean sediment is
22 overlain by a thin layer of contaminated sediment, the numerical model will immediately mix the
23 contaminant over the top layer (say 5 cm), whereas, with a bio-diffusivity of 5×10^{-7} cm²/s,
24 mixing will take $(5\text{cm})^2/5 \times 10^{-7}$ cm²/s or about 1.5 years to achieve this mixing. Thus, from a
25 numerical modeling standpoint, **the vertical grid size is too large.**

26 The sediment-water interface can rise or fall due to deposition and erosion, and EPA argues that
27 this should not affect the rates of mixing. This may not be true since you could expect different
28 rates of organism mixing in relatively fine grained sediments that have been recently deposited,
29 versus older, more consolidated sediments that have been eroding. Indeed, Figure 13 of the
30 DRM handouts on sediment mixing shows a strong increase in V_s with percent fines. However,
31 to honor their assumption, they make V_s dependent only on the depth below the (moving)
32 interface. But because the individual layer thicknesses are changing, the amount of vertical
33 mixing will change. (A constant value of V_s will result in more mixing between thick layers
34 having the same concentrations as thin layers.) Using a bio-diffusivity (dimensions of L^2/T)
35 would take this effect into consideration since it is effectively V_s times the mixing length.

1 Response 3D-EA-1:

2 See the General Response above. The Reviewer comment focuses exclusively
3 on biological mixing. Biological mixing is believed to be the slowest process of all
4 the processes that are believed to cause particles in upper sediment layers to
5 mix over time. As presented in Appendix A.3 to the FMD, sediment profile
6 images conclusively show that mixing depths in the Housatonic River range from
7 3 to 16 cm. The model framework is consistent with these site-specific
8 observations.

9 W. Frank Bohlen

10 The model/data comparisons for PCBs should be extended to include consideration of
11 distributions over the vertical. Any assumption of a well mixed layer extending over depths in
12 excess of a few inches doesn't seem to agree with field data (see e.g. Fig. 4-21c, BBL,2003,
13 attached). How are these differences to be reconciled? (i.e. use of 6" well mixed layer vs.
14 detailed core data showing little mixing beyond 1-2in). These core data and associated radio-
15 dating also allow estimates of sedimentation rate to be compared to the mass flux data provided
16 by the model. This comparison was not part of the validation report. It would provide an
17 additional check on model results and is recommended.

18 Response 3D-FB-1:

19 See FMD Section 2.3.2 and Appendix B.8 for a review of sediment transport
20 process formulations and bed representation. Active bed thickness in the model
21 (specifically EFDC) is on the order of 4 to 7 cm (1.5 to 2.75 inches). Further, the
22 thickness of disturbed sediment in the bed has been quantified through sediment
23 profile imagery as presented in Appendix A.3 to the FMD. Additional discussion
24 of the representation of the sediment bed (with supporting sediment profile
25 imagery) is presented in FMD Appendix B.5. See General Response above.

26 In addition to testing of the erosion formulation additional sensitivity analyses should be
27 performed to assess model response to the thickness of the active sediment column. This has
28 been a matter of concern for some time. Experience in other riverine/bayou systems as well as
29 the detailed core data (Fig. 4-21c, attached) indicate to me that the active bed used in the model
30 is too thick. It may be that this specification in terms of physical transport characteristics has
31 relatively little effect on overall model results (although that might bring up another set of
32 questions). A test of model response to this characterization is recommended.

33 Response 3D-FB-2:

34 With respect to active layer thickness, see General Response above. Although
35 the thickness of the active sediment layer was not explored as part of the model
36 sensitivity analyses, it was included in the model uncertainty assessment
37 conducted in the MVR.

1 Next, additional work is required to develop an accurate formulation of sediment transport. The
2 suggestions of Dr. Lick in terms of both equation parameters and the structure of the sediment
3 bed should be carefully evaluated. There seems to be an abundance of data and experience to
4 suggest that 6in is an overestimate of the active bed thickness. There is also concern that the
5 model as it exists may be biased to high flow conditions. Add to these questions regarding side
6 bank erosion and floodplain dynamics.

7 **Response 3D-FB-3:**

8 See Response to 3D-FB-1. Bank erosion is constrained to reproduce site-
9 specific long-term and short-term average erosion rates. Also see the General
10 Response above and FMD Appendix B.7.

11 **Douglas Endicott**

12 The vertical representation of the sediment bed in the PCB fate and transport model: The
13 thickness of the surficial sediment layers have been specified as either 4 cm (Reach 5A) or 7 cm
14 (Reaches 5B thru 6). These layers are assumed to be well-mixed, via a combination of physical
15 and biological processes. In addition, sediments from the surficial layers are mixed with deeper
16 layers, down to a depth of 30 cm below the sediment-water interface. Analysis of benthic
17 invertebrate data is offered to justify these assumptions. However, these data show that below
18 Reach 5A the benthos are predominantly filter feeders or surficial sediment feeders/dwellers.
19 Such organisms are unlikely to cause sediment mixing below the top couple of centimeters. 7 cm
20 of surface sediment mixing is too deep, and mixing of sediment between the surface layer and
21 deeper layers is inconsistent with the life history data for the resident benthos in these reaches.
22 The consequence of too much sediment mixing (and too-thick surficial layers) is that the PCB
23 fate and transport model will predict an unreasonably slow rate of decline in surficial sediment
24 PCB concentrations, which is observed in both Phase 2 calibration and validation periods.

25 **Response 3D-DE-1:**

26 EPA strongly disagrees with this Reviewer comment. First, it must be noted that
27 this comment is predicated on an erroneous assumption that surface sediment
28 PCB concentrations are declining rapidly. As documented in the RFI, FMD
29 Appendix A.1, and elsewhere (see General Topic 1 and General Topic 2), the
30 rate of change of PCB concentrations in surface sediments is slow and cannot be
31 distinguished from zero (i.e., slow to no change over time). Second, although the
32 Reviewer's comment recognizes that physical mixing processes can occur, it
33 presumes that benthic organisms are the sole cause of mixing in sediments. In
34 contrast, SPI results demonstrate that well-mixed layer thicknesses in
35 Housatonic River sediment range from 3 to 16 cm on average. In many of these
36 profiles, the cause of mixing was attributed to physical and chemical processes
37 rather than biological processes.

1 Marcelo H. Garcia

2 In the case of low flow conditions, the model predictions seem to be very sensitive to diffusion
3 parameters, suggesting the representation of pore water diffusion as well as the thickness of the
4 so-called “mixed layer” need to be carefully analyzed.

5 Response 3D-MG-1:

6 See the General Response above and FMD Appendix A.3. The representation
7 of the mixed layer in the model is consistent with site conditions as confirmed
8 through sediment profile imagery.

9 Wilbert Lick**10 The Sediment-Water Flux of HOCs Due to “Diffusion”**

11 The non-erosion/deposition flux of contaminants from the sediments to the overlying water is
12 primarily due to molecular diffusion, bioturbation, and ground-water flow. Each of these
13 processes behaves in a different way and hence needs to be modeled in a different way. EPA has
14 chosen to describe all of these processes by means of a “diffusion” model based on the concept
15 of bioturbation and the assumption of a well-mixed layer. This is the conventional, but not
16 necessarily accurate, approach. It is not accurate simply because the mass transfer
17 approximation (which is not a diffusion approximation) actually used by EPA does not describe
18 or adequately approximate the HOC fluxes of molecular diffusion, bioturbation, or ground-water
19 flow, not even in functional form. The correct functional form (especially its dependence on
20 time) is important because, otherwise, even calibration doesn’t work for long term predictions.

21 EPA did an extensive review of the literature on bioturbation and listed 139 documents of which
22 43 were retained for detailed review. This listing is somewhat misleading. Of the 43 most
23 relevant documents, almost all are general observations, surveys of the literature, or even surveys
24 of surveys; only about six report quantitative data or laboratory measurements of mixing due to
25 benthic organisms. For example, the figure shown at the last meeting entitled “Bioturbation and
26 Bioavailable Sediment Depths” is from Clarke et al. (2001) and is their interpretation of what
27 organisms do. There is no data (given by Clarke et al. or anywhere else) to support this figure.
28 Clarke et al. is an excellent manuscript, but it is another survey. There is no new data there.
29 None of the documents listed by EPA report on the sediment-water flux or sediment mixing of
30 hydrophobic organic chemicals (HOCs) due to benthic organisms. Since then, EPA has listed
31 additional reports concerned with the flux of HOCs due to benthic organisms. However, these
32 HOCs had relatively low partition coefficients. The only quantitative data that I know of on the
33 effects of benthic organisms on the flux of HOCs with large partition coefficients and their
34 resulting vertical distribution in the sediments is that by Luo et al. (2006) which is attached.
35 Some of my comments are based on this article.

36 In EPA’s modeling, assumptions are (1) a constant (independent of space and time) sediment-
37 water mass transfer coefficient, k , with a value of 1.5 cm/day and (2) a surficial, well-mixed
38 layer whose thickness is constant in time but varies spatially from 4 cm upstream to 7 cm
39 downstream. Measured biomass varies by about a factor of 20 from upstream to downstream.

1 Benthic mixing is described by EPA in terms of a mixing rate (a diffusion process), also termed a
2 subduction velocity (a convection process), a quantity which I believe is used in the model as a
3 mass transfer coefficient between the sub-surface sediment layers. For the biologically mixed
4 layer, the subduction velocity (values from EPA's table) varies from about 1×10^{-9} m/s (1×10^{-2}
5 cm/day) upstream to 2×10^{-9} m/s (2×10^{-2} cm/day) downstream. This factor of two between
6 upstream and downstream seems surprising since the biomass increases by a factor of 20 in the
7 downstream direction. Even more surprising is that the mass transfer coefficient, k , is assumed
8 constant everywhere at 1.5 cm/day. Why doesn't k increase downstream as the biomass
9 increases by a factor of 20?

10 A surficial well-mixed layer whose thickness is constant in time is assumed in the analysis. An
11 approximate and minimum time for formation of this layer can be calculated from $t = h/v_b$, where
12 h is the thickness of the layer and v_b is the subduction velocity. For the upstream area, $h = 4$ cm,
13 $v_b = 1 \times 10^{-9}$ m/s = 1×10^{-2} cm/day, and therefore $t = 400$ days. For the downstream area, $h = 7$
14 cm, $v_b = 2 \times 10^{-9}$ m/s = 2×10^{-2} cm/day and therefore $t = 350$ days. In other words, these so-
15 called well-mixed layers are not formed instantaneously and take a minimum of 350 to 400 days
16 to form.

17 This becomes a little confusing upon examination of the figure presented at the meeting entitled
18 "Contribution to Db from different groups of benthos". Upstream, Db (for all benthos) is
19 approximately 2×10^{-3} cm/day while downstream, oligochaetes (the main vertical burrowers and
20 subductionists) contribute a Db of approximately 2.5×10^{-2} cm/day. The upstream number is an
21 order of magnitude less than the number in the table cited above as v_b , is probably correct, but
22 gives a time for formation of the well-mixed layer of almost 2000 days (6 years).

23 Despite the confusion, the numbers for Db are probably correct (to within less than an order of
24 magnitude). This demonstrates (as does Luo et al. more accurately and convincingly) that so-
25 called well-mixed layers for HOCs, if they exist, take a long time (years) to form. Is there any
26 evidence that a well-mixed layer even exists in the Housatonic? I don't believe so.

27 The mass transfer coefficient, k , for the transport of HOCs by molecular diffusion alone is
28 approximately 1.2 cm/day and decreases slowly with time at a rate which decreases as K_p
29 increases (Deane et al. 1999, Lick et al. 2006, attached). If there is only a small number of
30 organisms, EPA's value of $k = 1.5$ cm/day compares well with this number. However, with
31 benthic organisms present, Luo et al. give a mass transfer coefficient for HOCs that varies up to
32 10 cm/day (for benthic organism densities of $10^4/\text{m}^2$) and somewhat higher for very dense
33 concentrations of organisms; these values for k are much higher than those that EPA assumes.

34 No consideration is given to ground-water flow, which can be significant, is a convection and not
35 a diffusion process, and does not involve a well-mixed layer of any sort.

36 **Response 3D-WL-1:**

37 EPA disagrees with the Reviewer's comment. It should be recognized that this
38 comment is predicated on the assumptions that: (1) particle mixing must always
39 be very slow as controlled by benthic bioturbation rates; and (2) a well-mixed
40 layer does not exist and will not form. Specifically, the Reviewer asks if there is

1 any evidence that a well-mixed layer exists in the Housatonic River. As
2 documented in Appendix A.3 to the FMD, 175 sediment profiles images were
3 obtained at 52 stations to further document the knowledge of sediment mixing in
4 the Housatonic River. Based on these observations, well-mixed sediment layers
5 exist and range in thickness from 3 to 16 cm. In many of these profiles, the
6 cause of mixing was attributed to physical and chemical processes rather than
7 biological processes. Therefore, in specific answer to the Reviewer's
8 speculations, the sediment profile images conclusively demonstrate that a well-
9 mixed layer exists in the Housatonic and that apparent rates of mixing can be
10 much larger than inferred by the Reviewer.

11 Further is should be noted that the "diffusion" term on which the Reviewer
12 comments is the sediment-water mass transfer process. This mass transfer
13 process represents an aggregation of individual processes that may include
14 diffusion, groundwater advection, bioirrigation, and others. The important issue
15 for a practical model application is whether the mass transfer of PCBs from the
16 bed to the water column is adequately represented. At the scales of interest for
17 the modeling study, there is no need to further determine which of the underlying
18 mechanisms are actually transporting PCBs from the bed as long as the net flux
19 from the bed is accurately represented. In the specific case of the Housatonic
20 River, the sediment-water mass transfer of PCBs from the bed is one of the most
21 well-defined elements of the model framework because the scale of this flux was
22 determined directly from measurements.

23 See Appendix B.10 to the FMD for further details regarding the sediment-water
24 mass transfer of PCBs.

1 **4. GENERAL TOPIC 4: MODEL EFFICIENCY, COMPUTER**
 2 **RESOURCES, AND RUN TIME**

3 **4.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 12, lines 37 to 44
	Page 13, line 21 to page 14, line 37
Bohlen	Page 14, line 32 to page 15, line 15
	Page 15, lines 16 to 23
Endicott	Page 7, lines 20 to 25
	Page 8, lines 8 to 12
Garcia	Page 2, lines 33 to 37
	Page 6, lines 13 to 17
Gobas	Page 4, lines 17 to 31
	Page 4, lines 38 to 45
	Page 14, lines 11 to 13
Lick	Page 10, lines 14 to 34
	Page 13, lines 17 to 19

4 **4.2 GENERAL TOPIC SUMMARY**

5 Mathematical models provide simplified or approximate representations of reality. In reality,
 6 chemical and physical properties can vary continuously in space and time. In a mathematical
 7 model, these continuous variations are represented by step-changes in discrete intervals of space
 8 (a grid cell) and time (the timestep). The use of a grid to represent a physical domain
 9 necessitates approximations of spatial variations in physical and chemical properties, because
 10 within each grid cell, a single representative value is used, even if properties within the grid cell
 11 vary in space. The continuous temporal change in a physical or chemical property is
 12 approximated by a sequence of steps, in which the property (e.g., concentration) is represented
 13 by a single value over the timestep. The finer the resolution in space and time, the more closely
 14 the step-changes in space and time can approximate the true continuous variations. (Temporal
 15 and spatial coverage of data, however, can impose limitations on the approximation of the

1 continuous solution). The choices of spatial and temporal resolution have direct impacts on the
2 run time and computer resources required for a particular simulation.

3 A number of techniques are used in model development to balance the conflicting objectives of
4 (1) high temporal and spatial resolution, and (2) acceptable run times. These techniques include
5 dynamic time-stepping, split time-stepping, and model linkage options. Dynamic time-stepping
6 refers to changing the timestep during the course of the simulation, in response to changes in
7 flow conditions. Split-time-stepping refers to the use of different timesteps in different parts of
8 the grid, such as in the sediment bed, where changes are much slower than in the water column,
9 or by skipping calculations on the floodplain, when cells are not inundated. EFDC includes
10 options to use both dynamic and split time-stepping. Another technique involves the linkage
11 between hydrodynamic, sediment transport, and contaminant fate submodels. EFDC runs all
12 three of these modules simultaneously.

13 Some model codes perform the calculations for hydrodynamics and sediment transport together
14 and then write output files, which are read as input to the contaminant fate model. It is also
15 possible with some models to run hydrodynamics and sediment transport independently.
16 Decoupling of models involves approximating more-finely resolved temporal variations in model
17 results, such as flow or water depth, by an average value over some specified averaging period,
18 for example, 1 hour. The choice of the averaging period represents a trade-off between the
19 accuracy of the approximation of the averages to the finer time-scale computations versus file
20 sizes required to pass hydrodynamic output to the sediment transport model or hydrodynamic
21 and sediment transport output to the contaminant fate model. The effort to decouple an existing
22 model depends on the structure of the code. Decoupling code includes re-structuring the code,
23 developing averaging algorithms for each model output passed to subsequent submodel, and
24 testing the results for mass balances and consistency with the results of the original fully
25 integrated code.

26 Five of the seven Reviewers commented on the computer resources required to run the model
27 and the consequent long run times necessary for the simulation of the effectiveness of remedial
28 alternatives. A number of recommendations were provided for decreasing the run time, with
29 four of the Reviewers suggesting the decoupling of various model components. Three of the

1 Reviewers recommended that some parts of the model could be used to generate “synthetic”
2 sequences such as 1 year of hydrology that is repeated many times or approximate low-flow
3 solutions that are substituted for long periods of low flow, interspersed with full solutions for
4 high-flow events. Three Reviewers recommended that the model grid be simplified, in most
5 cases by increasing cell size in the floodplain, and even, as recommended by one Reviewer,
6 eliminating the use of the model in the floodplain and substituting a reach-specific dimensionless
7 number that could be used to quantify PCB deposition.

8 **4.3 GENERAL TOPIC RESPONSE**

9 The physical characteristics of the Housatonic River present a challenging setting for
10 grid development and contaminant fate and transport modeling, which is further
11 complicated by the need to include the floodplain in the computational domain. The
12 floodplain was included in the computational grid because it has been estimated that
13 60% of the PCBs present in the PSA are in the floodplain, and risks to human health
14 and the environment were identified from exposure to PCBs in the floodplain. Coupling
15 grid cells in the meandering channel with grid cells on the floodplain complicated the
16 development of the grid, and required careful balancing of grid resolution versus
17 simulation run time objectives.

18 The modeling team clearly recognizes the significance of run time issues associated
19 with decadal-scale EFDC simulations, and appreciates the Reviewers’ thoughtful
20 recommendations of potential options for reducing run time. Many of these same
21 recommendations were made at the time of the Model Calibration Peer Review. These
22 recommendations were considered then, and reevaluated based on the additional
23 comments received following the Model Validation Peer Review.

24 Several Reviewers commented that decoupling the channel grid from the floodplain grid
25 could provide a reduction in run time. However, EFDC already contains logic tests,
26 which provide a means of bypassing computations for floodplain cells that are not
27 inundated, so the floodplain and channel are effectively decoupled during the majority of
28 the time when in-bank flows are simulated.

1 Reviewers suggested that increased grid resolution in the channel could be included
2 without increasing run time, if there were a reduction in the grid resolution on the
3 floodplain. The change in model run time resulting from decreasing grid cells on the
4 floodplain and increasing grid cells in the channel goes beyond comparing the total
5 number of grid cells in the model domain. The logic checks in EFDC, which allow
6 computations on the floodplain to be bypassed if the cells are not flooded, results in
7 calculations in floodplain cells at only a fraction of the time calculations are performed in
8 channel cells. Including a higher resolution grid in the channel and decreasing the
9 resolution on the floodplain would result in an increased number of cells that would be
10 constantly active, and therefore would result in substantially increased model run time.
11 These factors are discussed in Appendix B.1 of the FMD, and in Response to General
12 Topic 3.

13 Four of the Reviewers recommended decoupling the hydrodynamic, sediment transport,
14 and contaminant fate submodels. This concept was thoroughly explored by the
15 modeling team during the Phase 1 Calibration (prior to the Calibration Peer Review).
16 While conceptually straightforward, as one Reviewer pointed out, “the devil is in the
17 details.” This task would have involved rewriting major portions of the code, and the
18 development of averaging schemes to write files containing average transport
19 information from one submodel, which could be read as input in the next submodel.
20 Averaging would be required because saving output at every time step is not feasible,
21 even with today’s large-capacity hard drives.

22 Members of the modeling team have participated in a similar effort to link decoupled
23 models (a hydrodynamic and sediment transport model, ECOMSED, with the water
24 quality model, RCA). This experience demonstrated that the task could be
25 accomplished. However, it highlighted the fact that the undertaking introduces
26 substantial uncertainties associated with estimates of the schedule for completion of the
27 programming and testing and associated costs. The modeling team estimated that the
28 impact to decouple the EFDC code would be to dramatically influence the Rest of River
29 project schedule/budget and also introduce a high degree of uncertainty into the
30 schedule/budget. It should be noted that this approach would have potentially benefited

1 the calibration and validation phases of the modeling study to an even greater degree
2 than the Corrective Measures Study (CMS), so the impetus was there to do it; however,
3 the implementation and resulting uncertainties rendered it impractical for a Peer-
4 Reviewed evaluation of model performance.

5 This topic was revisited based on the Reviewers' recommendations made as part of the
6 Calibration Peer Review and Validation Peer Review. The modeling team reached the
7 same conclusion, judging that the uncertainties/risks are of greater consequence than
8 any issues associated with proceeding with the proven, linked model code.

9 The decision not to decouple EFDC was made with consideration of the simulations
10 needed to support the CMS. It was recognized that some of these simulations may be
11 considerably longer than the validation simulation of 26 years. It should be noted that
12 the modeling during the CMS can utilize the capability of EFDC to include multiple PCB
13 state variables in a single simulation. Scenarios that can be represented by the same
14 hydrodynamic and sediment transport conditions (e.g., different estimates of residual
15 PCB concentrations) can be simulated in a single simulation, providing an "economy-of-
16 scale" to the evaluation. For different scenarios that include different sediment bed
17 conditions, separate hydrodynamic and sediment transport simulations would be
18 required to account for differences in bed roughness and grain size distributions
19 associated with the differing representations of the sediment bed. In these cases,
20 decoupling the individual sub-models of EFDC would not provide additional
21 computational benefit.

22 Recent hardware advances have reduced model simulation times to between half and
23 two-thirds of the run times experienced during the Phase 2 Calibration/Validation
24 modeling effort. In addition, these faster chips are available in dual-CPU servers at a
25 nominal cost. With these computers, a single computer can process two 50-year
26 simulations in approximately 2 weeks. At a cost of \$50,000 (the investment made by
27 EPA in computing hardware in 2004 to conduct the modeling study), 20 50-year
28 simulations could be completed every 2 weeks for Reaches 5 and 6.

1 The application of the model in the CMS will be discussed in the Model Working Group
2 and subsequently proposed by GE and reviewed by EPA.

3 **4.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 4**

4 **Eric Adams**

5 The issue of model resolution conflicts directly with the issue of computational time. Clearly,
6 with the current coupled in-channel/overbank modeling system, one cannot afford the extra
7 computational cost of reducing Δy , and still be able to afford multiple simulations of multiple
8 scenarios each over multiple decades. I share GE's concern that the existing model is already
9 too cumbersome to be used effectively to study corrective measures. Indeed, this is probably the
10 biggest model issue: as Yogi Berra might say, "If you can't use the model, you can't use the
11 model." The following are some thoughts on the related issues of grid resolution and
12 computational cost.

13 **Response 4-EA-1:**

14 The computational requirements of EFDC are significant, but EPA disagrees with
15 the Reviewer's concern that the model is too cumbersome to be used effectively
16 to evaluate remedial alternatives. See the General Response above.

17 **Computational Costs**

18 A number of options have been mentioned by the Peer Review Panel and by GE to improve
19 model efficiency. These included splitting the calculation of hydrodynamics, sediment transport
20 and PCB fate; running synthetic hydrological sequences; and employing alternate grid schemes.
21 EPA did implement some efficiency measures (dynamic and split time steps, by-passing sections
22 of the model that change slowly and running simulations of selected portions of the calibration
23 period), but seemed to have dismissed the bigger ticket items. I think some of these have to be
24 revisited.

25 There is no reason, in principle, why the model calculation of hydrodynamics, sediment transport
26 and PCB transport/fate could not be de-coupled. In particular, the hydrodynamics could be run
27 first. These results could be stored and used to transport sediment and PCBs. Since the
28 hydrodynamics would only need to be computed once (hydrology does not depend significantly
29 on scenario), considerable saving could be obtained. The devil is in the details of course, and
30 this would probably take a few months of time. But since EPA is a model developer, and such a
31 decoupled model would have future applications, EPA may want to invest in such a project,
32 possibly calling in the model developer (J. Hamrick).

33 **Response 4-EA-2:**

34 The modeling team clearly recognizes the significance of run time issues
35 associated with decadal-scale EFDC simulations, and acknowledges that the

1 Reviewer has accurately summarized options mentioned by the Reviewers to
 2 improve run time. It is noted, however, had the various options summarized by
 3 the Reviewer been adopted for the model calibration, it would have been difficult
 4 to quantify the degree to which the approximations contributed to the residuals
 5 (measures of bias) between the model results and data. See the General
 6 Response above.

7 In addition, while the development of the EFDC code for the Housatonic River
 8 application has resulted in benefits to further applications of the code (including
 9 within the Agency), generic model development is not a primary concern in this
 10 modeling study.

11 Further savings could be obtained using *synthetic hydrologic flows*. Based on the relatively
 12 large data base, a suitable discrete distribution could be generated that includes representative
 13 flows of different magnitudes and recurrence intervals. The model (with or without the
 14 hydrodynamics disaggregated from transport) could then be run for a synthetic year (or a short
 15 period of years large enough to include the largest/least frequent flow of interest), and the
 16 changes per year documented. Perhaps, without rerunning the model, *the long term effects*
 17 *could be computed by extrapolation of the one year results*.

18 **Response 4-EA-3:**

19 The application of the model in the CMS will be discussed in the Model Working
 20 Group and subsequently proposed by GE and reviewed by EPA. Screening
 21 techniques, such as that described by the Reviewer, may be considered.

22 Also, it still seems to me that in channel and over bank calculations could be de-coupled, saving
 23 additional computational time, and/or allowing more detail during the vast majority of time when
 24 the flow is within the banks and essentially one-dimensional. EPA claims there are coupling
 25 issues such as loss of momentum conservation, which may be true. But exact coupling is not
 26 critical. We are only expecting the model to predict gross trends in PCB concentrations (over
 27 time and the longitudinal direction), so a temporary mis-match might be acceptable. In general, I
 28 would support more a somewhat more approximate model (e.g., with parameterizations) that
 29 could be more efficiently used.

30 **Response 4-EA-4:**

31 It has been estimated that 60% of the PCBs present in the PSA are in the
 32 floodplain, and risks to human health and the environment were identified from
 33 exposure to PCBs in the floodplain. This was an important factor in the decision
 34 to include the floodplain in the computational grid. Logic tests in EFDC provide a
 35 means of bypassing computations for floodplain cells that are not inundated, so
 36 the floodplain and channel are effectively decoupled during the majority of the
 37 time when in-bank flows are simulated. The Reviewer's suggestion of adding
 38 more detail to the in-channel grid for within-bank flow conditions would increase
 39 the computational burden for periods that are less important for solids and PCB
 40 transport. Evaluation of options, such as different grids for high-flow and low-flow

1 conditions, or decoupling the hydrodynamic, sediment transport, and PCB fate
2 submodels of EFDC, were evaluated. In these evaluations, an important
3 consideration was whether the potential reduction in run time would shorten the
4 calibration and validation tasks by more than the time required to develop and
5 test the linkages or code modifications. See the General Response above.

6 In this regard, I like M. Garcia's idea of a flood plain number to quantify deposition of PCBs
7 within portions of the floodplain. PCBs appear to be on a conveyor belt whereby they are
8 resuspended from within the channel at high flow, partly deposited on the banks, then gradually
9 eroded from the bank back into the river, until some of them are deposited in Woods Pond.
10 These processes are all in the model, but it might be nice to document the life history of a
11 "numerically marked" cohort of sediment, and to test the sensitivity of the ultimate fate of this
12 cohort to processes such as the bank erosion rate, frequency of over bank flows, etc. By
13 decoupling the sediment transport and fate, this could lead to a model simplification, whereby
14 the over bank processes (deposition and bank erosion) are parameterized as simple first order
15 sinks and sources whose rates are determined by calibration to detailed simulation over the
16 calibration period. These rates could vary with flow conditions, but would be independent of
17 PCB concentration, allowing simple calculations during the Corrective Measures Study.

18 **Response 4-EA-5:**

19 A discussion of the limitations of Dr. Garcia's recommendation regarding a
20 dimensionless floodplain number is provided in Appendix B.7 to the FMD and in
21 the response to General Topic 3C. It is noted that the Reviewer's conceptual
22 description of PCB transport does not mention PCB deposition onto the
23 floodplain in locations distant from the river channel in locations where
24 remobilization due to bank erosion is not possible. The Reviewer's concept of
25 numerically marking a "cohort of sediment" has been simulated in the source-
26 specific (tracer) simulations. For those simulations, the "numerically marked"
27 sediment included all of the sediment in an individual reach, or in floodplain soil.
28 Changes in input and/or output processing would permit a similar analysis at finer
29 or coarser spatial scales.

30 In summary, it is a shame that the longitudinal and transverse grid sizes (Δx and Δy) must be
31 similar since the former need not be nearly so small (fish average their exposure over large
32 distances) and the latter should be smaller. In my previous comments I suggested eliminating Δx
33 as a dependent variable (substituting, instead, grain size by reach), but I recognize this was a
34 radical idea that might take too much time to implement.

35 **Response 4-EA-6:**

36 The physical character of the Housatonic River presents a challenging setting for
37 grid development and contaminant fate and transport modeling, which is further
38 complicated by the need to include the floodplain in the computational domain.
39 As a result of the meandering channel, the upstream-downstream direction is
40 along the north-south axis in some places and along the east-west axis in others.
41 In terms of the grid, this means that the main channel runs along columns of the

1 grid in some locations and along rows of the grid in other locations. This is the
 2 basis for the Reviewer’s observation that “the longitudinal and transverse grid
 3 sizes (Δx and Δy) must be similar.” The dimension that is transverse in one
 4 portion of the grid is longitudinal in another. It was not clear how the Reviewer’s
 5 suggestion of eliminating Δx could be accomplished in light of the comments from
 6 other Reviewers that an even finer spatial representation of bathymetry was
 7 desirable to compute finer spatial resolution of bed shear stress. Comments
 8 regarding grid scale are addressed in the responses to General Topic 3.

9 Finally, while the above discussion refers to lateral resolution (and its relationship to
 10 computational cost), I am also concerned that the vertical resolution within the sediment bed that
 11 may be insufficient to resolve near bed gradients that might result from remedial efforts (see
 12 Question 1). Clearly, calculations in the sediment bed can use a different (much longer) time
 13 step than those in the water column. It is not clear how costly additional vertical resolution in
 14 the sediment bed would be, but I think it should be considered.

15 **Response 4-EA-7:**

16 The vertical resolution of the bed was based on an extensive effort that included
 17 the use of site-specific benthic taxonomic data, and a considerable literature
 18 review on the topics of mixing depth and mixing rates. In response to additional
 19 concerns about the representation of the bed, which were expressed by the
 20 Reviewers at the Document Overview Meeting and at the Peer Review, sediment
 21 profile imaging was conducted. These images support the model’s vertical
 22 representation of the bed. Additional details on these topics are provided in FMD
 23 Appendices B.4 and B.5. Further responses are provided in General Topic 3D.

24 The Reviewer is correct in noting that calculations within the sediment bed can
 25 use a different time step than the water column. This option was invoked, and
 26 sediment calculations were performed at a multiple (16) of the time step used in
 27 the water column. Additional resolution in the vertical dimension in the bed was
 28 evaluated and substantial increases in run time were encountered because the
 29 increase in memory requirements forced the use of virtual memory.

30 **W. Frank Bohlen**

31 Even with these process questions resolved there remains the issue of run-time. It seems clear
 32 that the model as presently configured requires entirely too much time for the completion of a
 33 single run to be useful within timely evaluations of a significant number of remedial schemes.
 34 We probably knew this several years ago and should have been more sensitive to the need to
 35 develop alternative formulations. A number of these, including the separation of the
 36 hydrodynamics from the transport estimates and subsequent FCM evaluations were previously
 37 mentioned. It is now necessary and possible to go further. Using the experience gained from
 38 “whole model” runs it should now be possible to develop a number of synthetic hydrographs
 39 detailing streamflow, stage, and TSS concentrations at the upstream boundary and each of the
 40 primary tributary streams. This would eliminate the need to run HSPF on a regular basis. EFDC

1 is a ponderous model and can be streamlined now that we have a better idea of the relative
2 importance of the governing variables. John Hamrick should be charged with this task (no more
3 than 6 months) as soon as possible. As part of this streamlining the model grid characteristics
4 should be carefully reviewed, again using what has been learned about the relative importance of
5 each of the domain regions (sidebanks, backwaters, floodplains etc.). My sense of the present
6 grid is that it underspecifies the channel region and overspecifies the floodplain. The latter could
7 almost be treated as a box with fluxes simply proportional to stage which could be specified
8 along its margin by EFDC. If in time more detail of the interior of the plain is needed for
9 remedial purposes consideration might be given to replacing the high resolution grid on the plain
10 while placing a box in some other area (channel sidebanks?). Finally, I'd consider eliminating
11 the FCM in favor of a parametric (flow, TSS concentrations?) approximation of body burden
12 uptake based on the results of the complete model runs.

13 **Response 4-FB-1:**

14 EPA disagrees with the Reviewer's comment that the run time prevents it from
15 being "useful within timely evaluations of a significant number of remedial
16 schemes." As discussed in the General Response above, EPA believes that a
17 considerable number of simulations can be executed concurrently, making the
18 model a useful tool for the CMS. EPA disagrees with the Reviewer's suggestions
19 to minimize the roles of the watershed and bioaccumulation models (HSPF and
20 FCM, respectively), since these models have significantly smaller run times than
21 EFDC and little time savings would be gained while considerable rigor would be
22 lost. The Reviewer's suggestion to trade existing grid-resolution in the floodplain
23 for additional resolution in the river channel ignores the potential impact that such
24 a change would have on run times, which would be expected to result in an
25 increase in run time. These factors are discussed in FMD Appendix B.1, and in
26 Response to General Topic 3.

27 In short, what I'm thinking about is the development of an supplementary modeling scheme for
28 use in the CMS. The complete model would serve as a guide assisting in the development of a
29 series of simpler, more efficient but less comprehensive, formulations that would be directed at
30 particular remedial schemes. The complete model framework would remain in place providing
31 guidance regarding the need for and type of data to supplement model formulations for both
32 calibration and verification purposes but would not be run as frequently as the supplementary
33 schema. The alternative might be to turn to a different series of models entirely. This is not
34 recommended without good reasons that I don't have at the moment.

35 **Response 4-FB-2:**

36 GE and their consultants will have the option of using techniques suggested by
37 the Reviewer, or other methods to screen scenarios before running the full
38 model. Such options will be discussed in the Model Working Group in the
39 formulation of the CMS.

1 **Douglas Endicott**

2 The low-flow simulations have been criticized by GE as underpredicting the increase in PCB
 3 concentrations observed between the upstream boundary condition and New Lenox Road, as
 4 well as the decrease in PCB concentrations across Woods Pond. In addition, the profiles show a
 5 consistent “drop” in PCB concentrations immediately below the upper boundary. These features
 6 have been interpreted as suggesting that processes related to PCB fluxes between the water and
 7 sediment may be misrepresented or miscalibrated.

8 **Response 4-DE-1:**

9 The Reviewer’s comments refer to different locations within the PSA. The
 10 consistent “drop” in water column PCB concentrations immediately downstream
 11 of the upper boundary reflects the effect of the West Branch inflow, which
 12 typically dilutes the PCB concentration from the East Branch. The following
 13 responses begin with comments related to the most-upstream location, and then
 14 progressively move to comments related to downstream locations.

15 EPA acknowledges that upstream boundary concentration estimates for PCBs
 16 affect the upstream portion of the spatial profiles of water column PCB
 17 concentrations; however, evaluations were conducted that indicate that this is not
 18 a concern (see General Topics 1 and 6, and Appendix B.2 to the FMD).

19 The issue of variability in water column concentrations on the ability to assess
 20 spatial patterns in PCB concentration across Woods Pond was discussed at the
 21 Document Overview Meeting. In response to this Reviewer’s comment regarding
 22 spatial patterns across Woods Pond, a t-test was performed to assess the
 23 difference in the average concentrations entering and leaving the Pond, which
 24 are presented on the low-flow spatial profiles (MVR Figures 4.2-69 and 6.2-45).
 25 The confidence interval of the difference in mean concentrations includes zero,
 26 so at a 95% confidence level, the low-flow data do not indicate that the mean
 27 concentrations entering and leaving the pond are different. The concentrations
 28 simulated by the model also show little change across Woods Pond.

29 Finally, the increase in surficial sediment PCB concentrations over time within the upper-most
 30 sediment reach (RM 135.13-134.89) seems problematic and should be corrected. Is this behavior
 31 related to sudden drop in water column PCB concentrations downstream of the boundary
 32 condition, for example in the way bed load is initiated? Without access to the model, it is
 33 impossible to sort this out.

34 **Response 4-DE-2:**

35 In response to this Reviewer’s comment on the artifact of the representation of
 36 bedload boundary conditions on sediment PCB concentrations in grid cells
 37 immediately below the confluence, a change was made in the f_{OC} of non-
 38 cohesive solids included in the upstream boundary condition to account for
 39 bedload solids. This change has eliminated the artifact noted by the Reviewer.

1 **Marcelo H. Garcia**

2 With the current computational mesh configuration, the application of the model is
3 computationally taxing, resulting in extremely long execution times. This has made the
4 calibration and validation of the model a very difficult exercise and will most likely affect the
5 analysis of remediation alternatives in the future.

6 **Response 4-MG-1:**

7 While the Reviewer is correct in recognizing the impact of run times on the
8 calibration/validation effort, recent computer hardware advances have resulted in
9 the ability to execute runs in 50% to 67% of the MVR run times. These recent
10 advances will provide significant benefit for the use of the model in the CMS.

11 While uncertainty in model inputs and outputs was recognized, the nature of the model does not
12 allow for a conventional uncertainty analysis. Once all the processes are accounted for and well
13 represented in the model and assuming that the EFDC code can be run more efficiently, it might
14 be feasible to conduct an uncertainty analysis.

15 **Response 4-MG-2:**

16 The Reviewer recognizes a practical limitation that computationally intensive
17 models impose on the feasibility of performing uncertainty analyses. Based on
18 Comments from the Review Panel and discussions of the Model Working Group,
19 EPA and GE have agreed to modify the approach for uncertainty analyses. This
20 topic is discussed in more detail in responses to General Topic 5.

21 **Frank Gobas**

22 The spatial resolution of the environmental fate and food-web model is unnecessarily complex.
23 A much simpler spatial model is consistent with the empirical data and the current model
24 calculations. The hydrodynamic model does not run on a low spatial resolution. However, it is
25 possible to run the hydrodynamic model on its optimal spatial resolution and aggregate the
26 hydrodynamic data for a much simpler PCB environmental fate model. The latter would also
27 reduce the model run-time from the current, unacceptable 30 to 50 d. This would also make the
28 model more transparent due to greater simplicity. The modelers could argue that in terms of
29 predicting spatially varying concentrations the current multi-compartment model is consistent
30 with a much simpler lower spatial resolution model, so there is no need to develop the simpler
31 model. This is true for the model's current application. However, the modelers should keep in
32 mind that when the current model is applied to make predictions of the impact of remedial
33 actions on PCB concentrations as a function of space (i.e. model objective #1), the model may
34 predict spatial differences in concentrations that have not been "validated" or "ground truthed".

35 The modelers should consider developing a simpler spatial representation of the environmental
36 fate and food-chain model by decoupling the hydrodynamic and sediment transport model from
37 the environmental fate and food-chain model. The current high spatial resolution of the model is
38 unnecessary for the environmental fate and food-chain model. Also, the time-step requirement

1 for the hydrodynamic model is too onerous and unnecessary for the environmental fate and food-
2 chain models. This change in model design will make it possible to make many model runs
3 within a reasonable computational time.

4 **Response 4-FG-1:**

5 The Reviewer suggests that the results of finer-resolution grids for
6 hydrodynamics (and presumably sediment transport) could be aggregated onto a
7 coarser grid for PCB fate modeling. Implementation of this approach would
8 require that, in addition to decoupling the hydrodynamics and sediment transport
9 sub-models, development of a linkage scheme would be necessary to map
10 erosion and deposition fluxes from the finer-resolution hydrodynamic and
11 sediment transport grids onto the coarser PCB fate grid. These modifications
12 could be accomplished and tested given time and resources. However, it is
13 highly unlikely that the reduction in run time for the PCB fate component would
14 offset the schedule delay introduced by the code modification effort, and the
15 resulting model performance is unknown.

16 The run times quoted by the Reviewer are consistent with 60- to 100-year
17 simulations, run on the computer hardware used during the Phase 2 calibration
18 and validation modeling. Recent upgrades in computing technology have
19 reduced the run times for these simulations to between 2 to 4 weeks.

20 When the model is applied to the evaluation of remedial alternatives, spatial
21 patterns of predicted PCB concentrations may very well represent conditions that
22 could not be ground-truthed because they haven't existed in the river due to the
23 ongoing input of PCBs from the East Branch. This is often the case when
24 models are used to simulate a response to a change in forcing that has not
25 occurred, and, in fact, this is the reason that such models are developed. The
26 model calibration and validation process was implemented to test the
27 parameterization of the mathematical representations of processes that relate
28 model forcing and responses over space and time, as documented by data
29 collected in the past 26 years. The calibration strategy (see FMD Section 3.3
30 and the response to General Topic 1) adopted for this study relied on site-
31 specific data, when available, for estimation of model parameters, which were
32 tested by focusing on conditions when a limited number, or only one process,
33 dominated the transport of solids or PCBs. By calibrating individual processes to
34 the extent possible, confidence is derived in the model's ability to represent the
35 relevant processes under a different set of forcing, such as lower sediment PCB
36 concentrations.

37 Reduce the model run-time from an unacceptable 30 to 50 days to 1 d (at most), such that
38 different model parameterization schemes can be explored for making model projections.

1 **Response 4-FG-2:**

2 While a model run time of 1 day is highly desirable, and EPA has explored many
3 different recommendations from the Peer Reviewer Panel or the Model Working
4 Group, none of these approaches will realize the goal of a 1-day run time.

5 **Wilbert Lick**

6 **Numerical Gridding**

7 With the present grid, the width of the river is generally approximated as one cell. In the
8 Housatonic, as in most rivers, there are large differences in erosion between the deeper and the
9 shallower parts of the river. Predicting the dissimilar amounts of erosion/deposition across a
10 cross-section of the river is crucial in predicting the long-term exposure of PCBs by erosion
11 and/or natural recovery by deposition. Averaging across the cross-section does not describe the
12 erosion/deposition process accurately. A minimum of three cells across the river (two shallow,
13 near-shore cells and one deeper, center cell) should be used.

14 In the floodplain, our knowledge of the basic processes of erosion/deposition and the non-
15 erosional/depositional flux is poor. Because of this, a very coarse grid can be used to
16 approximate the processes in this area.

17 A better description of the bathymetry of the river will increase the computational time.
18 Drastically decreasing the number of grid cells in the floodplain will significantly decrease the
19 computational time. The computational time can also be decreased by (a) separating the
20 hydrodynamics, sediment transport, and contaminant transport calculations and (b) for small and
21 moderate flows, approximate and calculate the hydrodynamics and transport as a sequence of
22 steady-state solutions and only treat big events in detail.

23 **Response 4-WL-1:**

24 The Reviewer's generalization about large differences in erosion in different parts
25 of a cross-section is not uniformly consistent with data obtained through repeated
26 surveys of 9 locations in Reaches 5A and 5B (see FMD Appendix B6). The
27 Reviewer's comments regarding the lateral grid resolution are addressed in
28 General Topic 3. The Reviewer's assumption that the increase in run time
29 associated with increasing the grid resolution of the channel can be offset by
30 drastically reducing the number of grid cells in the floodplain is incorrect. Logic
31 tests in EFDC provide a means of bypassing computations for floodplain cells
32 that are not inundated, so the floodplain and channel are effectively decoupled
33 during the majority of the time when in-bank flows are simulated. Increasing the
34 number of grid cells in the channel would increase the time required for
35 computations in channel cells under all flow conditions.

36 The calculations of the hydrodynamics, sediment transport, and PCB transport should be
37 separated.

1 **Response 4-WL-2:**

2 The modeling team considered options, such as decoupling the hydrodynamic,
3 sediment transport, and PCB fate portions of EFDC. An important factor in the
4 evaluation was whether the potential reduction in run time would have shortened
5 the calibration and validation tasks and CMS study by more than the time
6 required to develop and test the linkages or code modifications. The approach
7 described in the MVR and FMD was followed because it was clear that the
8 proposed options would not provide a benefit that would outweigh the potential
9 cost in terms of dollars and delay in the schedule.

1 **5. GENERAL TOPIC 5: SENSITIVITY AND UNCERTAINTY**

2 **5.1 GENERAL TOPIC 5A: SENSITIVITY**

3 **5.1.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 9, lines 18 to 31
Bohlen	Page 12, line 28 to page 13, line 3
	Page 13, lines 5 to 11
Endicott	Page 16, line 19 to page 17, line 18
Garcia	Page 5, line 39 to page 6, line 2
Gobas	Page 9, lines 1 to 21
	Page 14, lines 15 to 19
Lick	Page 1, lines 37 to 39
List	Page 5, lines 31 to 34

4 **5.1.2 General Topic Summary**

5 The sensitivity of model output to a particular input parameter is defined as the ratio (expressed
6 as a percentage) of the average absolute percent change in model output for the two model runs,
7 to the average absolute percent change in input parameters. Selected model input parameters
8 were varied individually and the response of selected model output variables was noted and
9 compared to the base case (e.g., the final Phase 2 Calibration). Additional types of analyses were
10 also used to investigate model sensitivity to factors that did not lend themselves to the formal
11 sensitivity approach.

12 Reviewers had differing opinions on the sensitivity analysis presented in the Model Validation
13 Report. Four of the Reviewers commented that the sensitivity analysis was adequate or good,
14 although most provided suggestions for additional analyses or evaluations that could or should
15 be conducted to improve the sensitivity analysis. Three Reviewers believed that the sensitivity
16 analysis was inadequate because the basic model processes had not been adequately
17 characterized and such characterization was a necessary first step. One Reviewer added that it
18 was not possible to conduct a proper sensitivity analysis due to the coarseness of the model grid.

1 Two Reviewers specifically questioned an apparently anomalous result that indicated limited
2 sensitivity of PCB concentrations in Woods Pond to parameters controlling diffusion of
3 contaminants from the sediment bed.

4 **5.1.3 General Topic Response**

5 EPA agrees with the majority of the Reviewers, who commented that the sensitivity
6 analysis presented in the Model Validation Report provides a reasonable
7 characterization of model sensitivity. EPA appreciates the Reviewers' suggestions
8 regarding additional sensitivity analyses that could be informative.

9 Although not conducted specifically as part of the sensitivity analysis, the effect of
10 various combinations of "shutting off" PCB sources was thoroughly investigated in the
11 process-based flux summaries (tracer runs) discussed in the FMD. Another additional
12 type of sensitivity analysis that was performed outside of the formal approach presented
13 in the MVR was to evaluate the effect of different grid cell sizes during model
14 development, in the MFD, and in Appendix B.1 to the FMD.

15 EPA believes that the sensitivity analyses conducted provide sufficient assurance that
16 the model(s) as currently structured and parameterized are responding correctly to the
17 forcing functions in the system. Although other analyses might assist in further
18 understanding model behavior, they are not necessary to achieve the purpose of the
19 modeling study.

20 With regard to the comments concerning the inability to conduct sensitivity analysis due
21 to errors in characterization of model processes or grid resolution, such comments are
22 not comments on the sensitivity analysis per se, but rather on other aspects of the
23 modeling study that are discussed elsewhere in this Responsiveness Summary and in
24 the FMD. The sensitivity analysis presented in the MVR is an evaluation of the
25 sensitivity of the model framework as currently structured and parameterized, and
26 comments regarding the validity of that structure and parameterization are addressed
27 under other General Topics and are not further addressed here.

1 5.1.4 Response to Specific Comments on General Topic 5A

2 Eric Adams

3 Most sensitivities seem reasonable. As expected, flows show strong sensitivity to upstream
4 boundary flows, TSS is sensitive to upstream boundary flow and TSS, and PCBs are sensitive to
5 upstream boundary flow, TSS and PCB concentration.

6 At low flow PCB there is strong sensitivity to K_f and partitioning (at least at New Lenox Rd),
7 which makes sense, since “diffusion” is the only important process, but this effect is largely
8 diluted out in the 10.5 year simulation. At high flow, there is strong sensitivity to parameters
9 dealing with particulate phase transport (settling, erosion).

10 While the model shows substantial sensitivity to diffusion parameters during low flow at New
11 Lenox Rd, GE points out that virtually no sensitivity is indicated at Woods Pond Footbridge.
12 Since the flow must pass from NLR to WPF, this is illogical. Unless there is a mistake in
13 plotting (and EPA suggested there was not), this could indicate a potential problem in model
14 formulation.

15 Response 5A-EA-1:

16 EPA agrees with the Reviewer that most sensitivity results seem reasonable.
17 The exception noted by the Reviewer and by GE for the low-flow tornado
18 diagrams at Woods Pond Footbridge was caused in the post-processing that
19 extracted the model results; this error has been corrected. The revised tornado
20 diagram for PCB fluxes at Woods Pond Footbridge, which is included in Section
21 3.7 of the FMD, shows sensitivities for the low-flow period that are similar to the
22 results for New Lenox Road.

23 W. Frank Bohlen

24 In most cases the sensitivity of each of the models to the significant state and process variables
25 has been adequately characterized. However, as discussed above, I remain concerned about the
26 accuracy of the sediment transport processes within the model domain and look to the sensitivity
27 analysis for some guidance. The sensitivity analyses provided in the MVR and the earlier
28 calibration report provide clear indication that sediment mass flux throughout the PSA is very
29 sensitive to the upstream boundary conditions. With these reasonably well specified, using a
30 combination of HSPF results and field observations, it may not be very difficult to achieve
31 reasonable model/data agreement despite inaccurate simulation of bed erosion within the PSA.
32 The sensitivity analyses do not take the next step to test the adequacy of the interior formulations
33 by shutting off the boundary contribution of sediment and PCB's. The importance of this
34 formulation will progressively increase as the upstream sources of contamination are reduced
35 and remedial measures for the downstream areas are being evaluated. A detailed analysis of the
36 sensitivity and accuracy of this formulation is recommended. The results of this effort might
37 serve to address the concerns raised in GE's review of the MVR dealing with the relative
38 importance of Reach 5A and 5B as sources of sediments and contaminants to Reach 5.

1 Response 5A-FB-1:

2 The Reviewer is correct that the sensitivity analyses indicate the sensitivity of
3 EFDC to the solids and PCB loads entering the domain at the upstream
4 boundary. However, EPA does not believe that the sensitivity analysis provides
5 the best tool to determine if such loads have been adequately characterized.

6 The absolute and relative magnitude (boundary loads versus internally generated
7 through erosion) of solids fluxes within the PSA can be evaluated more directly
8 from the output of the example scenario and tracer simulations (MVR Figure 4.2-
9 51, FMD Figures 4.2-1 and 4.2-2) rather than through sensitivity analyses in
10 which upstream sources are set to zero. Because the settling velocity of
11 cohesive solids is dependent on the cohesive solids concentration, sensitivity
12 analyses with a zero upstream boundary condition will alter the settling velocity
13 applied to the suspended solids, which in turn will affect the transport of solids
14 through the system.

15 Model output from the Phase 2 calibration simulation was processed to
16 summarize solids fluxes from upstream boundaries and sediment erosion
17 between various locations in the river for a range of flow conditions (MVR Figure
18 4.2-51). The information presented in this figure can be used to compute the
19 ratio of erosion fluxes to upstream boundary inputs, and how the ratio changes
20 with river flow. The process-based flux summaries for Phase 2 calibration and
21 validation simulations indicate the magnitude of solids (FMD Figures 4.2-1 and
22 4.2-2) and PCB fluxes (FMD Figures 4.2-6 and 4.2-7) from various sources and
23 processes. The spatial pattern of erosion fluxes and the variation in the flux rate
24 with flow are consistent with the conceptual model in that more erosion is
25 calculated in the higher energy upstream areas and erosion increases
26 dramatically with flow.

27 In addition to testing of the erosion formulation additional sensitivity analyses should be
28 performed to assess model response to the thickness of the active sediment column. This has
29 been a matter of concern for some time. Experience in other riverine/bayou systems as well as
30 the detailed core data (Fig. 4-21c, attached) indicate to me that the active bed used in the model
31 is too thick. It may be that this specification in terms of physical transport characteristics has
32 relatively little effect on overall model results (although that might bring up another set of
33 questions). A test of model response to this characterization is recommended.

34 Response 5A-FB-2:

35 The thickness of the surface sediment layer, as well as the general structure and
36 dynamics of the entire sediment bed, were extensively evaluated at different
37 stages throughout the model development process and a number of different
38 configurations were tested. Based on the results of that testing and evaluation,
39 the sensitivity of the model to variations in the thickness of the sediment surface
40 layer is well understood by the EPA modeling team, and it was apparent that the
41 model behavior was reasonable after performing these tests and also in

1 evaluating the balance of fate processes. The issue of surface sediment layer
2 thickness is not one of sensitivity per se, but rather of whether the thickness of
3 the surface layer in the model properly represents the actual configuration in the
4 river (see Appendix B.5 to the FMD).

5 **Douglas Endicott**

6 The MVR does a good job of illustrating the sensitivity of the EFDC model predictions to input
7 parameters. Several additional model inputs should be added to the sensitivity analysis, and these
8 are identified below. As pointed out by GE, there are also some sensitivity analysis results that
9 are counter-intuitive; these should be explored and explained.

10 Sediment transport sensitivity analysis is displayed in terms of peak and mean TSS fluxes, for
11 the entire calibration period as well as 2 different flow events (Figures 5.1-3 thru 5.1-5). It would
12 be useful to also see the sensitivity of the model displayed as changes in bed elevation.

13 Part of the sensitivity analysis for the sediment transport model should include the sensitivity to
14 the grid resolution because, as discussed previously, the prediction of sediment bed scour may
15 depend on the number of lateral cells in the channel cross-section. This is only needed for a “test
16 reach” of the river channel, preferably the reach where bathymetry transects were measured.
17 Note that Earl Hayter’s previous analysis was not informative on this issue.

18 PCB fate and transport sensitivity analysis is displayed in terms of peak and mean PCB fluxes,
19 again for the entire calibration period as well as the two flow events (Figures 5.1-6 thru 5.1-11).
20 The sensitivity of the Woods Pond PCB flux predictions at low flow (Figure 5.1-9) is puzzling,
21 since it suggests practically no sensitivity to parameters associated with sediment-water
22 exchange of PCBs. While there may be little exchange within Woods Pond itself, considerable
23 PCB exchange in upstream reaches should be reflected in the sensitivities of these parameters in
24 Woods Pond. Instead, Figure 5.1-9 show that low-flow PCB fluxes in Woods Pond are only
25 mildly sensitive to the upstream boundary inflow, and really nothing else. It remains for EPA to
26 explain how this result is evidence that “the model is properly representing the physics of the
27 river as it relates to the movement of solids and contaminants”.

28 As stated previously, the initial PCB concentrations specified for the sediment bed should be
29 added as parameters in the sensitivity analysis, for all reaches where they are not independently
30 determined from data. Likewise, the surficial sediment layer thickness should be included as a
31 parameter in the sensitivity analysis.

32 **Response 5A-DE-1:**

33 EPA agrees with the Reviewer’s comment that the results presented in the MVR
34 illustrate the sensitivities in the EFDC parameterization. Between the Model
35 Calibration Report and the Model Validation Report, the sensitivity simulations
36 were increased to the 10½-year Phase 2 Calibration period, and additional
37 parameters were included in the analysis. A decision was also made to show the
38 sensitivity of the response of each EFDC submodel to parameters tested for all
39 preceding submodels (e.g., sensitivity of PCB fluxes to the hydrodynamic

1 parameter for bottom friction, z_0). In addition, an alternate presentation format for
2 the results, referred to as a tornado diagram (see Section 3.7 of the FMD), was
3 adopted to allow a consistent presentation of the results of the sensitivity analysis
4 for all three models. In the interest of focusing the EFDC sensitivity analysis on
5 the output variables of most importance, the food chain exposure concentrations
6 were added as response variables because they synthesize the effect of several
7 EFDC variables, and represent the most important output of the EFDC
8 simulation.

9 The effect of grid resolution was investigated as part of the MFD phase of the
10 modeling study. The suggestion of performing sensitivity analyses for the grid
11 resolution was not implemented because this analysis was estimated to involve a
12 substantial effort that could provide only limited benefit beyond the analyses that
13 had been previously performed. Simply applying all of the calibration parameters
14 on a more refined grid could lead to inappropriate and uninterpretable
15 comparisons. For example, sub-grid-scale features in the current grid, such as
16 undulations in the bed elevation, have been subsumed into the parameterization
17 of the effective roughness height (z_0). If the resolution of the grid was increased
18 to explicitly represent these features, a reassessment of the appropriate z_0 would
19 be required to produce the same hydrodynamic transport through the new grid.
20 Data would be required to develop boundary conditions for a laterally segmented
21 grid, and the length of a "test reach" would have to span approximately 5 miles,
22 to include locations where monitoring data, including water-surface elevations,
23 were collected. Obtaining different results from a refined grid of a "test reach,"
24 compared to the results for the same reach from the original grid, would not be
25 meaningful because there would be no basis for concluding that one result was
26 better than the other.

27 A valuable check on the calculations for the current grid applied in Reaches 5
28 and 6 is the simulated sedimentation rate in Woods Pond, where model-data
29 comparisons of sedimentation rates are available for 12 locations. This check
30 would not be available for simulations performed in only a portion of the domain.
31 Because EPA and GE concur that lateral segmentation of the river channel is not
32 necessary and that the current grid is appropriate for use in the CMS, the effort
33 required to perform the recommended sensitivity analysis is not justified.

34 The Reviewer recognizes that data were too limited to develop sediment PCB
35 initial conditions for the Phase 2 calibration period for the the validation period
36 (except for Reach 6). EPA recognizes that the use of the model to make
37 hindcast estimates of initial conditions for times when data are not available does
38 not eliminate the uncertainty resulting from lack of data. In the sensitivity
39 analysis, model inputs were varied by $\pm 50\%$. Based on the temporal trends in
40 sediment data and fish tissue concentrations (see Appendix A.1 of the FMD), a
41 variation of $\pm 50\%$ in sediment initial conditions would greatly overstate the likely
42 range in sediment concentrations and could be misinterpreted as an indication of
43 uncertainty.

1 In response to comments from the Peer Reviewers, sediment profile imaging
 2 (SPI) was conducted in early September 2006 to obtain additional site-specific
 3 information on the structure of the sediment bed of the Housatonic River. The
 4 information obtained in the SPI work supported the bed layering used in the
 5 Phase 2 Calibration and Validation modeling (see FMD Appendix B.5 for
 6 additional information). Based on the conclusions drawn from the site-specific
 7 information, and considerable investigation of the response of the model to
 8 surface sediment layer thickness during model development, the thickness of the
 9 sediment layers was not added as a parameter in the sensitivity analysis.

10 EPA's assessment that EFDC properly represents the transport of solids and
 11 PCBs (including in Woods Pond) was based on the evaluation of more extensive
 12 model output than the graphical presentations of the sensitivity analysis results.
 13 The post-processing that extracted the model results for the low-flow tornado
 14 diagrams contained an error, which has been corrected. The revised tornado
 15 diagram for PCB fluxes at Woods Pond Footbridge shows sensitivities for the
 16 low-flow period that are similar to the results for New Lenox Road.

17 **Marcelo H. Garcia**

18 Given the facts that several processes are yet to be fully characterized in the model and that a
 19 coarse computational grid has been used for the model calibration, I do not think that a full
 20 sensitivity analysis can be conducted at this time.

21 **Response 5A-MG-1:**

22 EPA disagrees that questions raised by Reviewers regarding the suitability of
 23 model structure and/or process formulations should preclude assessment of the
 24 model sensitivity. As noted above, the sensitivity analysis presented in the MVR
 25 is an evaluation of the sensitivity of the model as currently structured and
 26 parameterized; questions regarding the validity of that structure and
 27 parameterization, including particularly the appropriateness of the computation
 28 grid used for the modeling study, are addressed under other topics in this
 29 Responsiveness Summary and in the FMD.

30 **Frank Gobas**

31 The modelers have done a good job describing parameter sensitivities. The latter is not easy as
 32 there are many parameters and the sensitivities of each of them depend on the values chosen for
 33 the others.

34 However, there is one area in the model where conducting a thorough sensitivity analysis is
 35 crucial because of the lack of good calibration data and difficulties in model parameterization.
 36 This is in the component of the Environmental fate model that controls the long term temporal
 37 response of the model. The selection of the thickness of sediment layers, diffusion rates, and
 38 bioturbation rates are all very difficult. Hence, a thorough sensitivity analysis is crucial to

1 determine the bounds within which temporal changes in concentrations can be expected to occur.
2 This analysis is not presented in the current reports and supports my conclusion that the long
3 term temporal response of the model is too uncertain to make meaningful predictions.

4 Recommendations:

5 Given the lack of calibration data, the sensitivity analysis is probably one of the few things that
6 can be done to increase confidence in any estimates of the temporal response in PCB
7 concentrations calculated by the model. I recommend that it is considered and added. For this
8 sensitivity analysis to be doable and convincing, the modelers could just focus on the part of the
9 model that controls the long term temporal response of the model.

10 **Response 5A-FG-1:**

11 In response to comments from the Reviewers, additional parameters were added
12 to the sensitivity analyses, so that the sensitivity analyses include all but one of
13 the parameters listed by the Reviewer (see FMD Section 3.7). The one
14 exception is related to the thickness of the surface layer of the sediment, and is
15 discussed above in Response 5A-FB-2.

16 In response to comments from the Reviewers, sediment profile imaging (see
17 Appendix A.3 to the FMD) was conducted in early September 2006 to obtain site-
18 specific information on the structure of the surface sediment of the Housatonic
19 River. The site-specific information obtained from that effort supported the bed
20 layering used in the Phase 2 calibration and validation modeling (see FMD,
21 Appendix B.5 for additional information).

22 Conduct sensitivity analyses with the goal to (i) further investigate the parameterization of the
23 sediment-water exchange of PCBs, on which the temporal response of PCB concentrations in the
24 River largely depends and (ii) improve the parameterization of the key processes if possible (see
25 under charge question #1 for additional details on this issue).

26 **Response 5A-FG-2:**

27 In response to comments from Reviewers, additional parameters were added to
28 the sensitivity analyses (see Section 3.7 of the FMD). Previously, the sensitivity
29 analyses included the sediment-water mass transfer coefficient, which is applied
30 to pore water PCBs, and the following parameters that affect the sediment-water
31 column transport of sorbed PCBs: cohesive solids settling velocity and critical
32 shear stress for deposition of cohesive solids; non-cohesive solids grain size,
33 which affects both the settling velocity and resuspension of non-cohesive solids
34 erosion; the critical shear stress for cohesive solids erosion; and the cohesive
35 solids erosion rate. Additional parameters that were added include the exponent
36 for the sediment particle mixing rate, cohesive solids erosion formulation, and the
37 non-cohesive solids erosion rate.

1 **Wilbert Lick**

2 The sensitivity of the model to the parameterization of the significant state and process variables
3 has not been adequately characterized. See discussion in the complete response.

4 **Response 5A-WL-1:**

5 The Reviewer's comment does not address model sensitivity but instead repeats
6 concerns discussed under General Topic 1, which relates to the balance of fate
7 processes. EPA disagrees that differences of opinion regarding the suitability of
8 model process formulations should preclude assessment of the model sensitivity,
9 and notes that the sensitivity analyses as conducted relate specifically to the
10 model as currently structured and parameterized. See also responses to
11 General Topic 1.

12 **E. John List**

13 My opinion is that the underlying processes involved with the PCB fate and transport do not
14 appear well enough understood for a meaningful model to be developed. If the processes that
15 seem to define the PCB fate and transport are not included in the model then their sensitivity
16 cannot be assessed.

17 **Response 5A-JL-1:**

18 See Response 5A-WL-1.

1 **5.2 GENERAL TOPIC 5B: UNCERTAINTY**

2 **5.2.1 Comment Summary**

Reviewer Name	Page Number/Line Number
Adams	Page 9, line 36 to page 11, line 16
Bohlen	Page 13, line 13 to page 14, line 2
Endicott	Page 1, lines 12 to 26
	Page 17, line 22 to page 18, line 22
Garcia	Page 6, lines 13 to 17
Gobas	Page 10, line 34 to page 11, line 41
	Page 13, lines 27 to 31
	Page 14, lines 1 to 9
Lick	Page 1, lines 41 to 42
List	Page 5, lines 39 to 40

3 **5.2.2 General Topic Summary**

4 Methods for the quantitative evaluation of modeling study results are in various stages of
 5 development and there is no commonly accepted way of quantifying or communicating to
 6 decisionmakers the accuracy of model predictions. Uncertainty is often discussed only
 7 qualitatively, or ignored, and beyond recognition of the fact that there is some measure of
 8 uncertainty in all predictions, uncertainty results are not used in making decisions based on
 9 model results.

10 Reviewers were sharply divided on the validity and utility of the uncertainty analysis presented
 11 in the MVR. One Reviewer described the approach to the analysis as “rather traditional,” but
 12 questioned the assumption of independence among input parameters, noting that it resulted in
 13 very large uncertainty bounds. Two other Reviewers, however, described the analysis as a “real
 14 attempt to develop new methodology” and “unprecedented,” and one of the Reviewers noted that
 15 the assumption of independence among parameters was common practice. One Reviewer
 16 described the uncertainty analysis as “seriously flawed.” Two Reviewers felt that because the
 17 model processes had been incorrectly described, no valid uncertainty analysis was possible, and
 18 two Reviewers felt the complexity of the model(s) did not allow for a typical probabilistic

1 uncertainty analysis. There was some consensus among the Reviewers that, whatever the
2 validity of the current uncertainty analysis, it was difficult to apply the results in a way that
3 would inform management decisions made based on model output.

4 **5.2.3 General Topic Response**

5 Given that methods for the quantitative evaluation of modeling study results are in
6 various stages of development and there is no commonly accepted way of quantifying
7 or communicating to decisionmakers the accuracy of model predictions, EPA
8 anticipated that the Reviewers would have a range of opinions regarding the validity and
9 utility of the uncertainty analysis presented in the Model Validation Report, and in fact
10 requested input from the Reviewers on an appropriate approach to evaluating model
11 uncertainty during the Peer Review of the Model Calibration Report. Most modeling
12 studies deal with uncertainty only qualitatively, and beyond recognition of the fact that
13 there is some measure of uncertainty in all predictions, uncertainty results are typically
14 not used in making decisions based on model results. The approach presented in the
15 MVR was intended to provide a methodology that could provide useful information to
16 those charged with making decisions based on model results. EPA does not suggest
17 that this is the only useful way of evaluating and presenting uncertainty and did not
18 intend for the approach to be prescriptive for future uses of the model.

19 In the MVR, EPA presented a probabilistic approach to evaluating and quantifying
20 model uncertainty. The approach featured the ability to propagate uncertainty through
21 the framework of linked models, e.g., the uncertainty in model results output from HSPF
22 that were used as input to EFDC, and the uncertainty in model results output from
23 EFDC that were then used as input to FCM, were maintained.

24 In subsequent discussions with the Model Working Group following the Peer Review of
25 the MVR, it was agreed that the uncertainty of the model results in the evaluation of the
26 relative performance of remedial alternatives would be addressed using the best
27 professional judgment of the Model Working Group. Responses to the specific issues
28 raised by Reviewers as summarized in this General Topic are provided below.

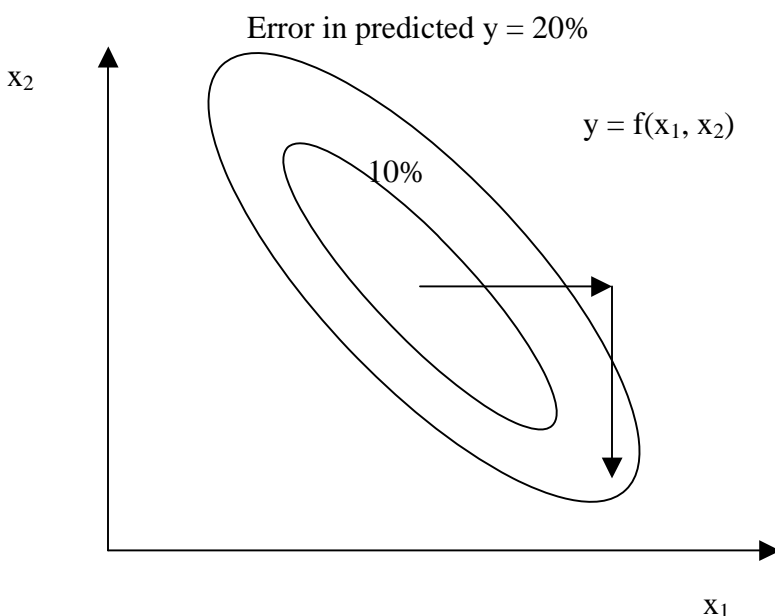
1 5.2.4 Response to Specific Comments on General Topic 5B

2 Eric Adams

3 In general, model uncertainty comes from two sources: imperfection in the basic model(s)
4 (including unknown unknowns) and imperfection in the selection of the (known) model
5 parameters. The former has been discussed to a certain degree under Question 1, which relates
6 to processes, so the following relates mainly to the latter issue.

7 Although they use some sophisticated approaches, the modelers performed a rather traditional
8 uncertainty analysis, varying known model parameters largely *independently* in a simulation of
9 *existing conditions*. If the model and data were both perfect, and the only uncertainty involved
10 the values of model parameters, one could expect most of the parameters to be independent.
11 (Some parameters that have a physical relationship, such as erosion parameters would still be
12 correlated.) But the model has been calibrated to observed data, and the calibrated model
13 parameters reflect both imperfection in the model (e.g., a parameter being used to cover more
14 than one real process) and imperfection in the data (e.g., due to sampling or analytical error,
15 insufficient sample resolution, etc). Thus, during uncertainty analysis, when one parameter is
16 changed, other parameters should also change (i.e., they are not independent), as is illustrated in
17 the following sketch. Here the dependent variable y is a function of two independent variables
18 x_1 and x_2 and the contours are plots of some measure of error between measured and predicted
19 values of y . If, as part of an uncertainty analysis, variable x_1 were changed (horizontal arrow),
20 one would expect a correlated change in x_2 (vertical arrow) in order to minimize the error
21 between measurements and predictions. Failure to take this correlation into account tends to
22 overestimate the uncertainties in the model prediction. And, as suggested in the following
23 paragraph, I suspect this issue becomes more extreme when the future conditions being predicted
24 are substantially different from those under which the model was calibrated.

25 Apart from the question of parameter independence, there is the question of whether there are
26 certain variables to which the model is more or less sensitive as a function of the remediation
27 scenario. For example, following remediation there may be thin patches of clean/dirty sediment
28 overlaying thicker regions of dirty/clean sediment, making calculations more sensitive to
29 diffusion and partitioning than they were in the base case scenario. If this is the case, we may
30 get a distorted impression of the effectiveness of remediation.



1
2 Based on sensitivity analysis, EPA tested the uncertainty of model outputs (e.g., PCB
3 concentrations in water, bed and fish) to uncertainties in model input parameters. As GE points
4 out, the model uncertainty is substantially greater than the uncertainty in the model (e.g., the
5 s.e.m.) If the goal were simply to predict the uncertainty in present conditions, the uncertainty in
6 the individual parameters could be scaled back until the uncertainties in the model and data
7 matched. But it is also important to see the *sensitivity of predicted model changes due to*
8 *possible remedial alternatives* to these same model input parameters. This is not difficult and
9 should be performed either before or after the model is transferred to GE.

10 Finally, one use of the model is simply to compute relative fluxes, as EPA as demonstrated
11 recently. Remedial decisions could be made on the basis of how much less PCB would be
12 transported, rather than on (or in addition to) the basis of quantitative predictions of
13 concentrations. Thus it would also be nice to see the *sensitivity of predicted fluxes to the same*
14 *model parameters*.

15 In summary, because of the lack of parameter correlation in the sensitivity study, and the fact
16 that predicted uncertainty exceeds the uncertainty in the existing data, I believe the predicted
17 uncertainty, when applied to future remedial conditions, will be too large.

18 **Response 5B-EA-1:**

19 It is true that correlations among input parameters can cause the output
20 distributions from a Monte Carlo analysis to deviate from the true underlying
21 distributions. However, it is not true that failure to quantitatively represent this
22 correlation necessarily results in overestimation of the uncertainties in the model

1 prediction. The effect of correlated inputs may result in either overestimation or
2 underestimation of uncertainty, depending on whether the correlation is positive
3 or negative, and also on the functional form of the relationship. Typically,
4 uncertainty will be overestimated if positive correlations between variables that
5 are added or multiplied are not included, or if negative correlations between
6 variables that are involved in subtraction or division are not included; not
7 including the reverse relationships will result in underestimation of uncertainty.

8 Specification of correlations among EFDC input parameters for the uncertainty
9 analysis was considered; however, no reliable basis was available to quantify
10 potential correlations, and, therefore, no intercorrelations were specified. Some
11 of the process descriptions in EFDC naturally result in correlations between
12 EFDC input parameters and simulated PCB concentrations (e.g., water column
13 K_{OC} and water column sorbed PCB concentrations). These intercorrelations
14 were included in the response surface model.

15 In the FCM Monte Carlo analysis, it was possible to specify the nature of some
16 correlations, and when such intercorrelations could be reliably specified they
17 were incorporated into the model. For example, for feeding preference
18 assignments, when the dietary contribution of a given item was adjusted, the
19 proportions of other dietary items were adjusted, such that the total amount
20 ingested remained constant. This approach is consistent with the sensitivity and
21 uncertainty assessment used in other published modeling applications. Burkhard
22 (1998), in a sensitivity/uncertainty assessment for two bioaccumulation models,
23 also applied a local sensitivity analysis method (generally assuming
24 independence of inputs) but adjusted some parameters for known
25 interdependencies. In that study, as with the FCM application, neither the lack of
26 complete parameter independence nor the use of professional judgment in
27 establishing input distributions was considered sufficiently problematic to render
28 the results unusable.

29 EPA believes that comparison of the computed uncertainty bounds to the
30 variability observed in the field data is an inappropriate means of determining
31 whether the uncertainty bounds are plausible. There are four principal reasons
32 for this opinion:

33 (1) The model, as a simplification of the complex natural processes governing
34 transport and bioaccumulation, contains model uncertainties (including both
35 uncertainties in represented processes/parameters and "unknown
36 unknowns") that would not be included in the field data.

37 (2) The field data contain natural variability over spatial and temporal scales finer
38 than the intended scale of the model. For example, the fish tissue data
39 include data on individual fish that have differing physical/biological properties
40 and differing exposure patterns among individuals, whereas the model
41 simulates the average condition within each reach.

1 (3) The field data incorporate analytical uncertainty (e.g., laboratory variability)
2 that cannot be represented by the linked fate, transport, and bioaccumulation
3 model.

4 (4) Field data are not available or are limited in number for some of the reaches
5 and/or species of interest in the modeling study. Where insufficient data are
6 available to assess model performance, model uncertainty evaluation cannot
7 rely solely upon model versus data comparisons.

8 In summary, direct comparison of model uncertainty to data uncertainty is an
9 inappropriate analysis, and cannot be used to assess the reasonableness of the
10 computed uncertainty distributions from the linked Monte Carlo analysis.

11 **W. Frank Bohlen**

12 The uncertainty analyses presented in the MVR are interesting and represent a real attempt to
13 develop new methodology for the assessment of complex models such as EFDC. Both
14 Kolmogorov-Smirnov (KS) and Response Surface Modeling (RSM) analyses were applied. The
15 KS methods require numerous model runs to develop a statistically robust data set. Given the
16 time required for each run this was an onerous task and one made no easier by the failure of four
17 of the EFDC runs. This effort yielded an initial estimate of uncertainties in the model prediction
18 of PCB concentrations both water column and sediment associated. These concentrations were
19 emphasized since they are passed to the food chain model (FCM). The KS analysis was
20 supplemented by RSM to evaluate model uncertainty due to uncertainty in input parameters
21 including flows, roughness parameters, critical erosion stresses, etc. The evaluations include
22 consideration of the effects of the calculated uncertainties on the FCM predictions.

23 Overall the results of the uncertainty analyses, while interesting, were difficult to interpret in
24 terms of model abilities to accurately simulate PCB transport and fate. The presentation of a
25 series of individual summary figures for each condition does not facilitate interpretation in the
26 absence of detailed description of cause and effect. The majority of the supporting text dealt
27 primarily with methodology rather than interpretation. It may be that this type of analysis and its
28 sophistication is premature and requires a greater understanding of the processes included in the
29 model and their interactions than we presently have. As this becomes available with model use a
30 better description and analysis of uncertainty might be possible.

31 Moving from the formal analyses of uncertainty to the general subject of model uncertainty, this
32 report (MVR) too often fails to provide detailed discussion of uncertainty including
33 consideration of causes. Statements such as "The simulated hydrographs....reproduced measured
34 hydrographs reasonably well, however in some cases the magnitude of the simulated flow
35 differed from the data in both positive and negative directions" (see pp 6-35) are too common.
36 Uncertainty is to be expected as is variability both due to the input data being used and numerical
37 model response. It should be introduced early in model discussions and included in logical
38 discussion of cause and effect relationships throughout the report. I would hope that any
39 summary report considers this as an absolute necessity. It will be of great value in building the
40 confidence of a general readership.

1 Response 5B-FB-1:

2 EPA agrees with much of the Reviewer's assessment of the uncertainty analysis.
3 The uncertainty approach presented in the MVR was intended to be
4 demonstrative rather than prescriptive, and EPA recognizes that other
5 approaches to evaluating model uncertainty may also be valid. In subsequent
6 discussions with the Model Working Group following the Peer Review of the
7 Model Validation Report, it was agreed that the uncertainty of the model results
8 in the evaluation of the relative performance of remedial alternatives would be
9 addressed using the best professional judgment of the Model Working Group.
10 During the development of the FMD, further effort was made to provide
11 discussion of the uncertainties associated with model outputs and data
12 relationships (see Sections 3 and 4 of the FMD).

13 Douglas Endicott

14 I do have several comments to make regarding the peer review process itself. In the *EPA*
15 *Response to Questions from Model Validation Document Overview Meeting*, EPA correctly notes
16 that models are uncertain and that a degree of uncertainty is inherent in "these types of
17 studies"(question: What scientific study does not include a degree of uncertainty?). They go on
18 to identify three principal sources of model uncertainty (models are
19 simplifications/approximations of reality, parameters are uncertain, future conditions are
20 unknowable). Although these can be significant sources of uncertainty, EPA chose not to
21 highlight several others, which may be equally important:

- 22 • Inappropriate process representations/formulations,
- 23 • Errors resulting from discretization of the model or the scale of its application,
- 24 • Errors in programming, preprocessing, running, linking and postprocessing the models,
25 and
- 26 • Untested model predictions.

27 These are "lurking" sources of model uncertainty, which are not typically revealed by
28 uncertainty analysis. I think it is useful to acknowledge these pitfalls, and keep them in mind
29 throughout the course of a project. I think much of the Peer Review deliberations, and more than
30 a few of the comments, reflect concern about these factors.

31 Response 5B-DE-1:

32 EPA agrees that the sources of uncertainty identified by the Reviewer are all
33 potentially relevant to this (and any other) modeling study. These uncertainties
34 are discussed individually below:

- 35 ■ Inappropriate process representations and formulations—This type of
36 uncertainty was acknowledged by EPA in comments (dating back to the

1 initial MFD) that models are a necessary simplification of reality. In
2 conducting a phased approach to model development, from the MFD
3 through Validation, and by engaging an independent Peer Review Panel
4 at each major step of model development, EPA has consistently
5 attempted to maximize the realism of the model processes and
6 formulations. The model processes can never be “correct” because they
7 are approximations of reality; however, they can be appropriate in the
8 sense that they are useful, practical, and scientifically defensible
9 representations of the environment that incorporate site-specific
10 understanding of system behavior. To this end, the model evaluation is
11 centered on determining “whether the simulation model is an acceptable
12 representation of the real system, given the purpose of the simulation
13 model” (Kleijnen, 1999). To this end, EPA believes that “error” in the
14 specified processes stems primarily from necessary approximation of
15 reality and not from erroneous application of processes. Further
16 discussion of the balance of fate processes in EFDC is provided in the
17 responses to General Topic 1 and in the FMD.

- 18 ▪ Errors resulting from discretization of the model or the scale of its
19 application—EPA acknowledges that errors can occur due to the need to
20 discretize the model over space and time. EPA has minimized the effect
21 of these potential errors by identifying relevant spatial and temporal
22 domains and levels of detail commensurate with the needs of each model.
23 The selection of a grid system, computational time step, and aggregation
24 of data for model linkages have all been rigorously evaluated throughout
25 model development, and have incorporated the feedback of the Peer
26 Review Panel. Further discussion of the spatial and temporal needs is
27 provided in Section 4 of the FMD.
- 28 ▪ Errors in programming, preprocessing, running, linking, and post-
29 processing the models—A thorough evaluation of model validity includes
30 the stage of model verification (EPA, 1994; Schwartz, 2000; Shelly et al.,
31 2000), which ensures that mathematical relationships posited by the
32 model are correctly translated into computer code, that model inputs are
33 free of numerical errors, and that software and data quality assurance has
34 been conducted. EPA conducted such model verification throughout the
35 modeling study.
- 36 ▪ Untested model predictions—EPA acknowledges that there are some
37 model predictions that cannot be evaluated using model-data comparisons
38 because field data are inadequate or lacking. However, this is not a “new”
39 or additional source of uncertainty because the component uncertainties
40 related to the model predictions have already been acknowledged.

41 Considerable effort went into the analysis of model uncertainty in this project, which is perhaps
42 unprecedented for a suite of water quality models of this complexity. The MVR evaluates the
43 uncertainty of the models using approaches based on Monte Carlo analysis. This approach

1 basically assumes that the models are correct, and errors in model predictions arise from
2 uncertainty or variability in parameter values. These are estimated based on subjective expert
3 judgment using probability distributions, and parameters are generally assumed to be
4 uncorrelated. While these assumptions are obviously suspect, they are nonetheless common
5 practice in uncertainty analysis. Analyzing the uncertainty of the linked model predictions is a
6 strength of this work.

7 **Response 5B-DE-2:**

8 EPA agrees with the Reviewer's comments. Although some of the assumptions
9 required for the Monte Carlo approach rely on professional judgment, EPA
10 concurs that such simplifications were necessary to conduct an uncertainty
11 assessment that was computationally feasible, and that such methods were
12 consistent with the state of the practice in complex environmental fate and
13 transport models.

14 The response surface modeling of EFDC uncertainty appeared to be very thorough and
15 comprehensive. EPA has provided a descriptive field for the parameters listed in Table 5.2-8,
16 which hopefully will be incorporated into the report. I would like to see EPA add initial and
17 boundary conditions for PCBs to this analysis, since these are both uncertain factors. I disagree
18 that the RSM approach is impractical or unworkable. The Responsiveness Document (p.2-110
19 and 111) discusses how uncertainty analysis can be used in context of evaluating differences
20 between remediation scenario predictions. Hopefully, no more than one RSM will be necessary
21 for evaluating uncertainty of these predictions.

22 **Response 5B-DE-3:**

23 The uncertainty approach presented in the MVR was intended to be
24 demonstrative rather than prescriptive, and EPA recognizes that other
25 approaches to evaluating model uncertainty may also be valid. EPA appreciates
26 the Reviewer's recognition of the value of the uncertainty analysis; however, in
27 subsequent discussions with the Model Working Group following the Peer
28 Review of the MVR, it was agreed that the uncertainty of the model results in the
29 evaluation of the relative performance of remedial alternatives would be
30 addressed using the best professional judgment of the Model Working Group.

31 The Monte Carlo analysis of the FCM is also quite thorough and informative. I agree with the
32 suggestion to evaluate model uncertainty in terms of 10th and 90th percentiles, as being
33 reasonably conservative, consistent with the distribution properties of the food chain model
34 outputs. This is probably the simplest way to deal with inflation of predictive uncertainty. The
35 critique of "unreasonable" parameter sets producing model predictions outside the bounds of the
36 data, is really a criticism of the subjective estimation of parameter variability. This can be
37 addressed using a Bayesian Monte Carlo approach, which builds posterior (informed) parameter

1 distributions based on computing the likelihood function for each model realization¹. The
2 method is simple and works very well - although the computational burden of BMC (i.e., effort
3 to achieve convergence in the likelihood function) can be heavy, unless there is some way to
4 substitute the RSM for the numerical model. I don't know whether this is a practical option for
5 computationally-intensive models such as EFDC.

6 **Response 5B-DE-4:**

7 EPA agrees with the Reviewer's comments. EPA believes that the
8 computational burden of a Bayesian Monte Carlo approach outweighs the
9 potential benefits of the more sophisticated approach.

10 There has also been much discussion about how residuals from comparisons between model
11 predictions and data can be used to improve the uncertainty analysis. It has been suggested to use
12 residuals to directly characterize uncertainty. This strikes me as a naïve approach, as I would
13 normally consider residual error to be a "best case" estimate of uncertainty. Forecasts will
14 seemingly always be more uncertain than calibration; the question is, how much more? It has
15 also been suggested that reporting average bias (e.g., Tables 4.2-4, 4.2-10 and 4.3-2) masks the
16 uncertainty due to variability in the PCB data itself. The remedy to this is straightforward:
17 calculate and report the variance of model bias. Moreover, statistical model could be developed
18 from the residuals to estimate the distribution of PCB concentrations from mean predictions.
19 This would compliment, instead of replace, the Monte Carlo results. The difficulty I can
20 foresee, is how do you determine the proper assumptions regarding homoscedacity (e.g., is the
21 variance in a constant factor of the mean or simply a constant?).

22 **Response 5B-DE-5:**

23 EPA agrees with the Reviewer's comments. Comparisons of model predictions
24 to data are useful, but do not provide an indication of overall model uncertainty,
25 particularly when the model is to be extrapolated to new exposure scenarios.
26 The reporting of the variation in the model bias metric had been added to the
27 FMD (Section 3.8); therefore, this gap in reporting has already been addressed.

28 EPA has not conducted statistical modeling to estimate concentrations in
29 individual fish (i.e., using modeled averages and estimating variation based on
30 observed variability in field data). Although the suggested approach is
31 reasonable, the model objectives do not require the estimation of PCB
32 concentrations in individual organisms, but instead rely on comparisons of
33 absolute and relative concentrations of average PCB concentrations for
34 alternative remedial scenarios.

¹ Dilks, D.W., Canale, R.P. and P.G. Meier. 1992. Development of Bayesian Monte Carlo techniques for model quality model uncertainty. *Ecological Modeling*. 62:149-162.

1 Marcelo H. Garcia

2 While uncertainty in model inputs and outputs was recognized, the nature of the model does not
3 allow for a conventional uncertainty analysis. Once all the processes are accounted for and well
4 represented in the model and assuming that the EFDC code can be run more efficiently, it might
5 be feasible to conduct an uncertainty analysis.

6 Response 5B-MG-1:

7 The Reviewer's comment does not address model uncertainty but instead
8 repeats concerns discussed under General Topic 1, which relates to the balance
9 of fate processes. EPA disagrees that questions regarding the suitability of
10 model process formulations preclude assessment of the model uncertainty.
11 Because models are iterative in nature, the results of sensitivity and uncertainty
12 assessments are commonly used to guide model refinements. It is not useful or
13 feasible to wait for consensus on all aspects of model development prior to
14 conducting or interpreting a model uncertainty assessment.

15 Frank Gobas

16 The calculation of model uncertainty in the report is seriously flawed. The report includes
17 several references to this. For example, based on findings that the uncertainty in the calculated
18 PCB concentrations is greater than the variability in the sampling data, the authors conclude that
19 "the results should not be interpreted to mean that the uncertainty in model predictions renders
20 the model predictions too uncertain to be usable" (p.5-56 Model Validation Report). The authors
21 further "acknowledge that a true statistical analysis of uncertainty, particularly when uncertainty
22 is propagated through the modeling framework, can produce bounds that may not be possible (or
23 likely) based on an understanding of that system. (p.5-57 Model Validation Report). I think that
24 these are important points.

25 Response 5B-FG-1:

26 EPA disagrees strongly with the Reviewer's comments and believes that the
27 Reviewer has misinterpreted the comments made by EPA in the MVR. The
28 comments by EPA regarding the differences between the width of the
29 concentration distributions in the data and those of the model simulations remain
30 appropriate, and are by no means an admission of a "flawed" approach. To the
31 contrary, EPA's comment was intended to provide a clear statement that the
32 uncertainty analysis includes quantification of uncertainty from all sources, not
33 just uncertainty in input data, and therefore, if conducted properly, can never
34 result in bounds that are smaller than the inherent variability in the data. The
35 Reviewer's comments are diametrically opposed to those of another Reviewer on
36 this topic (see Response 5B-DE-2).

37 I agree that in models of this complexity, it is virtually impossible to meet some key criteria for a
38 meaningful Monte Carlo Simulation, namely (i) that the model parameters included in the
39 simulations are independent, and (ii) there is insufficient data to properly characterize the

1 variability/uncertainty/error in the many parameters used in the model. Also, it should be
2 recognized that the MCS method does not recognize error in the functional relationships of the
3 model. The KS method is subject to the same limitations as the MCS method and the failure of 4
4 out of the 56 runs may be due to implausible parameter selections causing the model to crash for
5 these runs due to the problems outlined.

6 In conclusion, the conditions for a meaningful MCS or KS uncertainty analysis are not met in
7 this study. The calculated uncertainty values are therefore seriously flawed. It is unclear what the
8 meaning of the calculated uncertainty is. The lack of a meaningful uncertainty analysis is a major
9 flaw of the current model because model projections are very difficult, if not impossible to
10 interpret.

11 **Response 5B-FG-2:**

12 EPA agrees that, in the strictest sense, it is not possible to meet some of the
13 statistical assumptions of the MCS approach (i.e., complete independence of
14 model inputs). However, EPA believes that the simplifications inherent in the
15 approach were necessary and do not unduly compromise the utility of the linked
16 model uncertainty assessment. EPA's opinion is substantiated by the comments
17 of another Reviewer on this topic (see 5B-DE-2), who indicated that, in spite of
18 the inability to fully satisfy the strict conditions of MCS, the overall approach was
19 "common practice" and "a strength of this work."

20 EPA acknowledges that professional judgment was sometimes required in the
21 establishment of input parameter distributions, and that the MCS approach does
22 not explicitly incorporate error in the functional form of model processes.
23 However, EPA does not believe that the conditions for a meaningful MCS or KS
24 analysis are not met and that the calculated uncertainty values are thus seriously
25 flawed. Further, as stated in the comments of 5B-DE-2, the MCS method can be
26 considered along with other types of uncertainty assessment. Finally, the MCS
27 approach used in the modeling study is consistent with published model
28 applications at other sites in the northern United States (Burkhard, 1998).

29 To include uncertainty and better characterize it, the modelers could consider using the
30 formidable empirical data set to calculate frequency distributions for the model predicted mean
31 concentrations. To formalize this method, the authors could further develop the MB method
32 described on p. 6-118 (Model Validation Report) by calculating the standard deviation of the
33 mean (i.e. MB). What this will do in the case of PCB concentrations in the sediments is simply
34 project the observed variation in PCB concentrations on the model predicted concentrations. The
35 result is now a distribution of predicted concentration that is grounded in empirical data. This is
36 not a major job, and could be done with little extra work.

37 **Response 5B-FG-3:**

38 EPA agrees that further assessment of the model-data comparisons is useful,
39 and has further developed the MB method as suggested by the Reviewer.
40 Results of the expanded analysis are presented in Section 3.8.3 of the FMD.

1 Recommendation:

2 My recommendation is to ignore the MCS and KS results and remove it from the model
3 framework when the model is to be applied in the next phase of the study. Instead I recommend
4 that the modelers use the discrepancy between model predicted concentrations and observed
5 concentrations as a measure of model uncertainty. This is simpler, easier to understand and
6 avoids current computational problems. For example, the data depicted in Figures 6.3.3 to 6.3.8
7 (Model Validation Report) can provide a reasonable description of the overall model uncertainty.
8 This can be achieved by calculating the confidence limits of the MB used in the report. See
9 Environ. Toxicol. Chem. 23, 2343-2355 for additional details on this method. The application of
10 this method will also generate frequency distributions of model outcomes that can be used in risk
11 assessments. The method that I recommend is not complicated and can be carried out in little
12 time. The main drawback of the application of this method is that it relies on the assumption that
13 the uncertainty identified in past application of the model is a good measure for uncertainty in
14 future model applications. I think that this is a reasonable assumption for some model
15 applications. However, if river functioning is drastically altered by the remediation efforts, this
16 assumption may not apply.

17 **Response 5B-FG-4:**

18 The Reviewer's proposed solution entails discarding all explicit assessment of
19 parameter uncertainty, and relying solely upon model-data comparisons. This
20 approach, if used in isolation, would be flawed for three main reasons:

- 21
- 22 ■ The alternative approach ignores many aspects of model uncertainty, and
23 in fact ignores more aspects of uncertainty than the MCS approach.
24 Simple model-data comparisons do not explicitly account for uncertainty in
25 model formulations, parameter uncertainty, analytical uncertainty in the
26 data, or aggregation errors. To this end, EPA concurs with the opinion of
27 another Reviewer (5B-DE-2) that reliance solely on model residuals is a
"naïve approach."

 - 28 ■ The alternative approach cannot assess objectively whether the model
29 has been overcalibrated. Assessment of magnitudes of model residuals
30 does not indicate whether these residuals can be expected to be stable
31 when the model is applied to new conditions. Taken to an extreme, the
32 model could be artificially forced to perfect numerical fit (i.e., zero bias and
33 zero residuals) by inappropriately manipulating model parameters, but the
34 model-data approach would not diagnose this problem. This is because all
35 sources of uncertainty are buried in a "black-box" using this method, such
36 that sources of deviation are not discernible from one another.

 - 37 ■ The alternative approach relies on the assumption that the magnitude of
38 uncertainty identified during Calibration will remain unchanged in future
39 model applications. This assumption may not hold if the model is applied
40 to new exposure conditions in remedial scenarios. The Reviewer
41 acknowledged this limitation.

1 EPA believes that ignoring the MCS and KS results would negatively influence,
 2 rather than benefit, the uncertainty analysis. However, the “observed
 3 discrepancy” approach suggested by the Reviewer has some merit, and for this
 4 reason, an expanded assessment of the MB approach is included in the
 5 uncertainty analysis in the FMD. The inability to strictly adhere to all
 6 assumptions is a limitation of any uncertainty analysis method, including the
 7 MCS and KS approaches and the Reviewer’s recommended alternative.

8 Any model has inherent uncertainty. So, this is normal. But where the model framework is
 9 inadequate is in the recognition of this uncertainty and in the development of adequate methods
 10 to characterize or estimate this uncertainty. Without the inclusion of uncertainty in the current
 11 model framework, I do not think that it is possible to convincingly distinguish between the
 12 effectiveness of different remedial options.

13 **Response 5B-FG-5:**

14 EPA strongly disagrees with the Reviewer’s comments. EPA has acknowledged
 15 uncertainties of many types, and was able to explicitly account for some, but not
 16 all, of these sources of uncertainty during the linked MCS approach. It is
 17 inappropriate to characterize the EPA uncertainty assessment as non-existent or
 18 inadequate when the alternative recommended approach suffers from some of
 19 the same, plus several additional, limitations.

20 EPA believes a more productive approach is to acknowledge that the methods
 21 can be considered in a complementary manner to evaluate model uncertainty. As
 22 noted in the FMD (Section 3.8), methods for the quantitative evaluation of
 23 uncertainty in modeling study results are in various stages of development and
 24 there is no commonly accepted way of quantifying or communicating to
 25 decisionmakers the accuracy of model predictions. By considering these
 26 approaches together, EPA believes that a meaningful and defensible evaluation
 27 of model uncertainty was conducted.

28 Include model uncertainty in the model framework and provide guidance about how the results
 29 from the uncertainty analysis are to be used when comparing outcomes resulting from different
 30 model scenarios.

31 Do not use the MCS or KS method for calculating model uncertainty.

32 Include an uncertainty analysis that takes full advantage of the empirical data that have been
 33 collected. As discussed earlier, this can be achieved by comparing observed and model predicted
 34 PCB concentrations.

35 **Response 5B-FG-6:**

36 Model uncertainty was included in the model framework, and has been explored
 37 in additional detail in the FMD based on Reviewer suggestions, including
 38 additional comparisons of observed and model-predicted PCB concentrations.

1 In subsequent discussions with the Model Working Group following the Peer
2 Review of the Model Validation Report, it was agreed that the uncertainty of the
3 model results in the evaluation of the relative performance of remedial
4 alternatives would be addressed using the best professional judgment of the
5 Model Working Group rather than using a formal uncertainty analysis as
6 proposed in the MVR.

7 **Wilbert Lick**

8 Because the basic processes are inaccurately described, the uncertainties in model outputs are not
9 correctly acknowledged or described.

10 **Response 5B-WL-1:**

11 The Reviewer comment does not address model uncertainty but instead repeats
12 concerns discussed under General Topic 1, which relates to model processes.
13 EPA disagrees that differences of opinion regarding the suitability of model
14 process formulations should obstruct all assessment of the model uncertainty.
15 See also the Response 5B-MG-1 above.

16 **E. John List**

17 Since the basic processes for the fate and transport of PCB are clearly not properly included in
18 the model their uncertainty cannot be assessed.

19 **Response 5B-JL-1:**

20 The Reviewer comment does not address model uncertainty but instead repeats
21 concerns discussed under General Topic 1, which relates to model processes.
22 EPA disagrees that differences of opinion regarding the suitability of model
23 process formulations should obstruct all assessment of the model uncertainty.
24 See also the Response 5B-MG-1 above.

1 **6. GENERAL TOPIC 6: UPSTREAM BOUNDARY CONDITIONS**

2 **6.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 5, lines 39 to 45
	Page 7, lines 1 to 23
Endicott	Page 4, line 33 to page 5, line 22
	Page 6, lines 5 to 16
	Page 10, line 18 to page 16, line 9
Gobas	Page 6, lines 34 to 40
	Page 7, lines 35 to 36

3 **6.2 GENERAL TOPIC SUMMARY**

4 PCB transport and fate in the Housatonic River is strongly influenced by the concentrations of
5 solids and PCBs that enter the study area from the East Branch of the river near the GE facility.

6 Three of the Reviewers commented, one extensively, on the relationships developed to provide
7 upstream boundary input of TSS and PCBs based on flow and stage. All three Reviewers noted
8 that the relationship overpredicted TSS loadings during low-flow periods and mentioned that this
9 issue affects the parameterization of the model throughout the PSA. One Reviewer noted that
10 the model results appear extremely sensitive to upstream boundary conditions and questioned
11 whether in-stream sediment processes were important in the model. Two Reviewers
12 recommended additional data collection, and all three recommended additional analysis of the
13 TSS and PCB data to refine the boundary loadings.

14 One Reviewer focused on the change in PCB boundary conditions between the Calibration and
15 Validation phases of the modeling study and requested additional explanation of and justification
16 for the changes. The same Reviewer made a number of suggestions for refined analyses of the
17 boundary condition data, including use of the Autobeale statistical approach.

1 **6.3 GENERAL TOPIC RESPONSE**

2 The upstream boundary at the confluence of the East and West Branches of the
3 Housatonic River is the largest source of solids and PCBs to the study area. Solids and
4 PCB loads from the upstream boundary must be estimated as accurately as practical to
5 ensure model reliability. Throughout the model development process, flow, solids, and
6 PCB concentrations and other measurements were repeatedly examined to ensure that
7 upstream loads were estimated in the most realistic manner possible. Because of their
8 relative importance to PCB transport, particular attention was paid to methods used to
9 estimate upstream boundary loads for the East Branch. The load estimation methods
10 used were refined during the modeling study, reflecting the improved understanding of
11 the system, as well as in response to Peer Review comments.

12 Solids and PCB loads are computed by multiplying paired values of concentration and
13 flow together in sequence over time. To develop inputs for EFDC, point-in-time
14 measurements of concentration must be extended to form a continuous record and
15 multiplied by flow of upstream loads to the river for the entire time period simulated by
16 the model. The flux analyses described in Attachment B.3 of the MCR provides an
17 overview of data and the initial methods used to estimate upstream boundary solids
18 loads. Further data explorations and analysis are presented in FMD Appendix B.2.

19 Data collected during storm event and monthly monitoring programs were used for
20 these analyses. It should be noted that solids and PCB concentrations measured at the
21 upstream boundary are highly variable. Across narrow ranges of flow, these measured
22 values can vary by more than two orders of magnitude. For all practical purposes, a
23 many-to-one relationship exists between measured concentration and flow. This
24 variability complicates load estimation efforts because load estimation techniques such
25 as regression estimators typically describe the central tendency (e.g., the mean or
26 median) of the relationship between variables such that there is a one-to-one
27 relationship between concentration and flow. When data are highly variable, there can
28 be considerable differences between the central tendency (the one value estimated for
29 a given flow) and any individual measurement. Extensive efforts were directed toward
30 determination of optimal methods for load estimation, assessment of variability, and an

1 evaluation of the significance of differences between boundary concentration estimates
2 and measurements.

3 As specifically recommended during Peer Review, the Autobeale method (Richards,
4 1998) to estimate loads as a function of concentration and flow was evaluated. The
5 Autobeale method uses a sequence of concentration and flow estimates to compute a
6 load based on the assumption that the ratio between load and flow is constant for a set
7 of conditions. The program can segregate (stratify) the data into different flow regimes
8 as needed to report the mean daily load for 1 year of data. The program contains an
9 algorithm to identify the optimal stratification based on the smallest pooled mean square
10 error.

11 Despite the conceptual appeal of this method, the Autobeale approach cannot be used
12 to estimate loads for EFDC because the program is designed to report an average daily
13 load for a 1-year period. This is a serious limitation because loads with high temporal
14 resolution must be specified for EFDC to generate the high-resolution model outputs
15 required as a primary objective of the modeling study. For example, loads for EFDC
16 must be estimated with a frequency of 15 minutes to 1 hour as needed to simulate high-
17 flow events. Further, the Autobeale program cannot be used to estimate loads for years
18 for which there are no concentration measurements. Moreover, when there are few
19 measurements in a year, the program typically assumes that concentration is constant
20 for long periods of time regardless of the flow record and the expectation that
21 concentration will increase substantially as flows increase. Because it cannot estimate
22 loads for years without concentration observations, the Autobeale program cannot
23 estimate loads for the majority of the years simulated as part of the modeling study (i.e.,
24 loads cannot be estimated for most of either the model calibration or validation periods).

25 Many other approaches for estimating TSS and PCB boundary loads were evaluated.
26 Relationships between TSS and PCB concentrations and flow, flow acceleration, rate of
27 acceleration, and precipitation were explored. None of these approaches produced
28 better estimates of TSS loads than the method first used for model calibration (see the
29 flux analysis presented in Appendix B.3 to the MCR). However, the stratified regression

1 estimation procedure described in the Section 2.3 of Appendix B.2 to the FMD resulted
2 in a revised estimate of PCB boundary conditions which yields estimates that fit the data
3 somewhat better than prior estimation methods did.

4 One issue extensively examined as part of model development efforts was the nature of
5 the error in boundary condition estimates. For this discussion, two terms must be
6 defined: (1) residual error; and (2) bias. Residual error is defined as a difference
7 between the value of an estimate and the value of a measurement. Bias is defined by
8 the sign (positive or negative) and consistency of residual errors. A positive (or high)
9 bias occurs when residual errors (residuals) are consistently greater than zero and a
10 negative (low) bias occurs when residuals are consistently less than zero.

11 In an ideal case, boundary condition estimates would exactly reproduce each and every
12 measurement so that the residual error for each estimate would be zero. However,
13 because concentration measurements for the Housatonic River have a wide range of
14 values across narrow ranges of flow, residual errors occur. Stochastic and deterministic
15 methods were extensively explored as part of efforts to minimize residual errors and
16 reduce the impact of bias in upstream boundary concentration estimates. However,
17 neither the stochastic nor deterministic bias correction methods were successful at
18 reducing bias without increasing residual error.

19 **6.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 6**

20 **Eric Adams**

21 **Boundary Loads**

22 The trend of the PCB concentration versus flow data for the E. Branch, shown in Figure 4.1-2
23 seems strange (why the sudden change at 550 cfs?). I guess this is simply what the data suggest.
24 Also the model fit exceeds the data at low flow (10 cfs) by a factor of 2-3 for both dissolved and
25 particulate PCBs. This excess upstream load may have led to an underestimation of calibrated
26 fluxes from other sources downstream. Given the prevalence of low flow periods, this is
27 important.

Response 6-EA-1:

The change at 550 cfs is related to the flow at which out-of-bank flow conditions occur in Reaches 5 and 6. As noted by the Reviewer, the increase in PCB concentrations when flows exceed 550 cfs is what the data suggest. Differences between model results and data at low flows are driven by the very wide range of measured PCB concentrations that occurs. At these flows, PCB concentrations are typically low but vary from non-detect to 40 mg/kg. TSS also varies over a wide range at any given flow. The regression estimators for the upstream load were formulated to accurately estimate the central tendency (mean) of the measurements at any flow rate for both TSS and PCBs. PCB loads are estimated as a function of the TSS concentration to reduce the potential for bias in the model.

However, it should be recognized that a factor of 2-3 difference in TSS and PCB concentrations at low flow (which is when low concentrations occur) results in a small difference between simulated and measured concentrations because both concentrations are low (i.e., the relative difference is small in an absolute sense because measured concentrations are low). Further, EPA took great care in establishing the TSS and PCB boundary conditions in EFDC to ensure that any potential biases in the boundary conditions did not translate to errors in food chain exposures.

Also, see the General Response above, the General Response to General Topic 1B, and Appendix B.2 and Section 4 of the FMD.

TSS

The model uses flux analysis for upstream TSS when there is no data and often this analysis overestimates TSS by a factor of 2-4 (Figures 4.2-31 and 6.2-12). There is some underestimate of TSS at high flow.

The model tends to overpredict TSS during the calibration period (Figure 4.2-39), especially at lower TSS concentrations. This is possibly because of the overprediction of upstream loading. The model seems to do better with the storm events, which EPA claims are more important. While bias in TSS at low flow may be insignificant in terms of the sediment budget, it does affect the water column PCB concentrations, and hence the relative uptake of PCBs from the water column and the sediment in the Food Chain Model. In general it would have been nice to have had more data on TSS.

The statistical summary (equivalence plot, Figure 4.2-61) indicates generally good agreement, but the model shows less variability than the data; i.e., the model overpredicts low concentrations and underpredicts high concentrations. There appears to be no significant bias with flow rate. Sedimentation rates agree reasonably well with measurements using Cs-137.

Bedload concentration is computed as bed load mass rate divided by river flow (pg. 4-56). Given that the bedload is traveling slower than the average stream velocity, this would seemingly give too low concentrations, but I suspect velocities are more important than concentrations.

1 Response 6-EA-2:

2 See Response 6-EA-1, the General Response above, and Appendix B.2 to the
3 FMD.

4 Douglas Endicott

5 This question also asks us to consider changes to the models resulting from additional (Phase 2)
6 calibration. This specifically applies to EFDC calibration, since little or no changes were made to
7 either the HSPF or FCN models. Previously, the Peer Review panel commented that the 14-
8 month calibration was too short to reflect many significant long-term model processes,
9 specifically the evolution of PCB concentrations in the sediment bed. So the EPA modeling team
10 went back and extended the calibration to cover a much longer, 10-year duration. I expected to
11 see some changes in the model parameters related to the residence time of PCBs in the surficial
12 sediment layer. Instead, as a result of Phase 2 calibration we see some dramatic changes in the
13 simulation of PCB transport and fate in the Housatonic River: There are now 3 times more PCBs
14 entering the Primary Study Area (PSA) at the upstream boundary, although the difference
15 (compared to the Phase 1 calibration & flux analysis) diminishes further downstream (2 times
16 more PCBs at New Lenox Road, 1.5 times more at Woods Pond). Export of in-place PCBs from
17 the sediments of Reach 5A is no longer the predominant contaminant source to the Rest-of-
18 River. To me, this is a breathtaking change in the PCB fate and transport simulation, which
19 rewrites the entire assessment going back all the way to the conceptual model presented in the
20 MFD. I was disturbed to see such a major change taking place so late in the model development
21 process, and was also somewhat surprised at the nonchalance with which this revision was
22 presented and received.

23 Does the hydrograph or the longer duration of the Phase 2 calibration explain these differences?
24 To some degree, maybe. In 10-year period, there are a number of high-flow years (e.g., '90,
25 '96,'98 and '00) as well as low-flow years ('91, '92 and '99). The hydrograph impacts the
26 balance of sediment erosion and deposition averaged over different durations. The MVR does
27 not discuss this to any significant extent. However, the change in the PCB fluxes mostly reflects
28 a new treatment of the boundary condition, apparently provoked by some new boundary
29 condition data. Comments regarding the boundary condition used in the Phase 2 calibration are
30 provided in my response to question 3. At this point, EPA should consider whether further
31 refinements and improvements to the model will occur in the future, as more data are collected
32 and the models are run. In other words, are the models only as good as the latest data point? How
33 can the model calibration be considered "final" if, as the Phase 2 recalibration demonstrates, a
34 few new data can so readily change the PCB flux analysis and possibly other model results?

35 Response 6-DE-1:

36 As the Reviewer notes, some differences between the Phase 1 and Phase 2
37 Calibrations results are attributable to the differences in flow over time. As the
38 Reviewer also comments, some of the difference is attributable to the changes in
39 upstream boundary PCB loads using the revised method used to estimate loads,
40 particularly at high flow. In the Housatonic River, measured sorbed PCB

1 concentrations (in mg PCB/kg solids) increase as TSS concentrations increase
2 when flows exceed 550 cfs. The PCB load function first developed for the MCR
3 (and used for the Phase 1 calibration) did not capture this trend in the
4 measurements. Using the original functions for TSS and PCB loads, the sorbed
5 PCB concentration estimated at the upstream boundary would decrease rather
6 than increase as measured. This condition was not noted during Phase 1 model
7 development because the range of flows over the 14-month period does not
8 include many high-flow events. However, when the original method was used to
9 estimate PCB loads for the Phase 2 calibration period, the dilution of sorbed PCB
10 concentrations at the upstream boundary that was introduced by the original load
11 estimation functions became apparent because of the numerous high-flow
12 periods that occur from 1990 through 2000.

13 Many methods to estimate loads were evaluated to address this limitation. The
14 best method to accurately simulate the increasing relationship between sorbed
15 PCB concentrations, TSS, and flow was to estimate PCB loads as a function of
16 TSS concentration and flow. This approach ensures that PCB concentrations at
17 the upstream boundary match observed trends at high flow and also minimizes
18 the potential for bias in water column biotic exposure concentrations at low flow.

19 EPA disagrees with the Reviewer's assessment that the difference in simulated
20 PCB fate is "breathtaking." In light of the extensive analyses devoted to this
21 issue, EPA further disagrees with the Reviewer's characterization that revisions
22 to PCB upstream boundary conditions were introduced with "nonchalance." It is
23 important to recognize that all other parameters (mass transfer coefficients,
24 erosion and deposition parameters, etc.) are unchanged. It should also be noted
25 that the model representation of erosion and deposition or other processes is not
26 directly tied to the method used to estimate upstream boundary loads. This
27 means the balance of fate processes is correctly represented and that the model
28 can be considered "final" because the model is able to accurately simulate water
29 column TSS and PCB concentrations, net sedimentations rates, and the trend of
30 surface sediment PCB concentrations in Woods Pond over time. Additional data
31 for the upstream boundary will not alter the parameterization of PCB transport
32 and fate processes in the model domain.

33 Further, it is also important to note that remediation efforts are being conducted
34 on the GE facility and nearby areas, including the 2 miles of the East Branch
35 between the facility and the confluence. These remediation efforts have altered
36 PCB loads at the upstream boundary. Consequently, the PCB upstream
37 boundary condition used for Calibration and Validation is not applicable for the
38 future application of the model in the CMS and must reflect the loads that are
39 currently measured or expected to occur in the future. It is expected that this will
40 be a topic of discussion for the Model Working Group.

41 EFDC predictions of flow, TSS and water column total PCB concentrations were compared to
42 data using both longitudinal profile and time series plots. Although the spatial profiles for TSS
43 predictions appear reasonable for several selected days (Figures 4.2-34 thru 4.2-37), the time

1 series plots indicate significant and persistent overprediction of low TSS measurements. This is
2 particularly evident at Holmes Road (Figure 4.2-38), but also at New Lenox Road (4.2-39) and to
3 a lesser degree at Woods Pond headwater (4.2-40). In the MVR (page 4-59), EPA offers that
4 “Simulated TSS concentrations pass through approximately one-third of the data...”, which is
5 surprisingly poor model performance. Similar overprediction of low TSS measurements is
6 apparent for the validation period as well. According to comments by both EPA and GE, the
7 overprediction of low TSS measurements is due to significant bias in the specification of the East
8 Branch boundary condition on days when TSS concentrations were not measured. Time series
9 plots for specific flow events (Figures 4.2-42 thru 4.2-48) indicate a better fit of TSS predictions
10 under high flow conditions.

11 **Response 6-DE-2:**

12 The greatest difficulty associated with TSS and PCB load estimation for the
13 Housatonic River is the very wide range of measured concentrations that occur
14 across narrow ranges of flow. As noted in Appendix B.2 to the FMD and other
15 documents, TSS and PCB concentrations are particularly variable at low flow,
16 when concentrations are typically lower. Natural variability reflects the diversity
17 of watershed conditions. Because of this variability, a many-to-one relationship
18 exists between measured concentration and flow. This complicates load
19 estimation efforts because regression estimators describe the central tendency of
20 the relationship between variables so there is a one-to-one relationship between
21 concentration and flow.

22 Given this variability, differences between boundary concentration estimates and
23 individual measurements occur and are unavoidable (i.e., the average is neither
24 the minimum nor the maximum). However, it should be recognized that small
25 errors in simulated TSS or PCB concentrations that occur under low-flow
26 conditions have relatively little impact on model performance in any context
27 because the mass flux (i.e., the product of flow and concentration) of solids
28 and/or PCBs is at a minimum when flows are low.

29 Further, EPA took great care to ensure that any potential biases in model results
30 were minimized and did not influence the EFDC or FCM calibration process.
31 Moreover, the endpoint of primary concern with respect to model bias is the
32 ability of the model framework to estimate PCB exposure concentrations and
33 body burdens. In this regard, there is no significant bias in model performance,
34 as demonstrated by the bounding analysis presented in the EPA Response to
35 Questions from the Model Validation Document Overview Meeting and further
36 described in FMD Section 4.

37 Therefore, EPA disagrees that there is a “serious overprediction” of low TSS and
38 PCB concentrations in EFDC as described by the Reviewer. Also see General
39 Response above.

1 The first two issues appear related to parameterization errors, as noted previously, and should be
2 satisfactorily addressed by the suggested corrections. The bias in TSS and PCB concentrations
3 due to the boundary condition deserves further consideration.

4 At sampling locations in the upper reaches of the PSA, the model fails to match half to two-
5 thirds of the TSS data. Predicted values at base flows are ~10 mg/L versus data in the 2-5 mg/L
6 range. There is less discrepancy in the lower reaches. In general, the bias is most apparent at
7 lower flow rates. Censoring TSS data <5 mg/L was offered by EPA as a way of correcting the
8 model performance metrics. A similar problem with low-flow bias for PCB predictions is also
9 apparent in the upper reaches of the PSA, and a similar censoring approach was suggested.
10 However, I do not believe it is appropriate to ignore or discount the bias in model predictions
11 under low-flow conditions. About 70% of an “average year” is low flow conditions, and
12 significant PCB uptake by fish coincides with low flow periods. It is unclear whether the low-
13 flow PCB bias has led to food chain miscalibration, as suggested by GE, because the food chain
14 model was initially calibrated using data-based exposure concentrations. These would not exhibit
15 the same low-flow bias as exposure concentrations predicted by the model. Nevertheless, I am
16 concerned that bias due to the TSS and PCB boundary conditions may result in model errors that
17 have not been addressed. We know very little about how the boundary condition will evolve over
18 time following upstream remediation; hopefully, ongoing monitoring will be used to update and
19 improve upon this situation.

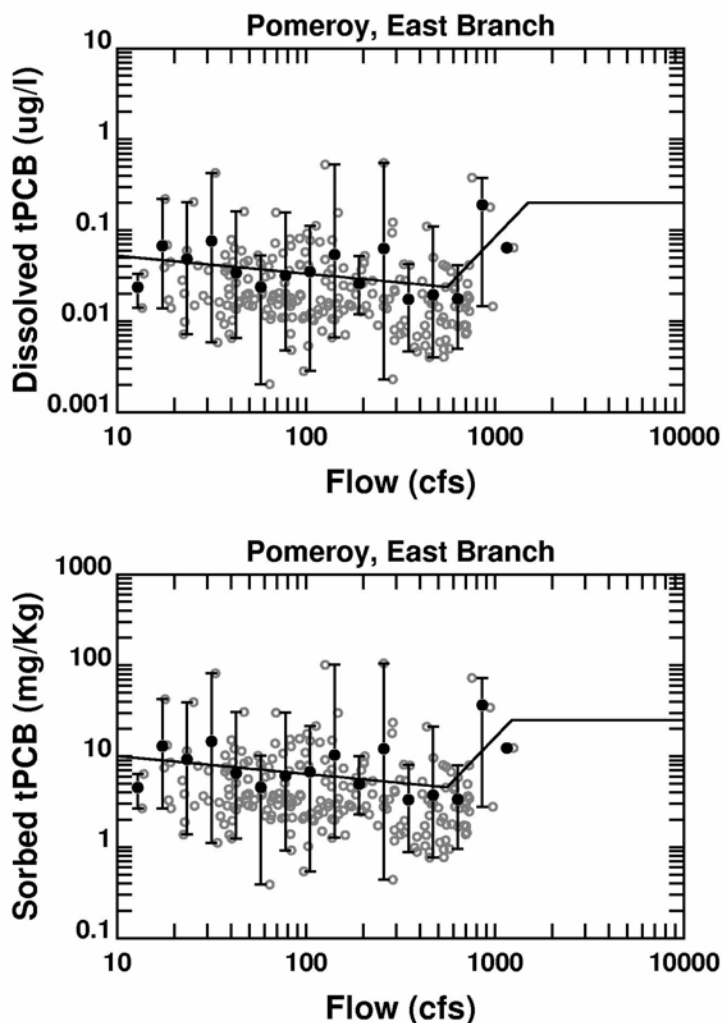
20 The specification of the upstream PCB boundary condition is an important component of
21 developing a reliable transport and fate model for the Housatonic River, for each of the time
22 intervals over which the model is to be applied (calibration, validation and forecasting). EPA has
23 developed different interpretations of the PCB boundary condition in the Phase 1 and Phase 2
24 Calibrations, and these differences produce dramatically different outcomes in terms of the PCB
25 flux analysis generated by the model predictions. The PCB boundary condition developed for
26 the Phase 2 calibration applies the partitioning model to estimate particulate and dissolved PCB
27 concentrations from total PCB measurements, which are then independently regressed to flow
28 rate. The PCB phase concentrations are “capped” to prevent the boundary conditions from
29 grossly exceeding the data at high flows. This is a creative approach; I tried something similar in
30 the Fox River. Unfortunately, it’s not clear whether this approach does a reasonable job of
31 describing the boundary condition data. Although this approach may improve the PCB boundary
32 condition at high flows, in comparison to the Phase 1 calibration, at base flow rates the Phase 2
33 PCB boundary conditions are substantially worse (e.g., Phase 1: ~40 ng/L at base flow vs. Phase
34 2 : ~100 ng/L). I am not convinced EPA has made the best use of the boundary condition data,
35 and offer some comments below regarding the approach they used to describe this data.
36 Regardless of these issues, it appears that much of the variability seen in PCB concentrations at
37 the upstream boundary cannot be explained, in the approaches taken in either the Phase 1 or
38 Phase 2 calibration, or other alternatives that have probably already been explored. If the TSS
39 and PCB boundary conditions cannot be improved, the best recommendation may be to add a
40 random error component to the boundary conditions in the sensitivity and uncertainty analyses.

41 The boundary condition data eres provided by EPA in the spreadsheet
42 “East_Branch_Boundary_Data.xls”. Their interpretation of this data, and the descriptive
43 approach used to model the boundary condition, is described in Section 4.1.5 of the Model
44 Validation Report, with further discussion offered in supplemental responses. Figure 4.1-2

1 (reproduced below) shows the regressions of dissolved and particulate PCB concentrations
 2 versus flow that were used to specify the total PCB boundary condition for the EFDC transport
 3 and fate model (except for days when measurements were available). I have a few comments to
 4 make based on this figure and review of the boundary condition spreadsheet:

- 5 1. As a general observation, I would say that if one focuses on the actual data plotted in
 6 these graphs (the open circles), it appears that EPA's regressions describe relatively little
 7 of the variability observed in PCB concentrations at the boundary condition. The
 8 regressions are especially tenuous at low and high flows. In fact, the regressions exceed
 9 all of the data in the lowest flow "bin".
- 10 2. I cannot find the PCB concentration data collected at flow rates smaller than 24 cfs¹.
 11 Therefore, I have no way to confirm the results shown in Figure 4.1-2 for the two lowest-
 12 flow "bins". At least for the lowest "bin", the regression line appears to be a poor fit. A
 13 noted above, it exceeds all of the measured data.
- 14 3. At high flows, the PCB concentrations are "capped" to prevent unrealistically high PCB
 15 concentrations during floods. The "cap" was specified as 25 mg/Kg for particulate PCBs,
 16 based upon concentrations measured in sediments deposited on vegetation and banks. I
 17 think this value may be somewhat too high. My own calculation of the unbiased mean
 18 PCB concentration from the 13 sediment deposit samples is 20.5 mg/Kg, although I was
 19 measuring the data off of a graph. Please check this calculation. If 25 mg/Kg is indeed
 20 too high, it will bias the high-flow PCB boundary condition.
- 21 4. According to EPA, the detection limit was used as replacement values for censored PCB
 22 concentrations. While this has little impact on the distribution of total PCB
 23 concentrations, it does bias the particulate PCB concentrations that are calculated from
 24 total PCB measurements using the partitioning model. I didn't check, but I suspect that
 25 dissolved PCB concentrations may be biased as well. I think it is generally preferable to
 26 use one-half of the detection limit as replacement values for censored PCB
 27 concentrations.

¹ I think this may be because East Branch daily flows were provided in the spreadsheet, while Coltsville (hourly?) gauge data were used in the regressions and possibly the graph. I couldn't find the source of the flow data in the MVR.



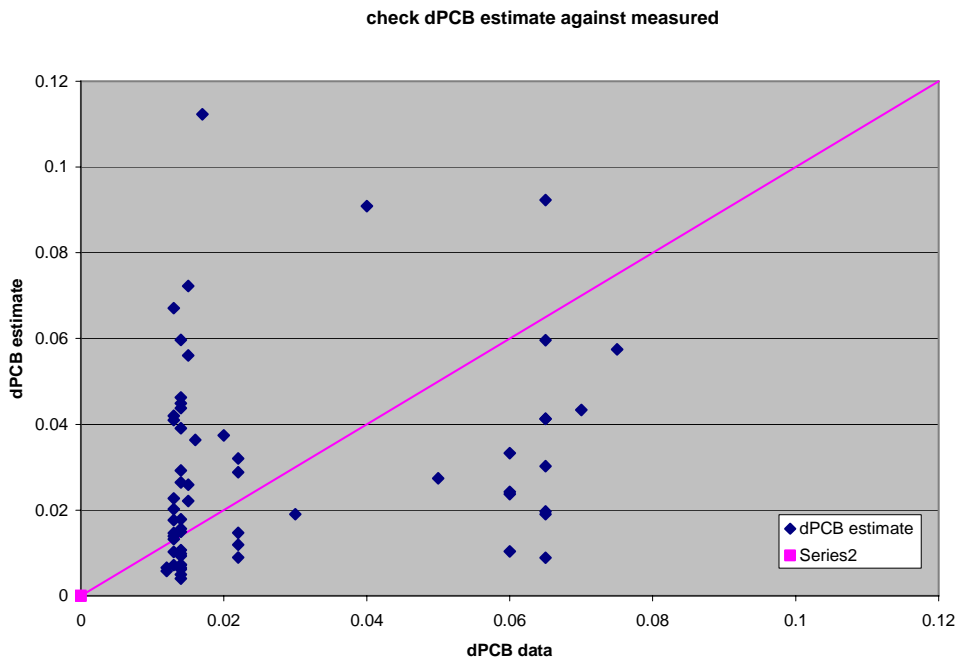
- 1
- 2 5. Another thing I noticed when I reproduced EPA’s partitioning calculation (which is used
- 3 to estimate the dissolved and particulate PCB concentrations from the total PCB
- 4 measurements), is that the dissolved PCB concentration estimates don’t agree very well
- 5 with the relatively few dissolved PCB concentrations measured at the boundary
- 6 condition. This is shown below in Figure 2. If the partitioning model is being used to
- 7 describe the boundary condition, shouldn’t it fit the data?
- 8 6. Frankly, some of this data is mystifying. For example, 2 samples were collected on
- 9 November 12, 1995. For both samples, the flow is reported to be over 1,100 cfs. In the
- 10 first sample, [TSS] was 450 mg/L and total [PCB] was 0.2 ug/L. In the second sample,
- 11 [TSS] was 17 mg/L and total [PCB] was 0.52 ug/L. Running these values through the
- 12 partitioning model, one obtains particulate PCB concentrations of 0.44 and 23 mg/Kg. It
- 13 is somewhat hard to believe that PCB concentrations on suspended solids could vary by a
- 14 factor of 50 within one day.

- 1 7. It is also curious to me that there has been no shift or evolution in PCB boundary
 2 concentrations over the past 16 years, and that seasonality is not evident in the data. If
 3 PCB boundary condition data for all years are plotted together, we see the familiar
 4 shotgun target (Figure 3). There appears to be some underlying behavior, however,
 5 within individual years of data. Figure 4 shows total PCB data for years (especially 2002)
 6 in which a positive relationship with flow is evident. Figure 5 shows total PCB data for
 7 years (2003 in particular) in which the flow relationship is generally negative. The
 8 highest total PCB concentrations in Figure 5 come from the warm (and presumably
 9 higher organic carbon²) months of July-September, while the lowest PCB concentrations
 10 at very high flow were sampled in October and November. While I am confident EPA
 11 has looked at this data in great detail, I think the patterns in the data hinted at here
 12 suggest some underlying behavior which could be exploited in the regression models
 13 used to describe the boundary condition. I believe this might, in turn, provide better PCB
 14 boundary condition estimates than the current approach in which all measurements are
 15 lumped into one sample.
- 16 8. The MVR doesn't discuss what other alternatives may have been tested, but here are
 17 some suggestions:
- 18 ▪ AutoBeale (Beal's Stratified Ratio Estimator) is an alternative statistical approach
 19 that works well for boundary conditions when the data are stratified by season as well
 20 as flow;
 - 21 ▪ When regressing the PCB data, were autocorrelation and Lag-1 or 2 considered as
 22 factors?
 - 23 ▪ Check bias correction formula;
 - 24 ▪ Have untransformed PCB data been regressed? How do results compare to log-
 25 transformed regressions?
- 26

² EPA is assuming a constant 7.3% organic carbon content on suspended solids, which cannot be confirmed from the data collected at the upstream boundary.

1

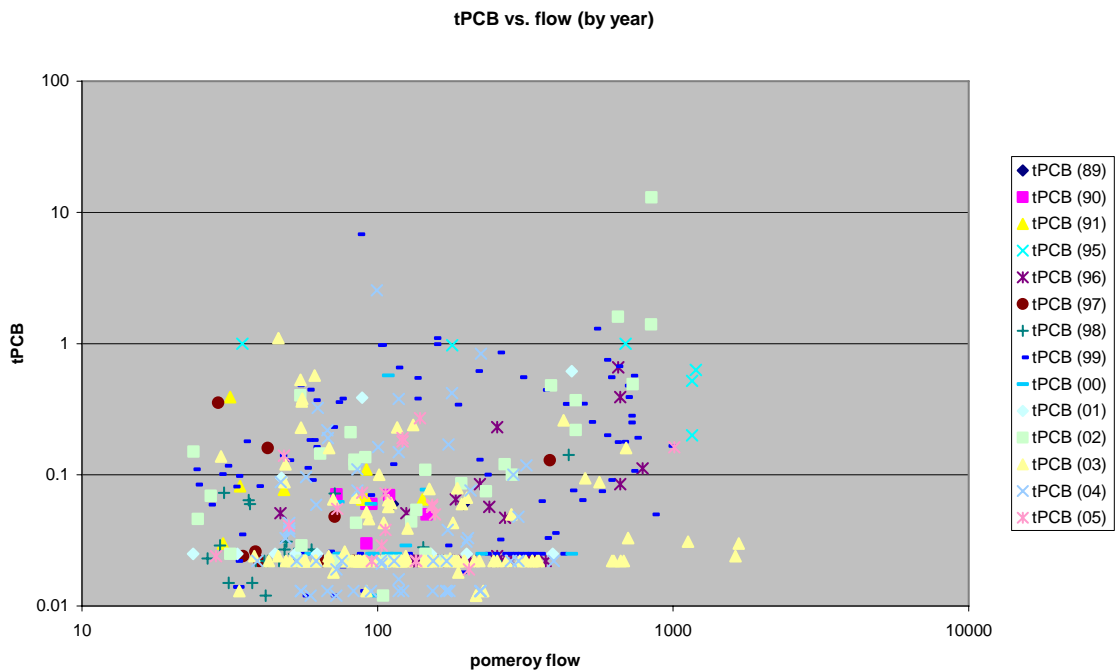
Figure 2



2

3

Figure 3

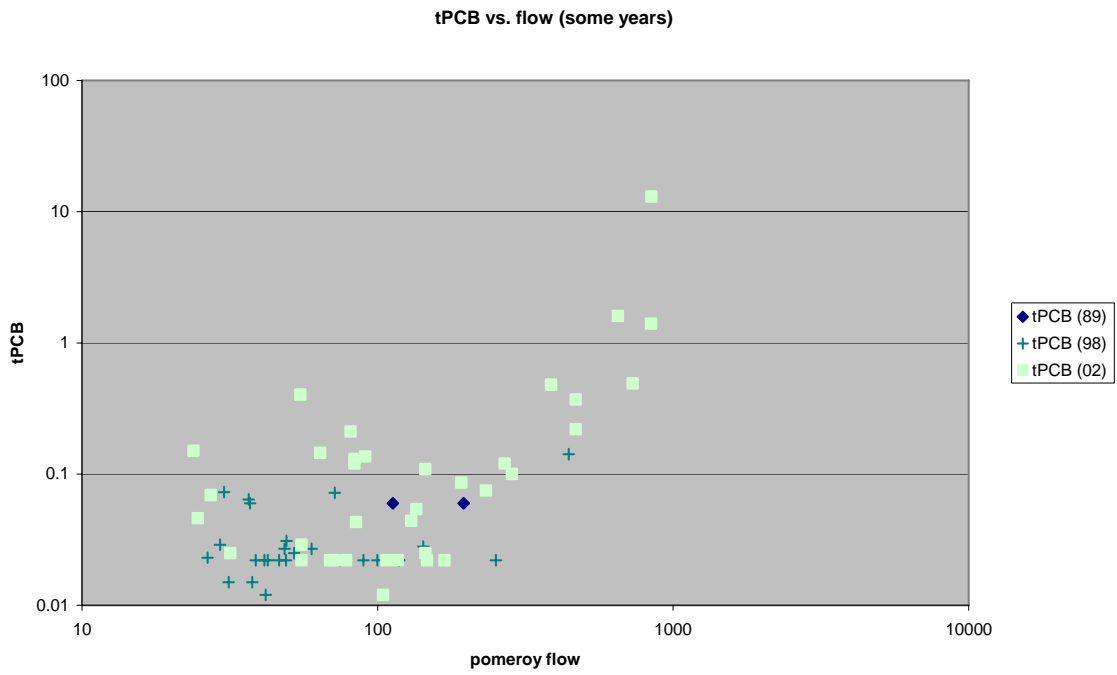


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5

1

Figure 4

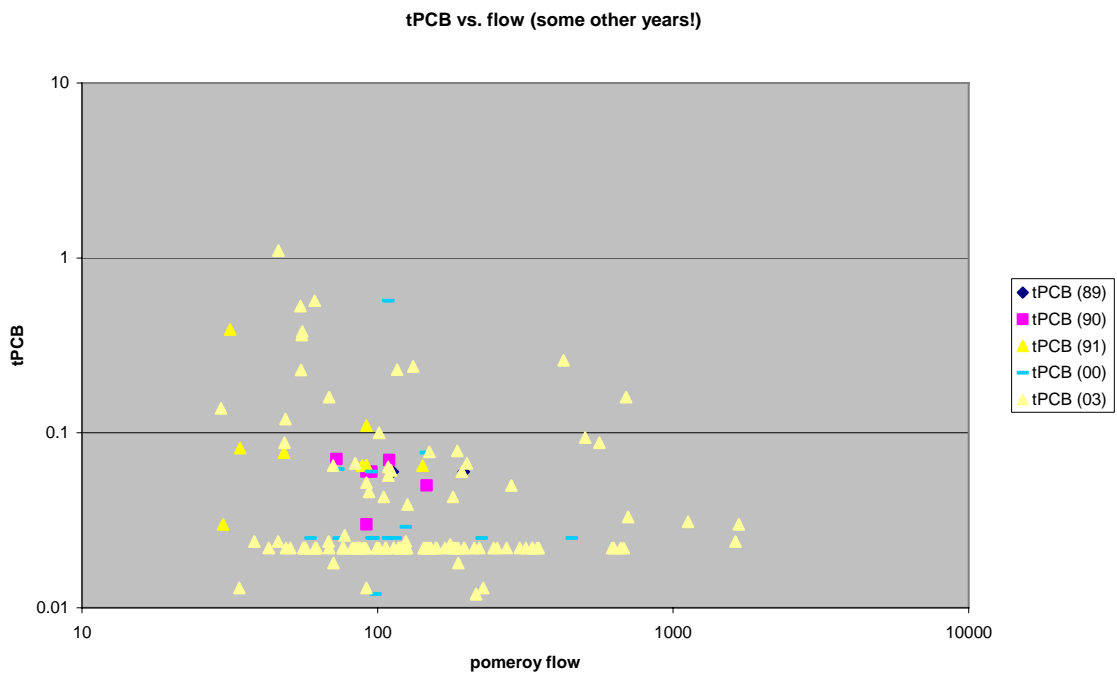


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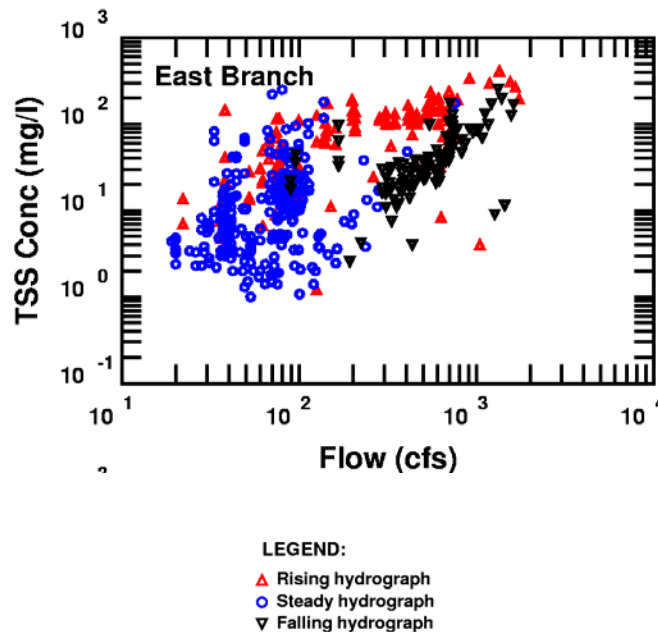
Figure 5



5

1 9. I also went back to look at the TSS boundary condition, which has not been changed
 2 from the Phase 1 calibration. Figure 6 is a reproduction of the plot displaying the East
 3 Branch TSS data as a function of flow (from: Volume 3—Appendix B Hydrodynamic
 4 and Sediment/PCB Fate and Transport Model Calibration, Attachment B.3 TSS and PCB
 5 Flux Analysis). The TSS data were partitioned according to 3 phases of the hydrograph –
 6 rising, steady and falling. TSS data are well-behaved during rising and falling
 7 hydrographs, but not at steady (and predominantly low) flow. This makes me wonder
 8 again about seasonal factors, intermittent upstream disturbances, or possibly sampling
 9 artifacts. It is hard to imagine TSS concentrations varying between 1 and 100 mg/L at
 10 base flow.

11 **Figure 6**



12
 13

14 **Response 6-DE-3:**

15 EPA appreciates the detailed and thoughtful comments provided by the Reviewer
 16 regarding suggested load estimation techniques and approaches. As
 17 documented in FMD Appendix B.2, as well as in the MCR and MVR, many load
 18 estimation methods were explored, including many of the Reviewer suggestions.
 19 In particular, the use of the Autobeale approach was evaluated and stochastic
 20 and deterministic methods to reduce differences between boundary
 21 concentration estimates and individual observations were explored.

22 The greatest difficulty associated with TSS and PCB load estimation for the
 23 Housatonic River is the very wide range of measured concentrations that occur
 24 across narrow ranges of flow. As noted in Appendix B.2 to the FMD and other
 25 documents, TSS and PCB concentrations are particularly variable at low flow,

1 when concentrations are typically lower. This natural variability reflects the
 2 diversity of conditions in the watershed. As a result of this variability, a many-to-
 3 one relationship exists between measured concentration (or load) and flow for all
 4 practical purposes. This variability complicates load estimation efforts because
 5 load estimation techniques such as regression estimators typically describe the
 6 central tendency (e.g., the mean or median) of the relationship between variables
 7 such that there is a one-to-one relationship between concentration and flow.

8 As a result of variability, differences between boundary concentration estimates
 9 and individual measurements occur and are unavoidable. However, EPA took
 10 great care to ensure that potential biases in model results were minimized and
 11 did not influence either the EFDC or FCM calibration process. In particular, FCM
 12 results are not biased as a result of PCB upstream boundary condition estimates.

13 It is worth noting that in several instances the Reviewer's comments focus on
 14 particulate PCB concentration (expressed as $\mu\text{g PCB/L}$). When TSS and PCB
 15 boundary conditions are considered jointly as the sorbed PCB concentration
 16 (expressed as mg PCB/kg of solids), there is little bias in the PCB boundary
 17 condition. This is the reason why there is little bias in FCM exposure results.

18 For further details, see the General Response above, FMD Appendix B.2, and
 19 FMD Section 4 (FCM bounding analysis), as well as the MCR and MVR.

20 **Frank Gobas**

21 First, in the majority of comparisons between measured and model predicted TSS concentrations,
 22 the TSS concentrations are over predicted. This does not appear to have a corresponding impact
 23 on the calculation of the PCB concentrations in water. The effect of this bias on the calculation
 24 of PCB concentrations under current conditions appears to be low. However, the bias may
 25 become important when the model is applied under different conditions. It is therefore important
 26 to explore the reasons for the bias in TSS and make appropriate corrections.

27 **Response 6-FG-1:**

28 See General Response above as well as Sections 3 and 4 and Appendix B.2 of
 29 the FMD. As previously noted, TSS and PCB concentrations are particularly
 30 variable at low flow, when concentrations are typically lower. As a result of this
 31 variability, a many-to-one relationship exists between measured concentration (or
 32 load) and flow for all practical purposes. This variability complicates load
 33 estimation efforts because load estimation techniques such as regression
 34 estimators typically describe the central tendency of the relationship between
 35 variables such that there is a one-to-one relationship between concentration and
 36 flow.

37 As noted by the Reviewer, this does not have a significant impact on simulated
 38 PCB concentrations in the water column. This is because the PCB boundary
 39 condition estimate accurately simulates sorbed PCB concentrations (mg PCB/kg

1 solids). Further, the parameterization of the model framework was specifically
2 developed to ensure that potential biases in one framework component would not
3 adversely impact subsequent results in any other component. In particular, TSS
4 boundary conditions for EFDC were extensively evaluated with respect to bias
5 and the impact that bias has on FCM results. It should be noted that the
6 apparent bias in EFDC results for low-flow conditions is almost entirely
7 attributable to the natural variability in TSS concentrations at the upstream
8 boundary.

9 I recommend that the modelers explore model parameterization schemes that remove bias in the
10 TSS model predictions.

11 **Response 6-FG-2:**

12 See General Response above as well as Sections 3 and 4 and Appendix B.2 of
13 the FMD. See also Response 6-FG-1.

1 7. GENERAL TOPIC 7: SEDIMENT INITIAL CONDITIONS

2 7.1 COMMENT SUMMARY

Reviewer Name	Page Number/Line Number
Adams	Page 6, lines 1 to 5
Bohlen	Page 10, lines 15 to 24
Endicott	Page 8, lines 5 to 8

3 7.2 GENERAL TOPIC SUMMARY

4 Finite difference models require the assignment of concentrations in each computational grid cell
5 at the beginning of each simulation; these are referred to as initial conditions. The application of
6 EFDC to the Housatonic River includes water column, bed sediment, and floodplain cells.
7 Specification of initial conditions is required in each type of cell.

8 Three Reviewers commented on the procedure used in model Validation to establish initial
9 conditions for sediment PCB concentrations. All three noted that the hindcasting approach did
10 not allow for a robust independent test of model performance, but differed on an appropriate
11 response.

12 7.3 GENERAL TOPIC RESPONSE

13 The majority of the data for PCB concentrations in environmental media were collected
14 in 1998-1999, at the end of the Phase 2 Calibration period. In conducting the 10½-year
15 Phase 2 Calibration from January 1990 to June 2000, it was recognized that use of the
16 initial sediment PCB concentrations from the short-term Phase 1 Calibration (i.e.,
17 projecting the conditions measured in 1998-1999 to the January 1, 1990 model
18 simulation start date), would result in initial conditions that could underestimate the PCB
19 concentrations in sediment in Reaches 5 and 6. There were insufficient data to
20 establish initial conditions using a data-based approach; therefore, an alternate
21 procedure was necessary. The method used to establish initial conditions was based
22 on using the rate of decline in PCB concentrations in surface sediment simulated by the
23 model as a hindcast to estimate PCB concentrations at the January 1, 1990 Phase 2

1 Calibration start date (see Section 4.1.7 of the MVR). These annualized rates of
2 attenuation were used to calculate scaling factors that were applied to the 1998-1999
3 data to adjust the initial PCB conditions in each model grid cell at the start of the Phase
4 2 calibration and validation periods, respectively.

5 The single exception to this procedure was for Woods Pond (Reach 6) for the validation
6 simulation, where adequate data were available from sampling conducted in 1980 to
7 allow the determination of initial sediment PCB concentrations from data. The
8 consistency between the initial condition of 975 mg/kg OC for Woods Pond, based on
9 1980 data, and the estimate of 999 mg/kg OC developed by applying the scaling factor
10 procedure used for the other reaches, provides evidence that the scaling factor
11 approach is reasonable. This approach is consistent with other components of model
12 parameterization, where site-specific data are used when available.

13 **7.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 7**

14 **Eric Adams**

15 **Initial conditions for sediment PCB concentrations**

16 I agree with GE that hindcasting predicted trends is not a robust way to establish initial
17 conditions. By playing the tape backwards, then forwards, they will get the same conditions they
18 started with. I am not sure what the alternative is, but the lack of independence should be
19 acknowledged.

20 **Response 7-EA-1:**

21 EPA agrees that hindcasting predicted trends is not a robust way to establish
22 initial conditions. The Reviewer's statement that "I'm not sure what the
23 alternative is..." reflects the assessment of the modeling team that led to the
24 approach that was implemented. EPA acknowledged in MVR Section 4.1
25 (Changes to EFDC Model Application) that this approach was adopted because
26 of the lack of historical data to set initial conditions. The discussion of temporal
27 changes in simulated PCB concentrations in bed sediment (MVR Section
28 6.2.3.2.3) states:

29 *Data collected during 1980 were used to establish initial conditions in Woods*
30 *Pond for the validation simulation. In other reaches, data were not available to*
31 *set initial conditions for the validation simulation, and instead, the model was*
32 *used to estimate initial conditions. Therefore, Woods Pond represents the only*

1 *portion of the PSA where sufficient historical data exist for a direct assessment of*
2 *simulated temporal changes in sediment PCB concentrations.*

3 In both the MVR and in discussions with the Peer Review Panel during the MVR
4 Document Overview Meeting, EPA attempted to make it clear that limited
5 historical data complicated the assessment of temporal trends simulated by the
6 model, in both the floodplain and in the river sediments. The one exception was
7 in Woods Pond, where historical data were available to develop initial conditions
8 for PCBs in the sediment. In that case, the estimated concentration of 999 mg/kg
9 OC, developed by applying hindcasting approach, was consistent with the initial
10 condition of 975 mg/kg OC derived directly from the 1980 data. This comparison
11 provided a degree of confidence in the approach.

12 **W. Frank Bohlen**

13 With regard to PCBs the data set allows at least an initial evaluation of the spatial and temporal
14 validity of the model. Specification of the initial concentrations used in the Validation remains a
15 concern since to some extent the hind cast method used to develop initial concentrations is not
16 entirely independent of the subsequent model run. This apparently was required by the limited
17 data available for 1979. Review of the RCRA Facility Investigation Report (BBL, 2003) shows
18 the results of sampling dating back to the 1979-1980 period. It seems possible to use this variety
19 of data to provide at least a check on the trends and associated initial concentrations suggested by
20 use of the model. Might this be possible? I'm assuming that extensive "data mining" has been
21 part of this exercise and that therefore some of this approach might already have been tried. If so,
22 a brief discussion of this in the report would be useful.

23 **Response 7-FB-1:**

24 The Reviewer is correct in concluding that the limited historical data was the
25 reason for the use of the hindcast method to develop initial conditions for 1979
26 (with the exception of Woods Pond, where sufficient data were available, and
27 were used). In Reaches 5A through 5C, the number of sediment samples
28 collected in 1980 averaged approximately 12 samples per mile. Given the
29 variability in PCB concentrations in Housatonic River sediment, which can be two
30 orders of magnitude within 1 m², this data density was considered far too sparse
31 to use to make reliable estimates of initial conditions.

32 In response to Reviewer's comments, additional descriptions of the data and
33 methods used to develop initial conditions for the sediment and floodplain soil
34 have been compiled in Appendix B.3 to the FMD.

35 **Douglas Endicott**

36 Furthermore, I agree that the approach for developing initial conditions for sediment PCBs (circa
37 1990 for the Phase 2 calibration and 1979 for the validation) precludes a "robust test" of the

1 long-term model predictions. Consequently, these initial conditions should become part of
2 sensitivity and uncertainty analyses.

3 **Response 7-DE-1:**

4 The sediment initial conditions were not added to the sensitivity analyses, which
5 involved a uniform adjustment of $\pm 50\%$ of the base case value, because this
6 level of change is not realistic based on available data, especially fish tissue
7 data.

1 **8. GENERAL TOPIC 8: UPSTREAM MODEL**

2 **8.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 8, lines 12 to 35
Bohlen	Page 12, lines 1 to 3
Endicott	Page 2, lines 23 to 24
	Page 5, lines 23 to 30
	Page 9, lines 29 to 32
	Page 18, lines 24 to 25
	Page 21, line 37
	Page 24, lines 7 to 21

3 **8.2 GENERAL TOPIC SUMMARY**

4 During Validation, the upstream boundary of the EFDC model for the East Branch was re-
 5 evaluated to address the morphological changes following remediation of the 2.4 kilometers (1.5
 6 miles, Reaches 3 and 4) immediately upstream of the confluence, which was completed in spring
 7 2006. The purpose of this exercise was to construct and test a revised upstream boundary model
 8 that would be representative of the upstream area for use in future-casts of the model to evaluate
 9 baseline conditions and potential remedial alternatives. The transport and fate of PCBs were not
 10 simulated in this model application because of the scarcity of applicable data from the
 11 downstream portions of Reach 4 due to the ongoing remediation over the past 6 years. The
 12 upstream model simulations were run using the hydrograph from the 25-year model validation
 13 period (excluding 2004).

14 Three Reviewers did not consider the upstream model to be adequately calibrated/validated and
 15 commented that insufficient data were available to evaluate the model performance, or
 16 recommended that more data be gathered or work be performed and/or more discussion of the
 17 model performance be provided. In addition, it was mentioned that no sensitivity or uncertainty
 18 analyses or scenario projections were performed for this component of the model framework.

1 8.3 GENERAL TOPIC RESPONSE

2 The modeling team has further evaluated the necessity for the application of the
3 upstream model and discussed it with the Model Working Group, including
4 representatives from GE and their consultants. The decision has been made not to
5 pursue the use of the upstream model. The collective belief is that application of the
6 upstream model within the modeling framework will not make a significant difference in
7 the output from the model simulations. Therefore, it is not necessary to use the
8 upstream model to achieve the goal of the modeling study to evaluate baseline
9 conditions and potential remedial alternatives.

10 8.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 8

11 Eric Adams

12 Upstream Model

13 The model was extended two miles upstream to include the 0.5 and 1.5 mile remediation areas.
14 Upstream Q and TSS were obtained from rating curves, while upstream tPCB = 0.019
15 microgram/L from boundary measurement. Comparisons were attempted against TSS and tPCB
16 measured at Lyman St. in 2001-2004 (some of this is reported in DRM handouts and not in the
17 MVR).

18 Predicted TSS varied from $\sim 3 \times 10^{-4}$ to $> 10^2$ mg/L while data were in the range of 3 to 30 mg/L
19 (mostly 3-10). [I am assuming these are the correct units for TSS; the vertical axis on the
20 handout distributed at the DRM says ng/L.] Can one really predict TSS as low as 3×10^{-4} mg/L?
21 Some data are in the range of the model, but model predictions show much more variability?
22 Where does this come from?

23 Predicted PCBs were 3×10^{-5} to 10^{-3} mg/L while data were in the range of ND up to 3×10^{-5} .
24 [Again, I am assuming these are the correct units; they are consistent with the 30 to 1000 ng/L
25 indicated on the handout GE provided, though EPA's handout during the document review
26 meeting indicates 3×10^{-5} to 10^{-3} ng/L.] In any case, the agreement is not very convincing, and *it*
27 *is hard to say that the upstream model is validated.*

28 The downstream concentrations of TSS and PCB from the upstream model are much lower than
29 the corresponding upstream boundary values used for the main model. Given that output from
30 the main model depends so heavily on its upstream boundary condition, more work should be
31 done on the upstream model, or at least more interpretation of the results. There is scant
32 discussion in the MVR.

1 **Response 8-EA-1:**

2 See General Response above.

3 **W. Frank Bohlen**

4 The above comments refer only to the PSA. It would appear that there are insufficient data to
5 adequately test model results in both the upstream (which is in a state of major change) and the
6 downstream model. Efforts to gather these data should be initiated immediately.

7 **Response 8-FB-1:**

8 See General Response above.

9 **Douglas Endicott**

10 I should note here that, since the upstream and downstream models share the same frameworks,
11 the same comments apply.

12 **Response 8-DE-1:**

13 See General Response above.

14 Another change that has been undertaken by EPA is to extend the spatial domain of the models
15 to cover the upstream reach of the East Branch through the area that has been remediated, as well
16 as downstream from Woods Pond dam to Rising Pond dam. It is encouraging to see this
17 development, because the modeling domain confined to the ROR was clearly too small to fully
18 address the extent of PCB contamination in the Housatonic River. However, I am not convinced
19 that either the upstream or downstream models are adequately calibrated and validated at this
20 time. It is obvious that much less effort has gone into these models, and the presentations made
21 by the EPA modeling team at the Document Review Meeting looked much more like progress
22 reports than finished products.

23 **Response 8-DE-2:**

24 See General Response above.

25 In the upstream model, there are too few TSS data to tell whether the model predictions are
26 reasonable or not. For both TSS and PCBs, my impression is that the model predictions are much
27 more variable than the few available data. PCB concentrations appear to be substantially
28 overpredicted (e.g., a factor of 5 to 10 overprediction in PCB concentrations).

29 **Response 8-DE-3:**

30 See General Response above.

1 No sensitivity or uncertainty analyses have been presented for the upstream and downstream
2 models.

3 **Response 8-DE-4:**

4 See General Response above.

5 No scenario projections were presented for either the upstream or downstream model.

6 **Response 8-DE-5:**

7 See General Response above.

8 I do not believe that either the upstream or downstream models are sufficiently developed to be
9 adequate to address the goals of the modeling study. Their development appears to have been
10 rushed, an impression reinforced by the fact that they apparently did not exist a year ago.
11 Sensitivity and uncertainty of the upstream and downstream models have not been reported, and
12 documentation of the development of these models has been inadequate. In its present status, the
13 upstream model is incomplete and not fully validated. PCB fate and transport have not been
14 simulated, and insufficient model-data comparisons have been made and/or reported.
15 Incorporation of the upstream model in the MVR appears premature, given that substantial
16 additional development efforts will be required before it can be used reliably. Likewise, the
17 downstream model has not been sufficiently validated. Limited model-data comparisons suggest
18 there may be significant bias in PCB concentration predictions. There also appears to be a lack of
19 adequate and appropriate data for this significant extension of the model domain. In their current
20 states of development, neither the upstream nor downstream models are suitable for use in
21 modeling future conditions in the Corrective Measures Study. I am hopeful that the inadequacies
22 of the upstream and downstream models can be addressed through continuing monitoring and
23 modeling activities.

24 **Response 8-DE-5:**

25 See General Response above.

26

1 **9. GENERAL TOPIC 9: MODEL APPLICATION TO REACHES 7 AND 8**
 2 **(DOWNSTREAM MODEL)**

3 **9.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 8, line 37 to page 9, line 13
Bohlen	Page 12, lines 1 to 3
Endicott	Page 2, lines 23 to 24
	Page 5, lines 23 to 30
	Page 9, line 32 to page 10, line 4
	Page 18, lines 24 to 25
	Page 21, line 37
	Page 24, lines 7 to 21

4 **9.2 GENERAL TOPIC SUMMARY**

5 The model domain for the Phase 1 Calibration included Reaches 5 and 6, the 10 ½-miles from
 6 the confluence of the East and West Branches to Woods Pond. Comments were received in
 7 previous Peer Reviews from the Reviewers and GE suggesting that the model domain be
 8 extended both downstream and upstream. EPA responded by extending the model domain
 9 downstream for EFDC and FCM to Rising Pond Dam (Reaches 7 and 8), an additional 19 miles.
 10 HSPF already included this portion of the watershed in the Calibration and Validation; therefore,
 11 no changes to the HSPF domain were necessary.

12 Three Reviewers commented directly on the need for further work on the downstream model.
 13 These Reviewers commented on the comparative lack of data from the downstream reaches, with
 14 two of these Reviewers recommending additional data collection efforts. Two Reviewers noted
 15 that there was some general correspondence between the limited TSS and PCB concentration
 16 data and concentrations predicted by the downstream model, but that there were insufficient
 17 model-data comparisons to demonstrate that the downstream model was sufficiently calibrated
 18 and/or validated for use in predicting PCB fate and transport following potential remedial
 19 alternatives.

1 9.3 GENERAL TOPIC RESPONSE

2 EPA recognized the relative scarcity of data useable for model development
3 downstream when originally making the decision to include only Reaches 5 and 6 in the
4 EFDC and FCM domain. In response to Reviewer comments, EPA expanded the
5 model domain downstream to include Reaches 7 and 8 following the MCR Peer
6 Review. Cross-sectional surveys of the river channel were performed to establish
7 channel bathymetry, and field surveys were conducted to verify the resulting elevation
8 data, floodplain conditions, and aquatic habitat. This information supported the
9 development of a model grid and initial assignment of parameters for EFDC for
10 Reaches 7 and 8 (see Section 3.5 of the FMD and Section 6.4 of the MVR). It also
11 provided the information necessary to subdivide Reach 7 by hydrologic regime and
12 aquatic communities. These subreaches were then assigned fish community types
13 comparable to the corresponding subreach in Reaches 5 and 6 for FCM simulations
14 (see Section 3.6 of the FMD and Section 6.4 of the MVR).

15 In response to Reviewer comments in this Peer Review, the model Calibration for
16 Reaches 7 and 8 was revisited to be consistent with the changes made to the
17 calibration parameters in Reaches 5 and 6. The time period for application of the model
18 was extended from 2 years (1997–1998) to a 15-year simulation (1990–2004). In
19 addition, changes were made to the parameterization of physical conditions to better
20 represent the very different hydrologic regimes (e.g., steep gradients, larger grain sizes)
21 that occur in Reach 7.

22 The model is driven entirely by the results from other models (i.e., flows and sediment
23 and PCB loads from Reach 6 [Woods Pond] simulated by EFDC, and tributary and
24 nonpoint source flows and loads simulated by HSPF). This factor, and the application
25 of the calibrated models for Reaches 5 and 6 to very different physical conditions and
26 PCB concentrations in Reaches 7 and 8, provides a demonstration of the robustness of
27 the EFDC and FCM applications for the Housatonic River. Model-data comparisons
28 show that the models performed adequately in this extended application. The final
29 model validation for EFDC and FCM in Reaches 7 and 8 is presented in Section 3.5 and
30 3.6, respectively, of the FMD.

1 9.4 REPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 9

2 Eric Adams

3 Downstream Model

4 The model was extended 19 miles downstream to Rising Pond Dam (not described in MVR; only
5 in DRM handouts). Upstream boundary conditions were taken from output of the main model at
6 Woods Pond. Model-data comparisons for TSS and tPCB were made between 1990 and 2004 ~
7 1-mile downstream from Rising Pond Dam.

8 Predicted TSS varies widely as do the data, with the peaks corresponding with peaks in flow.
9 They are in the same ballpark, but the variability is so great that you need a statistical
10 comparison to determine how well they match on average.

11 Predicted PCB concentrations also vary substantially ($\sim 3 \times 10^{-3}$ to ~ 3 microgram/L), with
12 predicted peak concentrations corresponding with peak TSS and peak flow, and non-peak
13 concentrations hovering generally around 0.03 micrograms/L. (But why are some up to 10 times
14 lower?) Measurements show much less variability with an average of around 0.1 microgram/L,
15 or about 3 times the predicted non-peak values. The data are too sparse to see if they respond to
16 peaks in flow. Again a statistical comparison would be helpful to quantify model-data
17 agreement. Both measurements and predictions seem to be 2-3 times lower than corresponding
18 values at Woods Pond Outlet, which makes sense given the 20 mile separation.

19 GE's plot of simulated versus measured PCBs at Rising Pond Dam shows very little correlation
20 between simulation and measurement ($r^2 = 0.01$). *At this point it is hard to say the downstream*
21 *model is validated.*

22 Response 9-EA-1:

23 In response to the Reviewers' comments, additional work on the downstream
24 model was performed following the Peer Review of the MVR as described above.
25 Model-data comparisons for flow and TSS, and PCB concentrations demonstrate
26 that EFDC adequately simulates these parameters (see Section 3.5 of the FMD).
27 The differences shown in the cross-plots of the simulated versus measured TSS
28 and PCB concentrations and the residual and relative residual plots in Section
29 3.5 of the FMD are attributed in large part to phasing differences between the
30 simulated results at Rising Pond Dam and the data collected from Division
31 Street. In addition, phasing and volumetric differences between actual and
32 simulated flows from HSPF for runoff and tributaries in Reach 7 contribute to the
33 phasing difference between measured and simulated PCB and TSS
34 concentrations. One example of this occurs when flows from HSPF are higher
35 than the actual flows, resulting in lower simulated PCB concentrations than
36 measured concentrations due to dilution.

37
38 The simulated water column and sediment PCB concentrations also result in
39 good agreement between the measured fish tissue PCB concentrations and

1 those simulated by FCM in the linked application. This is another line of
2 evidence for the adequacy of the downstream model validation and in general for
3 the robustness of the EFDC parameterization.

4 **W. Frank Bohlen**

5 The above comments refer only to the PSA. It would appear that there are insufficient data to
6 adequately test model results in both the upstream (which is in a state of major change) and the
7 downstream model. Efforts to gather these data should be initiated immediately.

8 **Response 9-FB-1:**

9 EPA does not believe that it is necessary to collect more data to demonstrate the
10 adequacy of the model for Reaches 7 and 8 for the reasons stated above.

11 **Douglas Endicott**

12 I should note here that, since the upstream and downstream models share the same frameworks,
13 the same comments apply.

14 **Response 9-DE-1:**

15 The Reviewer comments that the application of EFDC to the upstream and
16 downstream models shares the same frameworks as those used for Reaches 5
17 and 6, thus his comments regarding the application for Reaches 5 and 6 apply.
18 The Reviewer's comments on the Reach 5 and 6 application of EFDC are
19 addressed in other sections of this Responsiveness Summary.

20 Another change that has been undertaken by EPA is to extend the spatial domain of the models
21 to cover the upstream reach of the East Branch through the area that has been remediated, as well
22 as downstream from Woods Pond dam to Rising Pond dam. It is encouraging to see this
23 development, because the modeling domain confined to the ROR was clearly too small to fully
24 address the extent of PCB contamination in the Housatonic River. However, I am not convinced
25 that either the upstream or downstream models are adequately calibrated and validated at this
26 time. It is obvious that much less effort has gone into these models, and the presentations made
27 by the EPA modeling team at the Document Review Meeting looked much more like progress
28 reports than finished products.

29 **Response 9-DE-2:**

30 See the General Response and additional responses provided above.

31 In the downstream model, predicted TSS and water column PCB concentrations are in the same
32 ranges as the data at the Rising Pond outlet, but there is not much fidelity beyond that. Initial
33 downstream model PCB predictions included in the MVR clearly indicated a problem with the
34 balance between erosion and deposition in high-gradient reaches. As presented at the Document

1 Review meeting, this has been addressed by adding an additional noncohesive sediment class in
2 the sediment transport simulation.

3 FCM predictions in the downstream model domain are compared to PCB concentrations
4 measured in fish for Reach 7 and Rising Pond. These predictions look favorable overall,
5 although there may be bias in the predictions for specific species. Results appear comparable in
6 data-based and linked exposure predictions.

7 **Response 9-DE-3:**

8 The model calibration was revisited to address the patterns of erosion and
9 deposition noted by the Reviewer, and subsequent validation was performed
10 following the Model Validation Peer Review Meeting.

11 EPA agrees that the model bias statistics for the downstream model are
12 "favorable overall." The Model Bias (MB*) statistic tracks the central tendency of
13 the ability of the model to simulate PCB concentrations by category. The overall
14 MB* for the downstream model (linked to EFDC predictions) is 1.08, meaning
15 that on average the model is overpredicting PCB concentrations by 8%.

16 With regard to possible bias for specific FCM species, Table 3.6-11 in the FMD
17 shows MB* broken down by species for the linked application of FCM.
18 Largemouth bass, bluegill, yellow perch, and pumpkinseed samples show no
19 consistent bias. Brown bullhead are somewhat overpredicted, by 44% on
20 average. Bluntnose minnows are systematically overpredicted; however, this
21 bias statistic is based on five samples. In addition, bluntnose minnows are not
22 modeled explicitly in FCM and, therefore, require extrapolation from a
23 representative species (dace).

24 No sensitivity or uncertainty analyses have been presented for the upstream and downstream
25 models.

26 **Response 9-DE-4:**

27 A sensitivity analysis for the application of EFDC to Reaches 7 and 8 was
28 performed and the results are presented in Section 3.7 of the FMD. The
29 sensitivity analysis for FCM (Section 3.7.3 of the FMD) was conducted using the
30 model application for Reaches 5 and 6. This model parameterization was
31 remained unchanged when applied to Reaches 7 and 8. Therefore, there was no
32 need to repeat the sensitivity analysis. The model sensitivities in Reach 8, if
33 calculated, would be virtually identical to those for the Reach 6 sensitivity
34 simulations. The Reach 7 sensitivities would be equivalent to the model
35 sensitivities for the corresponding subreaches in Reach 5.

36 No uncertainty analyses were performed for the downstream model. See
37 General Topic 5B.

1 No scenario projections were presented for either the upstream or downstream model.

2 **Response 9-DE-5:**

3 The Reviewer is correct, the example scenarios were simulated for Reaches 5
4 and 6.

5 I do not believe that either the upstream or downstream models are sufficiently developed to be
6 adequate to address the goals of the modeling study. Their development appears to have been
7 rushed, an impression reinforced by the fact that they apparently did not exist a year ago.
8 Sensitivity and uncertainty of the upstream and downstream models have not been reported, and
9 documentation of the development of these models has been inadequate. In its present status, the
10 upstream model is incomplete and not fully validated. PCB fate and transport have not been
11 simulated, and insufficient model-data comparisons have been made and/or reported.
12 Incorporation of the upstream model in the MVR appears premature, given that substantial
13 additional development efforts will be required before it can be used reliably. Likewise, the
14 downstream model has not been sufficiently validated. Limited model-data comparisons suggest
15 there may be significant bias in PCB concentration predictions. There also appears to be a lack of
16 adequate and appropriate data for this significant extension of the model domain. In their current
17 states of development, neither the upstream nor downstream models are suitable for use in
18 modeling future conditions in the Corrective Measures Study. I am hopeful that the inadequacies
19 of the upstream and downstream models can be addressed through continuing monitoring and
20 modeling activities.

21 **Response 9-DE-6:**

22 EPA agrees that the downstream model benefited from further development and
23 subsequent Calibration and Validation following the Peer Review (see Sections
24 3.5 and 3.6 of the FMD), and believes that it is now adequate for use in
25 evaluating the relative performance of potential remedial alternatives. It was
26 recognized at the outset of model development that the data available for
27 calibration and validation of any model of downstream reaches were more limited
28 than the data available for Reaches 5 and 6. Additional information was
29 collected to allow the application of EFDC and FCM to Reaches 7 and 8. One of
30 the purposes of modeling Reaches 7 and 8 was to test the robustness of the
31 EFDC model as calibrated for Reaches 5 and 6. As noted in presentations to the
32 Peer Review Panel and in the FMD, the parameterization of the EFDC model
33 used in Reaches 5 and 6 was changed slightly (e.g., the addition of the fourth
34 non-cohesive sediment class) for the downstream model during the calibration
35 process.

36 Statistical evaluation of EFDC model-data comparisons for TSS and PCB
37 concentrations indicate that the relative bias at Rising Pond Outlet is well within
38 the model performance measure of $\pm 30\%$ for TSS (-11.93%) and just outside the
39 measure for PCB concentrations (-31.97%). For median relative error, the model
40 performance measure is also $\pm 30\%$, and the EFDC model is within the
41 performance measure for both TSS (-27.12%) and PCB (-3.32%) concentrations.

1 Model performance, as quantified by the relative bias and the median relative
2 error, and by the ability of the linked application of FCM to simulate PCB
3 concentrations measured in fish tissue, is judged to be adequate to achieve the
4 goal of the modeling study.

1 **10. GENERAL TOPIC 10: EXAMPLE SCENARIOS**

2 **10.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 11, lines 23 to 41
	Page 12, lines 4 to 8
Bohlen	Page 14, lines 6 to 16
Endicott	Page 19, line 5 to page 20, line 32
	Page 21, lines 4 to 36
Garcia	Page 6, lines 26 to 28
Gobas	Page 12, lines 7 to 45
Lick	Page 2, lines 1 to 3
List	Page 5, lines 5 to 25
	Page 6, lines 2 to 15

3 **10.2 GENERAL TOPIC SUMMARY**

4 Upon request from a Reviewer during the Calibration Peer Review, a qualitative assessment of
 5 model performance was conducted by examining model simulations using the 26-year validation
 6 period hydrograph. These two hypothetical scenarios were run altering the initial conditions
 7 similar to what might be done when using the model in the Corrective Measures Study. The first
 8 example scenario was simulated with a zero PCB load at the East Branch upstream boundary.
 9 The second example scenario was also simulated with a zero PCB load from the East Branch
 10 upstream boundary, but in addition included zero PCB concentrations in Reach 5A sediment, and
 11 no PCB or solids loadings from the banks in Reach 5A.

12 The input parameters for each hypothetical scenario were adjusted to reflect a change in river
 13 conditions, and the simulation was allowed to proceed without further adjustment. Changes in
 14 final PCB concentrations in the main channel sediment and floodplain soil resulting from each
 15 simulation were qualitatively reviewed for reasonableness of model behavior.

16 Four Reviewers commented that the model response from the two scenarios appeared reasonable
 17 in the sense that most locations experienced some decline in PCB concentrations in surficial

1 sediment. A Reviewer considered the response in PCB concentrations in the water column and
2 fish tissue concentrations simulated in the example scenarios to be reasonable and plausible.

3 In addition, single Reviewers commented on very specific aspects of the simulations. These
4 comments and responses are listed in Section 10.4.

5 **10.3 GENERAL TOPIC RESPONSE**

6 EPA agrees with the Reviewer comments that the model results from the two scenarios
7 are reasonable. Changes in final PCB concentrations in the main channel sediment
8 and floodplain soil resulting from each simulation were qualitatively reviewed for
9 reasonableness of model behavior. Within this context, the model reasonably reflects
10 system-level responses that might be anticipated when loads are reduced or eliminated.
11 The pattern of changes in bed sediment PCB concentrations is consistent with known
12 properties and dynamics of sediment transport in the river. The nature and magnitude
13 of the reductions of PCB concentrations in the surficial floodplain soil are consistent with
14 the expectation that the input of clean solids and subsequent transport onto the
15 floodplain during out-of-bank flood events would reduce PCB concentrations over time.
16 The spatial pattern of these simulated reductions is generally consistent with the
17 locations of known high-deposition areas on the floodplain. EPA believes these
18 simulations provided an additional test of model performance.

19 It is important to recognize that the scenarios simulated in this exercise are not intended
20 to reflect actual, proposed, or anticipated remedial alternatives, and no further
21 significance should be attached either to the hypothetical scenarios evaluated or the
22 simulation results. Under the terms of the Consent Decree, baseline conditions and
23 potential remedial alternatives are to be identified and evaluated as part of the
24 Corrective Measures Proposal and Study to be conducted by GE.

1 10.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 10

2 Eric Adams

3 I appreciate the inclusion of the two example simulations that shed some light on how the model
4 might perform when simulating remediation options. This is clearly a start. There would seem to
5 be two issues to consider. The first is how well the remediation measures themselves will work.
6 For instance, will a cap erode? The second is what will happen downstream (in space and time)
7 after remediation? For example, will dirty sediments cover up capped or dredged sediments?
8 The example simulations don't consider the first question (though it is very important), but
9 partially address the second. However, several considerations come to mind. First, the example
10 simulations were begun with "cold start" initial sediment conditions, which seems to explain, at
11 least in part, why sediment concentrations increased in some areas downstream from simulated
12 remediation (i.e., places where there was no PCB source). Better that the model be spun up to
13 initial sediment conditions that reflect an equilibrium with the modeled hydrology and
14 bathymetry. Also, the model seems to ignore any particulate PCBs that might have wanted to
15 deposit in the channel of Reach 5A. (What happens to these in the model?) Ultimately, the
16 model could be generalized to look at "different colored" PCBs emanating from different source
17 locations and to see where they end up, with implications as to which would be the best
18 sediments to remediate. This might require subscribing certain variables in the code so the
19 calculations could be run in parallel. EPA has started to do some of this, but more would be
20 instructive.

21 Response 10-EA-1:

22 In response to the Reviewer's first question, EPA does not expect EFDC to
23 predict how well specific remedial engineering techniques will perform. It is
24 standard practice to use other applications specifically designed for such
25 analyses (e.g., the U.S. Army Corps of Engineers approaches to engineering cap
26 stability). Such an approach was used in both the ½-Mile and 1½-Mile
27 Removals, conducted by GE and EPA, respectively. EPA expects that similar
28 tools will be used when the final design of the selected alternative is performed,
29 not EFDC.

30 EPA agrees that the second question posed by the Reviewer is one that is
31 addressed by the example scenarios, but is also addressed by the tracer
32 simulations (see Section 4.2 of the FMD).

33 The Reviewer's comment regarding a "cold start" is unclear, and may represent a
34 misunderstanding of the conditions at the start of these example simulations.
35 Initial conditions assigned in the example simulations were the same as those
36 used in the Phase 1 Calibration (post spin-up), as described in Section 7.1 of the
37 MVR, and therefore do not constitute a "cold start." The only exception was for
38 Example Simulation 2, in which Reach 5A sediment PCB concentrations were
39 set to zero for the purpose of the demonstration.

1 The deposition of particulate PCBs in Reach 5A is noted in the discussion of
2 Example Simulation 2 (no PCBs from East Branch boundary, no PCBs in Reach
3 5A sediment, and no bank erosion in Reach 5) in Section 4.1.2 of the FMD. In
4 that simulation, PCBs entering the PSA from the West Branch represent the only
5 source of PCBs to Reach 5A sediment, and contribute to a small increase in PCB
6 concentrations in sediment in Reach 5A.

7 The tracer simulations presented at the Document Overview Meeting and
8 discussed in Section 4.2 of the FMD provide the ability to analyze the origin and
9 disposition of PCBs in a manner equivalent to the Reviewer's suggestion to
10 evaluate "different colored" PCBs.

11 Figure 4.2-53 shows areas of net deposition indicating ~ 42% of net deposition is to floodplain,
12 and ~ 10% is to Woods Pond. The remaining ~48% is to the sediment bed upstream of Woods
13 Pond. It would be nice to keep track of the deposited sediments. My guess is that those
14 deposited to the flood plain and to Woods Pond stay put, or are slowly released, while those in
15 the sediment bed move on. Can this be quantified?

16 **Response 10-EA-2:**

17 The Reviewer is correct that PCBs deposited to the river sediment can be
18 released back into the water column. In addition, the model suggests that the
19 floodplain serves as a sink for solids with the exception of erosion from the
20 banks. The tracer simulations provide a quantification of the disposition of PCBs
21 in the river channel and floodplain under a base case and seven different
22 scenarios. Similar quantification could be conducted for solids.

23 **W. Frank Bohlen**

24 The model response for the two examples shown seems reasonable in the sense that most
25 locations experience some decline in PCB concentrations over the upper 6in of the sediment
26 column. I would have expected to see more of a change in Example 2 since virtually all of the
27 major sources of PCB to the system have been shut off. This may point to the importance of the
28 floodplain as a continuing source of PCBs to the system and/or point to the fact that change can
29 only be expected to occur over depositional depths. These depths, controlled by sediment rates in
30 the area, will seldom exceed 3in except in the vicinity of point bars or similar channel features
31 that are not well modeled because of the coarse grid scales used in the river channel. Since the
32 model is averaging over a significantly greater depth (6in) the changes over 26 years may be
33 difficult to assess. I'd be interested in seeing what a model run of 50 years or more would show.

34 **Response 10-FB-1:**

35 As noted by the Reviewer, the major external source of PCBs to Reaches 5 and
36 6 was set to zero loadings in the example simulations. The Reviewer comments
37 that contributions from the floodplain may be an important continuing source, and
38 EPA agrees that bank erosion appears to be an important continuing source. An

1 additional internal source of PCBs is sediment resuspension. Both represent
2 continuing sources of PCBs to downstream reaches.

3 However, it should be clarified that the model results from the vertical
4 segmentation of multiple layers simulated in the bed were averaged to develop
5 the graphical summaries of the example scenarios. The presentation of the
6 results as 6-inch averages (of these layers) was chosen to facilitate the
7 comparison of these results with data (which were typically collected in 6-inch
8 increments).

9 Longer simulations (e.g., 50 years) will likely be conducted as part of CMS.
10 Under the terms of the Consent Decree this work will be conducted by GE.

11 **Douglas Endicott**

12 The MVR presented 25-year forecasts made with the linked models, in the Rest-of-River and
13 Downstream domains, for 2 (or 3)¹ hypothetical remediation examples. These were intended to
14 illustrate the performance of the models in forecasting the outcome of remediation alternatives in
15 terms of PCB concentrations in sediment, water and especially fish. These forecast predictions
16 (“projections”) are really the unique product of water quality models, and are the only defensible
17 means of anticipating the long-term outcome of remedial action and the relative effectiveness of
18 remedial alternatives. We are asked in this question to address the “reasonableness” and
19 “plausibility” of the projections, which are both subjective criteria. Dom DiToro called this sort
20 of evaluation the “laugh test”, where we compare the numerical model’s projections to those of
21 the models we carry around in our heads. The modeling team is correct in pointing out that it is
22 not possible to determine whether the example projections are “correct” in terms of accuracy
23 (MVR, p 7-3), because there is really nothing to compare them to except one another.

24 Model projections for the example scenarios were presented a number of ways in the MVR and
25 its supplements. These included the predicted time series of PCB concentrations in water, at the

¹ I am somewhat confused by what is referred to as a “base case” projection in a number of the time series figures (e.g., “Time series of water column concentrations for PCBs and TSS”, “Time series of sediment PCB concentrations in each spatial bin” and “Time series of plots of FCM exposure concentrations” in *the EPA Response to Questions* document, and “Food chain model results” in the Document Overview presentation of Example Scenarios, which included a graph subtitled “Base case for the example runs - existing boundary loads”). The “base case” scenario is not mentioned or described in Section 7 of the MVR, or anywhere else I could find in the materials provided for our review. This makes it difficult to evaluate the example scenario projections, because I want to compare them to a “base case” (as is intended by the graphs mentioned above) but am not sure what this is. Initially I thought the “base case” was simply the validation prediction, since the hydrograph and boundary conditions are the same. Upon inspection, however, it appears that the initial conditions for PCBs are somewhat different, most noticeably in Woods Pond. A description of the “base case” scenario should be added to Section 7 of the MVR to resolve this ambiguity. Furthermore, EPA should consider whether a scenario should be added or modified which specifies the East Branch PCB boundary condition to be 20 ng/L, the assumed nominal concentration following cleanup.

1 conventional monitoring locations (Holmes Road, New Lenox Road, ...); PCB concentrations in
2 surficial sediment in the mile reaches; and, PCB concentration in largemouth bass in the river
3 reaches 5A thru 6. For EFDC, the projections were also presented as plan maps of the grid
4 displaying PCB concentrations in surficial sediment and soil, and changes in concentration, at
5 the end of the 25 year projections. For the top 6" of the sediment bed, the end-of-projection
6 results are also shown as profiles. Each of these is discussed below.

7 **Response 10-DE-1:**

8 Simulation of the base case used the model inputs and the PCB initial conditions
9 in sediment and floodplain from the Phase 1 Calibration (based on data collected
10 primarily in 1998 and 1999), and hydrograph used for the validation simulation
11 (as described in Section 7 of the MVR).

12 The differences between the validation simulations and base-case initial
13 conditions noted by the Reviewer reflect the use, for validation, of 1980 data to
14 develop initial conditions for PCBs in Woods Pond and estimates of initial
15 conditions in other reaches, based on the scaling procedures described in FMD
16 Section 2.3.3 and Appendix B.3, and MVR Section 4.2.

17 The projected timeseries of water column TSS and PCB concentrations are plotted together in
18 the figure "Time series of water column concentrations for PCBs and TSS" in *the EPA Response*
19 *to Questions* document. The base case projection is qualitatively similar to the validation
20 predictions, with TSS and PCB concentrations increasing to high levels during flow events,
21 although over time the base case PCB concentration projections decline during low-flow periods.
22 PCB concentrations projected for the example 1 scenario are lower than the base case, and
23 projections for the example 2 scenario are lower than for example 1. In each scenario, there is a
24 similar "event responsiveness" of PCB concentrations to fluctuations in the hydrograph. TSS
25 concentration projections are comparable in each scenario, as would be expected since the TSS
26 boundary condition and grain size distribution in the sediment bed are unchanged from the base
27 case. I would consider the water column projections for each of these scenarios to be reasonable
28 and plausible.

29 **Response 10-DE-2**

30 EPA agrees with the Reviewer's assessment that the concentrations computed in
31 the example scenarios are plausible.

32 The projected timeseries of surficial (top 6") sediment PCB concentrations in river mile reaches
33 are plotted together in the figure "Time series of sediment PCB concentrations in each spatial
34 bin" in the *EPA Response to Questions* document. The base case projections for surficial
35 sediment PCB concentrations are qualitatively similar to the validation predictions, and suffer
36 similar errors. PCB concentrations are projected to increase in the first half-mile reach (an
37 apparent artifact), and show almost no change after start-up in the other reaches. The rate of
38 change in PCB concentrations in sediment is (again) unreasonably slow. Even 25 years is not
39 long enough to see a discernable change in surficial sediment PCB concentrations, which I
40 would certainly expect to see. Nothing shown in the MVR or at the peer review meetings

1 convinces me that the model is correct in its predictions of the rate of change in sediment PCB
2 concentrations. For example scenario 1, a decline in sediment PCB concentrations is projected in
3 comparison to the base case, which is more encouraging. The difference is most dramatic in the
4 first half-mile reach (RM 135.13-134.89), and is also apparent in reaches RM129.19-128.88,
5 128.88-128.69, and 126.99-126.47. In other reaches, especially in Woods Pond and its
6 headwater, there is no difference in PCB concentrations between example 1 and the base case.
7 For example scenario 2, negligible (1 mg/Kg or less; I can't tell the actual value due to the axis
8 scaling) sediment PCBs are projected for reach 5A due to remediation. In the other reaches,
9 sediment PCB concentrations are projected to be nearly the same or identical to example 1
10 projections. Although I don't believe that the model's projections of rates of change in sediment
11 PCB concentrations are reasonable, at least the relative differences in projected sediment PCB
12 concentrations between the scenarios are plausible.

13 **Response 10-DE-3:**

14 The Reviewer is correct in noting that the base case results are similar to the
15 validation results for reasons described in the response above. The two
16 simulations use the same inflow hydrographs and boundary conditions, and differ
17 only in the sediment PCB initial conditions.

18 The Reviewer's comment regarding the artifact of the bed load boundary
19 condition on sediment PCB concentrations in the most upstream spatial bin is
20 also correct. This has subsequently been addressed through a change in the f_{oc}
21 associated with bed load.

22 It should be noted that the opinion provided by the Reviewer that "The rate of
23 change in PCB concentrations in sediment is (again) unreasonably slow" is not
24 consistent with the results of the statistical analysis of sediment PCB data
25 described in Appendix A.1 of the FMD, the RFI, and other materials provided to
26 the Reviewer by EPA. Appendix A.1 of the FMD provides further statistical
27 analyses of temporal and spatial trends in sediment data.

28 The Reviewer's evaluation of model results, when placed in context of the
29 determination of lack of statistically significant trend in PCB concentrations in
30 sediment, led to the erroneous conclusion that the simulated rate of sediment
31 PCB concentration decline is too slow. The simulated slow rate of decline in
32 concentrations is well within the uncertainty envelope of the data and totally
33 consistent with the statistical analyses.

34 EPA agrees with the Reviewer's comment that the relative differences in
35 projected sediment PCB concentrations between scenarios are plausible.

1 The grid map diagrams (Figures 7-1 and 7-3) show the cumulative change of PCB concentrations
2 in the top 6" of sediment and floodplain soil over the 25 year projection, for scenarios 1 and 2². It
3 appears that the sediments in reach 5A, which are cleaned up in example scenario 2,
4 recontaminate to 1 or 2 mg/Kg over 25 years, due to continuing transport of PCBs from the West
5 Branch boundary condition. It would be useful to see a similar grid map diagram in which the
6 difference in end-of-projection PCB concentrations was plotted.

7 **Response 10-DE-4:**

8 The results of the example simulations were presented in various formats. The
9 Reviewer suggests an additional way of viewing the information from the
10 example scenarios that is potentially useful. This may be considered in
11 displaying model results in the CMS.

12 The surficial sediment PCB concentration profiles offer a useful alternative view of the
13 cumulative change of PCB concentrations over the 25 year projection. Projections for example 1
14 show the now-familiar redistribution of sediment PCBs in the high-energy reach 5A, but also
15 significant changes (approaching $\pm 100\%$ of the IC) in reaches 5B and the upper end of 5C. At
16 the lower end of reach 5C and reach 6, sediment PCB concentrations decline by 20 to 80%. This
17 seemingly contradicts what I interpreted from the "Time series of sediment PCB concentrations
18 in each spatial bin" figures. Could it be that the combination of reach averaging, displayed on a
19 log-axis plotting, makes it difficult or impossible to properly interpret the projection results?

20 **Response 10-DE-5:**

21 The Reviewer comments that changes in sediment concentrations by 20 to 80%
22 in Reaches 5C and 6 in individual grid cells "... seemingly contradicts what I
23 interpreted from the 'Time series of sediment PCB concentrations in each spatial
24 bin' figures."

25 EPA notes that the changes in concentration over the course of the simulations
26 used in this exercise (base case or example simulations) are consistent with the
27 changes simulated over the course of the validation simulation (MVR Figure 6.2-
28 51). The Reviewer is correct in noting that spatial averaging precludes the ability
29 to view cell-to-cell variability in concentrations, which are displayed on the plan-
30 view figures. Log-scales were used to display the results for the spatial bins,
31 allowing the comparison of all spatial bins on a consistent scale. However, use
32 of the log-scale minimizes the visual difference among the results of the base
33 case and two example simulations. As noted previously, each graphical display
34 has advantages and disadvantages; therefore, the results of the example
35 simulations were presented in a variety of formats.

² I suppose the comparable graphic for the base case would be the validation figure (Figure 6.2-55) although I am forced to speculate here.

1 At the Peer Review meeting last month, there were questions and discussion about whether it
2 was reasonable that the EFDC model projected a significant reduction in PCB concentrations in
3 the water column, but little or no change in sediment concentrations. In fact, such behavior is
4 expected in water quality models incorporating both water column and sediment sedimentation.
5 In such models, the concentrations of particle-associated constituents change much more rapidly
6 in water than they do in sediment, whenever there is a change in the constituent loadings or
7 boundary conditions. Since PCB boundary conditions and loadings (actually fluxes from reach
8 5A sediments) are being manipulated in the example scenarios, the differences in the projections
9 of PCB concentrations in the water column versus sediments are entirely expected and
10 reasonable.

11 **Response 10-DE-6:**

12 EPA agrees with the Reviewer's comment that differences in the water column
13 and sediment responses are reasonable.

14 Example scenario projections made by the FCM were presented at the Document Overview
15 meeting (13 - Example Scenarios.pdf) as timeseries of PCB concentrations in largemouth bass.
16 In reach 5A, bass in the base scenario are forecast to have a body burden of 50 mg/kg at the end
17 of the 25 year projection; for example 1, the comparable forecast is 30 mg/kg, and 0
18 concentration for example 2. In reach 5B, bass in the base scenario are forecast to have the
19 highest PCB body burden at the end of the 25 year projection: 70 mg/kg; for example 1, the
20 comparable forecast is 40 mg/kg, and less than 20 mg/kg for example 2. Further downstream in
21 the Rest-of-River, the remediation examples are projected to considerably less effective in
22 reducing PCB concentrations in comparison to the base case. In reach 5C, bass in the base
23 scenario are forecast to have a body burden of 30 mg/kg after 25 years; for example 1, the
24 comparable forecast is 20 mg/kg, while for example 2 the forecast is 10 mg/kg. At the end of the
25 25 year projections in reach 6 (Woods Pond), bass in the base scenario are forecast to have a
26 body burden of 50 mg/kg; for example 1, the comparable forecast is 40 mg/kg, while for
27 example 2 the forecast is 30 mg/kg. To me, this progression in the declining effectiveness of
28 remediation as one moves downstream appears reasonable in the context of PCB water and
29 sediment exposure projections for these example scenarios. In "no data" reach 5D, the least
30 reduction in bass PCB concentrations due to remediation is projected. I suppose this may be
31 because this reach is relatively isolated from the rest of the river.

32 **Response 10-DE-7:**

33 EPA agrees with the Reviewer's comment that the FCM results from the example
34 simulations are reasonable.

35 **Marcelo Garcia**

36 Model projections seem reasonable but I would have liked to see more potential scenarios,
37 particularly for extreme conditions such as low flow summer-like conditions and floods.

1 Response 10-MG-1:

2 Both example scenarios were simulated using the 26-year validation hydrograph.
3 This hydrograph includes extreme conditions such as low-flow summer-like
4 conditions and floods.

5 Frank Gobas

6 The patterns in the data indicate a slow temporal response of the PCB concentrations in the
7 River. The example scenarios also indicate a small decline of somewhere between 0 to 5% (it is
8 hard to spatially average the concentrations depicted without additional information) over 26
9 years in response to the assumed loading reductions. I think that this is consistent with the
10 observations.

11 The data illustrate large small-scale spatial variability in PCB concentrations in sediments. The
12 model appears to capture this to some degree as changes in concentrations relative to the control
13 vary between grid cells within many transects.

14 I have trouble understanding why PCB concentrations in so many cells of the lower part of the
15 River (Figure 7-1b and 7-3b) increase in concentrations as a result of the loading reductions. This
16 is not what I would expect to happen intuitively given the long history of the PCB contamination
17 problem and the slow response time of PCB concentrations in the river. I would expect
18 concentrations to go down throughout the river, but at higher rates at some locations and lower
19 rates at others.

20 Comparing scenarios 1 and 2, one would expect that elimination of additional PCB loads in
21 scenario 2 would produce a greater change in PCB concentration over time in scenario 2 than 1.
22 Perhaps, this is the case. It is hard to see from the graphs. However, even if this is not the case, it
23 is possible that concentrations decline over the 26 years are comparable for scenarios 1 and 2.
24 Without more information, it is hard to be more definite.

25 Based on the current information presented, there is no basis for concluding that the patterns
26 provided in the example scenarios are not plausible given the patterns observed in the data. But
27 more data is needed to support a more positive and definitive conclusion. The example scenarios
28 in the validation report provide little information about the functioning of the model. To address
29 the charge question properly, it is important that the model outcomes of the example scenarios
30 are further analyzed. In particular, it is important to average model outcomes over space and time
31 such that the model predictions can be compared to available data.

32 Recommendation

33 I recommend that the behavior of the combined model is explored in greater detail than is
34 presented in the validation report. I recommend that the model outcomes in the model scenarios
35 are aggregated to depict the overall response of the PCB concentrations in the River. This will
36 provide the opportunity to better compare model projections to available data sets and judge
37 whether the model projections are plausible.

1 Response 10-FG-1:

2 EPA agrees with the Reviewer's comment that the small decline shown in the
3 example simulations are consistent with the data. The Reviewer commented that
4 small increases in PCB concentrations in downstream grid cells were
5 unexpected. However, EPA believes that these results are expected because
6 similar increases are simulated in the base case. These small increases are
7 computed in floodplain cells that start with very low initial concentrations of
8 PCBs.

9 Comparing Examples 1 and 2, there is minimal difference in patterns of PCB
10 concentration changes in main channel sediment. Minor increases in PCB
11 concentrations (relative to the initial PCB conditions of zero) occur in Reach 5A.
12 In these simulations, these small increases are caused by PCB inputs from the
13 West Branch.

14 In response to recommendations made by Reviewers at the MVR Document
15 Overview Meeting, model results were aggregated in the additional presentations
16 of results from the example scenarios included in Attachment 5 to the document,
17 EPA Response to Questions from Model Validation Document Overview
18 Meeting. These included figures showing water column, sediment, and food-
19 chain exposure concentrations, presented in formats consistent with those used
20 to present data in the MVR.

21 Wilbert Lick

22 Because the basic processes are inaccurately described and the correct processes may possibly
23 differ by factors of two to ten from those in the present model, the projections of the present
24 model have large potential errors.

25 Response 10-WL-1:

26 See General Response above and also the responses to General Topic 1. It
27 must be recognized that the Reviewer conclusions are based on erroneous
28 assumptions regarding the scale of processes such as sediment-water mass
29 transfer flux of PCBs.

30 E. John List

31 With respect to the PCB modeling the results are so tenuous (see Figure 6.2-49) that it is not
32 possible to draw any really solid conclusion with respect to bias. However, an important point is
33 demonstrated by Figure 6.2-50. This figure indicates that the sediment concentrations of PCB in
34 the lower reaches of the project study area have declined somewhat since 1990 (i.e., since
35 remediation activity started). Furthermore, there appears to be a similar decline in the water
36 column concentrations of PCB, as is somewhat evident in the lower panel of Figures 6.2-44. (It
37 is noted that there is no statistical measure of the significance of the decline in either the

1 sediment or the water column, but the data are very suggestive). However, the modeling does
2 not give any indication that any similar rate of decline has occurred (see Figure 6.2-50). In fact
3 the comparison between the data and the model in this figure is strongly suggestive that the
4 model does have a bias.

5 **Response 10-JL-1:**

6 The Reviewer states that the data shown on Figures 6.2-49 and 6.2-50 are
7 suggestive of statistically significant declines in sediment PCB concentrations.
8 The data are presented as the mean \pm 2 standard errors, which approximates the
9 95% confidence interval of the mean. At that time, the wide range in the
10 confidence interval of the mean and the small number of samples in earlier years
11 were identified by the modeling team as factors that complicated characterization
12 of trends in the data and comparisons with trends computed by the model.

13 In response to the misconception of the Reviewers regarding the existence of a
14 trend in PCB concentrations in sediment, a more rigorous statistical analysis was
15 performed (see Appendix A.1 of the FMD and the Response to General Topic
16 1). This analysis confirms previous conclusions that there is no statistically
17 significant decline in sediment PCB concentrations. The results from this (and
18 prior) analyses contradicts the basis for the Reviewer's conclusion that these
19 model-data comparisons indicate a bias in the model.

20 The bias of the model is further reinforced by the results of the hypothetical remedial scenarios
21 plotted in the un-numbered figure on page 56 of the EPA Response to Questions from Model
22 Validation (Document DCN: GE-061406-ADFI), where, despite a reduction in the flux of PCB
23 from the sediments in the upper river reaches, there is no significant change in projected
24 sediment concentration of PCBs in the lower reaches. Thus the model does not match the
25 reduction in sediment concentration that has occurred subsequent to actual post-upstream
26 remediation, and projects no reduction as a result of an hypothetical reduction in the upstream
27 PCB flux, as in the hypothetical examples. This problem needs to be understood and/or fixed
28 before the model is used in real applications.

29 **Response 10-JL-2:**

30 The results from the simulations of the example scenarios show a gradual
31 decline in PCB concentrations in sediment in downstream reaches for the base
32 case and Examples 1 and 2 (which include elimination of upstream sources).
33 The differences among the rates of decline in sediment PCB concentrations in
34 the base case and example simulations are small, which is consistent with the
35 statistical analysis that concludes that conditions in the river are changing slowly.

36 It must be noted that the Reviewer's statement that impacts of remediation
37 should have an appreciable influence on the model results is incorrect. With the
38 exception of limited activity associated with Building 68, the remediation in the ½-
39 Mile Reach began in October 1999, and remediation in the 1½-Mile Reach began
40 in 2002. While the model simulation used the 26-year validation hydrograph, the

1 initial conditions were derived using data that pre-dated remediation. The
2 Reviewer's evaluation of example scenario simulations is based on the incorrect
3 assumption that the data reflect 9 years of remediation activities.

4 I am not a biologist, but having said that, to a layperson the broad distributions of the PCB in the
5 biota appear to be reasonably well described, at least at the central tendency level. This may
6 well be due to the fact that partitioning of PCB into biota appears to be closely associated with
7 the spread of concentrations in the environment. In the example scenarios there is no projected
8 effect on the mean PCB concentration in the Woods Pond sediments, which does seem
9 surprising, especially given the results in Figure 6.2-50, where there is a seemingly significant
10 drop in the PCB concentration in the sediment between 1990 and 2000. However, there is a
11 projected rough order of magnitude reduction in the water concentration of PCB in Woods Pond
12 as a result of the hypothetical scenarios. The actual data for Woods Pond referenced above seem
13 to show that there is a reduction in both water column and sediment concentrations coincident
14 with the remediation that has occurred so far. It is not clear why the modeling should necessarily
15 uncouple the water concentration from the sediment concentration in Woods Pond in the
16 hypothetical examples.

17 **Response 10-JL-3:**

18 The Reviewer's statement that "In the example scenarios there is no projected
19 effect on the mean PCB concentration in the Woods Pond sediments..." is
20 incorrect. Small declines in concentration were simulated over the course of the
21 26-year simulation in the base case and the example scenarios. Differences in
22 the rate of decline among the base case and two example scenarios were also
23 simulated. The differences in the rates of decline are small, as is expected in a
24 system in which PCB concentrations are changing slowly.

25 It should be noted that the modeling does not decouple the response in the water
26 column and sediment, as suggested by the Reviewer. It is expected that much
27 slower responses will be simulated in sediment compared to the water column in
28 a system with a relatively low sedimentation rate, as is the case in Reaches 5
29 and 6.

1 **11. GENERAL TOPIC 11: FOOD CHAIN (BIOACCUMULATION)**
 2 **MODEL**

3 **11.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Bohlen	Page 15, lines 13 to 15
Endicott	Page 9, lines 4 to 27
	Page 10, lines 1 to 4
	Page 10, lines 24 to 27
Gobas	Page 4, lines 17 to 18 and page 4, lines 42 to 43
	Page 5, lines 29 to 31
	Page 5, line 44 to page 6, line 2
	Page 6, line 42 to page 7, line 17
	Page 7, lines 38 to 42
List	Page 6, lines 1 to 5

4 **11.2 GENERAL TOPIC SUMMARY**

5 The model framework for the Housatonic River is comprised of three models, a watershed model
 6 (HSPF), a hydrodynamic, sediment transport, and PCB fate model (EFDC), and a food chain
 7 bioaccumulation model (FCM). This section provides responses to comments regarding FCM.

8 FCM was calibrated in two ways. The first was to perform a calibration of the model using the
 9 data. This calibrated model was then used in a linked mode (receiving exposure concentrations
 10 from EFDC and temperature data from HSPF). The results from the linked simulation were
 11 evaluated and no additional calibration was necessary.

12 It should be noted that many of the comments regarding FCM were related to the presentation
 13 and/or interpretation of the uncertainty analysis. These comments are discussed under General
 14 Topic 5.

15 Three Reviewers commented that FCM yielded estimates of PCB central tendencies in
 16 organisms that were in reasonable agreement with data. Three reviewers made statements

1 regarding the suitability of the model-data comparisons used to evaluate FCM model
2 performance.

3 **11.3 GENERAL TOPIC RESPONSE**

4 EPA agrees with the general conclusion expressed by several Reviewers that
5 model/data comparisons of average PCB concentrations in fish tissue using the results
6 from FCM are in reasonable agreement. In addition, these simulations show little or no
7 systematic bias. The FCM Calibration and Validation (both linked and data-driven) in
8 Reaches 5 and 6 and also the simulations in Reaches 7 and 8 all generated overall
9 model bias statistics that were close to the zero bias value of 1.0. The range of overall
10 model bias values (MB*) for the above modeling components ranged from 0.88 to 1.11,
11 which demonstrates an unbiased model, particularly in light of the uncertainties in
12 measured fish tissue and exposure concentrations. EPA disagrees with some of the
13 Reviewer comments made regarding perceived bias and/or believes that the perceived
14 bias is overstated. In some cases it appeared that Reviewer comments did not reflect
15 all of the information provided (including the EPA Response to Questions from the
16 Document Overview Meeting). These comments are discussed individually below.

17 **11.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 11**

18 **W. Frank Bohlen**

19 Finally, I'd consider eliminating the FCM in favor of a parametric (flow, TSS concentrations ?)
20 approximation of body burden uptake based on the results of the complete model runs.

21 **Response 11-FB-1:**

22 This comment was made in the context of a suggestion to reduce the overall
23 computational burden of the model framework. EPA strongly disagrees with this
24 recommendation for two reasons. First, replacement of the mechanistic food
25 chain bioaccumulation model with a black-box empirical model would be
26 inconsistent with the need to represent the important biological processes
27 (balance of fate processes) that govern PCB uptake in the Housatonic River. In
28 response to recommendations from Reviewers made during previous Peer
29 Reviews, a tiered approach was used to identify, characterize, and parameterize
30 the bioaccumulation and fate processes necessary to achieve the goal of the

1 modeling study. EPA believes that to deviate from this analysis and eliminate
 2 these important processes would compromise the scientific integrity of the linked
 3 model application. Second, the elimination of FCM would not have an
 4 appreciable effect on the computational requirements of linked model runs. The
 5 FCM code operates on a level of spatial and temporal resolution that is orders of
 6 magnitude coarser than EFDC, requiring only minutes for each simulation.

7 **Douglas Endicott**

8 The food chain model (FCM) predictions should be compared to the mean or other central
 9 tendency of the fish species, reach, and age-specific data, because the model is designed to
 10 simulate “average” fish according to these categories. This is confirmed by analyses and graphics
 11 (e.g., Figure 4.3-8) displaying that the residuals tend to be smaller when the data are averages of
 12 6 or more fish. Unfortunately, many calibration and validation graphics persist in using
 13 individual data.

14 **Response 11-DE-1:**

15 EPA agrees with the Reviewer that model-data comparisons should emphasize
 16 central tendencies for unique combinations of fish age, species, and river reach.
 17 Unfortunately, the sample sizes for such comparisons are sometimes insufficient
 18 to conduct meaningful evaluations using this approach. Therefore, while the
 19 central tendencies in calibration and validation graphics and statistics were
 20 emphasized, individual samples were reported in model-data comparisons where
 21 only individual data or small sample sizes were available. This approach was
 22 considered preferable to the censoring of data with small sample sizes because it
 23 provided a comprehensive analysis of the available data. Figure 4.3-8 of the
 24 MVR provides an example of such a combined presentation, allowing the reader
 25 to differentiate between comparisons made using either small or large sample
 26 sizes.

27 Nonetheless, there is overall good agreement between predictions and the averaged total PCB
 28 concentration data, with most residuals falling within a factor of 2 of the predicted values. EPA
 29 has revised Figure 4.3-7 to use the 95% confidence limits (or ± 2 standard errors) to better
 30 quantify the measurement precision, and the FCM predictions fall within these limits. FCM
 31 model performance is similar in calibration and validation periods.

32 **Response 11-DE-2:**

33 EPA agrees with the Reviewer comments. The “factor of 2” mentioned by the
 34 Reviewer was selected a priori as the model performance measure for model
 35 Calibration; therefore, the Reviewer’s observation supports EPA’s conclusion that
 36 the model is adequately calibrated. Furthermore, the model performance during
 37 Validation was conducted using a model that was not changed from the
 38 Calibration, and applied a fully independent data set. It should be noted that the
 39 a priori model performance measure for Validation was a factor of 2.5. The
 40 similar quality of model performance observed between calibration and validation

1 periods provides additional evidence of model robustness and assurance that the
 2 model is adequate for use in achieving the goal of the modeling study.

3 Figure 3-9 (Comparison of mean measured biota tissue tPCB concentrations to FCM results
 4 [simulation using linked models]) provides a summary illustration of the FCM calibration. PCB
 5 concentrations predicted for invertebrates are in good agreement with the D-Net sample data,
 6 except for infauna in Reach 5A (which are substantially overpredicted).

7 **Response 11-DE-3:**

8 EPA agrees with the Reviewer's observation that the FCM simulations for
 9 invertebrates are in good agreement with the D-Net sample data. As discussed
 10 in the MVR, the D-net data contained primarily epifaunal invertebrates and
 11 therefore cannot be directly compared to the infauna simulations. EPA disagrees
 12 that the simulation for Reach 5A infauna can be described as "substantially
 13 overpredicted." The reason is that there are no field data specific to infauna to
 14 assess this. Therefore, the accuracy of model simulations for infauna is
 15 unknown, not biased. EPA acknowledges that the PCB concentrations in Reach
 16 5A organisms exposed via sediment are more uncertain than in other reaches
 17 due to the atypical partitioning behavior of PCBs in this reach.

18 The model fits for bullhead and sunfish are very good; PCB concentration in these fish vary little
 19 between river reaches. Model-to-data comparisons are not as good for suckers, cyprinids and
 20 bass, although the PCB concentration data for these species is also considerably more variable. I
 21 assume that at least some of the variability of PCB concentrations in fish reflects the wide range
 22 of PCB exposure and/or failure of the food chain to spatially average these exposures on a reach
 23 basis.

24 **Response 11-DE-4:**

25 The model fit for all representative species is well within the model performance
 26 measures specified for Calibration and Validation; however, the Reviewer is
 27 correct that model fit is stronger for bullhead and sunfish relative to other FCM
 28 representative species. As noted in the MCR and MVR, the model-data
 29 comparisons for cyprinids must be interpreted with caution because FCM
 30 simulates a generalized cyprinid in downstream reaches whereas the data
 31 collected were for golden shiners. This species has a different life history than
 32 the generalized cyprinid simulated. The data for golden shiners also exhibited
 33 lower than average lipid content. These factors contributed to the differences
 34 observed in the model-data comparisons.

35 EPA agrees with the Reviewer's observation that the wide range of PCB
 36 exposures within any given reach may explain some of the variability of PCB
 37 concentrations in fish. Fish integrate their exposures over portions of a reach.
 38 However, many fish are territorial and are exposed to localized portions of a
 39 reach that may have higher or lower sediment PCB concentrations relative to the
 40 reachwide averages used in the model. For example, EPA evaluated the home

1 range of largemouth bass relative to the spatial distributions of PCBs in
 2 sediment. Order of magnitude differences in exposure concentrations are
 3 expected for fish occupying non-overlapping territories within a river reach.

4 If I look for an overall pattern in the residuals on this figure, it would be a tendency for the
 5 predicted PCB concentrations to increase moving downstream, which is not reflected by the data.
 6 PCBs predicted in Reach 5D for cyprinids, sunfish and bass significantly exceed the measured
 7 (as well as predicted) concentrations for these species in other reaches. Since PCB concentrations
 8 were not measured in fish from this reach, these predictions are untested. Reach 5D is the only
 9 portion of the FCM where predictions based on PCB exposures derived from data meaningfully
 10 diverge from predictions based on EFDC exposures.

11 **Response 11-DE-5:**

12 EPA disagrees that there is a systematic tendency for simulated PCB
 13 concentrations to increase with distance downstream. The slight increase in
 14 concentrations in Reach 6 (Woods Pond) is due to the higher PCB
 15 concentrations in Woods Pond surface sediment relative to upstream reaches.
 16 Both the model and data indicate relatively flat (slightly declining) trends in fish
 17 tissue concentrations across the PSA. The PCB concentrations simulated by
 18 FCM demonstrate the same trends (within the uncertainty of the data) as the
 19 statistical analyses provided in the RFI and in Appendix A.1 of the FMD.

20 EPA agrees that the PCB concentrations simulated in Reach 5D (for the linked
 21 model) are greater than in adjacent reaches and that these simulations cannot be
 22 tested due to the lack of fish tissue data for Reach 5D. The uncertainty in fish
 23 tissue and exposure concentrations for Reach 5D is greater than in other
 24 reaches.

25 FCM predictions in the downstream model domain are compared to PCB concentrations
 26 measured in fish for Reach 7 and Rising Pond. These predictions look favorable overall,
 27 although there may be bias in the predictions for specific species. Results appear comparable in
 28 the data-based and linked exposure predictions.

29 **Response 11-DE-6:**

30 EPA agrees that the model predictions for Reaches 7 and 8 are favorable and
 31 that the linked and data-based applications of the model yielded similar results.
 32 Revised model performance statistics are presented in Sections 3.6.4 and 3.6.5
 33 of the FMD (Table 3.6-11 and Table 3.6-13). These statistics indicate that all
 34 species with a sample size >5 exhibited model bias (MB*) measures between
 35 0.72 (perch in data-driven model) and 1.44 (bullhead in linked model). These
 36 results indicate only a slight bias. Overprediction of bluntnose minnow PCB
 37 concentrations was also observed; however, this was based on only five
 38 samples, includes an interspecies extrapolation, and the MB* values were less
 39 than 2.0 for both the linked and data-based model. The model bias for all
 40 species was within the model performance measure for Model Validation.

1 It is unclear whether the low-flow PCB bias has led to food chain miscalibration, as suggested by
2 GE, because the food chain model was initially calibrated using data-based exposure
3 concentrations. These would not exhibit the same low-flow bias as exposure concentrations
4 predicted by the model.

5 **Response 11-DE-7:**

6 The Reviewer has correctly identified that the data-based FCM calibration results
7 provide an independent assessment of the reasonableness of bioaccumulation
8 predictions. Because both the data-based and linked model calibrations
9 produced similar acceptable model performance, and because no modifications
10 (i.e., process or parameter changes) were made between these calibrations,
11 there is no evidence of “miscalibration.”

12 During the Validation Peer Review, GE’s consultant incorrectly implied that
13 calibration of the bioaccumulation model was used to compensate for bias in
14 model linkages. As described in the response to General Topic 1, all models in
15 the framework were calibrated independently as presented in FMD Figure 1-11.
16 Information was passed forward from one model to the next in sequence as
17 presented in FMD Figure 1-11. Outputs from HSPF were used as inputs to
18 EFDC and FCM. Further outputs from EFDC were used as inputs to FCM.
19 Information was never passed backwards from FCM to EFDC or HSPF. No
20 compensation was made in one model for a performance issue in another model.
21 For example, FCM was not recalibrated to achieve acceptable model/data
22 comparisons in fish tissue compensate for the any potential bias in flow, TSS, or
23 PCBs outputs from EFDC or HSPF.

24 A quantitative bounding calculation was performed to evaluate the impacts of
25 underestimating TSS and PCB concentrations at low flows, which results in
26 offsetting effects on calculated exposure concentrations of PCBs sorbed to
27 particulate organic matter in the water column, thereby minimizing the concern
28 over these features of the boundary estimates. This bounding analysis showed
29 that replacing all water column PCB concentrations less than 0.06 µg/L (scaled
30 up to account for overprediction) with 0.0 µg/L PCBs had little impact on the
31 simulation of PCB concentrations in fish tissue (less than 5%, averaged across
32 species, and less than 8% in game fish).

33 **Frank Gobas**

34 The spatial resolution of the environmental fate and food-web model is unnecessarily
35 complex....Also, the time-step requirement for the hydrodynamic model is too onerous and
36 unnecessary for the environmental fate and food-chain models.

37 **Response 11-FG-1:**

38 The Reviewer is incorrect in his assumption that the spatial resolution of the
39 environmental fate (EFDC) and food-web (FCM) models are the same; in fact

1 they are very different. The model grid for EFDC was optimized to provide output
 2 at the scales of individual grid cells (20 to 70m), spatial bins (~1 to 2 km), or for a
 3 subreach/reach. FCM provides output at the subreach and reach scale. These
 4 spatial scales of model output bound the spatial scales of interest to achieve the
 5 goal of the modeling study. The Reviewer is also incorrect in his assumption that
 6 the time-step requirement for the hydrodynamic model has any relationship to
 7 that used in FCM. The temporal resolution (daily time step) of the FCM exposure
 8 linkages are much larger than those used in the hydrodynamic and
 9 environmental fate and transport model (EFDC).

10 Due to the heavy reliance on calibration during model development, the relative PCB
 11 concentration data in water, sediments and biota that are calculated by the model are overall
 12 consistent with the model predictions of the mean concentrations.

13 **Response 11-FG-2:**

14 Although EPA agrees that concentrations of PCBs in biota are consistent with
 15 model predictions of mean concentrations, the Reviewer is incorrect in attributing
 16 such agreement to “heavy reliance on calibration” in FCM. In fact, as specifically
 17 stated in the MFD and MCR, the overall modeling approach for FCM was to
 18 minimize the level of parameter calibration from the initial best estimates.
 19 Furthermore, because FCM remained essentially unchanged across Phase 1
 20 Calibration, Phase 2 Calibration, and Validation, this provides confidence that
 21 model performance is not attributable to overcalibration.

22 The FCM model can be expected to properly estimate the relevant contributions of water and
 23 sediment concentrations as sources of PCB bioaccumulation in benthos and fish species from
 24 PCB concentrations in water and sediments delivered by the EFDC model.

25 **Response 11-FG-3:**

26 EPA agrees with the Reviewer’s comment.

27 Secondly, the combined or linked model (Table 6-4.7) shows a systematic underprediction of the
 28 mean PCB concentrations as high as a factor of about 2 for some of the species. Overall,
 29 including all species, the underprediction of PCB concentrations in biota is about a factor of
 30 1/0.60 or 1.67. This systematic bias does not appear to be due to the bioaccumulation model
 31 itself. Judging from Table 6-4.6 (Model Validation Report), the bioaccumulation model itself
 32 appears to have little or no systematic bias.

33 **Response 11-FG-4:**

34 EPA agrees that the results of the linked model for Reaches 7 and 8 summarized
 35 in Table 6.4-7 of the MVR exhibit a systematic underprediction that was
 36 attributable to the exposure linkages from EFDC. However, the downstream
 37 model calibration was subsequently reevaluated and revised output was
 38 generated. These results are presented in Section 3.6 of the FMD. Based on
 39 changes made to the model for Reaches 7 and 8, the overall model bias

1 changed from $MB^*=0.60$ to $MB^*=1.08$; therefore, the systematic under-prediction
 2 is no longer present. EPA agrees that the data-based FCM model indicates little
 3 or no systematic bias.

4 Judging from Figures 6.3.3 to 6.3.8, the uncertainty in the characterization of the model bias is
 5 large. The authors could have calculated the standard deviation of the mean, but did not do this.
 6 If they would have done this, they would have found that the standard deviations of the model
 7 bias for any of the PCB concentration in fish data sets are quite substantial due to the large
 8 variability in the observed PCB concentrations in the biota. This means that while the mean
 9 model bias for the PCB concentration predictions in fish is relatively low, the uncertainty of the
 10 mean model bias is high. I think that it is important in any model to be upfront about the ability
 11 of the model to make predictions of reality. The reporting of the model bias without its
 12 uncertainty is misleading in my view. The reality is that PCB concentrations in biota vary
 13 substantially and we do not really understand why this is. So, we should not pretend that we can
 14 predict PCB concentrations in fish with the accuracy that the mean model bias measures suggest.
 15 I therefore suggest that the authors provide a full reporting of the model bias of the PCB
 16 concentrations (i.e. report uncertainty in the mean model bias) using the linked model and
 17 interpret the findings in terms of model uncertainty when the model is applied.

18 **Response 11-FG-5:**

19 In response to the Reviewer's comment, measures of the variability around the
 20 mean model bias have been included in Section 3.8 of the FMD. The 95%
 21 confidence limits about the mean model bias were calculated for calibration and
 22 validation applications. Further discussion of comments related to FCM
 23 uncertainty is provided in the response to General Topic 5.

24 I recommend that the authors calculate the standard deviations of the mean model bias of the
 25 linked model and make appropriate corrections to account for the systematic underprediction of
 26 the mean PCB concentrations in the biota by the model. The systematic underprediction of the
 27 mean PCB concentrations in fish by the model needs to be either corrected or recognized when
 28 the model is applied.

29 **Response 11-FG-6:**

30 See responses above. There is no longer any systematic underprediction of
 31 mean PCB concentrations in fish by the model. Therefore, there is no need for
 32 "correction" or recalibration of FCM.

33 **E. John List**

34 I am not a biologist, but having said that, to a layperson the broad distributions of the PCB in the
 35 biota appear to be reasonably well described, at least the central tendency level. This may well be
 36 due to the fact that partitioning of PCB into biota appears to be closely associated with the spread
 37 of concentrations in the environment.

- 1 **Response 11-JL-1:**
- 2 EPA agrees with the Reviewer's comments.

1 **12. GENERAL TOPIC 12: USE OF THE MODEL TO EVALUATE**
 2 **REMEDIAL ALTERNATIVES**

3 **12.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 11, line 43 to page 12, line 3
	Page 14, lines 40 to 45
Bohlen	Page 2, lines 16 to 35
Endicott	Page 22, lines 5 to 30
Garcia	Page 1, line 39 to page 2, line 18
	Page 3, lines 15 to 26
Gobas	Page 9, line 29 to page 10, line 25
	Page 13, lines 33 to 39
List	Page 6, line 22

4 **12.2 GENERAL TOPIC SUMMARY**

5 One of the purposes of the modeling study required by the Consent Decree is to provide a tool
 6 that is adequate to assess relative performance among proposed remedial alternatives and against
 7 baseline conditions. Under the terms of the Consent Decree, after completion of the Model
 8 Validation Report Peer Review, EPA is to provide the model and all inputs and outputs from
 9 Model Validation to GE for its use in evaluating remedial alternatives in the Corrective Measures
 10 Study (CMS).

11 Reviewers expressed comments on the use of the model for evaluating remedial alternatives.
 12 Two common themes were noted, the first was that four Reviewers believed that the model was
 13 either incomplete or not good enough to be used to assess remedial alternatives. There was also
 14 the sense that the Reviewers expected EPA to provide further information with regard to model
 15 performance for specific remedial alternatives. The Reviewers' specific comments and
 16 responses are provided in Section 12.4.

1 **12.3 GENERAL TOPIC RESPONSE**

2 EPA believes that the model framework developed for the Housatonic River is adequate
 3 for projecting baseline conditions and evaluating the relative performance of potential
 4 remedial alternatives. The justification supporting this conclusion is summarized below,
 5 and is further described in other responses to comments and in the FMD.

- 6
- 7 ▪ Model-data comparisons demonstrate that the models accurately simulate
 8 flow and concentrations of solids and PCBs in sediment and fish tissue. The
 9 Reviewers' comments that the model did not predict an "apparent" decline in
 10 PCB concentrations in surface sediment are incorrect because the "apparent"
 11 decline is not statistically significant (see General Topic 1). Instead, the
 12 model accurately simulates the trend in PCB data, that is, the model
 13 accurately predicts that there is little to no decline in PCB concentrations.
 14 The simulated concentrations are within the uncertainty envelope of the data.

 - 15 ▪ The models were parameterized using site-specific data to the extent
 16 possible. Model calibration was limited only to those parameters that could
 17 not be completely defined using site data. Model Validation and application to
 18 Reaches 7 and 8 provide an independent test of model performance and
 19 robustness, because the model parameterization was not changed between
 20 calibration and these simulations.

 - 21 ▪ The models accurately predict average PCB concentrations in water,
 22 sediment, floodplain soil, and aquatic biota. Model performance also
 23 demonstrates that the model framework appropriately characterizes the
 24 balance of fate processes affecting PCB concentrations and exposures over
 25 time.

 - 26 ▪ In virtually all cases, the results of the three models in the framework were
 27 well within the model performance measures established a priori. The
 28 models accurately simulate the central tendencies of the data, and show
 29 negligible indications of bias. Detailed sensitivity analyses indicate that the
 30 models are responding appropriately to the processes that control PCB
 31 transport and fate.

 - 32 ▪ The most significant of the relevant pathways describing PCB fate in EFDC
 33 are upstream boundary loads, deposition onto the floodplain, bank erosion,
 34 and PCB loss by erosion of sediment in Reach 5A as described by the
 35 process-based flux summaries, example scenarios, and tracer analyses.
 36 These analyses confirm the balance of processes simulated in the model and
 37 provide additional verification of model performance.

1 Therefore, EPA believes that the model framework is a tool that can be used as one line
2 of evidence, with other information including data analyses and the risk assessments, to
3 achieve the goal of the modeling study.

4 As noted above, it was explicitly specified in the Consent Decree that it was not EPA's
5 responsibility to use the models in the three Peer-Reviewed phases of model
6 development specified in the Decree, the Modeling Framework Design, Model
7 Calibration, and Model Validation, to either project baseline conditions or to evaluate
8 remedial alternatives. Therefore, such analyses were not performed.

9 **12.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 12**

10 **Eric Adams**

11 As I expressed at the DRM, I am concerned with the absence of validation data appropriate to
12 remedial measures. Dredging would result in horizontal gradients in sediment concentration
13 over 10s to 100s of meters, while capping would result in vertical gradients in sediment
14 concentrations over a few cm. The current sediment concentration distributions do not show
15 variability over these scales, so it is difficult to tell whether or not the model will be able to
16 successfully predict the effects of such remedial measures.

17 **Response 12-EA-1:**

18 It is not the state of the practice to have collected remediation data to validate the
19 model before making a decision that the model provides an adequate tool for use
20 in evaluating the relative response of the river system to potential remedial
21 alternatives versus baseline conditions.

22 Considering the difficulty of the modeling task, the current state-of-the-art, the amount of effort
23 that has already gone into the modeling, and the difficulty in arriving at a consensus (when our
24 review panel is not allowed to), I would say that *the current work is "acceptable"*. However, in
25 view of the many reservations that many of us have, the model users (GE) will have to exercise
26 considerable professional judgment in their use of the model, and EPA should grant them this
27 judgment.

28 **Response 12-EA-2:**

29 EPA agrees that the model is acceptable for use in evaluating remedial
30 alternatives. It is GE's responsibility to submit a Corrective Measures Study
31 (CMS) Proposal for EPA review and approval, and then to subsequently prepare
32 the CMS, again for EPA review and approval. EPA expects to work with GE to

1 discuss questions as they arise in the preparation of these documents, including
 2 those related to application of the model in the CMS.

3 **W. Frank Bohlen**

4 This has been and remains an ambitious project. In hindsight it may have been overly ambitious
 5 to expect a single model formulation to efficiently and accurately predict future PCB
 6 concentrations throughout a morphologically complex region over extended periods of time
 7 given what was known about historical distributions and the range of processes governing
 8 transport and fate. Some of this seems to have been recognized by EPA in their recent refinement
 9 of the modeling goals placing primary emphasis on the need for the model to be able to establish
 10 the relative performance of selected remedial alternatives rather than on its ability to yield certain
 11 prediction of absolute PCB concentrations (EPA, 2006). While this refinement is advisable and
 12 will be taken into consideration in model evaluations it must be remembered that it does not
 13 relieve the modeler’s responsibility to develop an efficient, stable and quantitatively accurate
 14 model. The evaluations to be conducted during the upcoming Corrective Measures Study (CMS)
 15 by GE will be considering the benefits of remedial alternatives over extended periods of time,
 16 often 40 years or more, i.e. times well in excess of the validation period. The utility of the
 17 relative comparisons over these extended periods will ultimately depend on the degree to which
 18 the model provides accurate simulation of all of the governing physical chemical and biological
 19 factors affecting transport and fate and the adequacy of the computational numerical schemes.
 20 Fundamentally, these are the same factors to be considered if the model was to be used for
 21 absolute predictions. The sufficiency to evaluate these characteristics depends in large part on
 22 our understanding of the PCB transport system structure and dynamics within the Housatonic
 23 River.

24 **Response 12-FB-1:**

25 The modeling team agrees with the Reviewer’s comments about the complexity
 26 of the Housatonic River system and the challenges that this presents for
 27 modeling. Model simulations that will be conducted in the CMS will benefit from
 28 recent advances in computer hardware since the time of the MVR Peer Review,
 29 which have resulted in 33% reductions in run times (see Response to General
 30 Topic 4 and Appendix B.1 to the FMD). The modeling team believes, as stated
 31 in the General Response, that the model accurately simulates the fate, transfer
 32 and bioaccumulation of PCBs and therefore is sufficient to address the goal of
 33 the modeling study and is adequate for use in the CMS study.

34 **Douglas Endicott**

35 I interpret this to be more than one question, so I will give two answers. If the goal is to forecast
 36 PCB concentrations in the Housatonic River in the absence of further remediation, then the
 37 current models may be adequate (i.e., “good enough”). In their current form, the EPA models
 38 (and probably many much simpler models) can provide meaningful answers to many questions
 39 about the future of PCBs the Housatonic River. The model calibration and validation show the
 40 relative magnitude of PCB inputs to system, and the resulting predictions and diagnostics are

1 instructive in terms of evaluating remediation targets. For example, eroding banks and sediment
 2 deposits in reach 5A are clearly targets for remediation. The 25-year validation and example
 3 scenario projections also address the need and possible effectiveness of remediation in the
 4 Housatonic River. Following the remediation of the East Branch reaches, upstream PCB
 5 concentrations of 20 ng/L and 0.4 mg/kg expected; these concentrations alone may support
 6 gamefish concentrations of 1 ppm or more in the PSA. In the absence of further remediation,
 7 PCB concentrations will decline very slowly from the current levels. Although water-column
 8 PCB concentrations will decline downstream of remediation conducted at the reach scale,
 9 surficial sediment PCB concentrations will be relatively unaffected in downstream reaches. The
 10 predicted response of PCB concentrations in fish to remediation is expected to be somewhat
 11 similar to the sediment. To substantially reduce (e.g., >50%) PCB concentrations in Reach 5D
 12 and 6 gamefish over 25 years appears to require remediation well beyond the spatial extent of
 13 hypothetical example 2. None of these conclusions require a highly accurate model.

14 However, if the goal is to forecast PCB concentrations to evaluate the effectiveness of
 15 further remediation, and to distinguish between the effectiveness of various remedial
 16 alternatives, then I believe that the current models are not adequate. Although they are good, they
 17 are not as good as they could be. I assume that GE will not willingly undertake additional
 18 remediation activity in the Housatonic River, unless EPA can convincingly demonstrate that
 19 such remediation is necessary and that the remedy will be effective. At their current stage of
 20 development, the EPA models are not ready to make such a demonstration. I am arguing that
 21 further model development and testing is warranted, and that EPA should be motivated to do so
 22 because the financial stakes are high. Otherwise, GE will likely exploit weaknesses in the models
 23 to argue against the need for further remediation.

24 **Response 12-DE-1:**

25 EPA believes that the modeling framework is adequate both to describe baseline
 26 conditions and to assess relative effectiveness of potential remedial alternatives,
 27 as stated in the General Response above. Beyond that, the Charge to the Panel
 28 did not include discussion of strategic considerations or motivations of the
 29 Consent Decree parties.

30 **Marcelo H. Garcia**

31 It is not enough to state that a given process is accounted for when the representation of the
 32 process is deficient and its implementation in the model is done with algorithms and assumptions
 33 that are not based on the physics of the process and cannot be supported by field observations.
 34 For instance, streambank erosion has been recognized as a very important process since large
 35 amounts of PCB-laden sediments can enter the river during medium to high flows. However,
 36 fluvial erosion and mass failure of the stream banks are currently modeled simply as functions of
 37 flow discharge, a rather crude approximation, which severely limits the capabilities of the model
 38 to assess the effect of this process.

39 How can one determine what regions of the banks are more prone to erosion and, therefore, need
 40 protection if the model does not compute the distribution of flow velocity and bed shear stress

1 along the banks? Could native vegetation or other bioengineering techniques be used to protect
2 the banks of the Housatonic River against erosion or more hard-core solutions such as rip-rap are
3 needed? Is it possible to use a combination of both? As it stands now, the model can not be used
4 to compare the merits of such remedial alternatives, which is one of the goals of the modeling
5 study as stated above.

6 **Response 12-MG-1**

7 EPA does not expect that EFDC will be used to evaluate specific localized areas
8 of bank erosion or the efficacy of particular remedial engineering approaches
9 such as use of native vegetation or hard engineering. There are other more
10 applicable and widely used techniques available. Application of these techniques
11 will inform specific engineering considerations, if appropriate, during the final
12 design of the selected remedial alternative. This was the approach used in both
13 the ½-Mile and the 1 ½-Mile Reach Removal Actions.

14 Due to the nature of the problem and the scale of the river system under consideration, it is
15 unlikely that a full validation of the model will be possible in the near future. From a practical
16 point of view, however, the main question in my mind would be: is the model good enough to
17 capture most of the process responsible for the transport and fate of PCBs so that it can be used
18 to assess the merits and drawbacks of different remediation strategies in the Housatonic River?

19 Right now my answer would be no but the effort by EPA and its consultants has provided a good
20 foundation towards the goal of having a useful tool that can be used to help the Housatonic and
21 other rivers experiencing similar problems.

22 **Response 12-MG-2:**

23 See General Response above.

24 **Frank Gobas**

25 1. While the report presents several efforts to calculate uncertainty, the model uncertainties are
26 not fully acknowledged. In essence, the report presumes that the model's ability to calculate
27 mean concentrations is sufficient to address the goals of the study. I think that this is a flaw in the
28 study design because the goal of the model is to compare PCB concentrations resulting from
29 different remedial scenarios. Such an application involves the comparison of mean
30 concentrations. However, comparing mean concentrations alone is insufficient to determine the
31 significance of the differences in mean concentrations. The calculation of the statistical
32 significance of a difference in the means is required. The latter is a well established practice in
33 scientific and engineering studies. I do not think that a convincing rationale is presented for why
34 this practice is not applicable in this study. The authors argued that ecological receptors
35 (including fish), due to their continuous movement, tend to be exposed to a large variation in
36 concentrations, which get "averaged out" to produce an internal concentration in the fish that
37 corresponds to the average or mean exposure concentration rather than the variation in
38 concentrations (l. 10-14, p.15 Responsiveness document). Figures 6-2-35, 6-2-56, 6-3-3 to 6-3-8
39 (Model Validation Report), and similar figures in the calibration documents demonstrate a one-to

1 two order variability in predicted concentrations of PCBs, which does not differ substantially
 2 between fish and sediments (i.e. the variability in fish concentrations does not appear to be any
 3 less than that in suspended solids). This indicates that the original assumption that PCB
 4 concentrations in fish may be less variable than the sediment concentrations may not hold.

5 The model's capability to estimate only mean concentrations, makes it difficult to apply the
 6 model to some objectives. For example, when the model is applied to address model objective
 7 #6, it can only calculate at what point in time the mean concentration falls below a target level
 8 that no longer poses a human health or ecological risk. This means that roughly (depending on
 9 the frequency distribution of the concentrations) half the concentrations are still above the target
 10 level. Risk assessment calculations typically depend on the distribution of the concentration and
 11 set limits based on a percentage of individuals exceeding a particular concentration. Hence, a
 12 frequency distribution of the concentrations is essential. Perhaps it is assumed that the risk
 13 assessment calculations can deal with the distribution of the concentration. However, in the
 14 application of the model, it is the model that has to generate the distribution of concentrations
 15 (since there are no data for the future) and at this point, none of the model components can do
 16 this. A comparable argument can be made for the application of the model to model objective #1,
 17 i.e. quantify future spatial and temporal distribution of PCBs (both dissolved and particulate
 18 forms) within the water column and bed sediment. The mean concentrations that will be
 19 produced by the model do not provide information on the statistical distribution of the predicted
 20 concentrations. Hence, as the model stands, it is impossible to determine whether any calculated
 21 difference in concentration (e.g. as a result of a remediation strategy) is significant and can be
 22 treated as a difference in effectiveness among remediation strategies.

23 **Response 12-FG-1:**

24 EPA disagrees with the Reviewer's comment that the uncertainties of the models
 25 have not been fully acknowledged. This was done throughout the MCR and
 26 formally in the MVR. EPA strongly believes that the model must only be
 27 expected, as an approximation of reality, to reasonably simulate the average
 28 concentrations measured in the system being studied. Such models can be
 29 appropriate in the sense that they are useful, practical, and scientifically
 30 defensible representations of the environment that incorporate a site-specific
 31 understanding of system behavior. To this end, the model evaluation is centered
 32 on determining "whether the simulation model is an acceptable representation of
 33 the real system, given the purpose of the simulation model" (Kleijnen, 1999).

34 EPA also disagrees with the Reviewer's assumption regarding the interaction
 35 between the risk assessment and the model results. The interim media
 36 protection goals considering the risk assessments are typically expressed in
 37 terms of exposure to the 95% of the UCL of the mean concentration.

38 The model as it currently stands is incomplete. A lot of excellent work has been done but there
 39 are some major gaps that need to be addressed before the model is ready for application. This
 40 may sound disappointing to some, especially for those living in the immediate vicinity of the
 41 River. However, the remediation options that can be expected to be considered have very large
 42 and long lasting impacts on the River and its ecology. Therefore, caution should be exercised and

1 there should be confidence in the outcome of remediation efforts before such remediation takes
2 place.

3 **Response 12-FG-2:**

4 EPA does not believe that there are any gaps in information that prevent the
5 model framework from serving as an adequate tool for use in evaluating baseline
6 conditions and the relative effectiveness of potential remedial alternatives.

7 **E. John List**

8 I do not think so. For the reasons stated above. (above refers to comment 10-JL-2)

9 **Response 12-JL-1:**

10 See General Response above.

1 **13. GENERAL TOPIC 13: OTHER COMMENTS**

2 **13.1 COMMENT SUMMARY**

Reviewer Name	Page Number/Line Number
Adams	Page 6, lines 7 to 14
	Page 14, line 45 to page 15, line 39
Bohlen	Page 2, line 36 to page 4, line 17
	Page 4, line 34 to page 5, line 19
	Page 9, lines 24 to 25
	Page 10, lines 3 to 14
	Page 14, line 32 to page 15, line 15
	Page 15, lines 16 to 23
Endicott	Page 1, lines 27 to 34
	Page 22, line 31 to page 24, line 4
Garcia	Page 6, lines 37 to 40
Gobas	Page 4, lines 1 to 5
	Page 5, line 21 to page 6, line 2
	Page 8, lines 34 to 37
	Page 14, lines 21 to 32
Lick	Page 2, lines 5 to 7
	Page 10, lines 1 to 5
	Page 13, lines 28 to 29
List	Page 1, lines 5 to 28
	Page 4, lines 9 to 17
	Page 5, lines 5 to 25
	Page 6, lines 31 to 44

3 **13.2 GENERAL TOPIC SUMMARY**

4 This General Topic is intended to provide responses to comments from Reviewers that did not
 5 relate to one or more of the preceding General Topics, but were not deemed of sufficient
 6 magnitude to justify the creation of an additional General Topic area, and/or were not repeated
 7 by other Reviewers. Thus, it is in effect a series of specific responses that are not necessarily

1 related to each other but are organized into one area of the Responsiveness Summary to allow
 2 readers to quickly review additional comments and their responses.

3 **13.3 GENERAL TOPIC RESPONSE**

4 Because these comments are not necessarily related to each other, no general response is
 5 provided.

6 **13.4 RESPONSE TO SPECIFIC COMMENTS ON GENERAL TOPIC 13**

7 **Eric Adams**

8 I believe that several processes could be better represented. But I recognize that several of these
 9 processes have been calibrated, so that *if one parameter were changed, others would have to be*
 10 *changed* as well. If there is time, I would like to see the model recalibrated using more
 11 appropriate values, within physical/chemical/biological constraints. (I do not think an
 12 independent validation is necessary.) In the absence of re-calibration, the model users must
 13 exercise considerable judgment in the interpretation of model output.

14 **Response 13-EA-1**

15 In response to comments from the Reviewers, some parameter changes have
 16 been made. The revisions are noted in the Final Model Documentation Report
 17 (FMD) and elsewhere in this Responsiveness Summary. Revised model results
 18 and model-data comparisons, reflecting these changes, are provided in the FMD.

19 And depending on how much time is available, *I would recommend some modest additional*
 20 *effort*, which I organize into three categories: easy, intermediate and difficult. I believe that GE
 21 should be involved with this as much as possible (rather than simply be given a black box),
 22 because it is their model judgment that will be relied upon, and this judgment can only come
 23 with experience using the model.

24 **Easy**

25 These are things that should be easy to accomplish within a framework of a few weeks to a
 26 couple of months. They are probably also the most important.

- 27 1. Develop a strategy to improve model efficiency so that remediation scenarios can be
 28 evaluated efficiently. I suspect that the best approach here is to make use of synthetic
 29 hydrological sequences that are repeated.

2. Perform additional uncertainty analysis that looks at the uncertainty of future remediation scenarios (as opposed to simply past natural attenuation), both in terms of absolute concentrations and in terms of PCB fluxes from different sources.
3. Improve the “upstream” and “downstream” models through further calibration (GE indicates that additional data are available for this purpose).

Response 13-EA-2

1. The application of the model in the CMS will be discussed in the Model Working Group and subsequently proposed by GE and reviewed by EPA. Techniques for improving efficiency, such as the one described by the Reviewer, may be considered.

2. The uncertainty approach presented in the Model Validation Report was intended to be demonstrative rather than prescriptive, and EPA recognizes that other approaches to evaluating model uncertainty may also be valid. The comments from Reviewers on this topic ranged from quite favorable to quite critical, so clearly, no consensus was developed. In subsequent discussions with the Model Working Group following the Peer Review of the Model Validation Report, it was agreed that the uncertainty of the model results in evaluating the relative performance of remedial alternatives would be addressed using the best professional judgment of the Model Working Group. The uncertainty associated with simulations performed for potential remedial alternatives in the CMS will be discussed.

3. The EPA modeling team has further evaluated the necessity for the application of the upstream model and discussed it within the Model Working Group. The decision has been made not to pursue the use of the upstream model (see responses to General Topic 8 for additional details).

In response to the Reviewers’ comments, additional work on the downstream model has been performed. The model was more extensively calibrated, and the final model validation run is presented in Section 3.5 of the FMD (see responses to General Topic 9 for additional details).

Intermediate

The time frame here might be several months to half-a-year.

4. Develop a more highly resolved grid within at least a portion of the channel and use the grid in a short term simulation to understand the sensitivity of model predictions (again, actual concentrations as well as fluxes) to grid resolution. Information parameterized from this sensitivity test could be used to adjust the coarse grid output, as suggested above.
5. Decouple the model of the channel and the floodplain (to improve model efficiency).

- 1 6. Decouple the hydrodynamics from the sediment transport and PCB fate within EFDC (to
2 improve model efficiency).
- 3 7. Re-calibrate the model based on suggestions made by reviewers under Question 1, and in
4 consideration of the several instances of bias noted under Question 3. (I don't believe a
5 separate validation is required.)

6 **Response 13-EA-3**

7 4. The suggestion of performing sensitivity analyses for the grid resolution was
8 not implemented because this analysis was estimated to involve a substantial
9 effort that could provide only limited benefit. Simply applying all of the calibration
10 parameters on a more refined grid could lead to "apples to oranges"
11 comparisons. Sub-grid-scale features in the current grid, such as undulations in
12 the bed elevation, have been subsumed into the parameterization of the effective
13 roughness height (z_0). If the resolution of the grid was increased to explicitly
14 represent these features, a reassessment of the appropriate z_0 would be required
15 to produce the same hydrodynamic transport through the new grid. Because
16 data would be required to develop boundary conditions for a laterally segmented
17 grid, the length of a "test reach" would have to span approximately 5 miles, to
18 include locations where monitoring data were collected, as well as water-surface
19 elevations. Obtaining different results from a refined grid of a "test-reach,"
20 compared to the results for the same reach from the original grid, would not be
21 meaningful unless there was a basis for concluding that one result was better
22 than the other. A valuable check on the calculations for the full grid of Reaches 5
23 and 6 is the simulated sedimentation rate in Woods Pond, where estimates of
24 sedimentation rates are available for 12 locations. This check would not be
25 available for simulations performed in only a portion of the domain. Because the
26 Model Working Group concurs that additional lateral segmentation of the river
27 channel is not necessary, EPA believes that the effort required to perform the
28 recommended sensitivity analysis is not justified.

29 5. The floodplain and channel are effectively decoupled during the majority of the
30 time when in-bank flows are simulated, as a result of logic tests in EFDC, which
31 provide a means of bypassing computations for floodplain cells that are not
32 inundated.

33 6. The issue of decoupling the hydrodynamics from the sediment transport and
34 PCB fate within EFDC is addressed in the response to General Topic 4.

35 7. In response to comments from the Reviewers, some parameter changes have
36 been made and the calibration reverified. Revised model results and model-data
37 comparisons, reflecting these changes, are included in the FMD.

38 **Difficult**

39 This step would lead to the greatest model accuracy and robustness, but might take a year or so
40 to accomplish.

- 1 8. Restructure the grid to allow more lateral resolution. This would have to include
2 computational efficiency measures so that extended model runs are feasible, as well as a
3 complete model re-calibration.

4 **Response 13-EA-4**

- 5 8. The issues of lateral grid resolution and code modifications for computational
6 efficiency are discussed in the responses to General Topics 1 and 4.

7 **W. Frank Bohlen**

8 On several occasions discussions with the model group and within the Peer Review Panel made
9 it clear that this required understanding of the variety of transport processes affecting PCB
10 transport in the PSA was less than perfect. Recall the discussions of floodplain dynamics, an area
11 known to represent a significant sink and possible longterm source of PCBs, the continuing
12 debate over sidebank transport, the specification of boundary conditions, and the proper
13 structuring of the sediment bed within the model. Each of these items represent an essential
14 element of the transport model and most will come up again individually in the following review
15 of the model validation effort. Viewed collectively this variety of unknowns makes clear that
16 what EPA and GE are dealing with is a research project rather than simple application of an
17 accepted formulation. With this fact in mind the future role of the model should change to
18 include guidance of monitoring efforts. The need for these additional data should be clear from a
19 scientific standpoint. Their availability would also serve to increase stakeholder confidence in
20 model results.

21 Monitoring to date has placed primary emphasis on PCB distributions within the sediment
22 column with relatively limited sampling of the water column TSS and PCB concentrations. The
23 latter have placed primary emphasis on flow/TSS relationships during high flow events with
24 sampling at a number of selected transects along the main stem of the river. This monitoring has
25 been supplemented by some few field observations of sidebank erosion and laboratory estimates
26 of bed erodability using SEDFLUME. With the exception of the sidebank observations the
27 majority of the field observations have not been directed at specific processes.

28 I'd recommend that consideration be given to the extension of these past monitoring efforts to
29 include, for example, the placement of instrument arrays at the Confluence and at the Woods
30 Pond Dam sufficient to provide long term, high frequency (e.g. 3-4 samples/hr), time series
31 observations of water temperature and TSS at the mid-point of the low flow water column. These
32 measurements would be supplemented by monthly sampling of concurrent PCB concentrations.
33 All instrument observations could be telemetered to a central station permitting conditional
34 sampling as unusual flow/transport conditions occur. In addition to the upstream and
35 downstream stations in the PSA consideration should be given to the placement of one or more
36 instrument arrays at selected sites adjoining the flood plain. Again these relatively high
37 frequency data should be supplemented by lower frequency drawn water sampling of concurrent
38 PCB concentrations. This latter sampling might occur on a monthly basis and aperiodically
39 during particular rainfall/runoff events. This combination is intended to significantly increase our
40 understanding of flood plain transport processes and their temporal (including seasonal)

1 variability. These observations would also take allow us to take full advantage of the ongoing
2 remedial efforts by providing quantitative data detailing effect at a number of locations. Such
3 data would seemingly be of value in future remedial planning.

4 The above observations should be supplemented by a variety of other process studies such as the
5 continuing survey of selected portions of the side banks and sequential bathymetric survey of
6 river channel transects or detailed cross-channel velocity/flux measurements to establish the
7 adequacy of the model grid. Model results would be used to specify siting as well as the need for
8 continuing observations. This close coupling between models and monitoring would be of clear
9 benefit to the long terms goals of this effort.

10 Beyond these technical issues, the reports provided this reviewer remain exceedingly difficult to
11 read. I understand all of the reasons why but cannot believe that the project would not benefit
12 from a clearer and more concise document. In this validation report there is entirely too much
13 use of “reasonable agreement” and the like with often insufficient demonstration. The Executive
14 Summary is too general and does little to build confidence in this modeling effort and its
15 subsequent application. Questions regarding many of the key points of the model require going
16 back to previous documents that were themselves obscure and it’s often difficult to figure out
17 just what is being presented in the report figures (e.g. was that streamflow instantaneous, daily
18 average or monthly average ? Are the TSS values a vertical average? Over what period of time?
19 Is it legitimate to compare longer term model results to shorter term data?). Too many
20 discussions end prematurely before any attempt is made to explain observed differences or
21 discrepancies (see pg. 4-90/91 Vol.1 discussion of Event 10. Why the underestimation?) Many of
22 these questions might be resolved by a search of our voluminous file but who but the most
23 dedicated would be expected to do it?

24 I’d recommend, now that the major components of this exercise are in place, that a technical
25 writer be charged with the preparation of a single document describing the model and the
26 resulting runs written for the stakeholder community. This document would include all major
27 features of the model and results with key supporting figures, references and an index. I’d
28 consider this a high priority.

29 **Response 13-FB-1**

30 EPA appreciates the Reviewer’s thoughts regarding additional data collection
31 efforts that could be conducted for the modeling study. Nonetheless, EPA
32 believes that no further additional study is necessary for the model framework to
33 adequately achieve the goal of the modeling study. A massive amount of data
34 has been collected on this site, both as part of the original model framework
35 design and in response to Reviewer comments from the two previous Peer
36 Reviews. These data were sufficient for the implementation of a model
37 calibration approach that ensured that: (1) each individual transport and fate
38 process was correctly parameterized; and (2) the relative importance of each
39 process is appropriately represented. The resulting model Validation provides a
40 further demonstration of model performance and robustness.

1 EPA agrees that the major components of the modeling study are now in place,
 2 and EPA has responded to the Reviewer's comment regarding the preparation of
 3 a single document that describes the components of the entire modeling study.
 4 The FMD was prepared to summarize the enormous effort resulting from 8 years
 5 of interpretation, analysis, and evaluation that occurred in support of the
 6 modeling study for the Housatonic River, incorporating input from GE and its
 7 consultants as part of the Model Working Group established under the Consent
 8 Decree, and in response to the Peer Reviews. The FMD finalizes the outcome of
 9 the modeling study and draws upon the information contained in the following
 10 documents:

- 11 ▪ Draft Model Framework Design (MFD) document and Quality Assurance
 12 Project Plan (QAPP) (October 2000)
- 13 ▪ Responsiveness Summary to the Peer Review of the MFD and QAPP
 14 (June 2002)
- 15 ▪ Final MFD (April 2004)
- 16 ▪ Model Calibration Report (MCR) (December 2004)
- 17 ▪ Responsiveness Summary to the Peer Review of the MCR (January 2006)
- 18 ▪ Model Validation Report (March 2006)
- 19 ▪ Responsiveness Summary to the Peer Review of the MVR (November
 20 2006)
- 21 ▪ Other materials prepared in response to the Peer Reviews that are
 22 included in the Peer Review record
- 23 ▪ The RCRA Facility Investigation (RFI) Report prepared by GE (September
 24 2003)

25 In general, comparisons with observed discharge indicates that the watershed model (HSPF)
 26 provides accurate simulation of the factors governing stream flow volumes to and through the
 27 PSA. These comparisons also suggest that the model is able to reproduce the timing of flow
 28 events. This matter of timing is an important factor if the data are to be used to calculate velocity
 29 and ultimately boundary shear, as they are in this study and will be in the upcoming Corrective
 30 Measures Study. The actual timing of stage/discharge at each section of the study area in large
 31 part determines the magnitude of the horizontal pressure gradient which affects speeds,
 32 turbulence intensity and boundary shear. These are the principal factors governing sediment/PCB
 33 transport both in the water column and across the sediment-water interface.

34 Given the importance of timing it is disappointing that the report provides so little detailed
 35 information on this factor and its effects. There is abundant reference to the model's ability to
 36 accurately reproduce event timing but these statements appear to be referring to timing in the
 37 most general sense. i.e. a precipitation event induces an increase in streamflow over a time

1 similar to that observed. These references to “event timing” leave the question of the adequacy of
2 the model simulation of timing with respect to flow velocities unanswered. Examination of
3 several of the figures (see Fig. 6.2-5 (attached) e.g.) shows substantial differences between
4 measured and modeled actual flow and stage timing at several stations along the PSA. In this
5 figure, it would appear that the modeled speeds produced by the associated pressure gradients
6 should be less than the measured and that the turbulence induced by adverse pressure gradients
7 would also be reduced. Actual estimation is, of course, complicated by the morphology of the
8 region with tributary inflows and/or backwater flows and storage complicating the simple stage
9 discharge relationship. This factor may be the reason for example that the simulated flows at
10 Holmes Road are higher than the measured despite a higher measured stage relative to that
11 simulated.

12 **Response 13-FB-2**

13 It appears that the Reviewer’s assessment that the watershed model, HSPF,
14 accurately predicts the magnitude and timing of flows, correctly recognizes the
15 performance that can be expected from a watershed model. Watershed models
16 are not expected to match measured hourly flows in point-in-time comparisons,
17 even though HSPF does an excellent job of reproducing the frequency
18 distribution of measured hourly flows at both Coltsville and Great Barrington.
19 The performance of watershed models typically improves with increasing
20 averaging periods, which is why the performance measures become more
21 stringent for longer averaging periods. Realistic expectations of HSPF
22 performance on short time scales (e.g., hourly) are important in interpreting
23 EFDC simulations of storm events because of the linkage between HSPF and
24 EFDC. In the simulation of the October 2003 storm event referenced by the
25 Reviewer (MVR Figure 6.2-5), approximately one-third of the flow passing Woods
26 Pond Footbridge is based on HSPF’s simulated tributary inflows and direct runoff
27 between the confluence and Woods Pond Footbridge. The discussion of this
28 simulation recognizes the sensitivity to HSPF results, particularly because the
29 double peak in the hydrograph indicates that two closely spaced events were
30 simulated.

31 Regressions between EFDC simulated and measured flows for New Lenox Road
32 and Woods Pond Footbridge result in coefficients of determination (r^2) of
33 approximately 0.8, with slopes of 0.92 and 1.01. Because these point-in-time
34 comparisons reflect any phase shifts between simulated and measured flows, it
35 is concluded that EFDC does not suffer from timing problems to a degree that is
36 of concern or that is unexpected given the inputs from HSPF.

37 Does the presence and movement of ice seasonally contribute to sediment erosion in the PSA?
38 Within the channels or along the flood plain?

39 **Response 13-FB-3**

40 In the past 8 years that EPA has worked on the Rest of River, the presence and
41 movement of ice has not been a major factor contributing to sediment erosion in

1 the PSA. In addition, in the design of the ½-Mile Removal and 1½-Mile Removal
2 Actions, ice was not considered to be a major design issue. The role of ice
3 influences may be given further consideration during the design of any remedial
4 action for the Rest of River.

5 The TSS data set appears to be moderately robust although I worry that too much emphasis
6 might have been placed on storm conditions. The data also appear to be primarily point
7 measurements with some representing integrated measurements over the vertical. The absence of
8 time series data prevents detailing of processes such as the time scales of resuspension and
9 deposition during rising or falling stage with particular emphasis on the onset of resuspension
10 during relatively low flow conditions. The influence of such low level but persistent
11 resuspension and transport on PCB fluxes is largely ignored in the present study which places
12 primary emphasis on storm events. Absent the low flow details its difficult to assess the role of
13 these processes in the long term. Such assessments will be a subject of study in the upcoming
14 CMS. As noted above I'd recommend immediate initiation of a monitoring program designed to
15 provide time series observations of TSS concentrations at a number of selected stations
16 throughout the PSA.

17 **Response 13-FB-4**

18 The emphasis given to storm conditions is warranted because it is under these
19 conditions that the majority of solids and PCB transport occurs. The storm event
20 sampling program did provide time series measurements of water-column solids
21 concentrations; however, the Reviewer may be considering a finer sampling
22 frequency than the 1-hour interval typical of the storm event sampling. The
23 subject of low-level persistent resuspension during low flow was raised by a
24 Reviewer during the Model Calibration Peer Review, and EPA's response was
25 that it was unclear how PCBs and fine-grained solids could accumulate in areas
26 subject to persistent resuspension at low-flow conditions. The Reviewer's
27 recommendation for a monitoring program is addressed as part of Response 13-
28 FB-1 above.

29 Even with these process questions resolved there remains the issue of run-time. It seems clear
30 that the model as presently configured requires entirely too much time for the completion of a
31 single run to be useful within timely evaluations of a significant number of remedial schemes.
32 We probably knew this several years ago and should have been more sensitive to the need to
33 develop alternative formulations. A number of these, including the separation of the
34 hydrodynamics from the transport estimates and subsequent FCM evaluations were previously
35 mentioned. It is now necessary and possible to go further. Using the experience gained from
36 "whole model" runs it should now be possible to develop a number of synthetic hydrographs
37 detailing streamflow, stage, and TSS concentrations at the upstream boundary and each of the
38 primary tributary streams. This would eliminate the need to run HSPF on a regular basis. EFDC
39 is a ponderous model and can be streamlined now that we have a better idea of the relative
40 importance of the governing variables. John Hamrick should be charged with this task (no more
41 than 6 months) as soon as possible. As part of this streamlining the model grid characteristics
42 should be carefully reviewed, again using what has been learned about the relative importance of
43 each of the domain regions (sidebanks, backwaters, floodplains etc.). My sense of the present

1 grid is that it underspecifies the channel region and overspecifies the floodplain. The latter could
2 almost be treated as a box with fluxes simply proportional to stage which could be specified
3 along its margin by EFDC. If in time more detail of the interior of the plain is needed for
4 remedial purposes consideration might be given to replacing the high resolution grid on the plain
5 while placing a box in some other area (channel sidebanks?). Finally, I'd consider eliminating
6 the FCM in favor of a parametric (flow, TSS concentrations?) approximation of body burden
7 uptake based on the results of the complete model runs.

8 **Response 13-FB-5**

9 EPA disagrees with the Reviewer's comment that the run time prevents the
10 model framework from being "useful within timely evaluations of a significant
11 number of remedial schemes." As discussed in the General Response to
12 General Topic 4, EPA believes that a considerable number of simulations can be
13 executed concurrently, making the model a useful tool for the CMS. EPA
14 disagrees with the Reviewer's suggestions to minimize the roles of the watershed
15 and bioaccumulation models (HSPF and FCM, respectively), since these models
16 have significantly shorter run times than EFDC and little time savings would be
17 gained while considerable rigor would be lost. The Reviewer's suggestion to
18 trade existing grid resolution in the floodplain for additional resolution in the river
19 channel does not appear to reflect the negligible impact that such a change
20 would have on run times. These factors are discussed in FMD Appendix B.1,
21 and in the response to General Topic 3.

22 In short, what I'm thinking about is the development of an supplementary modeling scheme for
23 use in the CMS. The complete model would serve as a guide assisting in the development of a
24 series of simpler, more efficient but less comprehensive, formulations that would be directed at
25 particular remedial schemes. The complete model framework would remain in place providing
26 guidance regarding the need for and type of data to supplement model formulations for both
27 calibration and verification purposes but would not be run as frequently as the supplementary
28 schema. The alternative might be to turn to a different series of models entirely. This is not
29 recommended without good reasons that I don't have at the moment.

30 **Response 13-FB-6**

31 GE and its consultants will have the option of using techniques suggested by the
32 Reviewer, or other methods to screen scenarios before running the full model.
33 Such options will be discussed by the Model Working Group.

34 **Douglas Endicott**

35 It is unfortunate that the peer review process was conducted in more of a confrontational, as
36 opposed to a collaborative manner. The scientific process is not well served by the former
37 approach.

38 I think more would have been accomplished in the peer review sessions, had a freer dialog and
39 more open exchange of information and ideas between the various parties been possible.

1 Because of the constraints of the Consent Decree, this was not allowed. As a result, the
 2 relationship between the modeling team and the peer review panel was sometimes adversarial,
 3 and our recommendations rebutted inappropriately (from my view). Although this may be as the
 4 lawyers intended, it also resulted in some lingering issues that have not been appropriately
 5 resolved through the entire peer review process.

6 **Response 13-DE-1**

7 EPA does not believe that the Peer Review process was designed or conducted
 8 in a manner to promote or result in a confrontational or adversarial relationship
 9 between the parties and the Panel. Nor does EPA believe that any Peer Review
 10 recommendation was rebutted in an inappropriate manner. The Peer Review
 11 Process outlined in the Consent Decree was developed with deliberate thought
 12 to promote an unbiased review of the work products without undue influence
 13 from any party to the extent possible.

14 Outlined below are the steps I believe are necessary to make the EPA models the best possible
 15 tools to accomplish the goals of the modeling study for the Housatonic River:

- 16 • Revise the MVR to incorporate supplemental material (*EPA Response to Questions*
 17 document , Document Overview presentations, etc.) and remove provisional results
 18 (mass balance diagrams, downstream model w/o boulders, ...) that have been
 19 superceded since the MVR was released.
- 20 • Make a number of near-term corrections to EFDC, which can be addressed/resolved
 21 within a ~1 yr time frame)
 - 22 ○ Correct parameterization errors identified in EFDC model:
 - 23 Reduce thickness of surficial sediment bed layers;
 - 24 Parameterize vertical mixing rates as functions of benthos density & vertical
 25 position in sediment bed;
 - 26 Increase diffusive PCB fluxes by calibration and parameterize spatially as
 27 functions of benthos density;
 - 28 Reanalyze SEDFLUME data using resuspension parameters constrained by
 29 literature (e.g., shear stress exponent $n=2.6\pm0.3$) and recalibrate deposition rates.
 30 Lick, Ziegler and coworkers have published much guidance on the specifics of
 31 parameterizing sediment resuspension¹, some of which the modeling team has
 32 chosen to ignore;

¹ See, for example: A Quantitative Framework for Evaluating Contaminated Sediment Sites. SETAC 20th Annual Meeting, Philadelphia, PA, November 14-18, 1999.

- 1 ○ Revise TSS and PCB boundary conditions to correct bias evident in low flow
2 range.
- 3 ○ Test sensitivity of EFDC hydrodynamics, sediment transport and PCB transport
4 simulations to alternative grid resolutions in a “test reach” of the PSA. In all prior
5 SEDZL applications I am aware of, at least a 2-dimensional model was used for
6 hydrodynamics and sediment transport. In river systems, this was usually a
7 vertically-integrated model. Furthermore, on rivers that bend as much as the
8 Housatonic, a curvilinear grid has commonly been applied. Since the EPA
9 modeling team has elected not to follow these conventions, they should at least
10 demonstrate via numerical testing that their primarily 1-dimensional model of the
11 Housatonic River channel produces comparable results for sediment and PCB
12 transport.
- 13 ○ Investigate methods to economize on hydrodynamic and sediment transport
14 simulations (e.g., using steady state design storms and flow-duration statistics,
15 such as the Saginaw River SEDZL application²)
- 16 ○ Consider using the calibrated and validated EFDC model to build a simpler box
17 model of the river, if the two models can be shown to produce comparable results.
18 The simpler model could be particularly useful for forecasting uncertainty. Don
19 Mackay suggested this “second simplified model” approach for modeling
20 hydrophobic contaminants in the Niagara River³.
- 21 ○ Develop and implement a process of ongoing model validation, using data
22 collected as remediation progresses. It goes with out saying that modelers want to
23 continue modeling... However, the reality is that no model is truly ever
24 “finished”. So long as new data are collected, model refinement must be expected
25 and accommodated by managers and decision makers.

Response 13-DE-2

- 27 ▪ In response to comments from several Reviewers, the Final Model
28 Documentation Report (FMD) has been prepared to synthesize
29 information presented in the MFD and the Model Calibration and
30 Validation reports, and contained in the various Peer Review documents.
- 31 ▪ In response to comments from the Reviewers, some parameter changes
32 have been made. Revised model results and model-data comparison,
33 reflecting these changes, are included in the FMD.

² Cardenas, M. and W. Lick. 1996. Modeling the Transport of Sediments and Hydrophobic Contaminants in the Lower Saginaw River. *J. Great Lakes Res.*, 22(3):669-682.

³ McLachlan, M. and Mackay, D., "A Model of Contaminant Fate in the Niagara River", report prepared for Environment Canada (1987).

- 1 ▪ In response to comments from the Peer Reviewers concerning the bed
2 layering in EFDC, sediment profile imaging was conducted in early
3 September 2006 to obtain site-specific information on the structure of the
4 sediment of the Housatonic River. The site-specific information obtained
5 from that effort supported the bed layering used in the Phase 2 Calibration
6 and Validation modeling, so no change was made to the sediment bed
7 layer thickness (see FMD Appendix B.5 for additional information).

- 8 ▪ Vertical mixing rates in the sediment bed are parameterized as a function
9 of benthic invertebrate density. During the Phase 2 Calibration, an
10 extensive literature review was conducted when parameterizing the bed
11 layering and mixing. The vertical structure of particle mixing in the bed
12 was revisited following the Model Validation Peer Review, including
13 attention to the issue of the vertical position of benthic organisms in the
14 sediment bed. Additional literature review was conducted as part of this
15 effort. An adjustment was made to the algorithm used in EFDC to specify
16 mixing between bed layers, as described in Appendix B.5 of the FMD.

- 17 ▪ EPA disagrees with the Reviewer's opinion that there is a need to
18 increase diffusive PCB fluxes. The recommendation to parameterize the
19 sediment-water mass transfer coefficient as a function of benthos density
20 presumes this to be the dominant factor controlling the mass transfer
21 coefficient, when this is not known to be the case. A more detailed
22 discussion of the parameterization of the sediment-water mass transfer
23 coefficient is provided in Appendix B.10 of the FMD and is discussed
24 further in General Topic 1.

- 25 ▪ In response to Reviewers' comments, the exponent of the normalized-
26 excess shear stress, used to compute the cohesive solids erosion rate,
27 was re-evaluated, as described in Appendix B.8 of the FMD. Revised
28 model results and model-data comparisons, reflecting these changes, are
29 included in the FMD.

- 30 ▪ In response to Reviewers' comments, additional effort was directed to the
31 estimation of upstream boundary conditions for times when data are not
32 available. Alternate analysis techniques were attempted, including the
33 Autobeale method recommended by this Reviewer. A detailed discussion
34 of the boundary condition estimation techniques is provided in Appendix
35 B.2 of the FMD.

- 36 ▪ A response to the recommendation of using a test reach to evaluate the
37 sensitivity of the simulation results to an alternate grid is provided in
38 Response 13-EA-3 above.

- 39 ▪ Responses to General Topic 4 address a variety of suggestions for
40 reducing the computational burden associated with the hydrodynamic and
41 sediment transport calculations. It is noted that the Reviewer's suggestion

1 of using steady-state design storms would eliminate the ability of the
2 model to simulate the flow acceleration at the onset of a storm event. The
3 importance of this factor was stressed by Dr. Bohlen in his comment
4 (preceding Response 13-FB-2 above) regarding the importance of
5 reproducing timing of flow events, "The actual timing of stage/discharge at
6 each section of the study area in large part determines the magnitude of
7 the horizontal pressure gradient which affects speeds, turbulence intensity
8 and boundary shear."

- 9 ▪ The application of the model in the CMS will be discussed in the Model
10 Working Group and subsequently proposed by GE and reviewed by EPA.
11 Techniques for improving efficiency, such as that described by the
12 Reviewer, may be considered.
- 13 ▪ The process and timeline for evaluation and selection of a remedy for the
14 Rest of River is specified in the Reissued RCRA Permit and the Consent
15 Decree. Within this process, the Model Working Group will have
16 continued discussions regarding the use of the model. Any consideration
17 to conduct further modeling will be given within that framework.

18 **Marcelo H. Garcia**

19 I do not think that the model is ready to accomplish the goals of the modeling study. If the
20 model is to be used to simulate future conditions, first it has to adequately simulate the existing
21 conditions throughout the river and its floodplain.

22 **Response 13-MG-1**

23 EPA strongly disagrees that the model is not ready to accomplish the goal of the
24 modeling study, and that it does not adequately simulate the existing conditions
25 in the Housatonic River and floodplain. The model framework was used to
26 successfully predict average PCB concentrations in water, sediment, floodplain
27 soil, and aquatic biota. In consideration of model performance, strengths and
28 limitations, the framework was judged to reasonably account for the important
29 processes that control PCB fate, transport, and bioaccumulation in the river
30 system at the relevant scales. The evaluations of model performance also
31 demonstrate that the model framework appropriately characterizes the balance of
32 fate processes affecting PCB concentrations and exposures over time. See
33 Responsiveness Summary General Topics 1 and 2.

34 **Frank Gobas**

35 The modelers should improve the calibration of the model by lengthening the model calibration
36 period. This most likely involves a continuation of monitoring the response of PCB
37 concentrations in the River to the remediation efforts that have recently taken place. Over time, a

1 more definite change in concentration may take place, which can be used to better calibrate the
2 model.

3 **Response 13-FG-1**

4 EPA does not believe that it is necessary or desirable to continue modeling
5 efforts. Remediation above the upstream boundary condition will not be
6 completed for a number of years, thus the collection of monitoring data to
7 characterize the full effects of the remediation would take years. EPA believes
8 that this would result in an unacceptable delay in the implementation of the Rest
9 of River remedy decision.

10 An alternative to the difficult characterization of the current mass of PCBs in the River, is using
11 the model to investigate under which set of model parameters historical sources are the main
12 contributor to the PCB concentrations in the Housatonic River and judge whether these model
13 parameter sets are reasonable. This would avoid having to characterize the actual current mass of
14 PCBs in the River.

15 Re. Model Objective #3:

16 Due to the heavy reliance on calibration during model development, the relative PCB
17 concentration data in water, sediments and biota that are calculated by the model are overall
18 consistent with the model predictions of the mean concentrations. The model can therefore be
19 used with confidence to address the relative contributions of current PCB sources to
20 bioaccumulation in target species (i.e. model objective #3). Dr. Connolly argued that the
21 potential underestimation of the overall PCB depuration rate in the River affects estimates of the
22 relative contributions of current PCB sources to bioaccumulation in target species. While this is
23 correct, I do not think that this will have a significant effect on the derivation of current relative
24 sources of PCBs to fish because PCB concentrations did not vary significantly over the time
25 period that calibration was performed.

26 The application of the model of the model to quantify the historic contributions of various PCB
27 sources to bioaccumulation in target species is dependent on the time dependent capabilities of
28 the environmental fate model, which are more uncertain (see discussions above). The FCM
29 model can be expected to properly estimate the relevant contributions of water and sediment
30 concentrations as sources of PCB bioaccumulation in benthos and fish species from PCB
31 concentrations in water and sediments delivered by the EFDC model.

32 **Response 13-FG-2**

33 EPA agrees with the Reviewer's comment that "The FCM model can be expected
34 to properly estimate the relevant contributions of water and sediment
35 concentrations as sources of PCB bioaccumulation in benthos and fish species
36 from PCB concentrations in water and sediments delivered by the EFDC model."
37 The Reviewer's concern about the ability of EFDC to assess the relative
38 importance of current and historical PCB sources appears to stem from the
39 Reviewer's opinion that the temporal response computed in EFDC is uncertain.
40 Despite wide confidence bands on mean sediment PCB concentrations in

1 different years, several Reviewers, including Dr. Gobas, expressed the opinion
2 that the data showed a significant decline over time, and that this decline was
3 underestimated by the EFDC simulation. The results of a statistical analysis
4 conducted in response to Reviewer's concerns as well as previous analyses
5 presented to the Reviewers, indicates that the surface sediment PCB
6 concentrations show no statistically significant change over time, and that the
7 temporal response simulated by EFDC was well within the uncertainty envelope
8 of the data. This information, which is presented in Appendix A.1 of the FMD,
9 should address the Reviewer's concerns regarding the temporal response
10 simulated by EFDC.

11 A second suggestion is to lengthen the model's calibration period. The calibration period for the
12 current model was too short for an evaluation of model capability. This would involve the
13 continuation of monitoring programs with the objective to develop PCB concentration data over
14 a longer period of time.

15 **Response 13-FG-3**

16 EPA lengthened the calibration period to 10 ½ years in response to Reviewers'
17 comments following the Peer Review of the Model Calibration Report. At that
18 time the Reviewers suggested that an appropriate calibration period would be
19 between 5 and 10 years. See also Response 13-FG-1.

20 Continue existing PCB concentration monitoring programs to measure the changes in PCB
21 concentrations over time as a result of the recently completed remediation. Use the data together
22 with calculations of PCB source reductions due to remediation to extend the calibration period
23 and improve the calibration and/or validation of the long term temporal response of the model.

24 Apply a staged and adaptive approach in the planning of River remediation. Plan to gauge the
25 river's response to remedial efforts at certain locations in the River throughout the River
26 remediation. A PCB concentration monitoring program can detect the effect of remedial actions
27 on PCB concentrations over time and space. These data can then be used in the model to further
28 optimize the model, such that the effects of newly planned remedial efforts can be better
29 estimated.

30 **Response 13-FG-4**

31 It is expected that GE will continue to conduct sampling for PCBs and TSS at the
32 established monthly monitoring locations that span the areas in which
33 remediation has been or is being conducted. See Response 13-FG-1.

34 The approach to evaluating and selecting a remedy for the Rest of River is
35 outlined in the Consent Decree and Reissued RCRA Permit. This is the process
36 that EPA and GE will follow in planning the remediation activities. It is expected
37 that any selected remedial strategy other than no action will include a monitoring
38 component.

39

1 Wilbert Lick

2 The present model is inadequate to achieve the goal of the modeling study to simulate future
3 conditions (1) in the absence of remediation and (2) for use in evaluating the effectiveness of
4 remedial alternatives.

5 Response 13-WL-1

6 EPA rejects the Reviewer's assertion that the model framework is inadequate.
7 As documented by the analyses and results in the FMD and in previous modeling
8 documents and in individual responses to the other comments in this
9 Responsiveness Summary, EPA believes that the model framework is adequate
10 to achieve the goal of the modeling study. EPA believes the Reviewer's
11 assertion is unfounded because it is the result of flawed logic that disregards site-
12 specific measurements, the model development methods used, and the stated
13 goal of the modeling study. The discussion below presents the technical basis for
14 EPA's conclusion that the model framework is adequate and that the Reviewer's
15 position is incorrect.

16 First, it should be recognized that the model framework for Housatonic River was
17 developed using site-specific data to the greatest extent practical. Some of the
18 most important site-specific measurements included net sedimentation rates,
19 cohesive sediment erosion properties, sediment profile images, surface sediment
20 PCB concentration trends over time, the characteristics of benthic organisms in
21 surface sediment, PCB partitioning, and the sediment-water mass transfer flux of
22 PCBs. These measurements define acceptable ranges of parameter values for
23 many model processes. In many cases, the processes defined by site-specific
24 data are the same ones the Reviewer characterized as inaccurate or incorrect
25 and in conflict with data. The following two specific examples highlight the
26 Reviewer's flawed logic. One basis the Reviewer uses to assert the model
27 calibration is "inaccurate" is that there is an infinite number of combinations of
28 erosion and net sedimentation rates that can reproduce observed suspended
29 solids concentrations as long as the deposition rate is changed accordingly (see
30 Appendix A, Lick comments, page 3). The Reviewer further stated that "for a
31 predictive model, the values of erosion rate and deposition rate can not both be
32 determined from calibration of the model by use of the suspended solids
33 concentration alone." The flaws in the Reviewer's logic are that the model
34 calibration in fact was not based on suspended solids concentrations alone and
35 that two additional parameterization constraints exist: (1) water column PCB
36 concentrations; and (2) the surface sediment PCB concentration rate of change.
37 These constraints limit the number of plausible model parameterizations to a
38 narrow range because a large fraction of the PCBs present in the water column
39 or sediment bed is associated with particles. When these particles are eroded
40 from or deposited to the bed, water column PCB concentrations change. Erosion
41 and deposition can also cause sediment bed PCB concentrations to change over
42 time. Consequently, the deposition rate cannot be artificially set to an unrealistic
43 value because the model parameterizations must simultaneously satisfy four

1 conditions: (1) water column suspended solids concentrations; (2) net
2 sedimentation rates; (3) water column PCB concentrations; and (4) surface
3 sediment concentration changes over time. As documented in Sections 3 and 4
4 of the FMD, the model framework successfully simulates water column solids
5 and PCB concentrations while simultaneously reproducing net sedimentation
6 rates and the surface sediment PCB concentration rates of change.

7 Another basis for the Reviewer's assertion that the model calibration is
8 "inaccurate" (and "incorrect") is that a PCB sediment-water mass transfer flux is
9 used to represent a number of individual processes such as groundwater
10 advection, diffusion, and bioturbation. The Reviewer comments that the model is
11 wrong because each of these processes must be modeled separately with each
12 having a different functional form (see Appendix A, Lick comments, page 6).
13 From this initial assertion, the Reviewer goes on further to say that the PCB
14 sediment-water mass transfer flux is dependent on bioturbation and the
15 existence of well-mixed sediment layers. The flaws in the Reviewer's logic are
16 that none of these assertions is individually or collectively true. Specifically, it
17 should be noted that the PCB sediment-water mass transfer process is used to
18 represent the composite effect of individual processes that cannot be readily
19 measured or otherwise quantified in a practical manner on an individual basis.
20 This means that, regardless of differences in functional form, the effect of each
21 process is so small that they cannot be simulated on an individual basis without
22 introducing new model parameters that cannot be defined from data.
23 Consequently, model accuracy cannot be improved by decomposing the
24 composite process into unmeasurable components. Further, EPA did not
25 assume (and there is no reason to assume) that PCB mass transfer from the
26 sediment bed is solely driven by bioturbation or that a well-mixed layer must exist
27 for PCB mass transfer to occur. Further, the composite effect of PCB mass
28 transfer from the sediment bed is well-defined by site-specific data as
29 documented in FMD Appendix B.10. Despite his critique, the Reviewer
30 nonetheless acknowledges that EPA used the generally accepted modeling
31 approach (i.e., representation of the sediment-water mass transfer flux as a
32 gradient-driven process). Given the site-specific basis for the sediment-water
33 mass transfer process parameterization, the Reviewer's assertions are
34 unfounded.

35 Second, it should be noted that a fundamental attribute of EPA's model
36 calibration strategy was that each transport and fate process was independently
37 parameterized. The site-specific data were examined to isolate conditions where
38 sediment or PCB transport was controlled by a single, predominant process.
39 This calibration strategy was particularly important to the overall model
40 development effort because it ensured that: (1) each transport and fate process
41 was correctly parameterized; and (2) the relative importance of each process
42 (termed the "balance of fate processes") was appropriately represented. This
43 approach is documented in FMD Section 3.3. Many comments leading to the
44 Reviewer's assertion that the model cannot meet the goal of the modeling study
45 are based on the Reviewer's failure to recognize that the model correctly

1 represents the balance of fate processes. A specific example of the Reviewer's
2 flawed logic in this regard is evident in his assessment of the impact that
3 sediment mixing has on PCB fate. The Reviewer falsely assumed that: (1) mixing
4 is exclusively driven by benthic organisms; and (2) that the mass transfer flux of
5 PCBs should necessarily change as the benthic biomass changes.

6 Third, the Reviewer neglected key elements of the stated goal of the modeling
7 study, particularly the intended spatial and temporal scales of model use. In his
8 analysis of model performance and recommendations, the Reviewer focused on
9 very fine spatial and temporal scale processes and did not recognize that the
10 detail he recommends is not necessary to meet the study goal. The Reviewer
11 repeatedly focused on very fine spatial and temporal scales and other factors
12 that cannot be accurately measured in the Housatonic River system. In contrast,
13 EPA focused on those processes and effects that could be measured. At the
14 intended scale of use, processes such as PCB release by diffusion and even
15 groundwater advection are not individually important. As previously noted, EPA
16 represented these processes in a composite manner because only the composite
17 effect of the individual processes is measurable at the intended scale of model
18 use. As documented in FMD Appendix B.10, EPA has correctly represented the
19 composite effect of processes contributing to the sediment-water mass transfer
20 flux of PCB at the intended spatial and temporal scales of model use.

21 Further, the Reviewer asserted that use of equilibrium partitioning (EqP) in the
22 model is necessarily wrong and has a "major effect" on PCB transport (see
23 Appendix A, Lick comments, pages 9 and 12). However, the Reviewer did not
24 examine if his initial premise was true that the use of EqP has a major effect on
25 PCB transport in the Housatonic River before concluding whether the use of EqP
26 is wrong. For the specific case of the Housatonic River, EPA's calculations
27 demonstrate that use of either kinetic or EqP partitioning approaches are
28 expected to differ by a mere 5 to 10% as documented in FMD Appendix B.9. A
29 potential 5 to 10% difference in model results is less than the measurement error
30 in PCB sorption rates or partition coefficients. On this basis, EPA concluded that
31 EqP is appropriate for this study while kinetic approaches are unnecessarily
32 complex and not demonstrably more accurate.

33 As applied to the Housatonic, sensitivity and uncertainty analyses are asking the wrong
34 questions. They do not question whether the basic processes are formulated correctly. As an
35 example, equilibrium partitioning is assumed. Sensitivity and uncertainty analyses never
36 question this assumption, never demonstrate that it is an inaccurate assumption, nor do they
37 propose a suitable reaction rate.

38 **Response 13-WL-2**

39 The central point of the Reviewer's comment is concern about the description of
40 processes or formulations included in EFDC. Responses to the Reviewer's
41 concerns about processes are addressed in the responses to General Topic 1.
42 The applicability of the specific formulation mentioned by the Reviewer,

1 equilibrium partitioning, is discussed in detail in Appendix B.9 of the FMD. EPA
2 strongly disagrees with the Reviewer's opinion that equilibrium partitioning "is an
3 inaccurate assumption." As discussed in Appendix B.9 of the FMD, equilibrium
4 partitioning is an approximation that is clearly valid for the Housatonic River.
5 Under relevant conditions for PCB remobilization, differences between the results
6 of the equilibrium partitioning assumption and the most extreme case of slow
7 desorption kinetics are less than 10% in calculated PCB concentrations on
8 suspended particles. This level of uncertainty is clearly tolerable considering
9 other, more significant sources of uncertainty (including measurement error) and
10 the computational burden associated with representing sorption and desorption
11 kinetics.

12 These suggested modifications to the model are relatively simple (except possibly for the re-
13 gridding) and should be able to be accomplished in a year.

14 **Response 13-WL-3**

15 See the body of the Responsiveness Summary for responses to the suggested
16 modifications. EPA has, where appropriate, evaluated the suggested
17 modifications.

18 **E. John List**

19 The Peer Review Committee (PRC) has spent much time reviewing the results of the modeling
20 exercises and analyzing the modeling performance. It has devoted a significant level of effort to
21 suggestions as to how to improve the model performance and enhance its predictive capabilities
22 in its application to remedial scenarios. However, to my mind the PRC has also perhaps focused
23 excessively on model omissions and shortcomings and, in the process, has tended to overlook the
24 very real benefits that have come from the modeling exercise, benefits that are substantial,
25 irrespective of the perceived model shortcomings.

26 First, I believe that the most valuable aspect of the modeling exercise has been the discipline that
27 has been imposed to the assessment of a detailed Housatonic River mass flux balance for the
28 PCBs, total suspended solids (TSS) and water. The key factor in the assessment of any remedial
29 strategy is going to be how it affects these mass fluxes. The modeling exercise enabled a
30 detailed assessment of the relative order of magnitude of the mass fluxes in the various river
31 system components and how these would change under different source flux hypotheses.
32 Although these absolute fluxes may be somewhat in error due to the model shortcomings (to be
33 discussed below), the relative order of magnitude under different hypotheses enables the key
34 leverage points of control for the PCB fluxes to be identified. The available flux data appear to
35 indicate that, although the modeling may have some problems, at least the predicted orders of
36 magnitude appear to be in the range of available data. This suggests that the flux distributions,
37 as described in Figures 1-5 and 1-6, and Figures 1-9 through 1-15, of the document "EPS
38 Responses to Questions from Model Validation Document Overview Meeting", are most
39 probably "in the ball park" and, when properly validated, can be used to develop potential
40 remedial strategies.

1 Response 13-JL-1

2 EPA agrees with the Reviewer's observation that some very real benefits have
3 come from the modeling exercise and the input from the Panel. EPA believes
4 that the result of the modeling study is a model framework that successfully
5 predicts average PCB concentrations in water, sediment, floodplain soil, and
6 aquatic biota. In consideration of model performance, strengths and limitations,
7 the framework is judged to reasonably account for the important processes that
8 control PCB fate, transport, and bioaccumulation in the river system at the
9 relevant scales. The evaluations of model performance also demonstrate that
10 the model framework appropriately characterizes the balance of fate processes
11 affecting PCB concentrations and exposures over time. Therefore, the model
12 framework provides a tool that can be used as one line of evidence with other
13 information, including data analyses and the risk assessments, to achieve the
14 goal of the modeling study.

15 In my professional opinion these two items are really key issues in the fate and transport analysis
16 for the PCB. If neither phenomenon can be explained then how can any model hope to represent
17 what is now occurring or, even more important from the point of view of this project, what will
18 occur in the future. The second item I suspect may be a result of not including wind stresses and
19 wind-induced mixing in Woods Pond. Wind waves continually stir up the sediment and when
20 the wind dies the fine sediment (which apparently is high in PCB) settles last and stays there
21 until the next set of wind waves occurs. The wind waves result in a preferential winnowing of
22 fine material into the surficial sediments of the pond.

23 Response 13-JL-2

24 The initial portion of the Reviewer's comment relates to concerns that EFDC
25 does not simulate variability in sediment PCB concentrations consistent with the
26 variability observed across individual samples. The Reviewer continues to
27 express this concern, even though EPA and the modeling team have described
28 that this should be expected because sediment PCB concentrations from 0.25
29 mile, or more, sections of the river were averaged to develop initial conditions for
30 sediment PCBs. More detailed discussion is provided in the responses to
31 General Topics 2 and 7.

32 The latter portion of the Reviewer's comment discusses potential effects of winds
33 on sediment resuspension and transport processes, which were evaluated by the
34 modeling team. The topography surrounding the Housatonic River limits the
35 wind fetch, which is an important parameter affecting wind-driven circulation and
36 bottom shear stresses from wind-waves. The wooded hills that rise in elevation
37 on both sides of Woods Pond limit the wind fetch in the section of Reaches 5 and
38 6 with the widest exposed surface area. The effect of wind on sediment
39 resuspension was investigated by specifying a time series of wind speed and
40 direction in EFDC. Because of the sheltering effects of the surrounding
41 topography, wind effects were negligible. The Reviewer's comment regarding

1 the potential role of winds on sediment resuspension and transport was not
2 supported by the evaluation performed with EFDC.

3 With respect to the PCB modeling the results are so tenuous (see Figure 6.2-49) that it is not
4 possible to draw any really solid conclusion with respect to bias. However, an important point is
5 demonstrated by Figure 6.2-50. This figure indicates that the sediment concentrations of PCB in
6 the lower reaches of the project study area have declined somewhat since 1990 (i.e., since
7 remediation activity started). Furthermore, there appears to be a similar decline in the water
8 column concentrations of PCB, as is somewhat evident in the lower panel of Figures 6.2-44. (It
9 is noted that there is no statistical measure of the significance of the decline in either the
10 sediment or the water column, but the data are very suggestive). However, the modeling does
11 not give any indication that any similar rate of decline has occurred (see Figure 6.2-50). In fact
12 the comparison between the data and the model in this figure is strongly suggestive that the
13 model does have a bias. The bias of the model is further reinforced by the results of the
14 hypothetical remedial scenarios plotted in the un-numbered figure on page 56 of the EPA
15 Response to Questions from Model Validation (Document DCN: GE-061406-ADFI), where,
16 despite a reduction in the flux of PCB from the sediments in the upper river reaches, there is no
17 significant change in projected sediment concentration of PCBs in the lower reaches. Thus the
18 model does not match the reduction in sediment concentration that has occurred subsequent to
19 actual post-upstream remediation, and projects no reduction as a result of an hypothetical
20 reduction in the upstream PCB flux, as in the hypothetical examples. This problem needs to be
21 understood and/or fixed before the model is used in real applications.

22 **Response 13-JL-3**

23 The Reviewer states that the data shown in Figures 6.2-49 and 6.2-50 are
24 suggestive of statistically significant declines in sediment PCB concentrations.
25 The data were presented as means \pm 2 standard errors, which approximate the
26 95% confidence interval of the mean. The wide range in the confidence interval
27 of the mean, and the small number of samples in earlier years was cited by the
28 modeling team as factors that complicated characterization of trends in the data
29 and comparisons with trends computed by the model. In response to comments
30 from Reviewers, a more detailed statistical analysis has been performed in
31 addition to the analyses previously conducted and presented to the Reviewers.
32 These analyses indicate that there is no statistically significant decline in
33 sediment PCB concentrations. The result of this analysis does not support the
34 basis for the Reviewer's conclusion that the model-data comparisons indicate a
35 bias in the model.

36 The results of the example simulations show a gradual decline in sediment PCB
37 concentrations in the sediments of downstream reaches in the base case and
38 simulations 1 and 2, which include elimination of upstream sources. The
39 differences among the rates of decline in sediment PCB concentrations in the
40 base case and example simulations 1 and 2 are small, which is consistent with
41 the observation that conditions in the river are changing slowly.

1 The Reviewer's statement that remediation began in 1990 is incorrect. With the
 2 exception of limited activity associated with Building 68, the remediation in the ½-
 3 Mile Reach began in October 1999, and remediation in the 1½-Mile Reach began
 4 in 2002. The Reviewer's evaluation of the results of the example scenarios in
 5 comparison to data is based on an incorrect assumption that the data reflect 9
 6 years of remediation activities.

7 The primary difficulty here is that the processes that result in the observed concentration
 8 distributions of PCBs in the sediment are not known and therefore cannot be included in the
 9 model. Second, the geometry of the system is probably too complex to apply properly the
 10 sediment transport theory that is known. However, these difficulties should not prevent the
 11 development of adequate empirically-based relationships between observed PCB concentrations
 12 and fluxes and the water and sediment fluxes. The sediment transport modeling attempts to use a
 13 fine scale theory that is applicable to a uniform flow and applies it over an entire river cross-
 14 section as if the river had this uniform flow. Many careful observations in the field, of PCB
 15 concentrations and fluxes together with stream flow and sediment fluxes, would have provided
 16 empirical relationships that would likely have proven much more accurate, useful and
 17 predictable. There is nothing wrong with such empirical relationships when the basic theory is
 18 unknown or too complex, and in fact EPA and the USGS already use such relationships (see the
 19 two websites referenced above).

20 **Response 13-JL-4**

21 Responses to the Reviewer's initial comment regarding processes are provided
 22 in the responses to General Topic 1. The remaining comment regarding an
 23 empirical approach that could have been developed, had different data been
 24 collected, does not represent an actionable recommendation for this modeling
 25 effort.

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APPENDIX A

PEER REVIEWER COMMENTS

APPENDIX A.1

COMMENTS OF ERIC ADAMS

1 **Final Comments on Model Validation Report**
2 **E. Adams, July 2006**
3
4

5 **Question 1 Considering the changes implemented in the Phase 2 Calibration, does**
6 **the model reasonably account for the relevant processes affecting PCB fate,**
7 **transport and bioaccumulation in the Housatonic River to a degree consistent with**
8 **achieving the goal of the modeling study?**
9

10 **► Sorption kinetics**

11 The model assumes that three chemical phases of PCBs are in equilibrium. As EPA
12 points out, this is a common modeling assumption, but I believe it is only reasonable
13 within a stationary sediment bed, and not within the water column during sediment
14 resuspension.

15
16 Following Wu and Gschwend (1986), and focusing only on sorption and desorption
17 among two phases (sorbed PCB with concentration C_s and dissolved PCB with
18 concentration C_d)
19

20
$$\frac{dC_s}{dt} = k_1 K_p C_d - k_1 C_s$$

$$\frac{dC_d}{dt} = k_2 C_s / K_p - k_2 C_d$$
 (1)

21
22 where k_1 and k_2 are rate constants constrained by
23

24
$$k_1 = k_2 / \rho K_p$$
 (2)

25
26 where ρ is the solid-water phase ratio $\rho = (1 - \phi) \rho_s / \phi$, ρ_s is the solid density, ϕ is
27 porosity and K_p is the partition coefficient. For a stationary sediment bed, ρ is about 1, so
28 for hydrophobic contaminants (large K_p), most of the contaminant is sorbed; hence the
29 processes of sorption and desorption cause C_d to vary in the range $0 \leq C_d \leq C_s / K_p$,
30 whereas C_s remains nearly constant. The characteristic time for sorption/desorption for
31 highly particle-reactive species in a stationary sediment bed ($\rho K_p \gg 1$) is thus k_2^{-1} .
32

33 Wu and Gschwend (1986) describe the sorption/desorption process as one of molecular
34 diffusion through particles (or particle aggregates). For large K_p and an assumed intra-
35 aggregate porosity, their effective (retarded) diffusion coefficient is given by
36

37
$$D_{eff} \cong \frac{0.2 D_m}{K_p \rho_s}$$
 (3)

38
39 where D_m is the molecular diffusivity of PCBs. Wu and Gschwend (1988) fit a first-
40 order sorption kinetics model to the radial diffusion model over the (initial) time during

1 which half of the sorption/desorption takes place. Comparing the two models, and for
2 $\rho K_p \gg 1$

$$3 \quad k_2^{-1} \sim \frac{(R/\rho K_p)^2}{D_{eff}} \quad (4)$$

5
6 where R is a characteristic aggregate radius. It can be seen that the time scale (k_2^{-1}) is
7 proportional to K_p^{-1} . In other words, for highly particle reactive species, little of the
8 initially sorbed mass is exchanged during desorption and that which is, is lost from the
9 outside of the particle (over an effective length of order $R/\rho K_p$). Even for a large R (0.01
10 cm) and $K_p = 10^5 \text{ cm}^3/\text{g}$, the time scale (k_2^{-1}) is less than one second, suggesting that
11 desorption is very fast, and that the assumption of ***equilibrium partitioning is probably***
12 ***acceptable within the sediment bed***. See also following discussion under diffusive
13 exchange.

14
15 During resuspension, where the sediment concentration in the water column (TSS) is
16 small, equilibrium partitioning would require that most contamination become desorbed.
17 Hence diffusion must take place through the entire particle, giving a time scale (k_1^{-1})

$$18 \quad k_1^{-1} \sim \frac{R^2}{D_{eff}} \quad (5)$$

19
20
21 Even for a small R (0.001 cm), the time scale is over a day, which exceeds the duration
22 during which most suspended particles remain in the water column. Hence the
23 assumption of ***equilibrium partitioning is not really valid for resuspended particles***.
24 Because much of the contamination on resuspended particles will not have time to de-
25 sorb, assuming equilibrium partitioning overestimates the PCB flux from bottom
26 sediments due to resuspension. Of course, during calibration, this could have been
27 compensated for, in part, by assuming less sediment resuspension. **(1C)**

28 **► *Biomixing and Bioavailable Depth***

29
30 Originally, the model used a bioavailable depth of 15 cm over which the biomixing
31 coefficient (bio-diffusivity) was $D_b = 10^{-9} \text{ m}^2/\text{s}$, or approximately $1 \text{ cm}^2/\text{d}$. I commented
32 that this seemed quite large, and EPA agreed. They have changed their formulation to
33 utilize a subduction velocity, V_s , which they get from a literature review of the rates of
34 sediment mass reworking per organism per time, and site-specific data on organism
35 abundances. Their chosen velocities are approximately $V_s \sim 10^{-9} \text{ m/s}$ over the top 4-7
36 cm, and $\sim 10^{-10} \text{ m/s}$ over the next 6-8 cm. In the absence of direct measurements of
37 mixing, this may be the best approach, but it is noted from figures presented at the May
38 10 Document Review Meeting (DRM) that there is tremendous variability in organism
39 reworking rates, suggesting much uncertainty.

40
41 Assuming a vertical distance of 5 cm between the top two sediment layers, their
42 equivalent new values of bio-diffusivity are $\sim (10^{-10} \text{ to } 10^{-9} \text{ m/s})(0.05 \text{ m}) \sim 5 \times 10^{-12} \text{ to } 5 \times 10^{-11}$
43 m^2/s or ~ 20 to 200 times smaller than previous. These are probably more reasonable,

1 but it is difficult to assess whether or not they are right, because there is not much vertical
2 variation in the existing sediment PCB concentrations. However, following remediation,
3 the vertical concentration gradients could increase substantially, so this is an important
4 process.

5
6 This also raises the issue of vertical resolution. If, following remediation, clean sediment
7 is overlain by a thin layer of contaminated sediment, the numerical model will
8 immediately mix the contaminant over the top layer (say 5 cm), whereas, with a bio-
9 diffusivity of $5 \times 10^{-7} \text{ cm}^2/\text{s}$, mixing will take $(5\text{cm})^2/5 \times 10^{-7} \text{ cm}^2/\text{s}$ or about 1.5 years to
10 achieve this mixing. Thus, from a numerical modeling standpoint, *the vertical grid size*
11 *is too large*.

12
13 The sediment-water interface can rise or fall due to deposition and erosion, and EPA
14 argues that this should not affect the rates of mixing. This may not be true since you
15 could expect different rates of organism mixing in relatively fine grained sediments that
16 have been recently deposited, versus older, more consolidated sediments that have been
17 eroding. Indeed, Figure 13 of the DRM handouts on sediment mixing shows a strong
18 increase in V_s with percent fines. However, to honor their assumption, they make V_s
19 dependent only on the depth below the (moving) interface. But because the individual
20 layer thicknesses are changing, the amount of vertical mixing will change. (A constant
21 value of V_s will result in more mixing between thick layers having the same
22 concentrations as thin layers.) Using a bio-diffusivity (dimensions of L^2/T) would take
23 this effect into consideration since it is effectively V_s times the mixing length. **(3D)**

24 25 ► *Diffusive exchange*

26 The calibrated mass exchange coefficient is $K_f = 1.5 \text{ cm/d}$, which actually seems to be on
27 the small side, since it incorporates a number of processes in addition to strictly pore-
28 water diffusion. The coefficient for pore-water diffusion by itself should reflect the rate
29 at which bioturbation brings PCB-sorbed sediment to the interface, the rate at which
30 PCBs are desorbed to the porewaters, and the rate at which diffusion transports the
31 dissolved PCBs into the overlying water column. These processes work like resistors in
32 series. Chen (1993) showed that the sediment-water flux can be expressed as

$$33$$
$$34$$
$$35 \quad J = \frac{C_{sL} / K_p}{\frac{\delta}{D_m} + \frac{2.2R}{(1-\phi)[(D_b + D')D_m \rho_s K_p]^{1/2}} + \frac{L}{(1-\phi)\rho_s K_p D_b}} \quad (6)$$

36
37 where C_{sL} is the sorbed phase PCB concentration at the depth of the mixed layer L , δ is
38 the water side boundary layer thickness, and D' is the effective diffusivity of PCBs
39 within the sediment (molecular diffusion as affected by tortuosity).

40
41 Jorgensen and des Marais (1990) suggest $\delta = 0.02$ to 0.1 cm , and Shaw and Hanratty
42 (1977) suggest

$$\delta = \frac{12D_m^{0.3} \nu^{0.7}}{u^*} \quad (7)$$

where ν is the kinematic viscosity of water ($\sim 10^{-2}$ cm²/s) and u^* is the friction velocity. Using $u^* = 0.25$ cm/s gives $\delta \sim 0.05$ cm. Assuming $L = 5$ cm, $K_p = 10^5$ cm³/g, $D_m = 0.5 \times 10^{-5}$ cm²/s, $D' = 0.3 \times 10^{-5}$ cm²/s, $D_b = 5 \times 10^{-7}$ cm²/s (EPA's surface value), $\rho_s = 2.5$ g/cm³, $\phi = 0.6$, and $R = 0.01$ cm, gives values for the three terms in the denominator of Eqn 6 of roughly 10^4 , 3×10^1 and 10^2 s/cm respectively. This suggests that the flux is indeed water-side controlled (i.e., biomixing supplies contaminant to the interface sufficiently fast, and the contaminant desorbs sufficiently fast, that diffusion on the water side limits the transport) and that the last two terms can be ignored. Even if D_b were smaller by an order of magnitude ($D_b = 5 \times 10^{-8}$ cm²/s), the three terms in the denominator would be 10^4 , 3×10^1 and 10^3 s/cm, leading to similar conclusions, albeit by a smaller margin. The second term represents the "resistance" due to desorption, and the fact that it is small suggests that equilibrium partitioning can indeed be assumed in computing the flux. The reciprocal of δ/D_m is K_f which, with the above numbers, is $\sim 10^{-4}$ cm/s (8.6 cm/d). This is in the range of the values computed directly from EPA's flux analysis (e.g., Figure B.4-30 of the MCR, which includes values between 0.8 and 250 cm/d, with the majority between 3 and 10 cm/d). However, it is significantly above the value of 1.5 cm/d identified in the Phase 1 model calibration. One possible reason for the calibrated value being significantly lower is that the PCB concentrations used for the upstream model boundary conditions are generally higher than the data, at low flow, which may cause the calibration to underestimate the sediment-water exchange flux downstream.

Although the flux analysis indicated significant temporal variability in K_f that seems like it is correlated with stream flow rate, EPA's values of K_f based on complete model calibration appeared to be independent of flow rate. There seemingly should be some dependence, since increased flow would increase stream turbulence, decreasing δ and increasing K_f . As EPA acknowledges, as flow rate increases, it dilutes the water column concentration of PCBs, making it difficult to test for flow dependent fluxes. But observations do show that the model over-predicts water column PCB concentrations during low flow (when diffusive fluxes would dominate) which could reflect, at least in part, the lack of flow-dependence.

The time scale for natural recovery is the mass inventory per unit area, $C_s(1-\phi)\rho_s L$, divided by the flux, $J = C_s L K_f / K_p$, or $\tau = (1-\phi)\rho_s L K_p / K_f$. For $K_f = 10^{-4}$ cm/s (my value), and using other parameter values from above, the time scale is 160 years. Thus diffusive exchange may not be very important for contaminated sediments that are buried at or below the assumed level of bio-mixing (i.e., most existing sediments). However, for recently transported sediments with smaller L (e.g., following remediation), the time scale could be much smaller, especially if K_f were even larger. For example, if L were only 1 and K_f were simply twice the above value (2×10^{-4} cm/s), the time scale would be reduced to 16 years. However, the model would not be able to resolve the resulting sharp gradients with the current, relatively coarse, vertical grid scheme. **(1B)**

1 **► Erosion**

2 The erosion formulation and parameters come from analysis of SedFlume data. W. Lick
3 argues that the exponent n (denoting dependency of erosion on shear stress) should be
4 significantly greater than the chosen value, which would produce proportionally more
5 erosion during high flow conditions. I agree with him, but am also leery of the fact that
6 shear stresses in the model are computed based on a grid width that is essentially equal to
7 the river width. Thus the computed hydrodynamics will yield cross-sectional average
8 velocities, which ignores regions within a cross-section with relatively high velocity and
9 erosion (refer to later discussion under Question 7). Unlike conditions in SedFlow, the
10 real river is non-uniform. Thus the formulation of erosion can not be divorced from the
11 question of grid resolution. Indeed, it would seem incorrect to simply import an erosion
12 calculation from SedFlume. **(1A)**

13
14 **► Spatial Variability**

15 Much has been said about the tremendous spatial variability in sediment PCB
16 concentrations over space scales of order one meter and the fact that the model can not
17 reproduce this variability. Whether or not this is a model failure, *per se*, or simply
18 unresolved variability in model input and output (sediment bed concentrations), depends
19 on what has caused the variability. I believe the variability was caused mainly by the
20 stochastic method in which the PCBs were introduced in the first place. In such case, we
21 cannot expect the model to predict this variability and the fact that the model averages
22 concentration over relatively large grid cells is not a problem (with the mean) unless
23 sediment-water exchange of PCBs varies non-linearly with concentration (and some non-
24 linearity is inevitable, given the averaging associated with the coarse grid). Of course,
25 we can not expect the model to tell us anything about the future variance of sediment bed
26 concentrations and to the extent this is important, we should rely on the observed
27 variability. The PCBs have been in the sediments for several decades, and to a first
28 approximation the variability expected in the next decade or two (presumably our focus)
29 will not be very much different from the variability observed historically (at least for
30 natural attenuation).

31
32 On the other hand, if the variability is due to active sediment transport processes that are
33 sorting the sediments and their contaminants, then the failure to pick this up could be a
34 significant model deficiency. For example, natural attenuation could conceivably
35 increase local PCB concentrations. The available time series data of PCB concentrations
36 within surficial sediments suggest a decrease in concentration (indeed more so than is
37 being modeled), so I don't believe this is a significant process. **(2B)**

38
39 **► Boundary Loads**

40 The trend of the PCB concentration versus flow data for the E. Branch, shown in Figure
41 4.1-2 seems strange (why the sudden change at 550 cfs?). I guess this is simply what the
42 data suggest. Also the model fit exceeds the data at low flow (10 cfs) by a factor of 2-3
43 for both dissolved and particulate PCBs. This excess upstream load may have led to an
44 underestimation of calibrated fluxes from other sources downstream. Given the
45 prevalence of low flow periods, this is important. **(6)**

46

1 ► ***Initial conditions for sediment PCB concentrations***

2 I agree with GE that hindcasting predicted trends is not a robust way to establish initial
3 conditions. By playing the tape backwards, then forwards, they will get the same
4 conditions they started with. I am not sure what the alternative is, but the lack of
5 independence should be acknowledged. (7)

6
7 ► ***Summary for Question 1***

8 I believe that several processes could be better represented. But I recognize that several
9 of these processes have been calibrated, so that ***if one parameter were changed, others***
10 ***would have to be changed*** as well. If there is time, I would like to see the model
11 recalibrated using more appropriate values, within physical/chemical/biological
12 constraints. (I do not think an independent validation is necessary.) In the absence of re-
13 calibration, the model users must exercise considerable judgment in the interpretation of
14 model output. (13)

15
16 **Question 2 Are the comparisons of the model predictions with data sufficient to**
17 **evaluate the capability of the model on the spatial and temporal scales of the final**
18 **calibration and validation.**

19
20 **Question 3 Is there evidence of bias in the models, as indicated by the distribution of**
21 **residuals of model/data comparisons.**

22
23 These questions are clearly related, so their answers are combined. The “upstream” and
24 “downstream” models are discussed at the end.

25
26 ► ***Flows and Velocities***

27 Flows were simulated for the 10.5 year Phase 2 calibration period (Figures 4.2-4 through
28 4.2-14). Unfortunately there is not much data to compare with. The most data are for
29 early 1999 when the model consistently under-predicts flow. (Yet it seems to do well in
30 the later validation periods, based on the pressure transducer data.) Similar agreement
31 with stage suggests that average velocities should be pretty good. (Figure 4.2-26 shows
32 reasonable agreement between measured and predicted velocities, but the predictions are
33 generally too low; EPA argues that discrepancies are due in part to coarse grid
34 resolution.) During storms there was reasonable agreement, with moderate
35 overprediction of flow at low flow. Agreement during storms shows times of over- and
36 under-prediction, but they seem OK on average. The model seems to do reasonably well
37 simulating the extent of overbank flow during August 1990 (Figure 4.2-25). Model
38 statistics seem generally within ranges specified by the QAPP and there are few
39 indications of bias.

40
41 In the validation period, flows and velocities look similar to or better than the calibration
42 period. There are some errors in the timing of flows, but these are not important. No
43 major bias is seen. (3B)

44

1 ► **TSS**

2 The model uses flux analysis for upstream TSS when there is no data and often this
3 analysis overestimates TSS by a factor of 2-4 (Figures 4.2-31 and 6.2-12). There is some
4 underestimate of TSS at high flow.

5
6 The model tends to overpredict TSS during the calibration period (Figure 4.2-39),
7 especially at lower TSS concentrations. This is possibly because of the overprediction of
8 upstream loading. The model seems to do better with the storm events, which EPA
9 claims are more important. While bias in TSS at low flow may be insignificant in terms
10 of the sediment budget, it does affect the water column PCB concentrations, and hence
11 the relative uptake of PCBs from the water column and the sediment in the Food Chain
12 Model. In general it would have been nice to have had more data on TSS.

13
14 The statistical summary (equivalence plot, Figure 4.2-61) indicates generally good
15 agreement, but the model shows less variability than the data; i.e., the model overpredicts
16 low concentrations and underpredicts high concentrations. There appears to be no
17 significant bias with flow rate. Sedimentation rates agree reasonably well with
18 measurements using Cs-137.

19
20 Bedload concentration is computed as bed load mass rate divided by river flow (pg. 4-
21 56). Given that the bedload is traveling slower than the average stream velocity, this
22 would seemingly give too low concentrations, but I suspect velocities are more important
23 than concentrations. **(6)**

24
25 ► **PCBs**

26 The spatial plots at low Q (Figure 4.2-69) and moderate Q (Figure 4.2-70) show that
27 upstream concentrations of both TSS and PCB are too low (a consequence of the BC) and
28 that there is more local variability (indicated by shading) than variability between
29 reaches. There is no way to verify the local variability. It is hard to say whether the
30 overall spatial trend is correct or not, because of variability in the data. The temporal
31 trends look OK.

32
33 The temporal changes in sediment PCB (top 6 inches) show that the model does not
34 reproduce the significant decline in Woods Pond over time (Figure 6.2-50). This is one
35 of GE's main points and suggests that the model might also underpredict the response to
36 remedial actions, including natural attenuation. ***I see this as a major concern.***

37
38 The model misses the decline in PCBs across Woods Pond that is both observed and
39 intuitively suspected. This would mean the model overpredicts loading downstream
40 (downstream model).

41
42 Like TSS, the equivalence plots for PCBs (Figure 4.2-85) shows less variability than the
43 data. However, there is little indication of (overall) bias.

44
45 And also like TSS, it would also be nice to have had more data on PCBs. Again, there is
46 better model-data agreement at relatively high (presumably more biologically relevant)

1 concentrations. As with other variables, the model shows less variability than the data
2 (i.e., it underpredicts the highs and overpredicts the lows).

3
4 Except for the transducers which record flow (through a stage discharge relationship),
5 better data seem to be available for the calibration (especially the original calibration)
6 period, than for the validation period. However, I am less concerned with traditional
7 model validation (the model's ability to predict absolute concentrations under different
8 hydrologic conditions) than I am with the model's ability to distinguish among different
9 remedial alternatives that would presumably be evaluated under the same hydrologic
10 conditions. See comments under Question 6. (2A)

11 12 ► **Upstream Model**

13 The model was extended two miles upstream to include the 0.5 and 1.5 mile remediation
14 areas. Upstream Q and TSS were obtained from rating curves, while upstream tPCB =
15 0.019 microgram/L from boundary measurement. Comparisons were attempted against
16 TSS and tPCB measured at Lyman St. in 2001-2004 (some of this is reported in DRM
17 handouts and not in the MVR).

18
19 Predicted TSS varied from $\sim 3 \times 10^{-4}$ to $> 10^2$ mg/L while data were in the range of 3 to 30
20 mg/L (mostly 3-10). [I am assuming these are the correct units for TSS; the vertical axis
21 on the handout distributed at the DRM says ng/L.] Can one really predict TSS as low as
22 3×10^{-4} mg/L? Some data are in the range of the model, but model predictions show much
23 more variability? Where does this come from?

24
25 Predicted PCBs were 3×10^{-5} to 10^{-3} mg/L while data were in the range of ND up to 3×10^5
26 ⁵. [Again, I am assuming these are the correct units; they are consistent with the 30 to
27 1000 ng/L indicated on the handout GE provided, though EPA's handout during the
28 document review meeting indicates 3×10^{-5} to 10^{-3} ng/L.] In any case, the agreement is
29 not very convincing, and *it is hard to say that the upstream model is validated.*

30
31 The downstream concentrations of TSS and PCB from the upstream model are much
32 lower than the corresponding upstream boundary values used for the main model. Given
33 that output from the main model depends so heavily on its upstream boundary condition,
34 more work should be done on the upstream model, or at least more interpretation of the
35 results. There is scant discussion in the MVR. (8)

36 37 ► **Downstream Model**

38 The model was extended 19 miles downstream to Rising Pond Dam (not described in
39 MVR; only in DRM handouts). Upstream boundary conditions were taken from output
40 of the main model at Woods Pond. Model-data comparisons for TSS and tPCB were
41 made between 1990 and 2004 ~ 1mile downstream from Rising Pond Dam.

42
43 Predicted TSS varies widely as do the data, with the peaks corresponding with peaks in
44 flow. They are in the same ballpark, but the variability is so great that you need a
45 statistical comparison to determine how well they match on average.

46

1 Predicted PCB concentrations also vary substantially ($\sim 3 \times 10^{-3}$ to ~ 3 microgram/L), with
2 predicted peak concentrations corresponding with peak TSS and peak flow, and non-peak
3 concentrations hovering generally around 0.03 micrograms/L. (But why are some up to
4 10 times lower?) Measurements show much less variability with an average of around
5 0.1 microgram/L, or about 3 times the predicted non-peak values. The data are too sparse
6 to see if they respond to peaks in flow. Again a statistical comparison would be helpful
7 to quantify model-data agreement. Both measurements and predictions seem to be 2-3
8 times lower than corresponding values at Woods Pond Outlet, which makes sense given
9 the 20 mile separation.

10
11 GE's plot of simulated versus measured PCBs at Rising Pond Dam shows very little
12 correlation between simulation and measurement ($r^2 = 0.01$). ***At this point it is hard to***
13 ***say the downstream model is validated.*** (9)

14
15 **Question 4 Have the sensitivities in the models to the parameterizations of the**
16 **significant state and process variables been adequately characterized?**

17
18 ► Most sensitivities seem reasonable. As expected, flows show strong sensitivity to
19 upstream boundary flows, TSS is sensitive to upstream boundary flow and TSS, and
20 PCBs are sensitive to upstream boundary flow, TSS and PCB concentration.

21
22 At low flow PCB there is strong sensitivity to K_f and partitioning (at least at New Lenox
23 Rd), which makes sense, since "diffusion" is the only important process, but this effect is
24 largely diluted out in the 10.5 year simulation. At high flow, there is strong sensitivity to
25 parameters dealing with particulate phase transport (settling, erosion).

26
27 While the model shows substantial sensitivity to diffusion parameters during low flow at
28 New Lenox Rd, GE points out that virtually no sensitivity is indicated at Woods Pond
29 Footbridge. Since the flow must pass from NLR to WPF, this is illogical. Unless there is
30 a mistake in plotting (and EPA suggested there was not), this could indicate a potential
31 problem in model formulation. (5A)

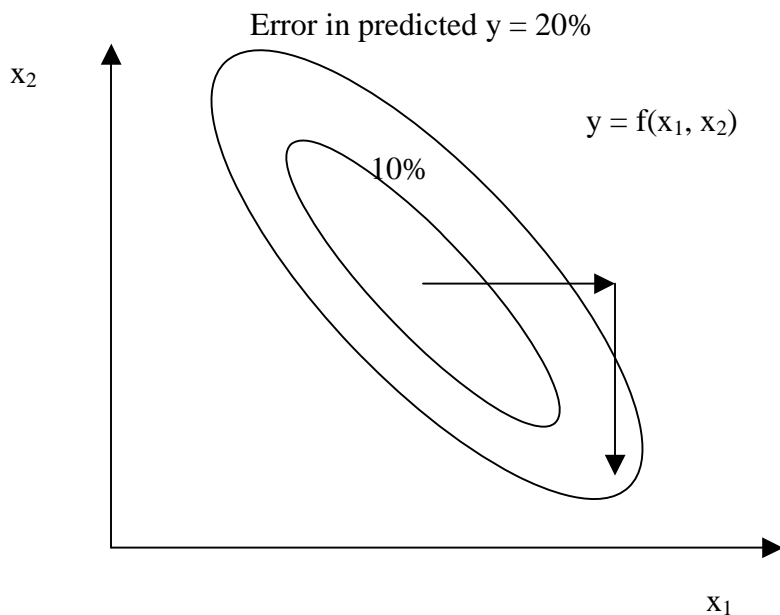
32
33 **Question 5 Are the uncertainties in the model output(s) acknowledged and**
34 **described?**

35
36 ► In general, model uncertainty comes from two sources: imperfection in the basic
37 model(s) (including unknown unknowns) and imperfection in the selection of the
38 (known) model parameters. The former has been discussed to a certain degree under
39 Question 1, which relates to processes, so the following relates mainly to the latter issue.

40
41 Although they use some sophisticated approaches, the modelers performed a rather
42 traditional uncertainty analysis, varying known model parameters largely ***independently***
43 in a simulation of ***existing conditions***. If the model and data were both perfect, and the
44 only uncertainty involved the values of model parameters, one could expect most of the
45 parameters to be independent. (Some parameters that have a physical relationship, such
46 as erosion parameters would still be correlated.) But the model has been calibrated to

1 observed data, and the calibrated model parameters reflect both imperfection in the model
2 (e.g., a parameter being used to cover more than one real process) and imperfection in the
3 data (e.g., due to sampling or analytical error, insufficient sample resolution, etc). Thus,
4 during uncertainty analysis, when one parameter is changed, other parameters should also
5 change (i.e., they are not independent), as is illustrated in the following sketch. Here the
6 dependent variable y is a function of two independent variables x_1 and x_2 and the
7 contours are plots of some measure of error between measured and predicted values of y .
8 If, as part of an uncertainty analysis, variable x_1 were changed (horizontal arrow), one
9 would expect a correlated change in x_2 (vertical arrow) in order to minimize the error
10 between measurements and predictions. Failure to take this correlation into account
11 tends to overestimate the uncertainties in the model prediction. And, as suggested in the
12 following paragraph, I suspect this issue becomes more extreme when the future
13 conditions being predicted are substantially different from those under which the model
14 was calibrated.

15
16 Apart from the question of parameter independence, there is the question of whether there
17 are certain variables to which the model is more or less sensitive as a function of the
18 remediation scenario. For example, following remediation there may be thin patches of
19 clean/dirty sediment overlaying thicker regions of dirty/clean sediment, making
20 calculations more sensitive to diffusion and partitioning than they were in the base case
21 scenario. If this is the case, we may get a distorted impression of the effectiveness of
22 remediation.



23
24
25 Based on sensitivity analysis, EPA tested the uncertainty of model outputs (e.g., PCB
26 concentrations in water, bed and fish) to uncertainties in model input parameters. As GE
27 points out, the model uncertainty is substantially greater than the uncertainty in the model

1 (e.g., the s.e.m.) If the goal were simply to predict the uncertainty in present conditions,
2 the uncertainty in the individual parameters could be scaled back until the uncertainties in
3 the model and data matched. But it is also important to see the *sensitivity of predicted*
4 *model changes due to possible remedial alternatives* to these same model input
5 parameters. This is not difficult and should be performed either before or after the model
6 is transferred to GE.

7
8 Finally, one use of the model is simply to compute relative fluxes, as EPA as
9 demonstrated recently. Remedial decisions could be made on the basis of how much less
10 PCB would be transported, rather than on (or in addition to) the basis of quantitative
11 predictions of concentrations. Thus it would also be nice to see the *sensitivity of*
12 *predicted fluxes to the same model parameters*.

13
14 In summary, because of the lack of parameter correlation in the sensitivity study, and the
15 fact that predicted uncertainty exceeds the uncertainty in the existing data, I believe the
16 predicted uncertainty, when applied to future remedial conditions, will be too large. **(5B)**

17
18 **Question 6 Upon review of the model projections of changes in PCB concentrations**
19 **in environmental media in the example scenarios, are such projections reasonable,**
20 **using your technical judgment, and are they plausible given the patterns observed in**
21 **the data?**

22
23 ► I appreciate the inclusion of the two example simulations that shed some light on how
24 the model might perform when simulating remediation options. This is clearly a start.
25 There would seem to be two issues to consider. The first is how well the remediation
26 measures themselves will work. For instance, will a cap erode? The second is what will
27 happen downstream (in space and time) after remediation? For example, will dirty
28 sediments cover up capped or dredged sediments? The example simulations don't
29 consider the first question (though it is very important), but partially address the second.
30 However, several considerations come to mind. First, the example simulations were
31 begun with "cold start" initial sediment conditions, which seems to explain, at least in
32 part, why sediment concentrations increased in some areas downstream from simulated
33 remediation (i.e., places where there was no PCB source). Better that the model be spun
34 up to initial sediment conditions that reflect an equilibrium with the modeled hydrology
35 and bathymetry. Also, the model seems to ignore any particulate PCBs that might have
36 wanted to deposit in the channel of Reach 5A. (What happens to these in the model?)
37 Ultimately, the model could be generalized to look at "different colored" PCBs
38 emanating from different source locations and to see where they end up, with
39 implications as to which would be the best sediments to remediate. This might require
40 subscribing certain variables in the code so the calculations could be run in parallel.
41 EPA has started to do some of this, but more would be instructive. **(10)**

42
43 ► As I expressed at the DRM, I am concerned with the absence of validation data
44 appropriate to remedial measures. Dredging would result in horizontal gradients in
45 sediment concentration over 10s to 100s of meters, while capping would result in vertical
46 gradients in sediment concentrations over a few cm. The current sediment concentration

1 distributions do not show variability over these scales, so it is difficult to tell whether or not
2 the model will be able to successfully predict the effects of such remedial measures. (12)

3
4 ► Figure 4.2-53 shows areas of net deposition indicating ~ 42% of net deposition is to
5 floodplain, and ~ 10% is to Woods Pond. The remaining ~48% is to the sediment bed
6 upstream of Woods Pond. It would be nice to keep track of the deposited sediments. My
7 guess is that those deposited to the flood plain and to Woods Pond stay put, or are slowly
8 released, while those in the sediment bed move on. Can this be quantified? (10)

9
10 **Question 7 Is the final model framework, as calibrated and validated, adequate to**
11 **achieve the goal of the modeling study to simulate future conditions 1) in the**
12 **absence of remediation, and 2) for use in evaluating the effectiveness of remedial**
13 **measures?**

14
15 Comments focus on the related questions of grid resolution and computational feasibility.
16 Recommendations follow at the end.

17
18 ► Like most other review panelists, I continue to be *concerned about the lack of lateral*
19 *resolution in the computational grid*. Having only about one grid cell over the river
20 width means that important processes must be parameterized. Because the existence and
21 magnitude of erosion and deposition depend non-linearly on stream velocity, a
22 trapezoidal section with depth varying linearly between 1 and 3 meters at the two banks
23 will look to the model like a section with uniform depth of 2 m, yet in practice the former
24 may have regions of strong erosion and deposition (as in re-surveyed cross-section
25 XS061 shown in the DRM handouts), whereas the latter might be marginal one way or
26 the other. Even if the model gets the net erosion/deposition correct (doubtful due to the
27 non-linearity), the failure to capture gross erosion/deposition is problematic, both for
28 evaluating remedial measures (such as capping) and natural attenuation. Assume an
29 entire channel cross-section is capped. If half of the channel is erosional and the other
30 half is depositional, the first half will require added protection to keep the cap intact,
31 while the second half will get covered with contaminated sediments from upstream.
32 Neither process would be forecast with a model that predicts marginal net
33 erosion/deposition. As for natural attenuation, contaminated sediments from an upstream
34 area with gross erosion can contaminate (or re-contaminate) downstream areas, but the
35 model would not predict this. (3A)

36
37 ► The issue of model resolution conflicts directly with the issue of computational time.
38 Clearly, with the current coupled in-channel/overbank modeling system, one cannot
39 afford the extra computational cost of reducing Δy , and still be able to afford multiple
40 simulations of multiple scenarios each over multiple decades. I share GE's concern that
41 the existing model is already too cumbersome to be used effectively to study corrective
42 measures. Indeed, this is probably the biggest model issue: as Yogi Berra might say, "If
43 you can't use the model, you can't use the model." The following are some thoughts on
44 the related issues of grid resolution and computational cost. (4)

45

1 ► **Grid resolution**

2 Too begin with, it must be recognized that the lateral grid size is a model parameter as
3 well as a numerical parameter. Ideally, when a set of equations are solved using a
4 discretized numerical model, one likes to reduce the grid size until results converge. **But,**
5 ***we are no where near that here.*** Hence if the model grid size were to be reduced, this
6 would affect other model processes (notably erosion, which depends heavily on velocity,
7 which would vary significantly across the river width). Thus ***if the model grid were to be***
8 ***reduced, the entire calibration would need to be redone.***

9
10 It is not clear how much resolution would be needed to properly compute transport.
11 Because of this uncertainty, and the time and effort involved, it may be too late in the
12 game to make major changes to the model grid. However, at a minimum, some
13 sensitivity tests could be conducted using a finer grid over a small portion of the (in-
14 channel) domain and run over a short duration of the 26 year simulation period. The
15 output from the more highly resolved model could be compared with that from the
16 coarser model and then parameterized. For example, it might be determined that the net
17 erosional flux with a resolved grid is X times that computed with the coarse grid, in
18 which case predicted erosional fluxes with the coarse grid would be multiplied by X.

19 **(3A)**

20
21 ► **Computational costs**

22 A number of options have been mentioned by the Peer Review Panel and by GE to
23 improve model efficiency. These included splitting the calculation of hydrodynamics,
24 sediment transport and PCB fate; running synthetic hydrological sequences; and
25 employing alternate grid schemes. EPA did implement some efficiency measures
26 (dynamic and split time steps, by-passing sections of the model that change slowly and
27 running simulations of selected portions of the calibration period), but seemed to have
28 dismissed the bigger ticket items. I think some of these have to be revisited.

29
30 There is no reason, in principle, why the model calculation of hydrodynamics, sediment
31 transport and PCB transport/fate could not be de-coupled. In particular, the
32 hydrodynamics could be run first. These results could be stored and used to transport
33 sediment and PCBs. Since the hydrodynamics would only need to be computed once
34 (hydrology does not depend significantly on scenario), considerable saving could be
35 obtained. The devil is in the details of course, and this would probably take a few months
36 of time. But since EPA is a model developer, and such a decoupled model would have
37 future applications, EPA may want to invest in such a project, possibly calling in the
38 model developer (J. Hamrick).

39
40 Further savings could be obtained ***using synthetic hydrologic flows.*** Based on the
41 relatively large data base, a suitable discrete distribution could be generated that includes
42 representative flows of different magnitudes and recurrence intervals. The model (with
43 or without the hydrodynamics disaggregated from transport) could then be run for a
44 synthetic year (or a short period of years large enough to include the largest/least frequent
45 flow of interest), and the changes per year documented. Perhaps, without rerunning the
46 model, ***the long term effects could be computed by extrapolation of the one year results.***

1
2 Also, it still seems to me that in channel and over bank calculations could be de-coupled,
3 saving additional computational time, and/or allowing more detail during the vast
4 majority of time when the flow is within the banks and essentially one-dimensional. EPA
5 claims there are coupling issues such as loss of momentum conservation, which may be
6 true. But exact coupling is not critical. We are only expecting the model to predict gross
7 trends in PCB concentrations (over time and the longitudinal direction), so a temporary
8 mis-match might be acceptable. In general, I would support more a somewhat more
9 approximate model (e.g., with parameterizations) that could be more efficiently used.

10
11 In this regard, I like M. Garcia's idea of a flood plain number to quantify deposition of
12 PCBs within portions of the floodplain. PCBs appear to be on a conveyor belt whereby
13 they are resuspended from within the channel at high flow, partly deposited on the banks,
14 then gradually eroded from the bank back into the river, until some of them are deposited
15 in Woods Pond. These processes are all in the model, but it might be nice to document
16 the life history of a "numerically marked" cohort of sediment, and to test the sensitivity
17 of the ultimate fate of this cohort to processes such as the bank erosion rate, frequency of
18 over bank flows, etc. By decoupling the sediment transport and fate, this could lead to a
19 model simplification, whereby the over bank processes (deposition and bank erosion) are
20 parameterized as simple first order sinks and sources whose rates are determined by
21 calibration to detailed simulation over the calibration period. These rates could vary with
22 flow conditions, but would be independent of PCB concentration, allowing simple
23 calculations during the Corrective Measures Study.

24
25 In summary, it is a shame that the longitudinal and transverse grid sizes (Δx and Δy) must
26 be similar since the former need not be nearly so small (fish average their exposure over
27 large distances) and the latter should be smaller. In my previous comments I suggested
28 eliminating Δx as a dependent variable (substituting, instead, grain size by reach), but I
29 recognize this was a radical idea that might take too much time to implement.

30
31 Finally, while the above discussion refers to lateral resolution (and its relationship to
32 computational cost), I am also concerned that the vertical resolution within the sediment
33 bed that may be insufficient to resolve near bed gradients that might result from remedial
34 efforts (see Question 1). Clearly, calculations in the sediment bed can use a different
35 (much longer) time step than those in the water column. It is not clear how costly
36 additional vertical resolution in the sediment bed would be, but I think it should be
37 considered. (4)

38 39 **Recommendations**

40 ► Considering the difficulty of the modeling task, the current state-of-the-art, the amount
41 of effort that has already gone into the modeling, and the difficulty in arriving at a
42 consensus (when our review panel is not allowed to), I would say that ***the current work is***
43 ***"acceptable"***. However, in view of the many reservations that many of us have, the
44 model users (GE) will have to exercise considerable professional judgment in their use of
45 the model, and EPA should grant them this judgment. (12) ► And depending on how
46 much time is available, ***I would recommend some modest additional effort***, which I

1 organize into three categories: easy, intermediate and difficult. I believe that GE should
2 be involved with this as much as possible (rather than simply be given a black box),
3 because it is their model judgment that will be relied upon, and this judgment can only
4 come with experience using the model.

6 *Easy*

7 These are things that should be easy to accomplish within a framework of a few weeks to
8 a couple of months. They are probably also the most important.

- 9 1. Develop a strategy to improve model efficiency so that remediation scenarios can
10 be evaluated efficiently. I suspect that the best approach here is to make use of
11 synthetic hydrological sequences that are repeated.
- 12 2. Perform additional uncertainty analysis that looks at the uncertainty of future
13 remediation scenarios (as opposed to simply past natural attenuation), both in
14 terms of absolute concentrations and in terms of PCB fluxes from different
15 sources.
- 16 3. Improve the “upstream” and “downstream” models through further calibration
17 (GE indicates that additional data are available for this purpose).

19 *Intermediate*

20 The time frame here might be several months to half-a-year.

- 21 4. Develop a more highly resolved grid within at least a portion of the channel and
22 use the grid in a short term simulation to understand the sensitivity of model
23 predictions (again, actual concentrations as well as fluxes) to grid resolution.
24 Information parameterized from this sensitivity test could be used to adjust the
25 coarse grid output, as suggested above.
- 26 5. Decouple the model of the channel and the floodplain (to improve model
27 efficiency).
- 28 6. Decouple the hydrodynamics from the sediment transport and PCB fate within
29 EFDC (to improve model efficiency).
- 30 7. Re-calibrate the model based on suggestions made by reviewers under Question 1,
31 and in consideration of the several instances of bias noted under Question 3. (I
32 don't believe a separate validation is required.)

34 *Difficult*

35 This step would lead to the greatest model accuracy and robustness, but might take a year
36 or so to accomplish.

- 37 8. Restructure the grid to allow more lateral resolution. This would have to include
38 computational efficiency measures so that extended model runs are feasible, as
39 well as a complete model re-calibration. **(13)**

41 **References**

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12

APPENDIX A.2

COMMENTS OF W. FRANK BOHLEN

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Model Validation:
Modeling Study of PCB Contamination In The Housatonic
River

A Peer Review

By

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July 20, 2006

Introduction

Under agreements developed between the General Electric Company and the U.S. Environmental Protection Agency future designs of remedial activities intended to reduce exposure to PCB contaminated sediments within the Housatonic River will make use of a predictive numerical fate and transport model. This model, under development since 2000, is intended to provide quantitative measures of sediment and PCB transport and associated uptake by selected biota over a variety of spatial and temporal scales. Initially, the model has been applied to a region extending downstream from the confluence of the East and West Branches of the River (approximately 2 miles downstream of the GE facility in Pittsfield, Ma.) To Woods Pond Dam, a distance of approximately 10.7 miles. This Primary Study Area (PSA) is believed to contain 90% of the mass of PCBs present in the River. The PSA is a morphologically complex area which in combination with regional hydrology and placed control structures (i.e. dams) establishes a multi-faceted transport regime. The complexity of this system, representing a particular challenge, has lead to the development of a model consisting of three primary elements, a watershed model (HSPF), a hydrodynamic/sediment-contaminant transport model (EFDC) and a bioaccumulation model (FCM). As presently configured, the models are linked but not interactive.

1 Model development proceeded first through the conceptual phase (~2000-2002) and then
2 through calibration (2002-2005). Over the past year emphasis has shifted to validation. This
3 included a revised calibration effort in which the initial 14 month calibration was extended to a
4 10.5 year period (Jan.1990-June 2000), a number of model changes to better treat key processes
5 associated with the complexity of the transport regime, and then validation over a 26 year period
6 1979-2004. Coincident with validation the model domain was extended in space to include a
7 region upstream to Newell Street in Pittsfield, Ma (a distance of approximately 1.5 miles up the
8 East Branch of the River from the Confluence) and a region downstream from Woods Pond to
9 Rising Pond in Great Barrington, Ma. , a distance of 19 miles.

10 The results of the revised calibration and independent validation were released in a two
11 volume report in March, 2006 (Weston, 2006) for public comment and review by a Peer Review
12 Panel. The following provides a summary of my review of this report, supplementary materials
13 provided by EPA associated with the Document Overview Meeting held in May, 2006, and
14 review comments submitted by General Electric Contractors and concerned citizens.

15 **General Comments**

16 ►This has been and remains an ambitious project. In hindsight it may have been overly
17 ambitious to expect a single model formulation to efficiently and accurately predict future PCB
18 concentrations throughout a morphologically complex region over extended periods of time
19 given what was known about historical distributions and the range of processes governing
20 transport and fate. Some of this seems to have been recognized by EPA in their recent refinement
21 of the modeling goals placing primary emphasis on the need for the model to be able to establish
22 the relative performance of selected remedial alternatives rather than on its ability to yield
23 certain prediction of absolute PCB concentrations (EPA, 2006). While this refinement is
24 advisable and will be taken into consideration in model evaluations it must be remembered that it
25 does not relieve the modeler's responsibility to develop an efficient, stable and quantitatively
26 accurate model. The evaluations to be conducted during the upcoming Corrective Measures
27 Study (CMS) by GE will be considering the benefits of remedial alternatives over extended
28 periods of time, often 40 years or more, i.e. times well in excess of the validation period. The
29 utility of the relative comparisons over these extended periods will ultimately depend on the
30 degree to which the model provides accurate simulation of all of the governing physical
31 chemical and biological factors affecting transport and fate and the adequacy of the
32 computational numerical schemes. Fundamentally, these are the same factors to be considered if
33 the model was to be used for absolute predictions. The sufficiency to evaluate these
34 characteristics depends in large part on our understanding of the PCB transport system structure
35 and dynamics within the Housatonic River. (12)

36 ►On several occasions discussions with the model group and within the Peer Review
37 Panel made it clear that this required understanding of the variety of transport processes affecting
38 PCB transport in the PSA was less than perfect. Recall the discussions of floodplain dynamics,
39 an area known to represent a significant sink and possible longterm source of PCBs, the
40 continuing debate over sidebank transport, the specification of boundary conditions, and the

1 proper structuring of the sediment bed within the model. Each of these items represent an
2 essential element of the transport model and most will come up again individually in the
3 following review of the model validation effort. Viewed collectively this variety of unknowns
4 makes clear that what EPA and GE are dealing with is a research project rather than simple
5 application of an accepted formulation. With this fact in mind the future role of the model should
6 change to include guidance of monitoring efforts. The need for these additional data should be
7 clear from a scientific standpoint. Their availability would also serve to increase stakeholder
8 confidence in model results.

9 Monitoring to date has placed primary emphasis on PCB distributions within the
10 sediment column with relatively limited sampling of the water column TSS and PCB
11 concentrations. The latter have placed primary emphasis on flow/TSS relationships during high
12 flow events with sampling at a number of selected transects along the main stem of the river.
13 This monitoring has been supplemented by some few field observations of sidebank erosion and
14 laboratory estimates of bed erodability using SEDFLUME. With the exception of the sidebank
15 observations the majority of the field observations have not been directed at specific processes.

16 I'd recommend that consideration be given to the extension of these past monitoring
17 efforts to include, for example, the placement of instrument arrays at the Confluence and at the
18 Woods Pond Dam sufficient to provide long term, high frequency (e.g. 3-4 samples/hr), time
19 series observations of water temperature and TSS at the mid-point of the low flow water column.
20 These measurements would be supplemented by monthly sampling of concurrent PCB
21 concentrations. All instrument observations could be telemetered to a central station permitting
22 conditional sampling as unusual flow/transport conditions occur. In addition to the upstream and
23 downstream stations in the PSA consideration should be given to the placement of one or more
24 instrument arrays at selected sites adjoining the flood plain. Again these relatively high
25 frequency data should be supplemented by lower frequency drawn water sampling of concurrent
26 PCB concentrations. This latter sampling might occur on a monthly basis and aperiodically
27 during particular rainfall/runoff events. This combination is intended to significantly increase our
28 understanding of flood plain transport processes and their temporal (including seasonal)
29 variability. These observations would also take allow us to take full advantage of the ongoing
30 remedial efforts by providing quantitative data detailing effect at a number of locations. Such
31 data would seemingly be of value in future remedial planning.

32 The above observations should be supplemented by a variety of other process studies
33 such as the continuing survey of selected portions of the side banks and sequential bathymetric
34 survey of
35 river channel transects or detailed cross-channel velocity/flux measurements to establish the
36 adequacy of the model grid. Model results would be used to specify siting as well as the need for
37 continuing observations. This close coupling between models and monitoring would be of clear
38 benefit to the long terms goals of this effort.

39 Beyond these technical issues, the reports provided this reviewer remain exceedingly
40 difficult to read. I understand all of the reasons why but cannot believe that the project would not

1 benefit from a clearer and more concise document. In this validation report there is entirely too
2 much use of “reasonable agreement” and the like with often insufficient demonstration. The
3 Executive Summary is too general and does little to build confidence in this modeling effort and
4 its subsequent application. Questions regarding many of the key points of the model require
5 going back to previous documents that were themselves obscure and it’s often difficult to figure
6 out just what is being presented in the report figures (e.g. was that streamflow instantaneous,
7 daily average or monthly average ? Are the TSS values a vertical average? Over what period of
8 time? Is it legitimate to compare longer term model results to shorter term data?). Too many
9 discussions end prematurely before any attempt is made to explain observed differences or
10 discrepancies (see pg. 4-90/91 Vol.1 discussion of Event 10. Why the underestimation?) Many of
11 these questions might be resolved by a search of our voluminous file but who but the most
12 dedicated would be expected to do it?

13 I’d recommend, now that the major components of this exercise are in place, that a
14 technical writer be charged with the preparation of a single document describing the model and
15 the resulting runs written for the stakeholder community. This document would include all major
16 features of the model and results with key supporting figures, references and an index. I’d
17 consider this a high priority. (13)

18 Moving now to the specific questions posed to the Peer Review Panel:

19 **1. Considering the changes implemented in the Phase 2 Calibration, does the model as**
20 **calibrated and validated, based on your technical judgement, reasonably account for the**
21 **relevant processes affecting PCB fate, transport, and bioaccumulation in the Housatonic**
22 **River to a degree consistent with achieving the goal of the modeling study?**

23 ►The global list of processes and governing factors incorporated in the linked three (3)
24 model system is comprehensive and includes all those necessary for a detailed evaluation of PCB
25 transport, fate and bioaccumulation (see Table 2-1 pp.2-3 Vol.1). In addition, the model, as
26 structured provides an excellent framework for the systematic evaluation of each of the factors
27 governing PCB transport and its ultimate bioavailability in the Housatonic River. This
28 framework directly complements quantitative study of transport and subsequent investigation
29 and ranking of remedial alternatives.

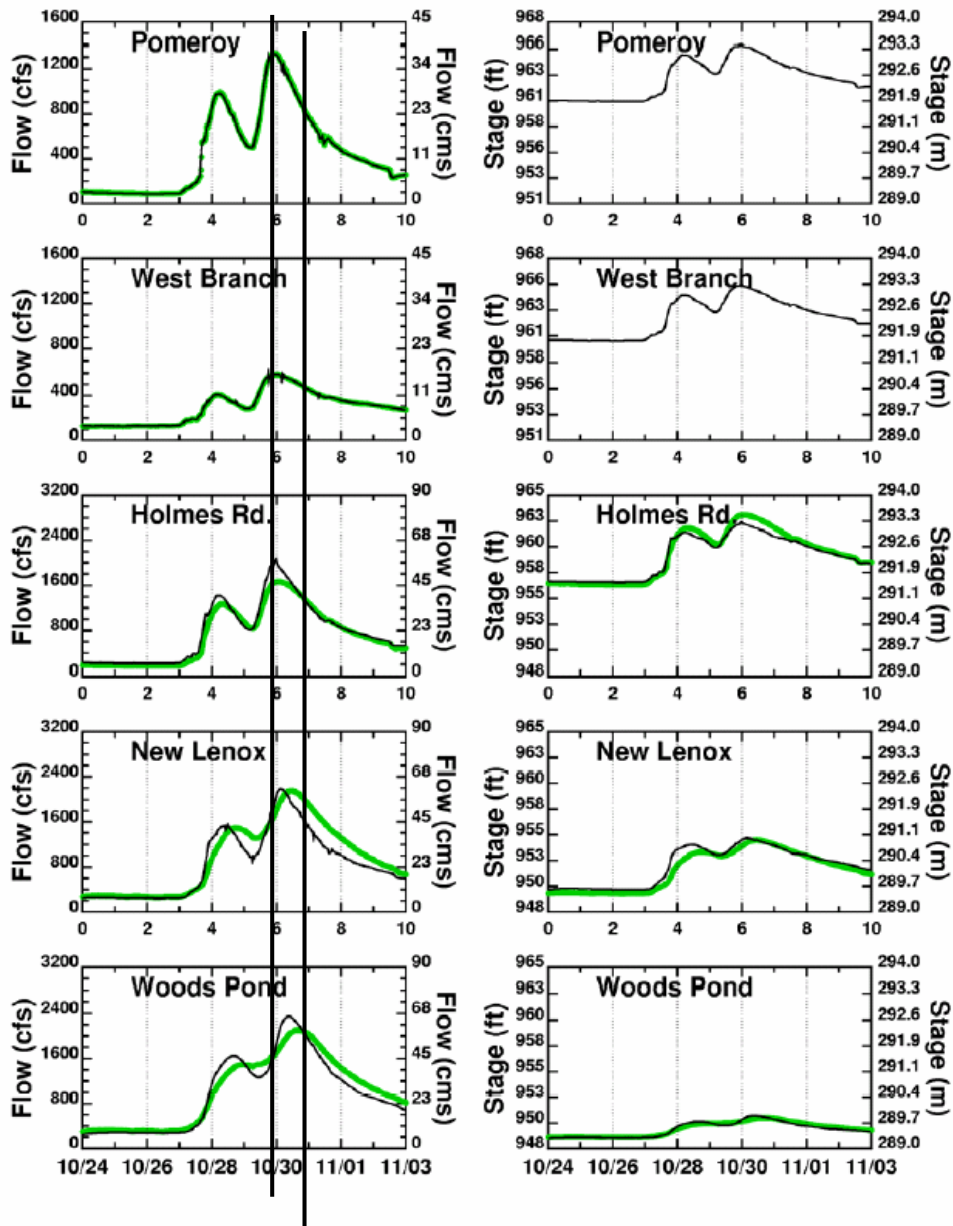
30 Despite the completeness of the global list, however, realization of the full potential of
31 the models is governed by the extent to which model formulation provides accurate process
32 simulation. Review indicates that model utility would benefit from improvements/modifications
33 in a number of areas. (1)

34 ►In general, comparisons with observed discharge indicates that the watershed model
35 (HSPF) provides accurate simulation of the factors governing stream flow volumes to and
36 through the PSA. These comparisons also suggest that the model is able to reproduce the timing
37 of flow events. This matter of timing is an important factor if the data are to be used to calculate
38 velocity and ultimately boundary shear, as they are in this study and will be in the upcoming

1 Corrective Measures Study. The actual timing of stage/discharge at each section of the study
2 area in large part determines the magnitude of the horizontal pressure gradient which affects
3 speeds, turbulence intensity and boundary shear. These are the principal factors governing
4 sediment/PCB transport both in the water column and across the sediment-water interface.

5 Given the importance of timing it is disappointing that the report provides so little
6 detailed information on this factor and its effects. There is abundant reference to the model's
7 ability to accurately reproduce event timing but these statements appear to be referring to timing
8 in the most general sense. i.e. a precipitation event induces an increase in streamflow over a time
9 similar to that observed. These references to "event timing" leave the question of the adequacy of
10 the model simulation of timing with respect to flow velocities unanswered. Examination of
11 several of the figures (see Fig. 6.2-5 (attached) e.g.) shows substantial differences between
12 measured and modeled actual flow and stage timing at several stations along the PSA. In this
13 figure, it would appear that the modeled speeds produced by the associated pressure gradients
14 should be less than the measured and that the turbulence induced by adverse pressure gradients
15 would also be reduced. Actual estimation is, of course, complicated by the morphology of the
16 region with tributary inflows and/or backwater flows and storage complicating the simple stage
17 discharge relationship. This factor may be the reason for example that the simulated flows at
18 Holmes Road are higher than the measured despite a higher measured stage relative to that
19 simulated. **(13)**

20 ▶ This matter of flow phase and velocity and associated effects on transport could be
21 better evaluated if the report had provided a more complete discussion of measured vs. modeled
22 velocities when presenting the results of EFDC hydrodynamic calculations (see pp.6-31 e.g.).
23 Although the model uses HSPF generated flows at the upstream boundary, the resulting
24 simulations are to some extent independent of the HSPF generated flow/stage through PSA and
25 as a result may be less sensitive to this matter of stage timing. Speeds were measured using both
26 electromagnetic and acoustic doppler currents meters for short periods of time at several
27 locations within the PSA (see Figs 4.2-26 and 6.2-8 (attached)). These comparisons, while taken
28 to be generally acceptable, indicate to me that there is very likely a substantial difference in
29 measured versus modeled sediment transport associated with these differences in velocity. These
30 flow induced differences will require substantial "calibration" within the model to yield
31 reasonable estimates of sediment/contaminant flux. Given the non-linearity of both the
32 velocity/shear stress and the shear stress/transport relationships it will be unlikely that such
33 calibration will result in accurate simulations across a wide range of flows. This may be the
34 principal reason that the model, at least some locations, seems to over-predict TSS values at low
35 flows while under-predicting them at high flows. The significance of such variations will tend to
36 increase with the duration of the model run and may become more of a problem during the
37 extended runs planned for the Corrective Measures Study. **(3B)**



Key: Black line — Simulated
 Green line — Measured

Figure 6.2-5 Comparison of Measured and Simulated Flow and Elevation at Five Stations During the October 2003 Storm Event

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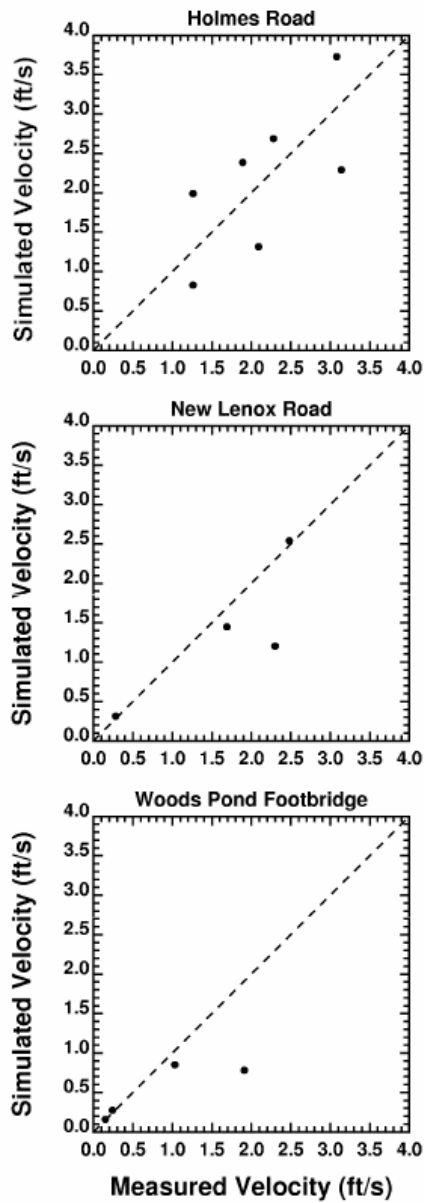


Figure 6.2-8 Comparison of Measured and Simulated Velocities for Holmes Road, New Lenox Road, and Woods Pond Footbridge During the 26-Year Validation Period

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2

1 ▶Comparisons between measured and modeled velocities are complicated by the model
2 use of a single grid cell across the main stem channel. If the single cell is to be retained
3 measurements should be designed to yield cross-sectional averages as opposed to point
4 measurements. The majority of available data do not appear to be suitable for this purpose.

5 While on the subject of model grid specification, I must repeat what has been stated
6 before regarding the advisability of increasing the number of grid cells across the channel. My
7 review of available data detailing bathymetry and sediment type indicates that accurate
8 simulation of these characteristics and their proper incorporation within transport models
9 requires a minimum of three grid cells rather than the present one. If this proves (or is known) to
10 result in an unacceptable increase in computation time then consideration should be given a
11 reduction in the lateral extent of the floodplain since there are a variety of data (see Example
12 Model Simulations, e.g.) that suggest that there are substantial areas along the inshore limits of
13 the floodplain that are only occasionally affected by flooding and where, as a result, minimal
14 longterm changes are to be expected. Alternatively, a coarser grid might be used on the
15 floodplain. **(3A)**

16 ▶Beyond this matter of flow, velocity and shear stress, I was pleased to see that the
17 current model includes direct calculation of side bank erosion. I'll leave the adequacy of this
18 formulation to those more qualified than I but must state my concern over the apparently simple
19 partitioning of the mass of sediment supplied by this process between surficial erosion (during
20 the rising hydrograph) and mass failure (during falling stage). It's hard for me to see why the
21 masses should in anyway be equivalent. This subject was also noted in GE's review of the Model
22 Validation Report (MVR). Justification for this approach should be carefully presented using the
23 field data and/or supplementary data from previous publications. **(1D)**

24 ▶The side bank issue affects both the margins of the river channel and the floodplain. All
25 indications suggest that this latter area is primarily a sink for sediment and PCBs. As I
26 understand it, the model treats each of the grids on the floodplain in a manner similar to those in
27 the river channel and seeks to erode the soil surface by flow induced shear during flooded
28 conditions. Given the presence of vegetation this very seldom occurs leading to continuing
29 deposition over most of the area. What sediment and PCB that is supplied by the floodplain
30 comes from aperiodic failure of the floodplain margin or sidebank.

31 If correct, this scheme seemingly neglects any transport associated with the movement of
32 leaf litter and/or the rainfall induced wash-off of materials adhering to the surfaces of vegetation
33 following flood inundation. Has consideration been given to the inclusion of these factors in the
34 model? If not, is there a solid basis for their neglect? It may be that this is a subject that could be
35 quantified in the revised monitoring program recommended above. It may also be that
36 phytoremediation should be included in this program (if it has not previously been investigated)
37 and/or included in the upcoming CMS. **(3C)**

38 ▶Moving to the areas of standing water in the main channel, the backwaters and Woods
39 Pond, I remain concerned about the accuracy of the sediment transport formulations. This

1 concern is not entirely alleviated by the sensitivity analyses presented in the previous calibration
2 report (Weston, 2004) and those included in the MVR. The response to a 50% variation in a
3 variety of parameters overall seems reasonable and makes clear that all of the model results are
4 sensitive to upstream boundary conditions. This, of course, is not surprising given the role of
5 streamflow across this boundary in model dynamics and the limited number of areas within the
6 PSA sufficient to serve as a sediment supply. What's demonstrated is in fact why one worries
7 about the accuracy of the sediment transport formulation. (1)

8 ▶Nor are concerns alleviated by model runs requiring what appear to be inordinately
9 high diffusive fluxes to explain the simulated increase in PCBs at New Lenox road relative to
10 those at Holmes Road (see pp.6-72 and Fig.6.2-42 MVR) during low flow conditions. This
11 response suggests that the calibration of the sediment transport formulation might, because the
12 majority of the available data were obtained during high flow events, have produced a function
13 that is overly specific to higher flow conditions. This calls to mind the comments of Dr. Lick
14 regarding the need to reduce the number of adjustable parameters in the transport formulation
15 and more accurately specify those that remain (comments that I second) so as to have confidence
16 that the algorithm is an accurate representation of governing physics and not simply some curve
17 fitting routine.

18 I would recommend that increased focus be placed on the sediment transport formulation
19 and that model runs be conducted in which the sediment supply across the upstream boundary is
20 set to zero. Minimal “tuning” and reasonable results under these conditions would increase
21 confidence in the formulation and directly benefit future evaluations in the CMS that very likely
22 will be dealing with transport in specific areas within the PSA and require accurate estimates of
23 local mass movements. (1)

24 ▶Does the presence and movement of ice seasonally contribute to sediment erosion in
25 the PSA? Within the channels or along the flood plain? (13)

26 **2. Are the comparisons of the model predictions with data sufficient to evaluate the**
27 **capability of the model on the spatial and temporal scales of the final calibration and**
28 **validation?**

29 ▶This depends to some extent on the characteristic being studied. For stream flow and
30 stage model/data comparisons are based on a relatively long data set covering a wide range of
31 seasonal, annual and intra-annual conditions at a number of sites throughout the PSA. The
32 resulting comparisons are clearly sufficient to evaluate model capabilities over a relatively long
33 period of time.

34 Moving to velocities and ultimately shear stress involves a significantly shorter data set at
35 a limited number of locations. This does not necessarily mean that the data are inadequate since
36 these characteristics are not expected to significantly change with time. As discussed above,
37 however, it is the comparisons presented in the MVR that are less than sufficient. Better use of
38 the available data would be the place to start. Careful review of the results of these analyses may

1 then point to the need for additional data from differing locations and/or modified measurement
2 procedures. **(3B)**

3 ▶The TSS data set appears to be moderately robust although I worry that too much
4 emphasis might have been placed on storm conditions. The data also appear to be primarily point
5 measurements with some representing integrated measurements over the vertical. The absence of
6 time series data prevents detailing of processes such as the time scales of resuspension and
7 deposition during rising or falling stage with particular emphasis on the onset of resuspension
8 during relatively low flow conditions. The influence of such low level but persistent
9 resuspension and transport on PCB fluxes is largely ignored in the present study which places
10 primary emphasis on storm events. Absent the low flow details its difficult to assess the role of
11 these processes in the long term. Such assessments will be a subject of study in the upcoming
12 CMS. As noted above I'd recommend immediate initiation of a monitoring program designed to
13 provide time series observations of TSS concentrations at a number of selected stations
14 throughout the PSA. **(1A, 13)**

15 ▶With regard to PCBs the data set allows at least an initial evaluation of the spatial and
16 temporal validity of the model. Specification of the initial concentrations used in the Validation
17 remains a concern since to some extent the hind cast method used to develop initial
18 concentrations is not entirely independent of the subsequent model run. This apparently was
19 required by the limited data available for 1979. Review of the RCRA Facility Investigation
20 Report (BBL, 2003) shows the results of sampling dating back to the 1979-1980 period. It seems
21 possible to use this variety of data to provide at least a check on the trends and associated initial
22 concentrations suggested by use of the model. Might this be possible? I'm assuming that
23 extensive "data mining" has been part of this exercise and that therefore some of this approach
24 might already have been tried. If so, a brief discussion of this in the report would be useful. **(7)**

25 ▶The model/data comparisons for PCBs should be extended to include consideration of
26 distributions over the vertical. Any assumption of a well mixed layer extending over depths in
27 excess of a few inches doesn't seem to agree with field data (see e.g. Fig. 4-21c, BBL,2003,
28 attached). How are these differences to be reconciled? (i.e. use of 6" well mixed layer vs.
29 detailed core data showing little mixing beyond 1-2in). These core data and associated radio-
30 dating also allow estimates of sedimentation rate to be compared to the mass flux data provided
31 by the model. This comparison was not part of the validation report. It would provide an
32 additional check on model results and is recommended. **(3D)**

33 ▶An additional check on model results that should be considered includes the use of time
34 series bathymetric data to check on the accuracy of sediment erosion/deposition estimates.**(1A)**
35 ▶Examination of these data might also be part the studies dealing with the recommended
36 increase in the number of model grid cells across the river channel. **(3A)**

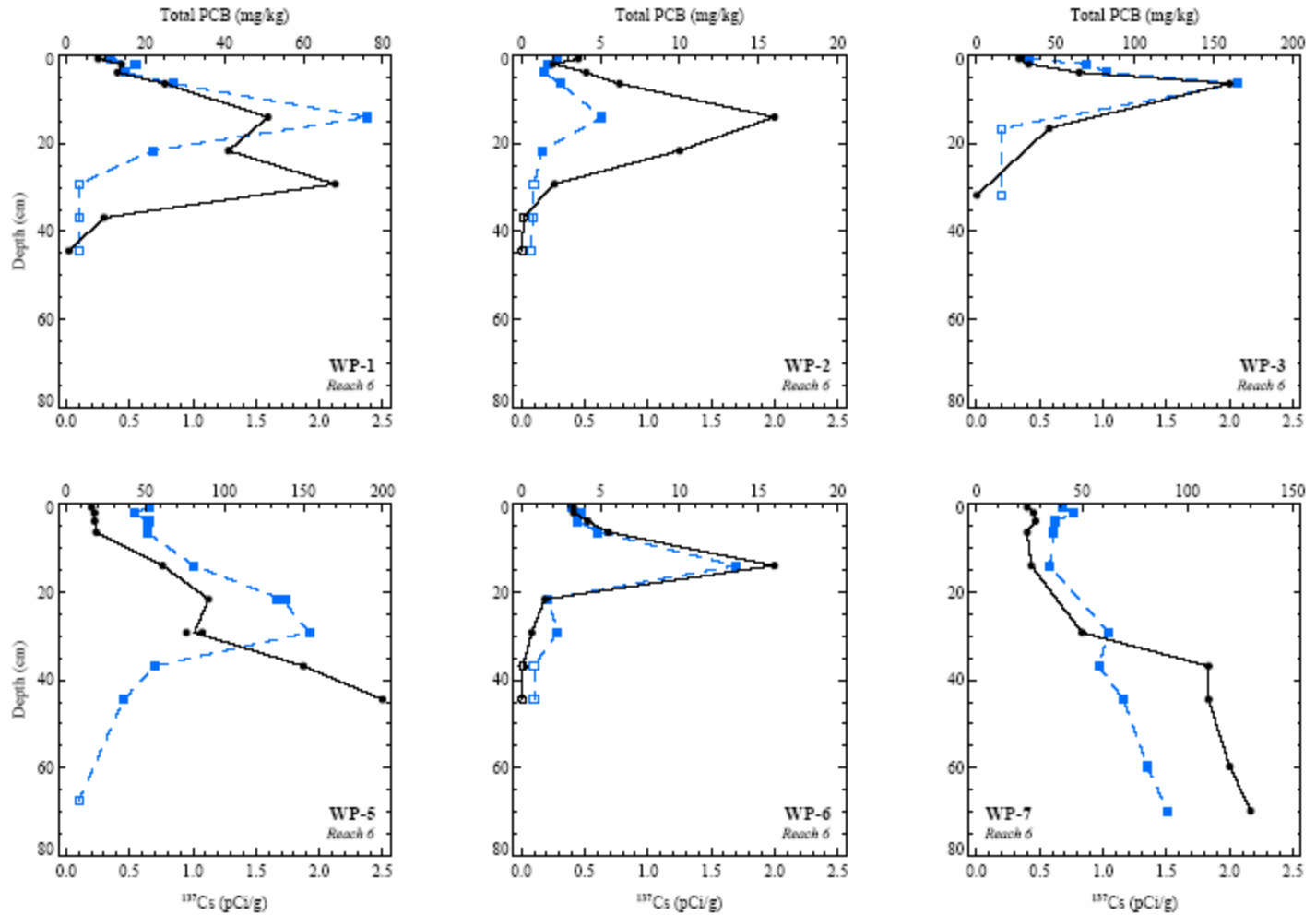
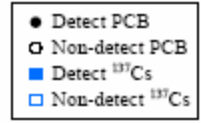


Figure 4-21c. Depth profiles of GE high resolution cores collected within Woods Pond during 1994 - 1995.

Note: Cesium-137 plots are all on the same scale; PCB scales vary by core. Line represents average of duplicate samples.



1 ▶The above comments refer only to the PSA. It would appear that there are insufficient
2 data to adequately test model results in both the upstream (which is in a state of major change)
3 and the downstream model. Efforts to gather these data should be initiated immediately. **(8, 9)**

4 **3. Is there evidence of bias in the models, as indicated by the distribution of residuals of**
5 **model/data comparisons?**

6 ▶As noted on several occasions above, visual examination of the figures suggests that
7 the model overpredicts TSS concentrations at low flows and underpredicts them at high flows.
8 The distribution of residuals provides clear indication of the overprediction at low flows for most
9 stations (see Table 6.2-6). Although a number of reasons for these differences (both high and low
10 flow) are presented there is no mention of the possibility that they are the result of less than
11 accurate formulation of the sediment transport process, in particular bed erosion/deposition, in
12 the model. As discussed above, this seems more than possible and should be carefully evaluated
13 since it will be of increasing concern during the CMS. **(1A)**

14 ▶In terms of PCBs, the model appears to overpredict concentrations in Woods Pond (see
15 Fig.6.2-50). This is likely the result of inaccurate specification of suspended sediment flux
16 associated with the above TSS predictions. Alternatively it may be associated with the
17 specification of boundary conditions and/or the model treatment of PCB sequestering in Woods
18 Pond. The model decline within the Pond appears to be approximately linear with time while the
19 data suggest an exponential distribution. The latter might be the result of progressive source
20 control (both natural due to burial and anthropogenic) acting in combination with sedimentation of
21 cleaner materials. The model might easily obscure this process since it assumes a well mixed
22 sediment column to 6in. With sedimentation rates in Woods Pond averaging approximately 2-3
23 mm/yr the above depositional processes might be expected to influence the upper 3in over 25
24 years. This might very well result in a reduction in actual PCB concentrations that would not be
25 well simulated by the model. **(2A)**

26 **4. Have the sensitivities of the models to the parameterization of the significant state and**
27 **process variables been adequately characterized?**

28 ▶In most cases the sensitivity of each of the models to the significant state and process
29 variables has been adequately characterized. However, as discussed above, I remain concerned
30 about the accuracy of the sediment transport processes within the model domain and look to the
31 sensitivity analysis for some guidance. The sensitivity analyses provided in the MVR and the
32 earlier calibration report provide clear indication that sediment mass flux throughout the PSA is
33 very sensitive to the upstream boundary conditions. With these reasonably well specified, using a
34 combination of HSPF results and field observations, it may not be very difficult to achieve
35 reasonable model/data agreement despite inaccurate simulation of bed erosion within the PSA.
36 The sensitivity analyses do not take the next step to test the adequacy of the interior formulations
37 by shutting off the boundary contribution of sediment and PCB's. The importance of this
38 formulation will progressively increase as the upstream sources of contamination are reduced
39 and remedial measures for the downstream areas are being evaluated. A detailed analysis of the

1 sensitivity and accuracy of this formulation is recommended The results of this effort might
2 serve to address the concerns raised in GE’s review of the MVR dealing with the relative
3 importance of Reach 5A and 5B as sources of sediments and contaminants to Reach 5. (5A)

4
5 ►In addition to testing of the erosion formulation additional sensitivity analyses should
6 be performed to assess model response to the thickness of the active sediment column. This has
7 been a matter of concern for some time. Experience in other riverine/bayou systems as well as
8 the detailed core data (Fig. 4-21c, attached) indicate to me that the active bed used in the model
9 is too thick. It may be that this specification in terms of physical transport characteristics has
10 relatively little effect on overall model results (although that might bring up another set of
11 questions). A test of model response to this characterization is recommended. (3D, 5A)

12 **5. Are the uncertainties in model output(s) acknowledged and described?**

13 ►The uncertainty analyses presented in the MVR are interesting and represent a real
14 attempt to develop new methodology for the assessment of complex models such as EFDC. Both
15 Kolmogorov-Smirnov (KS) and Response Surface Modeling (RSM) analyses were applied. The
16 KS methods require numerous model runs to develop a statistically robust data set. Given the
17 time required for each run this was an onerous task and one made no easier by the failure of four
18 of the EFDC runs. This effort yielded an initial estimate of uncertainties in the model prediction
19 of PCB concentrations both water column and sediment associated. These concentrations were
20 emphasized since they are passed to the food chain model (FCM). The KS analysis was
21 supplemented by RSM to evaluate model uncertainty due to uncertainty in input parameters
22 including flows, roughness parameters, critical erosion stresses, etc. The evaluations include
23 consideration of the effects of the calculated uncertainties on the FCM predictions.

24 Overall the results of the uncertainty analyses, while interesting, were difficult to
25 interpret in terms of model abilities to accurately simulate PCB transport and fate. The
26 presentation of a series of individual summary figures for each condition does not facilitate
27 interpretation in the absence of detailed description of cause and effect. The majority of the
28 supporting text dealt primarily with methodology rather than interpretation. It may be that this
29 type of analysis and its sophistication is premature and requires a greater understanding of the
30 processes included in the model and their interactions than we presently have. As this becomes
31 available with model use a better description and analysis of uncertainty might be possible.

32 Moving from the formal analyses of uncertainty to the general subject of model
33 uncertainty, this report (MVR) too often fails to provide detailed discussion of uncertainty
34 including consideration of causes. Statements such as “The simulated hydrographs....reproduced
35 measured hydrographs reasonably well, however in some cases the magnitude of the simulated
36 flow differed from the data in both positive and negative directions” (see pp 6-35) are too
37 common. Uncertainty is to be expected as is variability both due to the input data being used and
38 numerical model response. It should be introduced early in model discussions and included in
39 logical discussion of cause and effect relationships throughout the report. I would hope that any

1 summary report considers this as an absolute necessity. It will be of great value in building the
2 confidence of a general readership. (5B)

3 **6. Upon review of the model projections of changes in PCB concentrations in**
4 **environmental media in the example scenarios, are such projections reasonable, using your**
5 **technical judgement, and are they plausible given the patterns observed in the data?**

6 ▶The model response for the two examples shown seems reasonable in the sense that
7 most locations experience some decline in PCB concentrations over the upper 6in of the
8 sediment column. I would have expected to see more of a change in Example 2 since virtually all
9 of the major sources of PCB to the system have been shut off. This may point to the importance
10 of the floodplain as a continuing source of PCBs to the system and/or point to the fact that change
11 can only be expected to occur over depositional depths. These depths, controlled by sediment
12 rates in the area, will seldom exceed 3in except in the vicinity of point bars or similar channel
13 features that are not well modeled because of the coarse grid scales used in the river channel.
14 Since the model is averaging over a significantly greater depth (6in) the changes over 26 years
15 may be difficult to assess. I'd be interested in seeing what a model run of 50 years or more would
16 show. (10)

17 **7. Is the final model framework, as calibrated and validated, adequate to achieve the goal of**
18 **the modeling study to simulate future conditions 1) in the absence of remediation and 2) for**
19 **use in evaluating the effectiveness of remedial alternatives ?**

20 ▶This model system is not yet ready for use in the CMS. Several issues remain to be
21 addressed. First, as discussed above, the hydrodynamics must be more thoroughly verified so as
22 to insure accurate specification of boundary shear stresses. This factor will be central to future
23 evaluations of selected remedial schemes such as capping and is presently essential within
24 evaluations of sediment and PCB transport. The information and data provided in the validation
25 report does little to build confidence in the present formulation. (3B)

26 ▶Next, additional work is required to develop an accurate formulation of sediment
27 transport. The suggestions of Dr. Lick in terms of both equation parameters and the structure of
28 the sediment bed should be carefully evaluated. There seems to be an abundance of data and
29 experience to suggest that 6in is an overestimate of the active bed thickness. There is also
30 concern that the model as it exists may be biased to high flow conditions. Add to these questions
31 regarding side bank erosion and floodplain dynamics. (1, 3C, 3D)

32 ▶Even with these process questions resolved there remains the issue of run-time. It
33 seems clear that the model as presently configured requires entirely too much time for the
34 completion of a single run to be useful within timely evaluations of a significant number of
35 remedial schemes. We probably knew this several years ago and should have been more
36 sensitive to the need to develop alternative formulations. A number of these, including the
37 separation of the hydrodynamics from the transport estimates and subsequent FCM evaluations
38 were previously mentioned. It is now necessary and possible to go further. Using the experience

1 gained from “whole model” runs it should now be possible to develop a number of synthetic
2 hydrographs detailing streamflow, stage, and TSS concentrations at the upstream boundary and
3 each of the primary tributary streams. This would eliminate the need to run HSPF on a regular
4 basis. EFDC is a ponderous model and can be streamlined now that we have a better idea of the
5 relative importance of the governing variables. John Hamrick should be charged with this task
6 (no more than 6 months) as soon as possible. As part of this streamlining the model grid
7 characteristics should be carefully reviewed, again using what has been learned about the relative
8 importance of each of the domain regions (sidebanks, backwaters, floodplains etc.). My sense of
9 the present grid is that it underspecifies the channel region and overspecifies the floodplain. The
10 latter could almost be treated as a box with fluxes simply proportional to stage which could be
11 specified along its margin by EFDC. If in time more detail of the interior of the plain is needed
12 for remedial purposes consideration might be given to replacing the high resolution grid on the
13 plain while placing a box in some other area (channel sidebanks?). (3A, 4, 13) Finally, I’d consider
14 eliminating the FCM in favor of a parametric (flow, TSS concentrations?) approximation of body burden
15 uptake based on the results of the complete model runs. (3A, 4, 11, 13)

16 ►In short, what I’m thinking about is the development of an supplementary modeling
17 scheme for use in the CMS. The complete model would serve as a guide assisting in the
18 development of a series of simpler, more efficient but less comprehensive, formulations that
19 would be directed at particular remedial schemes. The complete model framework would remain
20 in place providing guidance regarding the need for and type of data to supplement model
21 formulations for both calibration and verification purposes but would not be run as frequently as
22 the supplementary schema. The alternative might be to turn to a different series of models
23 entirely. This is not recommended without good reasons that I don’t have at the moment. (4, 13)

24 **Personal Comment**

25 With all these reviews it’s easy to loose sight of the amount of work and dedication that it
26 has taken EPA and GE and their contractors to get us to this point. As indicated earlier this has
27 been and continues to be an ambitious project dealing with a complex subject. You have made
28 significant progress and in many cases developed new methodology that will benefit future
29 investigators. You are to be complimented on your dedication, skill, and patience. Stay the
30 course! This can be accomplished.

31 **References**

- 32 BBL 2003 Housatonic River-Rest of River RCRA Facility Investigation Report. prepared for
33 General Electric Company, Pittsfield, Ma. by Blasland,Bouck & Lee Inc and Qualitative
34 Environmental analysis, LLC (QEA).
- 35 EPA 2006 EPA Response to Questions From the Model Validation Document Overview
36 Meeting. DCN:GE-061406-ADFI June, 2006

- 1 Weston 2004 Model Calibration: Modeling Study of PCB Contamination in the Housatonic
- 2 River. Appendix B Hydrodynamic and Sediment/ PCB Fate and Transport Model
- 3 Calibration. Prepared for U.S. Army Corps of Engineers, Boston, Ma. and U.S.
- 4 Environmental Protection Agency by Weston Solutions Inc. West Chester, Pa.
- 5 DCN:GE122304-ACMG.

- 6 Weston 2006 Model Calibration: Modeling Study of PCB Contamination in the Housatonic
- 7 River. Vol 1 and Vol 2. Prepared for U.S. Army Corps of Engineers, Boston, Ma. and
- 8 U.S. Environmental Protection Agency by Weston Solutions Inc. West Chester, Pa.
- 9 DCN:GE-030706-ADBR

APPENDIX A.3

COMMENTS OF DOUGLAS ENDICOTT

1 **PEER REVIEW COMMENTS ON**
2 **THE MODEL VALIDATION REPORT**
3 **Douglas Endicott**

4
5
6 **Introduction**

7
8 I appreciate the opportunity to review the work of the modeling team for the Housatonic River.
9 This has been an interesting learning experience for me. I would also like to compliment the modeling team
10 for having conducted this project in a thoroughly professional manner. In addition, I appreciate their
11 responsiveness in the short time frames allowed for the peer review process.

12 ►I do have several comments to make regarding the peer review process itself. In the *EPA*
13 *Response to Questions from Model Validation Document Overview Meeting*, EPA correctly notes that
14 models are uncertain and that a degree of uncertainty is inherent in “these types of studies”(question: What
15 scientific study does not include a degree of uncertainty?). They go on to identify three principal sources of
16 model uncertainty (models are simplifications/approximations of reality, parameters are uncertain, future
17 conditions are unknowable). Although these can be significant sources of uncertainty, EPA chose not to
18 highlight several others, which may be equally important:

- 19 • Inappropriate process representations/formulations,
20 • Errors resulting from discretization of the model or the scale of its application,
21 • Errors in programming, preprocessing, running, linking and postprocessing the models, and
22 • Untested model predictions.

23 These are “lurking” sources of model uncertainty, which are not typically revealed by uncertainty analysis.
24 I think it is useful to acknowledge these pitfalls, and keep them in mind throughout the course of a project.
25 I think much of the Peer Review deliberations, and more than a few of the comments, reflect concern about
26 these factors. **(5B)**

27 ►It is unfortunate that the peer review process was conducted in more of a confrontational, as
28 opposed to a collaborative manner. The scientific process is not well served by the former approach.
29 I think more would have been accomplished in the peer review sessions, had a freer dialog and more open
30 exchange of information and ideas between the various parties been possible. Because of the constraints of
31 the Consent Decree, this was not allowed. As a result, the relationship between the modeling team and the
32 peer review panel was sometimes adversarial, and our recommendations rebutted inappropriately (from my
33 view). Although this may be as the lawyers intended, it also resulted in some lingering issues that have not
34 been appropriately resolved through the entire peer review process. **(13)**

35

1 **Questions for the Model Validation Report**

2
3 **1. Considering the changes implemented in the Phase 2 Calibration, does the model as calibrated and**
4 **validated, based on your technical judgment, reasonably account for the relevant processes affecting**
5 **PCB fate, transport, and bioaccumulation in the Housatonic River to a degree consistent with**
6 **achieving the goal of the modeling study?**
7

8 The modeling frameworks (HSPF, EFDC and FCN) applied in the Housatonic River are state-of-
9 the-art. Within each model, all relevant processes are represented in a conventional manner. Therefore, I
10 conclude that the models reasonably account for the relevant PCB transport, and bioaccumulation
11 processes.

12 Of course, this question is somewhat ridiculous because a successful model must do more than
13 just “account” for processes! Instead, it is necessary to reevaluate the modeling framework, its
14 implementation, and its parameterization in light of our understanding of PCB fate, transport, and
15 bioaccumulation processes as well as the behavior of the Housatonic River as an ecosystem. Two primary
16 criticisms emerge from this reevaluation:
17

- 18 1. ►EFDC fails to address lateral variation in hydrodynamics and sediment transport
19 processes, and (3A)
- 20 2. ►There appear to be parameterization errors in specific sediment transport and PCB
21 fate and transport processes. (1)

22
23 ►I should note here that, since the upstream and downstream models share the same frameworks, the same
24 comments apply. (8, 9)

25 ►On the first point, EFDC appears to fail to address lateral variation in hydrodynamics and
26 sediment transport processes, because the model grid in the river channel is one-dimensional over most of
27 the Rest-of-River (ROR). Prior applications of SEDZL (the model upon which the EFDC sediment
28 transport code was apparently based) to river systems have used a 2-dimensional, vertically-integrated grid,
29 using 5 to 10 lateral grid cells to represent the channel cross section. The 2-dimensional sediment transport
30 models have been demonstrated to predict scour and deposition in river channels with reasonable
31 accuracy¹. These applications have demonstrated that lateral variation in current velocities and bottom
32 shear stresses result in considerable variation in sediment scour depending upon location in the channel.
33 This behavior is often observed in natural channels as a pattern of erosion from mid-channel/deposition
34 nearshore, or erosion on the outside of a bend/deposition on the inside. Because the relationships between
35 current velocity, shear stress and sediment erosion are nonlinear, it appears likely that sediment scour

¹ See: Gailani, J.Z., W. Lick, K. Ziegler, and D. Endicott. 1996. Development and Calibration of a Fine-Grained Sediment Transport Model for the Buffalo River. *J. Great Lakes Res.*, 22(3):765-778.

1 predicted by the 1-dimensional model of sediment transport in the Housatonic River will be different than
2 the scour predicted by a 2-dimensional model. How *much* different is unknown, because the EPA modeling
3 team have not tested the sensitivity of the EFDC sediment transport model to the number of lateral grid
4 cells in the river channel. This is a significant issue, because release of PCBs from eroding sediments is a
5 major source of the contaminant in the ROR. **(3A)**

6 On the second point, there appear to be parameterization errors in specific sediment transport and
7 PCB fate and transport processes. These include the parameterization of sediment scour and deposition, the
8 thickness of vertical sediment segments and rate of bulk mixing between these segments, and the diffusive
9 exchange between sediment pore water and the overlying water column. In addition, the appropriateness of
10 the equilibrium partitioning assumption for PCBs on resuspended sediments has been repeatedly
11 questioned. These issues are discussed below. Where there appears to be a tie-in between parameterization
12 errors and lack-of-fit or bias in model predictions, this will be noted.

- 13 ○ ► The vertical representation of the sediment bed in the PCB fate and transport model:
14 The thickness of the surficial sediment layers have been specified as either 4 cm (Reach
15 5A) or 7 cm (Reaches 5B thru 6). These layers are assumed to be well-mixed, via a
16 combination of physical and biological processes. In addition, sediments from the
17 surficial layers are mixed with deeper layers, down to a depth of 30 cm below the
18 sediment-water interface. Analysis of benthic invertebrate data is offered to justify these
19 assumptions. However, these data show that below Reach 5A the benthos are
20 predominantly filter feeders or surficial sediment feeders/dwellers. Such organisms are
21 unlikely to cause sediment mixing below the top couple of centimeters. 7 cm of surface
22 sediment mixing is too deep, and mixing of sediment between the surface layer and
23 deeper layers is inconsistent with the life history data for the resident benthos in these
24 reaches. The consequence of too much sediment mixing (and too-thick surficial layers) is
25 that the PCB fate and transport model will predict an unreasonably slow rate of decline in
26 surficial sediment PCB concentrations, which is observed in both Phase 2 calibration and
27 validation periods. **(3D)**
- 28 ○ ► Sediment transport parameterization: Cohesive sediment resuspension is parameterized
29 based on the analysis of data from SEDFLUME experiments conducted on a number of
30 sediment cores. Results of this analysis produced shear stress exponents of 1.59 for
31 sediments in Reaches 5A and 5B and 0.95 in Reaches 5C and 6². These values are
32 considerably lower than shear stress exponents reported in the literature. For example,
33 Lick, Ziegler and coworkers have reported that for cohesive sediments tested at a
34 significant number of sites, the shear stress exponent is generally constrained within a
35 fairly narrow range ($n=2.6\pm 0.3$). Based upon this, it appears that parameterization of

² Model Calibration Report, Volume 3 - Appendix B Hydrodynamic and Sediment/PCB Fate and Transport Model Calibration, Attachment B.5 Analysis of Sediment Erosion Data

1 cohesive sediment resuspension in the model is erroneous, and should be corrected
2 consistent with the guidance offered by Dr. Lick. As a consequence, it will also be
3 necessary to recalibrate deposition rates. **(1A)**

- 4 ○ ► The diffusive flux (i.e. sediment-water exchange) of PCBs from sediment pore water
5 to the overlying water column was parameterized as a constant mass transfer coefficient
6 during Phase 1 calibration. Phase 2 calibration has altered the spatial profiles of PCB
7 water column concentrations at low flow conditions, suggesting that sediment-water
8 exchange should be recalibrated. In all likelihood, the mass transfer coefficient should be
9 increased, and made a reach-specific parameter via a relationship between the mass
10 transfer coefficient and the benthos density. **(1B)**
- 11 ○ ► EFDC uses the same equilibrium partitioning (EP) model as every other fate and
12 transport model in use today. EP generally works quite well, and simplifies the model
13 computation by requiring only a single state variable for each chemical. It has been
14 suggested that desorption kinetics should be incorporated into the Housatonic River
15 model, because PCBs desorbing from resuspended sediment might not reach equilibrium
16 within the timeframe they remain in suspension. This disequilibrium may help explain
17 the pattern of PCBs moving in “ribbons” of sediment downstream, and the high surficial
18 PCB concentrations in Woods Pond sediment. I think this is mostly speculation and,
19 although I am curious to see if it is true, it is well and beyond the objectives and goals of
20 this modeling study. **(1C, 2B)**
- 21 ○ ► I have already commented on the misattribution of the assumption made regarding
22 PCB partitioning to non-filterable organic carbon in the water column ($K_{doc} = K_{poc}/100$),
23 and EPA has responded (less than satisfactorily) to this issue. Regarding the
24 parameterization of the 3-phase equilibrium partitioning model for PCBs, a useful
25 citation (i.e., the Burkhard references) is: USEPA, 2003. *Methodology for Deriving*
26 *Ambient Water Quality Criteria for the Protection of Human Health (2000), Technical*
27 *Support Document Volume 2: Development of National Bioaccumulation Factors*. United
28 States Environmental Protection Agency, Office of Water, Office of Science and
29 Technology. EPA-822-R-03-03
30 (www.epa.gov/waterscience/criteria/humanhealth/method/tsdvol2.pdf) **(1C)**

31
32
33 ► This question also asks us to consider changes to the models resulting from additional (Phase 2)
34 calibration. This specifically applies to EFDC calibration, since little or no changes were made to either the
35 HSPF or FCN models. Previously, the Peer Review panel commented that the 14-month calibration was too
36 short to reflect many significant long-term model processes, specifically the evolution of PCB
37 concentrations in the sediment bed. So the EPA modeling team went back and extended the calibration to

1 cover a much longer, 10-year duration. I expected to see some changes in the model parameters related to
2 the residence time of PCBs in the surficial sediment layer. Instead, as a result of Phase 2 calibration we see
3 some dramatic changes in the simulation of PCB transport and fate in the Housatonic River: There are now
4 3 times more PCBs entering the Primary Study Area (PSA) at the upstream boundary, although the
5 difference (compared to the Phase 1 calibration & flux analysis) diminishes further downstream (2 times
6 more PCBs at New Lenox Road, 1.5 times more at Woods Pond). Export of in-place PCBs from the
7 sediments of Reach 5A is no longer the predominant contaminant source to the Rest-of-River. To me, this
8 is a breathtaking change in the PCB fate and transport simulation, which rewrites the entire assessment
9 going back all the way to the conceptual model presented in the MFD. I was disturbed to see such a major
10 change taking place so late in the model development process, and was also somewhat surprised at the
11 nonchalance with which this revision was presented and received.

12 Does the hydrograph or the longer duration of the Phase 2 calibration explain these differences?
13 To some degree, maybe. In 10-year period, there are a number of high-flow years (e.g., '90, '96, '98 and
14 '00) as well as low-flow years ('91, '92 and '99). The hydrograph impacts the balance of sediment erosion
15 and deposition averaged over different durations. The MVR does not discuss this to any significant extent.
16 However, the change in the PCB fluxes mostly reflects a new treatment of the boundary condition,
17 apparently provoked by some new boundary condition data. Comments regarding the boundary condition
18 used in the Phase 2 calibration are provided in my response to question 3. At this point, EPA should
19 consider whether further refinements and improvements to the model will occur in the future, as more data
20 are collected and the models are run. In other words, are the models only as good as the latest data point?
21 How can the model calibration be considered "final" if, as the Phase 2 recalibration demonstrates, a few
22 new data can so readily change the PCB flux analysis and possibly other model results? (6)

23 ► Another change that has been undertaken by EPA is to extend the spatial domain of the models
24 to cover the upstream reach of the East Branch through the area that has been remediated, as well as
25 downstream from Woods Pond dam to Rising Pond dam. It is encouraging to see this development, because
26 the modeling domain confined to the ROR was clearly too small to fully address the extent of PCB
27 contamination in the Housatonic River. However, I am not convinced that either the upstream or
28 downstream models are adequately calibrated and validated at this time. It is obvious that much less effort
29 has gone into these models, and the presentations made by the EPA modeling team at the Document
30 Review Meeting looked much more like progress reports than finished products. (8, 9)

31
32 **2. Are the comparisons of the model predictions with data sufficient to evaluate the capability of the**
33 **model on the spatial and temporal scales of the final calibration and validation?**
34

35 Graphical and statistical comparisons between model predictions and data are the most objective
36 measures of model performance. In general, sufficient comparisons have been presented in the MVR and
37 supplemental material with which to evaluate the capabilities of each of the models. Specific comments are

1 offered below, regarding the strengths and weaknesses of the various prediction-data comparisons, as well
2 as identifying several comparisons that have not been made, but should be. In addition, errors in model
3 predictions are revealed by some of the comparisons, and these are pointed out so that they can be corrected
4 by the modeling team.

5 ▶ EFDC predictions of flow, TSS and water column total PCB concentrations were compared to
6 data using both longitudinal profile and time series plots. Although the spatial profiles for TSS predictions
7 appear reasonable for several selected days (Figures 4.2-34 thru 4.2-37), the time series plots indicate
8 significant and persistent overprediction of low TSS measurements. This is particularly evident at Holmes
9 Road (Figure 4.2-38), but also at New Lenox Road (4.2-39) and to a lesser degree at Woods Pond
10 headwater (4.2-40). In the MVR (page 4-59), EPA offers that “Simulated TSS concentrations pass through
11 approximately one-third of the data...”, which is surprisingly poor model performance. Similar
12 overprediction of low TSS measurements is apparent for the validation period as well. According to
13 comments by both EPA and GE, the overprediction of low TSS measurements is due to significant bias in
14 the specification of the East Branch boundary condition on days when TSS concentrations were not
15 measured. Time series plots for specific flow events (Figures 4.2-42 thru 4.2-48) indicate a better fit of TSS
16 predictions under high flow conditions. (6)

17 ▶ Sedimentation rates predicted by EFDC for individual grid cells in the river channel over the
18 10-year Phase 2 calibration period are plotted in Figure 4.2-58. This figure shows a highly variable pattern
19 of deposition and erosion, especially in Reach 5A, where deposition fluxes exceeding 5 cm/yr are predicted
20 for cells in close proximity to others in which erosion fluxes of 1-2 cm/yr are predicted. Predicted
21 sedimentation rates are not tested by any data at this scale, however. On a reach basis, relatively small
22 deposition fluxes (0.2-0.5 cm/yr) are predicted throughout the ROR for both the calibration and validation
23 periods. Figure 4.2-60 graphs the sedimentation rate in grid cells within Woods Pond, along with
24 sedimentation rates measured in cores. There are many EFDC grid cells in Woods Pond, and a significant
25 number of dated sediment cores. I specifically examined the 1995 sediment core data suggested to be most
26 representative in terms of cesium-137 profiles, and found that both measured and predicted sedimentation
27 rates are in the range of 1 to 10 mm/y. On a pond-wide average basis, sedimentation rates predicted for the
28 calibration period agree fairly well with the sediment core data (Table 4.2-5). Over the 26-year validation
29 period, the predicted sedimentation rates appear to be somewhat low in comparison to data (Table 6.2-7).

30 Predicted sedimentation rates were also compared to measurements of bathymetric change made
31 between 2000 and 2006 at a series of transects in Reach 5A (Figure 6.2-33). The measurements of bed
32 elevation change (positive and negative) were consistently larger and more variable than the corresponding
33 model prediction although, since the predictions and data were both spatially averaged, I have trouble
34 interpreting the significance of this comparison. As with other EFDC results for the sediment bed, grid cell
35 predictions were aggregated to mile or sub-mile intervals. At finer spatial scales, there appear to be
36 problems with the fidelity of the model. For example, the transect data from location XS153 show several

1 feet of deposition while EFDC predicts significant erosion at this location, both during calibration
2 (erosion=1") and validation (4") periods. The transect data themselves (presented at the Document
3 Overview meeting: 09 - Erosion & Deposition - Garland.pdf) show relative nonuniformity in sedimentation
4 both longitudinally (between transects) and laterally (within transects). To me, the data show that lateral
5 resolution is warranted for hydrodynamics (shear stresses) and sediment transport. Other subgrid features
6 (lateral variations in bathymetry, bends, trees in river) are also significant physical features, which are not
7 represented in the model. (2C)

8 ▶ Model predictions of total PCB concentrations in the Housatonic River water column were
9 compared to data using time series plots and longitudinal profiles. The time series plots (Figures 4.2-65
10 thru 4.2-68 and 6.2-41 thru 6.2-44) indicate that, for PCB concentrations, there are significant gaps in data
11 collection over the Phase 2 calibration and validation periods. As was the case for TSS, the model tends to
12 overpredict low PCB concentrations, and the overprediction of these two state variables appear to coincide.
13 This is most apparent at the Holmes Road station. Again, this is primarily due to significant bias in the
14 specification of the East Branch boundary condition on days when PCB concentrations were not measured.
15 Inspection of the timeseries of East River PCB boundary conditions (Figure 4.2-64) reveals that the only
16 time East River PCB boundary concentrations are lower than 60 ug/L is when data have been measured
17 below this value, yet probably more than half of the data fall below this concentration. There are sufficient
18 PCB data to evaluate the storm event predictions on only one occasion (May 19-21, 1999 at New Lenox
19 Road; Figure 4-2.76); the model prediction timeseries agrees well with this data. The spatial profiles for
20 PCB water column predictions appear to be quite variable. (2A) ▶ The low-flow simulations have been
21 criticized by GE as underpredicting the increase in PCB concentrations observed between the upstream
22 boundary condition and New Lenox Road, as well as the decrease in PCB concentrations across Woods
23 Pond. In addition, the profiles show a consistent "drop" in PCB concentrations immediately below the
24 upper boundary. These features have been interpreted as suggesting that processes related to PCB fluxes
25 between the water and sediment may be misrepresented or miscalibrated. (4) ▶ In the *EPA Response to*
26 *Questions from Model Validation Document Overview Meeting*, a statistical test (overlapping 95%
27 confidence limits) is offered to show that the apparent decrease in PCB concentrations across Woods Pond
28 may reflect sampling variability. It may be useful to use a statistical test to evaluate the gradient in PCB
29 concentration data between two river locations; however, wouldn't it be better (more powerful) to test
30 whether the *difference* in PCB concentrations between locations is significantly different than zero?

31 Timeseries plots comparing the predictions of PCB concentrations in the top 6" of sediment in
32 mile reaches to data are shown in Figure 4.2-77 for the Phase 2 calibration period, and Figures 6.2-49 for
33 the validation period. The predictions appear to exceed the majority of data at the end of both the
34 calibration and validation periods, in some or most mile reaches. Although data prior to 1999 are not
35 abundant, the model also appears to underpredict the rate of PCB sediment decline in many mile reaches,
36 including Woods Pond (Figure 6.2-50) as suggested by the overprediction of the majority of 1999 data. The
37 failure of the model to reproduce the rate of decline in sediment PCB concentrations is a major problem,

1 since in the long-term, PCB concentrations in biota will respond to this rate of change. The MVR fails to
2 address this discrepancy and it's possible explanations, even though this error is evident in both calibration
3 and validation periods. It would also be useful to compare sediment PCB concentration predictions to data
4 for deeper, sub-surficial layers. Slower changes in PCB concentrations would be expected in deeper
5 intervals, reflecting slower transport in deeper sediments. **(2A)** ► Furthermore, I agree that the approach for
6 developing initial conditions for sediment PCBs (circa 1990 for the Phase 2 calibration and 1979 for the
7 validation) precludes a "robust test" of the long-term model predictions. Consequently, these initial
8 conditions should become part of sensitivity and uncertainty analyses. **(7)** ► Finally, the increase in
9 surficial sediment PCB concentrations over time within the upper-most sediment reach (RM 135.13-
10 134.89) seems problematic and should be corrected. Is this behavior related to sudden drop in water column
11 PCB concentrations downstream of the boundary condition, for example in the way bed load is initiated?
12 Without access to the model, it is impossible to sort this out. **(4)**

13 ► Figures 4.2-79 and 6.2-51 are intriguing plots of the change in spatial profiles of the grid cell
14 PCB sediment concentrations over the duration of the calibration and validation, respectively,
15 superimposed with the "shotgun pattern" of data for individual sediment PCB samples. Although no
16 interpretation of the model-to-data comparison is offered, it does suggest that the greater than 90% change
17 in sediment PCB concentrations within many sediment grid cell is both plausible and may help explain the
18 spatial variability observed in sediment PCB data throughout the river sediments. In other words, the model
19 simulation suggests that sediment PCB variability arises from contaminated sediments remaining in
20 locations where erosion is not significant, and (relatively) uncontaminated sediments replacing older
21 contaminated sediments in locations where erosion is significant. **(2B)**

22 ► I remain concerned that we may be falsely confident in the erosion/deposition predictions made
23 by this model, because the model is being applied and validated at relatively coarse spatial scales. Due to
24 practical constraints, the modeling team did not simulate sediment transport at the resolution demonstrated
25 in other successful sediment transport applications (Thompson Island Pool: HydroQual, 1995; Watts Bar
26 Reservoir: Ziegler and Nisbet, 1995; Fox River: Lick et al., 1995; Saginaw River: Lick et al, 1995 and
27 Cardenas and Lick, 1996; Buffalo River: Lick et al., 1995 and Gailani et al., 1996). The unstated
28 assumption is that applying a similar model on a cruder resolution will correctly average the sub-grid scale
29 phenomena, even though some of these phenomena are demonstrably nonlinear. This assumption is not
30 supported by either data comparisons or numerical convergence testing using alternative grid resolutions.
31 Predictions of net sediment accumulation can only be tested for Woods Pond, because that is the only
32 portion of the ROR where a reach-wide average accumulation could be inferred from sediment data.
33 Predictions of net sediment accumulation are untested in other reaches. This is of more than academic
34 interest, because we are asked to believe in the model primarily on the basis of the water column
35 predictions of TSS and PCB concentrations. Yet these only indirectly measure erosion and deposition.
36 Reach 5A, for example, is described as a dynamic environment with rapid exchange of solids and
37 associated PCBs. Within this and other reaches, there are locations where both deposition and erosion are

1 taking place. If aggregated spatially (into either reaches or miles) much of this behavior is “averaged out”.
2 Aren’t there advantages to validating sediment transport predictions without this spatial averaging? In fact,
3 that is the only way it can be done. **(2C)**

4 ►The food chain model (FCM) predictions should be compared to the mean or other central
5 tendency of the fish species, reach, and age-specific data, because the model is designed to simulate
6 “average” fish according to these categories. This is confirmed by analyses and graphics (e.g., Figure 4.3-8)
7 displaying that the residuals tend to be smaller when the data are averages of 6 or more fish. Unfortunately,
8 many calibration and validation graphics persist in using individual data. Nonetheless, there is overall good
9 agreement between predictions and the averaged total PCB concentration data, with most residuals falling
10 within a factor of 2 of the predicted values. EPA has revised Figure 4.3-7 to use the 95% confidence limits
11 (or ± 2 standard errors) to better quantify the measurement precision, and the FCM predictions fall within
12 these limits. FCM model performance is similar in calibration and validation periods.

13 Figure 3-9 (Comparison of mean measured biota tissue tPCB concentrations to FCM results
14 [simulation using linked models]) provides a summary illustration of the FCM calibration. PCB
15 concentrations predicted for invertebrates are in good agreement with the D-Net sample data, except for
16 infauna in Reach 5A (which are substantially overpredicted). The model fits for bullhead and sunfish are
17 very good; PCB concentration in these fish vary little between river reaches. Model-to-data comparisons
18 are not as good for suckers, cyprinids and bass, although the PCB concentration data for these species is
19 also considerably more variable. I assume that at least some of the variability of PCB concentrations in fish
20 reflects the wide range of PCB exposure and/or failure of the food chain to spatially average these
21 exposures on a reach basis. If I look for an overall pattern in the residuals on this figure, it would be a
22 tendency for the predicted PCB concentrations to increase moving downstream, which is not reflected by
23 the data. PCBs predicted in Reach 5D for cyprinids, sunfish and bass significantly exceed the measured (as
24 well as predicted) concentrations for these species in other reaches. Since PCB concentrations were not
25 measured in fish from this reach, these predictions are untested. Reach 5D is the only portion of the FCM
26 where predictions based on PCB exposures derived from data meaningfully diverge from predictions based
27 on EFDC exposures. **(11)**

28 There are insufficient comparisons between data and predictions for both the upstream and
29 downstream models. ►In the upstream model, there are too few TSS data to tell whether the model
30 predictions are reasonable or not. For both TSS and PCBs, my impression is that the model predictions are
31 much more variable than the few available data. PCB concentrations appear to be substantially
32 overpredicted (e.g., a factor of 5 to 10 overprediction in PCB concentrations). **(8)** ►In the downstream
33 model, predicted TSS and water column PCB concentrations are in the same ranges as the data at the
34 Rising Pond outlet, but there is not much fidelity beyond that. Initial downstream model PCB predictions
35 included in the MVR clearly indicated a problem with the balance between erosion and deposition in high-
36 gradient reaches. As presented at the Document Review meeting, this has been addressed by adding an
37 additional noncohesive sediment class in the sediment transport simulation **(9)**.

1 FCM predictions in the downstream model domain are compared to PCB concentrations measured
2 in fish for Reach 7 and Rising Pond. These predictions look favorable overall, although there may be bias
3 in the predictions for specific species. Results appear comparable in data-based and linked exposure
4 predictions. (9, 11)

5
6 **3. Is there evidence of bias in the models, as indicated by the distribution of residuals of model/data**
7 **comparisons?**

8
9 ►A number of significant model biases have been identified and discussed above (Question 2).
10 The most significant are:

- 11
- 12 ○ The predicted changes in sediment PCB concentrations are slower than observed,
- 13 ○ Spatial gradients in water column PCB concentrations do not match data under low flow
- 14 conditions, and
- 15 ○ The treatment of the upstream boundary condition results in serious overprediction of
- 16 low TSS and PCB concentrations. (2A)

17
18 ►The first two issues appear related to parameterization errors, as noted previously, and should
19 be satisfactorily addressed by the suggested corrections. The bias in TSS and PCB concentrations due to the
20 boundary condition deserves further consideration.

21 At sampling locations in the upper reaches of the PSA, the model fails to match half to two-thirds
22 of the TSS data. Predicted values at base flows are ~10 mg/L versus data in the 2-5 mg/L range. There is
23 less discrepancy in the lower reaches. In general, the bias is most apparent at lower flow rates. Censoring
24 TSS data <5 mg/L was offered by EPA as a way of correcting the model performance metrics. A similar
25 problem with low-flow bias for PCB predictions is also apparent in the upper reaches of the PSA, and a
26 similar censoring approach was suggested. However, I do not believe it is appropriate to ignore or discount
27 the bias in model predictions under low-flow conditions. About 70% of an “average year” is low flow
28 conditions, and significant PCB uptake by fish coincides with low flow periods. (6) It is unclear whether
29 the low-flow PCB bias has led to food chain miscalibration, as suggested by GE, because the food chain
30 model was initially calibrated using data-based exposure concentrations. These would not exhibit the same
31 low-flow bias as exposure concentrations predicted by the model. (6, 11) Nevertheless, I am concerned that
32 bias due to the TSS and PCB boundary conditions may result in model errors that have not been addressed.
33 We know very little about how the boundary condition will evolve over time following upstream
34 remediation; hopefully, ongoing monitoring will be used to update and improve upon this situation.

35 The specification of the upstream PCB boundary condition is an important component of
36 developing a reliable transport and fate model for the Housatonic River, for each of the time intervals over
37 which the model is to be applied (calibration, validation and forecasting). EPA has developed different

1 interpretations of the PCB boundary condition in the Phase 1 and Phase 2 Calibrations, and these
2 differences produce dramatically different outcomes in terms of the PCB flux analysis generated by the
3 model predictions. The PCB boundary condition developed for the Phase 2 calibration applies the
4 partitioning model to estimate particulate and dissolved PCB concentrations from total PCB measurements,
5 which are then independently regressed to flow rate. The PCB phase concentrations are “capped” to
6 prevent the boundary conditions from grossly exceeding the data at high flows. This is a creative approach;
7 I tried something similar in the Fox River. Unfortunately, it’s not clear whether this approach does a
8 reasonable job of describing the boundary condition data. Although this approach may improve the PCB
9 boundary condition at high flows, in comparison to the Phase 1 calibration, at base flow rates the Phase 2
10 PCB boundary conditions are substantially worse (e.g., Phase 1: ~40 ng/L at base flow vs. Phase 2 : ~100
11 ng/L). I am not convinced EPA has made the best use of the boundary condition data, and offer some
12 comments below regarding the approach they used to describe this data. Regardless of these issues, it
13 appears that much of the variability seen in PCB concentrations at the upstream boundary cannot be
14 explained, in the approaches taken in either the Phase 1 or Phase 2 calibration, or other alternatives that
15 have probably already been explored. If the TSS and PCB boundary conditions cannot be improved, the
16 best recommendation may be to add a random error component to the boundary conditions in the sensitivity
17 and uncertainty analyses.

18 The boundary condition data eres provided by EPA in the spreadsheet
19 “East_Branch_Boundary_Data.xls”. Their interpretation of this data, and the descriptive approach used to
20 model the boundary condition, is described in Section 4.1.5 of the Model Validation Report, with further
21 discussion offered in supplemental responses. Figure 4.1-2 (reproduced below) shows the regressions of
22 dissolved and particulate PCB concentrations versus flow that were used to specify the total PCB boundary
23 condition for the EFDC transport and fate model (except for days when measurements were available). I
24 have a few comments to make based on this figure and review of the boundary condition spreadsheet:
25

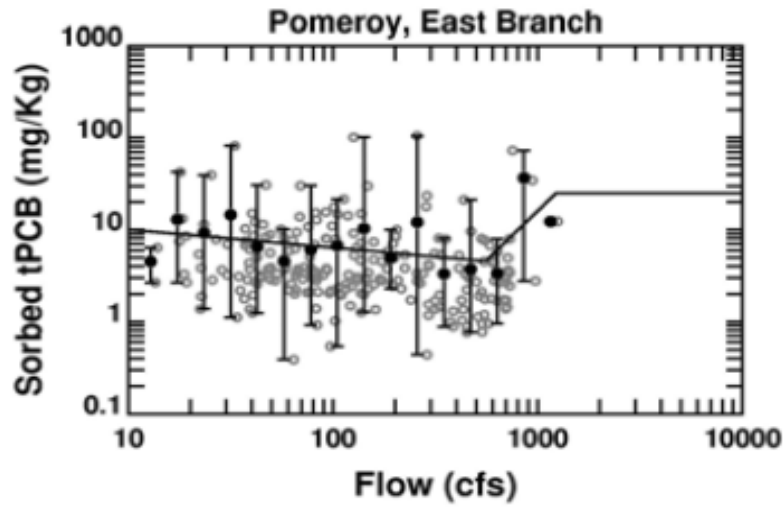
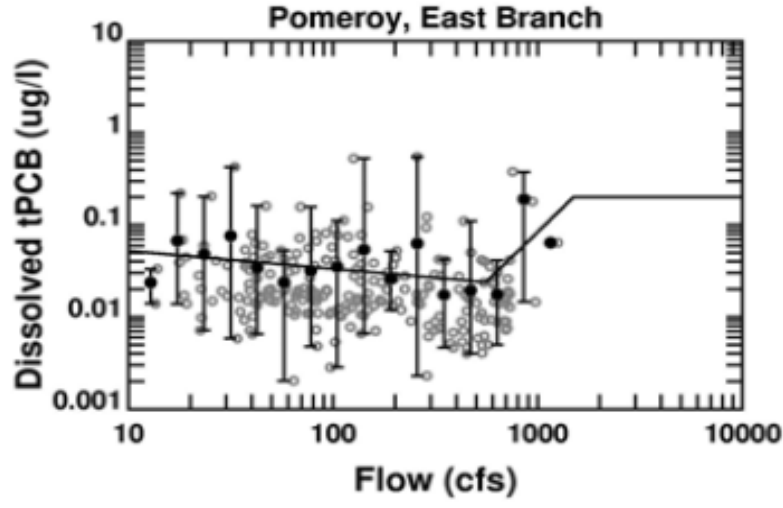
- 26 1. As a general observation, I would say that if one focuses on the actual data plotted in these graphs
27 (the open circles), it appears that EPA’s regressions describe relatively little of the variability
28 observed in PCB concentrations at the boundary condition. The regressions are especially tenuous
29 at low and high flows. In fact, the regressions exceed all of the data in the lowest flow “bin”.
- 30 2. I cannot find the PCB concentration data collected at flow rates smaller than 24 cfs³. Therefore, I
31 have no way to confirm the results shown in Figure 4.1-2 for the two lowest-flow “bins”. At least
32 for the lowest “bin”, the regression line appears to be a poor fit. A noted above, it exceeds all of
33 the measured data.
- 34 3. At high flows, the PCB concentrations are “capped” to prevent unrealistically high PCB
35 concentrations during floods. The “cap” was specified as 25 mg/Kg for particulate PCBs, based

³ I think this may be because East Branch daily flows were provided in the spreadsheet, while Coltsville (hourly?) gauge data were used in the regressions and possibly the graph. I couldn’t find the source of the flow data in the MVR.

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upon concentrations measured in sediments deposited on vegetation and banks. I think this value may be somewhat too high. My own calculation of the unbiased mean PCB concentration from the 13 sediment deposit samples is 20.5 mg/Kg, although I was measuring the data off of a graph. Please check this calculation. If 25 mg/Kg is indeed too high, it will bias the high-flow PCB boundary condition.

- 4. According to EPA, the detection limit was used as replacement values for censored PCB concentrations. While this has little impact on the distribution of total PCB concentrations, it does bias the particulate PCB concentrations that are calculated from total PCB measurements using the partitioning model. I didn't check, but I suspect that dissolved PCB concentrations may be biased as well. I think it is generally preferable to use one-half of the detection limit as replacement values for censored PCB concentrations.



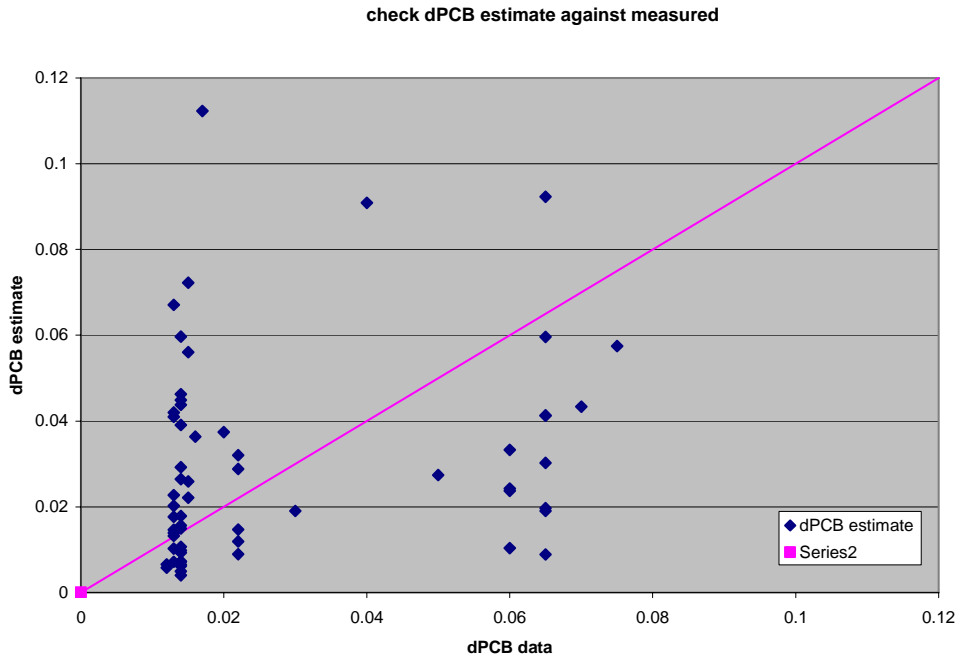
14

- 1 5. Another thing I noticed when I reproduced EPA's partitioning calculation (which is used to
2 estimate the dissolved and particulate PCB concentrations from the total PCB measurements), is
3 that the dissolved PCB concentration estimates don't agree very well with the relatively few
4 dissolved PCB concentrations measured at the boundary condition. This is shown below in Figure
5 2. If the partitioning model is being used to describe the boundary condition, shouldn't it fit the
6 data?
- 7 6. Frankly, some of this data is mystifying. For example, 2 samples were collected on November 12,
8 1995. For both samples, the flow is reported to be over 1,100 cfs. In the first sample, [TSS] was
9 450 mg/L and total [PCB] was 0.2 ug/L. In the second sample, [TSS] was 17 mg/L and total
10 [PCB] was 0.52 ug/L. Running these values through the partitioning model, one obtains
11 particulate PCB concentrations of 0.44 and 23 mg/Kg. It is somewhat hard to believe that PCB
12 concentrations on suspended solids could vary by a factor of 50 within one day.
- 13 7. It is also curious to me that there has been no shift or evolution in PCB boundary concentrations
14 over the past 16 years, and that seasonality is not evident in the data. If PCB boundary condition
15 data for all years are plotted together, we see the familiar shotgun target (Figure 3). There appears
16 to be some underlying behavior, however, within individual years of data. Figure 4 shows total
17 PCB data for years (especially 2002) in which a positive relationship with flow is evident. Figure
18 5 shows total PCB data for years (2003 in particular) in which the flow relationship is generally
19 negative. The highest total PCB concentrations in Figure 5 come from the warm (and presumably
20 higher organic carbon⁴) months of July-September, while the lowest PCB concentrations at very
21 high flow were sampled in October and November. While I am confident EPA has looked at this
22 data in great detail, I think the patterns in the data hinted at here suggest some underlying behavior
23 which could be exploited in the regression models used to describe the boundary condition. I
24 believe this might, in turn, provide better PCB boundary condition estimates than the current
25 approach in which all measurements are lumped into one sample.
- 26 8. The MVR doesn't discuss what other alternatives may have been tested, but here are some
27 suggestions:
- 28 • AutoBeale (Beal's Stratified Ratio Estimator) is an alternative statistical approach
29 that works well for boundary conditions when the data are stratified by season as
30 well as flow;
 - 31 • When regressing the PCB data, were autocorrelation and Lag-1 or 2 considered as
32 factors?
 - 33 • Check bias correction formula;
 - 34 • Have untransformed PCB data been regressed? How do results compare to log-
35 transformed regressions?

⁴ EPA is assuming a constant 7.3% organic carbon content on suspended solids, which cannot be confirmed from the data collected at the upstream boundary.

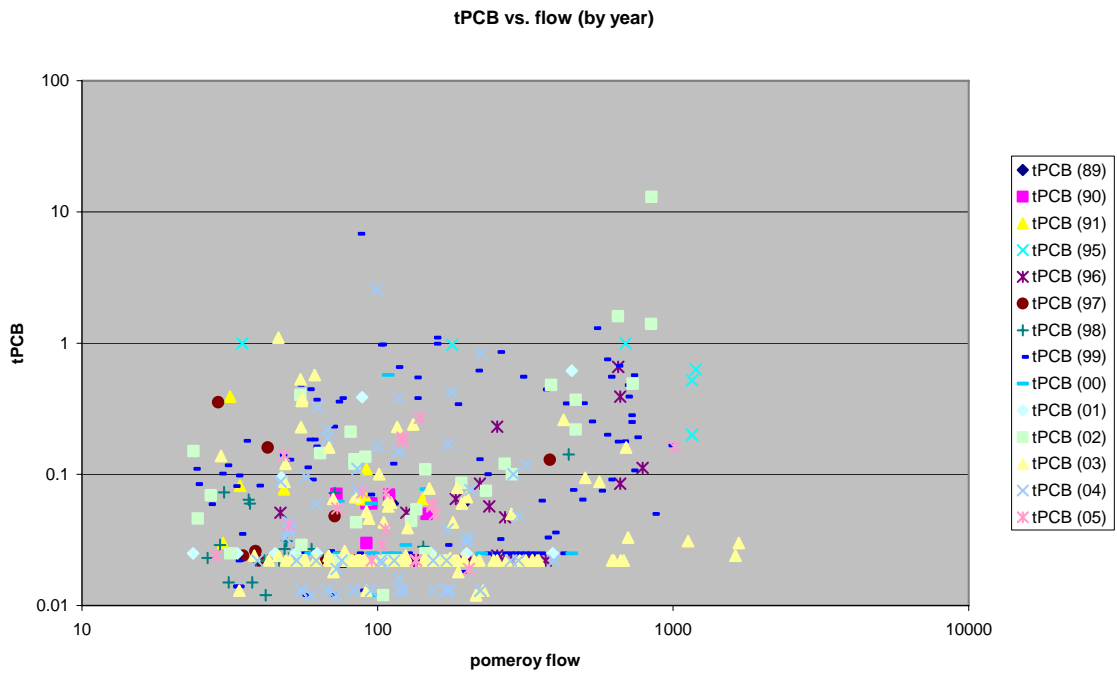
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Figure 2



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Figure 3

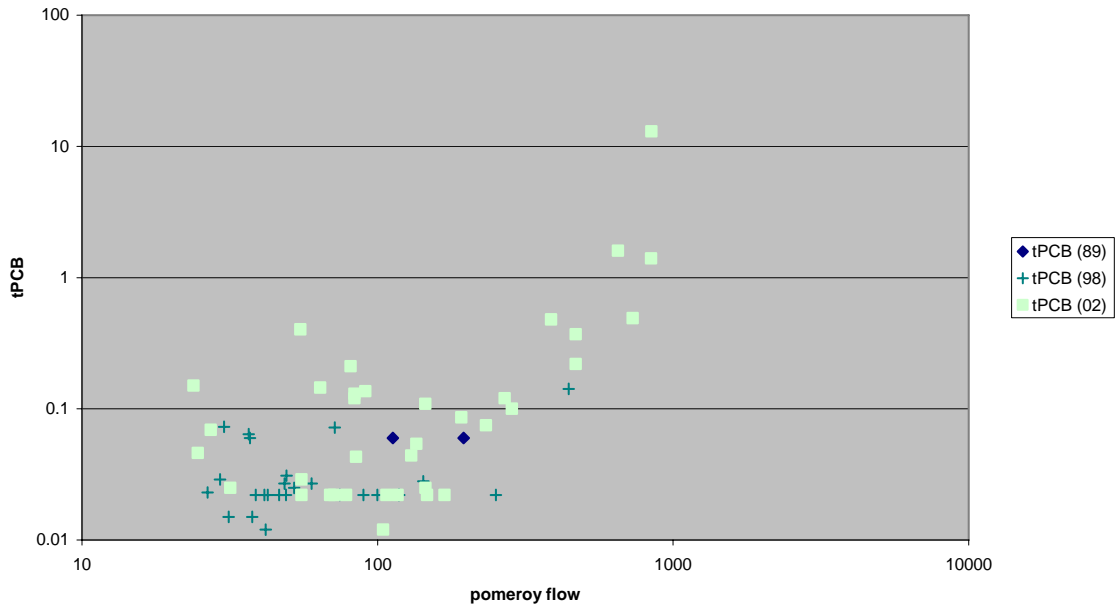


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Figure 4

tPCB vs. flow (some years)



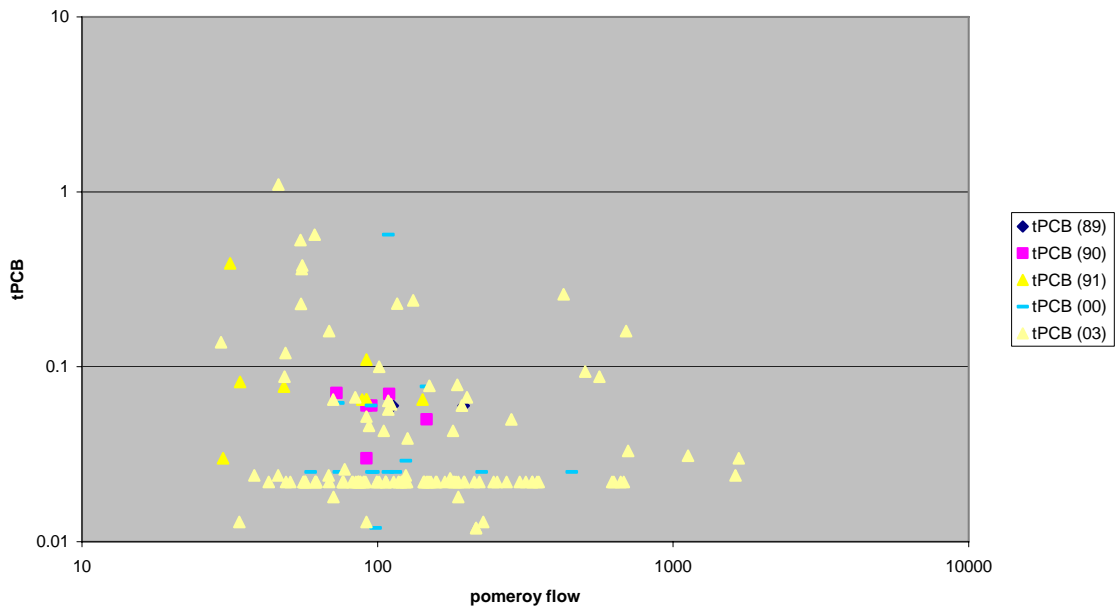
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Figure 5

tPCB vs. flow (some other years!)



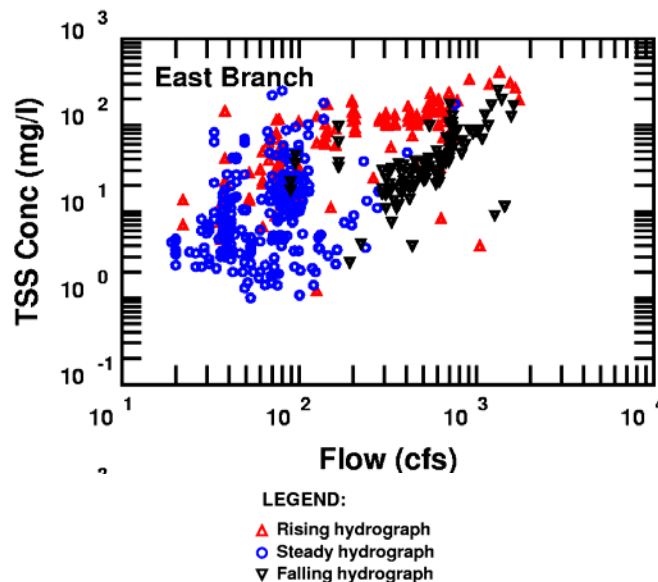
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1 9. I also went back to look at the TSS boundary condition, which has not been changed from the
2 Phase 1 calibration. Figure 6 is a reproduction of the plot displaying the East Branch TSS data as a
3 function of flow (from: Volume 3—Appendix B Hydrodynamic and Sediment/PCB Fate and
4 Transport Model Calibration, Attachment B.3 TSS and PCB Flux Analysis). The TSS data were
5 partitioned according to 3 phases of the hydrograph – rising, steady and falling. TSS data are well-
6 behaved during rising and falling hydrographs, but not at steady (and predominantly low) flow.
7 This makes me wonder again about seasonal factors, intermittent upstream disturbances, or
8 possibly sampling artifacts. It is hard to imagine TSS concentrations varying between 1 and 100
9 mg/L at base flow. (6)

11 **Figure 6**



19 **4. Have the sensitivities of the models to the parameterization of the significant state and process**
20 **variables been adequately characterized?**

21 **►**The MVR does a good job of illustrating the sensitivity of the EFDC model predictions to input
22 parameters. Several additional model inputs should be added to the sensitivity analysis, and these are
23 identified below. As pointed out by GE, there are also some sensitivity analysis results that are counter-
24 intuitive; these should be explored and explained.

25 Sediment transport sensitivity analysis is displayed in terms of peak and mean TSS fluxes, for the
entire calibration period as well as 2 different flow events (Figures 5.1-3 thru 5.1-5). It would be useful to
also see the sensitivity of the model displayed as changes in bed elevation.

1 Part of the sensitivity analysis for the sediment transport model should include the sensitivity to
2 the grid resolution because, as discussed previously, the prediction of sediment bed scour may depend on
3 the number of lateral cells in the channel cross-section. This is only needed for a “test reach” of the river
4 channel, preferably the reach where bathymetry transects were measured. Note that Earl Hayter’s previous
5 analysis was not informative on this issue.

6 PCB fate and transport sensitivity analysis is displayed in terms of peak and mean PCB fluxes,
7 again for the entire calibration period as well as the two flow events (Figures 5.1-6 thru 5.1-11). The
8 sensitivity of the Woods Pond PCB flux predictions at low flow (Figure 5.1-9) is puzzling, since it suggests
9 practically no sensitivity to parameters associated with sediment-water exchange of PCBs. While there may
10 be little exchange within Woods Pond itself, considerable PCB exchange in upstream reaches should be
11 reflected in the sensitivities of these parameters in Woods Pond. Instead, Figure 5.1-9 show that low-flow
12 PCB fluxes in Woods Pond are only mildly sensitive to the upstream boundary inflow, and really nothing
13 else. It remains for EPA to explain how this result is evidence that “the model is properly representing the
14 physics of the river as it relates to the movement of solids and contaminants”.

15 As stated previously, the initial PCB concentrations specified for the sediment bed should be
16 added as parameters in the sensitivity analysis, for all reaches where they are not independently determined
17 from data. Likewise, the surficial sediment layer thickness should be included as a parameter in the
18 sensitivity analysis. (5A)

19 20 **5. Are the uncertainties in model output(s) acknowledged and described?**

21
22 ► Considerable effort went into the analysis of model uncertainty in this project, which is perhaps
23 unprecedented for a suite of water quality models of this complexity. The MVR evaluates the uncertainty of
24 the models using approaches based on Monte Carlo analysis. This approach basically assumes that the
25 models are correct, and errors in model predictions arise from uncertainty or variability in parameter
26 values. These are estimated based on subjective expert judgment using probability distributions, and
27 parameters are generally assumed to be uncorrelated. While these assumptions are obviously suspect, they
28 are nonetheless common practice in uncertainty analysis. Analyzing the uncertainty of the linked model
29 predictions is a strength of this work.

30 The response surface modeling of EFDC uncertainty appeared to be very thorough and
31 comprehensive. EPA has provided a descriptive field for the parameters listed in Table 5.2-8, which
32 hopefully will be incorporated into the report. I would like to see EPA add initial and boundary conditions
33 for PCBs to this analysis, since these are both uncertain factors. I disagree that the RSM approach is
34 impractical or unworkable. The Responsiveness Document (p.2-110 and 111) discusses how uncertainty
35 analysis can be used in context of evaluating differences between remediation scenario predictions.
36 Hopefully, no more than one RSM will be necessary for evaluating uncertainty of these predictions.

1 The Monte Carlo analysis of the FCM is also quite thorough and informative. I agree with the
2 suggestion to evaluate model uncertainty in terms of 10th and 90th percentiles, as being reasonably
3 conservative, consistent with the distribution properties of the food chain model outputs. This is probably
4 the simplest way to deal with inflation of predictive uncertainty. The critique of “unreasonable” parameter
5 sets producing model predictions outside the bounds of the data, is really a criticism of the subjective
6 estimation of parameter variability. This can be addressed using a Bayesian Monte Carlo approach, which
7 builds posterior (informed) parameter distributions based on computing the likelihood function for each
8 model realization⁵. The method is simple and works very well - although the computational burden of BMC
9 (i.e., effort to achieve convergence in the likelihood function) can be heavy, unless there is some way to
10 substitute the RSM for the numerical model. I don’t know whether this is a practical option for
11 computationally-intensive models such as EFDC.

12 There has also been much discussion about how residuals from comparisons between model
13 predictions and data can be used to improve the uncertainty analysis. It has been suggested to use residuals
14 to directly characterize uncertainty. This strikes me as a naïve approach, as I would normally consider
15 residual error to be a “best case” estimate of uncertainty. Forecasts will seemingly always be more
16 uncertain than calibration; the question is, how much more? It has also been suggested that reporting
17 average bias (e.g., Tables 4.2-4, 4.2-10 and 4.3-2) masks the uncertainty due to variability in the PCB data
18 itself. The remedy to this is straightforward: calculate and report the variance of model bias. Moreover,
19 statistical model could be developed from the residuals to estimate the distribution of PCB concentrations
20 from mean predictions. This would compliment, instead of replace, the Monte Carlo results. The difficulty
21 I can foresee, is how do you determine the proper assumptions regarding homoscedacity (e.g., is the
22 variance in a constant factor of the mean or simply a constant?). **(5B)**

23
24 ▶ No sensitivity or uncertainty analyses have been presented for the upstream and downstream
25 models. **(8, 9)**

⁵ Dilks, D.W., Canale, R.P. and P.G. Meier. 1992. Development of Bayesian Monte Carlo techniques for model quality model uncertainty. *Ecological Modeling*, 62:149-162.

1 **6. Upon review of the model projections of changes in PCB concentrations in environmental media in**
2 **the example scenarios, are such projections reasonable, using your technical judgment, and are they**
3 **plausible given the patterns observed in the data?**
4

5 ▶The MVR presented 25-year forecasts made with the linked models, in the Rest-of-River and
6 Downstream domains, for 2 (or 3)⁶ hypothetical remediation examples. These were intended to illustrate
7 the performance of the models in forecasting the outcome of remediation alternatives in terms of PCB
8 concentrations in sediment, water and especially fish. These forecast predictions (“projections”) are really
9 the unique product of water quality models, and are the only defensible means of anticipating the long-term
10 outcome of remedial action and the relative effectiveness of remedial alternatives. We are asked in this
11 question to address the “reasonableness” and “plausibility” of the projections, which are both subjective
12 criteria. Dom DiToro called this sort of evaluation the “laugh test”, where we compare the numerical
13 model’s projections to those of the models we carry around in our heads. The modeling team is correct in
14 pointing out that it is not possible to determine whether the example projections are “correct” in terms of
15 accuracy (MVR, p 7-3), because there is really nothing to compare them to except one another.

16 Model projections for the example scenarios were presented a number of ways in the MVR and its
17 supplements. These included the predicted time series of PCB concentrations in water, at the conventional
18 monitoring locations (Holmes Road, New Lenox Road, ...); PCB concentrations in surficial sediment in the
19 mile reaches; and, PCB concentration in largemouth bass in the river reaches 5A thru 6. For EFDC, the
20 projections were also presented as plan maps of the grid displaying PCB concentrations in surficial
21 sediment and soil, and changes in concentration, at the end of the 25 year projections. For the top 6” of the
22 sediment bed, the end-of-projection results are also shown as profiles. Each of these is discussed below.

23 The projected timeseries of water column TSS and PCB concentrations are plotted together in the
24 figure “Time series of water column concentrations for PCBs and TSS” in *the EPA Response to Questions*
25 document. The base case projection is qualitatively similar to the validation predictions, with TSS and PCB
26 concentrations increasing to high levels during flow events, although over time the base case PCB

⁶ I am somewhat confused by what is referred to as a “base case” projection in a number of the time series figures (e.g., “Time series of water column concentrations for PCBs and TSS”, “Time series of sediment PCB concentrations in each spatial bin” and “Time series of plots of FCM exposure concentrations” in *the EPA Response to Questions* document, and “Food chain model results” in the Document Overview presentation of Example Scenarios, which included a graph subtitled “Base case for the example runs - existing boundary loads”). The “base case” scenario is not mentioned or described in Section 7 of the MVR, or anywhere else I could find in the materials provided for our review. This makes it difficult to evaluate the example scenario projections, because I want to compare them to a “base case” (as is intended by the graphs mentioned above) but am not sure what this is. Initially I thought the “base case” was simply the validation prediction, since the hydrograph and boundary conditions are the same. Upon inspection, however, it appears that the initial conditions for PCBs are somewhat different, most noticeably in Woods Pond. A description of the “base case” scenario should be added to Section 7 of the MVR to resolve this ambiguity. Furthermore, EPA should consider whether a scenario should be added or modified which specifies the East Branch PCB boundary condition to be 20 ng/L, the assumed nominal concentration following cleanup.

1 concentration projections decline during low-flow periods. PCB concentrations projected for the example 1
2 scenario are lower than the base case, and projections for the example 2 scenario are lower than for
3 example 1. In each scenario, there is a similar “event responsiveness” of PCB concentrations to fluctuations
4 in the hydrograph. TSS concentration projections are comparable in each scenario, as would be expected
5 since the TSS boundary condition and grain size distribution in the sediment bed are unchanged from the
6 base case. I would consider the water column projections for each of these scenarios to be reasonable and
7 plausible.

8 The projected timeseries of surficial (top 6”) sediment PCB concentrations in river mile reaches
9 are plotted together in the figure “Time series of sediment PCB concentrations in each spatial bin” in the
10 *EPA Response to Questions* document. The base case projections for surficial sediment PCB concentrations
11 are qualitatively similar to the validation predictions, and suffer similar errors. PCB concentrations are
12 projected to increase in the first half-mile reach (an apparent artifact), and show almost no change after
13 start-up in the other reaches. The rate of change in PCB concentrations in sediment is (again) unreasonably
14 slow. Even 25 years is not long enough to see a discernable change in surficial sediment PCB
15 concentrations, which I would certainly expect to see. Nothing shown in the MVR or at the peer review
16 meetings convinces me that the model is correct in its predictions of the rate of change in sediment PCB
17 concentrations. For example scenario 1, a decline in sediment PCB concentrations is projected in
18 comparison to the base case, which is more encouraging. The difference is most dramatic in the first half-
19 mile reach (RM 135.13-134.89), and is also apparent in reaches RM129.19-128.88, 128.88-128.69, and
20 126.99-126.47. In other reaches, especially in Woods Pond and its headwater, there is no difference in PCB
21 concentrations between example 1 and the base case. For example scenario 2, negligible (1 mg/Kg or less; I
22 can’t tell the actual value due to the axis scaling) sediment PCBs are projected for reach 5A due to
23 remediation. In the other reaches, sediment PCB concentrations are projected to be nearly the same or
24 identical to example 1 projections. Although I don’t believe that the model’s projections of rates of change
25 in sediment PCB concentrations are reasonable, at least the relative differences in projected sediment PCB
26 concentrations between the scenarios are plausible.

27 The grid map diagrams (Figures 7-1 and 7-3) show the cumulative change of PCB concentrations
28 in the top 6” of sediment and floodplain soil over the 25 year projection, for scenarios 1 and 2⁷. It appears
29 that the sediments in reach 5A, which are cleaned up in example scenario 2, recontaminate to 1 or 2 mg/Kg
30 over 25 years, due to continuing transport of PCBs from the West Branch boundary condition. It would be
31 useful to see a similar grid map diagram in which the difference in end-of-projection PCB concentrations
32 was plotted. **(10)**

33 ▶As pointed out by GE, predictions of PCB concentrations in flood plain soils are untested. There
34 appear to be substantial increases in PCB concentrations in the top 6” of much of the floodplain soil in both
35 example projections, which is somewhat surprising. However, since no data have been shown to establish

⁷ I suppose the comparable graphic for the base case would be the validation figure (Figure 6.2-55) although I am forced to speculate here.

1 rates of PCB concentration change in floodplain soils, the “reasonableness” of the flood plain projections
2 cannot be determined. Really, this illustrates the absurdity of devoting so many EFDC model grid cells to
3 the flood plain, which it seems dictated using a single footpath of tiles for the grid of the river. (3C)

4 ►The surficial sediment PCB concentration profiles offer a useful alternative view of the
5 cumulative change of PCB concentrations over the 25 year projection. Projections for example 1 show the
6 now-familiar redistribution of sediment PCBs in the high-energy reach 5A, but also significant changes
7 (approaching $\pm 100\%$ of the IC) in reaches 5B and the upper end of 5C. At the lower end of reach 5C and
8 reach 6, sediment PCB concentrations decline by 20 to 80%. This seemingly contradicts what I interpreted
9 from the “Time series of sediment PCB concentrations in each spatial bin” figures. Could it be that the
10 combination of reach averaging, displayed on a log-axis plotting, makes it difficult or impossible to
11 properly interpret the projection results?

12 At the Peer Review meeting last month, there were questions and discussion about whether it was
13 reasonable that the EFDC model projected a significant reduction in PCB concentrations in the water
14 column, but little or no change in sediment concentrations. In fact, such behavior is expected in water
15 quality models incorporating both water column and sediment sedimentation. In such models, the
16 concentrations of particle-associated constituents change much more rapidly in water than they do in
17 sediment, whenever there is a change in the constituent loadings or boundary conditions. Since PCB
18 boundary conditions and loadings (actually fluxes from reach 5A sediments) are being manipulated in the
19 example scenarios, the differences in the projections of PCB concentrations in the water column versus
20 sediments are entirely expected and reasonable.

21 Example scenario projections made by the FCM were presented at the Document Overview
22 meeting (13 - Example Scenarios.pdf) as timeseries of PCB concentrations in largemouth bass. In reach
23 5A, bass in the base scenario are forecast to have a body burden of 50 mg/kg at the end of the 25 year
24 projection; for example 1, the comparable forecast is 30 mg/kg, and 0 concentration for example 2. In
25 reach 5B, bass in the base scenario are forecast to have the highest PCB body burden at the end of the 25
26 year projection: 70 mg/kg; for example 1, the comparable forecast is 40 mg/kg, and less than 20 mg/kg for
27 example 2. Further downstream in the Rest-of-River, the remediation examples are projected to
28 considerably less effective in reducing PCB concentrations in comparison to the base case. In reach 5C,
29 bass in the base scenario are forecast to have a body burden of 30 mg/kg after 25 years; for example 1, the
30 comparable forecast is 20 mg/kg, while for example 2 the forecast is 10 mg/kg. At the end of the 25 year
31 projections in reach 6 (Woods Pond), bass in the base scenario are forecast to have a body burden of 50
32 mg/kg; for example 1, the comparable forecast is 40 mg/kg, while for example 2 the forecast is 30 mg/kg.
33 To me, this progression in the declining effectiveness of remediation as one moves downstream appears
34 reasonable in the context of PCB water and sediment exposure projections for these example scenarios. In
35 “no data” reach 5D, the least reduction in bass PCB concentrations due to remediation is projected. I
36 suppose this may be because this reach is relatively isolated from the rest of the river. (10)

37 ►No scenario projections were presented for either the upstream or downstream model. (8, 9)

1 **7. Is the final model framework, as calibrated and validated, adequate to achieve the goal of the**
2 **modeling study to simulate future conditions 1) in the absence of remediation and 2) for use**
3 **in evaluating the effectiveness of remedial alternatives?**
4

5 ▶ I interpret this to be more than one question, so I will give two answers. If the goal is to forecast
6 PCB concentrations in the Housatonic River in the absence of further remediation, then the current models
7 may be adequate (i.e., “good enough”). In their current form, the EPA models (and probably many much
8 simpler models) can provide meaningful answers to many questions about the future of PCBs the
9 Housatonic River. The model calibration and validation show the relative magnitude of PCB inputs to
10 system, and the resulting predictions and diagnostics are instructive in terms of evaluating remediation
11 targets. For example, eroding banks and sediment deposits in reach 5A are clearly targets for remediation.
12 The 25-year validation and example scenario projections also address the need and possible effectiveness
13 of remediation in the Housatonic River. Following the remediation of the East Branch reaches, upstream
14 PCB concentrations of 20 ng/L and 0.4 mg/kg expected; these concentrations alone may support gamefish
15 concentrations of 1 ppm or more in the PSA. In the absence of further remediation, PCB concentrations
16 will decline very slowly from the current levels. Although water-column PCB concentrations will decline
17 downstream of remediation conducted at the reach scale, surficial sediment PCB concentrations will be
18 relatively unaffected in downstream reaches. The predicted response of PCB concentrations in fish to
19 remediation is expected to be somewhat similar to the sediment. To substantially reduce (e.g., >50%) PCB
20 concentrations in Reach 5D and 6 gamefish over 25 years appears to require remediation well beyond the
21 spatial extent of hypothetical example 2. None of these conclusions require a highly accurate model.

22 However, if the goal is to forecast PCB concentrations to evaluate the effectiveness of further
23 remediation, and to distinguish between the effectiveness of various remedial alternatives, then I believe
24 that the current models are not adequate. Although they are good, they are not as good as they could be. I
25 assume that GE will not willingly undertake additional remediation activity in the Housatonic River, unless
26 EPA can convincingly demonstrate that such remediation is necessary and that the remedy will be
27 effective. At their current stage of development, the EPA models are not ready to make such a
28 demonstration. I am arguing that further model development and testing is warranted, and that EPA should
29 be motivated to do so because the financial stakes are high. Otherwise, GE will likely exploit weaknesses in
30 the models to argue against the need for further remediation. **(12)**

31 ▶ Outlined below are the steps I believe are necessary to make the EPA models the best possible
32 tools to accomplish the goals of the modeling study for the Housatonic River:

- 33
- 34 • Revise the MVR to incorporate supplemental material (*EPA Response to Questions* document ,
35 Document Overview presentations, etc.) and remove provisional results (mass balance diagrams,
36 downstream model w/o boulders, ...) that have been superseded since the MVR was released.
- 37

1 • Make a number of near-term corrections to EFDC, which can be addressed/resolved within a ~1 yr
2 time frame)

- 3 ○ Correct parameterization errors identified in EFDC model:
 - 4 Reduce thickness of surficial sediment bed layers;
 - 5 Parameterize vertical mixing rates as functions of benthos density & vertical
 - 6 position in sediment bed;
 - 7 Increase diffusive PCB fluxes by calibration and parameterize spatially as
 - 8 functions of benthos density;
 - 9 Reanalyze SEDFLUME data using resuspension parameters constrained by
 - 10 literature (e.g., shear stress exponent $n=2.6\pm 0.3$) and recalibrate deposition rates.
 - 11 Lick, Ziegler and coworkers have published much guidance on the specifics of
 - 12 parameterizing sediment resuspension⁸, some of which the modeling team has
 - 13 chosen to ignore;
- 14 ○ Revise TSS and PCB boundary conditions to correct bias evident in low flow range.
- 15 ○ Test sensitivity of EFDC hydrodynamics, sediment transport and PCB transport
- 16 simulations to alternative grid resolutions in a “test reach” of the PSA. In all prior
- 17 SEDZL applications I am aware of, at least a 2-dimensional model was used for
- 18 hydrodynamics and sediment transport. In river systems, this was usually a vertically-
- 19 integrated model. Furthermore, on rivers that bend as much as the Housatonic, a
- 20 curvilinear grid has commonly been applied. Since the EPA modeling team has elected
- 21 not to follow these conventions, they should at least demonstrate via numerical testing
- 22 that their primarily 1-dimensional model of the Housatonic River channel produces
- 23 comparable results for sediment and PCB transport.
- 24 ○ Investigate methods to economize on hydrodynamic and sediment transport simulations
- 25 (e.g., using steady state design storms and flow-duration statistics, such as the Saginaw
- 26 River SEDZL application⁹)
- 27 ○ Consider using the calibrated and validated EFDC model to build a simpler box model of
- 28 the river, if the two models can be shown to produce comparable results. The simpler
- 29 model could be particularly useful for forecasting uncertainty. Don Mackay suggested
- 30 this “second simplified model” approach for modeling hydrophobic contaminants in the
- 31 Niagara River¹⁰.

⁸ See, for example: A Quantitative Framework for Evaluating Contaminated Sediment Sites. SETAC 20th Annual Meeting, Philadelphia, PA, November 14-18, 1999.

⁹ Cardenas, M. and W. Lick. 1996. Modeling the Transport of Sediments and Hydrophobic Contaminants in the Lower Saginaw River. *J. Great Lakes Res.*, 22(3):669-682.

¹⁰ McLachlan, M. and Mackay, D., "A Model of Contaminant Fate in the Niagara River", report prepared for Environment Canada (1987).

- 1 • Develop and implement a process of ongoing model validation, using data collected as
2 remediation progresses. It goes with out saying that modelers want to continue modeling...
3 However, the reality is that no model is truly ever “finished”. So long as new data are collected,
4 model refinement must be expected and accommodated by managers and decision makers. **(13)**
5
6

7 ►I do not believe that either the upstream or downstream models are sufficiently developed to be
8 adequate to address the goals of the modeling study. Their development appears to have been rushed,
9 an impression reinforced by the fact that they apparently did not exist a year ago. Sensitivity and
10 uncertainty of the upstream and downstream models have not been reported, and documentation of the
11 development of these models has been inadequate. In its present status, the upstream model is
12 incomplete and not fully validated. PCB fate and transport have not been simulated, and insufficient
13 model-data comparisons have been made and/or reported. Incorporation of the upstream model in the
14 MVR appears premature, given that substantial additional development efforts will be required before
15 it can be used reliably. Likewise, the downstream model has not been sufficiently validated. Limited
16 model-data comparisons suggest there may be significant bias in PCB concentration predictions. There
17 also appears to be a lack of adequate and appropriate data for this significant extension of the model
18 domain. In their current states of development, neither the upstream nor downstream models are
19 suitable for use in modeling future conditions in the Corrective Measures Study. I am hopeful that the
20 inadequacies of the upstream and downstream models can be addressed through continuing monitoring
21 and modeling activities. **(8, 9)**
22

APPENDIX A.4

COMMENTS OF MARCELO H. GARCIA

1 **FINAL COMMENTS ON HOUSATONIC RIVER MODEL VALIDATION**
2 **REPORT**

3 **By Marcelo H. Garcia, PhD**
4

5 According to the charge for the Model Validation Report Peer Review, the
6 goal of the modeling study is to develop a tool that will:

- 7
- 8 • Predict future concentrations in various media (e.g., sediment, fish, and
9 water);
 - 10 • Assess relative performance among remedial alternatives against baseline
11 conditions; and,
 - 12 • Be the best estimate available of the potential magnitude of the expected
13 reductions in exposure and, thereby, provide useful information in
14 evaluating the performance of remedial alternatives.

15
16 Question 1:

17
18 Considering the changes implemented in the Phase 2 Calibration, does the
19 model as calibrated and validated, based on your technical judgment,
20 reasonably account for the relevant processes affecting PCB fate, transport,
21 and bioaccumulation in the Housatonic River to a degree consistent with
22 achieving the goal of the modeling study?
23

24 Response:

25 ►While a substantial effort has gone into improving the capabilities of the
26 Housatonic River Model since its calibration, it is clear that there is still a
27 long way to go before the model can truly be used as a “predictive tool” to
28 quantify future spatial and temporal distributions of PCBs (both dissolved
29 and particulate forms) within the water column and the bed sediment.
30

31 This reviewer is of the opinion that the Housatonic River Model will need to
32 be continuously improved until all the processes (biological and physical
33 bed sediment mixing, streambank erosion, floodplain deposition, etc.)
34 relevant to the transport and fate of PCBs are not only accounted for in the
35 model but are also well represented and based on sound knowledge of
36 sediment transport mechanics, stream biology, ecology and
37 morphodynamics. **(1, 3C)**
38

39 ►It is not enough to state that a given process is accounted for when the
40 representation of the process is deficient and its implementation in the model

1 is done with algorithms and assumptions that are not based on the physics of
2 the process and cannot be supported by field observations. For instance,
3 streambank erosion has been recognized as a very important process since
4 large amounts of PCB-laden sediments can enter the river during medium to
5 high flows. However, fluvial erosion and mass failure of the stream banks
6 are currently modeled simply as functions of flow discharge, a rather crude
7 approximation, which severely limits the capabilities of the model to assess
8 the effect of this process.

9
10 How can one determine what regions of the banks are more prone to erosion
11 and, therefore, need protection if the model does not compute the
12 distribution of flow velocity and bed shear stress along the banks? Could
13 native vegetation or other bioengineering techniques be used to protect the
14 banks of the Housatonic River against erosion or more hard-core solutions
15 such as rip-rap are needed? Is it possible to use a combination of both? As it
16 stands now, the model can not be used to compare the merits of such
17 remedial alternatives, which is one of the goals of the modeling study as
18 stated above. **(1D, 12)**

19
20 ►Arguably the main shortcoming of the model is not the Housatonic River
21 model itself but rather its numerical implementation which, in my opinion,
22 has rendered the model calibration and validation unreasonably difficult.
23 Assuming that all the processes are eventually accounted for in the model
24 and the right algorithms are used to simulate them, the most vexing issue
25 will continue to be the characteristics of the computational grid used to
26 simulate the river hydrodynamics, sediment transport and associated PCB
27 transport and fate. The computational mesh (Figure 3-6) is “hard-wired” to
28 water stages in the floodplain associated with a flood having a recurrence
29 time of 10 years. This results in the main river channel being modeled with
30 the same spatial resolution (i.e. a single computational cell) regardless of the
31 flow discharge, not just the 10 year flood. **(3A)**

32
33 ►With the current computational mesh configuration, the application of the
34 model is computationally taxing, resulting in extremely long execution
35 times. This has made the calibration and validation of the model a very
36 difficult exercise and will most likely affect the analysis of remediation
37 alternatives in the future. **(4)** ►At the same time, the use of a course grid
38 hinders the ability of the model to resolve the flow velocity distribution
39 inside the main channel as well as the associated boundary shear stresses
40 throughout its wetted perimeter. Given that erosion and sediment transport

1 vary non-linearly with increments in flow velocity and shear stress, it is
2 rather imperative to find a way to increase the spatial resolution of the model
3 so that at least three “streamtubes” are used to model flow and sediment
4 transport in the main channel of the Housatonic River. This will in turn
5 facilitate and make more meaningful the computation of streambank erosion
6 as well bed sediment erosion and resuspension. **(1D, 3A)**

7
8 ►While the model capabilities have been improved since its calibration, my
9 professional opinion is that the validation of the model is not complete at
10 this stage. In particular the model does not capture the variability and
11 spectrum of PCBs concentrations observed in river. There are several
12 aspects of the model that need to be improved as stated above before
13 validation of the model can be accomplished. **(2B)**

14
15 ►Due to the nature of the problem and the scale of the river system under
16 consideration, it is unlikely that a full validation of the model will be
17 possible in the near future. From a practical point of view, however, the
18 main question in my mind would be: is the model good enough to capture
19 most of the process responsible for the transport and fate of PCBs so that it
20 can be used to assess the merits and drawbacks of different remediation
21 strategies in the Housatonic River?

22
23 Right now my answer would be no but the effort by EPA and its consultants
24 has provided a good foundation towards the goal of having a useful tool that
25 can be used to help the Housatonic and other rivers experiencing similar
26 problems. **(12)**

27
28 Question 2:

29 Are the comparisons of the model predictions with data sufficient to evaluate
30 the capability of the model on the spatial and temporal scales of the final
31 calibration and validation?

32
33 Response:

34
35 ►Of particular relevance for this reviewer is the validation of flood plain
36 deposition throughout the river system as well as sediment erosion and
37 deposition in Woods Pond, since the record shows that this pond is a major
38 deposit for PCB-contaminated sediments.

39

1 Regarding the sedimentation of Woods Pond, the calibration/validation
2 exercise has produced results showing rates of (*net*) sedimentation for the
3 period going from 1979 to 2004 (Figure 6.2-34). The results seem
4 reasonable with predicted sedimentation rates (mm/year) that are within an
5 order of magnitude of sedimentation rates determined from Cesium data.
6 The model also reproduces fairly well the distribution of PCBs with depth as
7 observed from sediment cores. However, as stated below, the model shows
8 some bias when predicting temporal variations of surface PCB
9 concentrations in Woods Pond.

10
11 Woods Pond is perhaps one of the few locations in the Housatonic River
12 where the capabilities of the model to predict the spatial and temporal
13 distribution of sediment and PCB can be extensively tested due to the large
14 amount of observations available. This has been done to some extent but
15 more effort should go into this since the pond could become a major source
16 of PCBs to the downstream portion of the river during a major flood event.
17 **(2A, 2C)**

18
19 ►Regarding floodplain sedimentation, the model has been used to predict
20 process-based (advection, erosion, deposition, volatilization, etc) sediment
21 and PCB fluxes (Kg/year) for the main channel and the floodplain, over the
22 validation period (Figures 6.2-62 and 6.2-63). The analysis results in an
23 estimate of yearly fluxes. However, it is well known that sediment erosion
24 and transport is most prominent during flood events, which can have
25 duration of a few hours to several days. Thus it would seem that the model
26 should be validated for time scales that are relevant to the processes
27 involved.

28
29 Since a large percentage of the river system consists of floodplain, it is
30 important to ensure that the model can indeed capture the process of
31 floodplain sediment/PCB deposition. To this end, a simple one-dimensional
32 approach was suggested that could be used to estimate a “Floodplain
33 Dimensionless Number” for different reaches of the Housatonic River
34 (Garcia, 2006-technical note on floodplain sedimentation). Once such
35 number is calibrated for each reach, it will be possible to test if indeed the
36 model can predict floodplain depositional rates that result in similar
37 Floodplain numbers for different flooding conditions (hydrologic event
38 scale), thus helping in the overall validation of the model. This approach
39 will clearly show the capabilities of the model. If there is any hope of

1 predicting PCBs fate in the floodplain, sedimentation has to be properly
2 simulated by the model. **(3C)**

3
4 ►As mentioned in the response to question one, the size of the
5 computational grid makes it difficult (and meaningless) to compare model
6 predictions for processes that take place at hydraulic and sedimentation
7 scales determined by the flow rate and the main channel width. This is not
8 the case for Woods Pond and the floodplains were the size of the
9 computational grid is appropriate for the scale of the flow field. **(3A, 3B)**

10
11 Question 3:

12 Is there evidence of bias in the models, as indicated by the distribution of
13 residuals of model/data comparisons?

14
15 Response:

16
17 ►As shown in MVR Figure 6.2-50, the model predictions of variation with
18 of surface PCBs concentrations are not consistent with the field observations
19 in Woods Pond. The model seems to underpredict the observed values in
20 the time period from 1979-1984 and to overpredict the observations in the
21 time period from 1995 to 2000.

22
23 There is evidence that model predictions do not match well with observed
24 surface sediment concentrations of PCBs in reaches 5A, 5B, and 5C as
25 displayed in Figure 6.2-49. **(2A)**

26
27 ►Model predictions in Figures 6.2-45 and 6.2-46, show that during low flow
28 conditions the model does not capture observed longitudinal gradients in the
29 water column. This results in the model underpredicting PCB fluxes from
30 the sediments along Reach 5A, which in turn could lead to an under estimate
31 of the bed sediments PCB contributions to fish in the Food Chain Model.
32 **(1B)**

33
34 Question 4:

35 Have the sensitivities of the models to the parameterization of the significant
36 state and process variables been adequately characterized?

37
38 Response:

39 ►Given the facts that several processes are yet to be fully characterized in
40 the model and that a coarse computational grid has been used for the model

1 calibration, I do not think that a full sensitivity analysis can be conducted at
2 this time. **(1, 3A, 5A)**

3
4 ►In the case of low flow conditions, the model predictions seem to be very
5 sensitive to diffusion parameters, suggesting the representation of pore water
6 diffusion as well as the thickness of the so-called “mixed layer” need to be
7 carefully analyzed. **(1B, 3D)**

8
9 Question 5:

10 Are the uncertainties in model output(s) acknowledged and described?

11
12 Response:

13 ►While uncertainty in model inputs and outputs was recognized, the nature
14 of the model does not allow for a conventional uncertainty analysis. Once
15 all the processes are accounted for and well represented in the model and
16 assuming that the EFDC code can be run more efficiently, it might be
17 feasible to conduct an uncertainty analysis. **(4, 5B)**

18
19 Question 6:

20 Upon review of the model projections of changes in PCB concentrations in
21 environmental media in the example scenarios, are such projections
22 reasonable, using your technical judgment, and are they plausible given the
23 patterns observed in the data?

24
25 Response:

26 ►Model projections seem reasonable but I would have liked to see more
27 potential scenarios, particularly for extreme conditions such as low flow
28 summer-like conditions and floods. **(10)**

29
30 Question 7:

31 Is the final model framework, as calibrated and validated, adequate to
32 achieve the goal of the modeling study to simulate future conditions 1) in the
33 absence of remediation and 2) for use in evaluating the effectiveness of
34 remedial alternatives?

35
36 Response:

37 ►I do not think that the model is ready to accomplish the goals of the
38 modeling study. If the model is to be used to simulate future conditions,
39 first it has to adequately simulate the existing conditions throughout the
40 river and its floodplain. **(13)**

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2
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Overall, this is a very challenging undertaking but the study and modeling of the Housatonic River is a worthwhile effort that will hopefully benefit future generations.

APPENDIX A.5

COMMENTS OF FRANK GOBAS

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Final Response to Charge Questions

Housatonic River

Frank Gobas, Ph.D., Professor

School of Resource & Environmental Management

Simon Fraser University

July 20, 2006

Response to Charge Questions

Charge Question 1

“Considering the changes implemented in the Phase 2 calibration, does the model as calibrated and validated, based on your technical judgment, reasonably account for the relevant processes affecting PCB fate, transport and bioaccumulation in the Housatonic River to a degree consistent with achieving the goal of the modeling study.”

Since the goal of the modeling study is to address 6 model goals (Table 1), I have organized my response to charge question #1 by specifying the various goals of the model.

Re. Model Objectives #1, #5 and #6 on the issue of temporal response:

The main goal of the model is to estimate the temporal response of the PCB concentrations in the River as a function of various remediation strategies and natural recovery. The model’s temporal response is key to (i) the quantification of future spatial and temporal distribution of PCBs (model objective #1), both dissolved and particulate forms) within the water column and bed sediment; (ii) the estimation of the time required for PCB-laden sediment to be effectively sequestered by the deposition of uncontaminated material (model objective #5) and (iii) the estimation of the time required for PCB concentrations in fish tissue to be reduced to levels established during the risk assessment process, that no longer pose either a human health or ecological risk (model objective #6) as well some of the other model objectives.

►The temporal response of the model is based (i) on the parameterization of the sediment-water exchange rate of PCBs (which is the rate determining step in the depuration of the River) and (ii) on model calibration. With regards to the parameterization of the sediment-water exchange of PCBs, there are several model parameters including the depth(s) of “accessible” and “non-accessible” bottom sediments, diffusion rates, bioturbation rates and subduction velocities that are currently difficult to measure or assess. The best strategy for parameterization is to use the best empirical data and best expert judgment possible. I am not convinced that this was achieved in this study. Dr. Lick has provided several papers to demonstrate that the current parameterization of the sediment-water exchange process in the model is not consistent with some key studies and observations. Also, I place considerable weight on Dr. Lick’s expert judgment and his lack of confidence in the selection of parameter values. However, that said, it is unknown at this time whether an alternative parameterization of the sediment-water exchange processes will produce a significantly different and better characterization of the temporal response of the PCB concentration in the River. (1)

►The model calibration has been complicated by the lack of a significant change in PCB concentration data in the River during the calibration period. Hence, the model calibration sheds little light on the issue of whether the model is able to account for

1 changes in PCB concentrations over time that may occur as a result of remediation. The
2 main conclusion from the calibration is that the temporal response of PCB concentrations
3 in the River is likely slow, but it cannot tell us accurately how slow.

4
5 Evidence to indicate that the current temporal response of the model may be flawed was
6 presented by Dr. Connolly, who suggested that the half-life time of PCBs in the River is
7 likely is closer to 36.5 yr (i.e. $0.693/0.019$) than the current model prediction of 110 yr
8 (i.e. $0.693/0.006$). I think that Dr. Connolly is probably correct, but the uncertainty in the
9 estimates of the half-lives is large and I have not been convinced that the current PCB
10 concentration data in the River allow one to distinguish between these two estimates.

11
12 In conclusion, the current characterization of the key temporal aspects of the model is too
13 uncertain to make reliable long term predictions of the concentrations of PCB in water,
14 sediments and biota of the Housatonic River. This said, it is clear from the empirical data
15 and the model calculations that the long term temporal response to changes in PCB
16 loadings is slow. There appears to be very large standing mass of PCBs in the River
17 sediments and its floodplains and the sediment removal rate from the PSA is relatively
18 small. Natural recovery therefore can be expected to take a long time, with a system half-
19 life time in the order of decades. Given this slow response time, the calculation of a more
20 accurate natural recovery time may in some cases be inconsequential. Under certain
21 conditions, the model, as it stands, may already be sufficient to address the long term
22 temporal response of PCB concentrations in the water column and bed sediments (model
23 objective #1).

24
25 The reason for the model's ability to convincingly assess the long term temporal response
26 of the PCB concentrations in water, sediments and biota of the River are twofold. First,
27 no significant long-term-changes in PCB concentrations over time were observed in
28 water, sediment or biota throughout the PSA during the calibration period. Secondly, the
29 key parameters controlling the temporal response of PCB concentrations are difficult to
30 measure or estimate. **(2A)** Based on this, the following recommendations can be made:

31
32 Recommendations:

33
34 ►The modelers should explore alternate parameterization schemes (possibly with the
35 help of Dr. Lick) of the sediment-water exchange processes with the goal to select model
36 parameterization schemes that are defensible based on available laboratory and field
37 observations. **(1)**

38
39 ►The modelers should revisit the calibration of the temporal response of the model based
40 on a more in-depth statistical analysis of the available model calibration data. I
41 specifically refer to the sediment concentration data as a function of time. Model
42 calibration schemes should be evaluated in terms of their ability to reproduce statistically
43 validated temporal PCB concentration data. **(2A)**

1 ►The modelers should improve the calibration of the model by lengthening the model
2 calibration period. This most likely involves a continuation of monitoring the response of
3 PCB concentrations in the River to the remediation efforts that have recently taken place.
4 Over time, a more definite change in concentration may take place, which can be used to
5 better calibrate the model. **(13)**

6
7
8 Re. Model Objective #1 on the issue of Space:

9
10 ►The model report reveals insufficient information to determine whether the capability
11 of the model to make accurate predictions of spatial differences in PCB concentrations is
12 adequate. The reason is that the calibration of the spatial characteristics of the model
13 revealed that differences in PCB concentrations (e.g. see Fig 6-2-45 and 6-2-46 Model
14 Validation Report) among River sections are small while variability in the PCB
15 concentrations in the sediments at individual river locations is high. **(2B)**

16
17 ►The spatial resolution of the environmental fate and food-web model is unnecessarily
18 complex. **(3A, 4, 11)** ►A much simpler spatial model is consistent with the empirical data
19 and the current model calculations. The hydrodynamic model does not run on a low
20 spatial resolution. However, it is possible to run the hydrodynamic model on its optimal
21 spatial resolution and aggregate the hydrodynamic data for a much simpler PCB
22 environmental fate model. The latter would also reduce the model run-time from the
23 current, unacceptable 30 to 50 d. This would also make the model more transparent due
24 to greater simplicity. The modelers could argue that in terms of predicting spatially
25 varying concentrations the current multi-compartment model is consistent with a much
26 simpler lower spatial resolution model, so there is no need to develop the simpler model.
27 This is true for the model's current application. However, the modelers should keep in
28 mind that when the current model is applied to make predictions of the impact of
29 remedial actions on PCB concentrations as a function of space (i.e. model objective #1),
30 the model may predict spatial differences in concentrations that have not been "validated"
31 or "ground truthed". **(3A, 4)**

32
33 Recommendations:

34
35 ►Better spatial statistical methods should be used to explore the current spatial PCB
36 concentration data for spatial trends in the available PCB concentration data. **(2B)**

37
38 ►The modelers should consider developing a simpler spatial representation of the
39 environmental fate and food-chain model by decoupling the hydrodynamic and sediment
40 transport model from the environmental fate and food-chain model. The current high spatial
41 resolution of the model is unnecessary for the environmental fate and food-chain model. **(3A,**
42 **4)** ►Also, the time-step requirement for the hydrodynamic model is too onerous and
43 unnecessary for the environmental fate and food-chain models. **(3A, 4, 11)** ►This change in
44 model design will make it possible to make many model runs within a reasonable
45 computational time. **(3A, 4)**

1
2 Re. Model Objective #2:
3

4 ►With regards to achieving model objective #2, i.e. ability to quantify the historical and
5 current relative contributions of various PCB sources to PCB concentrations in water and
6 bed sediment, I do not think that the model reasonably accounts for the relevant fate
7 processes. The reason is that the model has difficulty assessing the amount of historical
8 PCB mass that is “accessible” by the River. Difficulties in the selection or determination
9 of an “accessible” sediment layer and decisions regarding the inclusion or exclusion of
10 flood plains as accessible sources of PCBs to the Housatonic River contribute to the
11 overall difficulty in assessing the current mass of PCBs in the River. As a result it is
12 difficult to assess the relative contribution of any current inputs of PCBs into the River.
13 The lack of any significant change in the PCB concentrations in the River over time over
14 the period that significant removal of PCB sources in the immediate vicinity of the GE
15 facility remediation took place may be an indication that historical sources of PCBs
16 throughout the PSA are likely the main contributor to current PCB concentrations in the
17 River. **(1)**

18
19 Recommendation:
20

21 ►An alternative to the difficult characterization of the current mass of PCBs in the River,
22 is using the model to investigate under which set of model parameters historical sources
23 are the main contributor to the PCB concentrations in the Housatonic River and judge
24 whether these model parameter sets are reasonable. This would avoid having to
25 characterize the actual current mass of PCBs in the River. **(13)**

26
27 Re. Model Objective #3:
28

29 ►Due to the heavy reliance on calibration during model development, the relative PCB
30 concentration data in water, sediments and biota that are calculated by the model are
31 overall consistent with the model predictions of the mean concentrations. **(11, 13)** ►The
32 model can therefore be used with confidence to address the relative contributions of
33 current PCB sources to bioaccumulation in target species (i.e. model objective #3). Dr.
34 Connolly argued that the potential underestimation of the overall PCB depuration rate in
35 the River affects estimates of the relative contributions of current PCB sources to
36 bioaccumulation in target species. While this is correct, I do not think that this will have a
37 significant effect on the derivation of current relative sources of PCBs to fish because
38 PCB concentrations did not vary significantly over the time period that calibration was
39 performed.

40
41 The application of the model of the model to quantify the historic contributions of various
42 PCB sources to bioaccumulation in target species is dependent on the time dependent
43 capabilities of the environmental fate model, which are more uncertain (see discussions
44 above). **(13)** ►The FCM model can be expected to properly estimate the relevant
45 contributions of water and sediment concentrations as sources of PCB bioaccumulation in

1 benthos and fish species from PCB concentrations in water and sediments delivered by
2 the EFDC model. **(11, 13)**

3
4 **►Re. Model Objective #4:**

5
6 The report indicates that the model reasonably accounts for the role of storm events. The
7 model appears to do a good job in describing the short term temporal response of river
8 flow rates in response to storm events. The comparison of simulated and observed river
9 flows is more than adequate. However, the excellent flow predictions do not translate in
10 equally impressive TSS concentrations. Figures 6.2-19 to 6.2-22 show considerable
11 discrepancies between observed and predicted short term TSS concentrations at Holmes
12 Road, Lennox Road and Woods Pond Outlet. On the other hand, Figures 6.2-39 to 6.2-41
13 show that the short term PCB concentration variations in the water phase (assuming that
14 the concentration data displayed are water column tPCB concentrations) are reasonably
15 well predicted. The reason for the poor predictability of TSS concentrations, but good
16 predictability of the PCB concentrations in the water column is somewhat surprising and
17 unclear. However, the data presented produce confidence in the model's ability to make
18 reasonable predictions of the effects of storm event(s) on the redistribution of PCB-laden
19 sediment in the study area (model objective #4).

20
21 **Recommendation:**

22
23 I recommend that the modelers investigate the source of error in the estimation of the
24 TSS. **(2A)**

25
26
27 **Charge Question #2**

28
29 *Is there evidence of bias in the model, as indicated by the distribution of residuals of*
30 *model/data comparisons?*

31
32 There is evidence of bias in certain model outcomes in the model validation.

33
34 **►First**, in the majority of comparisons between measured and model predicted TSS
35 concentrations, the TSS concentrations are over predicted. This does not appear to have a
36 corresponding impact on the calculation of the PCB concentrations in water. The effect of
37 this bias on the calculation of PCB concentrations under current conditions appears to be
38 low. However, the bias may become important when the model is applied under different
39 conditions. It is therefore important to explore the reasons for the bias in TSS and make
40 appropriate corrections. **(6)**

41
42 **►Secondly**, the combined or linked model (Table 6-4.7) shows a systematic
43 underprediction of the mean PCB concentrations as high as a factor of about 2 for some
44 of the species. Overall, including all species, the underprediction of PCB concentrations
45 in biota is about a factor of 1/0.60 or 1.67. This systematic bias does not appear to be due

1 to the bioaccumulation model itself. Judging from Table 6-4.6 (Model Validation
2 Report), the bioaccumulation model itself appears to have little or no systematic bias.
3 Judging from Figures 6.3.3 to 6.3.8, the uncertainty in the characterization of the model
4 bias is large. The authors could have calculated the standard deviation of the mean, but
5 did not do this. If they would have done this, they would have found that the standard
6 deviations of the model bias for any of the PCB concentration in fish data sets are quite
7 substantial due to the large variability in the observed PCB concentrations in the biota.
8 This means that while the mean model bias for the PCB concentration predictions in fish
9 is relatively low, the uncertainty of the mean model bias is high. I think that it is
10 important in any model to be upfront about the ability of the model to make predictions
11 of reality. The reporting of the model bias without its uncertainty is misleading in my
12 view. The reality is that PCB concentrations in biota vary substantially and we do not
13 really understand why this is. So, we should not pretend that we can predict PCB
14 concentrations in fish with the accuracy that the mean model bias measures suggest. I
15 therefore suggest that the authors provide a full reporting of the model bias of the PCB
16 concentrations (i.e. report uncertainty in the mean model bias) using the linked model and
17 interpret the findings in terms of model uncertainty when the model is applied. **(11)**

18
19 ►Thirdly, the analysis presented by Dr. Connolly during the June 28 Public Meeting
20 indicates that there may be a bias in the temporal response of the model, i.e. it appears
21 that the rate of temporal response of PCB concentrations in the River is underestimated
22 by the model. However, there is considerable uncertainty in the data on which the
23 calculations are based and it is unclear whether the uncertainty in the data is sufficiently
24 small to distinguish between the temporal response rates calculated by the model and Dr.
25 Connolly's analysis. A bias in the temporal response of the model could have large
26 implications for model projections of remedial actions. More detailed evaluations of the
27 bias in temporal response need to be conducted. This should involve the calculation of
28 PCB concentration response times from observed data and the comparison of the
29 measured response times to the calculated response times to determine whether a bias
30 exists. Alternative model parameterization schemes may need to be explored to
31 investigate whether the model bias (if it exists) can be reduced. **(2A)**

32
33 Recommendations:

34
35 ►I recommend that the modelers explore model parameterization schemes that remove
36 bias in the TSS model predictions. **(6)**

37
38 ►I recommend that the authors calculate the standard deviations of the mean model bias
39 of the linked model and make appropriate corrections to account for the systematic
40 underprediction of the mean PCB concentrations in the biota by the model. The
41 systematic underprediction of the mean PCB concentrations in fish by the model needs to
42 be either corrected or recognized when the model is applied. **(11)**

43
44 ►The possible bias in the model's temporal response of the PCB concentrations in the
45 River needs to be investigated by comparing observed and predicted PCB concentration

1 decline rates over time. In case, significant bias exists, alternative model parameterization
2 schemes need to be explored to improve the long term temporal response of the model.

3 **(2A)**

4 **Charge Question #3**

6
7 *Are the comparisons of model predictions with data sufficient to evaluate the capability*
8 *of the model on the spatial and temporal scales of the final calibration and validation*
9

10 ►With regard to the temporal scale, the comparisons of model predictions with data are
11 not sufficient to evaluate the capability of the model to make accurate estimates of the
12 temporal response of PCB concentrations in the River. As discussed under charge
13 question #1, this is largely due to the considerable variability in observed PCB
14 concentrations and the lack of a significant decline in PCB concentrations over the
15 calibration period. Hence, a temporal trend is difficult to discern from the data and the
16 lack of temporal trends makes it very difficult to evaluate the temporal characteristics of
17 the model. With regards to the spatial scale of the model, a similar conclusion can be
18 reached at. The small-scale spatial variability in the PCB concentration in the sediments
19 is so great that spatial differences in PCB concentrations among River sections are
20 difficult to discern. The comparison between observed and predicted concentrations
21 therefore provides little information with regards to the capability of the model to make
22 accurate predictions of PCB concentrations as a function of time or space.

23 24 **Recommendations:**

25
26 Dr. Connolly's analysis suggests that with the application of suitable statistics it may be
27 possible to use the current data sets to better characterize temporal and spatial PCB
28 concentration trends. Spatial statistics and the application of geographical averaging
29 methods may help to better characterize spatial trends in the data that can be used to
30 evaluate the applicability of the model. Temporal trend analysis can be used to discern
31 temporal trends. I recommend that this is done as it may provide better data for a
32 comparison of observed and predicted concentrations. **(2A)**

33
34 ►A second suggestion is to lengthen the model's calibration period. The calibration
35 period for the current model was too short for an evaluation of model capability. This
36 would involve the continuation of monitoring programs with the objective to develop
37 PCB concentration data over a longer period of time. **(13)**

38 39 40 **Charge question #4**

41
42 *Have the sensitivities of the models to the parameterization of the significant state and*
43 *process variables been adequately characterized?*
44

1 ►The modelers have done a good job describing parameter sensitivities. The latter is not
2 easy as there are many parameters and the sensitivities of each of them depend on the
3 values chosen for the others.

4
5 However, there is one area in the model where conducting a thorough sensitivity analysis
6 is crucial because of the lack of good calibration data and difficulties in model
7 parameterization. This is in the component of the Environmental fate model that controls
8 the long term temporal response of the model. The selection of the thickness of sediment
9 layers, diffusion rates, and bioturbation rates are all very difficult. Hence, a thorough
10 sensitivity analysis is crucial to determine the bounds within which temporal changes in
11 concentrations can be expected to occur. This analysis is not presented in the current
12 reports and supports my conclusion that the long term temporal response of the model is
13 too uncertain to make meaningful predictions.

14
15 Recommendations:

16
17 Given the lack of calibration data, the sensitivity analysis is probably one of the few
18 things that can be done to increase confidence in any estimates of the temporal response
19 in PCB concentrations calculated by the model. I recommend that it is considered and
20 added. For this sensitivity analysis to be doable and convincing, the modelers could just
21 focus on the part of the model that controls the long term temporal response of the model.
22 **(5A)**

23 24 25 **Charge question #5**

26
27 *Are the uncertainties in the model output(s) acknowledged and described?*

28
29 ►1. While the report presents several efforts to calculate uncertainty, the model
30 uncertainties are not fully acknowledged. In essence, the report presumes that the model's
31 ability to calculate mean concentrations is sufficient to address the goals of the study. I
32 think that this is a flaw in the study design because the goal of the model is to compare
33 PCB concentrations resulting from different remedial scenarios. Such an application
34 involves the comparison of mean concentrations. However, comparing mean
35 concentrations alone is insufficient to determine the significance of the differences in
36 mean concentrations. The calculation of the statistical significance of a difference in the
37 means is required. The latter is a well established practice in scientific and engineering
38 studies. I do not think that a convincing rationale is presented for why this practice is not
39 applicable in this study. The authors argued that ecological receptors (including fish), due
40 to their continuous movement, tend to be exposed to a large variation in concentrations,
41 which get "averaged out" to produce an internal concentration in the fish that corresponds
42 to the average or mean exposure concentration rather than the variation in concentrations
43 (l. 10-14, p.15 Responsiveness document). Figures 6-2-35, 6-2-56, 6-3-3 to 6-3-8 (Model
44 Validation Report), and similar figures in the calibration documents demonstrate a one-to
45 two order variability in predicted concentrations of PCBs, which does not differ

1 substantially between fish and sediments (i.e. the variability in fish concentrations does
2 not appear to be any less than that in suspended solids). This indicates that the original
3 assumption that PCB concentrations in fish may be less variable than the sediment
4 concentrations may not hold.

5
6 The model's capability to estimate only mean concentrations, makes it difficult to apply
7 the model to some objectives. For example, when the model is applied to address model
8 objective #6, it can only calculate at what point in time the mean concentration falls
9 below a target level that no longer poses a human health or ecological risk. This means
10 that roughly (depending on the frequency distribution of the concentrations) half the
11 concentrations are still above the target level. Risk assessment calculations typically
12 depend on the distribution of the concentration and set limits based on a percentage of
13 individuals exceeding a particular concentration. Hence, a frequency distribution of the
14 concentrations is essential. Perhaps it is assumed that the risk assessment calculations can
15 deal with the distribution of the concentration. However, in the application of the model,
16 it is the model that has to generate the distribution of concentrations (since there are no
17 data for the future) and at this point, none of the model components can do this. A
18 comparable argument can be made for the application of the model to model objective
19 #1, i.e. quantify future spatial and temporal distribution of PCBs (both dissolved and
20 particulate forms) within the water column and bed sediment. The mean concentrations
21 that will be produced by the model do not provide information on the statistical
22 distribution of the predicted concentrations. Hence, as the model stands, it is impossible
23 to determine whether any calculated difference in concentration (e.g. as a result of a
24 remediation strategy) is significant and can be treated as a difference in effectiveness
25 among remediation strategies. **(12)**

26
27 ►I agree with the EPA that it is not necessary to understand the processes causing small
28 scale variability in concentrations (1.3-4, p.15 Model Validation Report). This is normal is
29 any scientific observation. However, when interpreting the observation or the model
30 calculation (in this case), it is then important to recognize the uncertainty that is
31 associated with the lack of understanding, so that it can be taken into account in the
32 decision analysis. **(2B)**

33
34 ►2. The calculation of model uncertainty in the report is seriously flawed. The report
35 includes several references to this. For example, based on findings that the uncertainty in
36 the calculated PCB concentrations is greater than the variability in the sampling data, the
37 authors conclude that "the results should not be interpreted to mean that the uncertainty in
38 model predictions renders the model predictions too uncertain to be usable" (p.5-56
39 Model Validation Report). The authors further "acknowledge that a true statistical
40 analysis of uncertainty, particularly when uncertainty is propagated through the modeling
41 framework, can produce bounds that may not be possible (or likely) based on an
42 understanding of that system. (p.5-57 Model Validation Report). I think that these are
43 important points. I agree that in models of this complexity, it is virtually impossible to
44 meet some key criteria for a meaningful Monte Carlo Simulation, namely (i) that the
45 model parameters included in the simulations are independent, and (ii) there is

1 insufficient data to properly characterize the variability/uncertainty/error in the many
2 parameters used in the model. Also, it should be recognized that the MCS method does
3 not recognize error in the functional relationships of the model. The KS method is subject
4 to the same limitations as the MCS method and the failure of 4 out of the 56 runs may be
5 due to implausible parameter selections causing the model to crash for these runs due to
6 the problems outlined.

7
8 In conclusion, the conditions for a meaningful MCS or KS uncertainty analysis are not
9 met in this study. The calculated uncertainty values are therefore seriously flawed. It is
10 unclear what the meaning of the calculated uncertainty is. The lack of a meaningful
11 uncertainty analysis is a major flaw of the current model because model projections are
12 very difficult, if not impossible to interpret.

13
14 To include uncertainty and better characterize it, the modelers could consider using the
15 formidable empirical data set to calculate frequency distributions for the model predicted
16 mean concentrations. To formalize this method, the authors could further develop the MB
17 method described on p. 6-118 (Model Validation Report) by calculating the standard
18 deviation of the mean (i.e. MB). What this will do in the case of PCB concentrations in
19 the sediments is simply project the observed variation in PCB concentrations on the
20 model predicted concentrations. The result is now a distribution of predicted
21 concentration that is grounded in empirical data. This is not a major job, and could be
22 done with little extra work.

23
24 **Recommendation:**

25
26 My recommendation is to ignore the MCS and KS results and remove it from the model
27 framework when the model is to be applied in the next phase of the study. Instead I
28 recommend that the modelers use the discrepancy between model predicted
29 concentrations and observed concentrations as a measure of model uncertainty. This is
30 simpler, easier to understand and avoids current computational problems. For example,
31 the data depicted in Figures 6.3.3 to 6.3.8 (Model Validation Report) can provide a
32 reasonable description of the overall model uncertainty. This can be achieved by
33 calculating the confidence limits of the MB used in the report. See Environ. Toxicol.
34 Chem. 23, 2343-2355 for additional details on this method. The application of this
35 method will also generate frequency distributions of model outcomes that can be used in
36 risk assessments. The method that I recommend is not complicated and can be carried out
37 in little time. The main drawback of the application of this method is that it relies on the
38 assumption that the uncertainty identified in past application of the model is a good
39 measure for uncertainty in future model applications. I think that this is a reasonable
40 assumption for some model applications. However, if river functioning is drastically
41 altered by the remediation efforts, this assumption may not apply. **(5B)**

1 **Charge Question #6**

2
3 *Upon review of the model projections of changes in PCB concentrations in*
4 *environmental media in the example scenarios, are such projection reasonable, using*
5 *your technical judgment, and are they plausible given the patterns observed in the data.*
6

7 ►The patterns in the data indicate a slow temporal response of the PCB concentrations in
8 the River. The example scenarios also indicate a small decline of somewhere between 0
9 to 5% (it is hard to spatially average the concentrations depicted without additional
10 information) over 26 years in response to the assumed loading reductions. I think that this
11 is consistent with the observations.

12
13 The data illustrate large small-scale spatial variability in PCB concentrations in
14 sediments. The model appears to capture this to some degree as changes in concentrations
15 relative to the control vary between grid cells within many transects.

16
17 I have trouble understanding why PCB concentrations in so many cells of the lower part
18 of the River (Figure 7-1b and 7-3b) increase in concentrations as a result of the loading
19 reductions. This is not what I would expect to happen intuitively given the long history of
20 the PCB contamination problem and the slow response time of PCB concentrations in the
21 river. I would expect concentrations to go down throughout the river, but at higher rates
22 at some locations and lower rates at others.

23
24 Comparing scenarios 1 and 2, one would expect that elimination of additional PCB loads
25 in scenario 2 would produce a greater change in PCB concentration over time in scenario
26 2 than 1. Perhaps, this is the case. It is hard to see from the graphs. However, even if this
27 is not the case, it is possible that concentrations decline over the 26 years are comparable
28 for scenarios 1 and 2. Without more information, it is hard to be more definite.

29
30 Based on the current information presented, there is no basis for concluding that the
31 patterns provided in the example scenarios are not plausible given the patterns observed
32 in the data. But more data is needed to support a more positive and definitive conclusion.
33 The example scenarios in the validation report provide little information about the
34 functioning of the model. To address the charge question properly, it is important that the
35 model outcomes of the example scenarios are further analyzed. In particular, it is
36 important to average model outcomes over space and time such that the model
37 predictions can be compared to available data.

38
39 **Recommendation**

40
41 I recommend that the behavior of the combined model is explored in greater detail than is
42 presented in the validation report. I recommend that the model outcomes in the model
43 scenarios are aggregated to depict the overall response of the PCB concentrations in the
44 River. This will provide the opportunity to better compare model projections to available
45 data sets and judge whether the model projections are plausible. **(10)**

1
2
3 **Charge question #7**
4

5 *Is the final model framework, as calibrated and validated, adequate to achieve the goal*
6 *of the modeling study to simulate future conditions 1) in the absence of remediation and*
7 *2) for use in evaluating the effectiveness of remedial alternatives?*
8

9 ►The model is the only available tool to simulate the future response of PCB
10 concentrations in response to remediation efforts. The model framework represents a
11 suitable approach to estimating the future time response of PCB concentrations in the
12 River and the calibration and validation of the model have involved significant efforts.
13 The most valuable information for the calibration and validation of the model is a change
14 in PCB concentrations in the River in response to a known reduction in PCB loading.
15 This kind of information was not obtained in the current study as concentrations of PCBs
16 in the River showed little or no significant variation with time. The current model
17 therefore has to rely on the characterization of a number of key state variables for the
18 estimation of the long term temporal response of PCB concentrations to remedial
19 scenarios. The key parameters include the amount of “available” River and floodplains
20 sediments and rates of resuspension, diffusion, bioturbation and subduction. All of these
21 model state variables are either currently unmeasurable or very difficult to measure or
22 estimate. As a result the model’s outcome with regards to the long term time response of
23 PCB concentrations in the River is uncertain. The model uncertainty translates in
24 considerable uncertainty about future PCB concentrations in the River resulting from
25 remediation efforts or the absence of remediation. **(1, 2A)**
26

27 ►Any model has inherent uncertainty. So, this is normal. But where the model
28 framework is inadequate is in the recognition of this uncertainty and in the development
29 of adequate methods to characterize or estimate this uncertainty. Without the inclusion of
30 uncertainty in the current model framework, I do not think that it is possible to
31 convincingly distinguish between the effectiveness of different remedial options. **(5B)**
32

33 ►The model as it currently stands is incomplete. A lot of excellent work has been done
34 but there are some major gaps that need to be addressed before the model is ready for
35 application. This may sound disappointing to some, especially for those living in the
36 immediate vicinity of the River. However, the remediation options that can be expected
37 to be considered have very large and long lasting impacts on the River and its ecology.
38 Therefore, caution should be exercised and there should be confidence in the outcome of
39 remediation efforts before such remediation takes place. **(12)**
40

41 Recommendations:

42
43 I have several recommendations for the completion of the model:
44

- 1 1. ►Include model uncertainty in the model framework and provide guidance about
2 how the results from the uncertainty analysis are to be used when comparing
3 outcomes resulting from different model scenarios.
4
- 5 2. Do not use the MCS or KS method for calculating model uncertainty.
6
- 7 3. Include an uncertainty analysis that takes full advantage of the empirical data that
8 have been collected. As discussed earlier, this can be achieved by comparing
9 observed and model predicted PCB concentrations. **(5B)**
10
- 11 4. ►Reduce the model run-time from an unacceptable 30 to 50 days to 1 d (at most),
12 such that different model parameterization schemes can be explored for making
13 model projections. **(4)**
14
- 15 5. ►Conduct sensitivity analyses with the goal to (i) further investigate the
16 parameterization of the sediment-water exchange of PCBs, on which the temporal
17 response of PCB concentrations in the River largely depends and (ii) improve the
18 parameterization of the key processes if possible (see under charge question #1
19 for additional details on this issue). **(5A)**
20
- 21 6. ►Continue existing PCB concentration monitoring programs to measure the
22 changes in PCB concentrations over time as a result of the recently completed
23 remediation. Use the data together with calculations of PCB source reductions due
24 to remediation to extend the calibration period and improve the calibration and/or
25 validation of the long term temporal response of the model.
26
- 27 7. Apply a staged and adaptive approach in the planning of River remediation. Plan
28 to gauge the river's response to remedial efforts at certain locations in the River
29 throughout the River remediation. A PCB concentration monitoring program can
30 detect the effect of remedial actions on PCB concentrations over time and space.
31 These data can then be used in the model to further optimize the model, such that
32 the effects of newly planned remedial efforts can be better estimated. **(13)**

Additional Comments

► DOC-water partitioning

The model assumption that the sorptive capacity of DOC is two orders of magnitude less than that of POC (1.27-28, p.6-67 Model Validation Report) seems out of touch with the literature. The lowest value I have seen to characterize the sorptive capacity of DOC compared to octanol was 0.08, i.e. DOC has 8% of the sorptive capacity of octanol (Burkhard, L.P. Estimating dissolved organic carbon partition coefficients for nonionic organic chemicals. *Environ. Sci. Technol.* 2000, 34 (22), 4663-4668. – Note that in response to p. 2-72 of EPA response, Burkhard states that $K_{DOC} = 0.08 \cdot K_{ow}$, not $K_{DOC} = 0.08 \cdot K_{POC}$). In comparison, the sorptive capacity of POC is approximately 35% of that of octanol (Seth, R.; Mackay, D.; Muncke, J. Estimating the organic carbon partition coefficient and its variability for hydrophobic chemicals. *Environ. Sci. Technol.* 1999, 33 (14), 2390-2394.). Following these papers, the difference in sorptive capacities between DOC and POC is approximately a factor of 35/8 or 4.38. Burkhard et al. did report 95% uncertainty limits of a factor of 20 for the 0.08 value, hence the 0.01 value used in the model is plausible, but it is very low.

Much higher values of the sorptive capacities of DOC in relation to octanol have also been measured. For example, Macintosh et al. report 1.16 (± 0.49) for spiked and 61 (± 47) for native PCBs and phthalates. This compared to 35 (± 19) for POC (Sorption of Phthalate Esters and PCBs in a Marine Ecosystem, Mackintosh et al. *Environ. Sci. Technol.*; 2006; 40(11); 3481-3488.). The latter results indicate no significant differences between sorptive capacities of DOC and POC and also evidence of DOC-water disequilibria.

The assumed two orders of magnitude difference in sorptive capacities of POC and DOC in the model is, albeit plausible, a very low value. Given the variation in literature data, I recommend that empirical data are used to calibrate this model input requirement. The recent EPA response document suggests that the latter has indeed been done. **(1C)**

► Diffusive Flux

The importance of a diffusive flux of PCBs from sediments to the water between Holmes Road and New Lennox Road during low flow periods is surprising (p.6-72 Model Validation Report) given the otherwise dominant roles of erosion and deposition (Fig 6.2-62 Model Validation Report). I have never seen a system, especially a riverine system, in which diffusion played such an important role. I think that it was necessary to invoke a high diffusion rate to explain the concentration data. I am not sure if there is any precedent for such a high diffusion rate though. This may be perhaps point to another parameterization problem in the model. I recommend the authors investigate this process in more detail and explore other options for calibrating the model. **(1B)**

Tables

Table 1: Model Objectives

Model objectives:

1. Quantify future spatial and temporal distribution of PCBs (both dissolved and particulate forms) within the water column and bed sediment
2. Quantify historical and current relative contributions of various PCB sources to PCB concentrations in water and bed sediment
3. Quantify historical and current relative contributions of various PCB sources to bioaccumulation in target species
4. Quantify relative risk(s) of extreme storm event(s) contributing to the resuspension of sequestered sediment or the redistribution of PCB-laden sediment in the study area
5. Estimate the time required for PCB-laden sediment to be effectively sequestered by the deposition of uncontaminated material (i.e., natural recovery)
6. Estimate the time required for PCB concentrations in fish tissue to be reduced to levels established during the risk assessment process, that no longer pose either a human health or ecological risk, based upon various response and restoration scenarios

APPENDIX A.6

COMMENTS OF WILBERT LICK

1
2
3 **HOUSATONIC RIVER**
4
5 **MODEL VALIDATION**
6
7 **FINAL COMMENTS**
8
9 **EPA FORMAT**

10
11
12 Wilbert Lick

13
14 University of California

15
16 Santa Barbara, California
17
18

19 ►1. In the present model, the processes of sediment erosion, sediment deposition, the
20 finite sorption rate of PCBs by the sediments, and the sediment-water flux due to
21 “diffusion” are described incorrectly and inaccurately. This is exacerbated by a very
22 coarse numerical grid used to define the bathymetry of the river and an unnecessarily fine
23 grid to define the bathymetry/topography of the floodplain. More specific reasons for
24 these comments as well as specific suggestions for improvement of the model are
25 presented in the complete response which is attached. I do not believe that the present
26 model can reasonably account for the relevant processes affecting PCB fate, transport,
27 and bioaccumulation in the Housatonic River to a degree consistent with achieving the
28 goal of the modeling study. **(1, 3A)**

29
30 ►2. A good comparison of the model predictions with data is necessary, **but not**
31 **sufficient**, to evaluate the capability of the model. The low surficial PCB concentrations
32 in Woods Pond and the large variability in PCB concentrations throughout the river are
33 unexplained by the present model. See discussion in the complete response. **(2A, 2B)**
34

35 3. Don't know.
36

37 ►4. The sensitivity of the model to the parameterization of the significant state and
38 process variables has not been adequately characterized. See discussion in the complete
39 response. **(5A)**
40

41 ►5. Because the basic processes are inaccurately described, the uncertainties in model
42 outputs are not correctly acknowledged or described. **(5B)**
43

- 1 ▶6. Because the basic processes are inaccurately described and the correct processes
2 may possibly differ by factors of two to ten from those in the present model, the
3 projections of the present model have large potential errors. **(10)**
4
- 5 ▶7. The present model is inadequate to achieve the goal of the modeling study to
6 simulate future conditions (1) in the absence of remediation and (2) for use in evaluating
7 the effectiveness of remedial alternatives. **(13)**

July 4, 2006

HOUSATONIC RIVER

MODEL VALIDATION

FINAL COMMENTS

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► Introduction

In the long term, the main source of contaminants in the Housatonic River is the bottom sediments (both those in the river and in the floodplain). In this long term, environmental conditions will change with time and will be different than they are at present, especially because of and after remediation. For purposes of predicting water quality, it is therefore essential to accurately determine not only the flux of contaminants between the bottom sediments and the overlying water but also the parameters on which this flux depends. Otherwise, long-term predictions of water quality will not be accurate or believable. Because of this, my comments will emphasize processes which govern the sediment-water flux of contaminants, i.e., sediment erosion, sediment deposition, the sediment-water flux due to “diffusion”, and equilibrium partitioning.

In my last review (Model Calibration, May 13, 2005), I commented extensively on the proposed calibration of both sediment erosion and deposition by means of the measured suspended solids concentration, C. A simple example was given whereby it was easy to see that a numerical model can “predict” the observed values for C with an almost arbitrary value of erosion rate as long as the deposition rate was changed accordingly, i.e., such that the two were equal and gave the observed C. I stated “For a predictive model, the values of erosion rate and deposition rate can not both be determined from calibration of the model by use of the suspended solids concentration alone.” I later stated that “ models with many unconstrained parameters and especially models which include processes that are not described correctly as far as their functional behavior is concerned can lead to non-unique solutions; these can lead to the incorrect predictions of long-term behavior.”

EPA responded by more-or-less agreeing with the above statements but then stating “This concern does not recognize that there is a constraint imposed by PCB transport that results from resuspension and deposition processes.” Although this argument has some validity, it is not sufficient or correct as I will argue below. This problem of non-unique

1 solutions is important, is more general than that indicated above, and is related to the
2 necessity for accurately determining the basic processes that govern the sediment-water
3 flux of PCBs and other hydrophobic organic chemicals (HOCs). Because of this, I will
4 return to this problem of non-unique solutions after discussing the flux processes
5 mentioned above. Accurate descriptions of the basic processes also depend on an
6 adequate resolution of the bathymetry/topography of the Housatonic. Because of this,
7 comments and suggestions on the problem of numerical gridding in the model will be
8 made. Some discussion on unexplained results of the present model will then be given.
9 A summary and specific suggestions for improvements to the model will conclude my
10 comments. (1)

11 ►Sediment Erosion

12 In the previous review on Model Calibration (May 13, 2005), I commented extensively
13 on sediment erosion. Although those comments are still valid, I won't repeat all of them
14 here. However, I would like to repeat the following from those comments.

15 "In a paper by Lick et al. (2005), approximate equations for sediment erosion rates are
16 examined. It is shown that, for fine-grained, cohesive sediments, a valid formula is

$$17 E = 10^{-4} \left(\frac{\tau}{\tau_c} \right)^n \quad (3)$$

18 where E is the erosion rate, τ is the shear stress, and τ_c is a critical shear stress defined as
19 the shear stress at which an erosion rate of 10^{-4} cm/s occurs; τ_c depends on the particular
20 sediment being tested and generally is a measured quantity. This equation is valid for
21 fine-grained, cohesive sediments but **not** for coarse-grained, non-cohesive sediments.

22 "For coarse-grained, non-cohesive sediments, the appropriate formula is

$$23 E = A(\tau - \tau_c)^n \quad (4)$$

24 where A, τ_c , and n are functions of particle diameter but not a function of density. This
25 equation is shown to be valid for coarse-grained, non-cohesive sediments but **not** for
26 fine-grained, cohesive sediments.

27 "To approximate erosion rates for all size sediments with a single, uniformly valid
28 equation, the appropriate equation is

$$29 E = 10^{-4} \left(\frac{\tau - \tau_{cn}}{\tau_c - \tau_{cn}} \right)^n \quad (5)$$

30 where $\tau_{cn}(d)$ is the critical shear stress for non-cohesive particles and is given by

$$31 \tau_{cn} = 0.414 \times 10^3 d \quad (6)$$

1 where d is the particle diameter. Eq. (5) is uniformly valid for both cohesive and non-
2 cohesive sediments. It reduces to Eq. (3) as $d \rightarrow 0$ and to Eq. (4) for large d .

3
4 “In all the work we’ve done with Sedflume on the determination of erosion rates as a
5 function of shear stress (the number of cores is on the order of 100), n in Eq. (5) is
6 typically about 2 or more (see Lick et al., 2005 and Chapter 3 of Notes). Because of this,
7 I suspect that the parameters $n = 1.59$ and $n = 0.95$ used in the Housatonic modeling (p. 4
8 of Attachment B.5) are incorrect.”

9
10 One reason for the low values of n determined for the Housatonic is that the above
11 equations are only applicable to sediments which have the same bulk properties. In order
12 to use these equations properly, sediments with similar bulk properties must be grouped
13 together. Properties of sediments in a single sediment core generally vary with depth due
14 to consolidation but also because of layering due to deposition after big events. Because
15 of consolidation with depth, sequential Sedflume measurements on one core will bias the
16 value of n since cores at depth will be more consolidated, more difficult to erode, and will
17 be measured later in the measurement cycle. I suggested an interpolation procedure that
18 we had used before and which gave us reasonable results. EPA did not seem to have
19 good results with this procedure. Attached is a description of a modified procedure
20 which I have applied to several randomly selected cores on each of the Kalamazoo,
21 Housatonic, and Passaic Rivers. This procedure is more fundamental and correct. In all
22 cases, it produces an n that is equal to two or greater in Eq. (5) above, just as has been
23 demonstrated by all Sedflume laboratory measurements that we have made. With this
24 procedure, the coefficient modifying $(\tau - \tau_{cn})^n$ and n are functions of depth for each
25 representative area core and are obtained from the Sedflume data. The fact that n is two
26 or greater is important in determining erosion rates at high shear stresses, i.e., during big
27 events, and can lead to shear stresses higher by an order of magnitude than the n ’s chosen
28 by EPA for the Housatonic.

29
30 In that previous report, I also stated the following. “Bed armoring is an important
31 process and causes large changes in bed shear stresses and hence large changes in
32 erosion/deposition. This occurs, for example, when a layer of coarse sediments (as little
33 as a few particle diameters thick) is deposited on a layer of finer, non-cohesive sediments.
34 As the EPA model is presently configured, any deposited sediments are immediately
35 mixed with the 6-inch surficial layer. Because of this, effective coarsening takes place
36 very slowly (a small amount of added sediment has little effect on the average properties
37 of the 6-inch layer). In reality, this mixing only occurs in a layer a few particle diameters
38 thick, and this thin layer must be present in the model for realistic coarsening to occur
39 (see SEDZLJ).”

40
41 EPA stated that the surficial layer was assumed to be 7 cm thick, not 6 inches as I stated.
42 Since bed coarsening occurs in a layer only a few particle diameters thick, the assumption
43 of a 7 cm mixed layer is also incorrect. **The above comments are still valid. (1A)**

1 **►Sediment Deposition**

2
3 I suggested the use of a dynamic flocculation theory that was recently developed and was
4 relatively simple. EPA seems to have had problems implementing the theory. I presume
5 from what they said that this was due to numerical stability problems. That's too bad
6 because it would have given reviewers more confidence in the modeling of deposition
7 rates. (1A)

8
9 **►The Sediment-Water Flux of HOCs Due to “Diffusion”**

10
11 The non-erosion/deposition flux of contaminants from the sediments to the overlying
12 water is primarily due to molecular diffusion, bioturbation, and ground-water flow. Each
13 of these processes behaves in a different way and hence needs to be modeled in a
14 different way. EPA has chosen to describe all of these processes by means of a
15 “diffusion” model based on the concept of bioturbation and the assumption of a well-
16 mixed layer. This is the conventional, but not necessarily accurate, approach. It is not
17 accurate simply because the mass transfer approximation (which is not a diffusion
18 approximation) actually used by EPA does not describe or adequately approximate the
19 HOC fluxes of molecular diffusion, bioturbation, or ground-water flow, not even in
20 functional form. The correct functional form (especially its dependence on time) is
21 important because, otherwise, even calibration doesn't work for long term predictions.

22
23 EPA did an extensive review of the literature on bioturbation and listed 139 documents of
24 which 43 were retained for detailed review. This listing is somewhat misleading. Of the
25 43 most relevant documents, almost all are general observations, surveys of the literature,
26 or even surveys of surveys; only about six report quantitative data or laboratory
27 measurements of mixing due to benthic organisms. For example, the figure shown at the
28 last meeting entitled “Bioturbation and Bioavailable Sediment Depths” is from Clarke et
29 al. (2001) and is their interpretation of what organisms do. There is no data (given by
30 Clarke et al. or anywhere else) to support this figure. Clarke et al. is an excellent
31 manuscript, but it is another survey. There is no new data there. None of the documents
32 listed by EPA report on the sediment-water flux or sediment mixing of hydrophobic
33 organic chemicals (HOCs) due to benthic organisms. Since then, EPA has listed
34 additional reports concerned with the flux of HOCs due to benthic organisms. However,
35 these HOCs had relatively low partition coefficients. The only quantitative data that I
36 know of on the effects of benthic organisms on the flux of HOCs with large partition
37 coefficients and their resulting vertical distribution in the sediments is that by Luo et al.
38 (2006) which is attached. Some of my comments are based on this article.

39
40 In EPA's modeling, assumptions are (1) a constant (independent of space and time)
41 sediment-water mass transfer coefficient, k , with a value of 1.5 cm/day and (2) a surficial,
42 well-mixed layer whose thickness is constant in time but varies spatially from 4 cm
43 upstream to 7 cm downstream. Measured biomass varies by about a factor of 20 from
44 upstream to downstream.

1 Benthic mixing is described by EPA in terms of a mixing rate (a diffusion process), also
2 termed a subduction velocity (a convection process), a quantity which I believe is used in
3 the model as a mass transfer coefficient between the sub-surface sediment layers. For the
4 biologically mixed layer, the subduction velocity (values from EPA's table) varies from
5 about 1×10^{-9} m/s (1×10^{-2} cm/day) upstream to 2×10^{-9} m/s (2×10^{-2} cm/day)
6 downstream. This factor of two between upstream and downstream seems surprising
7 since the biomass increases by a factor of 20 in the downstream direction. Even more
8 surprising is that the mass transfer coefficient, k , is assumed constant everywhere at 1.5
9 cm/day. Why doesn't k increase downstream as the biomass increases by a factor of 20?

10
11 A surficial well-mixed layer whose thickness is constant in time is assumed in the
12 analysis. An approximate and minimum time for formation of this layer can be
13 calculated from $t = h/v_b$, where h is the thickness of the layer and v_b is the subduction
14 velocity. For the upstream area, $h = 4$ cm, $v_b = 1 \times 10^{-9}$ m/s = 1×10^{-2} cm/day, and
15 therefore $t = 400$ days. For the downstream area, $h = 7$ cm, $v_b = 2 \times 10^{-9}$ m/s = 2×10^{-2}
16 cm/day and therefore $t = 350$ days. In other words, these so-called well-mixed layers are
17 not formed instantaneously and take a minimum of 350 to 400 days to form.

18
19 This becomes a little confusing upon examination of the figure presented at the meeting
20 entitled "Contribution to Db from different groups of benthos". Upstream, Db (for all
21 benthos) is approximately 2×10^{-3} cm/day while downstream, oligochaetes (the main
22 vertical burrowers and subductionists) contribute a Db of approximately 2.5×10^{-2}
23 cm/day. The upstream number is an order of magnitude less than the number in the table
24 cited above as v_b , is probably correct, but gives a time for formation of the well-mixed
25 layer of almost 2000 days (6 years).

26
27 Despite the confusion, the numbers for Db are probably correct (to within less than an
28 order of magnitude). This demonstrates (as does Luo et al. more accurately and
29 convincingly) that so-called well-mixed layers for HOCs, if they exist, take a long time
30 (years) to form. Is there any evidence that a well-mixed layer even exists in the
31 Housatonic? I don't believe so.

32
33 The mass transfer coefficient, k , for the transport of HOCs by molecular diffusion alone
34 is approximately 1.2 cm/day and decreases slowly with time at a rate which decreases as
35 K_p increases (Deane et al. 1999, Lick et al. 2006, attached). If there is only a small
36 number of organisms, EPA's value of $k = 1.5$ cm/day compares well with this number.
37 However, with benthic organisms present, Luo et al. give a mass transfer coefficient for
38 HOCs that varies up to 10 cm/day (for benthic organism densities of $10^4/m^2$) and
39 somewhat higher for very dense concentrations of organisms; these values for k are much
40 higher than those that EPA assumes.

41
42 No consideration is given to ground-water flow, which can be significant, is a convection
43 and not a diffusion process, and does not involve a well-mixed layer of any sort. **(3D)**

1 **►Equilibrium Partitioning**

2
3 After sediment particles are resuspended, they will be transported downstream by the
4 current and eventually settle out of the water column. During this time, the contaminant
5 sorbed to the particle will desorb at some finite rate. The time for a particle to settle out
6 of the water column depends on the settling speed and water depth, while the distance
7 traveled by the particle before depositing depends on the settling time and current speed.
8 For a reasonable range of settling speeds, w , for fine-grained particles/flocs (2×10^{-3} to 1
9 $\times 10^{-1}$ cm/s) and water depths, h , typical of the Housatonic (1 to 3 m), the settling times (t
10 $= h/w$) are in the range (see table) from 10^3 s (15 min) to 1.5×10^5 s (1.5 days). For
11 medium and coarse grained particles, the settling times are less.

12
13
14
15 Settling Times (Seconds) for Fine-Grained Particles in the Housatonic

16

h(cm)	w(cm/s)	
	2×10^{-3}	1×10^{-1}
1×10^2	0.5×10^5 (0.5 days)	1×10^3 (15 min)
3×10^2	1.5×10^5 (1.5 days)	3×10^3 (45 min)

17
18
19
20
21 Some experimental results for the adsorption and desorption of HOCs are shown in the
22 appended figures. These sorption times depend on the sediment concentration, particle
23 and floc sizes, conditions of the experiment, and the value of the partition coefficient.
24 The first three figures are for hexachlorobenzene ($K_p = 10^4$ L/kg), while the fourth figure
25 is for the adsorption of HOCs with K_p 's from 10^3 to 6.6×10^4 L/kg. The last figure is for
26 the desorption of a PCB with one chlorine (MCB, $K_p = 10^3$ L/kg), hexachlorobenzene
27 (HCB, $K_p = 10^4$ L/kg), and a PCB with six chlorines (HPCB, $K_p = 6.6 \times 10^4$ L/kg, a K_p
28 which is smaller than, but comparable to, the average K_p of about 10^5 L/kg for PCBs in
29 the Housatonic). In 10 days, only about 25% of the HPCB has desorbed; in 50 days, only
30 about 55% has desorbed. As the partition coefficient increases, the amount of desorption
31 in these time intervals will be even less. For PCBs with $K_p = 10^5$ L/kg, the desorption
32 times would be approximately 1.5 times greater than those for HPCB shown here.

33
34 Since desorption times are much greater than settling times, it follows that contaminants
35 on resuspended particles will not desorb completely, or even close to completely, in the
36 water column before the particles settle out of the water column. The chemical sorbed to
37 the suspended particles will therefore not reach chemical equilibrium with the chemical
38 dissolved in the water column. It follows that the assumption of equilibrium partitioning
39 is not valid, nor even a good approximation, for the sediments in suspension or in the
40 surficial layers of the bottom sediments.

1 Incidentally, finite rates of adsorption/desorption (1) will assist in explaining the high
2 observed values of PCBs in the surficial sediments of Woods Pond, (2) the high
3 variability in observed PCB concentrations in the sediments, and (3) probably will force a
4 higher n in erosion formulas (consistent with all other data) since non-equilibrium
5 sorption will not be consistent with EPA's imposed constraint due to equilibrium
6 partitioning.

7
8 The conclusion is that finite rates of PCB adsorption and desorption have a major effect
9 on the sediment-water flux due to resuspension/deposition and must therefore be
10 considered in the modeling. (1C)

11 **Calibration and Non-Unique Solutions**

12
13
14 ►As discussed above, the processes which govern the sediment-water flux of HOCs
15 (sediment erosion, sediment deposition, the sediment-water flux due to "diffusion", and
16 equilibrium partitioning) are described incorrectly and inaccurately. Each of these
17 processes can modify the flux by factors of two to ten. Nevertheless, EPA documents
18 indicate that there is good agreement between the calculated and measured suspended
19 solids concentrations as well as contaminant concentrations. At the same time, sensitivity
20 and uncertainty analyses also seem to say that the model is doing a good job. **How can**
21 **this be? Are accurate models of sediment and contaminant transport and fate really**
22 **unnecessary?**

23
24 The answers to these questions are in the non-uniqueness of calibrated solutions and the
25 nature of sensitivity and uncertainty analyses. More specifically, it seems that a modeler
26 can assume a wide range of parameters to describe a particular process and still
27 "calibrate" the model so as to determine a mathematical solution which agrees with
28 observations over some time interval. As discussed above, examples of parameters
29 which significantly affect flux processes are (1) different values of the power n in erosion
30 formulas (this gives greatly different erosion rates at high shear stresses depending on the
31 value of n), (2) different parameterizations for settling speeds, (3) different process
32 models and parameters for the sediment-water flux due to "diffusion", and (4)
33 equilibrium partitioning (equivalent to high reaction rates), frozen reaction rates, or
34 anything in between. Calibration of a model does not guarantee that the processes in the
35 model are described properly. At the risk of being repetitive, a water quality modeler can
36 always get good agreement between calculated and observed quantities for a limited time
37 interval and limited conditions, whether the fundamental processes are described properly
38 or not. Another modeler, with quite different descriptions of processes and/or different
39 parameters in his/her model, can get equally good agreement between the calculated and
40 observed quantities. However, future predictions by the different models and modelers
41 will be quite different. This has been demonstrated repeatedly (e.g., see comments on
42 Fox River modeling (Tracy and Keane 2000) in my comments of May 2005). In other
43 words, **calibration is necessary but not sufficient. (1)**

1 ►As applied to the Housatonic, sensitivity and uncertainty analyses are asking the wrong
2 questions. They do not question whether the basic processes are formulated correctly.
3 As an example, equilibrium partitioning is assumed. Sensitivity and uncertainty analyses
4 never question this assumption, never demonstrate that it is an inaccurate assumption, nor
5 do they propose a suitable reaction rate. **(13)**

6
7 ►Since equilibrium partitioning is not valid, a new parameter (the sorption rate) is
8 introduced into the problem. Among other things, this invalidates EPA's statement
9 (when speaking of non-unique solutions) that "there is a constraint imposed by PCB
10 transport that results from resuspension and deposition processes." This constraint, if it
11 exists, is incorrect because non-equilibrium sorption would impose an entirely different
12 constraint than that imposed by equilibrium partitioning. **(1C)**

13 14 ►Numerical Gridding

15
16 With the present grid, the width of the river is generally approximated as one cell. In the
17 Housatonic, as in most rivers, there are large differences in erosion between the deeper
18 and the shallower parts of the river. Predicting the dissimilar amounts of
19 erosion/deposition across a cross-section of the river is crucial in predicting the long-term
20 exposure of PCBs by erosion and/or natural recovery by deposition. Averaging across
21 the cross-section does not describe the erosion/deposition process accurately. A
22 minimum of three cells across the river (two shallow, near-shore cells and one deeper,
23 center cell) should be used.

24
25 In the floodplain, our knowledge of the basic processes of erosion/deposition and the
26 non-erosional/depositional flux is poor. Because of this, a very coarse grid can be used to
27 approximate the processes in this area.

28
29 A better description of the bathymetry of the river will increase the computational time.
30 Drastically decreasing the number of grid cells in the floodplain will significantly
31 decrease the computational time. The computational time can also be decreased by (a)
32 separating the hydrodynamics, sediment transport, and contaminant transport calculations
33 and (b) for small and moderate flows, approximate and calculate the hydrodynamics and
34 transport as a sequence of steady-state solutions and only treat big events in detail. **(4)**

35 36 Unexplained Results of the Present Model

37
38 ►During previous peer review meetings, John List as well as others including myself
39 (but John was most vocal) have emphasized (a) the large unexplained variance in the
40 PCB concentrations in the surficial (six inch) layer of the sediments and (b) the
41 unexplained high concentrations of PCBs in the surficial layers of the sediments in
42 Woods Pond.

43
44 EPA had no explanations for these latter two problems, but also stated that an
45 understanding of these problems was not necessary. An understanding of these problems
46 may not be necessary, depending on your point of view, but the problems themselves are

1 quite interesting, deserve some discussion, and are related to the inaccurate modeling of
2 the basic sediment and contaminant flux processes mentioned above. Some discussion of
3 these problems is given here. **(2A, 2B)**

4
5 ►In my comments above, I emphasized that PCB sorption times are slow relative to
6 particle settling times and that, because of this, equilibrium partitioning (as assumed in
7 the model) was not a good assumption. Consider the effects of this on PCB transport to
8 Woods Pond. The upstream region of the Housatonic is erosional (on the average), and
9 PCB concentrations near the sediment surface are relatively high (because they were
10 deposited at an earlier time before remediation). As these sediments are eroded, PCBs
11 tend to desorb from the suspended sediments but do not reach anywhere near chemical
12 equilibrium before the sediments are deposited, i.e., the PCB concentrations of depositing
13 sediments are much higher than if they had equilibrated in the overlying water. This
14 erosion/deposition may occur several times before the sediments and their sorbed PCBs
15 reach Woods Pond, or it may only occur once, depending on the flow rate and turbulence.
16 Either way, the sediments deposited in Woods Pond will have higher PCB concentrations
17 than if equilibrium partitioning was assumed, as is observed in field measurements but is
18 not predicted by the present model. **(1C)**

19
20 ►As far as the high PCB variance throughout the river is concerned, consider the
21 following. Sediment erosion/deposition depends on the hydrodynamics, e.g., high rates
22 of erosion where the flows are fastest and low rates of erosion (or deposition) where the
23 flows are slow. Because of this, large variations in erosion rates occur across the river
24 (shallow, near-shore areas versus deeper channels in the middle) as well as along the
25 river. This is well illustrated in previous calculations of sediment transport in rivers
26 (Saginaw River (Cardenas et al. 1995), Fox River (Jones et al. 2000)) when a reasonably
27 fine grid was used, i.e., 5 to 11 grid points across the river. Because of the coarse
28 numerical grid, this is not described by the present model. i.e., everything in the model is
29 averaged or smoothed. In some areas (e.g., upstream and/or in the center of the channel
30 where flows are high), mostly erosion occurs and PCB concentrations reflect deposition
31 at an earlier time and are relatively high. These sediments will be transported
32 downstream and will deposit in a non-uniform manner depending on the hydrodynamics.
33 These sediments will retain their high PCB concentrations. In other areas (e.g.,
34 sediments from above the upstream boundary, near-shore depositional areas which have
35 received clean sediments from further upstream, or areas where deposition is slow such
36 that surficial sediments can equilibrate with the cleaner overlying water), the PCB
37 concentrations of surficial sediments may be quite low. Slow transport and multiple
38 resuspension/deposition events can also cause low PCB concentrations of surficial
39 sediments.

40
41 Because of episodic events, the dependence of erosion/deposition of sediments on highly
42 variable hydrodynamics, the highly variable sources of PCBs (e.g., clean from far
43 upstream, contaminated from deep in the sediments, differences between near-shore,
44 shallow areas and the deeper channel in the center), and of course slow PCB desorption
45 rates (which causes sediments to retain their PCB sorbed concentrations, either high or

1 low), it seems quite plausible that PCB concentrations will be highly variable in space
2 and time in the Housatonic. The present model smooths this all out.

3 **Does this matter?** If the only purpose of the model is to duplicate known results, then
4 accurate models of sediment and contaminant transport and fate don't matter. However,
5 if the model is to be used for predictive purposes, then accurate process models do
6 matter. In the predictive mode, future conditions (such as sediment properties,
7 contaminant concentrations in the sediments, concentrations and types of benthic
8 organisms, sediment-water fluxes, flow rates, etc.) will be modified (for example by
9 dredging, capping, or extreme environmental conditions), will change with time, and will
10 be different from those for which the model was calibrated. The basic processes in the
11 present and future are the same. However, their relative effects and significances depend
12 on the modified conditions and will change with time. If the models describing the basic
13 processes have incorrect functional behavior and/or inaccurate parameters, then the
14 model will not predict the long-term behavior properly. Because of this, for the long-
15 term prediction of sediment and contaminant fluxes, it is essential that the functional
16 behavior and parameters of the most significant processes in the model be described
17 correctly. (3A)

18 19 **Summary and Suggestions**

20
21 ►In the present model, erosion rates are too low (n is too small). During big events,
22 erosion rates may be as large as, or greater than, 10 times that predicted at present. The
23 major effect of this will be on the maximum depth of erosion during big events. A better
24 analysis of Sedflume results as suggested in the attached report will determine a higher
25 and more reasonable value for n. The coefficients in Eqs. (3), (4), and (5) should vary
26 throughout the river as required by the data. (1A)

27
28 ►In the present model, deposition rates are also too low. Deposition rates are essentially
29 a calibrated parameter and are determined such that the suspended solids concentration is
30 calculated properly. If erosion rates are increased, deposition rates must also be
31 increased in order to maintain good agreement between calculated and observed
32 suspended solids concentrations. (1A)

33
34 ►Equilibrium partitioning is not a valid assumption. Desorption rates are relatively slow
35 such that, when bottom sediments are resuspended, the sorbed PCBs do not desorb
36 sufficiently rapidly for equilibrium partitioning to be approached before particle
37 deposition occurs. The result is that PCBs sorbed to the suspended solids are not in
38 equilibrium with the PCBs dissolved in the water. The sediment-water flux of PCBs due
39 to resuspension/deposition is therefore much lower than that predicted by equilibrium
40 partitioning, as is assumed in the present model. A finite sorption rate between the PCBs
41 sorbed to the solids and the dissolved PCBs needs to be added to the model and will
42 replace the equilibrium assumption. (1C)

43
44 ►The sediment-water flux of PCBs due to "diffusion" as calculated by the present model
45 is too low. The formulation of this flux and its parameters are also incorrect. The mass
46 transfer coefficient, k, was given a value of 1.5 cm/day, constant throughout the river;

1 this value was chosen on the basis of calibration, not on the basis of any field or
2 laboratory measurements.

3 Since the PCB flux due to resuspension/deposition should be smaller than that predicted
4 by the present model, the PCB flux due to “diffusion” must increase, strictly on a
5 calibration basis, to compensate for this; it must also increase on the basis of a more
6 fundamental investigation of molecular diffusion and bioturbation (Deane et al. 1999,
7 Lick et al. 2006, Luo et al. 2006). In these articles, it is shown that k due to “diffusion”
8 of HOCs has a lower limit of 1.2 cm/day (no organisms) and increases to 10 cm/day (10^4
9 oligochaetes/m²) and even greater for larger numbers of organisms, i.e., the sediment-
10 water flux due to “diffusion” may be significantly greater than that predicted by the
11 present model. A realistic value for k should be determined on the basis of the
12 concentrations and types of benthic organisms. When this is done, k will be significantly
13 larger on the average than it is now and will be relatively low upstream but will increase
14 in the downstream direction. **(1B)**

15

16 ►The numerical gridding can be improved by increasing the number of grid cells across
17 the river and decreasing the number of grid cells in the floodplain. **(3A)** ►The
18 calculations of the hydrodynamics, sediment transport, and PCB transport should be
19 separated. **(4)**

20

21 ►The higher than predicted PCB concentrations in Woods Pond as well as much of the
22 variability seen in the sediment PCB concentrations can be explained by finite PCB
23 sorption rates as well as by the variability in the PCB sources and the hydrodynamics.
24 The improved model should be able to predict some of this and at least suggest the
25 reasons for the remaining variability if finite sorption rates are assumed and a finer grid is
26 adopted. **(2A)**

27

28 ►These suggested modifications to the model are relatively simple (except possibly for
29 the re-gridding) and should be able to be accomplished in a year. **(13)**

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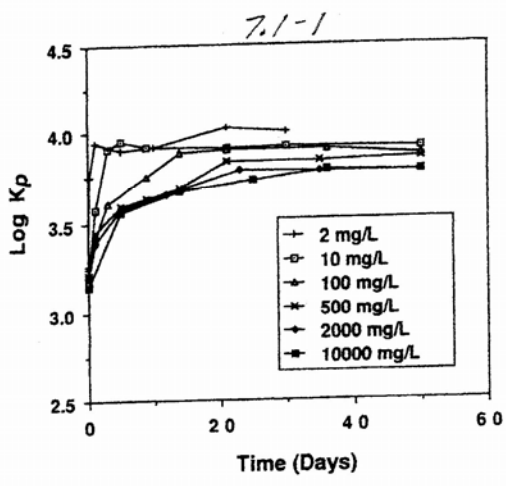
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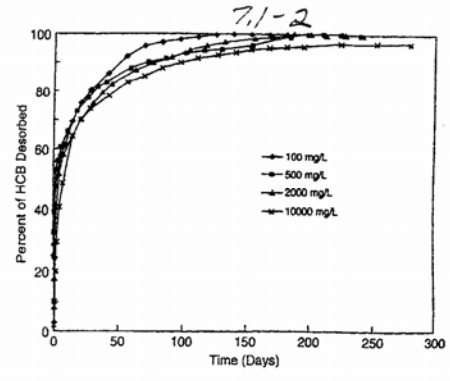
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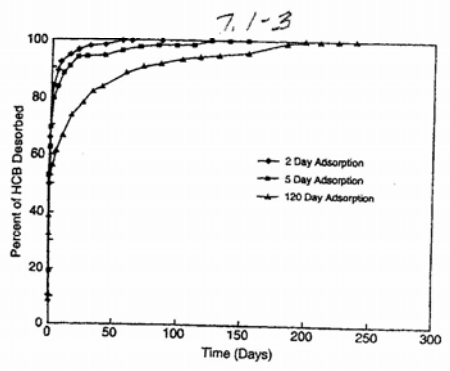
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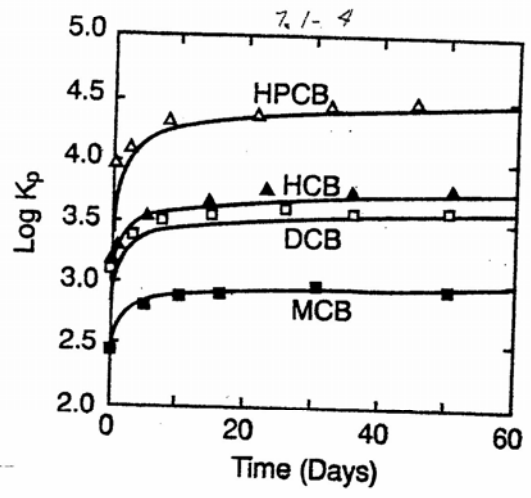
Adsorption experiments with hexachlorobenzene (HCB) and pure water. Log K_p as a function of time for sediment concentrations of 2, 10, 100, 500, 2,000, and 10,000 mg/L [8].



Desorption experiments with hexachlorobenzene (HCB) and pure water. Percent of the initially sorbed HCB which has desorbed is shown as a function of time. Sediment concentrations are 100, 500, 2,000, and 10,000 mg/L [10].



Hexachlorobenzene (HCB) short-term adsorption followed by desorption experiments. The sediment concentration is 500 mg/L. The HCB was first adsorbed to sediments for either 2 d or 5 d and then desorbed. Also shown is long-term adsorption (120 d) followed by desorption, i.e., the standard desorption experiment [10].



Partition coefficients for the adsorption of HCB and three PCB congeners (MCB, DCB, and HPCB) to sediments from the Detroit River. Log K_p is shown as a function of time. Experimental data is shown as open and closed symbols while the modeling results are shown as solid lines.

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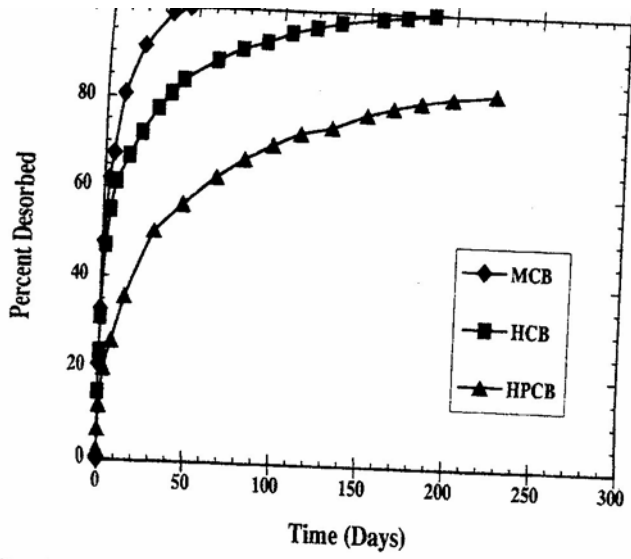


Fig. 8. Desorption experiments with HCB, a monochlorobiphenyl (MCB) and a hexachlorobiphenyl (HPCB). Sediment concentration of 2,000 mg/L.

1

APPENDIX A.7

COMMENTS OF E. JOHN LIST

1 **FINAL RESPONSE TO QUESTIONS FOR MODEL VALIDATION REPORT**

2 by E. John List, Ph.D., P.E.

3

4 ***Introduction***

5 ►The Peer Review Committee (PRC) has spent much time reviewing the results of the
6 modeling exercises and analyzing the modeling performance. It has devoted a significant
7 level of effort to suggestions as to how to improve the model performance and enhance
8 its predictive capabilities in its application to remedial scenarios. However, to my mind
9 the PRC has also perhaps focused excessively on model omissions and shortcomings and,
10 in the process, has tended to overlook the very real benefits that have come from the
11 modeling exercise, benefits that are substantial, irrespective of the perceived model
12 shortcomings.

13 First, I believe that the most valuable aspect of the modeling exercise has been the
14 discipline that has been imposed to the assessment of a detailed Housatonic River mass
15 flux balance for the PCBs, total suspended solids (TSS) and water. The key factor in the
16 assessment of any remedial strategy is going to be how it affects these mass fluxes. The
17 modeling exercise enabled a detailed assessment of the relative order of magnitude of the
18 mass fluxes in the various river system components and how these would change under
19 different source flux hypotheses. Although these absolute fluxes may be somewhat in
20 error due to the model shortcomings (to be discussed below), the relative order of
21 magnitude under different hypotheses enables the key leverage points of control for the
22 PCB fluxes to be identified. The available flux data appear to indicate that, although the
23 modeling may have some problems, at least the predicted orders of magnitude appear to
24 be in the range of available data. This suggests that the flux distributions, as described in
25 Figures 1-5 and 1-6, and Figures 1-9 through 1-15, of the document “EPS Responses to
26 Questions from Model Validation Document Overview Meeting”, are most probably “in
27 the ball park” and, when properly validated, can be used to develop potential remedial
28 strategies. **(13)**

29 ►In general terms, the modeling tends to show excellent agreement for water mass
30 fluxes, which is not at all surprising as models to simulate the flow of water in channels
31 have been in use for a long time and a failure on this score would be cause for real alarm.
32 There is only one adjustable parameter for such models and this is the friction factor for
33 the stream, if this parameter is correctly chosen, and the stream cross-sectional area is
34 correct, then the water levels and flow rates can be very accurately simulated. **(3B)** ►On
35 the other hand, models to simulate the movement of sediment in a fluvial stream are
36 significantly more problematic. The basic difficulty lies in the erodible stream bed. Bed
37 erosion is uniform neither transversally nor longitudinally in the stream. In addition, the
38 bed erosion and the consequent bed form changes result in a change in the stream friction
39 factor, which feeds back into a modification of the hydrodynamics of the flow. **(1A)** ►If,
40 in addition, the stream bank erodes then long term changes in the direction and shape of
41 the channel can result. **(1D)** ►Because the PCBs are an integral part of the stream
42 sediments the difficulties of TSS mass balances carry through to the PCBs. To
43 compound the difficulty, the PCB mass flux has two components: one associated with the
44 sediments and the other with the dissolved phase in the water. A further complication is

1 the kinetics of the partitioning process of the PCB between the water and the sediment,
2 which was a matter of some discussion at the Peer Review meeting and may need
3 addressing. **(1C)**

4 ►EPA and its contractors decided to finesse the problems associated with the non-
5 uniformity of stream bed sediment erosion by using a single computational cell to define
6 the entire width of the river. This means that the bed erosion at any specific river station
7 is defined by the mean bottom shear stress. However, because the actual shear stress on
8 the bed at any location is proportional to the local *depth-averaged* velocity, and the rate
9 of bed erosion (when the shear stress significantly exceeds the critical shear stress) is
10 proportional to the shear stress squared (or an even higher power), it means that the rate
11 of bed erosion in these circumstances is proportional to the fourth power (or even higher)
12 of the mean velocity. Thus, if there is a transverse non-uniform depth-averaged velocity
13 profile *across* the river the rate of bed erosion may vary quite substantially with location
14 on the river cross section. At locations where the depth-averaged velocity is twice that at
15 another location the rate of erosion can be 16 times as great (or even higher). The fact of
16 the matter is that real streams do have widely varying flow velocities across the width of
17 the river and this is the basic reason why the water depth is seldom uniform across the
18 width of the river. It is my professional opinion that it is really inappropriate to attempt
19 to describe the net result of the widely varying rates of erosion that occur in the
20 Housatonic River by using a *cross-sectionally* averaged velocity. The probability that the
21 mean erosion can be parameterized in the model on the basis of cross-sectionally
22 averaged flow properties seems low to me. However, development of a sediment rating
23 curve from the stream data may show that this is possible (see discussion below).

24 It is acknowledged that it is probably quite impracticable to model the sediment transport
25 and at the same time compute the resulting changes in river bottom topography and their
26 effects on the hydrodynamics. It would seem that a logical approach would be to use a
27 quasi-steady approach in which the stream bed is divided transversally into three or more
28 computational elements that enable at least a partial simulation of the bottom profile and
29 the resulting velocity distribution and bed erosion. An alternative would be to take a
30 longitudinal section of the stream and do a detailed three-dimensional computational
31 fluid dynamics (CFD) analysis of the flow distribution and resulting erosion, then
32 compare the results of this analysis to the one-dimensional approach to determine if a
33 realistic one-dimensional parameterization is at all possible. Perhaps the single best
34 alternative approach to this problem is simply to use empirical sediment and flow rating
35 curves, which is the “old fashioned” empirical way these problems were solved before
36 computers became involved (see, for example,
37 <http://www.epa.gov/warsss/sedsource/rivrelat.htm> and
38 <http://water.usgs.gov/osw/techniques/TSS/Horowitz.pdf>, where it is shown that
39 accuracies of $\pm 20\%$ are possible for empirically-derived sediment concentration
40 predictions). Incidentally, the hydraulic modeling could probably also benefit from a
41 comparison of the predicted and actual stage-discharge curves, if this has not already
42 been done. **(3A)**

43 Apart from this basic problem, which is of particular concern to me, other members of
44 the PRC have other fundamental problems that will only be peripherally referenced here
45 in the specific responses to charge questions that follow.

1

2 **Question 1:**

3 Considering the changes implemented in the Phase 2 Calibration, does the model as
4 calibrated and validated, based on your technical judgment, reasonably account for the
5 relevant processes affecting PCB fate, transport, and bioaccumulation in the Housatonic
6 River to a degree consistent with achieving the goal of the modeling study?
7 “i.e., quantify future spatial and temporal distributions of PCBs (both dissolved and
8 particulate forms) within the water column and the bed sediment”

9 **Response:**

10 ►It is my professional opinion that the model does not “reasonably account for the
11 relevant processes”, nor, *in its present state*, can it reliably “quantify future spatial and
12 temporal distributions of PCBs”.

13 One of the reasons for this opinion is encompassed in Figure 4.2-79 of the validation
14 report. This figure indicates, from measured data, that 0-6 inch sediment PCB
15 concentrations within the river and flood plain are spread over three orders of magnitude
16 (0.2-200 mg/kg) at locations that are very close together along the river. Furthermore, for
17 almost 12 miles along the river the variance in the distribution of concentrations appears
18 to be fairly uniform. From the fact that the PCB concentrations appear this way after 30-
19 40 years of river action involving sediment erosion and deposition it is reasonable to
20 conclude that the sediment transport processes are not smoothing the sediment PCB
21 concentration distributions. **(2B)**

22 ►A second reason for this opinion is that recent river bottom survey profiles indicate
23 quite clearly that sediment erosion and deposition is very definitely non-uniform across
24 the river cross-section. By contrast, and as discussed above, the modeling uses a single
25 computational cell to define the entire width of the normal river channel and the local
26 erosion is defined by the fluid shear stress that is averaged across the river cross-section.
27 Because of the non-uniform nature of the actual erosion, and the fact that the model uses
28 an average shear stress to define the erosion, it is highly probable that river bed erosion
29 occurs long before the model predicts its occurrence. Furthermore, the PCB
30 concentration of the sediment that is eroded in the model is the average of the local
31 concentration over that cell. Thus the modeling uses cell averages that reduce the very
32 broad PCB concentration distributions to a local average, and then redeposits that PCB-
33 laden sediment at this average concentration. The net effect of the modeling therefore
34 must be to smooth out the distribution of PCBs, but in reality this has not occurred in the
35 significant length of time in which, according to the model, it should have occurred.

36 Thus, given the fact that the very broad spectrum of PCB sediment concentrations has
37 been present in the river for more than 30-40 years despite continuous sediment erosion
38 and deposition over these years, it is clear that river erosion and deposition processes
39 actually at work do not smooth the PCB distributions. Absent any explanation of how
40 these PCB concentration distributions are developed and maintained over such a long
41 period of time it seems very unlikely that the modeling will provide any believable
42 answers to remediation strategies. This point has been made by me and others
43 previously. Nevertheless, EPA and its contractors still say they do not know what
44 processes are involved with the PCB fate and transport that would give rise to the very

1 wide concentration spectrums observed. However, it is conceivable that the non-uniform
2 erosion and sediment sorting processes not included in the model are indeed responsible
3 for the non-uniform PCB distributions. **(2B)**

4 ►A similar point arises in connection with the Validation Report, on Page 4-12 from line
5 23 et seq. through page 4-13. The high concentrations of PCB in the surface layers of the
6 sediment in Woods Pond (apparent also in Figure 4.2-79) and the lack of an explanation
7 thereof are troubling. Again EPA has thrown up its hands and states that no explanation
8 has been found (see p. 4-13 of the Validation Report). **(2A)**

9 ►In my professional opinion these two items are really key issues in the fate and
10 transport analysis for the PCB. If neither phenomenon can be explained then how can
11 any model hope to represent what is now occurring or, even more important from the
12 point of view of this project, what will occur in the future. The second item I suspect
13 may be a result of not including wind stresses and wind-induced mixing in Woods Pond.
14 Wind waves continually stir up the sediment and when the wind dies the fine sediment
15 (which apparently is high in PCB) settles last and stays there until the next set of wind
16 waves occurs. The wind waves result in a preferential winnowing of fine material into
17 the surficial sediments of the pond. **(13)**

18 ►I recognize the fact that these a very difficult problems to address, but if the modeling
19 is to provide believable predictions of the future fate of the PCB in the sediments it seems
20 to me that the processes that have resulted in the existing PCB concentration distributions
21 have to be understood first. **(2A, 2B)**

22 ***Question 2:***

23 Are the comparisons of the model predictions with data sufficient to evaluate the
24 capability of the model on the spatial and temporal scales of the final calibration and
25 validation?

26 ***Response:***

27 ►The EFDC comparisons between measured and simulated flow and stage offered in
28 Figures 6.2-3 of the Model Validation Report for years 1979-1999 present essentially no
29 measured data and should not be offered up as part of the validation. The comparisons
30 for years 2002-2004 are convincing that EFDC does a good job of representing flow and
31 stage. However, the equivalent time series of Total Suspended Solids (TSS)
32 concentrations for 2002-2004 (Figures 6.2-19 through 6.2-22) do not really provide an
33 adequate basis to conclude that the sediment transport is being properly modeled (which
34 is not surprising considering the points made above). The field data are simply too sparse
35 to make any meaningful comparison between simulation and measured data. Even the
36 data for two specific flow events modeled (Figures 6.2-23 and 6.2-24) offer only a few
37 measured data points for comparison. The use of actual measured sediment rating curves
38 either for calibration or for analysis is urged. The PCB sediment data offered in Figures
39 6.2-49, 6.2-50, and Figure 6.2-51 indicate just how difficult is the process of validating
40 the PCB fate and transport model and how unlikely it will be that the existing model will
41 provide any real hope of predicting the future fate and transport of the PCB. **(3B)**

1 **Question 3:**

2 Is there evidence of bias in the models, as indicated by the distribution of residuals of
3 model/data comparisons?

4 **Response:**

5 ►With respect to the PCB modeling the results are so tenuous (see Figure 6.2-49) that it
6 is not possible to draw any really solid conclusion with respect to bias. However, an
7 important point is demonstrated by Figure 6.2-50. This figure indicates that the sediment
8 concentrations of PCB in the lower reaches of the project study area have declined
9 somewhat since 1990 (i.e., since remediation activity started). Furthermore, there
10 appears to be a similar decline in the water column concentrations of PCB, as is
11 somewhat evident in the lower panel of Figures 6.2-44. (It is noted that there is no
12 statistical measure of the significance of the decline in either the sediment or the water
13 column, but the data are very suggestive). However, the modeling does not give any
14 indication that any similar rate of decline has occurred (see Figure 6.2-50). In fact the
15 comparison between the data and the model in this figure is strongly suggestive that the
16 model does have a bias. The bias of the model is further reinforced by the results of the
17 hypothetical remedial scenarios plotted in the un-numbered figure on page 56 of the EPA
18 Response to Questions from Model Validation (Document DCN: GE-061406-ADFI),
19 where, despite a reduction in the flux of PCB from the sediments in the upper river
20 reaches, there is no significant change in projected sediment concentration of PCBs in the
21 lower reaches. Thus the model does not match the reduction in sediment concentration
22 that has occurred subsequent to actual post-upstream remediation, and projects no
23 reduction as a result of an hypothetical reduction in the upstream PCB flux, as in the
24 hypothetical examples. This problem needs to be understood and/or fixed before the
25 model is used in real applications. **(2A, 10, 13)**

26
27 **Question 4:**

28 Have the sensitivities of the models to the parameterization of the significant state and
29 process variables been adequately characterized?

30 **Response:**

31 ►My opinion is that the underlying processes involved with the PCB fate and transport
32 do not appear well enough understood for a meaningful model to be developed. If the
33 processes that seem to define the PCB fate and transport are not included in the model
34 then their sensitivity cannot be assessed. **(1, 5A)**

35
36 **Question 5:**

37 Are the uncertainties in model output(s) acknowledged and described?

38 **Response:**

39 ►Since the basic processes for the fate and transport of PCB are clearly not properly
40 included in the model their uncertainty cannot be assessed. **(1, 5B)**

41
42 **Question 6:**

43 Upon review of the model projections of changes in PCB concentrations in
44 environmental media in the example scenarios, are such projections reasonable, using
45 your technical judgment, and are they plausible given the patterns observed in the data?
46

1 **Response:**

2 ►I am not a biologist, but having said that, to a layperson the broad distributions of the
3 PCB in the biota appear to be reasonably well described, at least at the central tendency
4 level. This may well be due to the fact that partitioning of PCB into biota appears to be
5 closely associated with the spread of concentrations in the environment. (10, 11) ► In the
6 example scenarios there is no projected effect on the mean PCB concentration in the
7 Woods Pond sediments, which does seem surprising, especially given the results in
8 Figure 6.2-50, where there is a seemingly significant drop in the PCB concentration in the
9 sediment between 1990 and 2000. However, there is a projected rough order of
10 magnitude reduction in the water concentration of PCB in Woods Pond as a result of the
11 hypothetical scenarios. The actual data for Woods Pond referenced above seem to show
12 that there is a reduction in both water column and sediment concentrations coincident
13 with the remediation that has occurred so far. It is not clear why the modeling should
14 necessarily uncouple the water concentration from the sediment concentration in Woods
15 Pond in the hypothetical examples. (10)

16
17 **Question 7:**

18 Is the final model framework, as calibrated and validated, adequate to achieve the goal of
19 the modeling study to simulate future conditions 1) in the absence of remediation and 2)
20 for use in evaluating the effectiveness of remedial alternatives?

21 **Response:**

22 ►I do not think so. For the reasons stated above. (12)

23
24
25 **Overall Response**

26
27 “.....the Panelist shall describe the alternative approach that, in their
28 opinion, would be sufficient to answer the question and achieve the goal of the modeling
29 study.”

30
31 ►The primary difficulty here is that the processes that result in the observed
32 concentration distributions of PCBs in the sediment are not known and therefore cannot
33 be included in the model. Second, the geometry of the system is probably too complex to
34 apply properly the sediment transport theory that is known. However, these difficulties
35 should not prevent the development of adequate empirically-based relationships between
36 observed PCB concentrations and fluxes and the water and sediment fluxes. The
37 sediment transport modeling attempts to use a fine scale theory that is applicable to a
38 uniform flow and applies it over an entire river cross-section as if the river had this
39 uniform flow. Many careful observations in the field, of PCB concentrations and fluxes
40 together with stream flow and sediment fluxes, would have provided empirical
41 relationships that would likely have proven much more accurate, useful and predictable.
42 There is nothing wrong with such empirical relationships when the basic theory is
43 unknown or too complex, and in fact EPA and the USGS already use such relationships
44 (see the two websites referenced above). (13)