



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

New England District  
Concord, Massachusetts



**U.S. Environmental  
Protection Agency**

New England Region  
Boston, Massachusetts

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

DCN: GE-080105-ACUD

January 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 CALIBRATION:  
Modeling Study of PCB Contamination  
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  
Boston, Massachusetts

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## LIST OF ACRONYMS

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ADCP	Acoustic Doppler Current Profiler
ANOVA	Analysis of Variance
BSAF	biota-to-sediment accumulation factor
cfs	cubic feet per second
cm/d	centimeters per day
CMS	Corrective Measures Study
DQO	data quality objective
EDS	energy-dispersive system
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
EqP	equilibrium partitioning
FCM	Food Chain Model
GE	General Electric Company
IMPG	Interim Media Protection Goal
IQG	Information Quality Guideline
m	meter
m <sup>2</sup>	square meter
µg/L	micrograms per liter
MDEP	Massachusetts Department of Environmental Protection
MFD	Modeling Framework Design
mg/kg	milligrams per kilogram
OC	organic carbon
PCB	polychlorinated biphenyl
POM	particulate organic matter
PSA	Primary Study Area
QA	quality assurance
QAPP	Quality Assurance Project Plan
RFI	Resource Conservation and Recovery Act Facility Investigation
SEM	scanning electron microscopy
SNL	Sandia National Laboratories
SOP	standard operating procedure
TEQ	toxic equivalence
TOC	total organic carbon
tPCBs	total polychlorinated biphenyls
TSS	total suspended solids

WOE	weight-of-evidence
WWTP	wastewater treatment plant
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 Calibration Report for the GE/Housatonic River Site Rest of River released in  
5 December 2004. The review was conducted by seven experts in the field of numerical modeling  
6 of aquatic and riverine systems. This document, referred to herein as the Model Calibration  
7 Responsiveness Summary, has been prepared as part of EPA's obligations under Paragraph 22.c  
8 and Appendix J of the comprehensive agreement relating to the cleanup of the General Electric  
9 Company (GE) Pittsfield, MA facility, certain off-site 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 stipulated that the models used will include a hydrodynamic component,  
18 a 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 public comment period provided the opportunity for the public and  
23 GE to submit written comments on the Model Calibration Report for consideration by the Peer  
24 Review Panel, within the context of the Peer Review Charge. On May 4 and 5, 2004, the Model  
25 Calibration Peer Review Panel ("Reviewers") met at a public forum in Lenox, MA, to review  
26 and discuss the Model Calibration Report within the framework of the Charge. During this  
27 meeting, the 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., of Arlington, VA. This  
31 document is EPA's formal response to the final written Peer Review comments.

## 32 APPROACH AND ORGANIZATION OF THIS DOCUMENT

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

## Model Calibration Responsiveness Summary

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1 As a result of these considerations, and to avoid unnecessary repetition and to increase clarity in  
2 the Model Calibration Responsiveness Summary, EPA organized this document so that  
3 responses to general issues are presented first, followed by responses to specific comments.

4 The first section, termed “Response to General Issues,” addresses issues that were raised by a  
5 number of Reviewers and/or had broad implications for the model calibration and for the  
6 modeling study in general. In this first section, EPA has identified 12 General Issues and has  
7 provided a Summary of Issue statement for each to frame the technical basis for the issue and to  
8 provide an indication of how often the issue was noted by the Reviewers. Each Summary of  
9 Issue statement is followed by EPA’s response to the General Issue. Many of the responses to  
10 specific comments from the Reviewers refer back to the responses to the General Issues.

11 The second section is entitled “Response to Specific Comments.” In this section, each  
12 Reviewer’s comments are repeated verbatim in their entirety, grouped according to the structure  
13 of the Model Calibration Report Peer Review Charge. Because some Reviewers also provided  
14 comments outside of the Charge questions, it was necessary to add a section entitled “Overview  
15 Comments” at the beginning of this section, and a section entitled “Additional Comments” at the  
16 end. In each subsection, the comments of the individual Reviewers are presented in alphabetical  
17 order, with responses from EPA inserted at appropriate intervals. As noted above, many of these  
18 comments refer the reader to one or more of the General Issues responses.

### 19 **RELATIONSHIP OF THE MODEL CALIBRATION RESPONSIVENESS SUMMARY** 20 **TO THE MODELING STUDY FOR REST OF RIVER**

21 The comments received from Reviewers on the Model Calibration Report will be used by EPA  
22 in conducting model validation, the third and final component of the Housatonic River modeling  
23 study, and in preparing the Model Validation Report, which will also be subject to Peer Review.  
24 Because the Peer Review comments will be addressed in the subsequent stages of the modeling  
25 study, EPA does not believe it is necessary or appropriate to issue a revised Model Calibration  
26 Report.

27 In conclusion, EPA recognizes the hard work and thought that the Reviewers contributed in  
28 conducting the Peer Review. Although EPA agrees with many of the comments provided by the  
29 Reviewers, EPA does not agree with some of the comments; these are documented in the  
30 responses and, in such cases, the technical basis for EPA’s position is provided. EPA appreciates  
31 the effort from the Reviewers in providing their insights and believes that the modeling study,  
32 and in particular the model validation and report, will benefit greatly from their comments.

1 **RESPONSE TO GENERAL ISSUES**

2 **1. GOALS OF THE MODELING STUDY**

3 **SUMMARY OF ISSUE:**

4 Two Peer Reviewers indicated in their comments that to evaluate the adequacy of model  
5 calibration, it would have been helpful to have a better understanding of how the model will be  
6 used in the evaluation of remedial alternatives. In particular, Reviewers noted in their  
7 comments, and also during discussions at the public meeting, that it is important to know if the  
8 model will be used in a relative manner to compare alternatives to each other, or in an absolute  
9 manner to test the effectiveness of remedial alternatives against some standard or benchmark.

10 **RESPONSE:**

11 Under the terms of the Consent Decree governing the work in the Rest of River,  
12 EPA is to develop a framework for the Housatonic River modeling study and  
13 have it undergo Peer Review at three points: completion of the Framework,  
14 Model Calibration, and Model Validation. Upon completion of the Peer Review  
15 for Model Validation, EPA is to provide the model and all inputs and outputs to  
16 GE for their use in evaluating alternatives in the Corrective Measures Study  
17 (CMS). Neither the Consent Decree nor the Reissued RCRA Permit (Permit)  
18 specify the alternatives to be considered; however, these documents specify that  
19 the alternatives will be proposed by GE after receipt of the model in their  
20 submittal of the Corrective Measures Study Proposal. Thus, it is premature to  
21 begin discussion of the specific alternatives that will be evaluated, other than  
22 baseline conditions.

23 That being the case, it is expected the alternatives for addressing PCBs in the  
24 river channel and floodplain that will be modeled will include not only baseline  
25 conditions (monitored natural recovery), but also various forms of active  
26 remediation. Among the possible active remediation scenarios to be considered  
27 are dredging/excavation, capping, and various combinations of these techniques.

28 Because no reliable long-term estimates of future boundary conditions are  
29 available, the use of the model to predict future concentrations of contaminants  
30 necessarily must be based on a projection of the boundary conditions (flow,  
31 solids, and PCBs) over a period of decades. Because such projections will have  
32 an unknown degree of uncertainty associated with them that will impact model  
33 predictions, predictions of absolute concentrations are not anticipated to be  
34 accurate. Therefore, EPA will focus primarily on comparisons of relative  
35 performance among remedial alternatives against baseline conditions. However,  
36 the model predictions, in spite of the uncertainties noted above, will be the best  
37 estimate available of the potential magnitude of the expected reductions in

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1 exposure and will provide useful information in evaluating the performance of  
2 remedial alternatives.

3 The Interim Media Protection Goals (IMPGs), after approval by EPA, will be used  
4 as preliminary goals in evaluating the performance of the alternatives along with  
5 other factors specified in the Permit. The cleanup standards will be established  
6 by EPA in the Statement of Basis. Therefore, although there are no absolute  
7 criteria that will be used to evaluate model output, the predictions of PCB  
8 concentrations, combined with the results of the uncertainty evaluation, will be  
9 used, in a general way, to assess the effectiveness of alternatives to achieve  
10 target levels.

11 Because the assumption in the risk assessments that receptors average their  
12 exposure across a particular media is carried forward into the application of the  
13 IMPGs, model predictions of interest are the average concentrations of PCBs in  
14 tissue of aquatic receptors, and in water, river sediment, and floodplain soil.  
15 Although it is recognized that there is substantial variability in individual sediment  
16 and fish concentrations within each river reach, reproduction of this variability in  
17 model output is not necessary to achieve the goals of the modeling study;  
18 therefore, EFDC and FCM were not developed to simulate the distributions of  
19 individual PCB concentrations in the media of interest.

## 20 2. APPROACH TO CALIBRATION AND VALIDATION

### 21 SUMMARY OF ISSUE:

22 A majority of the Reviewers commented that the time period of 14 months over which EFDC  
23 was calibrated was too short to reflect many transport processes that may be significant over a  
24 longer duration. One Reviewer suggested a calibration period of 5 years, while another  
25 suggested 10 years. One Reviewer commented that the modeling strategy relied too heavily on  
26 model calibration.

27 In addition, some Reviewers suggested that some years of data be set aside for a “true”  
28 validation simulation, with no adjustments to the model parameterization. One Reviewer  
29 suggested an approach in which some of the originally planned validation period could be used  
30 to improve the calibration, with the remainder reserved for a true validation.

### 31 RESPONSE:

32 EPA agrees with the Reviewers and recognizes the importance of evaluating the  
33 performance of EFDC over periods longer than 14 months. The rationale for  
34 selecting the calibration period for EFDC was summarized in the  
35 Responsiveness Summary to the Peer Review of the Modeling Framework  
36 Design (MFD) and Quality Assurance Project Plan (QAPP) (WESTON, 2002):

37 “The 1999 to 2000 calibration period was selected because this period  
38 coincides with the most recent, detailed data set collected by EPA,

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1 including the data obtained under storm event conditions. In selecting this  
2 1-year period, which was characterized by a fairly wide range of flow  
3 conditions, the strategy is to first perform preliminary calibrations of the  
4 hydrodynamic, sediment transport, and PCB fate models under the higher  
5 flow (out-of-bank) storm event conditions. Next, the model calibration  
6 process will focus on the base flow conditions. Finally, because data were  
7 not collected for an event greater than 1.5 years during the calibration  
8 period, EPA will compare the model simulations to observations for two  
9 large storm events that occurred outside the calibration period (see  
10 Section 11, Rare Flood Events).

11 “EPA believes that the advantages of using the high quality/intensity data  
12 set for model calibration outweigh the fact that the period is too short to  
13 see evidence of natural recovery, which has not been observed over the  
14 entire period of record in the PSA, and that a properly calibrated model will  
15 reliably represent conditions on a decadal scale. The 20-year period  
16 identified for model validation (1979-2000) is sufficient to demonstrate the  
17 ability of the model to simulate processes occurring on decadal time  
18 scales (see Section 22, Validation).”

19 Subsequently, the issue of the lack of change in PCB concentrations over the 14-  
20 month calibration period was discussed in Appendix B, Section B.1.1, of the  
21 Model Calibration Report:

22 “Because the time scale of significant changes in PCB concentrations in  
23 the sediment bed is typically on the order of years, [model validation] will  
24 provide a test of processes that could not be evaluated completely in the  
25 14-month calibration period. It is anticipated that adjustments to some  
26 calibration parameters will be required as part of the long-term validation  
27 phase. Subsequent to model validation, the models will be used to  
28 determine baseline conditions and to evaluate the effectiveness of  
29 remediation alternatives for the PSA.”

30 It is also noted in the Model Calibration Report that longer-term simulations will  
31 provide a more robust or complete test of sedimentation rates and changes in  
32 sediment PCB concentrations simulated by the model.

33 Although the duration of the calibration period received little attention in the  
34 Reviewers’ comments at the time of the Peer Review of the MFD (WESTON,  
35 2000a) and the QAPP (WESTON, 2000b), this topic received attention from a  
36 majority of the Reviewers during the Model Calibration Peer Review. In  
37 response to these comments, EPA has modified the approach for the long-term  
38 simulations. EPA has reallocated the time periods used for calibration and  
39 validation by using the period from 1990 through June 2000 as a Phase 2  
40 Calibration. This time period is consistent with the recommendations of several  
41 Reviewers, with suggestions that the longer calibration period range from 5 to 10

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1 years. The Phase 2 Calibration simulations may result in adjustment to some  
2 model parameters, as expected in a model calibration exercise.

3 After completion of the Phase 2 Calibration, a continuous model simulation of the  
4 period 1979 through 2004 will be executed with no adjustments to model  
5 parameters. Model-data comparisons for the periods from 1979 through 1989,  
6 and July 2000 through 2004 will be presented as demonstrations of this model  
7 validation. With this approach, the model-data comparisons from the calibration  
8 period will be distinct from the model validation. In addition, EPA has extended  
9 the model domain downstream to include Reaches 7 and 8 for inclusion in the  
10 validation runs.

## 11 **References:**

12 WESTON (Weston Solutions, Inc.). 2000a. *Modeling Framework Design:*  
13 *Modeling Study of PCB Contamination in the Housatonic River.* Prepared for  
14 U.S. Army Corps of Engineers and U.S. Environmental Protection Agency.  
15 DCN GE-100500-AADX.

16 WESTON (Weston Solutions, Inc.). 2000b. *Quality Assurance Project Plan:*  
17 *Modeling Study of PCB Contamination in the Housatonic River.* Prepared for  
18 U.S. Army Corps of Engineers and U.S. Environmental Protection Agency.  
19 DCN GE-100500-AADY.

20 WESTON (Weston Solutions, Inc.). 2002. *Responsiveness Summary to the Peer*  
21 *Review of the Modeling Framework Design and Quality Assurance Project*  
22 *Plan: Modeling Study of PCB Contamination in the Housatonic River.*  
23 Prepared for U.S. Army Corps of Engineers and U.S. Environmental  
24 Protection Agency.

## 25 **3. MODEL CONSTRUCT**

### 26 **SUMMARY OF ISSUE:**

27 Three Reviewers commented on the structure of the linked models, primarily with the limitation  
28 that the computational requirements of EFDC place on addressing other desirable model  
29 questions. One Reviewer noted that the time necessary for each model run impacts the number  
30 of runs that can be used to explore model sensitivity and uncertainty. Another Reviewer  
31 recommended that a three-dimensional model be used for the river and a two-dimensional model  
32 be used for the floodplain. All three of these Reviewers suggested ways in which the  
33 computational burden could be reduced by modifying the way in which certain components of  
34 the models are linked and/or making changes to the model grid.

### 35 **RESPONSE:**

36 Innovative methods for reducing computational time have been considered over  
37 the course of model development. Several of these innovative approaches were

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1 implemented, while others were judged to be either ineffective or unnecessarily  
2 complex.

3 Ways to reduce computational time that were implemented during the model  
4 development effort included use of both a dynamic time step and a split time  
5 step; bypassing sections of model grid that are only changing slowly, if at all,  
6 during discrete periods of time; and conducting simulations for selected portions  
7 of the calibration period (e.g., high-flow events).

8 Unlike many models, which require a fixed time step during the entire simulation,  
9 EFDC allows the use of a dynamic time step; longer time steps were used during  
10 low-flow periods and shorter time steps were used during the less-frequent high-  
11 flow periods. EFDC also allowed implementation of a “split” time step  
12 (calculating derivatives in sediment cells less often than in the water column),  
13 which is appropriate because processes in the sediment generally occur on  
14 longer time scales than those in the water column.

15 Large portions of the model grid were bypassed during most of the simulation  
16 period, when flows were within the riverbanks. A majority of the grid cells in the  
17 model domain represent the floodplain, and it is only necessary to perform  
18 calculations in these cells during the infrequent periods when the floodplain is  
19 inundated.

20 Simulations for monitored storm events during which high-frequency data were  
21 collected were performed to evaluate the effect of model parameterizations  
22 without incurring the computational time necessary to conduct the full time-  
23 variable simulations. These selected periods were eventually included within a  
24 longer continuous simulation to eliminate potential artifacts that were introduced  
25 by assigning initial conditions in the sediment for the individual storm events.

26 Additional modifications that were examined and implemented included  
27 optimization of solution schemes and benchmarking performance of the model  
28 with a range of FORTRAN compilers and compiler options to determine the best  
29 combination for model simulations.

30 Ways to reduce computational time that were evaluated but not implemented  
31 included separating the three submodels of EFDC, use of a hybrid grid, flow  
32 binning, and parallel processing.

33 Separating the EFDC hydrodynamic simulation from the sediment transport and  
34 PCB fate simulations could be useful, but this would also decouple the feedback  
35 between the hydrology and sediment transport models in each time step, which  
36 was considered to be an important feature of a model of the Housatonic River  
37 system given the morphological changes in the river that have been observed.

38 Use of a model grid that differs substantially with respect to the degree of  
39 resolution and dimensionality in the main channel and the floodplain (three-  
40 dimensional versus two-dimensional, respectively) would make it more difficult to

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1 achieve conservation of momentum. The severity of this problem depends on  
2 how finely the bathymetry is represented with the variable grid resolution that is  
3 assigned to the channel and to the floodplain. The implementation of this  
4 approach for the Housatonic River would be extremely difficult, given the sharp  
5 meanders and variations in channel bathymetry.

6 Further, if the recommendations of the Reviewers were implemented it would  
7 also be necessary to incorporate a higher-resolution three-dimensional grid in the  
8 channel. This modification by itself would increase model simulation time and it is  
9 not clear if the net effect of the changes would, in fact, be a reduction in  
10 simulation time (see response to General Issue 4).

11 Use of average concentrations and/or flows to represent discrete flow intervals is  
12 another approach that has been used in other modeling studies with varying  
13 success. The effectiveness of this approach, commonly referred to as “binning,”  
14 depends on how coarsely the model inputs are binned. Use of steady-state flow  
15 conditions to span extended periods of time will reduce run time, but could also  
16 introduce a cumulative error that could become significant over a long-term  
17 simulation. There is a tradeoff between accuracy and the degree of binning that  
18 can be implemented, with greater improvements in simulation time but decreased  
19 accuracy as the number of discrete flows (i.e., flow bins) used to represent the  
20 hydrograph is decreased. Use of a series of steady-state flow bins would also  
21 produce a reduction in the variability of results simulated by the model, another  
22 issue that Reviewers commented on.

23 The approaches recommended by the Reviewers discussed above would also  
24 impact the evaluation of uncertainty, which the Reviewers indicated to be of  
25 importance. Analyses to evaluate some aspects of uncertainty would become  
26 more feasible with reduced computational requirements, but the uncertainty  
27 associated with the approximations could not be assessed readily.

28 The parallelization of the EFDC code was also evaluated as a means of reducing  
29 run time. However, it was concluded that the benefit of running EFDC on  
30 multiple processors was less than could be achieved by running the entire code  
31 on separate processors simultaneously.

### 4. NUMBER OF GRID CELLS ACROSS CHANNEL

#### SUMMARY OF ISSUE:

All seven Reviewers commented that the representation of the main river channel with a width of one cell in the EFDC model grid was problematical and did not allow for accurate simulation of the lateral variation for certain important processes and variables. Processes and parameters noted most often in this regard included flow, sediment-water contaminant flux, bottom shear stress, and erosion potential. One Reviewer noted that the necessary lateral averaging of parameters used to evaluate the calibration (e.g., TSS) would have the effect of artificially improving the apparent goodness of calibration. Most Reviewers recommended a minimum of three lateral cells to represent the channel.

In general, the Reviewers recognized that the use of multiple lateral cells to represent the channel may lead to computational difficulties, and in some cases, suggested ways in which the computational burden of additional channel cells might be reduced.

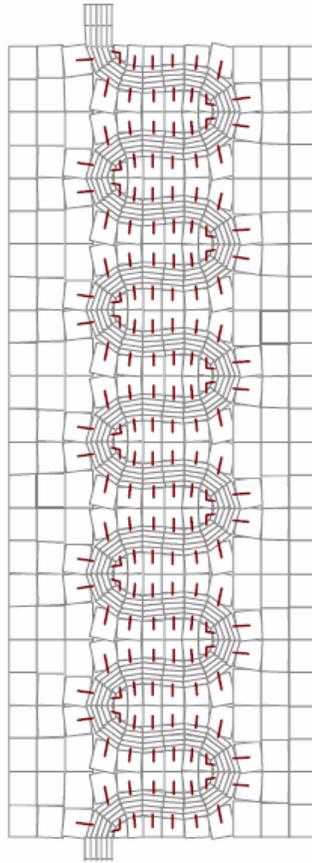
#### RESPONSE:

The complexity of the Primary Study Area (PSA) poses a challenge for developing a computationally efficient but physically comprehensive model. Due to the complex bathymetry and morphology of the Housatonic River, the circulation and flow regimes are also complex.

At the time of the MFD Peer Review, EPA proposed the following regarding the EFDC grid:

“The primary focus of the grid development effort proposed in the MFD is on the use of a curvilinear grid for primary channel/proximal floodplain (called the “main channel”) and a separate linked grid which represents the distal floodplain (see the following Figure, where the inner three cells represent the river channel, the outer two cells represent the proximal floodplain, connected to the distal floodplain cells).” (EPA Response to Peer Review Panelist Questions on the Housatonic River Modeling Framework Design, 4/12/2001, pp. 54-55).

Several Reviewers criticized this representation of the river by three grid cells across the channel width. One Reviewer discussed the importance of secondary flows, implying that he thought a three-dimensional representation of the river channel was required, and recommended against the use of the computational grid shown in Figure GI-4-1. Another Reviewer commented that a three-dimensional grid was not necessary, but recommended additional resolution in the river channel that would result in 4 to 5 cells across the river in much of the model domain. Other Reviewers believed that simpler approaches would be better.



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**Figure GI-4-1 Grid Proposed by EPA During MFD Peer Review**

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It is well known that flow in a river, especially in the vicinity of a river bend, is fundamentally a three-dimensional process. Rozovskii (1957) conducted one of the first hydraulic experiments of secondary circulation created by a steady, open channel flow around a bend. In his research he showed that as the river flow enters the bend, it veers toward the outside bank due to centrifugal acceleration. This, in turn, piles up water at the outer wall of the bend, creating a water level slope in the cross-channel direction, a phenomenon known as superelevation. A secondary (lateral) circulation cell is thus established by the three-dimensional balance of centrifugal acceleration, barotropic pressure gradient, and vertical shear stress; water flows toward the outer bank at the surface, downwells, flows back toward the inner bank at the bottom, and upwells there. Superimposed on this secondary circulation is the primary movement of water downstream, completing the phenomenon known as helical motion. Boxall et al. (2003) conducted hydraulic experiments to evaluate the effect of channel curvature on the transverse mixing coefficient of a meandering open channel, concluding that the transverse mixing coefficient varies in direct relation to channel curvature and that the variation is cyclic with geometry: it increases at the apex of the bend, and decreases in straighter regions.

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1           However, recognizing the practicalities associated with modeling large, complex  
2 river systems, the state-of-the-art in river modeling (Choi and Kang, 2004;  
3 Makhanov et al., 1999; Yoon and Kang, 2004) is to use vertically integrated  
4 model physics (one layer), which is the approach used in the Housatonic River  
5 modeling study. Although previous studies use this approach, it is recognized  
6 that the limitations on the representation of the physics impose certain  
7 constraints.

8           To properly represent the cross-section of a river, on the order of 10 grid cells are  
9 required (Alan Blumberg, personal communication, 2005). The use of three  
10 boxes may seem to provide a way to include lateral structure in the flow field, but  
11 three boxes in a numerical model cannot simulate any of the lateral dispersion  
12 because at least five boxes are required to represent the second derivative of the  
13 velocity field (Alan Blumberg, personal communication, 2005). In addition,  
14 incorporating lateral segmentation in the channel would increase the time  
15 required to perform multi-decadal simulations to several months. Moreover, it  
16 makes little sense to dramatically increase the lateral grid resolution without also  
17 using three-dimensional model physics, which is infeasible because of  
18 computational resource constraints.

19           Several Reviewers, in their comments on the MFD, recognized that a three-  
20 dimensional model was neither feasible nor necessary, and in several cases  
21 recommended that EPA consider a one-dimensional model:

22                   “A three-dimensional, time-dependent model consumes much more  
23 development and computational time and is probably no more accurate in  
24 practice than a two dimensional, time-dependent model (with a correction  
25 for quasi-equilibrium distribution of sediment in the vertical). This latter  
26 model is also much more computationally efficient. This has been shown  
27 in numerous cases. Even for the pond, a two-dimensional model is  
28 sufficiently accurate to predict sediment and PCB transport.” (W. Lick, May  
29 17, 2001)

30                   “It is likely that a useful model could be developed that was restricted to in-  
31 bank flow. It is also highly likely that modeling of the significant over bank  
32 flows could also be successfully completed. However, it would require a  
33 different model in each case. In fact, one-dimensional models are widely  
34 used for these purposes. Specific examples include HEC-2 (Corps of  
35 Engineers), NWS Flood Wave, Fischer Delta Model (Hugo B. Fischer,  
36 Inc.), DWRDSM2 (Calif. Dept. of Water Resources), and there are  
37 probably many others.” (J. List, May 22, 2001)

38           Once the decision was made in response to the Reviewers’ comments on the  
39 MFD not to use a three-dimensional segmentation of the water column, much of  
40 the ability to explicitly account for the lateral processes was eliminated.  
41 Therefore, the use of a vertically integrated equation set introduces the need to  
42 use parameterizations in place of an explicit representation.

## Model Calibration Responsiveness Summary

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1 A practical, numerically efficient, yet accurate approach using a variable-  
2 resolution orthogonal curvilinear grid was taken to discretize the entire PSA. The  
3 grid is designed to follow the main channel as much as possible. The typical grid  
4 spacing is on the order of 20 meters (m). The use of a grid resolution of 20 m  
5 within the main channel results in nearly the entire channel width being covered  
6 by a single cell. This coarse segmentation does not provide the ability to  
7 simulate the lateral variations in flow known to exist in a meandering channel.  
8 However, the grid is able to incorporate the floodplain, main channel, adjacent  
9 backwaters, and the complex oxbows near the headwaters of Woods Pond as a  
10 contiguous system, responding to Reviewers' concerns about the "nested grid"  
11 proposed in the MFD.

12 Decisions on grid resolution need to balance the level of physics the model is  
13 capable of simulating and that is needed to achieve the goals of the study,  
14 computational resources, and other considerations. EPA believes that the  
15 current curvilinear grid achieves such a balance, including the extent of coverage  
16 of the PSA by the grid, the ability of the grid to adequately represent the river  
17 channel, and the use of vertically integrated physics.

### 18 **References:**

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23 natural open channel flows. *J. Hydraulic Res.* 41:153-165.

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28 Review Panelist Questions on the Housatonic River Modeling Framework  
29 Design. April 2001.

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32 4, pp. 407-414. April 1999.

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35 Engineering, Kiev. Translated from Russian by Y. Prushansky, Israel Program  
36 for Science Translation, S. Monson, Jerusalem. PST Catalog No. 363. 233  
37 pp.

## Model Calibration Responsiveness Summary

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1 Yoon, T., and S. Kang, 2004. Finite volume model for two-dimensional shallow  
2 water flows on unstructured grids. ASCE, *J. Hydraulic Engineering*, Vol. 130,  
3 No. 7, pp. 678-688. July 2004.

### 4 **5. PCB FATE**

#### 5 **SUMMARY OF ISSUE:**

6 Four Reviewers commented on the high degree of small-scale spatial variability in PCB  
7 concentrations in main channel sediment, but differed on the implications of the variability for  
8 achieving the goals of the modeling effort. One Reviewer indicated that the inability of the  
9 model to reproduce variability on such a small scale is to be expected and does not constitute a  
10 problem for the modeling. Another Reviewer simply indicated that the spatial variability was  
11 “perplexing” because of the lack of apparent temporal variability. A third Reviewer, however,  
12 saw both the lack of knowledge concerning the process or processes that led to such variability,  
13 and the inability of the model to reproduce the variability, as a major issue that makes the  
14 modeling approach followed thus far “inappropriate.”

15 Five of the seven Reviewers recommended that volatilization be considered for inclusion as a  
16 loss process in the contaminant transport portion of the model, with most indicating that they  
17 believed volatilization could be significant and therefore, should be included. One Reviewer  
18 noted that any calculations done to estimate potential loss due to volatilization should be based  
19 on more current values for Henry’s Law constant than were used in the Resource Conservation  
20 and Recovery Act Facility Investigation (RFI). Two Reviewers noted that volatilization loss  
21 would be particularly important from the floodplain because of the relatively greater exposure  
22 area and solar heating.

23 One Reviewer recommended that the modeling effort focus on modeling of individual PCB  
24 congeners, rather than the current approach of modeling total PCBs (tPCBs) within EFDC and  
25 adding the modeling of selected coplanar congeners in FCM. This Reviewer noted that  
26 modeling of tPCBs is not the “state-of-the-art in modeling methodology” but also recognized  
27 that computational considerations for EFDC would make such an approach difficult. The  
28 Reviewer also provided an approach to evaluating model bias that makes use of congener-  
29 specific model results, and further recommended that congener-specific degradation rates be  
30 included in the modeling.

#### 31 **RESPONSE:**

#### 32 **Small-Scale Spatial Variability and Equilibrium Partitioning**

33 EPA is also not satisfied with the lack of a mechanistic explanation of PCB fate  
34 processes for the small-scale variability, and spent considerable effort attempting  
35 to develop such an explanation. However, EPA does not agree with the  
36 Reviewers who believed that the lack of such an explanation compromises the  
37 ability of the model to achieve the goals of the modeling study. In addition, EPA  
38 does not agree that there is any inconsistency between the presence of

## Model Calibration Responsiveness Summary

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1 pronounced small-scale variability and the inability to resolve temporal variability  
2 in the data. The sampling design was not intended to provide data relative to  
3 short-term temporal variability and any such temporal variability that does exist  
4 would be masked by the spatial variability.

5 The small-scale variability noted by Reviewers was identified as part of the  
6 benthic community investigations, which involved collection of 12 replicate grab  
7 samples of sediment from a small area, in some cases less than 1 square meter  
8 (m<sup>2</sup>). Results of PCB analyses of aliquots from these samples indicated  
9 variability in some locations of over two orders of magnitude in PCB  
10 concentrations, with no such differences apparent in other factors known to be  
11 correlated with contaminant concentration (e.g., sediment grain size, total organic  
12 carbon [TOC]). Although this high degree of variability was observed in eight of  
13 the nine benthic community sampling locations in the PSA, it is assumed to occur  
14 throughout the PSA because other efforts were made to resample specific  
15 locations with the result being highly variable PCB concentrations over small time  
16 scales as well.

17 In addition to the small-scale spatial variability in PCB concentrations, EPA also  
18 noted that a subset of the samples in Reach 5A did not follow traditional  
19 equilibrium partitioning (EqP) behavior. In these samples, PCB concentrations  
20 were elevated well above concentrations that would be predicted based on  
21 organic carbon content and, consequently, these samples appeared as outliers  
22 when the data were carbon-normalized. As part of the investigation of this latter  
23 phenomenon, microscopic examination of samples of Reach 5A sediment  
24 indicated the presence of a film or coating on individual quartz grains. Samples  
25 were sent to Sandia National Laboratories (SNL) and examined by scanning  
26 electron microscopy (SEM), X-ray diffraction (XRD), and energy-dispersive  
27 system (EDS) via microprobe. These studies indicated the presence of carbon  
28 and chlorine in the film, which was identified by the Sandia scientists as  
29 representing PCBs present in the film. This resulted in EPA's working hypothesis  
30 that PCBs in these samples are present as a recalcitrant coating on individual  
31 quartz particles, with consequent reduced bioavailability.

32 It is possible that the two phenomena, i.e., small-scale spatial variability and high  
33 PCB concentration surface films on individual sand particles, are related.  
34 Transport of the coated grains is a stochastic process that could result in greater  
35 numbers of these grains in some samples than others, even over very small  
36 spatial scales. The presence of a greater or lesser number of such particles  
37 could affect the overall PCB concentration in a sample without apparent  
38 differences in other sediment characteristics. This hypothesis would also explain  
39 the observation that some sediment does not conform to EqP theory because of  
40 the presence of greater amounts of coated sands. The greatest amount of small-  
41 scale spatial variability in PCB concentrations was observed in Reach 5A, where  
42 higher energy hydrodynamics result in greater amounts of coarse sand in bed  
43 sediment. This hypothesis, however, would not appear to explain the variability  
44 also observed at benthic community sampling locations in Reach 5C, where

## Model Calibration Responsiveness Summary

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1 relatively small fractions of the sediment are sand, unless a similar phenomenon  
2 is occurring on the cohesive size fractions, which is not known.

3 Regardless of the explanation(s), or lack thereof, for these phenomena, EPA  
4 believes that it is not necessary to understand the processes that underlie them,  
5 or to include such processes, or the resultant variability, in the modeling  
6 framework. With regard to small-scale variability in PCB concentrations, the  
7 variability occurs on a spatial scale that is far smaller than the cells of the  
8 modeling grid; therefore, the model grid is unable to resolve these differences or  
9 to make use of any process-oriented explanation that might be developed.  
10 Because both human and ecological receptors are exposed to the range of  
11 concentrations in an area rather than only to the concentration in an area  
12 equivalent to a benthic grab sample, they act as integrators of the variability in  
13 concentrations and the exposure point concentration (EPC) of interest is larger  
14 than an individual model grid cell. Transport processes are simulated on a scale  
15 that affects the bed sediment in each model cell equally, so again it is not  
16 necessary to explicitly account for the small-scale variability.

17 In the case of sediment that does not conform to EqP theory, the only component  
18 of the modeling framework that is potentially affected is the bioaccumulation  
19 model. The issue of sediment that does not conform to EqP theory was analyzed  
20 and discussed at length in the Model Calibration Report (Section C.3.1.2)  
21 (WESTON, 2004b) and a procedure was developed to arrive at adequate  
22 calibration. EPA believes that the proposed approach will achieve the goals of  
23 the modeling study.

### 24 **Volatilization**

25 In the October 2000 Modeling Framework Design (MFD) document that was  
26 reviewed by the Peer Review Panel in 2002, volatilization was described as a  
27 potentially important process that was still being evaluated for inclusion in the  
28 modeling framework (Section 3.3.4.2). No comments were received from the  
29 Reviewers on the inclusion or exclusion of volatilization as a process in the  
30 model during Peer Review of that document.

31 As discussed in Section 4.5.5 of the final MFD (WESTON, 2004a), an analysis of  
32 the potential importance of volatilization was conducted by BBL and QEA and  
33 presented in the RFI Report. Using conservative assumptions to derive an  
34 upper-bound estimate, and using a Henry's Law constant derived from published  
35 values (Brunner et al., 1990), that analysis concluded that the loss of water  
36 column PCBs via volatilization in Woods Pond under low-flow conditions would  
37 be only 5%. Accordingly, EPA indicated in the final MFD that the process of  
38 volatilization was not sufficiently significant to be included in the modeling study.

39 In response to comments received from Reviewers regarding the decision to  
40 exclude volatilization as a PCB fate process, and particularly in response to a  
41 comment from one Reviewer providing a reference to more recent Henry's Law

## Model Calibration Responsiveness Summary

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1 constants for PCBs (Bamford et al., 2000), EPA has reanalyzed the potential loss  
2 of PCBs from the PSA via volatilization. The reanalysis was conducted based on  
3 congener-specific Henry's Law constants and the relative congener composition  
4 of the predominant Aroclors present in the PSA (A1260 and A1254). The results  
5 of the reanalysis indicate that volatilization loss of PCBs from the main channel  
6 reaches is likely still an insignificant fate process; however, the increased  
7 residence time of contaminated surface water in backwaters could result in  
8 sufficient loss of PCBs to justify inclusion of volatilization in the modeling  
9 framework. Accordingly, EPA will now include volatilization as a loss process in  
10 the contaminant transport component of the model, and has modified the EFDC  
11 code to activate the volatilization subroutine.

12 EPA does not believe, however, that it is necessary or advisable to include  
13 volatilization from the floodplain as a loss process. The concentration of PCBs  
14 present in the vapor phase in the soil is extremely low, even considering the  
15 updated Henry's Law constants; therefore, volatilization loss of PCBs from the  
16 floodplain does not represent a significant PCB fate process in the PSA.  
17 Inclusion of this process in the floodplain would require each floodplain cell to be  
18 evaluated at every time step, rather than the current practice of performing  
19 calculations in floodplain cells only when the floodplain is inundated. This would  
20 represent a considerable computational burden and would compromise many  
21 other aspects of the modeling study, without commensurate gain, particularly  
22 considering the substantial uncertainty involved in parameterizing this process.

### 23 **Modeling of PCB Congeners**

24 As discussed in Section 4.5.4 of the final MFD, EPA recognizes that individual  
25 PCB congeners exhibit different behavior with respect to chemical, physical, and  
26 biological processes that control transport and fate, and agrees that modeling of  
27 individual congeners could be included in a "state-of-the-art" modeling study. It is  
28 important, however, to evaluate the efficacy of the current modeling framework  
29 and model calibration in the context of the goals of the modeling study and the  
30 intended use of the model. As discussed in the response to General Issue 1, the  
31 Housatonic River model is intended to be used to differentiate between the  
32 effectiveness of a limited number of remedial alternatives, and to estimate the  
33 time necessary for tPCBs, which is the primary measure of PCB concentrations  
34 of interest in the risk assessments, in fish tissue and other media to reach certain  
35 concentrations under those alternatives. With that overall objective in mind, the  
36 question of whether it is necessary to model individual congeners can be  
37 addressed in two forms:

- 38     ▪ Is it necessary to have information on congener concentrations to distinguish  
39       between the relative effectiveness of remedial alternatives?
  
- 40     ▪ Is it necessary to model individual congeners to arrive at a simulated  
41       concentration of tPCBs that can be used to compare relative effectiveness of  
42       remedial alternatives, or to compare to a standard or other established  
43       concentration?

## Model Calibration Responsiveness Summary

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1 EPA believes it is clear that the response to the first question is that it is not  
2 necessary. Whatever processes may be operating differentially on individual  
3 congeners, and whatever errors, if any, may be introduced by simplifying the  
4 complex behavior of a mixture of PCBs into “average” properties for the mixture,  
5 would operate similarly for the various remedial alternatives tested via the model.  
6 Consequently, modeling tPCBs will satisfy the first overall goal of the modeling,  
7 that of comparing the relative effectiveness of remedial alternatives.

8 The second question will be addressed by the results of the model calibration  
9 and validation, which is being conducted on tPCBs (except for the modeling of a  
10 few selected congeners as a test of the robustness of the bioaccumulation  
11 model). If the calibration and validation efforts can achieve adequate agreement  
12 with data using the tPCB approach, that outcome will be sufficient demonstration  
13 that it is not necessary to model individual congeners. Based on the results seen  
14 to date, EPA believes that the final results of the ongoing calibration and  
15 validation will provide just such a demonstration.

16 In addition, as discussed in detail in Section 3.5 of the final MFD, PCB congener  
17 composition is relatively stable throughout the various reaches and media in the  
18 PSA and downstream. Because of this relative stability, it is possible to use  
19 observed ratios of concentrations of individual congeners to tPCBs to calculate  
20 probable concentrations for selected congeners from data on tPCBs. This  
21 approach was used, for example, in the Human Health Risk Assessment to  
22 evaluate risk due to coplanar PCB congeners that contribute to TEQ risk.  
23 Therefore, the fact that individual congeners are not modeled explicitly does not  
24 preclude applying the results of the modeling study to specific questions involving  
25 individual congeners.

### 26 **References:**

27 Bamford, H., D. Poster, and J. Baker. 2000. Henry's Law constants of  
28 polychlorinated biphenyl congeners and their variation with temperature. *J.*  
29 *Chem. Eng. Data* 45:1069-1074.

30 Brunner, S., E. Hornung, H. Santi, E. Wolff, O.G. Piringer, J. Altschuh, and R.  
31 Brüggemann. 1990. Henry's Law constants for polychlorinated biphenyls:  
32 Experimental determination and structure-property relationships. *Environ. Sci.*  
33 *Technology* 24:1751-1754.

34 WESTON (Weston Solutions, Inc.). 2004a. *Modeling Framework Design:*  
35 *Modeling Study of PCB Contamination in the Housatonic River.* Prepared for  
36 U.S. Army Corps of Engineers and U.S. Environmental Protection Agency.  
37 DCN GE-042104-ACDP.

38 WESTON (Weston Solutions, Inc.). 2004b. *Model Calibration: Modeling Study of*  
39 *PCB Contamination in the Housatonic River.* Prepared for U.S. Army Corps of

## Model Calibration Responsiveness Summary

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1 Engineers and U.S. Environmental Protection Agency. DCN GE-122304-  
2 ACMG.

### 3 **6. DEPTH OF SEDIMENT BIOAVAILABLE LAYER**

#### 4 **SUMMARY OF ISSUE:**

5 Three Reviewers indicated that the 6-inch active (mixed or bioavailable) layer depth used in the  
6 model during the Calibration was too thick. These Reviewers did not agree on an alternative  
7 depth for this layer, and suggested values that ranged from 3 inches (7.5 cm) to as little as  
8 approximately 1 inch (2.5 cm). All three Reviewers agreed that the value assigned as the depth  
9 of this layer would have a significant effect on model results, and particularly on the estimated  
10 time necessary for natural recovery of the system.

#### 11 **RESPONSE:**

12 EPA agrees that the depth of the bioavailable sediment layer is important for the  
13 prediction of long-term PCB fate. In Attachment C.19 of the Model Calibration  
14 Report, rationales were provided for the use of a 6-inch surface layer in providing  
15 unbiased estimates of a biologically relevant exposure depth over the calibration  
16 period. For longer-term simulations, a better estimate of the well-mixed sediment  
17 layer was required. It was acknowledged in Attachment C.19 that a 6-inch (15-  
18 cm) layer may “overestimate the depth to which most bioturbation occurs in  
19 Housatonic River sediment.”

20 An extensive literature review has been conducted to refine the estimates of the  
21 depth of biological mixing in sediment. The methods and results of the literature  
22 review are provided in Attachment 1 (Freshwater Bioturbation Depth) to this  
23 Responsiveness Summary. A summary of the main findings is provided in Table  
24 GI-6-1. Based on the review of the literature on freshwater bioturbation, and  
25 considering site-specific data on habitat and resident benthic communities,  
26 bioturbation depths were estimated for each of three PSA habitat types. The  
27 biologically mixed depth, which represents the sediment layer that is thoroughly  
28 mixed due to bioturbation, is estimated to range from approximately 4 cm to  
29 approximately 10 cm across the PSA, depending on habitat. Deeper, but less-  
30 pronounced, biological mixing is estimated to occur at depths up to 20 cm below  
31 the sediment-water interface (i.e., biologically influenced depth). The ranges of  
32 biologically mixed depths provided in Table GI-6-1 are similar to the estimates  
33 provided by the Reviewers and also by GE in the comments on the Model  
34 Calibration Report (QEA, 2005).

35 In the application to long-term model simulations, the range of values for  
36 bioturbation depths in Table GI-6-1 will be used as one factor to guide the  
37 specification of biologically mixed depth and biologically influenced depth. The  
38 selected values will be combined with mixing coefficients that reflect the  
39 differences in magnitude of mixing within these surface sediment layers and the

## Model Calibration Responsiveness Summary

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1 final parameterization will be compared to the site-specific data to ensure  
2 reasonableness. Additional abiotic sediment mixing (i.e., erosion and deposition)  
3 is handled separately within EFDC. For the EFDC to FCM model linkage, the  
4 bioavailable depth will be defined as computationally equivalent to the  
5 biologically mixed depth.

6 **Table GI-6-1**

7 **Summary of Biological Mixing Depths Applicable to the PSA**

Habitat		Biologically Mixed Depth Interval *	Biologically Influenced Depth Interval *
1	Upstream main channel (Reach 5A)	0 – 4 cm	4 – 10 cm
2	Downstream (Reaches 5B, 5C, Woods Pond)	0 – 8 cm	8 – 15 cm
3	Backwaters (Reach 5D)	0 – 10 cm	10 – 20 cm

9 \* The depths shown represent depth intervals below the sediment surface. The total bioturbation  
10 depth is represented by the bottom of the biologically influenced depth interval (e.g., 10 cm for  
11 Reach 5A). Definitions for terms are provided in Section 1.2 of Attachment 1.

12 **Reference:**

13 QEA (Quantitative Environmental Analysis, LLC). 2005. *Comments of the*  
14 *General Electric Company on the U.S. Environmental Protection Agency's*  
15 *Model Calibration: Modeling of PCB Contamination in the Housatonic River.*  
16 Prepared for General Electric Company, Pittsfield, MA by Quantitative  
17 Environmental Analysis, LLC, Liverpool, NY. February 7, 2005.

18 **7. RESUSPENSION AND DEPOSITION**

19 **SUMMARY OF ISSUE:**

20 Three Reviewers commented on the formulation and calibration of the processes of resuspension  
21 and deposition in the EFDC sediment transport model. These Reviewers indicated that processes  
22 involving multiple variables may be inadvertently calibrated incorrectly because offsetting errors  
23 in individual parameters may produce satisfactory agreement with the data to which the  
24 parameters are being calibrated. These Reviewers also expressed concern that incorrect values  
25 for the parameters of resuspension and deposition could nonetheless lead to correct prediction of  
26 total suspended solids (TSS).

27 In extensive comments regarding this issue, one Reviewer provided a detailed discussion of  
28 resuspension processes, indicating the exponent used in the model formulation for calculating  
29 resuspension on the basis of excess shear stress was incorrect and recommending additional  
30 Sedflume experiments. This Reviewer was also critical of the effect that the 6-inch sediment  
31 active layer would have on the process of bed armoring. The Reviewer also commented on the

# Model Calibration Responsiveness Summary

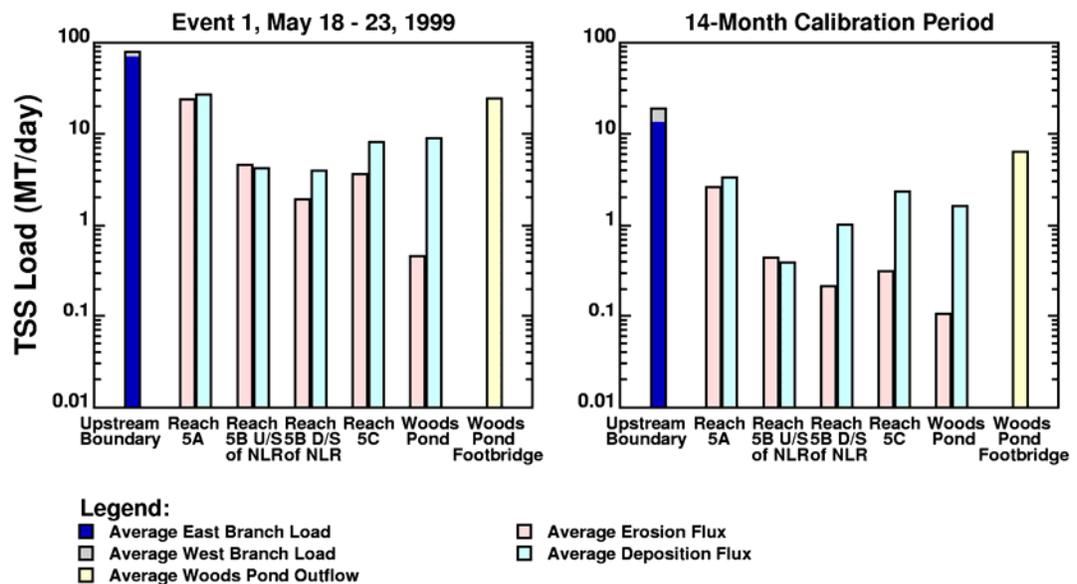
1 deposition formulation used in the EFDC model, indicating that a formulation for time-  
 2 dependent flocculation is available and should be included.

## 3 **RESPONSE:**

4 There are several technical issues included within this General Issue; they are  
 5 discussed individually below.

## 6 **Role of Resuspension Flux in Overall Solids Balance**

7 Numerous figures in the Model Calibration Report summarize the net effect of  
 8 sediment resuspension and deposition processes. Evaluation of these figures  
 9 led one Reviewer to question if the sediment bed of the PSA is a significant  
 10 source of solids transported within the model domain. In Figure GI-7-1, the  
 11 magnitudes of erosion and deposition are summarized by reach and compared to  
 12 the solids entering the upstream boundary and exiting the downstream boundary.  
 13 Because water column measurements at New Lenox Road reflect the effect of  
 14 resuspension and deposition processes in Reach 5A and only a portion of Reach  
 15 5B, results for Reach 5B are separated into two subreaches, upstream and  
 16 downstream of New Lenox Road. Results are summarized for two time periods,  
 17 Event 1 (May 18-23, 1999), which was the largest monitored event, and the 14-  
 18 month Phase 1 Calibration period.



19

20 **Figure GI-7-1 Erosion and Deposition Flux by Reach for Storm Event 1 and**  
 21 **14-Month Calibration Period**

## Model Calibration Responsiveness Summary

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1 During the 5-day period associated with Event 1, the mass of solids resuspended  
2 from the main channel of the PSA was 43% of the mass of solids entering the  
3 upstream boundaries. Over the 14-month Phase 1 Calibration period,  
4 resuspension within the PSA was approximately 20% of the solids input at the  
5 upstream boundaries. Resuspension mass fluxes during the May 1999 high-flow  
6 event were approximately an order of magnitude greater than the averages over  
7 the Phase I Calibration period, a difference that is consistent with the conceptual  
8 model for sediment transport. A consistent pattern of decreasing magnitude of  
9 resuspension fluxes in the downstream direction was apparent over both periods  
10 due to the decreasing velocity resulting from the increase in cross-sectional area  
11 and backwater effects from Woods Pond Dam. Resuspension fluxes in the  
12 higher-energy environment of Reach 5A account for approximately 70% of the  
13 resuspension fluxes from the river channel over both time periods. These results  
14 are consistent with EPA's conceptual model, in which resuspension is an  
15 important process in the Housatonic River PSA.

### 16 **Constraints on Resuspension and Deposition Rates**

17 Data describing changes in channel cross section, radioisotope data (used to  
18 estimate net sedimentation rates), and water column suspended solids  
19 concentrations reflect the net effect of solids deposition and resuspension. Some  
20 Reviewers expressed concern that an infinite number of combinations of different  
21 resuspension and deposition rates could be specified to reproduce water column  
22 suspended solids, without any constraints on the pairs of rates selected. This  
23 concern does not recognize that there is a constraint imposed by PCB transport  
24 that results from resuspension and deposition processes.

25 Mr. Endicott recognized this point in his comments, noting:

26 "In some other river systems, errors in deposition and resuspension fluxes  
27 are revealed during calibration of water column PCB concentrations,  
28 because the concentration gradient between sediment and water amplifies  
29 the error. In the PSA this will not work so well, because there is only a  
30 small gradient between suspended and bedded particulate PCB  
31 concentrations." (see Specific Response 1-DE-8).

32 It is acknowledged that the difference between water column and bed sediment  
33 particulate PCB concentrations in the Housatonic River may not be as large as in  
34 some other systems, when compared on a whole sediment basis. However, the  
35 difference in concentrations is amplified considerably when the PCBs associated  
36 with the fine sediment fraction are compared to the water column particulate  
37 PCBs. This is because the fine sediment fraction is higher in organic carbon  
38 content and thus, has a relatively high dry weight PCB concentration as well (see  
39 Calibration Report Figures B.4-22 through B.4-25).

40 Because the fine sediment fraction is the predominant fraction that contributes to  
41 the resuspension flux, the PCB concentration associated with the fines serves as

## Model Calibration Responsiveness Summary

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1 a useful tracer that places a constraint on the flux of solids to the water column.  
2 The solids flux between the water column and sediment bed needs to be such  
3 that water column TSS levels are correctly simulated, although it is  
4 acknowledged that correct simulation of TSS can be achieved by a combination  
5 of incorrect settling and resuspension rates and therefore, is not, in itself,  
6 sufficient for demonstrating calibration. However, the spatial profile of water  
7 column PCB concentrations provides an additional constraint on the magnitude  
8 of the settling and resuspension fluxes of TSS to the water column. In  
9 combination, these comparisons (for both solids and PCBs) indicate the  
10 reasonableness of the calibrated model.

11 To demonstrate the constraints that water column PCB concentrations place on  
12 the specification of resuspension and settling rates, an alternate parameterization  
13 of resuspension and deposition was specified for a simulation of Event 1. The  
14 alternate parameterization consisted of a reduction in the critical shear stress for  
15 cohesive solids resuspension and an increase in the cohesive solids settling  
16 velocity, resulting in an increase in the exchange between water column and bed  
17 solids. Results from the original Phase 1 Calibration and this alternate  
18 parameterization of resuspension and deposition are presented in Figure GI-7-2.  
19 Although the increased resuspension flux of solids from the bed was offset by  
20 increased deposition, and similar water column TSS profiles were achieved,  
21 water column PCB concentrations increased by approximately a factor of five,  
22 making the simulation results from the alternate parameterization inconsistent  
23 with the data. Thus, Mr. Endicott's observation regarding the constraint that  
24 reproducing both suspended solids and water column PCB concentrations  
25 imposes on parameterization of resuspension and deposition applies to the  
26 Housatonic River, and the satisfactory reproduction of water column PCB  
27 concentrations demonstrates that resuspension and deposition processes have  
28 been parameterized correctly.

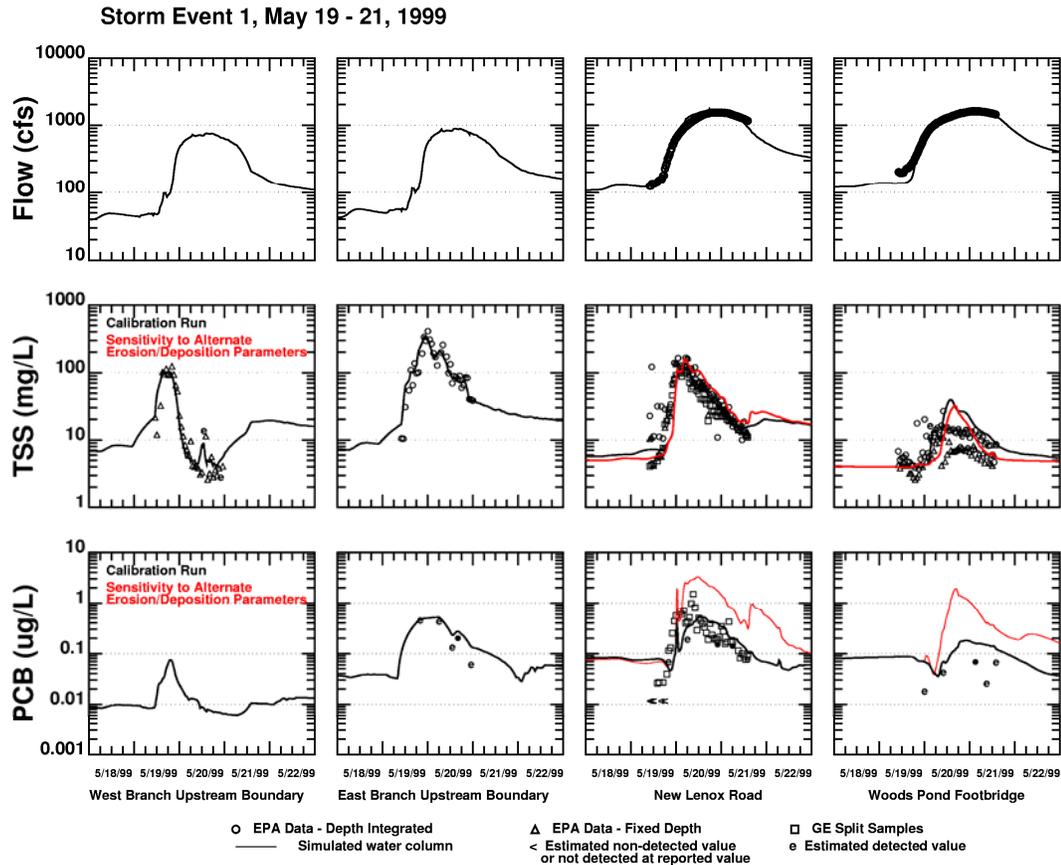
### 29 **Non-Cohesive and Cohesive Transport Formulations**

30 With regard to the questions raised regarding transport formulations, there are a  
31 number of formulations accepted by modelers in common practice representing  
32 transport in riverine systems, with no consensus on which formulation is most  
33 applicable to a particular system. There are five individual processes that,  
34 collectively, comprise the transport formulations:

- 35 ▪ Deposition of non-cohesive solids.
- 36 ▪ Deposition of cohesive solids.
- 37 ▪ Erosion of non-cohesive solids.
- 38 ▪ Resuspension of cohesive solids.
- 39 ▪ Bedload transport of non-cohesive solids.

40 Deposition of non-cohesive solids is described by the formulations in van Rijn  
41 (1984), which are well established and have been used in numerous sediment  
42 transport models.

# Model Calibration Responsiveness Summary



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**Figure GI-7-2 Concentrations of Total Suspended Solids (TSS) and PCBs for Original and Alternate Phase 1 Model Calibration**

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Deposition of cohesive solids is a complicated process that is affected by variations in, for example, mineralogy, grain size distribution, and suspended solids concentration. This process can be represented at different levels of complexity, ranging from constant settling velocity to complex flocculation models. The settling velocity used in EFDC is a function of the weighted average of the settling velocities for washload and suspended load. The EPA modeling team's efforts to implement Dr. Lick's simple flocculation model, in response to a recommendation provided during the Calibration Peer Review, are discussed below.

12

13

The equations used to describe the erosion of non-cohesive solids were developed by Garcia and Parker (1991) based on comparisons between simulations and experimental and field observations. Particle sorting and hiding mechanisms that are responsible for bed armoring for non-uniform sediment mixtures are included in the formulation.

17

## Model Calibration Responsiveness Summary

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1 Resuspension of cohesive solids is highly site-specific, and generic equations  
2 similar to those discussed above for erosion of non-cohesive solids are not  
3 available for cohesive solids. The parameterization of resuspension of cohesive  
4 solids used in EFDC was based on analysis of erosion data collected in the  
5 Sedflume experiments on Housatonic River sediment. This analysis was  
6 presented in Attachment B.5 of the Model Calibration Report.

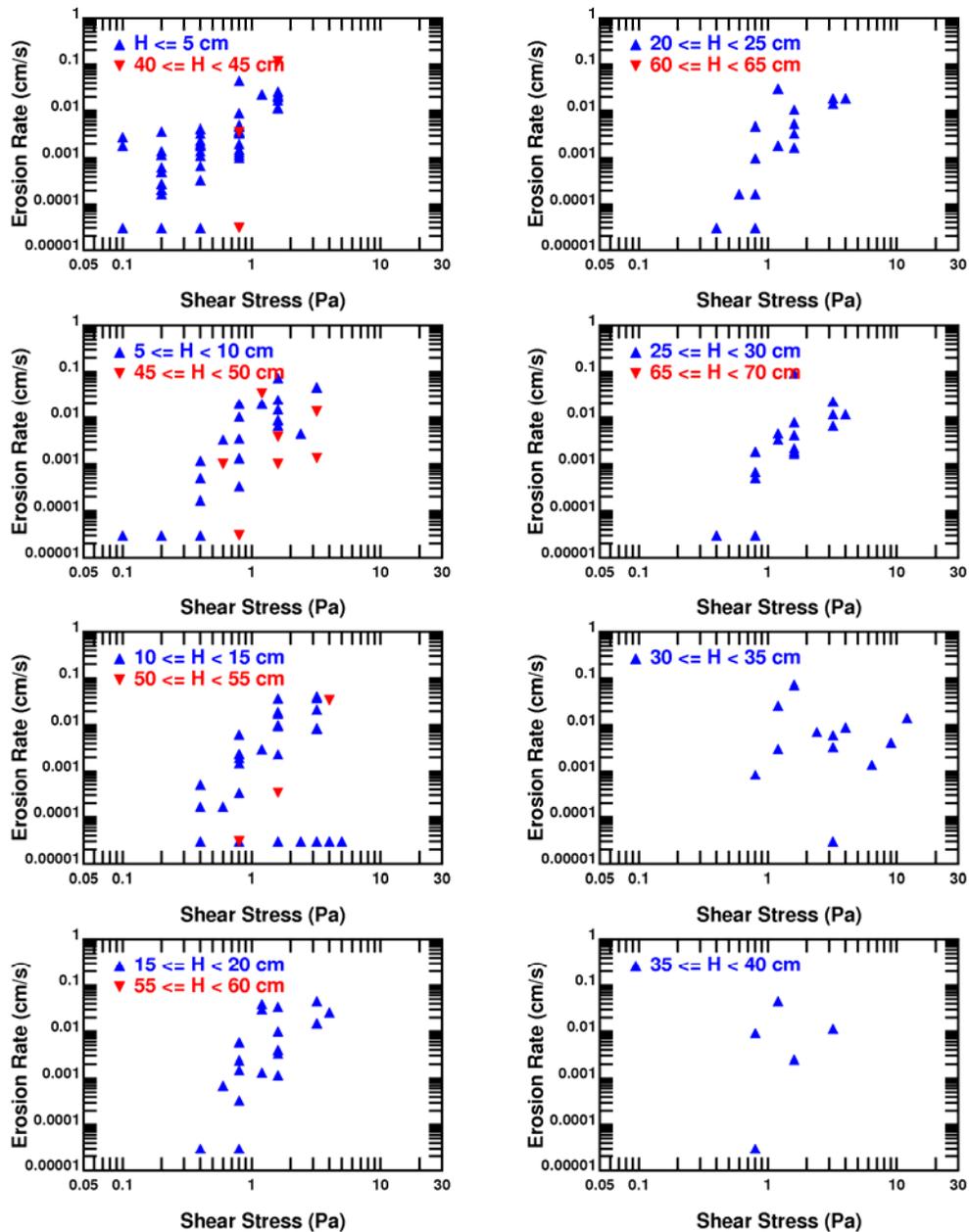
7 The Sedflume data were also reanalyzed in accordance with the approach and  
8 formulations suggested by Dr. Lick in his review comments; however, the  
9 variability in the Housatonic River data was not explained by those equations and  
10 analytical approach. The results of the analysis are shown in Figures GI-7-3a, b,  
11 and c. Each figure displays the data for a different particle size ( $D_{50} < 30 \mu\text{m}$ ,  $30$   
12  $\mu\text{m} \leq D_{50} < 100 \mu\text{m}$ , and  $D_{50} \geq 100 \mu\text{m}$ , respectively) to reduce the particle size  
13 effect, and each panel presents data for different depth intervals (<5 cm, 5–10  
14 cm, 10-15 cm, etc.) in an effort to account for changes in bulk density. When  
15 stratified in this manner, there is still considerable scatter in the data, an  
16 indication that factors other than particle size and bulk density are affecting the  
17 magnitude of the shear stress needed to resuspend Housatonic River sediment.

18 The range of shear stresses applied in the Sedflume experiments conducted on  
19 Housatonic River sediment cores encompassed a high percentage of the range  
20 of shear stresses encountered in the PSA, and therefore, the formulations  
21 derived from the site-specific data do not need to be extrapolated substantially  
22 beyond the range of the data, even in application to extreme flow conditions.  
23 Differences between the exponent of the cohesive solids erosion formulation  
24 derived from analysis of site-specific Sedflume data and the central tendency of  
25 values derived from Sedflume experiments on other systems do not contribute to  
26 substantial differences in cohesive solids erosion because of the relatively small  
27 range of extrapolation beyond the range of the site-specific data.

28 Non-cohesive bedload transport was described by the modified Engelund-  
29 Hansen formulation (Wu et al., 2000), which has been used in other sediment  
30 transport models. The Engelund-Hansen formulation was selected from the  
31 formulations available within EFDC because it had a number of desirable  
32 characteristics, including the ability to represent the effect of variation in sediment  
33 grain size within an individual grid cell, and the parameterization could be  
34 assigned from available site-specific information. The formulation also produced  
35 reasonable agreement with site-specific bedload data (Section B.3.2.3.2; Figure  
36 B.3-22) collected as part of EPA's monitoring efforts to support the modeling  
37 study.

38 EPA believes that the model, as modified in response to the Peer Reviewers'  
39 comments, is able to adequately simulate sediment/contaminant transport in the  
40 study area and will provide a useful tool to evaluate the relative performance of  
41 potential remedial alternatives.

# Model Calibration Responsiveness Summary



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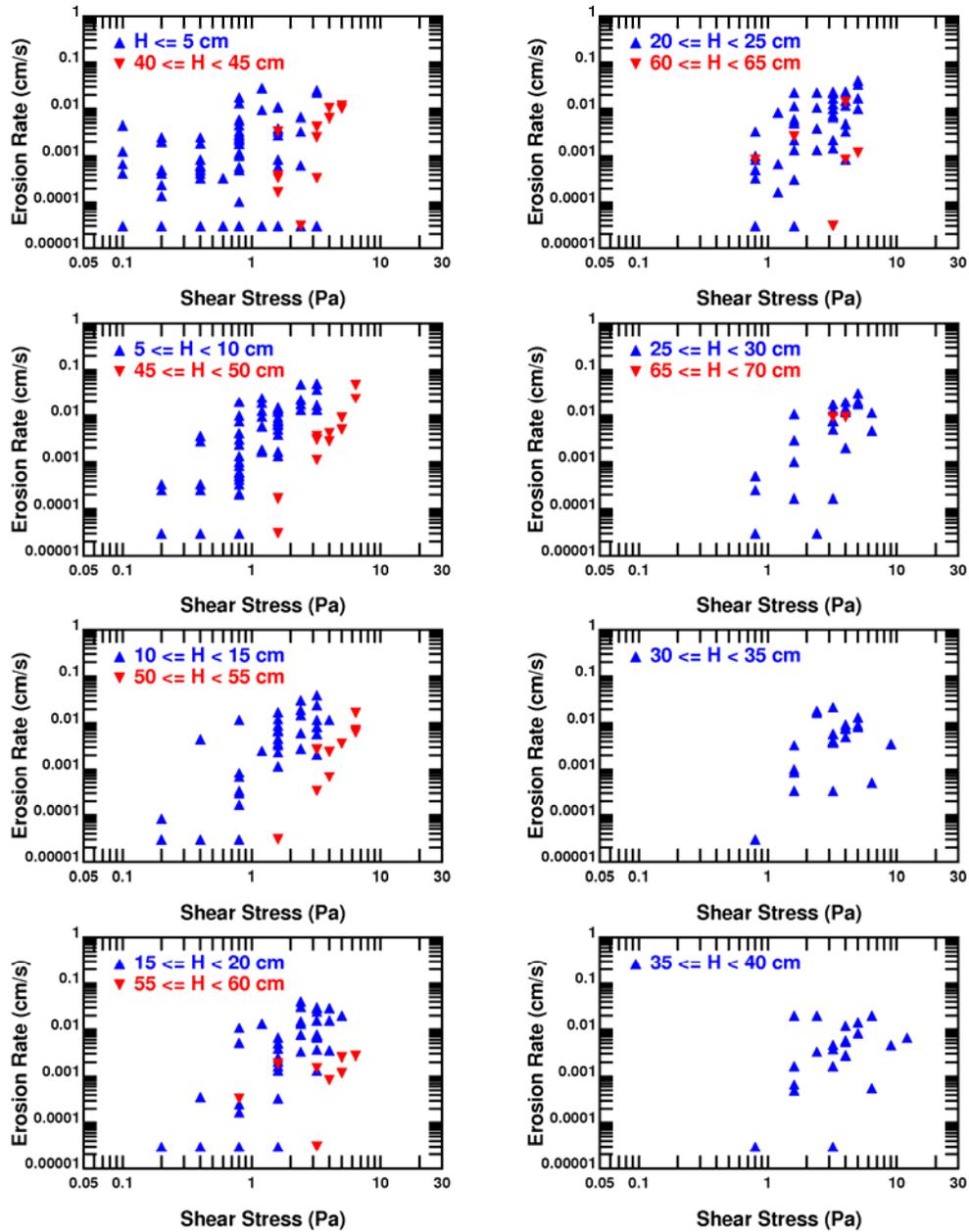
2

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4

**Figure GI-7-3a Erosion Rate Versus Shear Stress (as a function of depth in core) for Sedflume Experiments on Sediment with Median Particle Diameter ( $D_{50}$ ) Less than 30  $\mu$ m**

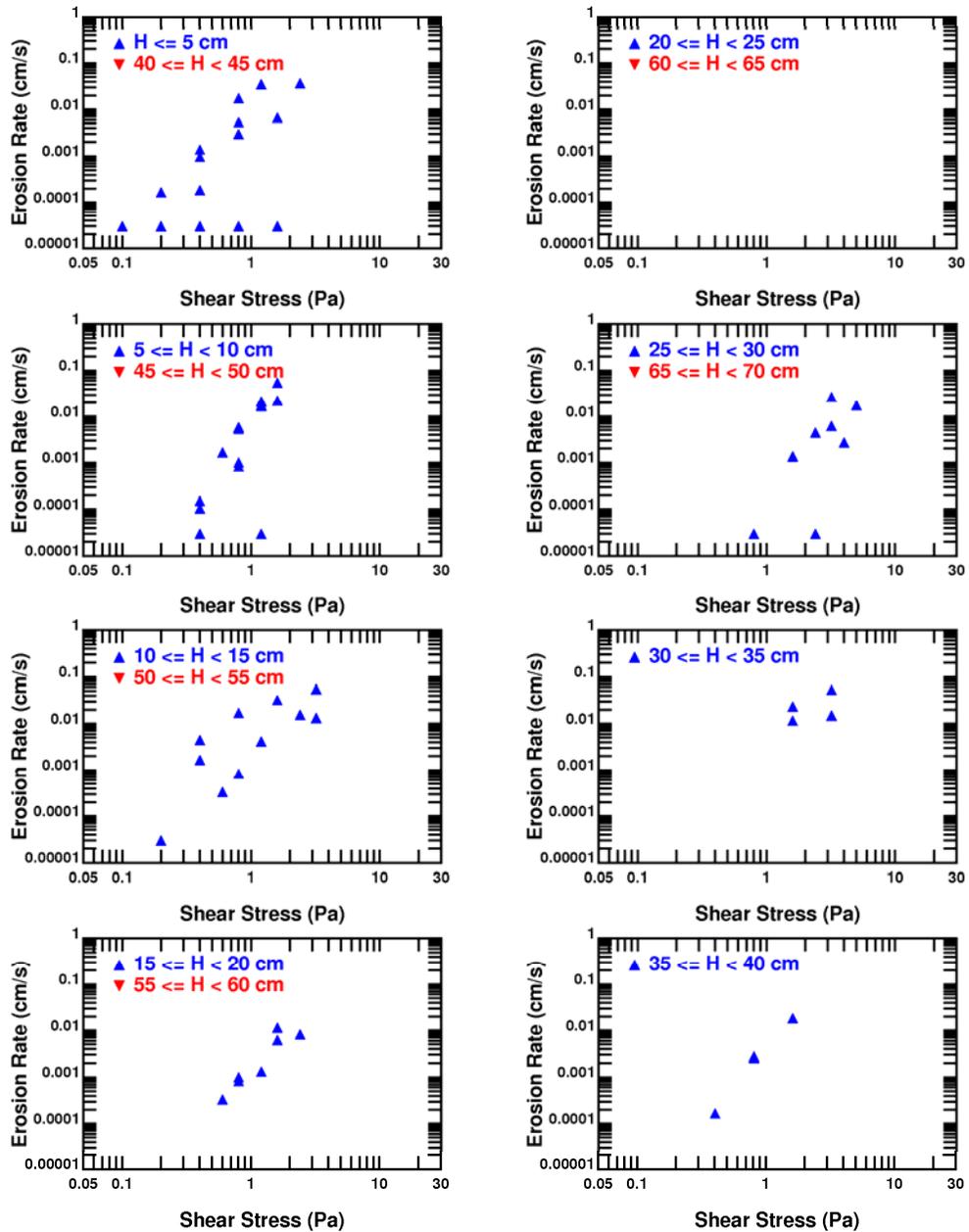
# Model Calibration Responsiveness Summary



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**Figure GI-7-3b Erosion Rate Versus Shear Stress (as a function of depth in core) for Sedflume Experiments on Sediment with Median Particle Diameter ( $D_{50}$ ) Greater than or Equal to 30  $\mu\text{m}$  and Less than 100  $\mu\text{m}$**

# Model Calibration Responsiveness Summary



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**Figure GI-7-3c Erosion Rate Versus Shear Stress (as a function of depth in core) for Sedflume Experiments on Sediment with Median Particle Diameter ( $D_{50}$ ) Greater than or Equal to 100  $\mu\text{m}$**

### 1           **Implementation of Dr. Lick's Simple Flocculation Model**

2           In response to comments received from Reviewers, the flocculation model  
3           suggested by Dr. Lick was implemented in EFDC and tested. The  
4           implementation included an implicit iterative solver for the non-linear equation for  
5           floc diameter (Equation 4.4-36 of the Course Notes [Lick et al., 2005]). Floc  
6           diameters were then used to calculate settling velocities. Testing began with the  
7           simulation of a closed recirculating flume configuration (to mimic the flocculator  
8           used by Dr. Lick in his experiments), where the outflow and concentration at the  
9           exit section were fed back into the entrance section. This configuration results in  
10          steady-flow conditions.

11          The first series of tests started with constant suspended solids concentration and  
12          deposition and resuspension disabled, such that the suspension concentration  
13          remained constant. Predicted floc diameters for different concentrations and flow  
14          rates agreed with graphical material in Dr. Lick's lecture notes (Lick et al., 2005).  
15          For verification purposes, a stand-alone integration of the differential equation for  
16          floc diameter was performed, and the calculated floc diameters agreed with those  
17          predicted by EFDC when the residence time of the cells comprising the flume  
18          was relatively short, i.e., approximately 100 seconds (the residence time for cells  
19          in the Housatonic River is also on this order or less). For longer residence times  
20          (approximately 10,000 seconds), variability of the computed floc diameters from  
21          cell to cell was observed.

22          The second series of tests involved gradually increasing the suspended solids  
23          concentration by adding solids to the inflow, with the flow rate remaining  
24          constant. This emulated the addition of suspended solids to a recirculating  
25          flume. For slow rates of increase, on the order of 10 mg/L per day to 100 mg/L  
26          per day, the floc diameter changed gradually from that associated with the initial  
27          suspended solids concentration to that associated with the final concentration for  
28          the short cell residence time case. The same was true for the case when the  
29          concentration was reduced while the flow rate was held constant.

30          The third series of tests used the same recirculating flume configuration with  
31          resuspension and deposition activated. The test started with a small initial  
32          suspended solids concentration and a constant flow rate, which produced  
33          gradual resuspension. The flow rate was then increased by a factor of 10 over a  
34          time period of 1 day and then reduced to the original flow rate after another day  
35          to mimic a high-flow event hydrograph. The flocculation calculation predicted floc  
36          diameters and settling velocities as the flow rate increased and suspended solids  
37          concentration increased due to resuspension up to a point at which the  
38          flocculation calculation suddenly produced a settling velocity that resulted in  
39          almost instantaneous settling of suspended solids, producing a zero floc  
40          diameter that did not allow the floc diameter equation to continue to be integrated  
41          forward in time without some arbitrary re-initialization.

## Model Calibration Responsiveness Summary

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1 The fourth series of tests was conducted with the Housatonic River calibration  
2 configuration. Similar problems as in the third series of tests were encountered  
3 during moderate flow increases.

4 In summary, the flocculation model performed well under idealized conditions,  
5 i.e., without deposition and resuspension, when the residence time of the model  
6 cells is relatively short. This suggests that the flocculation model is calculating a  
7 sequence of steady-state conditions consistent with the constant concentration  
8 assumption inherent in the model formulation. However, the flocculation model  
9 failed under conditions of unsteady flow with resuspension and rapidly increasing  
10 suspended solids concentration, conditions that are obviously inconsistent with  
11 the constant concentration assumption. Although the flocculation model appears  
12 to have promise, it would require additional development to be sufficiently robust  
13 for application to the Housatonic River.

### 14 Evaluation of Sediment Transport Results Over Longer Time Periods

15 Several Reviewers recommended that sediment transport results from longer-  
16 term simulations be compared to additional types of data, such as estimates of  
17 sedimentation rates derived from vertical profiles of radioisotopes, and erosion  
18 and deposition patterns described by surveying of river cross-sections conducted  
19 multiple times since October 2000. EPA agrees that these are important  
20 comparisons and, as discussed in the Calibration Report, they will be included as  
21 part of the evaluation of the longer-term modeling, which will be presented in the  
22 Validation Report.

### 23 References:

24 Garcia, M., and G. Parker. 1991. Entrainment of bed sediment into suspension.  
25 *J. Hydraul. Eng.* 117:414-435.

26 Lick, W., J. Gailani, C. Jones, E. Hayter, L. Burkhard, and J. McNeil, 2005. The  
27 Transport of Sediments and Contaminants in Surface Waters. Short Course  
28 Notes, University of California, Santa Barbara. January 2005.

29 van Rijn, L.C. 1984. Sediment transport, Part II. Suspended load transport. *J.*  
30 *Hydraul. Eng.* 110(11):1613:1638.

31 Wu, W., S. Wanh, and Y. Jia. 2000. Nonuniform sediment transport in alluvial  
32 rivers. *J. Hydraulic Research* 38(6):427-434.

## 33 8. DIFFUSIVE FLUX

### 34 SUMMARY OF ISSUE:

35 Three Reviewers expressed concerns regarding the rate used in the model for diffusive flux of  
36 contaminants from the sediment to the overlying water, and the related topics of bioturbation and

## Model Calibration Responsiveness Summary

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1 the depth of the active layer in the bed sediment (see General Issue 6). These Reviewers noted  
2 that the value used for this parameter was very high in comparison to values found in the  
3 literature. One Reviewer suggested that the value of this parameter should not be constant, but  
4 should vary with flow. Another Reviewer recommended a supplemental study to provide  
5 information that could be used to assign a value to this parameter.

### 6 **RESPONSE:**

7 In the Conceptual Site Model discussion (Section 4.5.2 of the final MFD), the  
8 processes of advection and diffusion are discussed. Both processes are  
9 included together in the concept of “vertical flux,” an analysis of this flux in the  
10 PSA is presented, and the lumped processes are concluded to be “. . . an  
11 important factor [for the] spatial distribution of water column PCBs . . .” This  
12 “vertical flux” is represented with a mass transfer coefficient,  $K_f$ , which can be  
13 thought of as a lumped parameter that accounts for several processes, in  
14 addition to diffusion. The flux from bio-irrigation, bioturbation, advection, and  
15 diffusion are subsumed into the sediment-water diffusive transfer term, which  
16 was calibrated to water column PCB data.

17 The value of  $K_f$  (1.5 centimeters per day [cm/d]), calibrated to Housatonic River  
18 data, is at the low end of the range of values summarized by Thibodeaux and  
19 others (Thibodeaux and Bierman, 2003; Thibodeaux et al., 2002). These authors  
20 noted intra-annual variations in  $K_f$  values in the Hudson, Grasse, and Fox Rivers,  
21 with lower values (3 to 10 cm/d) in the winter and higher values (20 to 40 cm/d) in  
22 the summer. One possible explanation for the Reviewers’ belief that the 1.5  
23 cm/d rate used for the Housatonic River PSA is high relative to values used in  
24 other systems might be a summary presented in Thibodeaux et al. (2002), a  
25 reference cited by one of the Reviewers. In that paper,  $K_f$  values were presented  
26 based on PCB concentrations on particles. The authors tabulated  $K_f$  values in  
27 that way to facilitate comparisons with particle resuspension velocities. They  
28 divided the original  $K_f$  values by a factor ranging between 4150 and 8640 (the  
29 product of the partition coefficient and particle concentration), which resulted in  
30 values that are not directly comparable to the value of 1.5 cm/d used for the  
31 Housatonic River. When expressed in a way that is consistent with the manner  
32 in which the coefficient is used in the model (see Table GI-8-1), the magnitudes  
33 of the  $K_f$  values from these other sites are in the tens of cm/d – values  
34 comparable to, or in some cases considerably higher than, the 1.5 cm/d  
35 developed from calibration to Housatonic River data.

36 It is noted that the minimum value of 0.2 cm/d for the Fox River above DePere  
37 Dam comes from a model (Velleux and Endicott, 1994) that includes  
38 “background” resuspension at low-flow conditions, which the authors  
39 acknowledge “substantially influences water column PCB concentrations, but has  
40 little impact on solids concentrations.” Although there is no evidence that such  
41 an approach is more realistic or preferable for explaining the spatial pattern of  
42 increasing water column PCB concentrations than the “lumped parameter”  
43 approach, use of a “background resuspension” approach in the Housatonic River

# Model Calibration Responsiveness Summary

Table GI-8-1

Summary of Mass Transfer Coefficients (after Thibodeaux et al., 2002)

Study	K <sub>f</sub> (cm/d) (based on PCB concentration on particles)*		Product of Partition Coefficient and Particle Concentration	Original K <sub>f</sub> (cm/d) (based on pore water concentration)	
	Minimum	Maximum		Minimum	Maximum
<b>Fox River</b>					
Above DePere Dam	2.60E-05	5.10E-03	7680	0.2	39.2
Below DePere Dam	5.20E-04	3.90E-03	7680	4.0	30.0
<b>Hudson River</b>					
Study 1	7.20E-04	9.60E-03	4150	3.0	39.8
Study 2	2.50E-03	6.00E-03	4150	10.4	24.9
<b>Grasse</b>	1.20E-04	8.10E-04	8640	1.0	7.0

\* Values in mm/d in Table III of Thibodeaux et al. 2002, converted to cm/d.

modeling study would not be possible with the more mechanistic sediment transport approach in EFDC without adding multiple cohesive solids classes, for which data are not available.

An evaluation of the Housatonic River data was performed to determine if there were indications of intra-annual variations in the mass transfer coefficient (see pages B.4-32 through B.4-35 and Figure B.4-30 of the Model Calibration Report); however, no such patterns were observed. Therefore, the value of 1.5 cm/d was used for all months of the year and all flow conditions. One Reviewer suggested that K<sub>f</sub> should be expected to vary with river flow based on changes in the thickness of the water column boundary layer. If the sediment-water PCB flux were strictly a diffusional process, this would be expected; however, the surface mass transfer coefficient, K<sub>f</sub>, represents the flux from a number of processes, including bio-irrigation, bioturbation, advection, and diffusion. The spatial patterns of water column PCB concentrations reflect the combined effect of all of these processes, and do not suggest a variation with river flow.

The calibrated value of 1.5 cm/day produces agreement between simulated PCB concentrations and those measured at extremely low-flow conditions between 16 and 25 cfs (Figure B.4-37) and at above-average flow conditions between 109 and 244 cubic feet per second (cfs) (Figure B.4-38). As river flow and velocity continue to increase, the effect of non-particulate PCB transport on water column concentrations decreases because of increasing dilution, and particulate transport becomes increasingly important. Because the mass transfer coefficient, K<sub>f</sub>, was calibrated to data collected at lower flow conditions when this

## Model Calibration Responsiveness Summary

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1 transport process is more important, EPA believes that additional field  
2 measurements are not necessary to refine or further constrain this parameter.

3 Two Reviewers expressed concern that the calibration of the sediment-water  
4 column mass transfer coefficient,  $K_f$ , was based on reproducing the measured  
5 increase in water column PCB concentrations between sampling stations. In one  
6 case the concern was related to the spatial resolution of the segmentation of the  
7 river channel, which led the Reviewer to question if the PCB flux from the  
8 sediment that was represented in EPA's model by a "non-particle" flux might  
9 have been due to resuspension of bed sediment in a portion of the river cross-  
10 section. The Reviewer questioned if concurrent resuspension and deposition of  
11 sediment could be occurring in different parts of the cross-section, which would  
12 not be simulated in the model because the channel cross-section is, in general,  
13 represented by one grid cell. The model results reproduced the spatial profile of  
14 water column PCBs described by data collected during the lowest-flow surveys,  
15 when peak flows at Coltsville were between 16 and 25 cfs, and resuspension is  
16 neither expected, because of the low velocities, nor indicated by the spatial  
17 profile of suspended solids. Hourly flows at Coltsville exceed 25 cfs over 85% of  
18 the time. It is unreasonable to assume that substantial PCB accumulation could  
19 occur in locations that erode over 85% of the time; therefore, EPA believes that  
20 the "non-particle" flux represented by the mass transfer coefficient,  $K_f$ , equal to  
21 1.5 cm/d, is a more reasonable explanation for the measured water column PCB  
22 profiles.

23 The second Reviewer who expressed concern over the calibration of the  
24 sediment-water column mass transfer coefficient,  $K_f$ , questioned whether EPA  
25 had adequately considered additional point and non-point sources of PCBs  
26 between the sampling locations. The only potential point source of PCBs in the  
27 PSA is the Pittsfield wastewater treatment plant (WWTP); however, sampling of  
28 sludge and effluent conducted by the City was non-detect for PCBs, indicating  
29 that the plant discharge is not a source of PCBs to the river. Those results are  
30 consistent with EPA's water quality sampling, which found no measurable  
31 increase in sediment or water column PCB concentrations downstream of the  
32 WWTP discharge. There is another mechanism in place under the direction of  
33 the Massachusetts Department of Environmental Protection (MDEP) to evaluate  
34 potential sources of PCBs in the watershed. This program did not identify any  
35 potential sources of PCBs located in the watershed (other than those that are  
36 known and are being addressed, such as Dorothy Amos Park on the West  
37 Branch) that would be expected to contribute runoff containing PCBs to the PSA.

### 38 **References:**

39 Thibodeaux, L.J. and V.J. Bierman. 2003. The bioturbation-driven chemical  
40 release process. *Environmental Science & Technology*, July 1, 2003. pp 252-  
41 258.

## Model Calibration Responsiveness Summary

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1 Thibodeaux, L.J., D.D. Reible, and K.T. Valsaraj. 2002. Non-Particle  
2 Resuspension Chemical Transport from Stream Beds. In *Chemicals in the*  
3 *Environment: Fate, Impacts, and Remediation*; ACS Symposium Series 806,  
4 American Chemical Society, Washington, DC., 2002. pp 130-149.

5 Velleux, M. and D. Endicott. 1994. Development of a mass balance model for  
6 estimating PCB export from the Lower Fox River to Green Bay. *J. Great*  
7 *Lakes Research* 20(2):416-434.

## 8 9. BANK EROSION

### 9 SUMMARY OF ISSUE:

10 Five of the seven Reviewers recommended that riverbank erosion and mass slumping be  
11 included as a process in the sediment/contaminant transport modeling. This process was  
12 variously termed “important” or “significant” by Reviewers.

### 13 RESPONSE:

14 EPA agrees that bank erosion/slumping is a process that should be included in  
15 the model, and, as discussed in the Model Calibration Report, has incorporated  
16 this process in the longer-term modeling (Phase 2 Calibration and Validation).  
17 EPA conducted several studies to collect the data that were used for estimating  
18 long-term rates of soil loss from the riverbanks.

19 Two different methods were used to develop estimates of soil erosion from the  
20 riverbanks in the PSA (see final MFD, pp. 7-8 to 7-11). One method provides  
21 long-term estimates and the other provides short-term estimates of soil erosion.  
22 The long-term erosion estimates were developed by overlaying georeferenced  
23 representations of the top of bank from aerial photographs of the river taken in  
24 1952, 1970, 1990, and 2000. Changes in riverbank locations were quantified  
25 and summarized as average migration rates of riverbanks per year for the period  
26 1952 through 2000. The mass of soil erosion was estimated from the average  
27 migration rate, height and length of eroding bank, and soil dry density. This  
28 analysis provides site-specific erosion estimates for each of the 69 erosion areas.

29 Estimates of short-term erosion rates were developed from measurements made  
30 in Reaches 5A (eight locations) and 5B (seven locations), which were selected to  
31 represent a range of erosion rates based on factors such as radius of the  
32 curvature of bends, bank vegetation, and soil characteristics. No areas of active  
33 erosion were observed in Reaches 5C or 6; therefore, no locations for short-term  
34 erosion rate estimates were selected downstream of Reach 5B. Three-  
35 dimensional terrain models were developed for each location from surveys  
36 conducted in November 2001 and June 2002. Differences between the two  
37 terrain models were used to estimate the average soil loss per linear foot of  
38 riverbank in Reaches 5A and 5B. These estimates were applied to the total

## Model Calibration Responsiveness Summary

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1 length of eroding riverbank in each reach, which was determined from field  
2 observations.

3 These long- and short-term erosion estimates will be used to constrain the  
4 parameterization of bank erosion in the Phase 2 Calibration modeling. The effect  
5 of the representation of bank erosion/slumping on simulated suspended solids  
6 and PCB concentrations during the monitored storm events will be assessed  
7 through model-data comparisons.

8 One Reviewer suggested the use of a one-dimensional model for meandering  
9 streams to assess how much sediment enters the river through stream erosion.  
10 As of late August 2005, this model was still under development and was not  
11 available to the public. The approach adopted by EPA relies on the short- and  
12 long-term erosion estimates based on site-specific information. If a model were  
13 used to supplement EFDC by generating soil erosion estimates, those estimates  
14 would be evaluated by comparison with the short- and long-term erosion  
15 estimates. Because the erosion estimates that will ultimately be used will be  
16 consistent with the site data, EPA believes it is reasonable to base the model  
17 inputs on the site data, rather than a supplemental one-dimensional model.

18 EFDC does not have the capability to calculate planform evolution and EPA does  
19 not plan to account for this process, other than through the representation of  
20 bank erosion/slumping. The analysis of aerial photographs of the river indicates  
21 that the river has not changed course substantially over the last half-century.  
22 Representing the erosion/slumping of bank soil and associated PCBs captures  
23 the primary impact of bank erosion.

## 24 **10. VARIABILITY IN MODEL RESULTS VS. DATA**

### 25 **SUMMARY OF ISSUE:**

26 Five Reviewers questioned that the variability in the model results was less than the variability in  
27 the data, but the Reviewers differed in their conclusions regarding how this decrease in  
28 variability would affect the utility of the model for evaluating remedial alternatives. One  
29 Reviewer indicated that the model should not be expected to reproduce the variability in the data  
30 and that this would be a potential problem only for processes that vary non-linearly with  
31 contaminant concentration. Another Reviewer considered the decrease in variability (referred to  
32 as a “filtering” of the data) to be a form of bias, but did not indicate it to be a major problem. A  
33 third Reviewer, however, considered the inability of the model to generate results with  
34 variability equivalent to that of the data to be a “serious problem.”

### 35 **RESPONSE:**

36 In their comments, Reviewers used the terms “variance” and “variability”  
37 interchangeably. Although these concepts are related, they are not identical.  
38 The term variance, whether used in the strict statistical sense referring to the

## Model Calibration Responsiveness Summary

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1 mean squared deviation from the mean of individual measurements, or in a more  
2 general statistical sense, is a measure of the variability (spread) of the data, and  
3 incorporates the concept of stochasticity or uncertainty. In the context of a  
4 modeling study, the variance of a parameter in a specific grid cell and time step  
5 would be represented by a distribution rather than a single deterministic value.  
6 The distribution would be characterized by a measure of central tendency (e.g.,  
7 mean) and a measure of dispersion (e.g., variance), along with other descriptors  
8 such as skewness and kurtosis.

9 Variability, on the other hand, refers to the range of values for an individual  
10 parameter in a specified time and space, even when each individual  
11 measurement or value of the parameter is made or calculated without any  
12 uncertainty (i.e., is deterministic). Translated into modeling terms, variability is  
13 the range of values of a parameter over a number of model grid cells and/or a  
14 number of time steps. Each grid cell/time step has only a single deterministic  
15 value for the parameter, but taken together the deterministic individual values  
16 have an associated range and variance. The remainder of this response  
17 addresses the concepts of variance and variability separately.

18 Regardless of whether the concept of variance or variability is the issue, EPA  
19 disagrees that a difference (reduction) in variability of the model results  
20 compared to the data represents a form of bias, and believes that the Reviewer  
21 was not using the term “bias” in the traditional sense. The distinction is  
22 important, however, because consistent under- or overprediction by the model  
23 (bias) could affect the response time of PCB concentrations in the PSA to  
24 remedial alternatives and complicate the comparison of various alternatives to  
25 each other and to natural recovery. Reviewers were in agreement that there is  
26 no indication of this type of bias.

### 27 **Variance**

28 In order for a model to truly provide a measure of variance in its output, the  
29 model must be probabilistic rather than deterministic. A probabilistic model,  
30 when run for multiple trials, does not always return the same value of an output  
31 parameter for a specific set of inputs. Instead, numerous runs of the model  
32 produce a distribution of results, which can be used to make certain inferences  
33 regarding the ability of the model to produce results that duplicate the system  
34 being modeled. Such distributions can also potentially be used to conduct  
35 statistical hypothesis testing of model results.

36 All three of the models comprising the Housatonic River modeling framework are  
37 deterministic, as are models of sediment/contaminant fate and transport  
38 generally. That means that, for a given set of model process formulations, state  
39 variables, and input parameters, the model will always return the same value for  
40 each parameter at each time step and grid cell (i.e., there is no distribution or  
41 spread of outputs for a given place and time). The only way to produce such a  
42 distribution is to run the models in a probabilistic mode, supplying distributions

## Model Calibration Responsiveness Summary

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1 rather than fixed values for the input parameters, and sampling from the  
2 distributions in the general manner of a Monte Carlo analysis. In principle, it is  
3 possible to do that provided realistic input distributions can be developed for the  
4 parameters of interest (which is not necessarily simple, or even possible).  
5 However, the computational demands of EFDC preclude such a probabilistic  
6 application. For HSPF and FCM, an uncertainty analysis will be conducted using  
7 probabilistic methods, but the uncertainty analysis for EFDC will require a  
8 different approach (see the response to General Issue 11 for a discussion of the  
9 uncertainty analyses).

10 In the absence of an explicit determination of the distribution, or variance,  
11 associated with each parameter for each model cell at each time step, it is  
12 possible to approximate the variance by assuming that the variability of results  
13 will be approximately equal to the variability in the input data when interpreting  
14 the model output. However, the same variance may not be applicable for longer-  
15 term runs in which the central tendency, or simulated, values for many  
16 parameters will show a greater difference at the end of the run than at the  
17 beginning. In that eventuality, scaling of the variance to the mean may be more  
18 appropriate

### 19 **Variability**

20 Although a number of Reviewers commented on the variability (and/or variance)  
21 of model output in their comments on the Model Calibration Report, similar  
22 concerns were not expressed in the comments received on the MFD document.  
23 In fact, only one Reviewer even mentioned variability of model output, stating:

24 “Models of PCB transport and fate, and underlying theory, are not  
25 sufficiently robust that parameter values determined a priori can account  
26 for all of the site-specific variability that is observed in critical model  
27 parameters. This is not a weakness of the models specifically, rather an  
28 acknowledgment that all transport and fate models are imperfect  
29 representations of chemical behavior in an extremely complex system.”  
30 (D. Endicott, May 24, 2001)

31 EPA agrees with the Reviewer’s assessment and recognizes that the output of  
32 the Housatonic River model does not reproduce the range of variability in the  
33 data used to develop the model input. Rather than a fault of the modeling  
34 framework or the models themselves, such a result is an inevitable and expected  
35 consequence of any modeling activity. Models are only representations of  
36 reality, and are not intended to include all of the components of the system being  
37 modeled, or of all the relationships between them. Indeed, if the model and the  
38 system being modeled are identical in all of their characteristics, the concept of  
39 modeling loses its usefulness (Gold, 1977). Therefore, it follows that models  
40 must be a simplification of the system being modeled, and simplification  
41 necessarily results in the inability of any model to completely simulate either the  
42 inputs to, or the outputs from, that system.

## Model Calibration Responsiveness Summary

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1 The range of values (the variability) of any parameter in the environment is a  
2 function of the range of values for the other parameters that affect the parameter  
3 in question. For example, surface runoff is a function of precipitation and land  
4 use (among other variables). In reality, any type of land use is a continuum that  
5 does not neatly fall into a discrete number of categories that in turn have two  
6 conditions, permeable and impermeable. In order to develop a model of surface  
7 runoff successfully, the continuum of land use must be simplified into a number  
8 of categories, and it is not possible for the categories to capture the extremes of  
9 the range of permeabilities. Accordingly, the range of surface runoff values  
10 calculated by the model will necessarily be truncated and will not span the range  
11 of variability in the original data used to parameterize the model. Increasing the  
12 number of input parameters (most models use substantially more parameters  
13 than this simple example), will in most cases increase the amount of attenuation  
14 of variability.

15 The question of importance for the modeling study is not whether the results of  
16 the model span the full range of variability in the input data, but whether certain  
17 features of the data that are important considering the goals of the modeling  
18 study are reproduced. Central tendency, or mean, predicted values averaged  
19 over a specified temporal and spatial scale are one obvious feature that should  
20 be reproduced with reasonable accuracy, as is the general pattern of variability.  
21 In the case of the Housatonic River modeling study, it is important for some  
22 parameters (e.g., flow) that the magnitude and frequency of peaks (but not  
23 necessarily the timing) be reproduced with some reasonable degree of fidelity;  
24 however, for other parameters (e.g., PCB concentrations in sediment) simulating  
25 the full range of variability is of relatively little importance because receptors  
26 integrate their exposure to various contaminant concentrations, and this is what  
27 is of interest to satisfy the goals of the modeling study.

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

### 33 **Reference:**

34 Gold, H. 1977. *Mathematical Modeling of Biological Systems*. J. Wiley & Sons,  
35 New York, NY. 357 pp.

## 36 **11. ANALYSIS AND EVALUATION OF MODEL UNCERTAINTY**

### 37 **SUMMARY OF ISSUE:**

38 Six of the seven Reviewers provided comments on the approaches and methods used to quantify  
39 and evaluate model uncertainty. The Reviewers correctly noted that uncertainty analyses have

## Model Calibration Responsiveness Summary

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1 been conducted only for FCM at this time, with analysis of uncertainty for HSPF and EFDC and  
2 for the linked modeling framework deferred until the Validation Report. Some of the Reviewers  
3 questioned whether it would be possible to conduct an uncertainty analysis for EFDC, primarily  
4 because of limitations arising from computational requirements. Several Reviewers noted that  
5 uncertainty arises from different sources (e.g., variability in data, uncertainty in model  
6 formulations).

### 7 **RESPONSE:**

8 As indicated by the Reviewers, only the uncertainty analysis for FCM was  
9 included in the Model Calibration Report. The uncertainty analyses for HSPF  
10 and EFDC, and the linked uncertainty analysis to investigate the propagation of  
11 uncertainty through the three models, were deferred and will be included in the  
12 Validation Report. There are no generally accepted methods for conducting  
13 uncertainty analyses for numerical transport and fate models, and EPA was  
14 looking for input and suggestions from the Reviewers prior to expending the  
15 considerable resources necessary to conduct uncertainty analyses involving  
16 HSPF and EFDC. Because the bioaccumulation model is comparatively simple  
17 and inexpensive to run, it was considered feasible to include a preliminary  
18 uncertainty analysis for FCM in the Model Calibration Report. This overall  
19 approach to analysis of uncertainty and the underlying reasons for adopting it  
20 were presented to the Peer Reviewers by EPA at the document overview  
21 meeting on April 13, 2005.

### 22 **Uncertainty Analysis for Watershed Model (HSPF)**

23 The details of the proposed approach to conducting the uncertainty analysis for  
24 HSPF were presented in Section A.6.2 of the Model Calibration Report.  
25 Reviewers did not comment directly on this proposed approach, but did provide  
26 comments relative to conducting uncertainty analysis that were generally  
27 consistent with the proposed approach for HSPF. Accordingly, the uncertainty  
28 analysis will be conducted substantially as described in the Model Calibration  
29 Report, with some refinements that will facilitate the analysis of uncertainty as it  
30 propagates through the linked models.

31 The uncertainty analysis for HSPF will be conducted for the Phase 2 Calibration  
32 period (1990 through 2000) using a Monte Carlo approach involving  
33 approximately 500 iterative model runs, with selected model parameters being  
34 chosen from assigned probability distributions. The model results will then be  
35 processed for the same output variables and locations used for the sensitivity  
36 analysis presented in the Model Calibration Report (Section A.6.1), and  
37 presented as measures of central tendency and confidence intervals for each  
38 output variable and location. The parameters to be varied for the HSPF Monte  
39 Carlo analysis will be the same 28 parameters evaluated in the sensitivity  
40 analysis.

### 1           **Uncertainty Analysis for Hydrodynamic-Sediment/Contaminant Transport** 2           **Model (EFDC)**

3           The plan for uncertainty analysis of EFDC was presented in Section B.5.3 of the  
4           Model Calibration Report. Based on comments received from Reviewers, and  
5           additional consideration by the modeling team of how the analysis of uncertainty  
6           could be conducted for a complex and computationally demanding model such  
7           as EFDC, EPA has further developed the approach to the EFDC uncertainty  
8           analysis beyond that outlined in the Model Calibration Report. Because it is  
9           computationally less intensive and conceptually simpler to understand, the  
10          Kolmogorov-Smirnov (K-S) confidence limits approach will be used to evaluate  
11          EFDC uncertainty. This approach is discussed in detail in Attachment 2  
12          (Kolmogorov-Smirnov Approach to Evaluation of Uncertainty for EFDC).

13          EPA agrees with the Reviewer who recommended not conducting the “bounding”  
14          analysis proposed by GE in their presentation at the Peer Review public meeting.  
15          Although such an approach has appeal due to ease of calculation and  
16          presentation, EPA believes that the proposed analysis has a number of  
17          fundamental problems. Chief among these are issues related to the selection of  
18          parameters to use in the analysis, difficulties associated with specifying true  
19          ranges for the parameters selected, and the problem of non-orthogonality. In  
20          combination, these and other issues lead to results that are not fully objective  
21          and do not represent true uncertainty bounds (in a statistical sense) on model  
22          predictions.

### 23          **Uncertainty Analysis for Food Chain Model (FCM)**

24          The procedure for conducting the uncertainty analysis for FCM will be identical to  
25          that presented in the Model Calibration Report. In addition, the FCM uncertainty  
26          analysis will incorporate the propagated uncertainty of the parameters output  
27          from EFDC, as described below.

### 28          **Propagation of Uncertainty through Linked Models**

29          The procedures outlined above provide a framework for conducting an  
30          uncertainty analysis that will evaluate the propagation of uncertainty through the  
31          linked models. Analysis of uncertainty for the linked models will focus on those  
32          parameters that are output from one model and used as input to another model:  
33          flow at the upstream boundary of the PSA (HSPF to EFDC) and PCB  
34          concentrations in sediment and on particulate organic matter (POM), respectively  
35          (EFDC to FCM). The uncertainty in the output for each of these parameters, as  
36          quantified by the approaches discussed above, will be used to describe the error  
37          distribution about each parameter when it is input to the next model in sequence.

38          Each of the 500 HSPF Monte Carlo simulations will produce a time-series of  
39          hourly flows for the 1990 through 2000 Phase 2 Calibration period. This group of  
40          model results will be ranked based on the effect of each time series on the EFDC

## Model Calibration Responsiveness Summary

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1 model simulation – i.e., average flow over the time period, or some similar  
2 parameter, will be evaluated for each time series and used to create a  
3 distribution. The 5<sup>th</sup>-percentile and 95<sup>th</sup>-percentile time series from this  
4 distribution will be used in the K-S analysis to provide bounding estimates on the  
5 EFDC results. These EFDC bounding estimates can then be used to  
6 parameterize a distribution for each of the EFDC output parameters that are  
7 passed to FCM, thereby propagating uncertainty through the series of three  
8 linked models.

## 9 12. DEMONSTRATIONS OF MODEL PERFORMANCE

### 10 SUMMARY OF ISSUE:

11 All of the Reviewers made some comments that suggested ways that the models could be  
12 improved or tested to better demonstrate model calibration and/or correct representations of  
13 processes. Examples of these (which are not represented by another General Issue) include:

- 14       ▪ Plots of measured versus simulated TSS as an “equivalence” plot.
- 15       ▪ Conduct a “trial” remediation (although this is not possible in a real sense, it can be  
16       simulated) and evaluation of the model response.
- 17       ▪ Comparison of velocity data to simulated velocities.
- 18       ▪ Compare simulated erosion and deposition patterns to the data showing locations and  
19       changes in bed elevation (including Woods Pond).
- 20       ▪ Show the proportion of PCB burden in different species/trophic levels attributable to  
21       water-related versus sediment-related sources.
- 22       ▪ Evaluate PCB fluxes between the river and floodplain during overbank flow  
23       conditions.
- 24       ▪ Use statistical methods such as mean squared error or confidence limits in making  
25       model/data comparisons to supplement the uncertainty analyses.

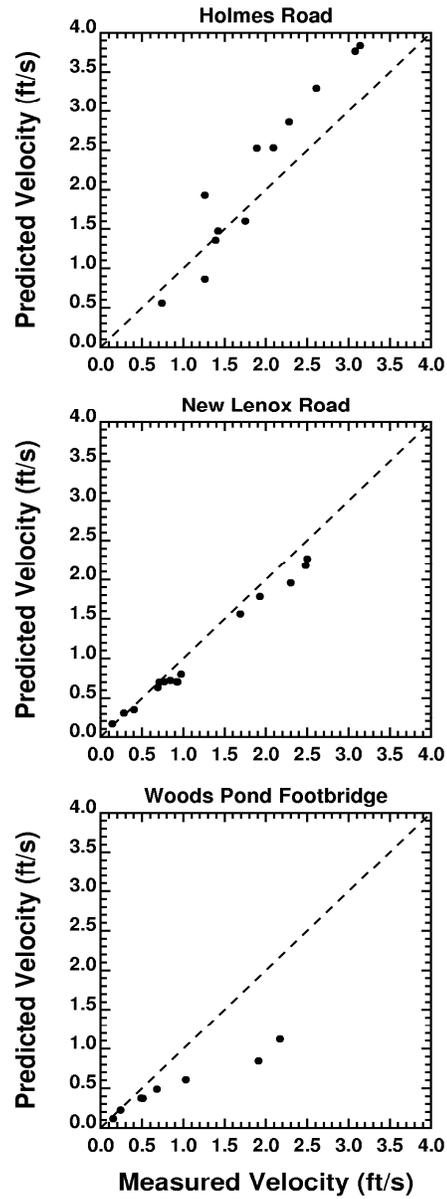
### 26 RESPONSE:

- 27       ▪ EPA agrees that plots of measured vs. simulated TSS would be useful  
28       and will include these figures in the Model Validation Report.
- 29       ▪ EPA agrees that simulation of an example remediation would be useful as  
30       a demonstration of model performance and will consider inclusion of one  
31       or more such simulations in the Model Validation Report.



# Model Calibration Responsiveness Summary

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**Figure GI-12-1 Comparisons of Simulated vs. Measured Velocities at Holmes Road, New Lenox Road, and Woods Pond Footbridge**

1

## RESPONSE TO SPECIFIC COMMENTS

2

### OVERVIEW COMMENTS

3

**W. Frank Bohlen:**

4

#### Introduction

5 Agreements developed between the General Electric Company and the U.S Environmental  
6 Protection Agency regarding means to optimize remedial activities intended to reduce or  
7 eliminate environmental and/or public health effects thought to be associated with exposure to  
8 PCB contaminated sediments include the development of a predictive numerical fate and  
9 transport model for application in the Housatonic River system. Given the complex of processes  
10 affecting this transport, this represents an ambitious project. The proposed model consists of  
11 three primary components, a watershed model (HSPF), a hydrodynamic/sediment-contaminant  
12 transport model (EFDC) and a bioaccumulation model (FCM). The models are linked but non-  
13 interactive. Details of each of these models and the results of the calibration phase are presented  
14 in a lengthy master volume and three detailed Appendices. A Peer Review Panel was asked to  
15 review this work and to answer a series of specific questions. Before I get to these questions I'll  
16 begin with a number of more general observations and recommendations.

17

#### General Comments

18 As discussed by several reviewers, assessments of model adequacy require a clear understanding  
19 of the intended application. Beyond the fact that the developing framework is to be used in the  
20 assessment of remedial alternatives, little detailed information is provided. It is not clear whether  
21 the model is to be used to assess benefits of one scheme relative to another or to provide an  
22 absolute assessment of selected schemes. One might argue that such specification is premature  
23 and in fact will be based on model results detailing the relative importance of particular source  
24 areas or processes. While this may ultimately prove to be the case, it still would be well to begin  
25 with a defined set of possibilities. In the case of the Housatonic River Study Area (PSA) this  
26 seems entirely possible due to the depth and breadth of data available detailing all primary site  
27 characteristics and the associated contaminant distributions. We know, for example, that a  
28 significant fraction of the total PCB mass in the river downstream of the confluence to Woods  
29 Pond is located in the floodplain. Given our less than perfect understanding of the range of  
30 processes affecting contaminant transport to and from the floodplain this fact might suggest that  
31 models would be best used to assess relative benefits so as to favor cancellation of errors.  
32 Alternatively, one might argue that the floodplain is primarily a trap and it is the more mobile  
33 components of the system such as the stream bed sediment column that is responsible for  
34 continuing exposure and the downstream flux of PCBs. This system, while still complicated may  
35 be more amenable to absolute assessment. Future discussions of model adequacy would benefit  
36 from a clear concise definition of the most probable primary use of the suite of models.

# Model Calibration Responsiveness Summary

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1           **RESPONSE O-FB-1:**

2           Please refer to the response to General Issue 1.

3   Beyond care in the definition of model application, this entire exercise would benefit from a  
4   careful (i.e. brutal) editing of the reports in the interest of clarity, understanding and the retention  
5   of the reader's interest. This is a complicated multi-faceted effort with a large number of  
6   investigators spread across the country (at least). I recognize that the coordination of the  
7   resulting writing effort is itself something of a herculean task. This must be faced however, if the  
8   goal is to produce a product that is at once comprehensive and amenable to detailed review and  
9   evaluation.

10           **RESPONSE O-FB-2:**

11           The U.S. Environmental Protection Agency (EPA) recognizes that the Model  
12           Calibration Report (WESTON, 2004), particularly the technical appendices,  
13           presents a large amount of highly technical information and that it may be difficult  
14           for some readers to process. In fact, the document did undergo careful and  
15           iterative technical editing to improve consistency, clarity, and readability.  
16           However, EPA also needs to ensure that the scientific analyses performed by  
17           EPA are thoroughly documented.

18           EPA will direct more effort toward streamlining and formatting the Model  
19           Validation Report to improve readability.

20           **Reference:**

21           WESTON (Weston Solutions, Inc.). 2004. *Model Calibration: Modeling Study of*  
22           *PCB Contamination in the Housatonic River*. Prepared for U.S. Army Corps of  
23           Engineers and U.S. Environmental Protection Agency.

24           The Executive Summary provides the framework to build on. It would however benefit from  
25           additional detail regarding boundary conditions applied for each model. These were spread  
26           through each of the individual model presentations and as such, easy to loose track of. A  
27           summary statement up-front would help.

28           **RESPONSE O-FB-3:**

29           Decisions regarding the type and amount of information, and the extent of  
30           technical detail, presented in an Executive Summary are always difficult. EPA's  
31           intention was to prepare an Executive Summary that would be useful to  
32           managers and other non-technical readers, and it was believed that such readers  
33           would not require technical information regarding boundary conditions. The  
34           Reviewer's comments will be considered during the preparation of the Model  
35           Validation Report.

## Model Calibration Responsiveness Summary

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1 The individual sections in Volume 1 dealing with each model would benefit from editing by a  
2 single hand to provide a consistent “story line” throughout. In general I found that the  
3 Appendices added little to the discussion. Much of the material presented was already available  
4 in Volume 1. Future editions might use the Appendices as the site for the majority of the data  
5 plots and in some few cases for detailed elaboration of some particular aspect of model  
6 formulation. This combination of efforts would reduce the overall size of the report and  
7 contribute to the acceptance of the model predictions by the broadest possible user group.

### 8 **RESPONSE O-FB-4:**

9 The Model Calibration Report technical appendices were necessarily prepared  
10 by the organizations responsible for each of the component models of the  
11 modeling framework. The appendices were extensively edited to improve  
12 readability and to present the material in a consistent manner. However,  
13 achieving consistency was not entirely possible because of the different structure  
14 of the individual models, which dictated somewhat different approaches to  
15 demonstrating calibration.

16 The Reviewer is correct that there is some repetition of information between  
17 Volume 1 and the technical appendices. This was intentional and was done with  
18 the understanding that few readers would likely read the Model Calibration  
19 Report in its entirety. It was assumed, however, that some individuals, such as  
20 the Peer Reviewers, would require far more detailed information than could be  
21 summarized in Volume 1. EPA will consider alternative approaches to formatting  
22 the Model Validation Report, including the Reviewer’s suggestion.

### 23 **Douglas Endicott:**

24 As a reviewer, it is interesting to see how much this project has progressed in the 4 years since  
25 the review of the Framework document. The Housatonic River is a challenging system to  
26 understand and model. The PCB transport and fate processes in this river are unique in a number  
27 of ways, some of which I do not fully understand. As I mentioned in my preliminary comments, I  
28 am very impressed by the modeling work that is presented in the calibration report. I think that  
29 the project team has done a thorough job in assembling a suite of models that address the major  
30 processes affecting PCBs in the Housatonic River, and along the way have overcome a number  
31 of obstacles presented by site-specific data that challenge conventional wisdom. I remain  
32 optimistic that the modeling tools under development here will be valuable in terms of  
33 forecasting the outcome of remediation alternatives. I am also hopeful that concerns raised  
34 during the Calibration peer review will be considered carefully by EPA, and used to guide  
35 refinement of the modeling tools.

36 The modeling framework which we reviewed 4 years ago has changed considerably since then.  
37 The AQUATOX model biological/food chain component has been abandoned, and the QEA  
38 FOODCHAIN model has taken its place to predict PCB bioaccumulation. EFDC is now the sole  
39 framework for PCB transport and fate, although a number of potentially significant processes  
40 appear to be missing from this model. The role of HSPF in simulating the flow and solids

## Model Calibration Responsiveness Summary

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1 boundary conditions to the PSA has been scaled back considerably. And perhaps most  
2 significantly, the modeling team has implemented EFDC using a 1-dimensional segmentation  
3 scheme in the water column for most of the PSA.

### 4 **RESPONSE O-DE-1:**

5 EPA agrees with the Reviewer's synopsis of the major features of the modeling  
6 framework and the changes that have been made as a result of the first Peer  
7 Review. Discussion of processes that may need to be modified or added to the  
8 modeling framework is provided in several other areas of this Responsiveness  
9 Summary, e.g., responses to General Issues 5, 6, 7, 8, and 9.

10 Calibration datasets have been generated for stage and flow, solids, organic carbon and PCBs in  
11 water, sediment, and biota compartments. An enormous number of sediment samples have been  
12 collected and analyzed to define initial conditions and characterize the variability of PCBs,  
13 organic carbon, grain size, porosity, etc. in the sediment bed. Unfortunately, much of the  
14 apparent variability in this data remains unexplained. Hints are provided in the RFI Report and  
15 Appendices that major components of this variability may be attributable to either measurement  
16 errors (including interlaboratory error) or the judgemental/focused bias applied in much of the  
17 sediment sampling. Variability arising from these factors was estimated, and could be used to  
18 better evaluate the sediment data.

### 19 **RESPONSE O-DE-2:**

20 There is no indication that either interlaboratory (measurement) error or focused  
21 selection of sampling locations is a major component of the observed variability  
22 in the PCB data, although each is recognized to be a potential source of bias. As  
23 referenced in the RFI Report (BBL and QEA, 2003), the field laboratory used by  
24 EPA for analysis of the majority of the samples from the intensive 1998 and 1999  
25 field program was recognized to have lower extraction efficiency than the fixed  
26 laboratories used for earlier studies. This bias, estimated to be approximately  
27 30%, admittedly complicates analysis of temporal trends, but is a minor source of  
28 variability.

29 Similarly, EPA recognized that focused sampling of known or suspected areas of  
30 higher contamination could potentially result in calculation of biased measures of  
31 central tendency. This is one reason that spatial averaging was used for  
32 calculation of exposure frequencies in the Human Health Risk Assessment  
33 (HHRA) for Rest of River. Again, such potential bias is only a minor contributor  
34 to variability.

35 The contribution of analytical variability to the observed total variability in the  
36 PCB data was evaluated in detail and reported in Attachment 4 to the Calibration  
37 Report. There is no indication that the magnitude or sources of such variability  
38 are unusual in any way for this type of study, and analytical variability is also a  
39 relatively minor contributor to the total variability in the data, resulting in the  
40 conclusion that the observed two to three order-of-magnitude small-scale

## Model Calibration Responsiveness Summary

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1 variability in sediment PCB concentrations is a real feature of the river sediment.  
2 Although EPA agrees that the lack of an explanation for this variability is  
3 somewhat unsatisfying, it is not necessary to develop such an explanation to  
4 achieve the goals of the modeling study; therefore, additional evaluation of the  
5 sediment data to better explain this phenomenon is not necessary. Please refer  
6 also to the response to General Issue 5.

### 7 **Reference:**

8 BBL (Blasland, Bouck & Lee, Inc.) and QEA (Quantitative Environmental  
9 Analysis, LLC). 2003. *Housatonic River – Rest of River RCRA Facility*  
10 *Investigation Report*. Volume 1. Report. Prepared for General Electric  
11 Company, Pittsfield, MA.

12 The observation of extreme spatial variability in sediment PCB concentrations, yet no apparent  
13 temporal trends is perplexing.

### 14 **RESPONSE O-DE-3:**

15 Please refer to the response to General Issue 5.

16 Manipulations of the sediment data are in some cases (e.g., organic carbon content of sediment  
17 particle size fractions and TOC normalization of PCB concentrations) so complex and torturous  
18 that their descriptions are unintelligible.

### 19 **RESPONSE O-DE-4:**

20 EPA used complex analysis techniques, including maximum likelihood estimation  
21 methods designed for censored data and log-normal distribution theory, to  
22 generate the best estimates for model inputs based on site data. The detailed  
23 descriptions of these analyses were included to meet the objective of  
24 transparency. EPA acknowledges that, like the analyses, the descriptions are  
25 complex. Given the complexity, it is appreciated that considerable effort would  
26 be required for a reader to grasp the details of the procedures.

27 Additional analyses were also conducted in an effort to explore possible  
28 explanations for some of the variability observed in the sediment data, most of  
29 which were unsuccessful. These analyses were presented in the Model  
30 Calibration Report to address potential questions regarding what was done to try  
31 to understand components of the variability.

32 Although observations of erosion and deposition were made at a series of transects, this  
33 important information has not been directly utilized in the model calibration. Likewise, bank  
34 erosion was monitored but this data was not used in model calibration.

### 35 **RESPONSE O-DE-5:**

36 Please refer to the responses to General Issues 9 and 12.

## Model Calibration Responsiveness Summary

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1 A less extensive sampling and measurement program was carried out for the water column,  
2 primarily based on monthly and event sampling at 5 fixed locations. The resulting data provide a  
3 good sense of the limited spatial trends in water column PCB concentrations through the PSA at  
4 low and moderate flow rates. These data were used primarily to calibrate a diffusive flux from  
5 sediment pore water. Because of the limited duration of monitoring in the water column,  
6 relatively few large flood events were sampled. In this and some other important ways (e.g., the  
7 boundary conditions and water column PCB partitioning) water column monitoring was limited  
8 to the point that the calibration suffered. In at least one case (the suspended solids composition at  
9 the upstream boundary), the modeling team creatively overcame this limitation.

### 10 **RESPONSE O-DE-6:**

11 The objective of the storm event sampling program was to capture large flood  
12 events. The magnitudes of the flows monitored during this program reflect the  
13 difficulty in executing a storm event sampling program. EPA and its contractors  
14 made every effort to be creative in obtaining as much information as possible  
15 regarding large flood events. Sampling of large flood events was complicated by  
16 two factors: (1) limitations associated with weather forecasting that resulted in  
17 events for which the sampling crew was mobilized, but which ultimately did not  
18 occur as predicted; and (2) storms that occurred but were not predicted with  
19 enough lead time to mobilize the sampling crew. A sampling crew of 28 was  
20 necessary to perform all of the tasks in the storm event sampling standard  
21 operating procedure (SOP) over a 24-hour period for a 2- to 5-day event duration  
22 (sampling had to continue until at least some samples were obtained on the  
23 falling limb of the hydrograph; the larger the storm, the longer the duration). The  
24 second factor was the cost of conducting storm event sampling. Mobilization  
25 alone for a single event cost more than \$30,000, and conducting a full storm  
26 event protocol cost more than \$120,000. In some cases, as is typical with such a  
27 large sampling program, some deviations from the SOPs occurred that  
28 necessitated careful analysis and use of the data and/or other approaches to  
29 resolve gaps in the data record. Although it would have been desirable to have  
30 monitored a larger flood event, the decisionmaking for Rest of River could not be  
31 delayed to obtain data from a storm with flows that occur with 10- to 100-year  
32 return intervals.

33 Monthly sampling (which is predictable and far less resource-intensive) has been  
34 performed continuously since 1996 (more limited data are available from earlier  
35 sampling efforts) and continues at approximately 10 stations, to develop a long-  
36 term record of water column data for both the PSA and areas further  
37 downstream. These data are very useful for evaluating spatial and temporal  
38 patterns. This program has been continued, as well as the monitoring associated  
39 with remediation and biennial fish sampling, in part in response to the comment  
40 from this Reviewer on the Modeling Framework Design (MFD) document  
41 (WESTON, 2004).

42 In addition, three water column PCB partitioning data sets were collected, at low-,  
43 intermediate-, and high-flow conditions.

## Model Calibration Responsiveness Summary

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1           **Reference:**

2           WESTON (Weston Solutions, Inc.). 2004. *Modeling Framework Design: Modeling*  
3           *Study of PCB Contamination in the Housatonic River*. Prepared for U.S. Army  
4           Corps of Engineers and U.S. Environmental Protection Agency.

5           To support calibration of the food chain model, biota were sampled and analyzed for congener-  
6           specific PCBs. Target fish species were sampled in 4 of 5 reaches in the PSA. Fish in each reach  
7           were treated as discrete populations, based on habitat and life history assessments. The data  
8           provide good measures of the variability in PCB concentrations between reaches and age classes  
9           of fish. The absence of data for the 5<sup>th</sup> reach (5D) is unfortunate, because the highest PCB  
10          concentrations were predicted by the bioaccumulation model for fish in this reach. The lower  
11          food chain (trophic levels 1 and 2) were underrepresented in the biota sampling effort.

12           **RESPONSE O-DE-7:**

13          EPA agrees that the fish tissue data from the field collections provide good  
14          overall characterization of differences in PCB bioaccumulation among river  
15          reaches and fish age classes. For most species and reaches, sample sizes were  
16          sufficient to characterize the relationship between PCB concentration and fish  
17          age, and also to demonstrate the variability of individual fish concentrations  
18          within local subpopulations.

19          During the period of greatest sampling intensity (fall 1998 EPA sampling), the  
20          river conditions prohibited passage of the electro-shocking boat into the  
21          backwater areas. The resulting lack of Reach 5D fish tissue data increases the  
22          uncertainty of model calibration for this reach. However, as indicated by another  
23          Reviewer (see Comment 1-FG-20 below), one of the objectives of the model is to  
24          estimate bioaccumulation concentrations where concentration data are not  
25          available.

26          EPA agrees that lower food chain levels (i.e., invertebrates, periphyton) were not  
27          sampled as intensively as fish. However, given that the Housatonic River  
28          exhibits large variability in sediment PCB concentrations over small spatial  
29          scales, emphasis on fish species that integrate their exposures over larger areas  
30          of sediment was considered appropriate and a more reliable means of evaluating  
31          model performance, and also provided necessary data for the risk assessments.  
32          The relatively low sample sizes of invertebrate tissues in some individual  
33          sampling events were offset by the multiple lines of evidence available for  
34          assessing bioaccumulation in lower trophic species. For example, model  
35          simulations for sediment epifauna were compared against tissue PCB  
36          concentrations measured in D-net invertebrate samples, in crayfish samples, and  
37          in tree swallow stomach contents (i.e., representative of emergent aquatic  
38          insects). In addition, model-generated biota-to-sediment accumulation factors  
39          (BSAFs) were compared against literature values for freshwater invertebrates.  
40          These comparisons provided evidence that model simulations of lower trophic  
41          level organisms were reasonable.

## Model Calibration Responsiveness Summary

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1 Additional sampling and experimental activities were conducted to support various aspects of the  
2 models (SEDFLUME, bed load, pore and surface water partitioning). However, a number of  
3 other fairly standard water quality measurements were not conducted, including point and  
4 nonpoint source PCB monitoring. Supplemental studies to constrain several ambiguous  
5 parameters (e.g., pore water PCB diffusion flux and vertical extent of sediment mixing) appear to  
6 be necessary to support the calibration.

### 7 **RESPONSE O-DE-8:**

8 The Rest of River modeling study is supported by extensive and intensive data  
9 collection efforts, greater than what is typically performed at a hazardous waste  
10 site. These efforts included the collection and analysis of water column samples  
11 as part of routine water quality monitoring and under many different flow regimes,  
12 including during large storms with out-of-bank flows.

13 The only point source in the Primary Study Area (PSA) is the Pittsfield  
14 wastewater treatment plant (WWTP); analyses of sludge and effluent conducted  
15 by the City of Pittsfield were non-detect for PCBs, indicating that the plant  
16 discharge is not a source of PCBs to the river. Those results are consistent with  
17 EPA's water quality sampling, which found no measurable increase in sediment  
18 or water column PCB concentrations downstream of the WWTP discharge. In  
19 addition, there is another mechanism in place under the direction of the  
20 Massachusetts Department of Environmental Protection (MDEP) to evaluate  
21 potential sources of PCBs in the watershed. This program did not identify any  
22 potential sources of PCBs located in the watershed (other than those that are  
23 known and are being addressed, such as Dorothy Amos Park on the West  
24 Branch) that would be expected to contribute runoff containing PCBs to the PSA.

25 EPA disagrees that additional studies need to be conducted to provide additional  
26 information to further constrain certain model parameters, and believes that the  
27 results of the studies conducted over the last several years provide sufficient  
28 information to meet the goals of the modeling study. In addition, because of the  
29 elevated risks documented in the human health and ecological risk assessments,  
30 EPA believes it is prudent to move forward with the modeling study rather than  
31 delay the project further to conduct additional studies.

32 An important aspect of model calibration is the reduction of data to achieve consistency with the  
33 model inputs, parameters, state variables, etc. This involves spatial and temporal averaging,  
34 normalization, and sometimes more involved transformations. There was much data to reduce in  
35 this project, and for the most part the modeling team did a masterful job. In several instances,  
36 however, the data were not appropriately reduced. Two significant examples, which were  
37 problematic for the peer reviewers, were the PCB concentrations in the sediment (used to  
38 initialize the sediment bed) and in fish (used to confirm the bioaccumulation simulation). In both  
39 cases, the individual data were inappropriately compared to aggregated/averaged quantities in the  
40 models. Much confusion resulted regarding what the models were intended to predict and  
41 whether the residuals were indicative of model bias.

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE O-DE-9:**

2           The Reviewer is correct that data reductions were necessary to provide  
3           appropriate data linkages among models, to convert input parameters to correct  
4           units, and to aggregate data to appropriate spatial/temporal scales. EPA  
5           believes that the appropriate data reductions were conducted during model  
6           simulations and model linkages, given the objectives of the modeling study (see  
7           response to General Issue 1). EPA acknowledges, however, that some  
8           confusion was evident in the interpretation of graphical depictions of data  
9           analyses, particularly from the presentation of individual sample concentrations  
10          plotted against central tendencies from the model simulations.

11          As noted in the response to General Issue 1, the purpose of the modeling study  
12          is to simulate the fate and bioaccumulation of PCBs, with the focus on average  
13          concentrations of PCBs in various abiotic and biotic compartments. To provide  
14          the most appropriate comparisons of model simulations to field observations,  
15          EPA agrees that the individual field observations should be represented by a  
16          measure of central tendency and compared to the simulated averages. EPA will  
17          address this in the Model Validation Report by: (1) including such comparisons in  
18          scatter-plots of simulated versus measured concentrations; (2) clarifying when  
19          differences in data reduction methods may have significance for interpretation of  
20          figures, and (3) providing a more informative footnote for each figure.

21          During the Peer Review deliberations, some specific graphs were discussed at  
22          length, and issues were raised with respect to: (1) the degree to which data  
23          reduction was applied; (2) the comparability of PCB data distributions to central  
24          tendency estimates/simulations; and (3) whether the graphs indicated model  
25          bias, the variability of individual measurements, or both. Examples are  
26          discussed below to clarify some of the specific issues raised:

- 27          ▪ “Binning” of Sediment PCBs – Figures 5-5 and 5-6 of the Model Calibration  
28          Report summarized PCB concentration data used to initialize the sediment  
29          bed. Figure 5-5 plotted measured concentrations in individual sediment  
30          samples, whereas Figure 5-6 plotted the central tendencies of the data used  
31          to initialize the sediment bed. As the Reviewer notes, the EFDC model  
32          simulates only the averaged concentrations in the sediment. In using  
33          average concentrations in sediment, EPA has implicitly assumed that the  
34          average concentrations in biota will be driven by the average concentrations  
35          in abiotic exposure media, which is consistent with the approach used in the  
36          risk assessments. Neither explicit modeling of the distribution of sediment  
37          PCB concentrations in EFDC nor a full mechanistic understanding of the high  
38          variability in sediment PCB concentrations was necessary to satisfy the model  
39          objectives (see also responses to General Issues 1 and 5).
- 40          ▪ Spatial Scale of Variability in Sediment PCBs – During Panel deliberations,  
41          questions were raised with respect to the magnitude of variability observed in  
42          sediment PCB concentrations, and whether the graphics shown in the Model

## Model Calibration Responsiveness Summary

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1 Calibration Report were internally consistent. Specifically, the degree of  
2 variability observed in Figure 5-5 was compared against the variability  
3 observed in the benthic community sampling program (i.e., 12 replicates  
4 collected over a few square meters). The latter indicates the variability over a  
5 small patch of relatively homogeneous substrate types, whereas the former  
6 indicates variability over larger areas of more variable substrate and  
7 hydrodynamic regimes. It is not unexpected that the variability in PCB  
8 concentrations associated with heterogeneous substrate across the river  
9 profile (i.e., 2 to 3 orders of magnitude) is larger than that observed at specific  
10 sampling locations (i.e., 1 to 2 orders of magnitude).

11 ■ Fish Tissue Scatterplots – Figures C.3-49 through C.3-52 portray individual  
12 PCB concentrations in fish used to evaluate the performance of the  
13 bioaccumulation simulation. EPA acknowledges that several of these  
14 scatterplots compare individual concentration data (measured) to central  
15 tendencies (simulated), resulting in confusion for some Reviewers. The large  
16 individual residuals shown on the graphs are indicative of variability in  
17 individual fish measurements, but do not indicate substantial bias. When  
18 FCM was run in a deterministic mode, average values of all input parameters,  
19 including lipid contents, growth rates, dietary patterns, etc., were applied.  
20 Individual variations observed in nature for these parameters will result in  
21 distributions about the central tendency. The purpose of these graphs was  
22 simply to evaluate whether the deterministic simulations systematically under-  
23 or overpredicted measured concentrations in the assessment of model bias.  
24 The magnitude of variability observed within each combination of species,  
25 reach, and fish age (i.e., model precision) is an issue separate from the  
26 assessment of model bias.

27 ■ Fish Tissue Comparisons of Means – In the Model Calibration Report, several  
28 figures compare central tendencies derived from data to central tendencies  
29 simulated by the model (e.g., Figure C.3-28, Figure C.3-51, and Figure 6-15).  
30 These figures provide the most robust assessment of model bias. In some  
31 cases, however, there was only a single sample for a unique combination of  
32 age, species, and river reach, and it is not known how well this single data  
33 point represents the central tendency. The analysis showed that magnitude  
34 of model residuals decreased as the sample size of each group increased  
35 (i.e., as the sample means for field data become better indicators of central  
36 tendency). This result strongly suggests that the largest residuals are  
37 attributable to variability in the data, rather than due to model uncertainty.

38 In summary, EPA acknowledges a need for improved clarity in the labeling and  
39 consistency of “model performance” graphical summaries. Future graphs will be  
40 clearly footnoted with an explanation of what is being depicted.

41 In general, calibration of the models was thorough, if limited by the relatively short time scale of  
42 the observations, the previously-mentioned lack of comparison to erosion and deposition  
43 measurements, and the omission of a number of processes (e.g., bank erosion) that appear to be

## Model Calibration Responsiveness Summary

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1 significant to the mass balance. The calibrated suspended solids, water column total PCB, and  
2 fish PCB concentration appear to be reasonably accurate and unbiased. Many specific comments  
3 regarding the calibration are offered below. The major problem with the calibration as reported is  
4 that these are short time scale simulations, which are not sensitive to important features of the  
5 sediment and contaminant transport models.

### 6 **RESPONSE O-DE-10:**

7 Please refer to the response to General Issue 2.

8 Overall, my sense is that the calibration report is an interim deliverable meant to satisfy the  
9 timetable of the Consent Decree. Many aspects of the calibration will necessarily be revisited,  
10 once a longer-term simulation is constructed and tested.

### 11 **RESPONSE O-DE-11:**

12 EPA does not view the Model Calibration Report as an interim deliverable  
13 produced to satisfy a timetable; it reflects the plan specified in the MFD and  
14 Modeling Study Quality Assurance Project Plan (QAPP) (WESTON, 2000). The  
15 Model Calibration Report was produced at this time to demonstrate model  
16 performance in simulating conditions observed in the data for the time period for  
17 which the most intensive data collection effort was conducted and to receive  
18 input from the Panel before conducting more resource-intensive efforts. The  
19 calibration timeframe was proposed in the original MFD. Please refer also to the  
20 response to General Issue 2.

### 21 **Reference:**

22 WESTON (Roy F. Weston, Inc.). 2000. *Quality Assurance Project Plan: Modeling*  
23 *Study of PCB Contamination in the Housatonic River*. Prepared for U.S. Army  
24 Corps of Engineers and U.S. Environmental Protection Agency.

25 The other efforts documented in the Calibration report (sensitivity analysis and uncertainty  
26 analysis) seem redundant at this point, given that much of the model calibration is unfinished.  
27 The sensitivity analyses of the models are thorough and informative, however.

### 28 **RESPONSE O-DE-12:**

29 The sensitivity analyses presented in the Model Calibration Report provided  
30 important insights to the modeling team regarding model behavior, focusing  
31 further calibration efforts. Therefore, EPA believes it was appropriate to conduct  
32 and present the sensitivity analyses as part of the Model Calibration Report.

33 Only the food chain model has been subjected to rigorous uncertainty analysis. I sense it may be  
34 the only one of the models for which this can be practically accomplished.

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1           **RESPONSE O-DE-13:**

2           Please refer to the response to General Issue 11.

3           **Wilbert Lick:**

4           Many of my concerns have to do with the modeling framework and data needs. The panel  
5           addressed this topic in 2001. However, at that time, the modeling framework was quite general,  
6           very ambitious, and had little detail. The framework and model details have changed  
7           considerably since then. Because of this, in answering the questions on Modeling Calibration,  
8           some preliminary comments on the modeling framework are necessary. Since Question 3 is  
9           closest to the concerns about the modeling framework, most of my preliminary comments are  
10          included as introductory material to Question 3.

11          **RESPONSE O-WL-1:**

12          EPA acknowledges that the modeling framework has been substantially refined  
13          and revised since the first Modeling Framework Design document and the Peer  
14          Review of that document. Many of the changes implemented since that time  
15          were made in response to the comments of the Peer Review Panel.

# Model Calibration Responsiveness Summary

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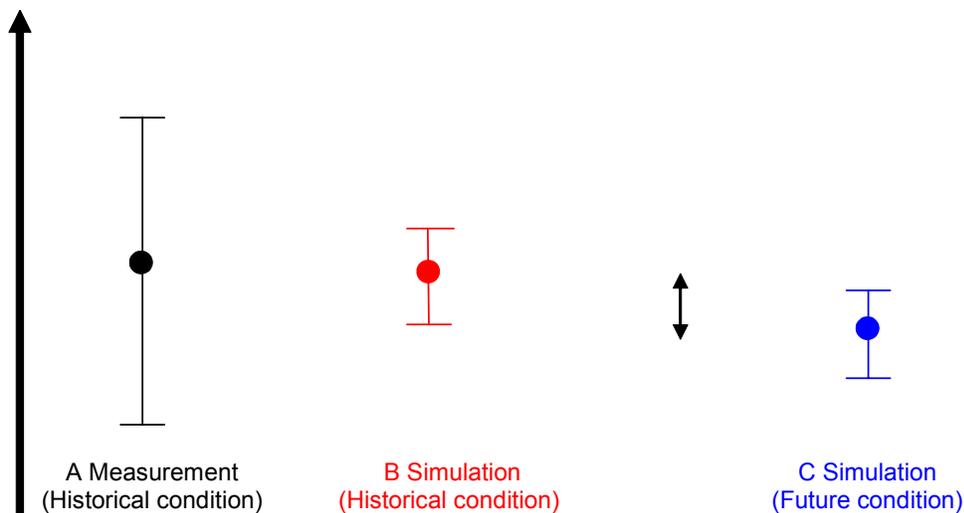
## 1 SPECIFIC COMMENTS

### 2 Comparison of Model Predictions with Data

3 **1. Are the comparisons of the model predictions with empirical data sufficient to evaluate**  
4 **the capability of the model on the relevant spatial and temporal scales?**

#### 5 E. Adams:

6 This is really the overarching question associated with model calibration: are the models good  
7 enough? But the question has to be asked in the framework of what the models will be asked to  
8 do, which is to evaluate remedial alternatives. (Problem identification is usually the first step in  
9 model evaluation; see, e.g., Ditmars et al., 1987.) The following sketch and discussion provide a  
10 framework for addressing this issue in general terms. Supplemental information is provided in  
11 the answers to the remaining five questions.



12

13 The black symbols on the left (A) represent, qualitatively, the range in space and time of  
14 measured state variables. The models have many state variables, but I will focus on three: flow  
15 rate; sediment concentration (bed load and suspended); and PCB concentrations (in the sediment,  
16 water column and fish). Some of the variables, such as sediment PCB concentrations, have  
17 tremendous variability as implied by the wide brackets. The mean is indicated by the circle. The  
18 red symbols in the center (B) represent the calibrated models' prediction of the same variables,  
19 while the blue symbols on the right (C) indicate the models' simulation of the same variables  
20 under a future remediation scenario.

21 We are being asked if, following calibration, the models are “good enough”. In model  
22 calibration, this traditionally means asking how well the simulations (B) match the historical data  
23 (A) with respect to the mean, the variance, etc. However, it is more relevant to ask how

## Model Calibration Responsiveness Summary

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1 confident we are that the models will correctly predict the environmental effectiveness of various  
2 remediation options, which we are told include removing contaminated sediments by dredging  
3 and/or dry excavation, burying them through in situ capping above and/or below water, and  
4 natural recovery.

### 5 **RESPONSE 1-EA-1:**

6 Please refer to the response to General Issue 1.

7 Evaluation of future options introduces the following questions concerning model skill: how well  
8 does the model predict absolute mean output (an absolute measure indicated by the blue circle in  
9 C), how well does the model predict relative mean output (i.e., change from existing conditions,  
10 indicated by the black arrow representing the difference between the red circle of B and the blue  
11 circle of C), and how well does the model simulate the range in output (both in absolute terms  
12 and relative to the existing condition). In general a model will perform *better* in a relative  
13 assessment, than in a calibration, because model errors tend to cancel. Conversely a model may  
14 perform *worse* in an absolute assessment, than in a calibration, because different data and  
15 processes (reflecting remediation options) are involved. Of course we don't have measurements  
16 of future conditions with which to compare model results so we have to make inferences. This is  
17 done qualitatively below for the various types of model output.

18 **Flow rates** are primarily an output of HSPF and measured inputs, as filtered by river  
19 hydrodynamics (EFDC). HSPF has been around for a long time, its developers have had lots of  
20 experience with it, and the available data for the Housatonic seems to be on par with (or better  
21 than) what is typically available for other sites. There are a lot of semi-empirical parameters that  
22 can be adjusted to achieve a good fit and the fits displayed seem generally acceptable with  
23 respect to both mean and variance. (Some errors come when simulating storm events, but this is  
24 due to the difficult of getting storms right—both magnitude and timing—with only one hourly  
25 rain gauge in the watershed. But this should not be a problem in a statistical sense: if sediment-  
26 laden PCBs are being eroded due to a storm, we aren't concerned about the exact timing of the  
27 storm.) Because the proposed remediation measures should not significantly affect flows there is  
28 no reason to believe the model will not be able to adequately simulate flows under future  
29 conditions.

### 30 **RESPONSE 1-EA-2:**

31 EPA agrees with the Reviewer's assessment that the HSPF watershed model is  
32 adequately calibrated to achieve the goals of the modeling study; however,  
33 additional calibration results for the Phase 2 period will be presented in the Model  
34 Validation Report.

35 **Sediment transport** is performed by EFDC (with inputs from HSPF) and results from the  
36 processes of erosion, bed load transport (primarily of coarser size fractions), resuspension  
37 (primarily of finer size fractions) and deposition. There are no direct field measurements of bed  
38 load transport, but the model has been calibrated to produce reasonable agreement with field  
39 measurements of mean total suspended solids (TSS) suggesting that the net effect of the  
40 contributing processes is satisfactory, at least with respect to the mean.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-EA-3:**

2           The Reviewer is not correct that there were no direct measurements of bed load  
3 transport. EPA conducted a bed load study that included three sampling events.  
4 The study is presented and discussed in Section 4.4.1.2 of the final MFD.  
5 Comparison of the results of the bed load study to simulations produced by the  
6 sediment transport model are summarized in Volume 1 (Section 4.2.3.1.3) of the  
7 Model Calibration Report, and discussed in detail in Appendix B (Section  
8 B.3.2.3.2). These comparisons indicate reasonable agreement between the  
9 simulated bed load and the data. EPA agrees with the Reviewer's assessment  
10 that the agreement between measured and simulated TSS is also reasonable.

11          The agreement on the variance would best be seen using an equivalence plot of TSS (graph of  
12 measured TSS on the vertical axis and simulated TSS on the horizontal axis, with a 45 degree  
13 line indicating perfect agreement). Apparently such plots have not been generated, but I suspect  
14 that they would show that the model under predicts the variance in TSS for two reasons: First,  
15 TSS is a function of erosion, which depends on shear stress to a power  $n$ . Shear stress, in turn,  
16 depends on the local velocity squared, making erosion dependent on velocity raised to the power  
17 of  $2n$ . Because EFDC uses approximately one grid cell per channel width, it can only output  
18 channel average velocities. Hence velocity extremes associated with lateral variations in channel  
19 depth and meandering are ignored.

20           **RESPONSE 1-EA-4:**

21           Please refer to the responses to General Issues 12 (equivalence plots will be  
22 provided in the Model Validation Report) and 4 (regarding the number of grid  
23 cells across the channel).

24          Furthermore, the calibrated values of  $n$  are approximately one, whereas W. Lick points out that  
25 the literature suggests the value should be more like two.

26           **RESPONSE 1-EA-5:**

27           Please refer to the response to General Issue 7.

28          Hence a model calibrated to produce the right amount of resuspension on average will likely  
29 smooth out the extremes, in particular under predicting resuspension during high-energy events.  
30 It would likewise be expected to under predict the extremes in bed load transport. The under  
31 prediction of both bed load and suspended load transport would cause the model to  
32 underestimate the potential for natural remediation, while the underestimate of bed load transport  
33 could cause the model to underestimate the threat of cap erosion if instream capping were to be  
34 considered for remediation. I recommend that measured and predicted TSS be plotted on an  
35 "equivalence plot" to assess the magnitude of this problem and, if significant, the erosion model  
36 be recalibrated. Of course this means that deposition and possibly other processes would also  
37 need to be recalibrated.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-EA-6:**

2           The equivalence plots recommended by the Reviewer were developed and  
3           evaluated. These plots indicated that there was no need to recalibrate the  
4           erosion model. Please refer also to the response to General Issue 12.

5           **PCB concentrations** are predicted using both EFDC and the Food Chain Model (FCM). EFDC  
6           has been calibrated to produce good agreement with measured average PCB concentrations in  
7           the water column. This means that the net effect of several exchange processes is in balance  
8           (though it doesn't say anything about the individual processes themselves). Over a short  
9           calibration period not much change can be expected in the sediment PCB concentrations so it is  
10          difficult to assess calibration here.

11          **RESPONSE 1-EA-7:**

12          EPA agrees that while the simulated concentrations are in reasonable agreement  
13          with the data, there is little change in sediment concentrations in the PSA during  
14          the period of model calibration. This issue may persist through both Phase 2 of  
15          Calibration, and in Validation, because of the lack of clear temporal trends in the  
16          sediment data over the period of record. Please refer also to the response to  
17          General Issue 2.

18          The FCM seems to be doing a good job of reproducing at least mean concentrations in fish and  
19          EPA claims that this is all they care about.

20          **RESPONSE 1-EA-8:**

21          The Reviewer is correct that EPA is most concerned about the average  
22          concentration in fish over time. The model performance targets specified in the  
23          Modeling Framework Design and the Modeling Study QAPP apply to mean  
24          concentrations within each unique combination of river reach, fish species, and  
25          fish age. The deterministic application of FCM does not simulate distributions of  
26          individual PCB concentration data. EPA believes that the reproduction of mean  
27          concentrations by FCM is adequate for application of the model to evaluation of  
28          alternate remediation scenarios. Please refer also to the response to General  
29          Issue 1.

30          Remediation may result in lower sediment PCB concentrations (e.g. if some of the PCBs are  
31          removed) or a redistribution of PCB mass (e.g., if the PCBs are sequestered under a cap). To the  
32          extent that the sediment-water exchange processes, and the biological uptake, are linear with  
33          respect to concentration, good agreement between model and data under existing conditions  
34          should imply good ability to predict future conditions when the concentrations are lowered due  
35          to remediation. To the extent that the remediation removes a fixed fraction of both fine and  
36          coarse-grained sediments (and their associated PCBs), which seems reasonable for a dredging  
37          scenario, the assumption of linearity is reasonable. (See discussion in the following paragraph.)

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-EA-9:**

2           Although it is premature to focus on specific remedial alternatives given the  
3           process specified in the Consent Decree, the exchange and uptake processes  
4           identified by the Reviewer are adequately approximated with the assumption of  
5           linearity with respect to PCB concentrations. EPA agrees that demonstration of  
6           the ability of the model to predict current conditions provides confidence in the  
7           ability of the model to predict future conditions following potential remediation,  
8           including natural recovery. Indeed, the concept of model calibration is based on  
9           just such an assumption.

10          I agree with the concern expressed by QEA/GE that the depth of PCB bioavailability within the  
11          sediments (6 inches) is too great. Since PCB concentrations are currently fairly well mixed in  
12          the upper 6 inches, this does not affect the ability to simulate uptake presently, but it would  
13          affect the ability to predict uptake under a future scenario in which the PCBs were buried under  
14          cleaner sediments (either by application of a cap, or over time by natural processes).

15           **RESPONSE 1-EA-10:**

16          EPA agrees that the data currently do not indicate strong gradients in PCB  
17          concentrations, or other sediment parameters, in the top 6 inches of the sediment  
18          bed. This vertical homogeneity reflects biological and physical processes in the  
19          PSA that affect the way sediment is deposited and resuspended.

20          In response to this and other comments received from the Panel, EPA is  
21          reevaluating the use of a 6-inch well-mixed layer in the model and is evaluating  
22          the implementation of a thinner layer. EPA agrees with the Reviewer that a 6-  
23          inch layer may not represent the most appropriate depth for evaluating remedial  
24          alternatives throughout the PSA. Please refer also to the response to General  
25          Issue 6 for a detailed discussion of the depth of the bioavailable layer.

26          During the Peer Review Meeting much was said about the tremendous spatial variability in  
27          sediment PCB concentrations over space scales of order one meter and the fact that the model  
28          can not reproduce this variability. The failure of the model to pick this up should not be  
29          considered model error, *per se*, but simply unresolved variability in model input and output  
30          (sediment bed concentration distributions).

31           **RESPONSE 1-EA-11:**

32          EPA agrees that it is not possible or necessary for the model to reproduce the  
33          observed small-scale variability in PCB concentrations in PSA sediment, and  
34          EPA also agrees that the lack of representation of this micro-scale variability is  
35          not model error. In addition, EPA believes that the lack of micro-scale modeling  
36          (or mechanistic explanation for the observed heterogeneity) is not a significant  
37          model limitation, given the objectives of the modeling effort (refer to the response  
38          to General Issue 1). The knowledge that this variability exists, however, will  
39          contribute to understanding some of the uncertainty in model predictions.

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1 This variability is real and most likely reflects the stochastic method in which the PCBs were  
2 introduced in the first place.

3 **RESPONSE 1-EA-12:**

4 EPA agrees with the Reviewer's comment.

5 We cannot expect the model to predict this variability and the fact that the model averages  
6 concentration over relatively large grid cells is not a problem (with the mean) unless sediment-  
7 water exchange of PCBs varies non-linearly with concentration.

8 **RESPONSE 1-EA-13:**

9 EPA agrees with the Reviewer that the model cannot be expected to predict the  
10 variability observed in the data and that the use of mean concentrations does not  
11 pose a problem because sediment-water exchange of PCBs is represented in the  
12 model by dissolved and particulate exchange that varies linearly with  
13 concentration.

14 The exchange of dissolved PCBs is computed based on a surface mass-transfer  
15 coefficient and the concentration gradient between the dissolved PCB  
16 concentration in the surface water and that in the pore water. Because the pore  
17 water concentrations are much greater than the dissolved concentrations in the  
18 surface water, the dissolved transport varies linearly with sediment PCB  
19 concentration. The model, therefore, simulates the correct average flux of PCBs  
20 between the water column and sediment compartments on the basis of the  
21 average concentrations.

22 The exchange of particulate PCBs is calculated based on PCBs associated with  
23 each of the four solids classes (i.e., one cohesive and three non-cohesive  
24 classes). In each grid cell, the PCB concentrations on the different solids classes  
25 are calculated based on the total PCB (tPCB) concentration, the fraction of the  
26 total sediment in each solids class, and the different organic fractions on each  
27 solids class. Based on these calculations, the exchange of particulate PCBs is  
28 also linear with concentration.

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

34 **RESPONSE 1-EA-14:**

35 EPA agrees with the Reviewer's comment.

36 Back to the mean, sediment-water exchange *would* be expected to vary non-linearly with  
37 sediment concentration to the extent that the PCBs are associated preferentially with finer

## Model Calibration Responsiveness Summary

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1 sediments that are more easily eroded. The model could be getting the flux of (primarily fine  
2 grained) sediments correct, but would be assigning an average PCB concentration to these  
3 sediments and hence underestimating the flux of PCBs. As a result I suspect the effect of  
4 averaging (sub-grid scale variability in sediment PCB concentrations) results in an underestimate  
5 of PCB flux during periods of high resuspension, for both existing and future conditions.

### 6 **RESPONSE 1-EA-15:**

7 Preferential sorption of PCBs to finer sediment is recognized and accounted for  
8 in the modeling approach. Formulations are used for erosion that account for bed  
9 composition, which eliminates the potential problem discussed by the Reviewer.

10 The distribution of PCBs among different solids size classes within individual  
11 sediment samples was investigated as part of the EPA Rest of River Study.  
12 Sediment solids were separated by grain size, and PCB and TOC were  
13 measured on each size fraction. Carbon normalization reduces the variability in  
14 PCB concentrations measured on the different size classes (see Model  
15 Calibration Report Appendix B, Figures B.4-22 through B.4-25).

16 In the model, the PCB concentrations on the different solids classes are  
17 calculated based on the tPCB concentration, the fraction of the total sediment in  
18 each solids class, and the different organic fractions on each solids class. The  
19 size fraction composition of the solids eroded from the bed is calculated based  
20 on the composition of the bed material and recognition that the bottom shear  
21 stress required to erode non-cohesive particles increases with increasing particle  
22 size. Resuspension of cohesive solids is calculated based on site-specific  
23 erosion data.

24 To assess this effect, the correlation of PCB concentration and sediment type should be checked  
25 in available measurements and, to the extent possible in prediction. (I realize that model output  
26 is averaged over spatial scales that include a range of sediment type.)

### 27 **RESPONSE 1-EA-16:**

28 Figures 4-16 and 4-17 of the RFI (BBL and QEA, 2003) illustrate the relationship  
29 observed in the data. These figures indicate that there is only a weak  
30 relationship (i.e., generally low  $r^2$  values) in the PSA between sediment properties  
31 and PCB concentrations. Similar figures will be included in the Model Validation  
32 Report to address this comment with respect to the model results.

33 Also, although it would be a major change at this point, I wonder if it wouldn't be better to have  
34 the model formulated to predict sediment PCB concentrations simply as a function of sediment  
35 type (e.g., coarse, medium and fine) with only very coarse longitudinal discretization (say by  
36 reach 5A, 5B, etc.) This would result in much less model output (by two orders of magnitude),  
37 making the calculations more tractable, and the output would be more environmentally relevant:  
38 we don't care which 20 m cell within a reach a fish is in when it feeds in contaminated  
39 sediments, but merely the likelihood that the particular sediments will actually be  
40 contaminated—and to what extent.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-EA-17:**

2           EPA agrees in principle with the Reviewer that coarse longitudinal binning of  
3           simulated contaminant concentrations is sufficient to achieve the goals of the  
4           modeling study; in fact, FCM operates on exactly such a scale, and EFDC output  
5           is averaged over subreach bins before it is passed to FCM. Simply relating  
6           contaminant concentrations to sediment type is not possible, however, because  
7           sediment characteristics are only one of many factors involved in contaminant  
8           transport and fate, as indicated by the sometimes weak relationships between  
9           sediment type and PCB concentrations in the PSA. The additional factors  
10          controlling contaminant transport and fate in the PSA are discussed in detail in  
11          Section 4 of the MFD, and in part determined the model selection and other  
12          aspects of the modeling framework. Adequate simulation of all the factors  
13          determined to be of importance in the PSA is necessary for satisfactory  
14          prediction of PCB fate, even if the output is subsequently integrated to larger  
15          spatial and temporal scales.

16          **W. Frank Bohlen:**

17          The calibration period extends from May 1, 1999 to June 30, 2000. Although this was a period  
18          that allowed for the sampling of a range of average ambient and aperiodic storm conditions it is,  
19          from the standpoint of sediment/contaminant transport in the Housatonic River study area, a very  
20          short period of time. Erosion processes affecting the side banks and the associated channel  
21          migration, sediment deposition in the backwaters and Woods Pond and many of the transport  
22          processes affecting the floodplains operate on time scales long compared to the calibration  
23          period. As a result the comparisons conducted over the calibration period provide only limited  
24          indication of the model's ability to accurately predict longterm change. There is some indication  
25          that this is recognized by the model developers and will be addressed during the verification  
26          phase. Such use of the verification phase for calibration purposes is not recommended.

27          **RESPONSE 1-FB-1:**

28          The time period used for model calibration was proposed in the MFD; only a  
29          single comment from the Reviewers was received on the appropriateness of the  
30          approach. In response to Reviewer comments on the Model Calibration Report,  
31          EPA is revising the approach to calibration and validation; please refer to the  
32          response to General Issue 2.

33          If 14 months is too short what might be an adequate calibration period? This is a question that  
34          would benefit from some amount of discussion by those most familiar with the study area. At  
35          present the reports provide relatively little discussion of the reasoning that lead to the selection of  
36          the 14 month period. Although I've been trying to encourage a shorter report this is a subject  
37          that would benefit from additional discussion. My brief review of available data detailing  
38          sedimentation in the study area as well as contaminant concentrations suggests that a five year  
39          period of calibration would result in a more robust test of model capability and complement the  
40          longer term validation runs.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-FB-2:**

2           Please refer to the response to General Issue 2.

3           **Douglas Endicott:**

4           I can't answer this question with a "yes" or "no" for the calibration of the EFDC model, because  
5           I do not believe it is being applied on spatial and temporal scales that are relevant to the PCB  
6           contamination problem in the PSA and its remedy. I will address the issues of relevant spatial  
7           and temporal scales in the following paragraphs.

8           **RESPONSE 1-DE-1:**

9           Please refer to the responses to General Issues 2 and 4.

10          In the case of the food chain model, it appears that comparisons made between predictions and  
11          observations are adequate, except in reach 5D where no fish were sampled.

12          **RESPONSE 1-DE-2:**

13          EPA agrees that the model performance measures for FCM were adequate. The  
14          implications of the lack of fish sampling in Reach 5D backwaters are discussed  
15          above in Response O-DE-7.

16          I have a fundamental objection with the application of EFDC as a predominantly 1-dimensional  
17          model to simulate hydrodynamics, sediment transport and PCB transport in the PSA. Accurate  
18          simulations of velocities, shear stresses, erosion and deposition patterns, and streambank  
19          undercutting/erosion are only possible if significant lateral variations are resolved in the model.  
20          At least 3 lateral segments should be used in the main river channel, and should consider river  
21          features such as bathymetric profiles. This lateral segmentation should also be used in the  
22          sediment bed, with initial sediment conditions recalculated from data on the basis of this  
23          segmentation. Fortunately, EFDC is a 3-dimensional model so it should be able to accommodate  
24          this additional resolution.

25          **RESPONSE 1-DE-3:**

26          Please refer to the response to General Issue 4.

27          The temporal scale of EFDC calibration is not particularly relevant to the PCB contamination  
28          problem in the PSA and its remedy. It should be noted that "calibration" in the context of this  
29          project has come to mean calibration of short-term (daily to seasonal) changes in model state  
30          variables. "Validation" now includes the calibration of long-term (annual to decadal) changes,  
31          which are the interesting changes in terms of managing toxic chemicals and making decisions  
32          about remedial alternatives. In other words, at this juncture we are unable to evaluate the model's  
33          capabilities in terms of its intended application. In order to fully evaluate the model's  
34          capabilities, it must be applied to a significantly longer simulation period (i.e., 10 years) and

## Model Calibration Responsiveness Summary

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1 compared to data over this longer duration. This limitation also has an impact on how thoroughly  
2 we can address questions 4, 5 and 6 below.

### 3 **RESPONSE 1-DE-4:**

4 Please refer to the response to General Issue 2.

5 Regarding the calibration of sediment transport in EFDC, there is too much emphasis on  
6 matching suspended solids concentrations, and not enough on scour and deposition in terms of  
7 changing sediment bed elevation. The calibration of suspended solids only fixes the magnitude  
8 of net settling/resuspension in the model, while the individual fluxes may or may not be correct.  
9 Confirming the change in sediment bed elevation can be much more revealing.

### 10 **RESPONSE 1-DE-5:**

11 EPA does not agree that too much emphasis was placed on suspended solids in  
12 the model calibration. Transport of suspended solids is the primary transport  
13 mechanism for PCBs in the system. However, it is true that the change in  
14 sediment bed elevation is also an important fate-controlling factor for PCBs in the  
15 system because, in depositional reaches at least, the rate of change in sediment  
16 bed elevation (i.e., the net sedimentation rate), in combination with the well-  
17 mixed layer depth and the concentration of PCBs associated with the depositing  
18 solids, control the rate of long-term recovery of the system. The model currently  
19 computes a net sedimentation rate that ranges from 0.07 to 0.24 cm/year on a  
20 reach-average basis. While this may be low in comparison to the limited  
21 information on net sedimentation rates for the system, it is necessary that the  
22 comparison be made using results from a longer term simulation period, as will  
23 be available at the conclusion of the model validation phase of the investigations.

24 The most robust data documenting changes in sediment bed elevation are from  
25 the river channel surveys collected at nine transect locations from September  
26 2000 to September 2003 (final MFD, Appendix H.2). An additional survey was  
27 performed at these locations in July 2005, and the locations were resurveyed  
28 following the high-flow event of October 2005. From examination of these  
29 results, and from additional anecdotal information and observations of channel  
30 bed elevation changes following storm events, it is apparent that scour and  
31 deposition in the PSA are phenomena that are extremely variable spatially, are  
32 occurring over small spatial and temporal scales, and appear to have a high  
33 degree of stochasticity. In combination, these factors make scour and deposition  
34 a difficult parameter for the model to reproduce exactly because the net scour or  
35 deposition in an individual model channel cell at any time step must reflect the  
36 net result of a number of individual scour and depositional areas, and because  
37 some parameters affecting scour and deposition (such as the presence of woody  
38 debris) cannot be represented in the model. Because the model is not intended  
39 or expected to represent small-scale scour and deposition, it is difficult to use the  
40 site-specific data to evaluate model calibration, except as an indicator of typical  
41 behavior over areas of the river.

## Model Calibration Responsiveness Summary

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1 In that regard, I have some trouble reconciling the 3 to 4 cm maximum change in sediment bed  
2 elevation predicted by the sediment transport model for the 14-month calibration period, with the  
3 several-foot change based on bathymetric transects and stratigraphic analysis. I am afraid the  
4 calibration results fail to demonstrate that the approach taken to calibrate settling and  
5 resuspension fluxes works.

### 6 **RESPONSE 1-DE-6:**

7 The difference between the model results and the observations referred to by the  
8 Reviewer is a result of several factors. First, no large-scale events of sufficient  
9 magnitude to redistribute several feet of sediment occurred during the Phase 1  
10 model calibration period. Additionally, the model cells are typically about 20  
11 meters long, while the bathymetric transects indicating marked erosion of the  
12 cross-section represent point observations along the longitudinal axis of the river.  
13 Thus, the model segments provide an estimate of reach averages and would be  
14 expected to smooth out finer scale changes in bathymetry that may occur. For  
15 this same reason it is important that the model correctly evaluate the water  
16 column TSS level over time because the TSS level reflects the cumulative impact  
17 over distance of the variable fine-scale changes in channel bathymetry that have  
18 occurred upstream of the point of sample collection.

19 The chronological order of the lines in the plots of changes in bathymetry at the  
20 cross-sections is another factor that needs to be considered because the  
21 beginning and end of storm profiles do not necessarily correspond to the  
22 maximum range in elevation that occurs over the course of a storm. Thus, the  
23 net change in elevation during the storm may be less than is suggested by the  
24 range in elevation that is reported throughout the storm. The comparison of  
25 these transects with the model must necessarily be performed during the  
26 validation phase of the analysis because the cross sections were not measured  
27 within the 14-month calibration period. Please refer also to the response to  
28 General Issue 12.

29 How do we know that the highly-nonlinear parameters describing things like cohesive sediment  
30 erosion, flocculation, and deposition can be determined by averaging data collected at a number  
31 of sites having different sediment properties? To a certain extent, the answer is obtained by  
32 running the model for a relatively long duration, and examining the results for anomalies in  
33 terms of the magnitude and pattern of sediment bed change.

### 34 **RESPONSE 1-DE-7:**

35 Please refer to the response to General Issue 12.

36 In some other river systems, errors in deposition and erosion fluxes are revealed during  
37 calibration of water column PCB concentrations, because the concentration gradient between  
38 sediment and water amplifies the error. In the PSA this will not work so well, because there is  
39 only a small gradient between suspended and bedded particulate PCB concentrations. The lack of  
40 gradient makes it relatively more difficult to tell if the model is grossly in error.

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### 1           **RESPONSE 1-DE-8:**

2           It is acknowledged that the water column and bed sediment particulate PCB  
3           concentrations in the Housatonic River may not be as different as in some other  
4           systems, when compared on a whole sediment basis. However, the difference is  
5           actually amplified considerably when the PCBs associated with the fine sediment  
6           fraction are compared to the water column particulate PCBs. This is because the  
7           fine sediment fraction is higher in organic carbon content and thus, has a  
8           relatively high dry weight PCB concentration as well (see Figures B.4-22 through  
9           B.4-25 in the Model Calibration Report).

10          Because the fine sediment fraction is the primary fraction that contributes to the  
11          resuspension flux, the PCB concentration associated with the fines serves as a  
12          useful tracer that places a constraint on the flux of solids to the water column.  
13          The solids flux between the water and sediment needs to be such that water  
14          column TSS levels are correctly simulated, although it is acknowledged that  
15          correct simulation of TSS can be achieved by a combination of incorrect settling  
16          and resuspension rates and therefore, is not, in itself, sufficient for demonstrating  
17          calibration. The spatial profile of water column PCB concentrations does,  
18          however, provide an additional constraint on the magnitude of the settling and  
19          resuspension fluxes of PCBs to the water column.

20          In combination, the reasonableness of these comparisons (for both solids and  
21          PCBs) indicates that the calibrated model is not “grossly in error.” The response  
22          to General Issue 7, “Resuspension and Deposition,” presents additional  
23          discussion of the constraint imposed by the gradient between particulate PCB  
24          concentrations in the water column, and on cohesive solids in the sediment bed.

25          The parameterized value of the mass transfer coefficient for pore water diffusion ( $K_f$ ) is very  
26          high in comparison to most values I can find in the literature.  $K_f$  is being calibrated to reproduce  
27          the observed increase in water column PCB concentrations under low-flow conditions. In other  
28          words, all of the increase in water column PCB concentrations is being allocated to this  
29          mechanism. Whether the  $K_f$  calibration is correct depends upon this assumption. It would be  
30          most desirable to somehow independently confirm this value, either via measurement or by  
31          ruling out other potential PCB sources.

### 32           **RESPONSE 1-DE-9:**

33          The value of  $K_f$  (1.5 cm/d), calibrated to Housatonic River data, is at the low end  
34          of the range of values summarized by Thibodeaux and others (Thibodeaux and  
35          Bierman, 2003; Thibodeaux et al., 2002). These authors noted intra-annual  
36          variations in  $K_f$  values in the Hudson, Grasse, and Fox Rivers, with lower values  
37          (3 to 10 cm/d) in the winter and higher values (20 to 40 cm/d) in the summer. It  
38          is noted that the minimum value of 0.2 cm/d for the Fox River above DePere  
39          Dam comes from a model (Velleux and Endicott, 1994) that includes  
40          “background” resuspension at low flow conditions, which the authors  
41          acknowledge “substantially influences water column PCB concentrations, but has

## Model Calibration Responsiveness Summary

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1 little impact on solids concentrations.” In addition, please refer to the response to  
2 General Issue 8.

### 3 **References:**

4 Thibodeaux, L.J. and V.J. Bierman. 2003. The bioturbation-driven chemical  
5 release process. *Environmental Science and Technology* 37:252A-258A.

6 Thibodeaux, L.J., G.A. Canin, and M. Cain. 2002. Recent advances in our  
7 understanding of sediment-to-water contamination fluxes: the soluble release  
8 fraction. Keynote presentation at the 5th International Symposium on  
9 Sediment Quality Assessment of Aquatic Ecosystems and Public Health,  
10 Chicago, IL. October 16-18, 2002.

11 Velleux, M. and D. Endicott. 1994. Development of a mass balance model for  
12 estimating PCB export from the Lower Fox River to Green Bay. *J. Great  
13 Lakes Res.* 20(2):416-434.

### 14 ***Rare flood events***

15 The calibration report shows that EFDC is capable of predicting the extent of flooding. However,  
16 this is not an *impact* per se. The impact of concern is the remobilization of significant quantities  
17 of previously in-place pollutants.

### 18 **RESPONSE 1-DE-10:**

19 EPA understands that flooding, in and of itself, does not represent an “impact”  
20 and that the goal of the modeling study is to be able to predict contaminant  
21 transport and fate under different remedial options and natural recovery. The  
22 comparison of historical aerial photographs taken during flooding events to model  
23 predictions of the extent of flooding during the same events was conducted  
24 simply as another means of comparing the reasonableness of model output  
25 during an extreme event. The model was able to reproduce both the general  
26 extent and certain important features of the flooding observed during the events  
27 tested, thereby providing additional confidence in the calibration of the  
28 hydrodynamic submodel.

29 Sediment transport models like SEDZL and now EFDC are being used in a growing number of  
30 river systems to predict bed erosion under event conditions. However, the state of the art still  
31 requires extensive site-specific and model process-specific data. As far as I know, confirmation  
32 of model predictions under extreme events must still be demonstrated on a site-specific basis.  
33 Based on the calibration report, this confirmation is lacking in the Housatonic River.

### 34 **RESPONSE 1-DE-11:**

35 EPA made every attempt to collect data during an extreme event until just  
36 recently; however, because of forecasting and/or logistical issues such efforts

## Model Calibration Responsiveness Summary

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1 were unsuccessful. EPA does not believe it is worthwhile to delay the modeling  
2 study to wait to gather data from such an event. In the absence of data, any  
3 available information that existed or could easily be collected (such as extent of  
4 flooding) for a large event was used to the extent possible to test model  
5 predictions.

6 EPA's field program included several elements specifically designed to provide a  
7 basis for parameterizing model processes (e.g., Sedflume erosion  
8 measurements), and evaluating model predictions (e.g., bed load sampling and  
9 storm event sampling). While it would have been fortunate to have obtained data  
10 at higher-flow conditions, and plans were in place to monitor such an event, it did  
11 not happen within the necessary timeframe. EPA has acknowledged that the  
12 longer-term modeling, which is underway, will provide a more rigorous test of the  
13 model parameterization. The longer-term modeling will cover time periods when  
14 additional data collection efforts were conducted, such as the resurveyed cross-  
15 sections, providing additional lines of evidence that can be included in the  
16 evaluation.

17 It is unclear whether the EFDC scour and deposition predictions are reasonable at very high flow  
18 rates, and the comparisons to data are problematic due to the spatial resolution of the model  
19 sediment bed. Although bathymetric data showing scour and deposition patterns were collected  
20 and reported at a number of transects in the PSA, this data has apparently not been used to  
21 confirm model predictions as it has in other river systems (e.g., Gailani et al., 1996.).

### 22 **RESPONSE 1-DE-12:**

23 Cross-sectional surveys measuring scour and deposition at a number of  
24 transects within the PSA were obtained during a time period outside the May  
25 1999 to June 2000 calibration period. These data will be used in qualitative  
26 comparisons with the longer-term modeling results, although as discussed in  
27 Response 1-DE-6, erosion and deposition patterns described by the resurveyed  
28 cross-sections reflect small-scale effects that may not be represented by average  
29 conditions over the length of a 20-m cell. Please refer to the response to  
30 General Issue 5 for additional discussion of the spatial resolution of the sediment  
31 bed in the model.

32 *Discriminating between water-related and sediment-related sources of PCBs to fish and other*  
33 *biota*

34 The transport/fate and food chain models address PCB bioaccumulation via both pelagic and  
35 benthic exposure routes. In principle, it would be simple to apply the models to discriminating  
36 between water-related and sediment-related sources of PCBs to fish and other biota. I have done  
37 this in other applications by running the model with two chemical state variables, one for the  
38 chemical initialized in the sediment bed and a second for the chemical originating from water  
39 column sources. Since the models are both linear with respect to chemical concentrations, the  
40 simulation can be decomposed in this manner to explicitly show the proportion of PCB body  
41 burden in different species and reaches contributed by PCB exposure originating in the sediment

## Model Calibration Responsiveness Summary

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1 bed versus the water column. If this discrimination is important, the models should be rerun to  
2 make this diagnosis.

### 3 **RESPONSE 1-DE-13:**

4 EPA agrees that the bioaccumulation model kinetics can be partitioned to  
5 discriminate between PCB uptake attributable to benthic versus pelagic sources.  
6 The model can also discriminate among other combinations of PCB sources  
7 (e.g., uptake derived from dietary uptake versus that derived from gill exchange).  
8 During model development and calibration, such tests were applied as a quality  
9 assurance (QA) procedure to ensure that model output was reasonable. EPA  
10 will consider documenting the results of similar tests applied during Phase 2  
11 Calibration and/or Validation.

### 12 **Marcelo H. Garcia:**

13 Comparisons between model predictions and observations have been made with some apparent  
14 success for a relatively short period of time (i.e. several months). In addition, the smallest spatial  
15 scale resolved by the model is on the order of the river channel width (i.e. tens of meters). The  
16 model seems capable of reproducing observations made during storm events. However, the  
17 capability of the model to predict long-term effects (i.e. years) and small-scale processes (i.e.  
18 mass transfer at sediment-water interface, bank erosion) remains to be shown.

### 19 **RESPONSE 1-MG-1:**

20 EPA believes that the addition of a second phase of calibration using a longer  
21 period of record and model validation will provide the capability to demonstrate  
22 model performance, to the extent that the data record allows. EPA agrees that  
23 the duration of the Phase 1 Calibration may not have sufficiently demonstrated  
24 the capability of the model to predict small-scale processes, and bank erosion  
25 was not included in the Phase 1 Calibration (but will be included in Phase 2).  
26 Please refer to the response to General Issue 2.

27 For example, the model should be capable of predicting sediment depositional patterns as well as  
28 PCB distribution in Woods Pond over a time period of decades. The data to test the model is  
29 already available in the sedimentary record.

### 30 **RESPONSE 1-MG-2:**

31 Simulated sedimentation rates for the calibration period were compared to  
32 sedimentation rates estimated from analysis of radioisotope-dated cores (see  
33 Model Calibration Report, page B.3-51). EPA acknowledges that comparisons of  
34 these data with longer-term model simulations will be more meaningful. Those  
35 comparisons, and comparisons of PCB distributions in Woods Pond, will be  
36 included in the Model Validation Report.

# Model Calibration Responsiveness Summary

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## 1 Frank Gobas:

2 Tables 2.5 and 2.6 demonstrate that *mean* water flow rates are very well predicted over time and  
3 space by the **HSPF** model. Despite the good agreement of model predicted and observed *mean*  
4 flow rates, daily and monthly scatter plots at Coltsville illustrate that there are considerable  
5 variations around the mean flow rates. The variability around the mean is almost one order of  
6 magnitude. This variability around the mean value is not represented in the measures used to  
7 characterize the quality of model calibration. I recommend that they are added.

## 8 **RESPONSE 1-FG-1:**

9 Tables 2-5, 2-6, and 2-7 include statistics for annual, monthly, and daily flow  
10 comparisons for the calibration period. Moreover, the flow duration curves for  
11 both daily and hourly flows (Figures 2-13 through 2-16) demonstrate a very good  
12 to excellent representation of the data over the full range of flows observed  
13 during the calibration period. This is an overall confirmation that the watershed  
14 model represents the hydrologic regime of the Housatonic River watershed, and  
15 is not focused on just the mean flows.

16 The variability in the scatterplots, which is about an order of magnitude for daily  
17 flows but is much less for monthly flows, is expected due to the large spatial  
18 variability in precipitation in the watershed. Only a single hourly record was  
19 available to mimic the rainfall timing across the watershed for the entire  
20 calibration period, and was used to distribute daily totals from three other long-  
21 term precipitation records (discussed in Section 2.2.2 and Section A.2.2.1). The  
22 “scatter” in the scatterplots is not a variation about a mean flow, but more a  
23 variation from a “perfect fit” of the model to the data. Perfect fits cannot be  
24 expected for watershed models when precipitation, which is the major boundary  
25 condition or forcing function, must be estimated from four point observations and  
26 extended to the entire 282 square miles of the watershed area. In spite of this  
27 necessary extension of the available precipitation data, the weight of evidence  
28 summary demonstrates a good to very good overall calibration, and one that  
29 meets the QAPP targets.

30 They it should be considered when applying the model under scenarios where temporal  
31 variations as well as maximum and minimum flow rates are important. The *mean* flow estimates  
32 of the HSPF model are likely sufficient for addressing the most important management questions  
33 such as the response time of contaminant concentrations following remediation options.

## 34 **RESPONSE 1-FG-2:**

35 Although it is important to adequately simulate mean flows, reproducing the  
36 general pattern of magnitude and timing of flow is of primary importance for input  
37 to EFDC. EPA believes that the general pattern of flow is also adequately  
38 simulated and will achieve the goals of the modeling study.

39 Table 2-12 and 2-13 illustrate that predicted and observed TSS loading rates are also in good  
40 agreement both on a spatial and temporal scale. In comparison to the water flow rates, the TSS

## Model Calibration Responsiveness Summary

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1 model predictions show larger discrepancies between observed and predicted values. Differences  
2 of up to 139% are reported. However, the average difference is approximately 10%. The  
3 comparison of model predictions and empirical data appears to be sufficient to make estimates of  
4 *mean* TSS loads under normal conditions. But again, I recommend that additional detail is  
5 provided in the report to better represent the capability of the model to make predictions on  
6 spatial and temporal scales.

### 7 **RESPONSE 1-FG-3:**

8 The model predictions for total suspended solids (TSS) loads show greater  
9 differences when compared to data than predictions for flow for a number of  
10 reasons:

- 11     ▪ The inherent nature of sediment erosion and transport is much more dynamic  
12       than stream flow, and is often represented as a power function of flow.  
13       Therefore, small to moderate differences in flow rates (i.e., simulated versus  
14       measured) are magnified many times when used as the basis for sediment  
15       erosion and transport calculations.
- 16     ▪ The entire annual TSS load is often transported in a few storm events. If flow  
17       differences occur in the simulation of those particular events, the  
18       discrepancies for the corresponding TSS loads are often magnified.
- 19     ▪ Measurements of TSS are more difficult to collect than flow measurements,  
20       and as a result, the data for the Housatonic River are more limited.  
21       Consequently, the data used for comparison of annual loads in Tables 2-12  
22       and 2-13 are not actual measurements, but estimates derived from the EPA  
23       flux analyses and the RFI report using various flow-sediment relationships.  
24       This also leads to greater percent differences than would be expected for the  
25       flow simulation.

26 Note that the greatest percent differences in Table 2-13 are during years with  
27 relatively low TSS loadings, and the smallest discrepancies are during the years  
28 with high TSS loadings. This is one reason why the mean annual differences are  
29 relatively minor compared to the year-to-year differences because the high load  
30 years will dominate the calculation of the mean value.

31 In response to the recommendation from the Reviewer, additional results will be  
32 provided in the Model Validation Report to demonstrate the model's capability for  
33 simulating TSS loadings.

34 Tables 2-15 and 2-16 show that differences between observed and predicted water temperatures  
35 are very small. These differences are essentially insignificant and the model's capability to  
36 predict temperature is very good.

### 37 **RESPONSE 1-FG-4:**

38 EPA agrees with the Reviewer's assessment.

## Model Calibration Responsiveness Summary

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1 With regards to the **hydrodynamic** model, empirical observations are to a large degree  
2 internalized in the model. The comparison of observed and predicted is therefore not an  
3 independent test of the capability of the model.

### 4 **RESPONSE 1-FG-5:**

5 The forcing functions for the hydrodynamic model are the boundary inputs, which  
6 are dominated by the East and West Branches. These inputs were based on  
7 data when available, and when data were not available, from estimates  
8 developed primarily from relationships between flow at the USGS Coltsville gage  
9 and flow upstream of the Confluence. Comparisons between data and model  
10 simulations at downstream locations reflect the response of the model's  
11 description of the physical system (bathymetry, topography, and friction) and the  
12 forcing functions.

13 EPA believes that these comparisons provide a successful demonstration of the  
14 capability of the model. In addition, the ability of the model to reproduce the  
15 spatial extent of flooding documented by aerial photographs following Hurricane  
16 Bertha support this conclusion. The ability of the model to reproduce the extent  
17 of flooding in the floodplain is an important element of the transport of PCBs onto  
18 the floodplain.

19 The model was tested for two extreme events and showed good results. This is promising, but it  
20 is not sufficient to conclude that the hydrodynamic model has the capability to predict the  
21 hydrodynamics at the relevant spatial and temporal scales.

### 22 **RESPONSE 1-FG-6:**

23 EPA believes that the spatial scales incorporated in the Phase 1 Calibration were  
24 sufficient to achieve the goals of the modeling study. The temporal scale will be  
25 addressed in the Phase 2 Calibration and Validation. Please refer to the  
26 responses to General Issues 2 and 4.

27 In my view, it is premature to comment on the capability of the model at this point. The real  
28 capability of the model will be revealed in the model validation phase, which will provide a  
29 relatively independent test of the capability of the model.

### 30 **RESPONSE 1-FG-7:**

31 Please refer to the response to General Issue 2.

32 There is a reasonable data base available to test the **sediment transport** model at two locations  
33 (i.e. New Lennox Road and Woods Pond Outlet). Data from other locations (i.e. Holmes Road  
34 and Woods Pond Headwater) exist but the sample size is not large. Figures 4-34 and 4.35  
35 illustrate that the sediment transport component of the EFDC model has reasonable central  
36 tendency characteristics.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-FG-8:**

2           EPA agrees with the Reviewer that Figures 4-34 and 4-35 in the Model  
3           Calibration Report indicate the model produces reasonable central tendencies.  
4           These figures also show differences between the amount of variability in the  
5           model results and variability in data, some of which is attributed to short-time-  
6           scale variations in data that the model is not expected or intended to reproduce.  
7           Time series plots of TSS data during storm events (e.g., Appendix B, Figures  
8           B.3-46 and B.3-47) show small time-scale variations in TSS concentrations of a  
9           factor of two or three, scattered, both higher and lower, around the model  
10          simulation.

11          In the case of TSS concentrations measured at New Lenox Road during the  
12          September 15-19, 1999 event, fluctuations of more than 100 mg/L in samples  
13          collected within the same hour were evident. These fluctuations are not  
14          reproduced by the model in part because of the approach used to specify the  
15          upstream boundary conditions. Because there is no reason to believe that linear  
16          interpolation between rapidly fluctuating concentrations at the boundaries would  
17          provide a reliable estimate of concentrations at times between measurements,  
18          the boundary conditions were developed as 3-hour moving averages of the storm  
19          event monitoring data. Given the unexplained variability at the upstream  
20          boundary, this approach is reasonable, even though it contributes to a reduction  
21          in the variability in simulated concentrations.

22          However, there are also significant discrepancies between observed and predicted data.  
23          Differences between measured and simulated TSS data show that predicted TSS produce a  
24          narrower range of concentrations of TSS concentrations than observed. Also, there appears to be  
25          a considerable variability in the measured TSS data at New Lenox Road and Woods Pond  
26          Outlet that is not explained by the model.

27           **RESPONSE 1-FG-9:**

28           Please refer to the response to General Issue 10.

29          In terms of assessing the spatial capabilities of the model, it would be beneficial to have access  
30          to more data for model-data comparison but the currently available data sets can be considered  
31          adequate as long as the magnitude of the uncertainties are recognized by the model and  
32          considered when remedial options.

33           **RESPONSE 1-FG-10:**

34          EPA agrees with the Reviewer that model uncertainty must be recognized and  
35          considered in the evaluation of remedial alternatives. The Model Calibration  
36          Report included a description of the plan for assessing uncertainty, which was  
37          presented to the Peer Review Panel at the Document Overview Meeting. This  
38          topic is also discussed in the response to General Issue 11.

## Model Calibration Responsiveness Summary

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1 I think that the reported analyses can be improved upon by explicitly recognizing the variability  
2 among the individual data/prediction comparisons.

3 **RESPONSE 1-FG-11:**

4 Please refer to the response to General Issue 10.

5 The capabilities of the sediment transport model on a temporal scale are tested over a 14 month  
6 period starting in May 1999. A reasonable number of data is available for model calibration.  
7 However, Figure 4-25 shows that significant discrepancies exist between observed and predicted  
8 TSS concentrations. Therefore, some doubts remain with regards to the temporal capability of  
9 the model.

10 **RESPONSE 1-FG-12:**

11 As the Reviewer pointed out in a previous comment (see Comment 1-FG-8),  
12 substantially more data are available for New Lenox Road and Woods Pond  
13 Outlet (Model Calibration Report Figures B.3-43 and B.3-45, respectively) than  
14 for Holmes Road (Figures 4-25 and B.3-42) or Woods Pond Headwaters (Figure  
15 B.3-44). The model-data comparisons for New Lenox Road and Woods Pond  
16 Outlet show better agreement than for the stations with fewer data. The  
17 substantial difference in the number of data points results from the fact that New  
18 Lenox Road and Woods Pond Outlet were sampled as part of the storm event  
19 monitoring program, but data at Holmes Road and Woods Pond Headwaters  
20 were collected primarily as part of GE's monthly monitoring program. The GE  
21 samples were collected starting over 20 miles downstream of the PSA and  
22 moving upstream, in some cases over more than a single day. Because of this  
23 sampling protocol, concentrations at downstream locations can be affected by  
24 boundary concentrations that entered the PSA several days before the time of  
25 collection of the data used to assign the upstream boundary conditions.

26 At this point it is unclear whether this quality of agreement between observations and predictions  
27 is due to systematic errors in the modeling approach or reflects statistical variability or  
28 uncertainty in TSS concentrations. In my view, much value will be added to the modeling effort  
29 if in addition to the central tendencies of the model, variability and uncertainty are recognized  
30 and explicitly stated.

31 **RESPONSE 1-FG-13:**

32 Please refer to the response to General Issue 10.

33 Comparisons of predictions of the sediment transport model and empirical data for several storm  
34 events are also presented. The agreement between measured and simulated TSS and flow data  
35 are with some exceptions are quite reasonable.

36 Regarding **EFDC**, Figure 5.11 shows the comparison between predicted and observed  
37 concentrations of PCBs in pore water. The comparison is quite good, suggesting that the  
38 assumption of equilibrium between PCB concentrations in sediments and pore water is justified.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-FG-14:**

2           EPA agrees with the Reviewer that the referenced model-data comparisons  
3           indicate good agreement.

4           Figures 5.17 to 5.19 show that the comparison between predicted and observed PCB  
5           concentrations in the water column over 14 months at 3 locations. Figures 5-20, and 5.21  
6           illustrate the comparison of observed and predicted PCB concentrations in the water column at  
7           various locations in the River. Figure 5.23 illustrates the comparison of PCB concentrations in  
8           water column after a storm event. The agreement of the model with the data appears quite  
9           reasonable. This is in some contrast to the results depicted in Figure 530, which illustrates a  
10          reasonable central tendency of the model in predicting PCB concentrations in the water column,  
11          but also considerable discrepancies between model predictions and observations.

12          **RESPONSE 1-FG-15:**

13          The various figures presented in the Model Calibration Report provide alternative  
14          ways to compare model results and data. Each has advantages and  
15          disadvantages, but collectively they provide what was intended to be an  
16          unbiased illustration of the strengths and weaknesses of the calibrated model.  
17          Generally, the model does reasonably well with regard to predictions of the  
18          central tendency of the data, but individual data points can be either over- or  
19          underpredicted at various times, particularly during high-flow events.

20          The spatial profiles display the cumulative effects on water column PCB  
21          concentrations from the interaction between water and sediment as water flows  
22          through the PSA. The model does reasonably well at capturing this response.  
23          Similarly, the 14-month time-series plots show how the model is able to  
24          consistently predict rapid increases in concentrations during runoff events,  
25          although the magnitude of the peaks and the detailed timing of the changes in  
26          concentration over very short time scales are difficult to discern on these graphs.  
27          These comparisons are more clearly displayed on the time-series plots for  
28          individual events (e.g., Figures 5-22 and 5-23 and related figures in Appendix B,  
29          such as Figure B.4-44). A phase shift of a few hours between the predicted  
30          concentrations and the data (e.g., tPCBs at New Lenox Road, Figure B.4-44) is  
31          judged to be inconsequential with respect to the evaluation of exposure levels for  
32          use in FCM and for the evaluation of remedial alternatives, as long as the longer-  
33          term average concentrations are reasonably well represented.

34          These differences between model results and data are highlighted when  
35          displayed on the cross plots of simulated versus measured concentration, such  
36          as those shown in Figure 5-30. The same deviations between model and data  
37          are displayed in both the time-series plots and the cross plots, but in the cross  
38          plot a large difference that results from a slight time shift of as little as 1 or 2  
39          hours appears the same as a clear over- or underprediction of the magnitude of  
40          the impact of a runoff event. As a result, the model results appear less favorable  
41          relative to comparisons that are made in the context of a storm (i.e., comparisons

## Model Calibration Responsiveness Summary

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1 on a time series plot). The discrepancy resulting from the time shift, however, is  
2 of little importance for the intended use of the model.

3 Additional attention could be devoted to the comparison of observed and predicted  
4 concentrations of PCBs in bottom sediments of the river. These data are likely to be very useful  
5 in assessing the fate of PCBs in the River.

### 6 **RESPONSE 1-FG-16:**

7 EPA agrees that the response of PCB concentrations in sediment over time is an  
8 important aspect of the model. Changes in sediment concentrations were, as  
9 expected, minor over the course of the 14-month Phase 1 Calibration. More  
10 attention will be given to comparisons of model and data as the longer-term  
11 Phase 2 Calibration work proceeds. Please refer also to the response to General  
12 Issue 2.

13 In terms of the adequacy of the model-data comparisons to evaluate the capability of the EFDC  
14 model on the relevant spatial and temporal scales, there appears to be a reasonable amount of  
15 data available to evaluate the capability of the model to assess water column transport. The  
16 capability of the model to assess some other key aspects of the fate of PCBs, such as long term  
17 response times of the PCB concentrations in the River, is not convincingly demonstrated in my  
18 view.

### 19 **RESPONSE 1-FG-17:**

20 The Reviewer is correct that changes in PCB concentrations in sediment over the  
21 14-month calibration period are minimal, and therefore, cannot be demonstrated  
22 as part of the calibration. The ability of the model to predict changes in  
23 concentration of PCBs in sediment will be further tested over the course of the  
24 longer-term Phase 2 Calibration period; however, the data do not show clear  
25 trends in PCB concentrations during that time frame as well. Please refer also to  
26 the response to General Issue 2.

27 As for the **bioaccumulation** model, comparisons of model predictions and empirical data on a  
28 spatial scale are shown in Figures 6.5 to 6.16. There are additional comparisons presented in  
29 Figures 2-34 of attachment C15. The concentrations of tPCBs in sediments and suspended solids  
30 show small differences among the reaches 5A to 6. Hence, the model calculations of the tPCBs  
31 in biota do not show a strong spatial dependence. As a result, the capability of the model to make  
32 spatially explicit estimates could not be fully explored in this study. However, this is not of great  
33 importance for the development of the bioaccumulation model as the spatial (and also temporal)  
34 differences in concentrations are predominantly determined by other components of the model.

### 35 **RESPONSE 1-FG-18:**

36 EPA agrees that the model simulations of PCB concentrations in biota do not  
37 show a strong spatial dependence due to the relatively flat gradient in PCB  
38 concentrations observed in exposure media across the PSA. EPA also agrees  
39 that the limitations in the ability to make spatially explicit estimates are not of

## Model Calibration Responsiveness Summary

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1 “great importance.” However, EPA has acknowledged the value of conducting  
2 activities during model validation that consider PCB exposure levels different  
3 from those observed in the PSA.

4 In conjunction with the model validation, EPA intends to model Reaches 7 and 8,  
5 downstream of Woods Pond to Rising Pond. The exposure concentrations in  
6 much of the area downstream of the PSA are lower than in the PSA; therefore,  
7 the downstream modeling exercise will explicitly address this issue. The  
8 downstream modeling is also advantageous from the perspective of evaluating  
9 data sets that are independent of data considered during FCM calibration.  
10 Please refer also to the response to General Issue 2.

11 The temporal capability of the bioaccumulation model is tested in terms of the relationship of the  
12 PCB concentration in fish species with age. Other temporal effects (e.g. summer vs. winter) are  
13 not explored.

### 14 **RESPONSE 1-FG-19:**

15 EPA emphasized the age-dependent bioaccumulation of PCBs in fish when  
16 evaluating the temporal response of the bioaccumulation model. Nevertheless,  
17 seasonal responses in model subcomponents (e.g., temperature-dependent  
18 growth and respiration) were considered during model development.

19 The ability of FCM to track the response of biota to inter-annual changes in PCB  
20 exposure concentrations could not be evaluated quantitatively during model  
21 calibration because PCB concentrations in exposure media were relatively stable  
22 across the 5-year calibration period. The seasonal responses of fish species  
23 (e.g., summer versus winter) also could not be explored in detail because there  
24 were only a few fish samples collected during winter and spring months.  
25 Sampling of fish by both EPA and General Electric has historically emphasized  
26 the late summer and early fall in order to control for potential seasonal influences  
27 (e.g., transient effects of reproduction/spawning). Some largemouth bass  
28 samples were collected in May 1999 to support the fish reproduction study  
29 performed for the ERA, but the sample sizes were not sufficient to conduct  
30 seasonal comparisons with adequate statistical power.

31 In addition to considering the seasonal responses to model subcomponents, EPA  
32 considered the seasonal patterns in FCM simulation output (i.e., reality checks of  
33 seasonal oscillations using professional judgment). EPA also conducted tests of  
34 rate parameters (e.g., elimination rates) and gauged the model output against  
35 values obtained from the literature. EPA will consider documenting some of  
36 these tests in the Model Validation Report.

37 Overall, though, there appears to be a good PCB concentration data set available to assess the  
38 capability of the model. There is a lack of fish tissue concentration data for Reach 5D. However,  
39 I do not think that this should preclude the calculation of fish concentration data for fish in this

## Model Calibration Responsiveness Summary

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1 reach. One of the goals of the model is to make estimates where concentration data are not  
2 available.

### 3 **RESPONSE 1-FG-20:**

4 EPA agrees that the ability to simulate concentrations where concentration data  
5 are not available is an important goal of the modeling exercise. The uncertainty  
6 associated with Reach 5D simulations is discussed in Responses O-DE-7 and 2-  
7 JL-1.

### 8 **Wilbert Lick:**

9 The variations in sediment erosion/deposition between shallow and deep waters of a cross-  
10 section of a river can be and generally are quite large. Averaging the suspended solids data and  
11 comparing it with the present model which only has one grid cell in it may give a good  
12 comparison but will not accurately predict erosion/deposition patterns now and over the long  
13 term.

### 14 **RESPONSE 1-WL-1:**

15 The purpose of the model is not to accurately predict erosion/deposition at a  
16 spatial scale smaller than an individual grid cell, and such predictive capability is  
17 not necessary to achieve the goals of the modeling study. Please refer also to  
18 the response to General Issue 4.

19 The thickness of the well-mixed sediment layer is an extremely difficult parameter to determine  
20 by calibration. Due to its assumed thickness, variations in contaminant concentrations are very  
21 slow (see numbers in Question 3) and will be difficult to detect. A determination based on  
22 scientific reasoning may be the only way to go.

### 23 **RESPONSE 1-WL-2:**

24 Please refer to the response to General Issue 6.

### 25 **E. John List:**

26 My opinion is that the watershed modeling program HSPF is adequately calibrated for use in a  
27 statistical sense, although there appears to be insufficient rain gauge information available to  
28 apply the model in a storm-by-storm prescriptive way. In other words, the model cannot be used  
29 to generate stream flows from a specific storm, but it will be satisfactory when applied to  
30 generate synthetic stream flow sequences appropriate for use in the comparison of remediation  
31 options. The reason for this is that remediation options will be compared based on a series of  
32 stream flow sequences and it is not relevant that these stream flow sequences will ever actually  
33 occur, it is enough that they properly represent the statistical variation for the watershed, which it  
34 appears they do. The overall strategy of producing a synthetic stream flow record from a rainfall  
35 record is a well-founded technique in hydrology and this work appears to have been done well.

## Model Calibration Responsiveness Summary

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1 However, it is of concern that the HPSF model, apparently because of a lack of adequate rainfall  
2 data, was unable to properly represent the two large flow events of May and September in 1999.

### 3 **RESPONSE 1-JL-1:**

4 EPA agrees that the watershed model is adequately calibrated to produce a  
5 representative hydrograph for use in evaluating remedial alternatives.  
6 Discrepancies in the representation of the May and September 1999 storms  
7 resulted in significant efforts to improve the simulation of those events without  
8 adversely impacting the simulation of the other years and events. After  
9 numerous efforts to improve (i.e., increase) the simulated flow for those events, it  
10 was concluded that any further calibration would lead to parameter values that  
11 would not be appropriate for the remaining years of the calibration period.

12 Examination of the annual flow simulations in Attachment A.4 (Figures 5 through  
13 15 for Coltsville, and Figures 20 through 30 for Great Barrington) indicates that  
14 the 1999 simulation is the worst of the 11 year simulations at Coltsville, but one  
15 of the better annual simulations at Great Barrington; the percent error values in  
16 Table 2-5 also confirm this conclusion. It is likely that the methodology used to  
17 assign rainfall above Coltsville resulted in an underestimate of the actual amount  
18 of rainfall for 1999. The rainfall patterns and amounts for the other years in the  
19 calibration were adequately represented, resulting in a very good overall  
20 calibration.

21 It is not uncommon for this type of situation to occur in watershed modeling,  
22 where unusual storm tracks, patterns, and movements in selected years can lead  
23 to inadequate, or excessive, estimates of rainfall. This is the primary reason that  
24 calibration over many years is recommended for watershed modeling.

25 On the other hand, the PCB fate and transport model EFDC application appears to have  
26 limitations in that the variance of the model output for water column tPCB does not reflect the  
27 variance in the measured data. This failing of the model is encapsulated in the comparisons  
28 presented in Figure 5-30, where it can be seen that the variance in the measured data is about two  
29 orders of magnitude larger than the predicted variance. Part of this problem is most likely  
30 associated with the high degree of variance that exists in the sediment PCB concentrations  
31 throughout the study area, as illustrated in Figure 5-26.

### 32 **RESPONSE 1-JL-2:**

33 Please refer to the response to General Issue 10.

34 Another issue with the EFDC modeling calibration is the relative lack of data that appear to exist  
35 in the last nine months of the calibration period. In reality, it is a stretch to claim that the model  
36 has been calibrated over a 14 month period when so few data exist for the last nine months, (see  
37 Figures 5-17, 5-18, and 5-19), especially since it appears that the intention is apply the model to  
38 time scales at least 20-30 times longer than the actual nine month calibration period.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 1-JL-3:**

2           The data richness for the last 9 months of the calibration period is typical for the  
3           majority of the timeframe from 1996 to present. Prior to 1996, even fewer data  
4           exist to make model-data comparisons. EPA does not agree with the implication  
5           by the Reviewer that these data are insufficient to be useful; they are typical of  
6           what is available for most modeling studies.

7           A longer calibration period is clearly appropriate.

8           **RESPONSE 1-JL-4:**

9           Please refer to the response to General Issue 2.

10          The comparison of average PCB mass flux with predicted mass flux, over the 14-month  
11          calibration period that is shown in Figure B.4-46, is essentially meaningless because there is no  
12          indication of the confidence limits that apply to either the field estimates of the flux or the  
13          predicted flux. On the face of the data presented it appears that the prediction is valid but in the  
14          absence of any error margins for both the field and modeling estimates the results in Figure  
15          B.4-46 cannot be used legitimately as a calibration basis for the EFDC model.

16          **RESPONSE 1-JL-5:**

17          The average PCB mass fluxes simulated by the model are presented in Figure  
18          B.4-46 to convey a general understanding of PCB transport in the Housatonic  
19          River PSA. PCB mass fluxes derived from an empirical analysis (the flux  
20          analysis) are presented in the figure to provide a qualitative comparison between  
21          the simulated concentrations and data. The fact that the two different  
22          approaches show similar patterns of PCB transport through the PSA provides  
23          support to the conclusion that the model results are reasonable. This summary  
24          represents only one of several types of comparisons used in the multiple lines of  
25          evidence approach to model calibration.

26          EPA does not agree that Figure B.4-46 and other presentations that do not  
27          include error statistics are “meaningless.” The majority of fate and transport  
28          models, including EFDC, are deterministic, not probabilistic; therefore, they do  
29          not produce predicted parameter values with associated confidence limits. The  
30          use of confidence limits to compare model predictions with data, however  
31          preferable such comparisons may be, is the exception rather than the norm in  
32          numerical fate and transport modeling. It may be possible to add approximate  
33          “error margins” to the comparison based on the uncertainty analysis; the  
34          uncertainty analysis for EFDC is being conducted as part of the Phase 2  
35          calibration effort. Please refer also to the response to General Issue 11.

36          A similar disparity in the variance of the predicted and measured PCB tissue concentrations is an  
37          outcome of the FCM modeling, as illustrated by Figures C.3-50 and C.3-51. However, the  
38          overall performance of the FMC model, as depicted in Figure C.3-51, is certainly encouraging,

## Model Calibration Responsiveness Summary

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1 given the difficulty associated with such food chain modeling. Nevertheless, it would be very  
2 nice to have this disparity resolved.

### 3 **RESPONSE 1-JL-6:**

4 EPA agrees that the central tendencies simulated by FCM are encouraging, as  
5 indicated by the achievement of the model performance criteria specified in the  
6 MFD/QAPP. The simulated fish tissue concentrations in Figures C.3-50 and  
7 C.3-51 are based on central tendencies of model input parameters, not  
8 distributions. Therefore, the individual variations in fish bioaccumulation are not  
9 represented by the FCM results shown in the figures, and comparisons against  
10 field measurements are not appropriate. The model simulations will always have  
11 lower variability than the field data. For the Model Validation Report, EPA will  
12 explore alternative presentation formats and will revise the description and  
13 interpretation of model-data comparisons to improve clarity. Refer to Responses  
14 O-DE-9 (above) and 2-FG-4 (below) for additional discussion of the interpretation  
15 of "simulated versus measured" PCB scatterplots. Please refer also to the  
16 response to General Issue 10.

17 The basic argument, if I understand it correctly, is that the model is only modeling average fish  
18 and not individual fish so the field variance in individual fish cannot be properly represented. I  
19 see this as a good reason to adopt a Monte Carlo approach that samples from populations of fish  
20 and the creatures that fish feed on. This Monte Carlo method has now become the norm in  
21 human health risk analysis and could easily be applied in this context.

### 22 **RESPONSE 1-JL-7:**

23 Probabilistic analyses were performed as a component of both the human health  
24 and ecological risk assessments. However, the PCB concentration in fish (or  
25 other) diet was not treated as a distribution but as a point estimate in these  
26 documents for two reasons. First, to be consistent with EPA's probabilistic risk  
27 assessment guidance, the 95<sup>th</sup> UCL of the mean was used and, second, because  
28 both human and ecological receptors integrate exposures over both space and  
29 time, thereby making the average concentration the appropriate concentration of  
30 interest. Please refer also to the response to General Issue 1.

31 EPA agrees that variability in field measurements of individual fish cannot be  
32 represented using the deterministic application of FCM. Monte Carlo approaches  
33 have some value for quantitatively describing variations in individual fish.  
34 However, Monte Carlo model techniques are also limited in the sense that they  
35 do not explicitly discriminate between model variability (i.e., observed variations  
36 in parameter values observed in the field, such as lipid contents) and model  
37 incertitude (i.e., uncertainty regarding the parameters that drive model  
38 simulations, such as chemical assimilation efficiency). Furthermore, as  
39 described in Comment 4-FG-5, the application of Monte Carlo techniques to  
40 complex models with correlated inputs is not straightforward.

## Model Calibration Responsiveness Summary

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1 The complexity inherent in the application of Monte Carlo techniques is illustrated  
2 in the following example, which considers only one sensitive FCM input  
3 parameter (organic carbon [OC]-normalized PCB concentrations in sediment).  
4 To model the variability in individual largemouth bass, it would be necessary to  
5 estimate the distribution of PCB concentrations in sediment to which the base of  
6 the food web is exposed. Because largemouth bass are territorial and forage  
7 over limited areas, the estimation of exposure sediment concentration  
8 distributions for individual fish must consider the variability in sediment  
9 concentrations observed among numerous subsections (home ranges) within  
10 each river reach. In this example, input distributions were estimated as follows:

- 11     ▪ All available surface sediment samples collected in the main channel of the  
12       PSA since 1990 were used to construct distributions of OC-normalized tPCB  
13       sediment concentrations.
- 14     ▪ Home range sizes for largemouth bass were estimated from the literature,  
15       and the river was broken up into segments or grids to approximate possible  
16       fish home ranges within each study reach.
- 17     ▪ All sediment samples within each segment were averaged, and the set of  
18       these averages formed the sediment distribution for each study reach.

19 The resulting distributions for sediment exposures are shown in Figure 1-JL-7.  
20 The figure suggests that sediment PCB exposure concentrations are likely to be  
21 highly variable among fish occupying different segments of the same PSA reach.  
22 This explains in part why PCB concentrations in individual fish specimens can  
23 vary by one or two orders of magnitude even within the same species and river  
24 reach.

25 The example illustrates that consideration of the input distributions of sensitive  
26 FCM parameters can help to explain the large variability observed in individual  
27 fish PCB measurements, relative to central tendencies simulated in the  
28 deterministic FCM simulations. However, EPA does not believe that a  
29 comprehensive Monte Carlo analysis to simulate distributions of individual fish is  
30 warranted, for the following reasons:

- 31     ▪ The driver for the evaluation of remediation alternatives is not individual fish,  
32       but rather average fish concentrations at spatial scales over which humans  
33       and wildlife integrate their fish consumption (see response to General Issue  
34       1).
- 35     ▪ The specification of input distributions usually includes a large number of  
36       uncertainties. In the above example, the estimated size of bass home  
37       ranges, treatment of statistical outliers, treatment of non-detected values, and  
38       other data processing considerations introduce uncertainty into the analysis.  
39       A number of simplifying assumptions are required for these analyses that can  
40       strongly influence the results. Accordingly, it is difficult to discern the

# Model Calibration Responsiveness Summary

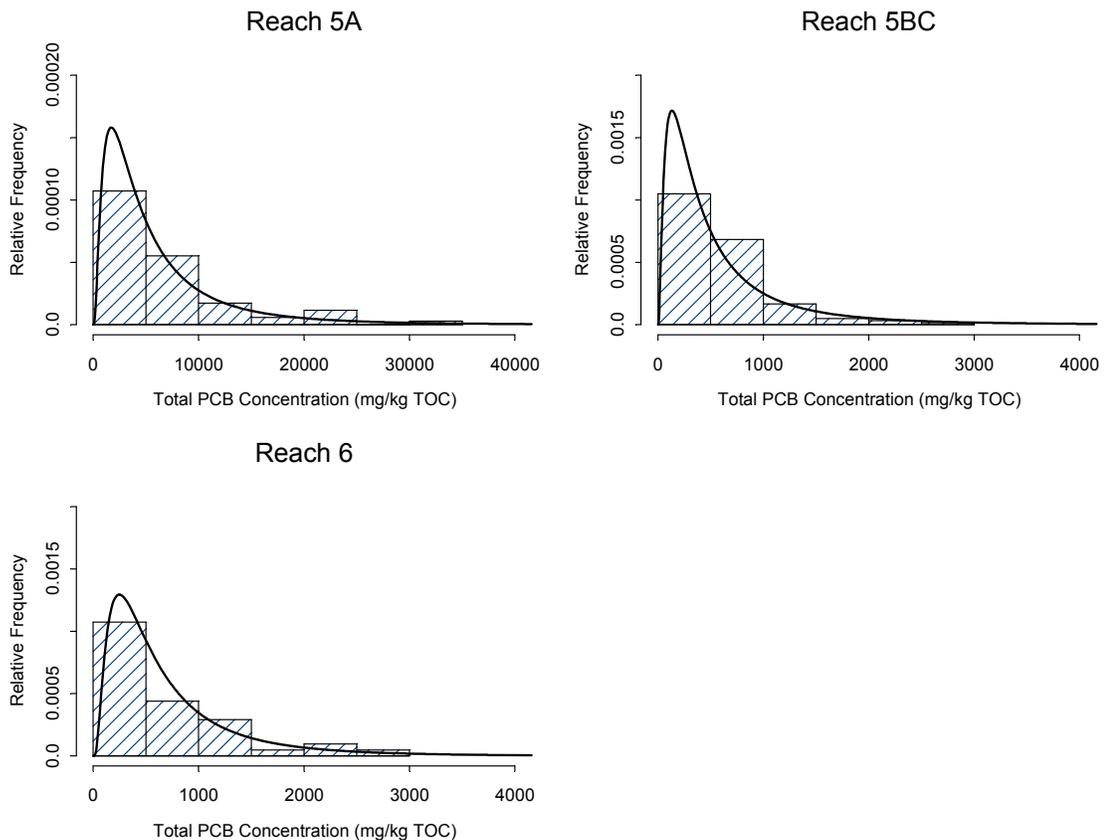
1           variability for each input parameter from the uncertainty inherent in the  
2           specification of each distribution.

- 3           ▪ The uncertainty described above is compounded by the number of input  
4           parameters in FCM, a number of which are intercorrelated. Accounting for  
5           multiple intercorrelated inputs further increases the complexity of the analysis  
6           and limits the degree to which Monte Carlo simulations can be quantitatively  
7           compared against field data distributions.

8           In summary, EPA does not believe that incorporation of a probabilistic model  
9           around the FCM simulations to predict concentrations in individual organisms is  
10          necessary, given the considerable effort and complexity of the task, the high  
11          uncertainty associated with the output, and the goal of the modeling study. The  
12          variability in individual field measurements is not unexpected given the large  
13          number of variables that mediate the exposure and bioavailability of PCBs to fish.

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**Figure 1-JL-7           Histograms of Estimated Average TOC-Normalized PCB Concentrations for Largemouth Bass Home Ranges**

1 **Evaluation for Evidence of Bias**

2 **2. Is there evidence of bias in the model, as indicated by the distribution of residuals as a**  
3 **function of the independent variables?**

4 **E. Adams:**

5 Comparison of predicted and measured mean values is reasonably good for most variables, as  
6 would be expected following calibration. But, as the discussion above implies, the models can  
7 be expected to under predict the fluxes of sediment and PCBs under extreme events, and these  
8 extremes will be most responsible for changes in PCB concentrations in the future. This is a type  
9 of bias.

10 **RESPONSE 2-EA-1:**

11 EPA agrees with the Reviewer's comment that good agreement has been  
12 achieved between mean model simulations and data; however, EPA disagrees  
13 that strong agreement between predicted and measured mean values is  
14 automatically "expected" for any model calibration. This would only be the case if  
15 the model parameters are deliberately tuned during calibration to maximize the fit  
16 (i.e., minimize the model residuals). The majority of the parameters in the  
17 modeling study were specified either as fixed values (a priori, based on site data  
18 or literature) or were only allowed to vary within limited and scientifically plausible  
19 ranges.

20 EPA disagrees with the Reviewer's expectation that simulated fluxes of sediment  
21 and PCBs will be underpredicted for extreme events. The Reviewer's comment,  
22 "But, as the discussion above implies ..." refers to an inaccurate assumption  
23 about the approach used to calculate PCB concentrations of each of the size  
24 classes. Response 1-EA-15 discusses how the modeling approach recognizes  
25 and accounts for the preferential sorption of PCBs to finer sediment and uses  
26 formulations for erosion that account for bed composition. These approaches  
27 avoid the potential problem discussed by the Reviewer.

28 **W. Frank Bohlen:**

29 The distribution of residuals provides no indication of model bias.

30 **RESPONSE 2-FB-1:**

31 EPA agrees with the Reviewer's assessment.

# Model Calibration Responsiveness Summary

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## 1 **Douglas Endicott:**

2 The models appear to be fairly unbiased in terms of the principal state variables. The following  
3 exceptions were noted during review:

- 4 ■ The gradient in total PCB concentrations across Woods Pond indicates bias, due possibly to  
5 the magnitude of the diffusive flux from sediment. The net loss of PCBs from Woods Pond  
6 contradicts expectation and conceptual model;

## 7 **RESPONSE 2-DE-1:**

8 The good agreement between the longitudinal profiles of model results and data  
9 collected at the lowest flows (Figure B.4-37) indicates that the representation of  
10 the diffusive flux in the model is reasonable because any problem with the  
11 diffusive flux would be highlighted during the low-flow conditions when dilution is  
12 reduced. However, EPA agrees that the model does underpredict the amount of  
13 settling that occurs across Woods Pond during a somewhat higher-flow condition  
14 (Figure B.4-38). Therefore, further effort will be directed toward refining the  
15 particle settling rate formulations used in the TSS model over the course of the  
16 Phase 2 Calibration. This effort will include consideration of the flocculation and  
17 settling model that has been recommended by Dr. Lick. Calculation of additional  
18 solids deposition in Woods Ponds would result in additional accumulation of  
19 PCBs.

- 20 ■ Dissolved PCB concentrations are consistently overpredicted in the storm event periods,  
21 suggesting either a weakness in the partitioning model or inadequacy in estimating low-end  
22 censored concentration data;

## 23 **RESPONSE 2-DE-2:**

24 EPA agrees in general with the Reviewer's observations, but does not agree that  
25 this indicates a weakness in the partitioning model. Most of the analytical results  
26 for dissolved PCBs collected during the storm events were non-detect, with  
27 detection limits near 0.01 µg/L. During the smaller storm events, the simulated  
28 dissolved PCB concentrations were higher than the detection limit of samples  
29 reported as non-detect by approximately a factor of two to four. For the data  
30 collected at higher flow conditions, simulated dissolved concentrations were  
31 typically within a factor of two of the data or detection limit. Because of the  
32 relative lack of importance of the surface water dissolved exposure route in the  
33 bioaccumulation calculations for this system, the comparisons between simulated  
34 dissolved PCB concentrations and data were considered acceptable.

35 Given the overall ability of the three-phase partitioning model to reproduce the  
36 surface water partitioning data set, EPA believes that the partitioning model is  
37 adequate.

- 38 ■ There also appears to be an unexplained factor in the sediment pore water partitioning data,  
39 possibly some kind of solids effect. Cross-plots of particulate organic carbon versus apparent

## Model Calibration Responsiveness Summary

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1  $K_{oc}$  show that  $K_{oc}$  declines with increasing  $f_{oc}$  for both total PCB and congeners, regardless of  
2 whether data from some sediment cores are censored. Dissolved and particulate PCB  
3 predictions look OK in comparison to the partitioning study data, but this is a very limited  
4 number of measurements.

### 5 **RESPONSE 2-DE-3:**

6 The effect noted by the Reviewer is evident in some of the sediment data,  
7 primarily the approximately 15% of the partitioning samples with low  $f_{oc}$ . This  
8 effect may reflect the relative increase in importance of inorganic surfaces as  
9 adsorption sites for PCBs in sediment with low organic carbon content, and the  
10 fact that this fraction of sorbed PCBs is included within the fraction sorbed to  
11 organic carbon in the 3-phase model.

12 This concept is demonstrated by considering a limiting condition where the  
13 carbon-normalized PCB concentration approaches infinity as the organic carbon  
14 content approaches 0, even though the total dry weight PCB concentration and  
15 the pore water concentration may be very low in such samples. The result would  
16 be an apparently high carbon-normalized PCB concentration and partition  
17 coefficient. The addition of an inorganic phase to the 3-phase representation of  
18 PCB sorption was considered; however, it did not provide additional predictive  
19 capability. The samples collected for the partitioning data set were intentionally  
20 biased to obtain a disproportionate number of low  $f_{oc}$  cores. On a mass basis,  
21 far more PCB mass is found in high  $f_{oc}$  areas (where carbon normalization works  
22 well) than in low  $f_{oc}$  areas; therefore, a decision was made to retain the 3-phase  
23 representation of PCB sorption. Please refer also to the response to General  
24 Issue 5.

- 25 ■ Some mild bias is evident in predictions of PCB in fish. Predicted PCB concentrations in  
26 bullhead, sucker, sunfish and bass are generally lower than mean observations, while  
27 cyprinid PCB concentrations are overpredicted in all reaches except 5A. There is really too  
28 little data to check bias in lower food chain predictions.

### 29 **RESPONSE 2-DE-4:**

30 Statistics that represent bias (e.g., mean error and mean percent error in Table  
31 C.3-16 and the MB\* statistic derived in Response 2-FG-5) do not support the  
32 Reviewer's comments. The referenced fish species are discussed below, in  
33 relation to the statistical and graphical measures of bias presented in Appendix  
34 C:

- 35 ■ Brown bullhead – Figure C.3-31, Figure C.3-34, and Figure C.3-36 all indicate  
36 that simulated and measured PCB concentrations are very similar, on both a  
37 wet weight and lipid-normalized basis. The mean error is slightly negative  
38 (-6.2 mg/kg) and the MB\* statistic is only slightly above one (1.28), both of  
39 which indicate minor *overprediction* of observed concentrations. From this  
40 information it is clear that simulated concentrations are not “generally lower

## Model Calibration Responsiveness Summary

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1 than mean observations” as suggested by the Reviewer; the reverse may be  
2 true depending on the definition of “mild.”

- 3     ▪ Sunfish – Figure C.3-31, Figure C.3-34, and Figure C.3-37 all indicate that  
4 simulated and measured PCB concentrations are very similar. In Figure  
5 C.3-31, tPCB concentrations in Reach 6 (Woods Pond) sunfish are slightly  
6 overpredicted, concentrations in Reach 5B/5C sunfish are slightly  
7 underpredicted, and measured and simulated values in Reach 5A sunfish are  
8 nearly identical. The mean error for pumpkinseed sunfish is slightly negative  
9 (-5.5 mg/kg) and the MB\* statistic is only slightly above one (1.30), both of  
10 which indicate minor *overprediction* of observed concentrations. From this  
11 information, the Reviewer’s conclusion that tPCB concentrations in sunfish  
12 are “generally lower than mean observations” is not supported by the data.
- 13     ▪ Largemouth bass – As shown in Figure C.3-31, the measured concentrations  
14 in bass are slightly underpredicted in Reaches 5A and 5B/5C, and are slightly  
15 overpredicted in Reach 6 (Woods Pond). The mean percent error of -21%  
16 and the MB\* statistic (1.28) both indicate a small overall *overprediction*. From  
17 this information, the Reviewer’s conclusion of mild bias toward  
18 underprediction is not supported by the data.
- 19     ▪ White sucker – As shown in Figure C.3-31, the average simulated  
20 concentrations in all reaches are slightly lower than the measured  
21 concentrations. Consequently, the MB\* statistic is slightly below one (0.82)  
22 and the mean percent error is positive (+20%), indicative of slight  
23 underprediction. EPA agrees that this pattern could be interpreted as a “mild  
24 bias.” Although this bias could be removed by conducting further calibration  
25 of the model, this was not done because the model results were already well  
26 within acceptable tolerance levels and because it was believed that “tuning” of  
27 the model in this manner would not improve the predictive value of the model.
- 28     ▪ Cyprinids – EPA agrees that cyprinids were systematically overpredicted in  
29 reaches downstream of Reach 5A, based on the 10 golden shiner tissue  
30 samples. The overprediction of downstream cyprinids is acknowledged on  
31 page 6-31 of the Model Calibration Report, which states:

32             “The FCM results for cyprinids are higher than the field measurements of  
33 golden shiners made in downstream PSA reaches. Golden shiners have a  
34 diet dominated by water-column-based prey; therefore, the mixed diet  
35 used in FCM for the cyprinid community is not intended to apply to golden  
36 shiners. Overall, FCM is not sensitive to this overprediction because the  
37 contribution of cyprinids to the diet of predators is minimal in downstream  
38 reaches.”

39 With respect to the “lower food chain predictions,” EPA agrees that the sample  
40 size of D-net invertebrate measurements is low relative to fish samples.  
41 However, the FCM predictions of tPCBs in epifauna (mg/kg ww; depicted in  
42 Figure C.3-9) were all close to the PSA mean invertebrate concentrations in

## Model Calibration Responsiveness Summary

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1 D-net samples, which consisted primarily of epifauna. Furthermore, the FCM  
2 simulations were also consistent with the crayfish and tree swallow diet  
3 concentration data presented in Section C.3.4.2. EPA believes there are  
4 sufficient data to conclude that there is no significant bias for epifaunal  
5 invertebrates.

6 I would not judge any of these biases to be so significant as to undermine the credibility of the  
7 models.

### 8 **RESPONSE 2-DE-5:**

9 EPA agrees with the Reviewer's assessment.

### 10 **Marcelo H. Garcia:**

11 The field observations indicate high variability of PCB concentrations over very small spatial  
12 scales. The model is incapable of capturing such variability. Thus if the model has a bias, it is  
13 toward the "filtering" of the high variability seen in the field.

### 14 **RESPONSE 2-MG-1:**

15 EPA agrees that the models will never reproduce the amount of variability  
16 observed in the field. Please refer to the response to General Issue 10.

17 At the same time, it is not clear how much of the observed variability is indeed natural and/or the  
18 result of the sampling protocol.

### 19 **RESPONSE 2-MG-2:**

20 Based on the rigorous sampling protocols and extensive QA implemented for the  
21 Rest of River study, EPA does not believe that any portion of the observed  
22 variability is an artifact of the sampling protocol. However, as discussed in the  
23 RFI Report (BBL and QEA, 2003) EPA previously identified a bias (low) in the  
24 sediment PCB data analyzed by the on-site laboratory, believed due to analytical  
25 protocols for sample extraction. Please refer also to the response to General  
26 Issue 5.

27 What is clear is that the model will not capture such "randomness" and then the question is if this  
28 capability is indeed necessary for the intended use of the model.

### 29 **RESPONSE 2-MG-3:**

30 EPA agrees that the model will not reproduce the variability observed in the data,  
31 and does not believe that it is necessary to do so to achieve the objectives of the  
32 modeling study. Please refer to Response 1-EA-11 and the response to General  
33 Issue 1.

## Model Calibration Responsiveness Summary

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1 **Frank Gobas:**

2 Figure 3-18 shows no bias in the distribution of residual flows as a function of the measured flow  
3 rates.

4 **RESPONSE 2-FG-1:**

5 EPA agrees with the Reviewer's assessment.

6 Figure 4.36 also shows no significant systematic bias for the calculations of TSS by the HSPF  
7 model although some considerable variation between observed and predicted TSS values was  
8 found in some cases.

9 **RESPONSE 2-FG-2:**

10 Figure 4-36 refers to residual and relative residual TSS simulated by EFDC, not  
11 HSPF. EPA agrees with the Reviewer that the residuals and relative residuals  
12 depicted in the figure indicate no systematic bias in the model results. EPA  
13 acknowledges that there are some residuals that indicate occasional  
14 discrepancies between model results and the data, but notes that the largest  
15 discrepancies are for relative residuals, which are a less important indicator of  
16 the utility of the model than actual residuals. EPA believes that the magnitude of  
17 the differences is not unusual for this type of modeling study, and does not  
18 indicate an issue with the overall adequacy of the model calibration.

19 The model necessarily simulates a TSS concentration that is integrated over  
20 space (i.e., over at least the area of a single grid cell) and over time. A  
21 measured datum reflects the concentration at a much smaller spatial scale and at  
22 a very discrete time. Accordingly, discrepancies between a simulated  
23 concentration and a measured concentration are to be expected. Of greater  
24 importance is whether the central tendency of the simulation is accurately  
25 depicting the central tendency of the data. As shown in Model Calibration Report  
26 Figures 4-21 through 4-24, and in other similar figures in Appendix B, EPA  
27 believes this to be the case.

28 With regard to the magnitude of the deviations, it is important to keep in mind that  
29 some of the events were sampled intensively over time, at selected stations. As  
30 a result, a slight discrepancy in the timing of an event could lead to marked  
31 deviations in point-wise comparisons of simulated and measured TSS levels,  
32 even though the pattern of the response over the course of the event is relatively  
33 well represented (e.g., Event 6, Figure B.3-50, at New Lenox Road). Many of the  
34 variations referred to by the Reviewer are related to results from storm events  
35 affected by timing rather than the magnitude of the response.

36 Estimates in the tPCB water column concentrations show no significant systematic bias at  
37 Holmes Road and Woods Pond Headwaters but some bias is apparent from the distribution of the  
38 residuals for data collected at New Lenox Road and Woods Pond Outlet (Figure 5-31).

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE 2-FG-3:**

2           The slight indication of bias in the results is only evident at the New Lenox Road  
3           and Woods Pond Outlet locations, and only with respect to the relative residuals.  
4           As discussed in Response 2-FG-2, above, EPA believes that actual residuals are  
5           a more important measure of model performance and that the indication of slight  
6           bias is of limited significance for achieving the overall goals of the modeling  
7           study.

8           As was the case for TSS, it is important to recognize that the event data were  
9           sampled relatively intensively for a few of the events, at selected stations. For  
10          example, in the case of New Lenox Road, numerous samples were analyzed for  
11          PCBs during Event 1 (May 19-21, 1999, Figure B.4-44). The concentrations  
12          during the rising part of the hydrograph for this event were underpredicted due to  
13          a slight phase shift, and peak concentrations were also somewhat under-  
14          predicted. This phase shift leads to differences in point-by-point comparisons of  
15          model and data, even though the pattern over the course of the event is judged  
16          to be well-represented by the model results. A slight error in timing can lead to a  
17          large deviation of the model from the instantaneous concentration data, while  
18          having an inconsequential impact on both the mass loading of PCBs from the  
19          PSA and the response of the food chain to the transient change in concentration.

20         Figures C.3-26, C.3-27 and C.3-29, and C.3-49, C.3-50 and C.3-52 (for the linked model) plot  
21         the residuals against the measured PCB concentrations. The plots do not lend themselves to  
22         explore issues of bias. A statistical treatment of the data would be more useful. Hence, it is  
23         difficult to confirm the statement on p. C.3-31 that there is no model bias across the range of  
24         PCB concentrations evaluated. Just looking at Fig C.3-26, it looks as if there are more data  
25         points below the zero line than above it. Figure C.3-27 appears to confirm this for coplanar  
26         PCBs. But again, this may not be so.

### 27           **RESPONSE 2-FG-4:**

28         EPA agrees that the figures cited above do not, in isolation, allow for a  
29         comprehensive evaluation of model bias. However, other materials supplied in  
30         Appendix C allow for a more rigorous evaluation of model bias. The following  
31         information should be used in conjunction with these figures in evaluating bias:

- 32         ▪ Figures C.3-28 and C.3-51 are more appropriate graphics for assessment of  
33         bias because they compare central tendencies of field data (shown in yellow  
34         square symbols) to central tendencies simulated by the model.
- 35         ▪ Attachments C.15 and C.16 provide numerous figures of simulated versus  
36         measured concentrations, as a function of age, reach, and species. These  
37         plots, expressed in both wet weight and lipid-normalized units, provide  
38         considerable information on the overall model performance and bias.

## Model Calibration Responsiveness Summary

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1       ▪ The quantitative measures of model performance presented in Section  
2       C.3.6.4 (Tables C.3-14 through C.3-16) provide the “statistical treatment” of  
3       data requested by the Reviewer.

4       EPA believes that the model performance measures presented in the report  
5       (both graphical and quantitative), provide sufficient information for assessment of  
6       model bias. However, in Response 2-FG-5 (below) EPA has provided  
7       supplemental quantitative information.

8       There are various ways to explore the issue of bias for PCBs on a congener or total-PCB basis.  
9       We have used the model bias MB, which is derived on a species-specific basis as:

$$MB_j = 10^{\left( \frac{\sum_{i=1}^n [\log(C_{P,i} / C_{O,i})]}{n} \right)}$$

10

11       In essence, MB<sub>j</sub> is the geometric mean (assuming a log- normal distribution of the ratio C<sub>P,i</sub> / C<sub>O</sub>,  
12       i) of the ratio of predicted (C<sub>P,i</sub>) and observed (C<sub>O,i</sub>) for all PCB congeners i in a particular  
13       species j included in the analysis. MB is a measure of the systematic over- (MB>1) or under-  
14       prediction (MB<1) of the model. It should be stressed that in the calculation of MB, over- and  
15       under-estimations of the observed concentration values for individual PCB congeners have a  
16       tendency to cancel out. Hence, MB tracks the central tendency of the ability of the model to  
17       predict PCB congener concentrations. It is a useful measure of model performance if total PCBs  
18       (ΣPCB) are of primary interest. The variability of over- and under-estimation of measured values  
19       can be represented by the 95% confidence interval of MB (i.e. 95% CI = antilog(geometric mean  
20       ± (t<sub>v</sub>, 0.05 × standard deviation)). The 95% confidence interval represents the range of  
21       concentrations that includes 95% of the observed concentrations. It can be viewed as a measure  
22       of the uncertainty of the model predictions. The same approach can also be applied to total PCB  
23       as well. In that case, model bias MB\* is:

$$MB_j^* = 10^{\left( \frac{\sum_{i=1}^m [\log(C_{P,\Sigma PCB} / C_{O,\Sigma PCB})]}{m} \right)}$$

24

25       MB\* is the geometric mean (assuming a log- normal distribution of the ratio C<sub>P, ΣPCB</sub> / C<sub>O, ΣPCB</sub>)  
26       of the ratio of predicted and observed concentrations for ΣPCB in species j (Arnot and Gobas,  
27       Environ. Toxicol. Chem. 23, 2343-2355 (2004)).

### 28       **RESPONSE 2-FG-5:**

29       In response to the Reviewer’s suggestions, EPA has reevaluated the model  
30       performance using the MB and MB\* statistics defined above (using the linked  
31       version of FCM) as shown in Table 2-FG-5 below.

# Model Calibration Responsiveness Summary

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1  
2  
3  
**Table 2-FG-5**

**Model Bias Statistics, by Species, for FCM Linked Model**

Species	n	MB	n*	MB*
Brown Bullhead	405	1.385	45	1.278
Cyprinid Fallfish	45	0.881	5	0.809
Cyprinid, Shiner	90	2.283	10	2.665
Pumpkinseed	540	1.300	60	1.270
Largemouth Bass	630	1.282	70	1.277
White Sucker	486	0.936	54	0.815

4  
5 EPA notes that the results of the MB and MB\* calculations result in conclusions  
6 that are very similar to the mean percent error calculations presented in Tables  
7 C.3-14 through C.3-16 of the Model Calibration Report.

8 The MB\* statistic (i.e., model bias for tPCBs) is just over 1.0 for three of six  
9 species (bullhead, sunfish, and bass), indicating a slight overprediction and just  
10 under 1.0 for two of six species (fallfish, sucker) indicating a slight  
11 underprediction. The magnitude of bias for these species is low (i.e., within  
12 MFD/QAPP performance targets, and well within the range of error expected for  
13 most bioaccumulation models). EPA believes that further adjustment of the  
14 models to push the MB\* statistic closer to 1.0 would constitute overcalibration  
15 and would not necessarily improve model predictive ability. The bias toward  
16 overprediction in the remaining fish group (downstream cyprinids) is discussed in  
17 Response 2-DE-4.

18 I do agree with the authors that the vast majority of the observed concentrations are within an  
19 order of magnitude of the mean simulated by the FCM. However, it is not clear why Figure C.3-  
20 29 only suggests a range of an order of 2 rather than 10 (in Fig C.3-26). The latter may be due to  
21 the fact that Fig C.3-26 refers to the combined data set while Fig C.3-29 refers to means of  
22 subsets of samples. (This needs to be clarified in the Figure legend).

23 **RESPONSE 2-FG-6:**

24 The error statistics presented in Figures C.3-26 and C.3-29 are computationally  
25 different, and cannot be compared in the manner implied by the Reviewer. The  
26 equation for mean percent error (as presented in Figure C.3-29) is defined on  
27 page C.3-34 as:

## Model Calibration Responsiveness Summary

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1 
$$MPE = \frac{100}{n} \sum_{i=1}^n \frac{e}{(y_i + \hat{y}_i)/2} \quad (C.3-2)$$

2 where:

3  $MPE$  = Mean percent error, a unitless measure of model bias (%).

4  $y_i$ , = Measured concentration.

5  $\hat{y}_i$  = Simulated concentration from model.

6  $e$  = Residual (measured – simulated value).

7  $n$  = Number of model/data pairs evaluated.

8 In contrast, the equation for the residual of the log-log transformed model (as  
9 presented in Figure C.3-26) is defined as:

10 
$$\log(y_i) - \log(\hat{y}_i)$$

11 These two error statistics result in different quantitative values. For example, for  
12 an observed value of 0.1 and a model simulation of 1.0, the derived MPE would  
13 be -164%, whereas the residual of the log-log transformed model would be -1.0  
14 (log mg/kg OC). Both statistics are indicative of a “factor of ten” difference  
15 between measured and simulated values.

16 Figure C.3-29 does not indicate a range “on the order of 2,” as suggested by the  
17 Reviewer. The graph indicates: (1) that individual PCB concentrations can range  
18 up to an order of magnitude or more from the mean model-predicted PCB  
19 concentrations; and (2) that there are approximately as many positive as  
20 negative model residuals. Because Figure C.3-29 depicts individual data points  
21 relative to simulated central tendencies, the magnitude of individual errors does  
22 not represent only model error, but also incorporates variability in the data.

23 While the residuals may not show a bias, Fig C.3-27 illustrates that the uncertainty in the model  
24 predictions can be large. It is possible that this uncertainty is to some degree caused by  
25 difficulties in modeling the bioaccumulation behavior of certain congeners. Metabolism can be a  
26 significant process for some congeners and not for others. It is therefore instructive to explore the  
27 issue of bias on a congener specific basis rather than combining many congeners in one analysis.  
28 I recommend this is done.

### 29 **RESPONSE 2-FG-7:**

30 Figure C.3-27 does not depict uncertainty in model predictions. Figure C.3-27,  
31 as well as Figures C.3-26 and C.3-29, depict individual data points relative to  
32 modeled central tendencies. As a result, the wide range of scatter in the graphs  
33 is attributable mainly to the variability in individual measured fish PCB

## Model Calibration Responsiveness Summary

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1 concentrations, not to model uncertainty. Figure C.3-28 demonstrates that when  
2 field data are aggregated and represented by a measure of central tendency (to  
3 make them comparable to deterministic model simulations), the measured values  
4 are generally close to FCM simulations.

5 EPA agrees that difficulties in the modeling of bioaccumulation of certain  
6 congeners can increase the uncertainty of the model. The congener-specific  
7 modeling yielded more uncertain results than the tPCB modeling, in part due to  
8 uncertainty in congener-specific bioavailability of coplanar congeners, and in part  
9 due to a lack of congener-specific information for some model parameters (i.e.,  
10 estimation based on physical/chemical properties). As a result of this  
11 uncertainty, the spread of the data in Figures C.3-28 and C.3-51 is somewhat  
12 wider for congeners than for tPCBs.

13 EPA agrees that, in addition to analyses with all congeners combined, model  
14 bias should be considered on a congener-specific basis. Appendix C already  
15 contains this information in both graphical and statistical forms. For example,  
16 Figures C.3-40 through C.3-48 provide summaries of simulated versus measured  
17 congener concentrations in fish, organized by river reach and species. Model fit  
18 statistics are also broken down by congener in Tables C.3-8 and C.3-14. From  
19 these analyses it was concluded (Section C.3.6.3.2) that most congeners were  
20 predicted without significant bias; some exhibited small systematic  
21 overpredictions, and some exhibited small systematic underpredictions.

22 Also, I recommend that, in addition to the mean model bias, the uncertainty around the mean  
23 model bias is explicitly stated. A high degree of uncertainty of the model calculations should not  
24 be viewed as criticism of the model but a reflection of the actual state of the modeling capability.

### 25 **RESPONSE 2-FG-8:**

26 EPA will consider characterizing the uncertainty around the model mean bias in  
27 the Phase 2 Calibration and Validation reporting using the confidence intervals  
28 about the MB statistic, as described in Response 2-FG-5.

### 29 **Wilbert Lick:**

30 [No comments]

### 31 **E. John List:**

32 There certainly appears to be bias in the FCM as indicated by the lipid-normalized PCB  
33 concentrations predicted by the FCM in Reach 5D of the PSA, as indicated by Figure 19 of  
34 Attachment C.16, and other portrayals of the FCM predictions for Reach 5D that are included in  
35 Attachment C.16. It is unfortunate that there appears to be no field data to substantiate the  
36 predictions of the FCM in this reach of the river, especially since the predictions appear to be  
37 incongruent with those for the rest of the PSA. In the absence of any explanation and/or

## Model Calibration Responsiveness Summary

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1 correction for this phenomenon it is not clear that it is real, in which case it makes the application  
2 of the model problematic, at least until the reason for this indicated bias is understood.

### 3 **RESPONSE 2-JL-1:**

4 The Reviewer is correct that the highest fish PCB concentrations were simulated  
5 for Reach 5D using the linked version of the bioaccumulation model. However, it  
6 is incorrect to characterize this observation as “bias” because there are no field  
7 tissue data for Reach 5D. Assessment of model bias can be made only if both  
8 measured and simulated values are available for comparison.

9 It appears that the Reviewer is commenting on the discrepancy between Reach  
10 5D simulations and the simulations in adjacent downstream reaches (i.e., Reach  
11 5C and Woods Pond). Although this difference is not bias per se, discussion of  
12 the uncertainty associated with the difference, and the implications for model  
13 application, is appropriate.

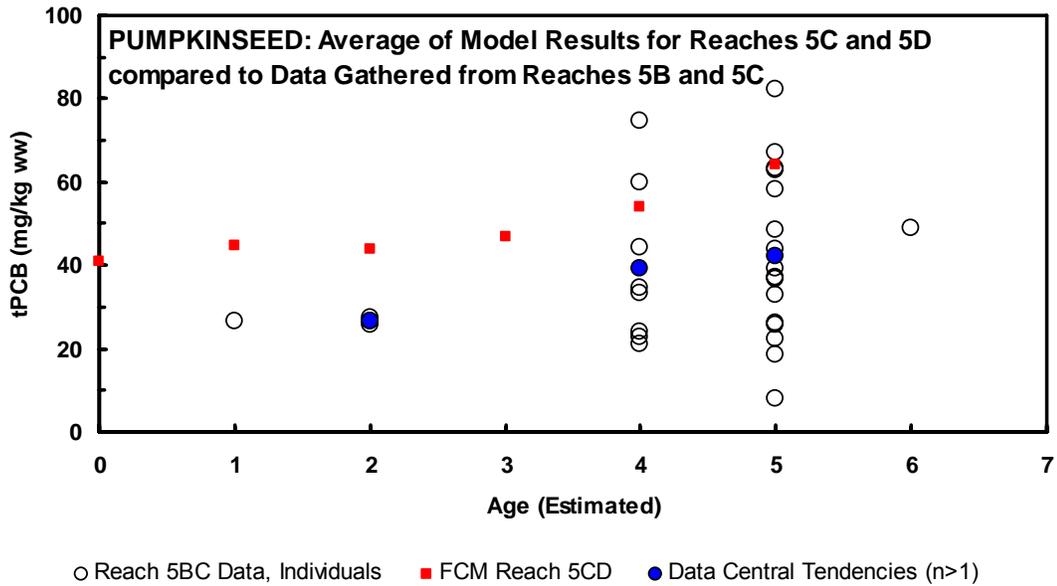
14 Fish samples were not collected within Reach 5D (i.e., large backwaters  
15 contiguous to Reach 5C) because the backwaters were not accessible at the  
16 time the samples were collected. However, evaluation of largemouth bass life  
17 history indicates that fish migrate back and forth between the backwaters and the  
18 main channel of the Housatonic River. Therefore, the fish tissue data collected  
19 for Reach 5C represent mixed exposures to contaminated media in both  
20 Reaches 5C and 5D, with the degree of backwater habitat use dependent on  
21 flow, temperature, dissolved oxygen, and other habitat factors. When the habitat  
22 uses of Reaches 5C and 5D are considered and weighted by expected exposure  
23 duration, the model predictions remain close to the observed main channel  
24 concentrations, and within the tolerance limits for calibration specified in the  
25 MFD/QAPP.

26 Figure 2-JL-1 shows the results of additional linked model simulations in which  
27 model estimates from Reaches 5C and 5D were averaged, assuming 50%  
28 exposure from each reach. Even after the influence of backwaters exposure is  
29 taken into account, the measured and simulated concentrations remain in  
30 reasonable agreement.

31

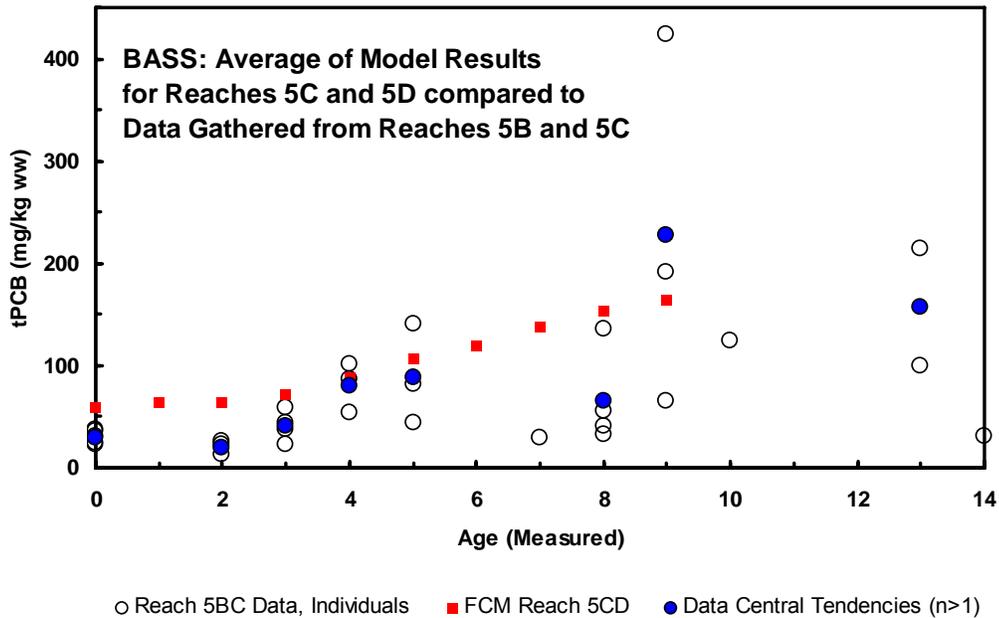
# Model Calibration Responsiveness Summary

## 1 (a) Pumpkinseed



2

## 3 (b) Largemouth Bass



4

5 Notes: Blue symbols represent means of all individual fish for each age class, and are directly  
6 comparable to FCM simulations.

7 Red symbols represent FCM simulations of mean concentrations for each age class.

8 Open symbols represent individual measured PCB concentrations; these data are portrayed to  
9 illustrate the variability and sample size of data for each age class.

10 **Figure 2-JL-1 Comparison of Measured Fish PCB Concentrations to FCM**  
11 **Simulations Assuming Mixed Habitat Use of the Mainstem and**  
12 **Associated Backwaters**

### 1 Ability of the Model to Account for Relevant Processes

2 3. Does the model, as calibrated, based upon your technical judgment, adequately account  
3 for the relevant processes affecting PCB fate, transport and bioaccumulation in the  
4 Housatonic River?

#### 5 E. Adams:

6 All three models are considered state of the art and hence come generally “fully equipped”. The  
7 model team is experienced and has added important features such as the effects of vegetation on  
8 stream flow and transport. Hence I believe that most processes are at least *represented* in the  
9 models. I do agree with QEA/GE that bank erosion/river meandering is an important process  
10 that should be included and could help explain the large vertical spread of PCBs observed in  
11 cores.

#### 12 RESPONSE 3-EA-1:

13 Please refer to the response to General Issue 9.

14 Having said that, it is not clear that the models have been properly calibrated when it comes to  
15 individual processes. While each of the three models has their own unique calibration issues,  
16 EFDC is perhaps the most problematic because: 1) it is relatively new and has not been used in  
17 the current framework (e.g., with both in-channel flows and above bank flows),

#### 18 RESPONSE 3-EA-2:

19 Although it is true that some capabilities of EFDC being used in the application  
20 for the Housatonic River are relatively new (e.g., bed load transport), the version  
21 of EFDC that is being applied to the Housatonic River has undergone extensive  
22 QA by the EPA National Exposure Research Laboratory in Athens, GA, and the  
23 model application team. In addition, EFDC is being applied at other  
24 contaminated sediment sites where both in-channel flows and out-of-bank flows  
25 are being simulated, e.g., the Kalamazoo River, Michigan. The modeling team is  
26 not aware of any other contaminant fate and transport model that has been used  
27 previously in a framework similar to the Housatonic River (including simulation of  
28 out-of-bank transport).

29 2) it is being calibrated over a short period of time (14 months) relative to the time constants of  
30 some of the biochemical processes,

#### 31 RESPONSE 3-EA-3:

32 Please refer to the response to General Issue 2.

33 and 3) compromises are being made because of computational expense.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-EA-4:**

2           The Conceptual Site Model for the PSA (WESTON, 2004) includes a number of  
3           processes, such as PCB transport onto the floodplain, that require a  
4           computationally demanding modeling framework. Accordingly, the fate and  
5           transport model selected for the modeling study is computationally demanding.  
6           The use of any such computationally intensive model necessarily requires  
7           compromise; EPA believes that such compromises have been made in a manner  
8           that is consistent with achieving the goals of the modeling study.

9           Including data from the earlier years (~1980-1999), as has been mentioned for the next phase,  
10          will help with the calibration. If this is done it would be nice if the last few years (2000-2004)  
11          could be set aside for a true validation (no more parameter tweaking).

12          **RESPONSE 3-EA-5:**

13          EPA has revised the approach to model calibration and validation, in part to  
14          address this Reviewer's comment; please refer to the response to General Issue  
15          2.

16          One issue with calibration is that multiple variables contribute to a particular observation so the  
17          net effect may be correct, while the individual effect is not. As mentioned previously, one  
18          example is water column TSS concentrations that reflect both resuspension and deposition.

19          **RESPONSE 3-EA-6:**

20          Please refer to the response to General Issue 7.

21          I am still a bit uncomfortable about the fact that most of the PCB mass is in the floodplain (and  
22          hence affected only by relatively rare flood flows), yet the vast majority of the computational  
23          time is taken with in-channel flows. Should the same model be used (in the same way) for both?

24          **RESPONSE 3-EA-7:**

25          The Reviewer is correct that the majority of the PCB mass resides in the  
26          floodplain. However, most of the PCB mass that is subject to scour during a  
27          flood event is in the river channel. Most of the computational time is associated  
28          with simulation of conditions in the river channel, mainly because the river is  
29          within its banks for the majority of the time and when the floodplain cells are dry  
30          computations in the cells are not performed. The river sediment serves as a  
31          source of PCBs to the floodplain, whereas the PCBs in the floodplain are  
32          relatively stable in comparison.

33          It is not clear whether storms or the routine flows will be most responsible for PCB transport, but  
34          the fact that the model can only afford one grid cell over the channel width and a couple of grid  
35          cells in the vertical seems to defeat the purpose of a 3D model.

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE 3-EA-8:**

2           EPA has not characterized this model application as being three-dimensional.  
3           The question of the optimal dimensionality for the hydrodynamic/sediment-  
4           contaminant transport and fate model was discussed extensively in Section  
5           16.4.2 of the MFD Responsiveness Summary (WESTON, 2002). In that  
6           document, EPA restated its belief that a two-dimensional application was the  
7           most desirable approach, but indicated that the selected model would be tested  
8           in both two-dimensional and three-dimensional modes and the results presented  
9           in the final MFD. The results of the testing were presented in Section 5.4 of the  
10          final MFD, and the final computation grid was specified as two-dimensional (see  
11          MFD, p. 5-56). Please refer also to the response to General Issue 4.

### 12          **Reference:**

13          WESTON (Weston Solutions, Inc.). 2002. *Responsiveness Summary to the Peer*  
14          *Review of the Modeling Framework Design and Quality Assurance Project*  
15          *Plan: Modeling Study of PCB Contamination in the Housatonic River.*  
16          Prepared for U.S. Army Corps of Engineers and U.S. Environmental  
17          Protection Agency.

18          The mass transfer coefficient used to compute sediment-water flux is being calibrated to match  
19          observed changes in contaminant flux between two stations. Since the model has only one grid  
20          cell per river width, the calculated flux is based on a cross-sectional average flow rate, and hence  
21          an average velocity, bottom shear stress and erosion potential. It is quite possible that at a given  
22          time portions of a reach are eroding while others are depositing and it is not clear if a calculation  
23          based on average flow is correct. Furthermore, I would expect to have seen the mass transfer  
24          coefficient increase with river flow, but this apparently was not the case.

### 25          **RESPONSE 3-EA-9:**

26          Please refer to the responses to General Issues 4 and 8.

27          I am also concerned about the bioturbation coefficients. I realize that limited actual calibration  
28          has taken place so far, but I wonder if true calibration will be possible in the future. The  
29          tentative value of  $E-9 \text{ m}^2/\text{s}$  is quite large; are there biological observations to support such a  
30          value (or any value)? 14 months is too short a period to determine if bioturbation (plus diffusive  
31          flux across the interface) will have much effect; will adding an additional 10-20 years be that  
32          much more helpful, especially if the coefficient turns out to be much smaller?

### 33          **RESPONSE 3-EA-10:**

34          Observations regarding bioturbation in the literature have been reviewed for  
35          applicability to the organisms observed in the Housatonic River, and the  
36          information is summarized in the response to General Issue 6. These data will  
37          be used to parameterize the long-term calibration and validation of the model  
38          (i.e., over simulation periods longer than 14 months). These analyses will, in

## Model Calibration Responsiveness Summary

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1 combination, provide improved support for the evaluation of the particle mixing  
2 rate(s) assigned in the model.

3 Finally, the measured PCB sediment concentrations are not an ideal data set for calibration. As  
4 mentioned above, one problem is that there is not much change over (14 months of) time. There  
5 is some change over space, but this is overwhelmed by the much greater change over very short  
6 (sub-grid scale) lengths, which cannot be resolved.

### 7 **RESPONSE 3-EA-11:**

8 Please refer to the responses to General Issues 2 and 5.

9 Finally, under historical conditions PCBs have been ubiquitous, appearing with the upstream  
10 inflow, and eroding/diffusing off the sediment bed, river banks, and floodplains. These PCBs  
11 “all look the same” and hence it is hard to diagnose transport mechanisms based on a model’s  
12 ability to “match” them. It was not discussed in detail at the Peer Review Meeting, but if there is  
13 time, serious consideration should be given to a tracer experiment of some sort. The best type of  
14 experiment, in theory, would be one in which sediment of different types (or placed in different  
15 locations) were uniquely labeled (e.g., with fluorescent colors) so that they could be tracked.  
16 This would take time and resources to think through, but it may be the only way to calibrate  
17 certain model parameters.

### 18 **RESPONSE 3-EA-12:**

19 Dye studies and the use of other tracers were considered by EPA earlier during  
20 the modeling study, and rejected because of lack of public acceptance.

21 An alternative approach would be to conduct a trial remediation on a patch of river and see how  
22 rapidly contaminated sediment from upstream fills in the clean spots. (In principle one could  
23 simulate the effect of clean upstream sediments that will result from ongoing remediation to see  
24 how fast they fill in the contaminated portions downstream, but it is better to simulate a clean  
25 downstream spot since a bit of contamination in an otherwise clean patch shows up more than a  
26 bit of clean sediment in an otherwise dirty patch, especially given the variability.)

### 27 **RESPONSE 3-EA-13:**

28 EPA will consider including a simulation of a hypothetical remedial scenario in  
29 the Model Validation Report to illustrate model performance. Please refer to the  
30 response to General Issue 12.

### 31 **W. Frank Bohlen:**

32 As noted, **The Model** consists of three primary components, a watershed model (HSPF), a  
33 hydrodynamic-sediment/contaminant transport model (EFDC), and a bioaccumulation model  
34 (FCM). This combination of models accounts for all relevant processes affecting PCB transport  
35 and fate in the Housatonic River study area. That is, all relevant processes can be accommodated  
36 in the models and have received some consideration in model development. Unfortunately this

## Model Calibration Responsiveness Summary

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1 does not mean that this combination of models, as presently structured, will provide the accurate  
2 simulations of PCB transport and fate needed to facilitate remedial designs.

### 3 **RESPONSE 3-FB-1:**

4 EPA recognizes that model code selection alone does not necessarily ensure  
5 that the final calibrated model will be adequate to achieve the goals of the  
6 modeling study. The objective of model selection was to provide a framework for  
7 the modeling that, if properly implemented, would include the relevant processes  
8 and achieve the goals of the modeling study.

9 Determining which processes in the PSA are relevant for contaminant transport  
10 and fate, and then selecting model code that includes all relevant processes was  
11 only one aspect of model selection. Of equal importance was the question of  
12 how the processes are simulated numerically within the model code, i.e., the  
13 model formulations. Both of these aspects of model selection, along with other  
14 considerations, were carefully evaluated in the selection of the three models  
15 used in the Housatonic River modeling study. That process is documented in  
16 Sections 4 and 5 of the Modeling Framework Design. EPA believes that the  
17 model framework that was selected for this study will achieve the overall  
18 modeling study objective of providing a predictive tool for use in the evaluation of  
19 remedial alternatives.

20 The watershed model (HSPF) has the potential to provide both estimation of surface water  
21 volume inflows as well as water temperature and the associated sediment loads entering the  
22 study area. The development of the model and subsequent comparisons of model outputs vs.  
23 measured flows indicated close agreement, well within the QAPP specified “very good” category  
24 of +/-10%. The agreement for the case of the suspended solids load was poorer which is not  
25 entirely unexpected. Unfortunately the discussion of the reasons for these latter differences was  
26 weak.

### 27 **RESPONSE 3-FB-2:**

28 Please refer to Response 1-FG-3, above.

29 Moreover, the comparisons relied on relatively long term averages (mean annual load).  
30 Examination of higher frequency TSS data/model comparisons for several storm events (May  
31 and September, 1999 e.g.) show differences exceeding 100% in concentrations as well as  
32 significant differences in timing. These differences make one wonder how it is that the annual  
33 average data is so well simulated. This was not subject to sufficient discussion in either Volume  
34 1 or Appendix A.

### 35 **RESPONSE 3-FB-3:**

36 It is not reasonable to expect a watershed model to predict suspended solids on  
37 the time scale of individual events. As stated on page 2-38 of the Model  
38 Calibration Report, the watershed model TSS calibration was based on  
39 comparisons to the annual loads from the EPA flux analysis, with the storm event

## Model Calibration Responsiveness Summary

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1 concentrations as an additional consistency check of the time-interval model  
2 predictions.

3 However, the model results sometimes differ from the data. For example, for the  
4 May 1999 storm data collected at Coltsville and West Branch (Figure 2-25), the  
5 simulated peak TSS concentrations are on the order of 100% greater than the  
6 measurements, as noted by the Reviewer. For this particular event, the  
7 simulated flow is lower than the measured flow; therefore, the resulting simulated  
8 loading (i.e., flow times concentration) for the event is closer to the measured  
9 loading than the predicted TSS concentrations indicate.

10 The significance of these differences for purposes of overall model calibration are impossible to  
11 assess since the upstream inputs of sediment used during the calibration runs relied on empirical  
12 data rather than the HSPF output. Since more than 75% of the stream associated input to the  
13 study area crosses this boundary this leaves HSPF inaccuracies affecting only 25% of the inputs  
14 an effective further diminished by the fact that these tend to be distributed along the length of the  
15 study area. Some consideration and subsequent discussion of this issue is recommended.

### 16 **RESPONSE 3-FB-4:**

17 EPA had considered this issue as part of the model calibration process, and  
18 agrees with the Reviewer that the fate and transport model is relatively  
19 insensitive to solids loadings predicted by HSPF. The predictions from HSPF  
20 provide a means of estimating solids loadings from the contiguous drainage area  
21 that would be difficult to derive from data. The effect of uncertainty in these  
22 estimates will be considered and subsequently discussed in the Model Validation  
23 Report.

24 In addition to consideration of high frequency TSS characteristics the presentation of HSPF  
25 would benefit from a more detailed discussion of the methodology leading to the specification of  
26 water temperature, a parameter passed to the bioaccumulation model. It appears that a  
27 moderately complex heat calculation is performed but details are not included in the calibration  
28 reports. A quick search indicates that they are also limited in the MFD.

### 29 **RESPONSE 3-FB-5:**

30 In HSPF, water temperature is modeled by performing an energy balance in each  
31 stream segment; the HTRCH submodule within the RCHRES module of HSPF  
32 performs these calculations. Heat and energy inputs to the stream are  
33 determined from the temperature of non-point, point, and boundary inflows, and  
34 from the following meteorological data: solar radiation, air temperature, dew point  
35 temperature, wind speed, and cloud cover.

36 Water temperature and heat content (in BTUs) of surface runoff and interflow  
37 (calculated in the PERLND and IMPLND modules) are estimated from air  
38 temperature using the following linear regression equation:

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1                   SLTMP       =     ASLT + BSLT\*AIRTC

2       where:

3                   SLTMP       =     Soil layer temperature (°C)

4                   ASLT         =     Y-intercept (°C)

5                   BSLT         =     Slope (-)

6                   AIRTC        =     Air temperature (°C).

7       For the Housatonic River watershed model, the air temperature is input from  
8       various gages on an hourly time step, and the ASLT and BSLT parameters are  
9       varied monthly to represent seasonal patterns.

10       The lower soil layer temperature and the groundwater layer runoff temperature  
11       (from which the groundwater heat contribution is determined) are user-defined,  
12       and are usually derived from local shallow groundwater temperatures. These  
13       temperatures are also specified on a monthly basis to represent seasonal  
14       variability.

15       For each of the stream reaches in the watershed model, the HTRCH submodule  
16       performs the energy balance and estimates the stream water temperature.  
17       HTRCH accounts for inputs and outputs of heat in a reach through three heat-  
18       transfer processes: (1) heat transfer by advection into or out of the reach;  
19       (2) heat transfer across the air-water interface; and (3) heat transfer across the  
20       sediment-water interface. Heat is considered to be a thermal concentration that  
21       is uniform within a reach and assumed to advect at the same rate as the stream  
22       flow. The net heat exchange ( $Q_T$  - kcal/m<sup>2</sup>/interval) at the water surface and  
23       sediment interfaces is represented by the following heat balance equation:

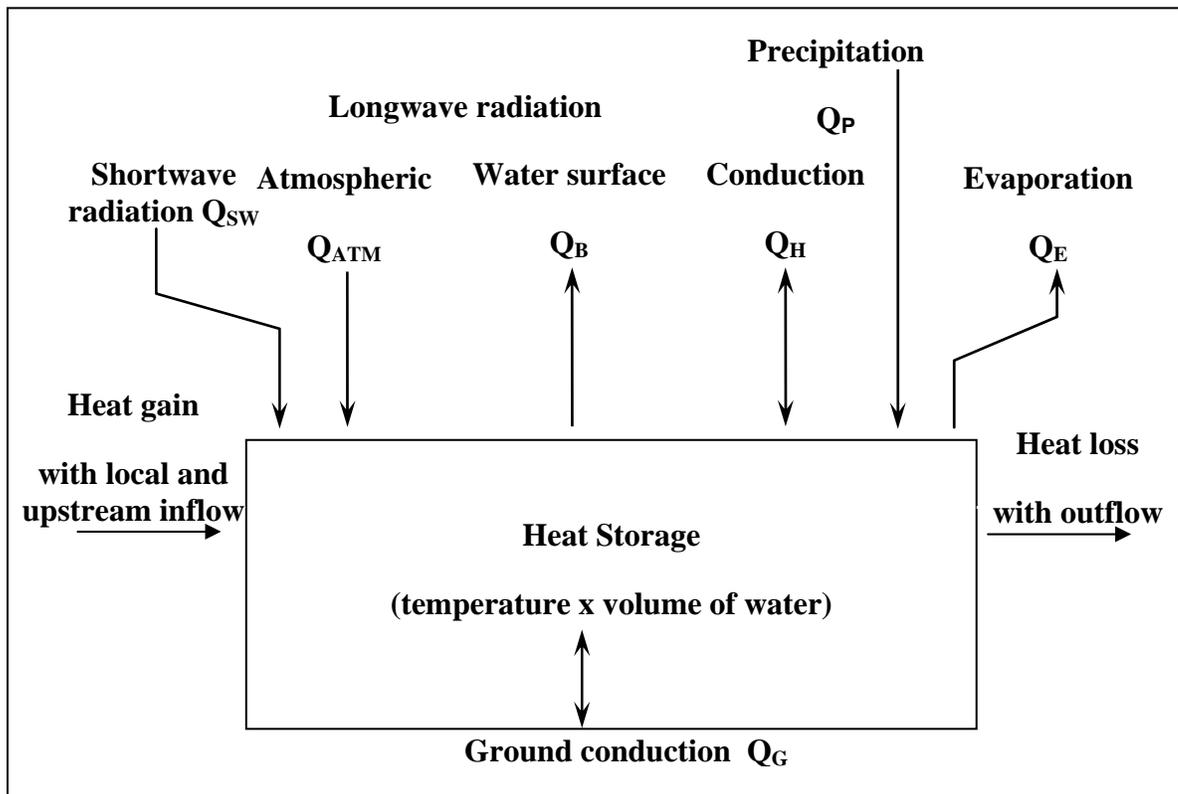
24                    $Q_T = Q_{SW} + Q_{ATM} + Q_B + Q_H + Q_E + Q_P + Q_G$

25       where the flux terms are as illustrated in Figure 3-FB-5.

26       Radiational energy transfers at the water surface are estimated from solar  
27       radiation (short-wave) and cloud cover and temperature (longwave) data.  
28       Evaporative transfers are determined from wind, air temperature, and dew point  
29       temperature data. Conduction/convection transfers are determined from air  
30       temperature and wind. Energy transfers between the sediment and the water  
31       column are estimated from sediment temperature, which is user-defined, and is  
32       varied on a monthly basis to allow for seasonal variations.

33

# Model Calibration Responsiveness Summary



1  
2 **Figure 3-FB-5 Heat Exchange Processes Represented in the HTRCH**  
3 **Submodule of HSPF**

4 The basic equations for each of the heat flux components were derived from a  
5 study of heat transfer processes between the atmosphere and water surfaces by  
6 TVA (1972). The formulations for each component are described below:

7 The shortwave radiation is estimated by the equation:

$$8 \quad Q_{sw} = 0.97 * CFSAX * SOLRAD * 10$$

9 where:

10 0.97 = Fraction of incident radiation absorbed

11 CFSAX = Ratio of radiation incident to water surface to  
12 measured radiation; includes shading

13 SOLRAD = Solar radiation (Langleys/interval)

14 10 = Conversion factor from Langleys to kcal/m<sup>2</sup>

## Model Calibration Responsiveness Summary

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1 The longwave radiation components are estimated by:

$$2 \quad Q_{SW} + Q_B = \text{SIGMA} * [(\text{KATRAD} * 10^{-6} * \text{CLDFAC} * \text{TAKELV}^6) -$$
$$3 \quad \text{TWKELV}^4] * \text{DELT60}$$

4 where:

5 SIGMA = Stephan-Boltzman constant multiplied by 0.97 to  
6 account for emissivity of water

7 TWKELV = Water temperature (°K)

8 KATRAD = Atmospheric longwave radiation coefficient

9 CLDFAC =  $1.0 + (0.0017 * \text{CLOUD}^2)$

10 CLOUD = Cloud cover, expressed as tenths (range = 0 - 10)

11 TAKELV = Air temperature corrected for elevation (°K)

12 DELT60 = Time interval (minutes) divided by 60

13 The conduction/convection heat transport is estimated by the following  
14 relationship, dependent on the difference between the water temperature and the  
15 air temperature:

$$16 \quad QH = \text{CFPRES} * (\text{KCOND} * 10^{-4}) * \text{WIND} * (\text{AIRTC} - \text{TW})$$

17 where:

18 CFPRES = Pressure correction factor (dependent on elevation)

19 KCOND = Conductive-convective heat transport coefficient

20 WIND = Wind speed (m/interval)

21 TW = Water temperature (°C)

22 AIRTC = Air temperature (°C)

23 The evaporative heat transfer is estimated by:

$$24 \quad Q_E = \text{HFACT} * (\text{KEVAP} * 10^{-9}) * \text{WIND} * (\text{VPRESA} -$$
$$25 \quad \text{VPRESW})$$

26 where:

27 HFACT = Heat conversion factor (latent heat of vaporization  
28 multiplied by density of water)

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1	EVAP	=	Quantity of water evaporated (m/interval)
2	KEVAP	=	Evaporation coefficient
3	WIND	=	Wind movement 2 m above the water surface
4			(m/interval)
5	VPRESW	=	Saturation vapor pressure at the water surface (mbar)
6	VPRESA	=	Vapor pressure of air above water surface (mbar)

7 The heat content of precipitation is determined by assuming that the rainfall has  
8 the same temperature as the water on which it falls.

9 The heat movement between the sediment and the overlying water is based on  
10 heat transfer through a surficial layer (consisting of water-saturated sediment)  
11 overlying the deeper layer, which is at an equilibrium temperature). Heat fluxes  
12 between the deeper layer and surficial layer, and between the surficial layer and  
13 water are computed, as well as sediment and water temperatures. The heat  
14 transfer between the deeper layer and surficial layer is computed as follows:

$$15 \quad \text{QGRMUD} = \text{KGRND} * (\text{TGRND} - \text{TMUD})$$

16 where:

$$17 \quad \text{QGRMUD} = \text{Heat transfer from deeper layer to surficial layer}$$

18 (kcal/m<sup>2</sup>/interval)

$$19 \quad \text{KGRND} = \text{Deeper layer – surficial layer heat conduction}$$

20 coefficient (kcal/m<sup>2</sup>/°C/interval)

$$21 \quad \text{TGRND} = \text{Equilibrium deeper layer temperature (°C)}$$

$$22 \quad \text{TMUD} = \text{Surficial layer temperature (°C)}$$

23 This heat transfer is used to update the surficial layer temperature as follows:

$$24 \quad \text{TMUD} = \text{TMUD} + \text{QGRMUD}/\text{CPR}/\text{MUDDEP}$$

25 where:

$$26 \quad \text{CPR} = \text{Heat capacity of surficial layer (CPR assumed to be}$$

27 equal to heat capacity of water)

$$28 \quad \text{MUDDEP} = \text{Thickness of surficial layer (m)}$$

## Model Calibration Responsiveness Summary

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1 The new surficial layer temperature is used to compute the heat transfer between  
2 the sediment and the water column as follows:

$$3 \quad Q_G \quad = \quad KMUD * (TMUD - TW)$$

4 where:

$$5 \quad KMUD \quad = \quad \text{Sediment-water column heat conduction coefficient}$$

6 (kcal/m<sup>2</sup>/°C /interval)

$$7 \quad TW \quad = \quad \text{Water temperature (°C).}$$

### 8 **Reference:**

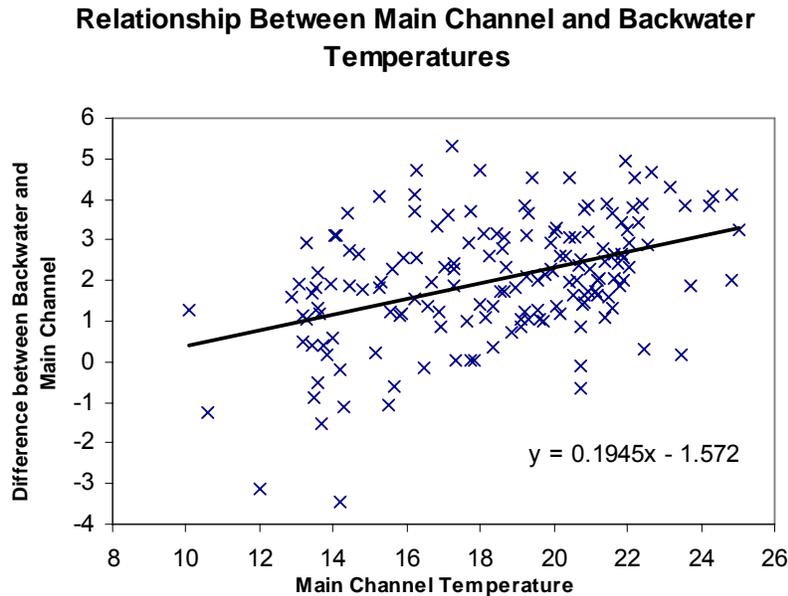
9 TVA (Tennessee Valley Authority). 1972. *Heat and Mass Transfer Between a*  
10 *Water Surface and the Atmosphere*. Tennessee Valley Authority, Norris, TN.  
11 Laboratory Report No. 14, Water Resources Research Report No. 0-6803.

12 For the most part I'd believe that water and air temperatures are equal through much of the study  
13 area. Where deviations might occur however, is in the deeper, lower energy backwater and/or  
14 pond areas. Are these areas stratified? How is that to be handled?

### 15 **RESPONSE 3-FB-6:**

16 For food chain modeling, the HSPF linkage is used to represent water  
17 temperatures within the PSA. As the Reviewer notes, water temperatures are  
18 not widely spatially variable over main channel PSA reaches. The Reviewer is  
19 correct that temperature deviations can occur in shallow, low energy  
20 environments. For this reason, FCM estimates of temperature for Reach 5D  
21 backwaters were adjusted based on site-specific measurements in the main  
22 channel and backwaters (R2 Resource Consultants Inc., 2002). Daily  
23 temperature data were collected between May 2 and October 10, 2001 for two  
24 sampling locations in the mainstem of Reach 5C and one sampling location in  
25 the Reach 5D backwaters.

26 These data indicated that backwater temperatures are two to three degrees  
27 warmer than Reach 5C temperatures during the summer, with no consistent  
28 differences during cooler periods. The linear relationship shown in Figure 3-FB-6  
29 was applied to temperatures greater than 10 °C; backwater temperatures were  
30 assumed to be equal to Reach 5D temperatures during the winter season.



1  
2 **Figure 3-FB-6 Temperature Deviations Between Main Channel Housatonic**  
3 **River and Large Backwater Areas (Reach 5D)**

4 Thermal stratification in the Reach 5D backwaters was not considered in the  
5 conceptual model. The depth of the backwater areas (typically, a few feet or  
6 less) is not sufficient to result in stratification over a vertical spatial scale relevant  
7 to fish bioaccumulation.

8 **Reference:**

9 R2 Resource Consultants, Inc. 2002. *Evaluation of Largemouth Bass Habitat,*  
10 *Population Structure, and Reproduction in the Upper Housatonic River, MA.*  
11 July 23, 2002.

12 The discussion of water temperature suggests that the water column throughout the study area is  
13 always well mixed. If this is the case this should be stated. If not the case, how will the water  
14 temperature near-bottom in Woods Pond be specified for bioaccumulation purposes?

15 **RESPONSE 3-FB-7:**

16 The Reviewer is correct that the water column was assumed to be well-mixed  
17 within each modeled reach. Therefore, the HSPF linkage was used to represent  
18 the temperature relevant to Woods Pond biota within FCM.

19 Woods Pond contains an area that is up to 16 feet deep, but the majority of the  
20 pond is 1- to 3-feet deep. The shallow banks of the pond provide extensive  
21 cover, including submerged macrophytes and woody debris, characteristics that  
22 make the habitat suitable for many resident fish species, particularly largemouth  
23 bass. As a result, the vast majority of fish habitat within Woods Pond consists of

## Model Calibration Responsiveness Summary

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1 water depths over which vertical temperature stratification would not occur over a  
2 spatial scale relevant to fish bioaccumulation.

3 Although small vertical differences in water temperature likely occur in all study  
4 reaches, these differences are not sufficiently large to warrant quantitative  
5 representation in the model. The uncertainties in the temperature-dependent  
6 respiration equations within FCM are larger than the uncertainties in the  
7 temperature inputs to the model.

8 The discussion of HSPF also provides no indication of how the model calculates instream  
9 sediment transport. The majority of the streams entering the study area appear to be treated as  
10 simply conduits for the transport of sediment supplied by surface water drainage across sections  
11 of the watershed. Is this so? This has implications with regard to the amount of sediment  
12 delivered, its quality and the timing of delivery.

### 13 **RESPONSE 3-FB-8:**

14 In HSPF, sediment transport calculations are performed in each of the 65 HSPF  
15 stream reaches shown in Figure 2-6 of the Model Calibration Report, and listed in  
16 Table A.3-6 of Appendix A. Only 16 of these stream reaches are on the  
17 mainstem of the Housatonic River within the PSA. Thus, all the streams feeding  
18 the PSA as upstream boundary conditions and local tributaries are modeled with  
19 the SEDTRN module of HSPF, and therefore, are not simply conduits for the  
20 land-derived TSS loadings. Scour, deposition, and transport are represented in  
21 each of the stream reaches within the watershed model, although not at the level  
22 of detail as in EFDC.

23 Model Calibration Report Sections 2.5.1 and A.5.2.1.2 provide brief overviews of  
24 the solids simulation capabilities within HSPF and discuss the solids  
25 parameterization and calibration process. In response to the Reviewer's  
26 comment, there is additional discussion available that provides details on the  
27 instream solids transport formulations. This information is available in a recent  
28 technical paper by Donigian and Love (2003) and the HSPF User's Manual,  
29 available for download from EPA ([www.epa.gov/waterscience/basins/bsnsdocs.html](http://www.epa.gov/waterscience/basins/bsnsdocs.html))  
30 and USGS ([http://water.usgs.gov/software/code/surface\\_water/hspf/doc/hspfhelp.zip](http://water.usgs.gov/software/code/surface_water/hspf/doc/hspfhelp.zip)).

### 31 **Reference:**

32 Donigian, A.S., Jr. and J.T. Love. 2003. Sediment calibration procedures and  
33 guidelines for watershed modeling. Water Environment Federation TMDL  
34 2003 Specialty Conference, November 16-19, 2003, Chicago, IL. WEF  
35 Specialty Conference Proceedings on CD-ROM (available at  
36 [www.aquaterra.com/publications](http://www.aquaterra.com/publications)).

37 Moving next to EFDC beginning with the hydrodynamic model. Here I'm completely at a loss to  
38 explain why so much emphasis is placed on stage/discharge relationship and so little on the  
39 associated velocity field.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-FB-9:**

2           Comparisons between simulated and measured stage and flow were developed  
3           using data collected within the 14-month calibration period. The emphasis  
4           placed on these data perceived by the Reviewer reflects the quantity of stage  
5           data collected during this time period. Compared to stage readings, fewer  
6           velocity measurements were made. The velocity data were used in model-data  
7           comparisons presented in the Model Calibration Report (see Section B.2.3.2.5).

8           The few direct current data presented in the report indicate that the model does a relatively poor  
9           job of specifying velocity despite its ability to define water level elevations. Review of the data  
10          presented indicated that this is most likely the result of two factors; the timing or phase of the  
11          stage along the study reach and/or the spatial segmentation used in the model.

12          **RESPONSE 3-FB-10:**

13          Comparisons between simulated and measured velocities (including velocities  
14          measured using the Acoustic Doppler Current Profiler (ADCP) were presented in  
15          Section B.2.3.2.5 of the Model Calibration Report. Because the velocity data  
16          were not collected within the 14-month calibration period, separate model  
17          simulations were conducted to develop these model-data comparisons. As  
18          described in Section B.2.3.2.5, the flow conditions at the time of the  
19          measurements were assigned in the model input, thus, the comparisons are not  
20          affected by timing or phase factors. The velocity data were obtained at Holmes  
21          Road, New Lenox Road, and Woods Pond Footbridge. The agreement between  
22          the model results and the data are directly related to the model representation of  
23          the constriction resulting from the bridge abutments. In the case of New Lenox  
24          Road, the distance between bridge abutments is reproduced well by the model  
25          grid and the agreement between the simulated and measured velocities is good.  
26          In the case of Woods Pond Footbridge, the constriction between the bridge  
27          abutments is, effectively, a sub-grid-scale effect that is not accounted for by the  
28          model grid. This is the cause of the underprediction of the velocities at that  
29          location.

30          The issues of phase shifts in model-data comparisons of stage and flow, and  
31          comparisons between simulated and measured velocities received careful  
32          attention as part of the hydrodynamic model calibration effort. The discussion of  
33          the hydrodynamic model performance, presented in the Model Calibration  
34          Report, Appendix B, Section B.2.3.2, addresses the issues of comparisons  
35          between simulated and measured flow and stage on storm-event time scales  
36          (Figures B.2-20 through B.2-29) and longer time scales (Figures B.2-14 through  
37          B.2-18). Comparisons between simulated and measured velocities (Figure B.2-  
38          37) and stage-discharge relationships (Figure B.2-19) are discussed.  
39          Comparisons of model simulations and observations during two extreme flow  
40          events are also discussed. The overall hydrodynamic calibration, summarized in  
41          the cross-plots of simulated vs. measured flow and stage (Figure B.2-38)

## Model Calibration Responsiveness Summary

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1 supports the assessment that the hydrodynamic model performance is  
2 reasonable.

3 In discussing the model results no mention is made of the fact that while the model does provide  
4 a reasonable simulation of water level magnitudes, the timing of these elevations often differs  
5 substantially from that observed. This produces substantial differences in free-surface slope  
6 affecting both absolute velocity as well as the structure of the boundary layer. Since it is these  
7 characteristics that ultimately go into the calculation of boundary shear stress any error at this  
8 point may have profound effect on subsequent sediment transport calculations.

### 9 **RESPONSE 3-FB-11:**

10 EPA agrees that the agreement between the magnitude of simulated and  
11 measured stage and flow is reasonable. Cross-plots of simulated vs. measured  
12 flow and stage (Figure B.2-38) include differences that result from phase shifts;  
13 however, regressions of simulated vs. measured flow and stage produce  
14 coefficients of determination ( $r^2$ ) of between 0.96 and 0.99, indicating that nearly  
15 all of the variance in the data is explained by the model. In cases where phase  
16 differences were indicated, these were attributed to uncertainty in the timing of  
17 inflows, not transport through the PSA. Calibration efforts have shown that  
18 attempting to substantially affect the timing of the simulated hydrographs for  
19 higher flow conditions did indeed result in simulated stage-discharge  
20 relationships that were inconsistent with observations. Application of the model  
21 to extreme flooding events that occurred outside the calibration period was  
22 performed to provide additional tests of the performance of the hydrodynamic  
23 model. It has been concluded from these calibration efforts that the phase shifts  
24 are related to uncertainty in the timing of flow inputs to the model domain and not  
25 the friction in the system that would affect the free surface slope, velocity, and  
26 the bed shear stresses.

27 Without care in the discussion of these factors this reviewer finds it hard to believe that this  
28 model can accurately simulate sediment/contaminant transport in the study area. This situation is  
29 best corrected by a careful analysis of the current meter data and comparisons with modeled  
30 velocity and a reasoned presentation of the results. If the existing data are not sufficient for this  
31 task an additional field effort should be initiated.

### 32 **RESPONSE 3-FB-12:**

33 EPA believes that adequate velocity data are available to support the modeling  
34 study. A careful analysis was performed of the ADCP data and cross-sectional  
35 velocity profiles; this analysis is presented in Section B.2.3.2.1.

36 In addition to questions regarding the temporal characteristics of the stage along the study area,  
37 the differences between modeled and observed velocities could be simply the result of the  
38 relatively coarse spatial segmentation selected for use in the model. Use of 20m square grids  
39 within the main stem channel results in nearly the entire channel width being covered by a single  
40 cell. This coarse segmentation will not accommodate the lateral variations in flow known to exist

## Model Calibration Responsiveness Summary

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1 in a meandering channel such as that found in many portions of the study area. As a result it's  
2 not surprising that the cell average velocity can differ substantially from values observed at  
3 discrete points across the channel. Examination of channel bathymetry, plan view contours and  
4 the associated sediment distributions indicates that a minimum of three grid cells should be used  
5 across the main stem channel in order to adequately simulate hydrodynamics for use within  
6 subsequent transport estimates.

### 7 **RESPONSE 3-FB-13:**

8 Please refer to the response to General Issue 4.

9 If this results in an unacceptable increase in computation times consideration should be given to  
10 alternatives to batch runs including separating the individual models and developing discrete  
11 runs based on a well defined series of scenarios.

### 12 **RESPONSE 3-FB-14:**

13 Regardless of the number of grid cells used, EPA does not believe that either  
14 approach proposed by the Reviewer is appropriate for the Housatonic River  
15 modeling study. Although the modeling team considered separating the  
16 individual models, this approach was rejected for several reasons. The feedback  
17 at each time step between sediment-transport-induced bathymetric changes and  
18 the hydrodynamic calculations was judged to be a feature that should be  
19 included in the modeling analysis. To retain this feedback, the hydrodynamic  
20 and sediment transport components need to be run together. Experience has  
21 shown that it is much more efficient to calibrate sediment transport and PCB  
22 transport concurrently because the gradient in sorbed PCB concentrations  
23 between the water column and bed sediment imposes an important constraint on  
24 the sediment transport calibration. To evaluate sediment transport effects on  
25 PCB transport, these component models were integrated.

26 Use of steady-state flow conditions to construct a well-defined series of scenarios  
27 that span extended periods of time will reduce run time, but it could also  
28 introduce cumulative errors that are propagated and become significant over the  
29 course of a long-term simulation. There is a tradeoff between accuracy and the  
30 number of discrete steady-state scenarios that can be used, with greater  
31 improvements in simulation time but decreased accuracy as the number of  
32 discrete flows (i.e., flow bins) used to represent the hydrograph is decreased. In  
33 addition, the "feedback" inherent in running a continuous simulation is lost,  
34 similar to that discussed above.

35 The Reviewer's recommendations would also impact the ability to evaluate  
36 variability and uncertainty, which the Reviewers stressed during deliberations.  
37 Use of a series of steady state flow scenarios would produce a reduction in the  
38 variability of results computed by the model. Adopting the recommended  
39 approaches for reducing the computational requirements of EFDC would also  
40 have the effect of increasing uncertainty in the results.

## Model Calibration Responsiveness Summary

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1 The combination of coarse segmentation and questionable hydrodynamics makes it hard to  
2 believe that the model being tested is able to accurately simulate sediment/contaminant transport  
3 in the study area. Adding in the questions raised by Dr. Lick regarding the transport formulations  
4 being used, the interpretation of the empirical data and the vertical segmentation of the sediment  
5 column only adds to this concern.

### 6 **RESPONSE 3-FB-15:**

7 The segmentation used to represent the channel and floodplain of the PSA was  
8 developed based on a balance between computational feasibility and adequate  
9 representation of the physical characteristics of the PSA. The modeling teams  
10 representing EPA and GE both believe that the segmentation resulting in  
11 approximately one grid cell across the river channel is adequate to achieve the  
12 goals of the modeling study. In addition, EPA disagrees with the Reviewer's  
13 characterization of the hydrodynamics as "questionable." Based on the  
14 agreement between simulated and measured hydrodynamic data, EPA believes  
15 that the hydrodynamic calibration is adequate to achieve the goals of the  
16 modeling study.

17 With regard to the questions raised regarding transport formulations, there are a  
18 number of formulations accepted by modelers in common practice representing  
19 transport in riverine systems, with no consensus on which formulation is most  
20 applicable to a particular system. There are five individual processes that,  
21 collectively, comprise the transport formulations:

- 22 ▪ Deposition of non-cohesive solids.
- 23 ▪ Deposition of cohesive solids.
- 24 ▪ Erosion of non-cohesive solids.
- 25 ▪ Resuspension of cohesive solids.
- 26 ▪ Bedload transport of non-cohesive solids.

27 Deposition of non-cohesive solids is described by the formulations in van Rijn  
28 (1984), which are well established and have been used in numerous sediment  
29 transport models.

30 Deposition of cohesive solids is a complicated process that is affected by  
31 variations in, for example, mineralogy, grain size distribution, and suspended  
32 solids concentration. This process can be represented at different levels of  
33 complexity, ranging from constant settling velocity to complex flocculation  
34 models. The settling velocity used in EFDC is a function of the weighted average  
35 of the settling velocities for washload and suspended load. In response to a  
36 recommendation provided during the Calibration Peer Review to use Dr. Lick's  
37 simple flocculation model (Section 4.4 of the Course Notes), EPA's modeling  
38 team implemented this flocculation model within EFDC. Although the model was

## Model Calibration Responsiveness Summary

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1 able to represent the data from Dr. Lick's Couette flocculator, it was not able to  
2 reproduce the Housatonic River data; therefore, the flocculation model will not be  
3 used.

4 The equations used to describe the erosion of non-cohesive solids were  
5 developed by Garcia and Parker (1991) based on comparisons between  
6 simulations and experimental and field observations. Particle sorting and hiding  
7 mechanisms that are responsible for bed armoring for non-uniform sediment  
8 mixtures are included in the formulation.

9 Resuspension of cohesive solids is highly site-specific, and generic equations  
10 similar to those discussed above for erosion of non-cohesive solids are not  
11 available for cohesive solids. The parameterization of resuspension of cohesive  
12 solids used in EFDC was based on analysis of erosion data collected in the  
13 Sedflume experiments on Housatonic River sediment. This analysis was  
14 presented in Attachment B.5 of the Model Calibration Report. The Sedflume  
15 data were also reanalyzed in accordance with the approach and formulations  
16 suggested by Dr. Lick in his review comments; however, the variability in the  
17 Housatonic River data was not explained by those equations and analytical  
18 approach. This analysis is presented in Response 3-WL-9.

19 Non-cohesive bedload transport was described by the modified Engelund-  
20 Hansen formulation, which has been used in other sediment transport models.  
21 The Engelund-Hansen formulation was selected from the formulations available  
22 within EFDC because it had a number of desirable characteristics, including the  
23 ability to represent the effect of variation in sediment grain size within an  
24 individual grid cell, and the parameterization could be assigned from available  
25 site-specific information.

26 EPA believes that the model, as modified in response to the Peer Reviewers'  
27 comments, is able to adequately simulate sediment/contaminant transport in the  
28 study area and will provide a useful tool to evaluate the relative performance of  
29 potential remedial alternatives. Please refer to General Issues 4, 6, and 7 for  
30 additional discussion on these topics.

### 31 **References:**

32 Garcia, M., and G. Parker. 1991. Entrainment of bed sediment into suspension.  
33 *J. Hydraul. Eng.* 117:414-435.

34 van Rijn, L.C. 1984. Sediment transport, Part II. Suspended load transport. *J.*  
35 *Hydraul. Eng.* 110(11):1613-1638.

36 How is it then that the model outputs dealing with TSS are in reasonable agreement with  
37 observations? This brings us back to the matter of the formulation of model boundary conditions  
38 and in particular how the modelers specify the boundary conditions at the confluence. As  
39 discussed above, these are based primarily on empirical data and can be assumed to be  
40 reasonably accurate. Given the short calibration period of 14 months it's likely that this input

## Model Calibration Responsiveness Summary

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1 represents the majority of the sediment moving through the area. The bed representing a small  
2 and generally negligible source. With this possibility, inaccurate specification of shear stress and  
3 the subsequent sediment transport would have little effect on model results be they TSS or  
4 estimates of deposition in low energy areas.

### 5           **RESPONSE 3-FB-16:**

6           EPA disagrees with the Reviewer regarding the significance of the bed as a  
7 source/sink for suspended sediment. As shown in the simulations during major  
8 storm events, e.g., for the May 1999 event (Event 1) (see Figure B.3-46 of the  
9 Model Calibration Report), a significant mass of sediment is resuspended on the  
10 rising limb of the runoff hydrograph and deposited on the falling limb. In this  
11 event, both the erosion and deposition fluxes in Reach 5A were approximately  
12 one-third that of the sediment load at the upstream boundary. Although the  
13 erosion and deposition fluxes were approximately equal in Reach 5A, the  
14 deposition flux in Reach 5C was slightly more than twice that of the erosion flux.  
15 Similar results were seen for Event 9 (Figure B.3-47). Thus, the reasonable  
16 agreement between measured and simulated TSS (especially for Reach 5C)  
17 would not have been achieved if the erosional and depositional processes were  
18 not simulated within an acceptable margin of error.

19 This lead to the uncomfortable postulate that what had been produced by all this work was in fact  
20 little more than a very complicated advection-diffusion model dominated by average cross-  
21 sectional flows and particle settling velocities.

### 22           **RESPONSE 3-FB-17:**

23           As indicated in Response 3-FB-16, EPA disagrees with the Reviewer's  
24 assessment of the model. Considering the resuspension, deposition, and bank  
25 slumping/erosion processes that occur in the PSA, the Reviewer's assessment is  
26 invalid because these sources/sinks of sediment are not negligible, as has been  
27 documented in the Model Calibration Report, during and immediately after runoff  
28 events.

29 To correct this situation several steps are required. First, the postulate might be tested by a test of  
30 the sensitivity of the model to upstream boundary conditions. This was not included in the  
31 present series of sensitivity tests.

### 32           **RESPONSE 3-FB-18:**

33           Evaluations of model sensitivity to upstream boundary conditions were performed  
34 and the results were reported in Section B.4.4 of the Model Calibration Report.  
35 EPA agrees that an evaluation of the response of the model to the reduction of  
36 PCB inputs at the upstream boundary to zero would be a useful demonstration of  
37 model performance and will consider the inclusion of such a simulation in the  
38 Model Validation Report.

## Model Calibration Responsiveness Summary

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1 Next, whatever the sensitivity run suggests, the structure of the velocity field must be better  
2 accommodated in EFDC. This will begin with a decrease in grid size followed by adjustments in  
3 channel friction factors to reduce the time differences between observed and modeled stage.

### 4 **RESPONSE 3-FB-19:**

5 EPA disagrees that the structure of the velocity field needs to be represented in  
6 greater detail to achieve the goals of the modeling study. As discussed in  
7 Response 3-FB-11, minor time differences between observed and modeled flows  
8 do not impact the ability of the model to simulate longer term changes in PCB  
9 concentrations. Please refer also to the response to General Issue 4.

10 With the hydrodynamics under control attention must turn to the sediment transport aspects of  
11 the model. I second all of Dr. Lick's comments with the additional proviso that even the  
12 sedflume results must be applied with care due to the differences in spatial scales affecting the  
13 flow regime in the river versus the flume.

### 14 **RESPONSE 3-FB-20:**

15 Responses to Dr. Lick's comments are provided below. With respect to the  
16 application of Sedflume results, the developers and those who have used the  
17 Sedflume (McNeil et al., 1996; Lick et al., 2005) indicate that differences in the  
18 spatial scales of the flow regime in the river versus the flume are less important  
19 than the bottom shear stress present in each. Erosion experiments involving  
20 similar size particles conducted in large-scale flumes and the Sedflume device  
21 produced similar erosion rates versus bottom shear stress (Roberts et al., 1998),  
22 suggesting that the scale effects are accounted for in the calculation of the  
23 bottom shear stress.

### 24 **References:**

25 McNeil, J., C. Taylor, and W. Lick. 1996. Measurements of erosion of  
26 undisturbed bottom sediments with depth. *J. Hydraulic Engng.* 122:316-324.

27 Lick, W., J. Gailani, C. Jones, E. Hayter, L. Burkhard, and J. McNeil, 2005. The  
28 Transport of Sediments and Contaminants in Surface Waters. Short Course  
29 Notes, University of California, Santa Barbara. January 2005.

30 Roberts, J., R. Jepsen, D. Gotthard, and W. Lick. 1998. Effects of particle size  
31 and bulk density on erosion of quartz particles. *J. Hydraulic Engng.*  
32 124:1261-1267.

33 This is where some additional field data such as bathymetric change and/or radionuclide based  
34 estimates of sedimentation rates come in providing a "weight of evidence" corroboration of the  
35 empirical measurements.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-FB-21:**

2           EPA has collected data to describe bathymetric changes, and both EPA and GE  
3           have collected sediment cores for measurement of radionuclide profiles that have  
4           been used to estimate sedimentation rates. The results of the Phase 2  
5           Calibration will be compared to these data.

6           This is also a subject that would benefit from an increase in calibration period.

7           **RESPONSE 3-FB-22:**

8           Please refer to the response to General Issue 2.

9           The ultimate accuracy of the sediment transport formulations would also benefit from inclusion  
10          of side bank erosion in the model. It appears that it was left from the initial calibration runs  
11          because of time considerations.

12          **RESPONSE 3-FB-23:**

13          Please refer to the response to General Issue 9.

14          If so this is another reason for an increase in the calibration period. I do not advocate using  
15          portions of the verification runs for calibration purposes. Too often, this is self defeating.

16          **RESPONSE 3-FB-24:**

17          Please refer to the response to General Issue 2.

18          In addition to the inclusion of the sidebanks I'd recommend additional discussion of the  
19          dynamics to be applied to the floodplains. At present, they appear to be being treated simply as  
20          sinks. I believe that they also have the potential to serve as sources particularly during immediate  
21          post-storm periods when rainfall-runoff may displace sediments freshly placed on vegetation  
22          and/or the adjoining soil surfaces. Such processes may become increasingly important as  
23          alternative source areas are eliminated.

24          **RESPONSE 3-FB-25:**

25          The conceptual model of the floodplain as a sink for PCBs is based on the data  
26          analyses, including the fraction of PCBs located in the PSA floodplain soil  
27          presented in the RFI Report (BBL and QEA, 2003) and by the spatial pattern of  
28          PCB concentrations in the floodplain, which is consistent with the pattern of  
29          flooding from out-of-bank flow events reported in the final MFD. PCB mass  
30          estimates indicate that approximately 90% of the total mass of PCBs in Rest of  
31          River (Confluence to Long Island Sound) sediment and floodplain soil is located  
32          in the PSA and over 60% of the PCB mass in the PSA is located in floodplain  
33          soil. If substantial amounts of contaminated sediment that had been freshly  
34          deposited on vegetation and/or the adjoining soil surfaces were returned to the

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1 river, the bulk of PCB contamination would be in downstream sediment, rather  
2 than in the floodplain soil.

3 However, under the appropriate conditions, solids can be eroded from the  
4 floodplain during model simulations. The transport equations for non-cohesive  
5 solids in the floodplain are the same as in the river channel. The equations for  
6 the cohesive solids are also the same, with specification of a higher shear stress  
7 for erosion that accounts for the effect of vegetation based on the Universal Soil  
8 Loss Equation (EPA, 1993).

### 9 **References:**

10 BBL (Blasland, Bouck & Lee, Inc.) and QEA (Quantitative Environmental  
11 Analysis, LLC). 2003. *Housatonic River – Rest of River RCRA Facility*  
12 *Investigation Report*. Prepared for General Electric Company, Pittsfield, MA.

13 EPA (U.S. Environmental Protection Agency). 1993. *PRZM-2, A Model for*  
14 *Predicting Pesticide Fate in Crop Root and Unsaturated Soil Zones: Users*  
15 *Manual for Release 2.0*. EPA Office of Research and Development,  
16 EPA/600/R-93/046. March 1993.

17 With the model including the proper range of dynamics and the range of source sink areas a mass  
18 balance calculation must be conducted to insure that numerical artifacts neither produce nor  
19 consume mass. There was no demonstration in the present reports that the models were tested for  
20 mass continuity. This should be considered for both sediment and PCBs.

### 21 **RESPONSE 3-FB-26:**

22 Conservation of mass is a basic model requirement. Tests for mass continuity  
23 have been performed for both PCBs and solids. The mass balance was  
24 performed over the course of the 14-month model calibration period. Solids and  
25 PCB mass were conserved; the differences were approximately 0.006% and  
26 0.003% in solids and PCB mass, respectively, over the course of the simulation.  
27 These small differences are well within what is typically considered to represent  
28 mass conservation, indicating that the numerical techniques within EFDC are  
29 operating properly.

30 An additional factor missing from the sediment/contaminant model is the matter of PCB  
31 volatility. A variety of studies have shown that this factor can result in significant PCB flux (see  
32 Thibodeaux et.al, 2002 - ACS Symposium Series 806:130-149). It is not clear from the  
33 discussion provided why it was neglected in the present models.

### 34 **RESPONSE 3-FB-27:**

35 Please refer to the response to General Issue 5.

# Model Calibration Responsiveness Summary

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## 1 **Douglas Endicott:**

2 Much effort has been devoted to collecting a robust data set for model calibration. However, in  
3 any project of this complexity there are always opportunities for additional data collection to  
4 address important gaps in the dataset. Supplemental data can be critical in terms of strengthening  
5 the model calibration. The adequacy of the models could be strengthened in a number of ways,  
6 each involving the collection of additional data and other information:

### 7 *Partitioning data:*

8 Since the modeling team don't understand what is going on at 15% of the coring locations (many  
9 but not all are very-low organic carbon sediments), it would be appropriate to do some  
10 adsorption experiments using sediments that deviate from the equilibrium partitioning behavior.

## 11 **RESPONSE 3-DE-1:**

12 As discussed in the MFD (Section 7.5), EPA conducted special studies to gain a  
13 better understanding of the behavior of PCBs in sediment with low organic  
14 carbon content. Samples of sediment were collected from Reach 5A. These  
15 samples were examined by light microscopy, and surface coatings were  
16 observed on many of the quartz grains. Subsequently, the samples were  
17 analyzed by Jesse Roberts and Dr. Rich Jepsen at Sandia National Laboratories  
18 using scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy-  
19 dispersive system (EDS) via microprobe. The coatings were observed in almost  
20 every sample and were found to be enriched in carbon and chlorine. Sandia  
21 interpreted these results to indicate that PCBs are present in this coating. EPA  
22 does not believe that additional experiments are necessary to explore this  
23 phenomenon further to achieve the goals of the modeling study. Please refer  
24 also to the response to General Issue 5.

### 25 *Low-flow sediment-water flux:*

26 Methods of measuring bioturbation activity and/or diffusive flux should be investigated and  
27 employed. Deploying benthic chambers is one option.

## 28 **RESPONSE 3-DE-2:**

29 The overall schedule for the modeling study does not allow for planning and  
30 conducting additional field studies, and EPA believes it is in the best interests of  
31 the public to move the Rest of River study forward as expeditiously as possible,  
32 consistent with achieving the goals of the program. In addition, EPA does not  
33 believe that additional studies are necessary to calibrate and validate a model  
34 that will be useful in evaluating remedial alternatives. However, supplemental  
35 analyses of bioturbation activity in the Housatonic River are being conducted that  
36 integrate freshwater bioturbation literature with site-specific observations of  
37 benthic community assemblages. Please refer also to the responses to General  
38 Issues 1 and 6.

## Model Calibration Responsiveness Summary

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1 *Sediment mixing:*

2 Experimental approaches that could be applied in the field should be investigated. At a  
3 minimum, the density of benthic invertebrates (including vertical distribution) could be measured  
4 in sediment core samples as a basis for evaluating mixing depth.

5 **RESPONSE 3-DE-3:**

6 Please see Response 3-DE-2.

7 *Potential PCB sources other than sediment bed and transport across confluence:*

8 Neglecting the WWTP, tributaries, and groundwater as PCB sources in the PSA is not justified  
9 by the available data. The WWTP effluent has apparently not been monitored for PCBs, which I  
10 think may be an unfortunate mistake. Rationale for this offered by EPA (no gradient in water or  
11 sediment near outfall) is not compelling. We have observed PCB concentrations of 20-30 ng/L  
12 routinely in untreated sewage throughout New York and New Jersey. If, for example, the  
13 Pittsfield WWTP effluent were to contain PCBs at 20 ng/L, that would constitute a source of 0.3  
14 kg/yr to the river. That doesn't sound like a lot in comparison to what's flowing across the  
15 confluence currently, but what about after remediation upstream is completed?

16 **RESPONSE 3-DE-4:**

17 EPA did not neglect the WWTP, tributaries, and groundwater as potential  
18 sources of PCBs to the PSA. In addition to the information provided to the Peer  
19 Reviewers as part of the Modeling Framework Design, Model Calibration Report,  
20 and related Rest of River documents, EPA has been working with GE on all  
21 aspects of PCB cleanup associated with the facility and does not believe there  
22 are other known sources of PCBs that must be accounted for in the modeling  
23 study.

24 The lack of any measurable increase in PCB concentrations in either water or  
25 sediment immediately downstream of the Pittsfield WWTP discharge is not the  
26 only basis for the conclusion that the WWTP is not a source of PCBs to the river.  
27 The City of Pittsfield has conducted analyses of sludge samples and final effluent  
28 from the facility. Analysis of these samples was non-detect for PCBs.

29 Similar arguments apply for tributaries and groundwater. EPA defends no groundwater  
30 monitoring by stating that too many measurements would be required to meet modeling accuracy  
31 requirements. Is this a rationale for neglecting the process? I am not sure EPA's QAPP process  
32 recommends "do nothing" in this situation.

33 **RESPONSE 3-DE-5:**

34 EPA did not neglect tributaries and groundwater influx as potential sources of  
35 PCBs to the river. In response to a similar question regarding tributaries raised  
36 by the Reviewer prior to the Peer Review Public Meeting, EPA indicated that it

## Model Calibration Responsiveness Summary

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1 was not necessary to consider potential contaminant contributions from  
2 tributaries because: (1) in its extensive characterization of potential  
3 contamination of residential/commercial properties in the Pittsfield area, MDEP  
4 did not find PCB contamination in the vicinity of the tributaries; (2) no other  
5 known or suspected sources of PCBs occur in the drainage basins of the  
6 tributaries to the PSA; and (3) investigations of surface water, sediment, and  
7 floodplain soil conducted by MDEP, GE, and EPA during the EPA Rest of River  
8 investigation support the conclusion that the tributaries are not a source of PCBs  
9 to the river.

10 In response to a similar previous question from the Reviewer regarding  
11 groundwater influx, EPA indicated that groundwater influx is included in the  
12 model as part of a lumped parameter termed “vertical flux” that combines the  
13 processes of advection and diffusion. In the Conceptual Site Model (Section  
14 4.5.2 of the final Modeling Framework Design), the processes of advection and  
15 diffusion are discussed in some detail, and the lumped processes are concluded  
16 to be “. . . an important factor [for the] spatial distribution of water column PCBs.  
17 It was noted in that response that advective flux is considered to be a calibration  
18 parameter and synoptic bed sediment and water column data were available to  
19 calibrate the flux...”

20 Therefore, sampling of groundwater flux was not necessary because it did not  
21 explicitly need to be parameterized for the model. In addition, sampling of  
22 groundwater flux would have required a program of vast scope to adequately  
23 characterize the substantial variability expected in the hyperheic zone across  
24 space and time throughout the PSA. A Quality Assurance Project Plan (QAPP)  
25 is designed to ensure that data quality objectives (DQOs) for a study are  
26 achieved. Because of the model construct, data sufficient to explicitly  
27 characterize groundwater flux were not identified as a DQO.

### 28 *PCB volatilization:*

29 Neglecting PCB volatilization in EFDC may not be justified. The accuracy of PCB flux  
30 estimates being used to justify the neglect of volatilization as a loss process in the PSA, depend  
31 upon good values of Henrys constant. The best experimental data I am aware of was published  
32 by Holly Bamford (Bamford, Poster and Baker, J. Chem Eng. Data, 2000, 45, 1069-1074). She  
33 measured H<sub>lc</sub>'s over a range of temperatures for numerous congeners, and also generalized the  
34 results into predictions for all of the PCBs. She found that PCB Henrys constants depended more  
35 on the number of ortho-chlorines than on the homolog. If I substitute one of her H<sub>lc</sub> values (a  
36 representative congener at 18 degrees C) for the value used in the RFI, and repeat the  
37 volatilization rate calculation, I get a rate and flux that is about twice as large. I suggest the  
38 modeling team evaluate Bamford's data and consider revising the PCB volatilization flux  
39 calculation accordingly.

### 40 **RESPONSE 3-DE-6:**

41 Please refer to the response to General Issue 5.

## Model Calibration Responsiveness Summary

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1 *Partitioning of PCBs to biotic organic carbon:*

2 This was lost with the departure of AQUATOX. Instead, we get the assumption that suspended  
3 solids (with seasonally-invariant organic carbon content) has the same PCB sorbent capacity as  
4 phytoplankton, periphyton, macrophytes, etc. This is an assumption that should be stated in the  
5 PCB transport and fate model, and justified by data. I am not convinced that POC and  
6 phytoplankton/ periphyton carbon are interchangeable as sorbents for PCBs. I would like to see  
7 the evidence from the PSA that supports this assumption.

8 **RESPONSE 3-DE-7:**

9 Site-specific data support the assumption that periphyton and water column  
10 suspended solids absorb approximately the same proportion of PCBs on an  
11 organic carbon-normalized basis. These media are the most important pools of  
12 organic carbon in the pelagic portion of the bioaccumulation model because they  
13 serve as the base of the food web (i.e., water column invertebrates are assumed  
14 to have a diet consisting of POM). Concentrations of PCBs in macrophytes are  
15 not considered in the linkage between EFDC and FCM because macrophytes do  
16 not comprise an important component of the aquatic food web for invertebrates  
17 and fish. Section 3 of Attachment C.14 of the Model Calibration Report  
18 discusses PCBs in POM data for the PSA as well as available plant/algae data  
19 (summarized in Table 3-DE-7 below).

20 **Table 3-DE-7**

21 **Analysis of PCBs in Suspended Organic Matter and Biological Organic**  
22 **Carbon Pools (mg/kg OC)**  
23

Sample/Analysis	Sample Size	Minimum	Maximum	Central Tendency
PCBs in POM (measured – high volume filter samples)	4*	150	256	211
PCBs in POM (estimated using 3-phase partitioning)	196	16	1,135	117
Periphyton (on macrophytes)	4	186	494	334
Periphyton (on hard substrate)	5	119	781	453
Macrophytes	5	29	77	49.1
Filamentous algae	4	0.4	3.8	1.4

24 \* Duplicates are averaged and counted as a single sample; high flow samples omitted  
25 from analysis.

## Model Calibration Responsiveness Summary

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1 Directly measured PCBs in POM taken from high-volume surface water samples  
2 had a mean tPCB concentration of 211 mg/kg OC. Measured concentrations in  
3 periphyton (on macrophytes) exhibited a central tendency 58% higher. However,  
4 the range of the samples measured (186 to 494 mg/kg OC) is similar to the range  
5 measured in POM (150 to 256 mg/kg OC). Furthermore, periphyton includes live  
6 biological material, including bacteria and various microorganisms. As such, a  
7 small degree of biomagnification from detritus to periphyton is expected.

8 In EFDC, it was not possible to represent differential PCB partitioning in algal and  
9 non-algal suspended solids and other organic carbon pools because the data  
10 required for these refinements were not available. Refinement of the partitioning  
11 formulation to explicitly represent biotic particles would be expected to be of  
12 limited importance in Reaches 5A, 5B, 5C, and 6, where the long term solids and  
13 PCB mass fluxes are mainly controlled by high-flow conditions (during which the  
14 contribution of algal solids is of limited importance). Although sorption to algal  
15 solids may be relatively more important in the backwater areas (Reach 5D), the  
16 degree of sorption to algal carbon does not necessarily warrant the abandonment  
17 of a generic carbon-normalized sorption model. This is consistent with the  
18 decision to pool organic carbon sources within the water column and the  
19 sediment bed that was influenced by Reviewer comments received during the  
20 initial Peer Review of the Model Framework Document (MFD) in 2000. As  
21 currently implemented in EFDC, the different carbon pools are considered in the  
22 representation of PCB partitioning to the extent that the presence of these carbon  
23 pools is reflected in the suspended solids data and water column partitioning  
24 data sets that were analyzed and/or modeled.

25 The 3-phase partitioning approach that was selected for use in EFDC has  
26 previously been used in a number of well-known and widely applied fate and  
27 transport models (e.g., WASP5 and EXAMSII; Ambrose et al., 1993; Burns,  
28 1997). It is also consistent with the partitioning formulation that was originally  
29 described in the MFD. EPA believes that, in the absence of more detailed data  
30 and a model that includes the simulation of algal productivity, use of a more  
31 refined representation of partitioning is not justified.

### 32 **References:**

33 Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. *The Water Quality Analysis*  
34 *Simulation Program, WASP5, Version 5.10, Part A: Model Documentation.*  
35 EPA, Office of Research and Development, Environmental Research  
36 Laboratory, Athens, GA.

37 Burns, L.A. 1997. *Exposure Analysis Modeling System (EXAMS II), User's Guide*  
38 *for Version 2.97.* EPA Research Laboratory, Athens, GA. 133 pp.

## Model Calibration Responsiveness Summary

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1 *Monitoring of flow, solids and PCB concentrations at the boundary condition:*

2 I am concerned that monitoring the flow, solids and PCB boundary condition above the  
3 confluence has not been emphasized enough. This results in unacceptable uncertainty in the  
4 upstream boundary condition. I think EPA and GE should consider adding more continuous  
5 instrumentation along with the pressure transducers, including ADCP and/or transmissometers.  
6 These would improve the flow measurements and allow continuous TSS monitoring, and could  
7 be used to make more robust estimates of the boundary conditions. Boundary conditions will  
8 become increasingly important as river remediation moves forward.

9 **RESPONSE 3-DE-8:**

10 EPA currently conducts continuous in-stream turbidity monitoring, with grab  
11 samples (4-point daily composite) collected for TSS and PCBs twice monthly  
12 upstream and downstream of the area being remediated. Flow is derived from  
13 the USGS Coltsville gage; continual changes in channel configuration due to the  
14 ongoing remediation make in-stream measurements in the remediation area  
15 questionable. In recognition of these changing conditions, EPA has established  
16 an alternative upstream boundary for the model at Newell Street (upstream of all  
17 in-stream remediation) with monitoring for flow, TSS, and PCBs. The new  
18 configuration of the reach of river between the new boundary and the confluence  
19 is represented in the model, which will be used after validation to evaluate future  
20 conditions and remedial alternatives.

21 *Streambank erosion:*

22 It appears that a major component of the interaction between the floodplain and the river occurs  
23 via erosion of the streambank. Active undercutting of sediments deposited on the riverbank is  
24 evident in the upper half of the PSA. This mechanism should be included in the sediment and  
25 contaminant transport model during calibration, not after.

26 **RESPONSE 3-DE-9:**

27 Please refer to the response to General Issue 9.

28 **Marcelo H. Garcia:**

29 Overall, the model does account for all the relevant processes. One exception is stream bank  
30 erosion which is currently not explicitly included and could be a major source of PCB.

31 **RESPONSE 3-MG-1:**

32 Please refer to the response to General Issue 9.

33 While the mathematical model does account for such processes, the computational grid used for  
34 the main river channel is too coarse and prevents the calibrated model from resolving the spatial  
35 scales needed to assess important processes within the channel itself and along its margins.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-MG-2**

2           Please refer to the response to General Issue 4.

3           **Frank Gobas:**

4           With regards to the EFDC model, the model contains several processes controlling the fate of  
5           PCBs. The key processes that are included in the model are sediment-water diffusive exchange,  
6           solids settling & resuspension and flow. There are some key processes that are acknowledged in  
7           the model architecture (Figure 5-1) but which are not fully considered in the application of the  
8           model.

9           For example, degradation in the sediment is not considered in the model. The authors state that  
10          the rate of dechlorination is too small to be significant. They base this conclusion on the lack of a  
11          change in CL:BP ratios between originally discharged and current Aroclor 1260 in Reach 5A.  
12          However, this ratio does decrease in the lower portion of Reach 5A (Figure 5.15), hence  
13          suggesting dechlorination.

14          **RESPONSE 3-FG-1:**

15          Degradation of sediment has been observed in Woods Pond (Bedard and May,  
16          1996); however, the magnitude of dechlorination was determined to be limited  
17          (Bedard et al., 1997; Wu et al., 1997), and the process was justifiably excluded  
18          from quantitative consideration in the modeling study (BBL and QEA, 2003).

19          Figure 5-15 depicts (at most) a very weak trend of declining Cl:BP ratios across  
20          the PSA. The decision to exclude dechlorination from the model was based on  
21          multiple lines of evidence, including more rigorous assessments than those  
22          depicted in Figure 5-15. For example, EPA conducted an extensive analysis of  
23          PCB congener composition (Attachment C.18 of the Model Calibration Report) to  
24          evaluate the degree of compositional change that occurs across sample type and  
25          river reach. Overall, the congener evaluation indicated that although some  
26          differences in profiles can be seen, most media exhibit congener profiles similar  
27          to Aroclor 1260 across all reaches. The degree of dechlorination of Housatonic  
28          River PCB mixtures was not large, especially in comparison to PCB sites with  
29          lower chlorination levels, such as the Hudson River (Chen et al., 1988). In the  
30          evaluation of congener profiles and specific individual congeners, major pattern  
31          differences across the PSA were not typically observed. The congener  
32          evaluation yielded findings consistent with site-specific assessments of sediment  
33          conducted by BBL and QEA (2003) as well as Bedard and May (1996), Bedard et  
34          al. (1996, 1997), and Bedard and Quensen (1995). Active dechlorination could  
35          not be detected in Woods Pond sediment that was incubated for more than a  
36          year (Bedard et al., 1995). Furthermore, because most of the PCBs in the PSA  
37          were discharged to the river several decades ago, any historic degradation that  
38          has occurred should largely be reflected in the current exposure levels that are  
39          assigned as initial conditions in the model.

## Model Calibration Responsiveness Summary

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1           **References:**

- 2           Bedard, D.L., L.A. Smullen, K.A. DeWeerd, D.K. Dietrich, G.M. Frame, R.J. May,  
3           J.M. Principe, T.O. Rouse, W.A. Fessler, and J.S. Nicholson. 1995. Chemical  
4           activation of microbially mediated PCB dechlorination: a field study.  
5           *Organohalogen Compounds* 24:23-28.
- 6           Bedard, D.L. and J.F. Quensen III. 1995. Microbial Reduction Dechlorination of  
7           Polychlorinated Biphenyls. Chapter 4. In L.Y. Young (Ed.), *Microbial*  
8           *Transformation and Degradation of Toxic Organic Chemicals*. Wiley-Liss. pp.  
9           127-216.
- 10          Bedard, D.J. and R.J. May. 1996. Characterization of the polychlorinated  
11          biphenyls in the sediments of Woods Pond: Evidence for microbial  
12          dechlorination of Aroclor 1260 in situ. *Environ. Sci. Technol.* 30(1):237-245.
- 13          Bedard, D.L., S.C. Bunnell, and L.A. Smullen. 1996. Stimulation of microbial  
14          para-dechlorination of polychlorinated biphenyls that have persisted in  
15          Housatonic River sediment for decades. *Environ. Sci. Technol.* 30:687-694.
- 16          Bedard, D.L., H.M. Van Dort, R.J. May, and L.A. Smullen. 1997. Enrichment of  
17          microorganisms that sequentially meta, para-dechlorinate the residue of  
18          Aroclor 1260 in Housatonic River sediment. *Environ. Sci. Technol.* 31:3308-  
19          3313.
- 20          Chen, M., C.S. Hong, B. Bush, and G.-Y. Rhee. 1988. Anaerobic biodegradation  
21          of polychlorinated biphenyls by bacteria from Hudson River sediments.  
22          *Ecotoxicology and Environmental Safety* 16:95-105.
- 23          Wu, Q., D.L. Bedard, and J. Wiegel. 1997. Temperature determines the pattern  
24          of anaerobic microbial dechlorination of Aroclor 1260 primed by 2,3,4,6-  
25          tetrachlorobiphenyl in Woods Pond sediment. *Applied and Environmental*  
26          *Microbiology* 63(12):4818-4825.

27          To shed more light on this issue it is beneficial to explore changes in PCB composition over time  
28          on a congener specific basis. Although dechlorination may be a slow process, it can have a  
29          significant effect on the overall fate of PCBs in the Housatonic River if other loss rates of PCBs  
30          from the River are also slow. The latter appears to be case since net loss of PCBs from the 5A to  
31          6 reaches is very small when expressed as a fraction of the mass of PCBs present in the River.  
32          This means that the river's response time to changes in PCB loadings is very long, i.e. it takes a  
33          long time for sediment concentrations to respond to a new loading regime. In slowly responding  
34          systems, slow processes can have an impact on the overall response time of the PCB  
35          concentration in the system and even be rate limiting. In that light I recommend that the authors  
36          include the degradation rates of PCBs in the model, preferably on a congener specific basis.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-FG-2:**

2           Please see Response 3-FG-1, above. The importance of simulating individual  
3           PCB congeners is greatest when the congener composition of the mixture  
4           changes significantly as a result of either PCB degradation (i.e., dechlorination,  
5           metabolism, or breakdown) or PCB transformation (i.e., selective enrichment or  
6           depletion of congeners governed by environmental partitioning). To this end,  
7           EPA conducted an extensive analysis of PCB congener composition (Attachment  
8           C.18 of the Model Calibration Report) to evaluate the degree of compositional  
9           change that occurs across sample type and river reach.

10           The lack of major pattern differences across the PSA indicates that congener-  
11           specific modeling is less important than for other PCB-contaminated sites.

12           I also recommend that the volatilization of PCBs to the atmosphere is considered in more detail  
13           as it may be a significant loss rate for PCBs in the River. While volatilization from the river may  
14           be small due to small surface area, this surface area is significantly increased during flooding  
15           events when particulate material and water are distributed over large areas of floodplain. When  
16           flooding subsides, these particulate materials will be in contact with air for considerable times  
17           and PCBs may volatilize.

18           **RESPONSE 3-FG-3:**

19           Please refer to the response to General Issue 5.

20           The decay of organic matter in suspended sediments is recognized in Figure 5, but it is not clear  
21           whether it is actually considered in the application of the model. In the Housatonic River, where  
22           PCBs have been associated in sediments for a long time, it is possible that as a result of the  
23           relatively rapid decay of organic matter compared to a slow desorption rate of PCBs to the water,  
24           organic carbon normalized PCB concentrations increase relative to the water concentration,  
25           causing a suspended sediment-water disequilibrium that affects the PCB concentration in the  
26           water available for respiratory uptake in biota. Evidence of this process has been observed in  
27           suspended and bottom sediments in some other system (Environ. Sci. Technol. 37(4): 735-741).

28           **RESPONSE 3-FG-4:**

29           EPA assumes that the Reviewer is referring to Figure 5-1 of the Model  
30           Calibration Report, which shows “decay” as a process relevant to dissolved  
31           contaminant and particulate contaminant. This figure was not intended to  
32           represent the decomposition of particulate organic matter, but instead the decay  
33           of contaminant that is sorbed to particulate organic matter. Modeling the decay  
34           of contaminant is a capability of EFDC, but one that was not applied as described  
35           in Section 5.2.3.3.5.

36           Regarding carbon decay, the EFDC model neither calculates the decay of  
37           organic carbon in suspended sediment nor considers the effects of such decay  
38           on PCB concentrations in water. In the water column, the fraction of organic  
39           carbon ( $f_{oc}$ ) was established based on site measurements. This spatial variation

## Model Calibration Responsiveness Summary

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1 in  $f_{oc}$  was maintained constant in time throughout the calibration. The partition  
2 coefficients derived from site data reflect the in situ condition of Housatonic River  
3 sediment. Thus, any degradation of organic matter that is taking place in the  
4 Housatonic River is inherently reflected in the bulk sediment and pore water data.  
5 EFDC does not model the organic carbon cycle, which would be necessary to  
6 explicitly represent the process referred to by the Reviewer. Instead, EFDC uses  
7 three-phase partitioning of PCBs to calculate the concentrations of PCBs in  
8 water, DOM, and POM. Site-specific data support this simple model of PCB  
9 partitioning, as described in the Model Calibration Report Section 5.2.3.3.1.  
10 Inclusion of a more complex model that would include suspended sediment-  
11 water disequilibria was considered. However, such a model was rejected on the  
12 basis that the simpler three-phase partitioning model matched site-specific data  
13 reasonably well. This is consistent with the decision to pool organic carbon  
14 sources within the water column and the sediment bed that was influenced by  
15 Reviewer comments received during the initial Peer Review of the MFD in 2000.  
16 At that time, several of the Reviewers expressed concerns regarding the overall  
17 complexity of the AQUATOX model (e.g., Dr. Lick, pages 3, 11; Mr. Endicott,  
18 page 3; Dr. Shanahan, pages 4-5, 7). Essentially, the Reviewers felt that the  
19 model was over-specified, with too many parameters and excessive model  
20 uncertainty. A specific review comment (Mr. Endicott) questioned the need for  
21 kinetic models of PCB partitioning to detrital and planktonic organic carbon on  
22 the basis of “seemingly excessive complexity.”

23 Gobas and Maclean (2003) describe some theoretical and empirical grounds for  
24 enrichment of contaminant concentrations in suspended sediment. EPA agrees  
25 that disequilibrium can occur between suspended sediment and the water  
26 column under certain conditions. However, there are several reasons why the  
27 simpler equilibrium model was retained for the PSA:

- 28 ■ The degree of disequilibrium between suspended sediment and water  
29 decreases as the octanol-water partition coefficient increases. Gobas and  
30 Maclean (2003; Figure 2) showed that deviations from chemical equilibrium  
31 occur in several systems (Lake Ontario, Lake Superior, Lake St. Clair, Lake  
32 Erie, Green Bay), particularly for  $\log K_{ow}$  values below 6.0. However, at  $\log$   
33  $K_{ow}$  of approximately 7.0 (i.e., representative of Housatonic River PCBs  
34 dominated by Aroclor 1260), the deviations from chemical equilibria were  
35 much smaller.
  
- 36 ■ The relationships between chemical disequilibrium and  $K_{ow}$  (i.e., fugacity  
37 ratio) were not identical among North American freshwater systems. Fugacity  
38 ratios of high- $K_{ow}$  substances ( $\log K_{ow}$  values above 7.0) were sometimes  
39 above 1.0 and sometimes below 1.0 (Gobas and Maclean, 2003). Therefore,  
40 there is uncertainty associated with a suspended sediment-water  
41 disequilibrium model that must be traded off against the increased level of  
42 mechanistic representation offered by such a model.

## Model Calibration Responsiveness Summary

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- 1           ▪ The magnitude of chemical disequilibrium exhibits an apparent positive  
2 relationship with lake depth. The data “suggest that the deeper lakes i.e.,  
3 Lake Ontario (86 m) and Superior (147 m) exhibit larger sediment-water  
4 disequilibria than the shallower Lakes Erie (19 m), St. Clair (9 m), and Green  
5 Bay (15 m)” (Gobas and Maclean, 2003). Much of the PSA has water depths  
6 typically less than 1 m; therefore, the degree of organic decomposition is  
7 probably low relative to deeper lakes with large surface-to-bottom  
8 decomposition times. Extrapolation from lake environments to the  
9 Housatonic River would have significant uncertainty.
- 10          ▪ Distribution coefficients for hydrophobic contaminants between suspended  
11 sediment and water can be increased as a result of organic carbon  
12 decomposition. However, this process can be compensated by internal  
13 primary production of organic matter. In the shallow reaches of the  
14 Housatonic River, primary production can be significant during warm months.  
15 Accordingly, the organic carbon cycle and budget are complex and would  
16 require significant increases in model complexity (and associated model  
17 uncertainty) to simulate mechanistically.
- 18          ▪ The effect of organic carbon decay is further complicated by the differences in  
19 partitioning to different types of organic carbon (i.e., refractory or labile nature  
20 of the carbon sources).

21 Overall, EPA believes that the uncertainties associated with the incorporation of  
22 organic carbon decomposition (and other aspects of the organic carbon cycle)  
23 are sufficiently large that they outweigh the benefits of increased model  
24 complexity. This conclusion echoes the general sentiments of the Peer Review  
25 Panel following deliberations on the Model Framework Document in 2001. At  
26 that time, substantial concerns were raised over the proposed modeling of  
27 multiple biological carbon types in AQUATOX.

### 28 **Reference:**

29 Gobas, F.A.P.C. and L.G. Maclean. 2003. Sediment-water distribution of organic  
30 contaminants in aquatic ecosystems: The role of organic carbon  
31 mineralization. *Environ. Sci. Technol.* 37(4):735-741.

32 In summary, the model is focused on the description of sediment dynamics and sediment:water  
33 partitioning of PCBs but does not fully explore several other fate controlling processes that,  
34 considering the slow temporal response of the system, may have a significant effect on the  
35 outcome of the model.

### 36 **RESPONSE 3-FG-5:**

37 During the specification of the conceptual model, fate-controlling processes were  
38 considered in detail on a process-by-process basis (please refer to Section 4.4 of  
39 the Modeling Framework Design). Processes such as sediment decay and  
40 biodegradation of congeners were considered and included if there was sufficient

## Model Calibration Responsiveness Summary

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1 evidence that they would have a significant effect on model outcome. Lacking  
2 such evidence, processes were not included.

3 EPA agrees that “slow” processes can become rate-limiting in systems with slow  
4 overall response times. However, the importance of these processes must be  
5 assessed in the context of the model objectives (please refer to the response to  
6 General Issue 1). For the purpose of comparing remedial options, including  
7 natural recovery, fate-controlling processes are included only if they improve the  
8 reliability of model simulations (and the differences among outcomes for remedial  
9 alternatives).

10 Another significant limitation of the EFDC model is its inability to model PCB congeners. The  
11 representation of PCBs with average properties (e.g. Kow) can produce a significant error in the  
12 calculations of PCB concentrations. The modeling of PCBs in terms of total PCBs has merits but  
13 it is not a state of the art modeling methodology. The tPCB modeling becomes a limitation when  
14 the model results of the EFDC model are transferred to the FCM model and used to assess  
15 ecotoxicological effects. With regards to assessing the ecotoxicological effects of PCBs, the  
16 current practice relies on assessing risks of effects based on congener concentrations. I strongly  
17 recommend that the EFDC model conducts congener specific calculations that can take  
18 advantage of available congener specific physical-chemical and biological data.

### 19 **RESPONSE 3-FG-6:**

20 The human health and ecological risk assessments considered congener-specific  
21 toxicity data. There were few relevant studies identified in the scientific literature  
22 that evaluated the toxicity of congeners relative to studies that evaluated tPCBs  
23 and/or Aroclors. Therefore, the emphasis in the risk characterizations was, in  
24 general, on tPCBs, and the interim media protection goals (IMPGs) will also be  
25 based primarily on tPCBs, with some consideration of toxic equivalence (TEQ).

26 Given this focus, the modeling study appropriately emphasizes simulation of the  
27 transport and fate of tPCBs using site-specific values empirically derived for such  
28 parameters as  $K_{ow}$  and BSAF. Such values implicitly integrate the properties of  
29 the congener mixture present at the site.

30 The lack of major differences in congener patterns across the PSA indicates that  
31 congener-specific modeling is less important than for other PCB-contaminated  
32 sites. The ecotoxicological effects of the PCB mixtures can still be assessed  
33 within the model framework by distributing the tPCB mass to individual  
34 congeners at the end of EFDC simulations, as is currently performed in the  
35 EFDC-FCM linkage. Please refer also to the response to General Issue 5 and  
36 Responses 3-FG-1 and 3-FG-2 above.

37 The bioaccumulation model contains the key processes controlling the uptake and elimination of  
38 PCBs in fish and invertebrates. Uptake from water and diet are included along with elimination  
39 to water and other excretion processes and growth dilution. The model also includes a de facto  
40 mechanism for biomagnification, apparently through a resistance factor CR that applies to the

## Model Calibration Responsiveness Summary

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1 gill elimination rate but not to the gill uptake rate. The fact that the resistance does not apply to  
2 both uptake and elimination for this reversible process is not correct in my view. However, this  
3 practice produces a biomagnification effect that is not explicitly included in the model. The  
4 resulting model with the resistance factor can be expected to work well as it appears to do.

### 5 **RESPONSE 3-FG-7:**

6 This issue refers specifically to the use of the parameter  $c_R$  in the  
7 bioaccumulation model. This parameter scales the calculation of the PCB  
8 elimination rate. It was developed in response to the apparently contradictory  
9 observations that (1) laboratory experiments indicate that the exchange of PCBs  
10 across the gill surface is generally rapid, although (2) the rates at which adult  
11 field-collected fish eliminate PCBs are relatively slow. The parameter  $c_R$  was  
12 added to the model to account for the slow elimination rates. It is a simple  
13 multiplier of the computed gill elimination rate and fulfills this function.

14 The process of exchange across the gill is diffusive; therefore, a reduction in the  
15 elimination rate should properly be matched by an equal reduction in uptake.  
16 There is literature available that suggests that the limiting process in PCB uptake  
17 and elimination across the gill is not transfer across the gill, but transfer between  
18 blood and fat. The basis for this is described in the documentation of the Hudson  
19 River bioaccumulation model developed by QEA (QEA, 1999). Furthermore, a  
20 pharmacokinetic model of PCB uptake in fish has been developed (Nichols et al.,  
21 1990, 2004a, 2004b) that explicitly models blood flow to body tissues and  
22 exchange between blood and body tissues. It supports the conclusion that  
23 limited perfusion of fat tissues is the primary mechanism causing reduced  
24 elimination of PCBs in fish.

25 Simulation of the kinetics of transfer between blood and fat would require a  
26 pharmacokinetic model, i.e., one that explicitly models individual body tissues  
27 and the kinetics of exchange between them. FCM does not model the kinetics of  
28 transfer of PCBs among body tissues. Therefore, the parameter  $c_R$  was  
29 introduced as an empirical means of accounting for the observed slow  
30 elimination rates. This parameter affects only elimination, not uptake.  
31 Nonetheless, this has been sufficient for past applications of the model because  
32 uptake across the gill was typically not a significant source of contaminant.  
33 Uptake from food was much more important.

34 To confirm the assumption that contaminant uptake across the gill is a less  
35 important vector for bioaccumulation relative to uptake from food, EPA re-ran the  
36 linked model with the resistance factor  $c_R$  applied to both the gill uptake rate and  
37 the gill elimination rate. In the modified model, gill uptake was calculated as  
38 follows for fish species:

## Model Calibration Responsiveness Summary

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$$GillUptake = K_{ui}c(C_R)$$

1 where:

<i>GillUptake</i>	=	Gill uptake of contaminant µg/g-wet day.
$K_{ui}$	=	Gill uptake rate constant for species i (L/g-wet day).
<i>c</i>	=	Concentration of PCBs dissolved in the water (µg/L), where “dissolved” is defined to mean truly dissolved or bioavailable concentration.
$C_R$	=	Resistance factor accounting for PCBs in deep storage compartments (unitless).

2 The results are shown in Figure 3-FG-7, which is comparable to Figure 6-6 of the  
3 Model Calibration Report. The differences between Figure 3-FG-7 and Figure 6-6  
4 are minor. Therefore, the approximation of the biphasic elimination process in the  
5 FCM kinetics is not appreciably affected by the inclusion or exclusion of the  
6 resistance factor in the model’s uptake kinetics.

### 7 **References:**

8 Nichols, J.W., J.M. McKim, M.E. Andersen, M.L. Gargas, H.J. Clewell III, and  
9 R.J. Erickson. 1990. A physiologically based toxicokinetic model for the  
10 uptake and disposition of waterborne organic chemicals in fish. *Toxicology and*  
11 *Applied Pharmacology* 106:433-447.

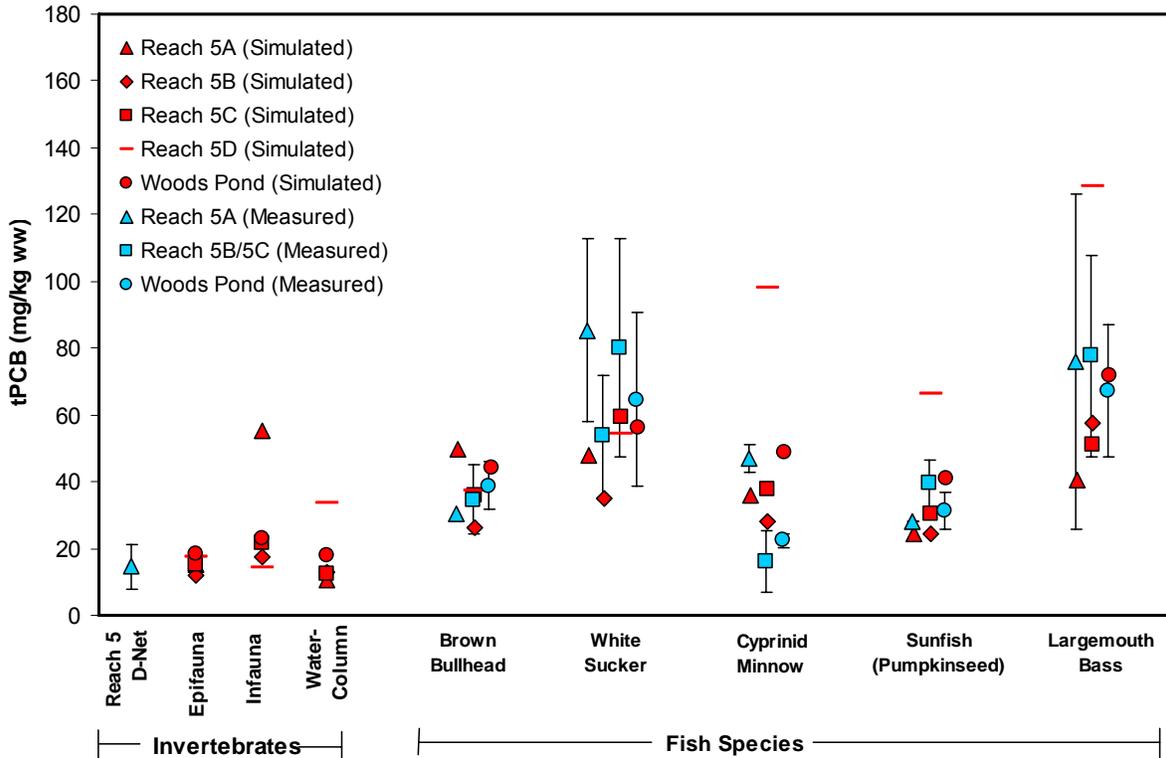
12 Nichols, J.W., P.N. Fitzsimmons, F.W. Whiteman, T.D. Dawson, L. Babeu, and J.  
13 Juenemann. 2004a. A physiologically based toxicokinetic model for dietary  
14 uptake of hydrophobic organic compounds by fish. I. Feeding studies with  
15 2,2',5,5'-tetrachlorobiphenyl. *J. Toxicological Sciences* 77:206-218.

16 Nichols, J.W., P.N. Fitzsimmons, and F.W. Whiteman. 2004b. A physiologically  
17 based toxicokinetic model for dietary uptake of hydrophobic organic  
18 compounds by fish. II. Simulation of chronic exposure scenarios. *J.*  
19 *Toxicological Sciences* 77:209-229.

20 QEA (Quantitative Environmental Analysis, LLC). 1999. *PCBs in the Upper*  
21 *Hudson River. Volume 2 - A Model of PCB Fate, Transport, and*  
22 *Bioaccumulation*. Report prepared for the General Electric Company, Albany,  
23 NY. Amended July 1999. URL:

24 [http://www.ge.com/files/usa/en/commitment/ehs/hudson/Volume\\_2.pdf](http://www.ge.com/files/usa/en/commitment/ehs/hudson/Volume_2.pdf)

# Model Calibration Responsiveness Summary



Notes: Simulated values represent FCM model simulations corresponding to the average age of all fish observed in the field (ages rounded to nearest whole number).

Measured values represent mean concentrations of tPCB ( $\pm 2$  standard errors), for all fish within each combination of organism type and river reach.

**Figure 3-FG-7 Simulated Versus Measured PCB Concentrations in Housatonic River Food Web Using Linked Model and Applying Resistance Factor to Both Gill Uptake and Elimination Rates**

There are some processes that could be included such as egg and sperm deposition for spawning fish. However, I do not recommend this. The model is calibrated to quite a significant extent and adding further parameters that are included in the calibration recipe makes the model less transparent while any improvements in predictability are unlikely to be significant.

## RESPONSE 3-FG-8:

EPA agrees that egg and sperm deposition for spawning fish should not be included in the model. Although maternal transfer of PCBs to eggs has been documented, there are inadequate site-specific data to assess the performance of a model that includes mechanistic representation of these processes.

## Model Calibration Responsiveness Summary

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1 As described in Response 2-EA-1, EPA does not agree that FCM has been  
2 calibrated “to quite a significant extent.” However, EPA agrees that addition of  
3 further parameters/processes that are difficult to validate would increase the  
4 complexity of the model without improving the predictive value of the model.

5 A gap, perhaps in the reporting only, concerns the model for accumulation in aquatic  
6 macrophytes and algae. A simple lipid-water type partitioning model is unlikely to be successful  
7 in describing the bioaccumulation of PCBs in algae & macrophytes. Adding this component to  
8 the model may not have a big effect on the model outcome given the apparently strong linkage of  
9 the food-web to the sediment. However, it is important to ensure that the reporting of the  
10 modeling approach is complete.

### 11 **RESPONSE 3-FG-9:**

12 As applied to the Housatonic River, FCM does not explicitly represent uptake in  
13 algae or macrophytes. The base of the food web is defined to consist of  
14 particulate organic matter in the water column and organic matter in the sediment  
15 bed. Although organic matter in each of these compartments is composed of a  
16 variety of organic carbon types, the model does not explicitly differentiate among  
17 carbon sources (i.e., living biological material versus detritus, or refractory versus  
18 labile carbon sources).

19 The decision to pool organic carbon sources within the water column and the  
20 sediment bed was influenced by Reviewer comments received during the initial  
21 Peer Review of the Model Framework Document (MFD) in 2000. At that time,  
22 several of the Reviewers expressed concerns regarding the overall complexity of  
23 the AQUATOX model (e.g., Dr. Lick, pages 3, 11; Mr. Endicott, page 3; Dr.  
24 Shanahan, pages 4-5, 7). Essentially, the Reviewers felt that the model was  
25 over-specified, with too many parameters and excessive model uncertainty. A  
26 specific review comment (Mr. Endicott) questioned the need for kinetic models of  
27 PCB partitioning to detrital and planktonic organic carbon on the basis of  
28 “seemingly excessive complexity.” The level of complexity that was included in  
29 AQUATOX was subsequently reduced through the use of the FCM  
30 bioaccumulation model.

31 The resulting assumption implicit in FCM is that food sources for invertebrates  
32 and fish contain (on average) approximately the same quantity of contaminant  
33 (on an organic carbon-normalized basis) as do suspended sediment and bottom  
34 sediment. Response 3-DE-7 indicates that periphyton and particulate organic  
35 matter have similar PCB concentrations. Other media, such as filamentous  
36 algae and macrophytes, appear to have different bioaccumulation potential but  
37 are not important components of the conceptual model food web.

38 While not a process, I question the wisdom of not including some other target species in the  
39 model such as muskrat, waterfowl and raptors. These organisms are susceptible to high  
40 concentrations of PCBs due to bioaccumulation and “dose-response” relationships exist for risk  
41 analysis purposes. This may have been addressed in an earlier bounding exercise.

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE 3-FG-10:**

2           The Ecological Risk Assessment considered eight Assessment Endpoints.  
3           These Assessment Endpoints were selected to represent the spectrum of  
4           susceptible and relevant ecological receptors in the PSA. Waterfowl and raptors  
5           were represented within these Assessment Endpoints; extensive work modeling  
6           exposures and effects for these taxa is presented in the Ecological Risk  
7           Assessment. IMPGs for these ecological receptors can be calculated for the  
8           aquatic components of the diet from contaminant concentrations predicted in the  
9           tissues of taxa that are explicitly modeled in FCM. With regard to muskrat, PCBs  
10          do not transfer appreciably from sediment to the types of aquatic vegetation  
11          preferred by muskrat, and there is no reason to expect that muskrats, or any  
12          other strict herbivore, would be at greater risk than the Assessment Endpoints  
13          (such as piscivorous mammals) that were selected; therefore, herbivorous  
14          mammals were not evaluated. Muskrat were commonly observed in the PSA  
15          during the ecological characterization.

### 16          **Reference:**

17          WESTON (Weston Solutions, Inc.). 2004. *Ecological Risk Assessment of the*  
18          *General Electric (GE)/Housatonic River Site, Rest of River*. Prepared for U.S.  
19          Army Corps of Engineers and U.S. Environmental Protection Agency.

### 20          **Wilbert Lick:**

21          In water quality models, the values for many parameters are commonly determined by  
22          parameterization, i.e., by varying the values of each parameter until the solution, however  
23          defined, fits some observed quantity. There are serious difficulties with this type of procedure.  
24          As a simple example, consider the erosion and deposition of sediments. In this case, a limiting  
25          situation is where there is a local steady-state equilibrium between erosion and deposition.  
26          Denote the erosion rate by  $E$  and the deposition rate by  $pw_sC$ , where  $p$  is the probability of  
27          deposition,  $w_s$  is the settling speed of the particles, and  $C$  is the suspended solids concentration.  
28          Local steady-state equilibrium then implies that

$$29 \qquad \qquad \qquad E = pw_sC \qquad (1)$$

30          Rearranging, one obtains

$$31 \qquad \qquad \qquad C = \frac{E}{pw_s} \qquad (2)$$

32          From this, it is easy to see that a numerical model can “predict” the observed value for  $C$  with an  
33          almost arbitrary value of  $E$ , as long as  $pw_s$  is changed accordingly, i.e., such that  $E/pw_s = C$ . For  
34          example, a particular value of  $C$  can be obtained by high values of erosion and deposition or by  
35          low values of erosion and deposition, as long as they balance to give the observed value of  $C$ .  
36          For a predictive model, the values of  $E$  and  $pw_s$  can not both be determined from calibration of  
37          the model by use of the suspended solids concentration alone.

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE 3-WL-1:**

2           Please refer to the response to General Issue 7.

3           As a practical illustration of this problem, consider the sediment and contaminant transport  
4           modeling in the Fox River (Tracy and Keane, 2000). Two groups independently developed  
5           transport models. Each group calibrated their model based on suspended sediment concentration  
6           measurements. Each group believed that the parameters used in their model were reasonable.

7           However, the results predicted by the two models were quite different, both in the transport of  
8           sediments and of contaminants. As an example, the amount of sediment resuspended at a shear  
9           stress of  $1.5 \text{ N/m}^2$  (a large but not the maximum shear stress in the Fox) was predicted by one  
10          group to be  $11.3 \text{ g/cm}^2$  (on the order of 10 cm) while the other group predicted  $0.1 \text{ g/cm}^2$  (or 0.1  
11          cm), a difference of two orders of magnitude.

12          This difference of course has a direct impact on the choice of remedial action. Small or no  
13          erosion at high shear stresses indicates that contaminants are probably being buried over the long  
14          term and natural recovery is therefore the best choice of action. Large amounts of erosion  
15          indicate that buried contaminants may be uncovered, be resuspended, and hence will contaminate  
16          surface waters; dredging or capping is therefore necessary. The differences in the model  
17          estimates by the two groups make it difficult to decide on the appropriate remedial action.

18          This may seem like a long and tedious introduction, but I want to make the point that models  
19          with many unconstrained parameters and especially models which include processes that are not  
20          described correctly as far as their functional behavior is concerned can lead to non-unique  
21          solutions; these can then lead to the incorrect predictions of long-term behavior.

### 22           **RESPONSE 3-WL-2:**

23          Please refer to the response to General Issue 7.

24          For the long-term prediction of sediment and contaminant fluxes, it is essential that the  
25          functional behavior of the most significant processes be described correctly. In this regard, the  
26          most significant processes are sediment erosion/deposition (including bank erosion and  
27          slumping) and the diffusional flux of contaminants between the bottom sediments and the  
28          overlying water. Erosion/deposition is significant not only because of the contaminants  
29          transported with the sediments, but a major question is whether erosion/deposition during big  
30          events will expose deeply buried contaminated sediments **or** deeply bury surficial contaminated  
31          sediments. Both are possible during big events and will strongly influence the contaminant flux  
32          in the future. Accurately predicting suspended sediment concentrations under present  
33          conditions, although necessary, is not sufficient for an accurate, long-term prediction of  
34          contaminant exposure and transport.

### 35           **RESPONSE 3-WL-3:**

36          Please refer to the response to General Issue 7.

## Model Calibration Responsiveness Summary

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1 As far as the diffusive flux between the sediments and overlying water is concerned, the  
2 magnitude of this flux is obviously important. However, for the long-term prediction, the depth  
3 over which this flux acts is also significant.

### 4 **RESPONSE 3-WL-4:**

5 Please refer to the response to General Issue 8.

6 I will concentrate my comments on the two processes of sediment resuspension/deposition and  
7 sediment-water flux of PCBs.

### 8 **a. Sediment Erosion**

9 The Shaker was developed and used in 1990-94 as a field device to measure the erosion potential  
10 of relatively undisturbed sediments in cores. No other device was available at that time. It was  
11 calibrated against the annular flume. Both the annular flume and Shaker measure net  
12 resuspension, i.e., resuspension of sediments in the presence of deposition. In contrast, Sedflume  
13 measures pure erosion, i.e., erosion of sediments with no deposition. Pure erosion is the quantity  
14 that is used in sediment flux equations and in water quality models.

15 In 1999 (Lick, et al., 1999; also see chapter 3 of class Notes), a comparison of the Shaker and  
16 Sedflume was made and the processes in each (as well as in the annular flume) were carefully  
17 examined. It was determined that, because of experimental artifacts in the annular flume (and  
18 hence inaccurate calibration of the Shaker), the annular flume and Shaker gave qualitatively  
19 correct results but did not give accurate quantitative results. Because of this, the use of the  
20 Shaker is not recommended.

21 However, the use of Sedflume is recommended, primarily to determine erosion rates as a  
22 function of shear stress and as a function of depth in the sediment. As a by-product, a critical  
23 shear stress for erosion as a function of depth is also determined. Sedflume should be used in  
24 conjunction with the Density Profiler (Gotthard, 1997; Roberts et al., 1998), which determines  
25 the bulk density of the sediments (including solids, water, and air) as a function of depth in the  
26 sediment core in a non-destructive manner. This allows the determination of sediment layering  
27 before erosion rates are measured (which is destructive) and allows the determination of erosion  
28 rates as a function of the bulk properties of the sediment in that layer. This has been done  
29 successfully in other places (e.g., the Kalamazoo River, McNeil et al., 2004 and Chapter 3 of  
30 Notes). Unfortunately, this was not done for the Housatonic. Because of this, it is difficult to  
31 differentiate between the effects on erosion rates of shear stress as compared with variable bulk  
32 properties.

### 33 **RESPONSE 3-WL-5:**

34 Please refer to the response to General Issue 7.

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

## Model Calibration Responsiveness Summary

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1 
$$E = 10^{-4} \left( \frac{\tau}{\tau_c} \right)^n \quad (3)$$

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

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

7 
$$E = A(\tau - \tau_c)^n \quad (4)$$

8 where A,  $\tau_c$ , and n are functions of particle diameter but not a function of density. This equation  
9 is shown to be valid for coarse-grained, non-cohesive sediments but **not** for fine-grained,  
10 cohesive sediments.

11 To approximate erosion rates for all size sediments with a single, uniformly valid equation, the  
12 appropriate equation is

13 
$$E = 10^{-4} \left( \frac{\tau - \tau_{cn}}{\tau_c - \tau_{cn}} \right)^n \quad (5)$$

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

15 
$$\tau_{cn} = 0.414 \times 10^3 d \quad (6)$$

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

18 In all the work we've done with Sedflume on the determination of erosion rates as a function of  
19 shear stress (the number of cores is on the order of 100), n in Eq. (5) is typically about 2 or more  
20 (see Lick et al., 2005 and Chapter 3 of Notes). Because of this, I suspect that the parameters  $n =$   
21  $1.59$  and  $n = 0.95$  used in the Housatonic modeling (p. 4 of Attachment B.5) are incorrect.

### 22 **RESPONSE 3-WL-6:**

23 Please refer to the response to General Issue 7.

24 One reason for this may be (especially for  $n = 0.95$ ) that Eq. (4) was used to describe erosion  
25 rates even though the sediments were fine-grained. In our work, when Eq. (4) was used to  
26 describe fine-grained sediments, the n determined by regression was quite low (1.31 in our  
27 experiments), but at the same time it was also shown that Eq. (4) was a poor approximation.  
28 However, Eq. (5) applied to the same data gave an  $n \cong 2$  for all particle sizes, and the agreement  
29 between data and Eq. (5) was very good.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 3-WL-7:**

2           Please refer to the response to General Issue 7.

3           Another reason for the low values of  $n$  determined for the Housatonic is that the above equations  
4           are only applicable to sediments which have the same bulk properties. In order to use these  
5           equations properly, sediments with similar bulk properties must be grouped together. Properties  
6           of sediments in a single sediment core generally vary with depth due to consolidation but also  
7           because of layering due to deposition after big events. Because of consolidation with depth,  
8           Sedflume measurements on one core will bias the value of  $n$  since cores at depth will be more  
9           consolidated, more difficult to erode, and will be measured later in the measurement cycle.  
10          Because the Density Profiler can give continuous density profiles as a function of depth with as  
11          little as 1 mm resolution, the use of the Density Profiler is important in determining the sediment  
12          structure and in interpreting sediment properties as a function of this structure.

13          **RESPONSE 3-WL-8:**

14          EPA agrees that the use of the University of California, Santa Barbara (UCSB)  
15          Density Profiler, if it had been applied to the Sedflume cores collected in the  
16          PSA, would have provided detailed bulk density profiles. However, EPA was not  
17          aware of the density profiler, and the USACE and Sandia National Laboratories  
18          contractors that performed the Sedflume analysis did not make this  
19          recommendation to EPA during the planning stages of the Sedflume analyses.  
20          In regard to the grouping of sediment with similar bulk densities for Sedflume  
21          analysis, please refer to the response to General Issue 7.

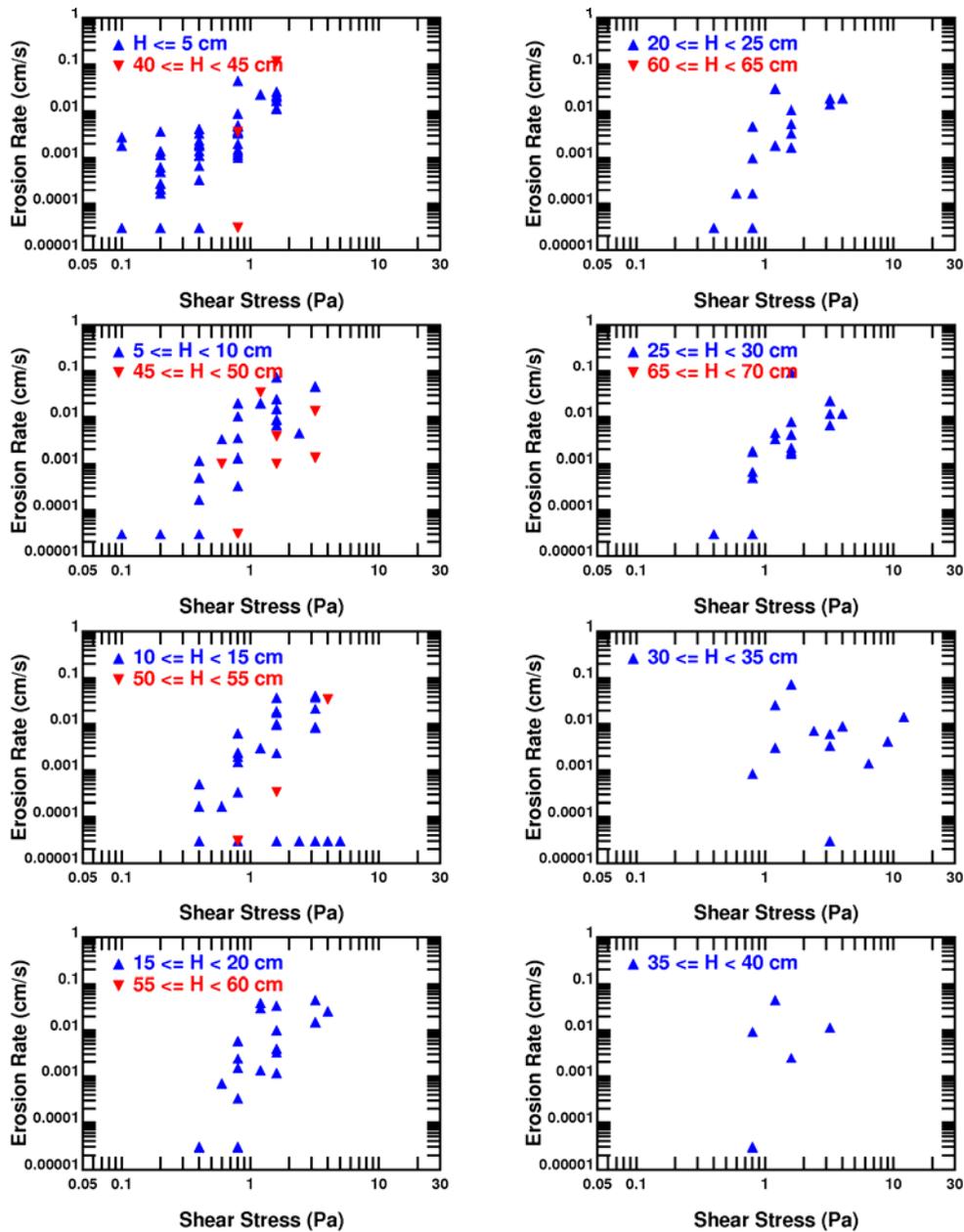
22          A way to group sediments with approximately the same bulk properties is as follows. (1)  
23          Separate sediments into fine, medium, and coarse sizes (this reduces the particle size effect) and  
24          (2) separate sediments by depth in the bottom sediments, e.g., 0 to 5 cm, 5 to 10 cm, 10 to 15 cm,  
25          etc. (the depth is a surrogate for changes in bulk density due to consolidation and hence this  
26          procedure normalizes the effect of density on the erosion rate).

27          **RESPONSE 3-WL-9:**

28          The approach for analyzing the data suggested above was followed, but it does  
29          not result in an improved characterization of the resuspension data. The results  
30          of the analysis are shown in Figures 3-WL-9a, b, and c. Each figure displays the  
31          data for a different particle size ( $D_{50} < 30 \mu\text{m}$ ,  $30 \mu\text{m} \leq D_{50} < 100 \mu\text{m}$ , and  
32           $D_{50} \geq 100 \mu\text{m}$ , respectively) to reduce the particle size effect, and each panel  
33          presents data for different depth intervals (<5 cm, 5–10 cm, 10-15 cm, etc.) in an  
34          effort to account for changes in bulk density. When stratified in this manner,  
35          there is still considerable scatter in the data, an indication that factors other than  
36          particle size and bulk density are affecting the magnitude of the shear stress  
37          needed to resuspend Housatonic River sediment.

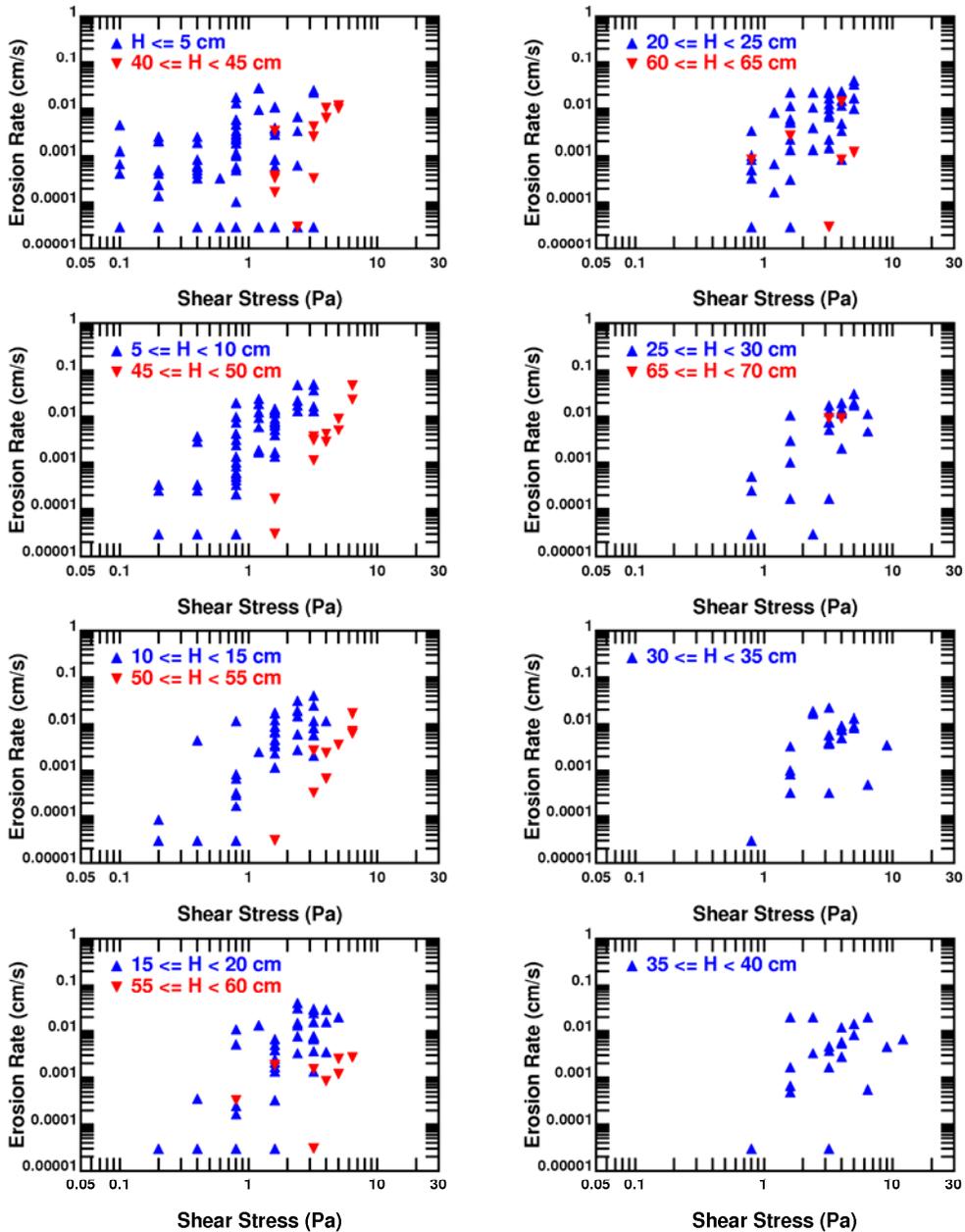
38          The values of  $n$  are crucial for extrapolating to and determining the effects of large storms (large  
39          stresses). The data as shown seemed to have large variability. Eq. (5) is probably a better

# Model Calibration Responsiveness Summary



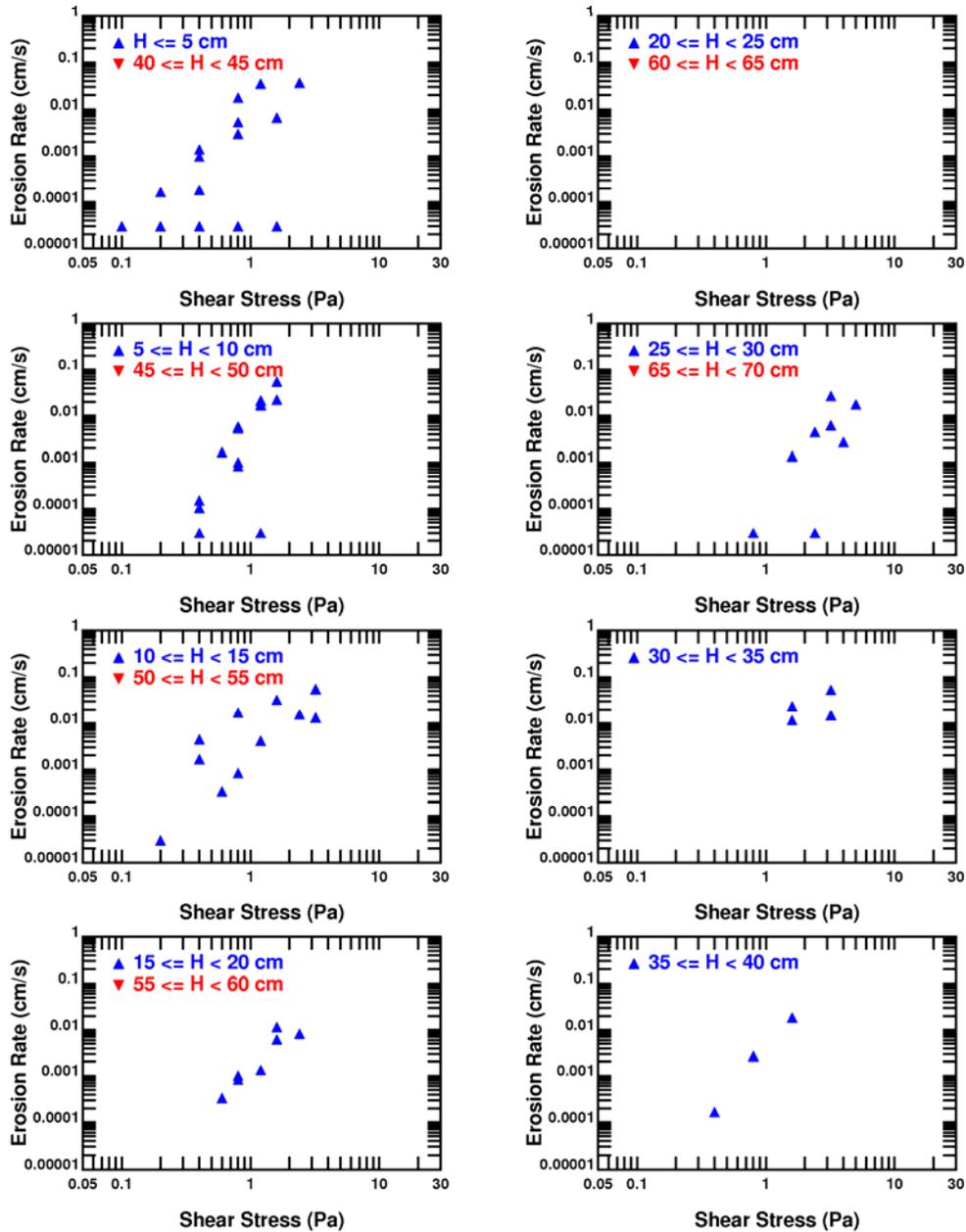
1  
2 **Figure 3-WL-9a Erosion Rate Versus Shear Stress (as a function of depth in core)**  
3 **for Sedflume Experiments on Sediment with Median Particle**  
4 **Diameter ( $D_{50}$ ) Less than  $30 \mu\text{m}$**

# Model Calibration Responsiveness Summary



1  
 2 **Figure 3-WL-9b Erosion Rate Versus Shear Stress (as a function of depth in core)**  
 3 **for Sedflume Experiments on Sediment with Median Particle**  
 4 **Diameter ( $D_{50}$ ) Greater than or Equal to 30  $\mu\text{m}$  and Less than 100**  
 5  **$\mu\text{m}$**

# Model Calibration Responsiveness Summary



1  
 2 **Figure 3-WL-9c Erosion Rate Versus Shear Stress (as a function of depth in core)**  
 3 **for Sedflume Experiments on Sediment with Median Particle**  
 4 **Diameter ( $D_{50}$ ) Greater than or Equal to 100  $\mu$ m**

## Model Calibration Responsiveness Summary

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1 equation to approximate the data and may reduce this variability. In any event, the fact that  
2  $n \cong 2$  or more is a very strong experimental fact and hence must be considered seriously.

3 Whatever was done, Fig. 4-19 on p. 4-35 showing critical shear velocity as a function of grain  
4 size is incorrect. In all measurements that I am aware of (e.g., see Roberts et al., 1998; Lick et  
5 al., 2004, 2005; and Chapter 3 of Notes), the critical shear velocity (or critical shear stress)  
6 increases as grain size decreases beyond a minimum at about 100 to 200  $\mu\text{m}$ .

### 7 **RESPONSE 3-WL-10:**

8 EPA reanalyzed the Sedflume data based on the Reviewer's comments;  
9 however, this reanalysis did not reduce the large variability in the data.  
10 Sensitivity analyses were also performed to evaluate the effect of larger  
11 exponents, but because of bed armoring effects the larger exponents did not  
12 produce the results anticipated by the Reviewer. The erosion of the non-  
13 cohesive fraction of the bed is described by the Garcia and Parker equations,  
14 and therefore, is not sensitive to changes in the value of  $n$ .

15 Bed armoring is an important process and causes large changes in bed shear stresses and hence  
16 large changes in erosion/deposition. This occurs, for example, when a layer of coarse sediments  
17 (as little as a few particle diameters thick) is deposited on a layer of finer, non-cohesive  
18 sediments. As the EPA model is presently configured, any deposited sediments are immediately  
19 mixed with the 6-inch surficial layer. Because of this, effective coarsening takes place very  
20 slowly (a small amount of added sediment has little effect on the average properties of the 6-inch  
21 layer). In reality, this mixing only occurs in a layer a few particle diameters thick, and this thin  
22 layer must be present in the model for realistic coarsening to occur (see SEDZLJ).

### 23 **RESPONSE 3-WL-11:**

24 The thickness of the surface layer used in the EFDC calibration was 7 cm, not 6  
25 inches; however, EPA agrees with the Reviewer that the rate at which armoring  
26 of bed sediments occurs in the simulation is a function of the thickness of the  
27 surficial sediment layer, among other factors. Examination of the changes in bed  
28 sediment grain size distribution during the Phase 1 Calibration indicates that  
29 coarsening is occurring with the current 7-cm surface layer under flow conditions  
30 that would be expected to result in bed armoring. An example of bed coarsening  
31 was shown in Figure B.3-36 of the Model Calibration Report, which indicates that  
32 the process occurs relatively quickly under high-flow conditions.

33 As discussed in the response to General Issue 6, the thickness of the surface, or  
34 the biologically mixed, layer used in EFDC is being re-evaluated with respect to  
35 literature information on biological mixing of sediments in freshwater  
36 environments.

### 37 **b. Flocculation and Deposition**

38 Extensive work has been done on the flocculation of cohesive sediments including a simple  
39 model of time-dependent flocculation and measurements of settling speeds (Lick and Lick, 1988;

## Model Calibration Responsiveness Summary

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1 Burban et al. 1989, 1990; Lick et al., 1993; for a summary, see Chapter 4 of Notes).  
2 Experimental results show quite clearly that the steady-state median diameter of flocs is  
3 inversely proportional to  $CG$  (where  $C$  is sediment concentration and  $G$  is fluid shear) and  
4 inversely proportional to  $C$  when fluid shear is negligible. Since settling speeds are proportional  
5 to the floc diameter, this also demonstrates that settling velocities are also inversely proportional  
6 to  $CG$  and  $C$ . In general, flocculation is time-dependent as well as dependent on  $CG$  and  $C$ .

7 Eq. B.3-34 on p. B.3-31, which is the formula for settling speed used in the modeling, has no  
8 dependence on time or fluid shear and has the incorrect dependence on sediment concentration.  
9 Fig. B.3-33 on p. 31 of B.3 Figures is completely inconsistent with experimental results.

### 10 **RESPONSE 3-WL-12:**

11 EPA notes that the relationships between the various parameters discussed by  
12 the Reviewer are not universally accepted by the scientific community. Indeed,  
13 other researchers have reported experimental results that reflect different  
14 relationships and invalidate the Reviewer's conclusions (Mehta and McAnally,  
15 2002). The relationship between settling velocity and concentration used in the  
16 EFDC model is consistent with these other studies and also with the site-specific  
17 data.

18 The settling function presented in the Model Calibration Report (Eq. B.3-34) is a  
19 simple weighted average of settling velocities for low flow/low concentration  
20 washload and high flow/high concentration large aggregates. The Reviewer is  
21 correct that this formulation does not incorporate terms for time or fluid shear;  
22 however, EPA does not agree that the lack of dependence on time and/or fluid  
23 shear, or the equation used to express dependence on sediment concentration,  
24 is incorrect.

25 Initial calibration efforts were focused on using a settling velocity function for  
26 cohesive solids that depended on the product of concentration and shear stress.  
27 The resulting large longitudinal gradients in simulated depositional patterns were  
28 not consistent with patterns estimated from dated cores. In response to a  
29 recommendation provided during the Calibration Peer Review to use Dr. Lick's  
30 simple flocculation model (Section 4.4 of the Course Notes), EPA's modeling  
31 team implemented this flocculation model within EFDC. Although the model was  
32 able to represent the data from Dr. Lick's Couette flocculator, it was not able to  
33 reproduce the Housatonic River data; therefore, the flocculation model will not be  
34 used.

35 The settling function adopted for the Housatonic River model accounts for both  
36 the variations in floc sizes and settling speeds related to particle sources and  
37 rapid transport during storms, and localized conditions. During low-flow  
38 conditions (see Figure B.4-37 of the Model Calibration Report) a spatially  
39 constant low level of suspended solids was observed, which was modeled as a  
40 "washload" component with a low settling velocity. However, as exhibited during

## Model Calibration Responsiveness Summary

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1 the high-flow event in October 2003, the relative concentrations of water column  
2 solids < 63  $\mu\text{m}$  increased as total suspended solids concentrations increased  
3 (see Figures 4-13 through 4-17 of the MFD). The range of modeled floc settling  
4 speeds established during calibration is very close to the range of estimated  
5 settling speeds from the Phillips and Walling (2005) data.

6 Although the Reviewer does not believe that Figure B.3-33 is consistent with the  
7 experimental results he is familiar with, the relationship of settling velocity  
8 increasing with increasing concentration shown in the figure is consistent with the  
9 experimental data of several other researchers.

### 10 **References:**

11 Mehta, A.J. and W.H. McAnally. 2002. Fine-Grained Sediment Transport,  
12 Chapter 4. In *Sedimentation Engineering*, American Society of Civil Engineers  
13 Manual 54, Volume 2.

14 Phillips, J.M. and D.E. Walling. 2005. Intra-Storm and Seasonal Variations in the  
15 Effective Particle Size Characteristics and Effective Particle Density of Fluvial  
16 Suspended Sediment in the Exe Basin, Devon, United Kingdom. In I.G.  
17 Droppo, G.G. Leppard, S.N. Liss, T. Milligan, editors. *Flocculation in Natural  
18 and Engineered Environmental Systems*. CRC Press, Boca Raton, FL. pp 47-  
19 70.

20 Despite what EPA says in their response to my initial comments, I did not recommend or suggest  
21 a “flocculation formulation based on local instantaneous conditions”. That is EPA’s  
22 misinterpretation. On the other hand, EPA’s model of flocculation and settling speed, since it has  
23 no dependence on time, does depend only on local instantaneous conditions. As EPA states, that  
24 is incorrect.

### 25 **RESPONSE 3-WL-13:**

26 The formulation for settling velocity used in EFDC is not based on a model of  
27 flocculation. Because the EFDC formulation is based on the weighted average of  
28 washload and suspended load, it is appropriately calculated using local  
29 conditions. Testing in EFDC of the flocculation model recommended by the  
30 Reviewer did not reproduce the site-specific data.

31 For the correct determination of the flocculation and settling of cohesive sediments, a simple  
32 model of time-dependent flocculation is necessary and is available (Chapter 4 of Notes). This  
33 model reproduces all of our experimental results on the steady-state floc diameter as a function  
34 of sediment concentration and fluid shear and also the time-to-steady-state behavior as a function  
35 of time, fluid shear, and sediment concentration. Together with experimental results on settling  
36 speeds, this will give a correct and quantitative prediction of flocculation and settling.

37 The flocculation model is quite simple and is simply a single conservation equation for the  
38 average diameter of the flocs (which replaces the conservation equation for cohesive sediments

## Model Calibration Responsiveness Summary

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1 already in the model) with a source term which determines the increase or decrease in the  
2 average size of the floc. The increase in computational time is negligible.

### 3 **RESPONSE 3-WL-14:**

4 Please refer to the response to General Issue 7.

### 5 **c. PCB Flux and Depth of Mixing Layer in River**

6 In the model as described (and in most water quality models), the depth of the mixing layer is  
7 absolutely crucial in the prediction of the long-term behavior of the PCB flux between the  
8 sediments and overlying water. In the absence of sediment resuspension/deposition, the time for  
9 natural recovery is directly proportional to the depth (thickness) of the mixing layer. Increasing  
10 the thickness by a factor of 2 increases the time for recovery by a factor of 2; decreasing the  
11 thickness by a factor of 2 decreases the time for recovery by a factor of 2, etc.

### 12 **RESPONSE 3-WL-15:**

13 EPA agrees that the thickness of the surface sediment layer is potentially an  
14 important parameter in long-term simulations of sediment PCB concentrations.  
15 Please refer also to the response to General Issue 6.

16 In the model, a six inch depth is prescribed. Why? This seems extraordinarily thick. GE says  
17 three inches would be better (thereby halving the time to natural recovery). Is there any  
18 theoretical or rational basis for 6 inches or 3 inches or any number? The depth of the mixing  
19 layer is a crucial parameter that determines the long-term behavior of natural  
20 recovery/remediation (basically it's the answer that you're looking for). Because of this, it  
21 should be a non-calibratable parameter.

### 22 **RESPONSE 3-WL-16:**

23 The question of mixing layer depth can be approached on both a theoretical and  
24 a rational basis. As part of the Phase 2 Calibration, EPA is evaluating  
25 hydrodynamic and biological information, as well as site-specific data, to  
26 constrain the range of plausible depths rather than allowing the value to range  
27 freely during calibration.

28 In fact, as explained below, I don't believe this parameter for this problem can be determined by  
29 calibration. As much as possible, this parameter should be based on scientific evidence and  
30 reasoning. Otherwise, as on the Fox and probably other locations, there will be different  
31 opinions and interminable arguments about the correct value for this parameter.

### 32 **RESPONSE 3-WL-17:**

33 Please refer to the response to General Issue 6.

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1 To introduce some science into this argument, let me briefly review some information about  
2 PCB fluxes and the depth of the mixing layer.

3 The flux of PCBs between the sediments and overlying water occurs primarily due to sediment  
4 resuspension/deposition, molecular diffusion, and bioturbation. Pore-water convection and gas  
5 transport are generally less important but may be significant in some cases.

6 The flux of PCBs due to sediment resuspension/deposition is modeled **as a separate process** by  
7 calculating sediment resuspension/deposition and assuming equilibrium partitioning of the  
8 chemical. This modeling includes changes in sediment thicknesses due to  
9 resuspension/deposition.

### 10 **RESPONSE 3-WL-18:**

11 Please refer to the responses to General Issues 6, 7, and 8.

12 The flux due to molecular diffusion is generally ignored but it can be a significant process in  
13 itself and interacts with and modifies all the other processes. It is always present. Molecular  
14 diffusion of hydrophobic organic chemicals (HOCs) has been and is being investigated fairly  
15 thoroughly (Deane et al., 1999; Lick et al., 2004; Luo, 2005). For HOCs with large  $K_p$ 's, it is  
16 known that (1) rapid changes in chemical concentration profiles are limited to a few millimeters  
17 near the sediment-water interface and (2) the magnitude of the flux is relatively large and  
18 constant for periods of 50 to 500 years and more. The profiles are limited to a few millimeters  
19 near the surface because in this region the diffusion is balanced by non-equilibrium sorption and  
20 only changes slowly with time. This leads to large gradients and hence high fluxes.  
21 Experiments give a mass transfer coefficient ( $h \equiv q/C_o$ ) of approximately  $10^{-5}$  cm/s or 1 cm/d.  
22 This is much higher than would be expected for a non-sorbing chemical. **This number is**  
23 **comparable to the 1.5 cm/d reported by the Housatonic modelers for their overall mass**  
24 **transfer coefficient.**

### 25 **RESPONSE 3-WL-19:**

26 Please refer to the response to General Issue 8.

27 Over time, the diffusion does penetrate into the sediments away from the interface, but at a very  
28 slow rate. As a first approximation, this rate can be shown to be  $h/K_p$ . For a  $K_p = 10^5$   
29 (approximately that for the Housatonic), this rate would be  $10^{-5}/10^5$  or  $10^{-10}$  cm/s =  $10^{-5}$  cm/d =  
30  $4 \times 10^{-3}$  cm/yr = 4 cm/1000 yr. It would take approximately 4000 years to diffuse through the 6  
31 inch layer assumed in the modeling. Even for  $h = 1.5$  cm/d as assumed in the model, it would  
32 take over 2000 years. If  $h = 1.5$  cm/d and the mixing layer is 6 inches thick, this says that  
33 (except for resuspension/deposition) we can ignore natural recovery; it takes far too long.

### 34 **RESPONSE 3-WL-20:**

35 EPA agrees that the time necessary for natural recovery based solely on the rate  
36 of molecular diffusion would be considerable, but notes that molecular diffusion is

## Model Calibration Responsiveness Summary

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1           only one of several processes that determine the rate of natural recovery, the  
2           most important of which are included in the modeling study.

3    A lot of work has been done on bioturbation, but the process is complicated because of many  
4    different organisms acting in different ways. As a result, bioturbation is not well understood  
5    quantitatively.

### 6           **RESPONSE 3-WL-21:**

7           EPA agrees that bioturbation is a complex process that is difficult to quantify.  
8           However, EPA has conducted a detailed literature review of freshwater  
9           bioturbation and evaluated the findings in the context of site-specific biological  
10          data to estimate the degree of biological mixing in the PSA. Please refer to the  
11          response to General Issue 6.

12       An important group of organisms is oligochaetes which burrow in the sediments. Their burrows  
13       generally extend 2 to 4 cm into the sediment; when disturbed, they may go deeper, up to as much  
14       as 10 cm, but only occasionally. They induce a contaminant flux by (1) diffusion of the  
15       chemical into and out of the burrow, (2) transporting fecal material to the sediment-water  
16       interface, and (3) slow mixing of the sediments due to their burrowing activities. Because of  
17       finite sorption rates, these processes are modified by molecular diffusion throughout but  
18       especially at the sediment-water interface, just as when molecular diffusion acts alone. The  
19       overall mass transfer coefficient is greater than that due to molecular diffusion alone by as much  
20       as a factor of 5 to 10, but only for the highest concentrations of oligochaetes as enumerated in the  
21       Great Lakes (EPA, 2004), and generally should be less (probably much less) than that. The  
22       magnitude of the mass transfer coefficient depends on the concentration of the organisms and  
23       decreases as the concentration decreases.

### 24          **RESPONSE 3-WL-22:**

25          EPA agrees that oligochaetes are important freshwater bioturbators and has  
26          considered the literature on these organisms, as well as others. Please refer  
27          also to the response to General Issue 6.

28       For other benthic organisms, the effects of bioturbation on the flux are probably smaller.  
29       Chironomids disturb the sediments to only 1 to 2 cm and the mass transfer coefficient seems to  
30       be smaller than that for oligochaetes. Hyallela cause even a smaller effect.

### 31          **RESPONSE 3-WL-23:**

32          Please refer to the response to General Issue 6.

33       In summary, benthic organisms disturb sediments primarily to a depth of 2 to 4 cm with some  
34       much smaller disturbances to as much as 10 cm. The mass transfer coefficient is on the order of  
35       1 to 10 cm/d depending on the types and concentrations of organisms and is probably closer to 1  
36       than it is to 10.

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1 These numbers are approximate and subject to change, but they are the right order of magnitude.  
2 They suggest that the depth of a well-mixed layer due to molecular diffusion and bioturbation is  
3 on the order of 2 to 4 cm; some lesser disturbances may extend to as much as 10 cm. Sediment  
4 resuspension/deposition probably acts to depths greater than this; but this process is considered  
5 separately and should not be included when considering the depth of the mixing layer.

### 6 **RESPONSE 3-WL-24:**

7 Please refer to the response to General Issue 6.

8 EPA determined the magnitude of the PCB diffusive flux by assuming that, in a reach of the  
9 Housatonic, resuspension and deposition of sediments were negligible and therefore the entire  
10 flux was due to diffusion. This diffusion was reported as  $h = 1.5$  cm/d; however, for PCBs, the  
11 rate of diffusion into sediments is  $h/K_p$ , or less than 0.1 mm/yr. In other words, this rate is  
12 equivalent to resuspension/deposition of about 0.1 mm/yr. Do we really know that  
13 resuspension/deposition is less than 0.1 mm/yr in this reach of the river? I doubt it.

### 14 **RESPONSE 3-WL-25:**

15 Please refer to the responses to General Issues 7 and 8.

16 Therefore, the assumption of  $h = 1.5$  cm/d is questionable; this value is probably too low based  
17 on laboratory experiments. A better approximation is needed, preferably based on laboratory  
18 experiments and field measurements. This is another example where the parameter may be very  
19 difficult or even impossible to determine accurately by calibration.

### 20 **RESPONSE 3-WL-26:**

21 Please refer to the response to General Issue 8.

22 Neither pore-water convection nor gas transport has been shown to be significant in the  
23 Housatonic.

### 24 **RESPONSE 3-WL-27:**

25 The Reviewer is correct that data were not collected that could be used to  
26 describe pore-water convection or gas transport. PCB transport associated with  
27 groundwater influx is included in the model as part of a lumped parameter termed  
28 "vertical flux" that combines the processes of advection and diffusion. In the  
29 Conceptual Site Model (Section 4.5.2 of the Final Modeling Framework Design),  
30 the processes of advection and diffusion are discussed in some detail, and the  
31 lumped processes are concluded to be an important factor for the spatial  
32 distribution of water column PCBs. It is noted that advective flux is considered to  
33 be a calibration parameter, and synoptic bed sediment and water column data  
34 are available to calibrate the flux.

35 As stated above, if erosion/deposition is ignored and the contaminants have a  $K_p = 10^5$ , this  
36 indicates a natural recovery time of approximately 2000 years. On this basis, natural recovery is

## Model Calibration Responsiveness Summary

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1 not an option; it takes too long. This applies throughout the river – bank to bank and from the  
2 confluence to Woods Pond. The entire river needs to be dredged and/or capped. No modeling is  
3 necessary for this conclusion.

### 4 **RESPONSE 3-WL-28:**

5 EPA does not dispute this conclusion based on the assumptions presented by  
6 the Reviewer; however, EPA notes that erosion and deposition are important  
7 processes that should not be, and have not been, ignored.

8 What happens when erosion/deposition is considered? Since the n's in EPA's erosion formulas  
9 are relatively small, I doubt that erosion/deposition will modify these results, even during big  
10 events, i.e., erosion will not penetrate down to the clean base sediments and there will not be  
11 enough erosion and hence subsequent deposition to cover the contaminated sediments by more  
12 than six inches of clean sediments in a reasonable time. These estimates should be checked by  
13 simple transport calculations (a big event and estimates of long-term deposition), but they are  
14 consistent with existing model results; my belief is that, to a first approximation, they are correct  
15 - based on EPA parameters.

### 16 **RESPONSE 3-WL-29:**

17 The Reviewer's concept that erosion through the entire depth of contaminated  
18 sediment is required to reach a supply of clean sediment that would be the only  
19 source contributing to natural attenuation ignores the solids entering the PSA  
20 from the East and West Branches, other tributaries, and runoff from the  
21 contiguous drainage area. PCB contamination extends as deep as 6 feet in  
22 Reaches 5A and 5B, 3 feet in Reach 5C, and 8.5 feet in Reach 6 (as reported in  
23 the Modeling Framework Design); therefore, the clean sediment is located deep  
24 in the sediment bed. Underlying "clean" sediment, in many cases, is a  
25 consolidated silty clay deposit, which is not easily erodable. The redistribution of  
26 contaminated sediment during extreme events will be evaluated and presented in  
27 the Model Validation Report. Additional discussion on the topic of resuspension  
28 and deposition is provided in the response to General Issue 7.

29 If dredging is done, sediments must be dredged down to clean base sediments, bank to bank, and  
30 along the entire river from the confluence to Woods Pond Dam. This follows from the model and  
31 EPA parameters.

32 If capping is done, the cap must be at least the mixing layer thickness plus whatever  
33 consideration of erosion requires.

### 34 **RESPONSE 3-WL-30:**

35 The evaluation of remedial alternatives will be performed in the Corrective  
36 Measures Study (CMS), and must consider a number of factors (beyond the  
37 model results) specified in the RCRA permit.

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1 These conclusions follow from the EPA parameters and simple estimates – no lengthy  
2 calculations are needed. However, I don't really believe these conclusions. They may be correct,  
3 but the proof isn't there. The reasons that these conclusion may not be correct are (1) the  
4 assumed value of 6 inches for the thickness of the mixing layer is much too large and has no  
5 justification

6 **RESPONSE 3-WL-31:**

7 Please refer to the response to General Issue 6.

8 and (2) the assumed values of n lead to low erosion during big events and are inconsistent with  
9 experimental results. Both of these assumptions are inadequate.

10 **RESPONSE 3-WL-32:**

11 Please refer to the response to General Issue 7.

12 The use of only one grid cell across the river just exacerbates the problem.

13 **RESPONSE 3-WL-33:**

14 Please refer to the response to General Issue 4.

15 **d. PCB Flux on the Floodplain**

16 In the calculation of the PCB diffusive flux on the floodplain, since nothing else was said, the  
17 parameters such as depth of mixing layer and PCB mass transfer coefficient are the same as  
18 those in the river.

19 **RESPONSE 3-WL-34:**

20 The Reviewer is correct; the values for bed layering and the mass transfer  
21 coefficient used for the floodplain in the Phase 1 Calibration were the same as  
22 those applied in the river. Diffusive flux on the floodplain occurs only when the  
23 floodplain is inundated.

24 I assume there are minimal benthic organisms on the floodplain (even if present at any time, they  
25 wouldn't survive dry conditions), and therefore the PCB flux should be primarily due to  
26 molecular diffusion. For hydrophobic organic chemicals, such as highly chlorinated PCBs, the  
27 magnitude of molecular diffusion is comparable to but generally less than diffusion by benthic  
28 organisms; however, as described above, molecular diffusion behaves quite differently compared  
29 to bioturbation and certainly does not act over a mixing depth of 6 inches (Deane et al., 1998).

30 **RESPONSE 3-WL-35:**

31 The Reviewer is correct that benthic invertebrates, which are by definition aquatic  
32 organisms, do not inhabit the floodplain. However, as indicated by another  
33 Reviewer during the Peer Review, there are numerous terrestrial invertebrates,

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1 notably earthworms, that rework soils and whose activity would contribute to  
2 mixing of floodplain soil and associated PCBs. These organisms, although  
3 taxonomically different from those found in permanently wetted areas, contribute  
4 significantly to biological mixing of floodplain soil. According to Vrije University  
5 (2005), "one of the processes which may be important with respect to pollutants  
6 in soil is the presence of bioturbators, like earthworms. By mixing the soil,  
7 earthworms affect the distribution of pollutants in the soil and change physical  
8 soil properties, which have an influence on the availability of contaminants."

9 As part of the data collection in support of the Housatonic River Ecological Risk  
10 Assessment, EPA conducted soil invertebrate surveys at three locations in the  
11 floodplain in August 2000 and confirmed that several species of earthworms and  
12 other soil-reworking invertebrates are present in PSA floodplain soil. The  
13 earthworm and soil invertebrate sampling programs are discussed in Appendix A  
14 (Ecological Characterization) of the Ecological Risk Assessment. Please refer  
15 also to the response to General Issue 6.

### 16 **Reference:**

17 Vrije University. 2005. The effects of earthworm bioturbation on metal availability  
18 in river floodplains. Life Sciences – Animal Ecology Department. Faculteit der  
19 Aard – en Levenswetenschappen, Vrije Universiteit, Amsterdam, The  
20 Netherlands. URL:  
21 [http://www.bio.vu.nl/do/Research/natureconservation/Earthworm\\_bioturbation](http://www.bio.vu.nl/do/Research/natureconservation/Earthworm_bioturbation)

### 22 **e. Grid Size and Number of Cells in River**

23 With the present grid, the width of the river is generally approximated as one cell. In most rivers  
24 (and this includes the Housatonic; see cross sections in BBL report), there are large differences  
25 in erosion between the deeper parts and the shallower parts along a cross-section of a river. In  
26 particular, erosion/deposition in the deeper parts is not the same as the erosion/deposition  
27 averaged across the river.

28 Predicting the dissimilar amounts of erosion in the deeper parts and erosion/deposition in the  
29 shallower parts is crucial in predicting the long-term exposure of PCBs by erosion in the bottom  
30 sediments and/or natural recovery by deposition. Averaging across the channel does not describe  
31 the erosion/deposition processes accurately. A minimum of three cells across the river (two  
32 shallow, near-shore cells and one deeper, center cell) should be used.

### 33 **RESPONSE 3-WL-36:**

34 Please refer to the response to General Issue 4.

35 Quite extensive and high quality work has been done on the modeling. However, as described  
36 above, the model has serious deficiencies as far as the descriptions of (a) erosion, especially at  
37 high shear stresses, (b) flocculation and deposition, (c) PCB flux and depth of mixing layer in the  
38 river, and (d) PCB flux and depth of mixing layer on the floodplain. In addition, the spatial scale  
39 of the model in the river is inadequate to even approximately describe the variability of

## Model Calibration Responsiveness Summary

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1 erosion/deposition across the river, and hence any remediation activities in the river. For these  
2 reasons, the model as is does not adequately account for the relevant processes affecting PCB  
3 fate, transport, and bioaccumulation in the Housatonic River. However, because of the extensive  
4 work already done and existing work done elsewhere, the model can be modified so that it can  
5 adequately predict PCB fate, transport, and bioaccumulation (see response to Question 6).

6 **RESPONSE 3-WL-37:**

7 Please refer to the responses to General Issues 4, 6, 7, and 8.

8 **E. John List:**

9 In short, the answer is no. The basic problem is with the specific application of EFDC model to  
10 the sediments in the Housatonic Valley. The difficulty arises in part because the PCB  
11 concentrations within the sediments show an extreme spatial variability. This variability exists  
12 on a very small length scale (see slides Number 3 and 4 of the presentation by Dick McGrath to  
13 the Peer Review Panel on April 13)

14 **RESPONSE 3-JL-1:**

15 Please refer to the response to General Issue 5.

16 and, what is even more important, it seems that this small-scale spatial variability is carried over  
17 essentially uniformly to the large scale, as is evident on Figure 5-26 of the calibration report.  
18 These figures show that PCB concentrations in the top six inches of sediment range almost  
19 uniformly from 0.5 mg/kg to 200 mg/kg (approximately three orders of magnitude) over 11  
20 miles of the river valley.

21 **RESPONSE 3-JL-2:**

22 Please refer to the response to General Issue 5.

23 There is no explanation for this essentially uniform distribution of extreme variability in the  
24 calibration report. When Ed Garland (presumptive leader of the modeling team) was directly  
25 asked for an explanation for this variability at the Peer Review Panel Meeting he responded that  
26 he did not know, and nobody from the EPA consulting team volunteered an explanation, other  
27 than to state it was a commonly observed phenomenon with PCB contaminated sediments.

28 **RESPONSE 3-JL-3:**

29 Please refer to the response to General Issue 5.

30 In the absence of any explanation for why this variability is present it is difficult to believe that  
31 the modeling exercise, which deals only in spatial averages across the entire width of the basic  
32 river channel, can properly represent the fate and transport of the PCB.

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1           **RESPONSE 3-JL-4:**

2           Please refer to the responses to General Issues 1 and 5.

3           The key point here is that there is no reason to believe that this extreme variability in the  
4           sediment concentration of PCB has not existed for many years; for it seems unreasonable to  
5           believe that it is a recent phenomenon. It is also unlikely that it is a mere sampling artifact. In  
6           other words, all of the sediment erosion and deposition since major PCB releases occurred has  
7           not caused the concentration of PCB's to average out, even over relatively short horizontal scales  
8           of a few meters. The importance of this observation is that the EFDC fate and transport model  
9           uses *spatially-averaged* PCB concentration data and therefore cannot possibly hope to reproduce  
10          either the observed current spatial variability or predict any future variability.

11          **RESPONSE 3-JL-5:**

12          Please refer to the responses to General Issues 1 and 5.

13          A long term application of the model is therefore simply going to smooth out the variance in  
14          concentration to produce a uniform concentration distribution; something that has not occurred  
15          naturally, at least so far.

16          **RESPONSE 3-JL-6:**

17          As discussed below (see Response 3-JL-7) and in the responses to General  
18          Issues 1 and 5, EPA does not agree that it is necessary for the model to  
19          reproduce the small-scale spatial variability in sediment PCB concentrations  
20          observed in the data.

21          In some respects, it is somewhat analogous to trying to predict the maximum force on a structure  
22          in a water body using a hydrodynamic model that includes tides but no waves. In this case a  
23          model is being used to project changes in average concentration over a relatively large spatial  
24          element when this large element includes sub-elements that have almost three orders of  
25          magnitude variability in concentration that are "washed out" in the averaging process. Since the  
26          output of the model provides concentration averages there can be no hope of it reproducing the  
27          observed spatial variation. In fact, since it is not known exactly what process sustains the spatial  
28          variability it seems entirely possible that the EFDC model does not even have that transport  
29          process properly represented. It may well be that the spatial variation is a legacy of the manner  
30          in which PCB releases occurred in the past and will not occur in the future; in the absence of any  
31          explanation we simply do not know.

32          **RESPONSE 3-JL-7:**

33          As discussed in several other areas of this Responsiveness Summary, primarily  
34          in the response to General Issue 1, EPA believes that reproduction of small-scale  
35          spatial variability, or variability generally, is not necessary in the model output.  
36          Integration of modeling results over larger spatial and temporal scales is entirely  
37          appropriate because the primary goal of the modeling study is to predict average  
38          tissue concentrations in biotic receptors, primarily fish. The majority of these

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1 receptors integrate exposure concentrations over space and time and therefore,  
2 reflect the average of the contaminant concentrations to which they are exposed.

3 An additional goal is to examine the effectiveness of remedial alternatives, again  
4 on a scale far larger than the grid size used in the model. Therefore,  
5 reproduction of spatial variability has no practical value toward achieving the  
6 goals of the modeling study.

7 Furthermore, EPA does not agree that the analogy posed by the Reviewer is  
8 applicable to the modeling study. Unlike physical structures, which may well be  
9 affected by the maximum hydraulic force rather than the average, biota in the  
10 system act as integrators of the exposure concentrations; therefore, they reflect  
11 the average rather than the maximum.

12 There is no compelling reason to believe that the observed small-scale spatial  
13 variability in PCB concentrations in PSA sediment is the result of the manner in  
14 which PCBs were released from the GE facility. More likely, the variability  
15 reflects the integrated results of several processes that are already incorporated  
16 into the modeling framework, and some that may not be included. Regardless,  
17 because it is not necessary to reproduce the small-scale spatial variability in  
18 contaminant concentrations, it is not necessary for the model to explicitly include  
19 the process or processes that control the variability.

20 It is recognized that if, in the model, “average” particles are entrained by the stream, transported  
21 and dropped at some new location, then it should lead in time to the generation of a sediment and  
22 water column with average concentrations of PCB, which are then input to the FCM model.

### 23 **RESPONSE 3-JL-8:**

24 EPA agrees with the Reviewer’s observation that the model appropriately  
25 evaluates the “average” particles resulting in concentrations of PCBs that are  
26 averages suitable for input to FCM. As discussed in the preceding response  
27 (3-JL-7), this is appropriate because biota integrate spatially and temporally  
28 variable exposure concentrations.

29 So, why not simply use the average concentrations and forget about the variability? The point is  
30 the use of spatially-averaged input data leads to a reduction in the variance of PCB  
31 concentrations that is solely an artifact of the modeling process, something that we have already  
32 seen to occur.

### 33 **RESPONSE 3-JL-9:**

34 Please refer to the response to General Issue 10.

35 On the other hand, the modeling process goes to great lengths to partition the PCB by sediment  
36 size while at the same time ignoring the spatial variability of the erosion/deposition processes  
37 across the river, where in fact there is significant particle size variability. Given the inherent

## Model Calibration Responsiveness Summary

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1 non-linearity of the sediment transport process, it is not at all clear that the approach of taking a  
2 single modeling element across the river is going to lead to the correct results.

### 3 **RESPONSE 3-JL-10:**

4 Please refer to the response to General Issue 4.

5 Regardless of the reason for the PCB spatial concentration variations, this failure of the model to  
6 directly address the spatial variability in PCB concentration, which appears to be uniformly  
7 distributed along the river (see Figure 5-26), is a serious problem. It is highlighted by the fact  
8 that most of the calibration exercises performed for the EFDC model to date simply address the  
9 prediction of *averages* and the comparison of *averages* of field data and *averages* of model  
10 output (e.g., Figure B.4-46).

### 11 **RESPONSE 3-JL-11:**

12 As discussed in numerous responses to specific comments in this section of the  
13 Responsiveness Summary, and in the responses to General Issues 1 and 10,  
14 EPA does not agree that it is necessary for the model to reproduce the spatial  
15 variability in PCB concentrations observed in the data. The model result of  
16 primary interest is contaminant concentrations in biota, which integrate the  
17 variability in exposure concentrations.

18 The ability of a model to predict the *variance* in a distribution can be just as important as  
19 predicting the mean, especially where confidence limits on the predicted result, or the resolution  
20 of comparative remedial hypotheses, are important. There is nowhere (at least nowhere that I  
21 could find) in the PCB fate and transport calibration presentation that addresses the predicted  
22 *variance* in PCB concentration or flux (e.g., Figure 5-24) and calibrates this prediction with field  
23 data. It is implicitly presented in Figure 5-30 for tPCB water concentrations, but there is no  
24 formal comparison that I could find for the PCB fluxes, which are surely a very important part of  
25 the remediation modeling.

### 26 **RESPONSE 3-JL-12:**

27 Please refer to the response to General Issue 10.

28 One PCB transport mechanism that appears to have been neglected is the contribution from  
29 groundwater inflow into the stream. I did not see where the mass flux of PCB to the stream by  
30 this mechanism had been properly quantified. My own experience in measuring groundwater  
31 inflow to streams indicates that this contribution can be quite substantial, and at times can far  
32 surpass any diffusive flux out of the river bed sediments.

### 33 **RESPONSE 3-JL-13:**

34 Due to the hydrophobic behavior of PCBs generally, and particularly of the highly  
35 chlorinated mixture of congeners present at this site, transport of PCBs present  
36 in the sediment bed via groundwater advection is, by itself, a process of minor  
37 importance for the model. In addition, in much of the PSA the glacial Lake

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1           Housatonic deposit, consisting of a fairly tight silty-clay layer observed at depth in  
2           the cores, likely controls the amount of groundwater advection that occurs  
3           directly to the stream channel. As discussed in Response 3-DE-5 above,  
4           groundwater inflow is included in the model as part of a lumped parameter  
5           termed “vertical flux” that combines the processes of advection and diffusion. In  
6           the Conceptual Site Model (Section 4.5.2 of the final Modeling Framework  
7           Design), the processes of advection and diffusion are discussed in some detail,  
8           and the lumped processes are concluded to be “. . . an important factor [for the]  
9           spatial distribution of water column PCBs. It was noted in that response that  
10          advective flux is considered to be a calibration parameter and synoptic bed  
11          sediment and water column data were available to calibrate the flux. . .”

12          Another mechanism for PCB loss that should be included in any analysis of the long term  
13          remediation process is the volatilization of PCB from the river flood plain sediments.  
14          Experience with other chlorinated hydrocarbons (DDT) has shown that the half-life for such  
15          compounds in soils exposed to solar heating can be in the range of 10-12 years.

16           **RESPONSE 3-JL-14:**

17           Please refer to the response to General Issue 5.

## 1 Methodologies for Evaluating Sensitivity and Uncertainty

2 **4. Based on your technical judgment, have adequate methodologies been employed to**  
3 **evaluate the sensitivity of the model to descriptions of the relevant processes, and to**  
4 **evaluate uncertainties of model predictions?**

### 5 **E. Adams:**

6 The analysis of sensitivity and uncertainty has been performed in the context of historical  
7 conditions; it should be repeated for future remedial conditions. That is, the model should be set  
8 up to assess the effectiveness of different remediation measures, and the sensitivity of this  
9 effectiveness to various model parameters assessed. This may lead to quite different  
10 conclusions. In some cases it might also be a lot easier. For example, if dredging is being  
11 considered, it is easy to simulate the effect in the model: the PCBs will simply be removed and  
12 the effectiveness of this remedial option (at least in a relative sense) will be totally insensitive to  
13 most model parameters. (There would be some short term disturbances during the actual  
14 dredging operation, but these would need to be simulated by different models, for which the  
15 current calibration study is irrelevant. Such disturbances are often considered part of an  
16 environmental impact assessment, but have not been mentioned; are they something to be  
17 considered?) Another example is capping which will introduce strong vertical gradients in PCB  
18 concentration within the sediments. Under this option the model may become much more  
19 sensitive to the way in which mixing between sediment layers is represented. Indeed, it may not  
20 be possible to calibrate some parameters based on historical field data (e.g., because the  
21 gradients are insufficient) so recourse must be made to literature values.

### 22 **RESPONSE 4-EA-1:**

23 EPA agrees that the sensitivity of the model to certain parameters may change in  
24 response to potential remedial alternatives and that sensitivity analyses  
25 performed in the context of historical conditions may not be representative of  
26 model sensitivities under future remedial conditions. This possibility will be  
27 considered when the model is used to simulate remediation scenarios.

28 A major difficulty with sensitivity and uncertainty analysis is that the model package is very  
29 expensive to run (owing principally to the long run time of EFDC reflecting, in turn, the small  
30 time step), and this problem will only get worse as the length of the simulation increases (from  
31 14 months to order 20 years). Here I think the consultants could have tried to “think outside the  
32 box” a bit more with respect to the way the hydrodynamics, sediment transport and water quality  
33 were coupled. For example, the hydrodynamics could be run off-line and saved. And perhaps  
34 synthetic hydrologic sequences could be used. Or different grids could be used for the in-bank  
35 versus over-bank flows. QEA/GE made several suggestions along these lines at the Peer Review  
36 Meeting. If there is time, these should be seriously considered as a way to decrease computation  
37 time and allow the modeling team to afford to be able to run additional calculations.

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1           **RESPONSE 4-EA-2:**

2           Please refer to the response to General Issue 3.

3   **W. Frank Bohlen:**

4   The methodologies used to evaluate sensitivity are generally accepted and adequate. Any  
5   deficiencies in the sensitivity analysis have more to do with omission. e.g. a test of the model  
6   sensitivity to upstream boundary conditions, noted above.

7           **RESPONSE 4-FB-1:**

8           The sensitivity analyses performed included upstream boundary inflows, TSS,  
9           and PCBs. These results are discussed in Sections B.2.4, B.3.4, and B.4.4,  
10          respectively, of the Model Calibration Report.

11   **Douglas Endicott:**

12   As mentioned previously, I thought the sensitivity analyses were well done. A couple of  
13   important parameters were omitted from the sensitivity analysis of EFDC, the settling rate and  
14   composition of particle types at the upstream boundary.

15          **RESPONSE 4-DE-1:**

16          The sensitivity analyses performed for EFDC included cohesive class settling  
17          velocity and critical shear stress for cohesive class deposition, and non-cohesive  
18          class particle diameters, which affect non-cohesive class settling velocities.  
19          These results are discussed in Section B.3.4 of the Model Calibration Report.  
20          The composition of particle types at the upstream boundary was not included as  
21          part of the sensitivity analyses, but will be considered as part of the Phase 2  
22          Calibration effort.

23   Significantly, the sensitivity of the EPDC model predictions to the grid resolution was not  
24   included in the report.

25          **RESPONSE 4-DE-2:**

26          Grid resolution was addressed in the final MFD; therefore, it was not reevaluated  
27          as part of the model calibration. Please refer also to the response to General  
28          Issue 4.

29   The modeling team will need to revisit sensitivity at latter stages of the project, when longer-  
30   term simulations are run. At validation stage (for example), surficial sediment bed thickness  
31   should be explored in the sensitivity analysis.

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1           **RESPONSE 4-DE-3:**

2           EPA agrees to revisit the sensitivity of the model predictions to the specification  
3           of the bed layering as part of the longer-term simulations (see Response 4-DE-1  
4           above). EPA recognizes the importance of the specification of bed layer  
5           thickness in longer-term simulations, and plans to include it in the sensitivity  
6           analysis (see Section 7.3.4 of the Model Calibration Report).

7           Formal uncertainty analysis was only conducted on the food chain model. It may be the only one  
8           of the models for which uncertainty analysis can be practically accomplished.

9           **RESPONSE 4-DE-4:**

10          Please refer to the response to General Issue 11.

11          Any analysis of model uncertainty should address propagation of uncertainty between the  
12          models, and include uncertainty in statistical models (rating curves) predicting upstream  
13          boundary conditions, as well as uncertainty in flow measurements.

14          **RESPONSE 4-DE-5:**

15          Please refer to the response to General Issue 11.

16          I do not favor “bounding” analysis (as suggested by GE) as a shortcut to uncertainty. It is too  
17          easily to subjectively manipulate such an approach to produce a desired outcome. Bounding  
18          analysis should be used only if absolutely necessary due to computational constraints.

19          **RESPONSE 4-DE-6:**

20          Please refer to the response to General Issue 11.

21          **Marcelo H. Garcia:**

22          Sensitivity analyses of the PCB transport and fate model seems adequate. However, an  
23          evaluation of PCB fluxes between the river and the floodplain during overbank flow conditions  
24          is needed. Since stream bank erosion was not included in the calibration, it is not possible to  
25          know how sensitive the model predictions will be when such process is included.

26          **RESPONSE 4-MG-1:**

27          Please refer to the response to General Issue 12.

28          The uncertainty analysis has been done only for the Food Chain Model (FCM). An uncertainty  
29          analysis for the rest of the model components should be conducted, included. the uncertainty  
30          once all the models are linked together.

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1           **RESPONSE 4-MG-2:**

2           Please refer to the response to General Issue 11.

3           **Frank Gobas:**

4           The methodologies used for the sensitivity analysis of the HSFP, EFDC and the Bioaccumulation  
5           models were carried out in an appropriate fashion. However, the sensitivity analyses would be  
6           more insightful if it they would focus on the key issues that the model needs to address. For  
7           example, the temporal response of PCB concentrations in water, sediment and biota to  
8           remediation efforts (and associated PCB loading reductions) is a key objective of the model. It  
9           would be helpful if the sensitivity analysis could report on the effect of various model parameters  
10          on the temporal response of the PCB concentrations in the area of concern. This is particularly  
11          important for the model parameters dealing with the sediment mixing (i.e. depth of active  
12          sediment layer, bed sediment mixing, resuspension and sedimentation) which have the largest  
13          effect on the time response of the PCB concentrations. However, it also important for other  
14          model parameters such as flow rates and lipid contents of fish. I therefore recommend that the  
15          sensitivity analysis is further developed. The current analysis provides useful information about  
16          which parameters are the most sensitive. The second phase of the sensitivity analysis can focus  
17          on these parameters and address how they affect key characteristics of the model, such as the  
18          temporal response of PCB concentrations in water, sediment and biota as a result of remediation  
19          options.

20          **RESPONSE 4-FG-1:**

21          The sensitivity of the models to parameters that may have a greater bearing on  
22          model results in long-term simulations is being considered. EPA recognizes that  
23          sensitivity analysis can and should be performed at various stages of model  
24          evaluation, and for this reason, the sensitivity of the model has been investigated  
25          at multiple stages, including Test Reach simulations, preliminary calibration, and  
26          Phase 1 Calibration. During Phase 2 Calibration and Validation, other  
27          parameters, such as depths of biologically mixed sediment, may exhibit greater  
28          sensitivity.

29          The methodology used to conduct the uncertainty analysis contains some significant limitations  
30          throughout the entire modeling effort. There are several issues. First, the basic modeling strategy  
31          relies heavily on model calibration. In model calibration, the observed data are used to  
32          parameterize the model. This produces a model where observed data cannot be used as an  
33          independent data set to test the performance of the model.

34          **RESPONSE 4-FG-2:**

35          EPA disagrees that the model for which formal uncertainty assessment has  
36          already been conducted (FCM) “relies heavily on model calibration.” The general  
37          calibration strategy for FCM is described in Section C.3.2 of the Model  
38          Calibration Report, and emphasized EPA’s reluctance to calibrate parameters in  
39          an unconstrained manner:

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1 “Calibration of the model required small adjustments to model parameters  
2 that were consistent with ranges of plausible values identified during the  
3 parameterization stage. In general, there was a strong preference to  
4 retain the ‘best estimate’ values identified in the parameterization stage.  
5 Although additional refinements of numerous model parameters would  
6 increase the statistical ‘goodness of fit’ of the model, such changes would  
7 not improve the predictive ability of the model (as measured by validation  
8 against independent data) if the changes were not justified based on the  
9 underlying science. Where possible, comprehensive reviews of parameter  
10 values were performed to develop distributions of values; in most cases  
11 the central tendency value was adopted for the calibration, and the  
12 variation and incertitude in the parameter was evaluated in the uncertainty  
13 assessment.”

14 Where calibration (i.e., fine-tuning of initial best estimates) was conducted,  
15 it was documented in the report, such that the quantitative effect of these  
16 modifications could be assessed by Reviewers. Because the model was  
17 not extensively calibrated to duplicate the calibration data, these data  
18 provide a reasonably independent test of model performance.

19 Comparing model predictions against independent data is probably one of the best and simplest  
20 ways to assess the uncertainty of the model. However, this method cannot be used to its fullest  
21 advantage in the model due to the reliance of calibration to make the models work.

### 22 **RESPONSE 4-FG-3:**

23 As described in Response 4-FG-2 (above), calibration was not always required to  
24 make the models work. The FCM uncertainty assessment evaluated the  
25 potential for bias (if any) in the model introduced by the limited calibration of the  
26 initial parameter estimates. Figures 29 through 93 of Attachment C.17 of the  
27 Model Calibration Report indicate that the central tendencies of PCB  
28 concentrations were similar pre- and post-calibration for most species and  
29 reaches.

30 EPA agrees that comparisons against independent data comprise a useful  
31 component of model uncertainty assessment. The FCM validation stage will  
32 include such independent comparisons by applying the model to data collected  
33 outside the calibration period. In addition, application of FCM to areas of the  
34 river downstream of the PSA will also assist in the model validation. Please refer  
35 also to the responses to General Issues 2 and 11.

36 Even without access to independent data (e.g. PCB concentration data in sediments and biota),  
37 there is still considerable merit to using differences between observed and simulated data as a  
38 measure of model uncertainty. I recommend that this is added to the modeling strategy given the  
39 limitations of the Monte Carlo Simulation technique that is the main method used to assess  
40 model uncertainty in this study. There are various statistical methods to do this such as mean  
41 squared error or calculating confidence limits of the model bias discussed above. The resulting

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1 uncertainty calculated should be treated with some caution as the uncertainty has a tendency to  
2 underestimate the actual uncertainty.

### 3 **RESPONSE 4-FG-4:**

4 The model framework already includes analysis of the difference between  
5 measured and simulated values as a part of model uncertainty and/or validation:

- 6     ▪ Model validation will entail tests of the Phase 2 calibrated model against  
7     independent data sets (i.e., temporal extrapolation).
- 8     ▪ The downstream modeling exercise will extend the model to additional  
9     reaches of the river with associated independent data sets (i.e., spatial  
10     extrapolation).
- 11     ▪ Statistical summaries of model fit have already been provided on both a  
12     percentage and absolute basis in the Model Calibration Report.

13 Please refer also to the responses to General Issues 11 and 12.

14 The second issue relates to the application of Monte Carlo simulations, which was conducted in  
15 the bioaccumulation model. The application of Monte Carlo simulations to complex models like  
16 EFDC and the bioaccumulation model is difficult. There are two conditions that need to be met  
17 for the Monte Carlo simulations to be informative. One is that the model variables included in  
18 the Monte Carlo simulations are independent and not correlated. This was done for the  
19 bioaccumulation model but the report does not provide details on how this was done. This issue  
20 could therefore be expanded and perhaps improved upon in future work.

### 21 **RESPONSE 4-FG-5:**

22 EPA agrees that the application of Monte Carlo analysis to complex models with  
23 potentially correlated parameters is challenging (see Response 1-JL-7). The  
24 assumption of independence of inputs was addressed in FCM in several ways:

- 25     ▪ The list of input parameters for which distributions were developed was  
26     constrained by identifying the parameters to which output was most sensitive.  
27     In this manner the potential for complex interactions among numerous  
28     distributions was reduced.
- 29     ▪ The known interactions were accounted for, when possible, by specifying  
30     distributions to eliminate strong correlations. For example, the model is  
31     sensitive to the ratio between food assimilation efficiency and chemical  
32     assimilation efficiency. Therefore, rather than specify separate distributions  
33     for these parameters (which are strongly related), the uncertainty analysis  
34     modeled only the ratio between the two parameters. In this manner, the  
35     uncertainty analysis captured the uncertainty in the model but without  
36     introducing unnecessary autocorrelation in Monte Carlo inputs.

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1           ▪ Where inputs were correlated but could not be eliminated, professional  
2 judgment was used to specify the form of the functional interaction among  
3 inputs. For example, prey switching assumptions were made to specify the  
4 linkages among the dietary matrices. This ensured that inputs were logical  
5 (e.g., sum of preferences always equal to 100%) and that changes in feeding  
6 preferences represented realistic prey-switching behavior (based on the life  
7 histories of the modeled organisms).

8           EPA documented the rationales for the selection of inputs and distributions in  
9 Section C.4.2.1.2 of the Model Calibration Report. Please refer also to the  
10 response to General Issue 11.

11          A second condition for an informative Monte Carlo simulation analysis is that the variability and  
12 error in the model variables can be determined or are known. For some model variables this can  
13 be done relatively easily, while for others (e.g. feeding preferences, growth rates) this is very  
14 difficult. The report does provide information on this issue and the authors are doing a good job  
15 to deal with this difficult issue.

### 16           **RESPONSE 4-FG-6:**

17          EPA agrees that the specification of input distributions was challenging for some  
18 parameters. Some parameters could be specified using routine statistical  
19 analysis of multiple data points; others, however, required professional judgment  
20 to evaluate multiple lines of evidence and/or to incorporate non-quantitative  
21 information. Please refer also to the response to General Issue 11.

22          An issue that requires further investigation, in my view, is why the MCS calculated uncertainty  
23 in the concentrations of PCBs in biota is considerably less than the observed uncertainty. The  
24 latter is indeed not impossible as the MCS method does not capture all sources of uncertainty.  
25 However, it raises issues about the value of the uncertainty analysis and how the results of the  
26 MC simulations should be interpreted when applying the model.

### 27           **RESPONSE 4-FG-7:**

28          The reason that the Monte Carlo distributions are narrower than the distributions  
29 derived from field data is that the Monte Carlo analysis generally did not  
30 incorporate all sources of variability in individual fish. Uncertainty consists of  
31 both variability and model incertitude. The Monte Carlo analysis attempted to  
32 characterize the incertitude associated with mean concentrations of fish for each  
33 combination of species, age, and reach. The distributions could easily have  
34 been made wider by specifying distributions around additional parameters that  
35 are relevant to individual fish PCB concentrations, such as variability in exposure  
36 to media at the base of the food web (see Figure 1-JL-7 for sediment  
37 concentration example). However, because the primary objective of the model  
38 was to simulate mean concentrations instead of individual concentrations (see  
39 response to General Issue 1), these additional distributions were not specified.  
40 Please refer also to the response to General Issue 11, and to Responses O-DE-9

## Model Calibration Responsiveness Summary

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1 and 1-JL-7.

2 In terms of uncertainty analysis for the EFDC and FCM models, there is considerable room for  
3 improvement and additional work. For example, there is no uncertainty analysis for the EFDC  
4 model at this point.

### 5 **RESPONSE 4-FG-8:**

6 Please refer to the response to General Issue 11.

7 As for the FCM model, the MC simulations provide useful information but the report makes  
8 qualitative statements (i.e. “two-fold” in an number of places e.g. p.C.4-24), which do not appear  
9 to be representative of the real model uncertainty as demonstrated by differences between model  
10 predicted and empirical PCB concentrations in biota.

### 11 **RESPONSE 4-FG-9:**

12 The qualitative statements regarding “two-fold” differences are accurate when  
13 applied to comparisons between mean observed tissue concentrations and FCM-  
14 simulated concentrations. Such comparisons are represented by yellow square  
15 symbols in Figure C.3-51. For sample sizes greater than 6, all of the tPCB  
16 comparisons were within a factor of 2 (represented by a thick dashed line), and  
17 the majority of individual congener comparisons were also within a factor of 2,  
18 which was established in the Modeling Study QAPP and the final MFD as the  
19 target tolerance for calibration of the bioaccumulation model (see final MFD,  
20 Table I-1 in Appendix I). The figure indicates that increased sample size results  
21 in stronger agreement between measured and simulated data, which is to be  
22 expected given the large variability in individual PCB concentrations.

23 In Figure C.3-51, EPA presented comparisons of measured and simulated data  
24 even if sample sizes were insufficient to calculate meaningful central tendency  
25 statistics (e.g., n = 1 cases represented by blue circle symbols). However,  
26 individual fish concentrations that deviate from simulated average values by  
27 more than a factor of 2 should not be interpreted as indications of lack of model  
28 fit, particularly because the individual tissue concentration variations in the field  
29 are more than an order of magnitude. The individual data points in Figure C.3-51  
30 were plotted to assess the model bias (or lack thereof), not to test the  
31 MFD/QAPP performance criteria that apply only to central tendency  
32 concentrations. Please refer also to the response to General Issue 11, and to  
33 Responses O-DE-9 and 1-JL-7.

34 My recommendation is:

35 1. To include an assessment of model uncertainty based on a comparison of observed and  
36 predicted concentrations (The 95% confidence intervals of the model bias, discussed earlier, can  
37 be a useful tool to do this).

## Model Calibration Responsiveness Summary

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1           **RESPONSE 4-FG-10:**

2           Please refer to the response to General Issue 11 and to Response 2-FG-8.

3           2. To conduct the planned MC analyses considering the importance of conducting the analyses  
4           with non-correlated state variables and supporting the distributions of state variables with  
5           scientific data or appropriate and documented judgment.

6           **RESPONSE 4-FG-11:**

7           EPA has already considered intercorrelations among inputs. Please refer to the  
8           response to General Issue 11 and to Response 4-FG-5 above.

9           Finally, it is important to stress that both approaches have their pros and cons and that they only  
10           arrive at estimates of model uncertainty. In the application of the model this should be  
11           recognized.

12           **RESPONSE 4-FG-12:**

13           Please refer to the response to General Issue 11.

14           **Wilbert Lick:**

15           As described in the introductory material for Question 3, rates of erosion and deposition are both  
16           questionable. The fact that the model predicts suspended sediment concentrations fairly  
17           accurately does not imply that the rates of erosion and deposition are correct.

18           **RESPONSE 4-WL-1:**

19           Please refer to the response to General Issue 7.

20           The well-mixed layer is very thick. Because of this, its thickness is insensitive to diffusional flux  
21           processes and resistant to calibration. I think it will be almost impossible to determine by  
22           calibration; some scientific reasoning is necessary.

23           **RESPONSE 4-WL-2:**

24           Please refer to the response to General Issue 6 and to Response 3-WL-16.

25           Sensitivity and uncertainty analyses are meant to measure differences between the model  
26           calculations and observations and determine the best parameters for the model as specified.  
27           These tests do not determine whether the physical formulations/equations in the model are  
28           adequate or correct. The model as is has the incorrect physical formulations; and  
29           sensitivity/uncertainty analyses will not demonstrate this.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 4-WL-3:**

2           EPA disagrees with the Reviewer's comment that the model "has the incorrect  
3           physical formulations"; additional discussion relative to this comment is provided  
4           in the response to General Issue 7. EPA also disagrees with the Reviewer's  
5           comment that one of the objectives of sensitivity and uncertainty analyses is to  
6           "determine the best parameters for the model..." This objective is part of the  
7           model calibration effort. Additional discussion of the uncertainty analyses  
8           planned for the Phase 2 Calibration is provided in the response to General Issue  
9           11.

10          **E. John List:**

11         The sensitivities of model predictions to the relevant processes that have been included within  
12         the models seem to have been exhaustively evaluated. The issue is the uncertainties in the model  
13         predictions, which are of two types. One type is the inherent uncertainty associated with the  
14         uncertainty in the input data, which of course arises from the precision and accuracy of sample  
15         laboratory work and the inability of a limited number of samples to exactly define the statistics  
16         of a population. All of these uncertainties are quantifiable, although this has not been done to the  
17         level one would have liked to have seen.

18           **RESPONSE 4-JL-1:**

19           Please refer to the responses to General Issues 5 and 11.

20         For example, the uncertainty in the predictions of PCB and sediment stream fluxes appears to  
21         have been omitted (e.g., in Figure 5-24).

22           **RESPONSE 4-JL-2:**

23         As discussed in Section B.5.3 of the Model Calibration Report, and in response  
24         to a preliminary question received from the Panel, EPA did not believe that  
25         performing the uncertainty analysis over the relatively short calibration period  
26         would have been very informative for either HSPF or EFDC.

27         In addition, there has been no known attempt to conduct a rigorous uncertainty  
28         analysis at other sites using a model such as EFDC. Given this, and also  
29         recognizing the amount of resources required to perform the analyses for both  
30         EFDC and HSPF, EPA had hoped to receive input from the Panel on the process  
31         to be used to conduct the uncertainty analysis prior to expending the significant  
32         time and resources required to conduct such analyses. The uncertainty analysis  
33         performed for FCM during model calibration was very straightforward and  
34         required relatively few resources; a similar approach will be applied during model  
35         validation.

36         Another omission that could have easily been included is whether the mean PCB concentrations  
37         in the upper 6 inches of sediment show any statistically significant difference along the 11 mile

## Model Calibration Responsiveness Summary

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1 river reach. This is exemplified by the model input data in Figure 5-26. Because there are no  
2 confidence limits on the estimates of the mean concentration of tPCB along the river reach it is  
3 not clear that the variations shown in the tPCB profile along the river have any statistical  
4 significance.

### 5 **RESPONSE 4-JL-3:**

6 Sediment PCB concentrations in the various modeling reaches were analyzed  
7 and discussed at some length in Section 4.5 of the RFI report (BBL and QEA,  
8 2003). Although statistical hypothesis testing was not conducted, error bars ( $\pm 2$   
9 standard errors, approximately equal to a 95% confidence interval) are provided  
10 for the mean PCB concentration by PSA reach in Figure 4-8 of the RFI.  
11 Examination of the means and their confidence intervals suggests considerable  
12 overlap in surficial sediment PCB concentrations in the PSA, with the exception  
13 of Reach 5B, which appears to have generally lower concentrations than the  
14 other reaches.

15 Because the distributions of the sediment PCB concentration data in each PSA  
16 reach are strongly positively skewed (i.e., lognormal), the arithmetic means are  
17 not the best measures of central tendency for use in statistical hypothesis testing  
18 and statistical comparisons based on these means are not valid. To investigate  
19 whether there are significant differences among the four main channel reaches in  
20 the PSA (5A, 5B, 5C, and 6), two different statistical tests were used.

21 The null hypothesis tested was of the form:

$$22 \quad H_0: x_{5A} = x_{5B} = x_{5C} = x_6,$$

23 where:

24  $x$  = A measure of central tendency.

25 5A, 5B, 5C, and 6 = The subreaches used for FCM.

26 The testing was conducted on all surficial (0 to 15-cm) sediment tPCB data in the  
27 project database; non-detects were included at the detection limit, but there were  
28 very few non-detects in the data set.

### 29 **Median Test**

30 First, the median values for the four reaches (5A = 11.3, 5B = 4.42, 5C = 6.81,  
31 6 = 17.8) were tested using the *median test* of Mood (1950, as discussed in Zar,  
32 1999). This procedure involves the use of the  $X^2$  distribution to test the number  
33 of data points in each reach that fall above or below the median value for all  
34 reaches combined. The results of this test were very highly significant  
35 ( $p \ll 0.001$ ), and the null hypothesis was rejected (i.e., at least one reach mean  
36 was significantly different from the others). Although it is theoretically possible to  
37 conduct a posteriori multiple comparison testing of medians to determine which

## Model Calibration Responsiveness Summary

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1 reaches are significantly different from the others, the test is not robust and  
2 requires equal sample sizes, which is not the case for the sediment PCB  
3 concentration data.

### 4 Analysis of Variance (ANOVA)

5 PCB concentrations in the four subreaches were also tested using one-way  
6 analysis of variance (ANOVA). The four groups of data were plotted and  
7 determined visually to be approximately lognormal, thus, the data were log-  
8 transformed ( $\log_{10} x+1$ ) and replotted. Based on a visual inspection, the  
9 transformation was successful in making all distributions approximately normal.  
10 The ANOVA based on the four transformed means (5A = 1.10, 5B = 0.73, 5C =  
11 0.95, 6 = 1.21, equivalent to geometric means of 11.6, 4.37, 7.91, and 15.2,  
12 respectively) was very highly significant ( $p \ll 0.001$ ), indicating that at least one  
13 of the means was significantly different from the others.

14 The differences among the reach means were tested pairwise using Tukey's  
15 honestly significant difference (HSD) test (Zar, 1999). All reach means were  
16 found to be significantly different from each other at  $\alpha = 0.05$ , although the  
17 difference between Reaches 5A and 6 was only marginally significant.

18 These results, which in part reflect the large amount of data available for the  
19 PSA, indicate that there are statistically significant differences between PCB  
20 concentrations in the surficial sediment of the modeling reaches. The  
21 differences, however, do not reflect a monotonic change with longitudinal  
22 distance downstream, in part because of differences in hydraulic regime, which in  
23 turn influence patterns of erosion and deposition, resulting in differences in grain  
24 size, TOC, and other parameters among the four reaches.

### 25 Reference:

26 Zar, J.H. 1999. *Biostatistical Analysis*. 4th Edition. Prentice Hall, Upper Saddle  
27 River, NJ. pp. 663.

28 The second type of uncertainty is created by the inability of a model to exactly replicate the  
29 processes active in the field and the very distinct possibility that a model may have inherent, and  
30 unrecognized, flaws. This type of uncertainty is very difficult to quantify and can only be  
31 properly defined by a careful calibration and validation procedure. If the calibration and  
32 validation procedures indicate, over a large number of evaluations, that the model is reproducing  
33 field results, then some degree of confidence can be ascribed to the output of the model.

### 34 RESPONSE 4-JL-4:

35 Please refer to the response to General Issue 11.

36 Of particular concern here is that despite reproducing the mean of several measured parameters  
37 adequately, the model is not indicating the proper degree of variance in the output, as was  
38 discussed above in the response to Charge Question No. 1.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 4-JL-5:**

2           Please refer to the response to General Issue 10.

3           On the other hand, as pointed out by another member of the Peer Review Committee (Dr. Lick),  
4           the model may be getting the “right” results despite incorrect science, simply because there are  
5           two compensating basic errors.

6           **RESPONSE 4-JL-6:**

7           The basis for Dr. Lick’s comment that the model may be getting the “right” results  
8           for the “wrong” reason was that the concentration of suspended solids could be  
9           fit with a wide range of combinations of settling and resuspension rates (see  
10          response to General Issue 7). Dr. Lick’s assumption ignores the examination of  
11          the gradient between sorbed PCB concentrations in the water column and the  
12          sediment. Although different combinations of settling and resuspension rates  
13          could be assigned to produce the same solids flux between the sediment and  
14          water, the PCB flux from the sediment to the water column will increase with  
15          increasing resuspension (even if settling is increased) because the PCB  
16          concentrations on sediment solids are higher than on water column solids. Thus,  
17          the PCB concentrations simulated by the model provide an important check on  
18          the combination of settling and resuspension rates. Please refer to Response  
19          1-DE-8 and the response to General Issue 7 for additional discussion.

20          Another issue in this regard was also commented upon above. The fact that the sediments show  
21          a very wide variability in concentration of PCB, three orders of magnitude on horizontal spatial  
22          scales of 2 meters or so and uniformly over the 11-mile river reach, is disturbing for two reasons.  
23          One is the fact that there is no known explanation for this and therefore the appropriate fate and  
24          transport mechanism cannot be included in the model. And the second is that despite the fact that  
25          the mechanism is not included in the model (because it is unknown), there is no proof that its  
26          omission is of no consequence to the outcome of the modeling exercise.

27          **RESPONSE 4-JL-7:**

28          Please refer to the response to General Issue 5.

### 1 **Use of the Model to Evaluate Differences in Remedial Options**

2 **5. Is the uncertainty indicated by model-data differences sufficiently inconsequential to**  
3 **permit use of the model to predict differences in remedial options?**

4 **E. Adams:**

5 See response to Question 4.

6 **W. Frank Bohlen:**

7 For the reasons discussed in Question 3 above answering this question seems premature.

8 **Douglas Endicott:**

9 This really is a judgment call that depends upon how ambitious the remedial options are.  
10 Uncertainty is “inconsequential” if it does not obscure the discrimination between outcomes (i.e.,  
11 PCB body burdens in fish) of different scenarios.

#### 12 **RESPONSE 5-DE-1:**

13 Please refer to the responses to General Issues 1 and 11.

14 At this point, uncertainty of EFDC predictions have not been determined. The uncertainty of  
15 food chain model predictions of total PCB bioaccumulation appear to be acceptable to evaluate  
16 remedial options. For most fish, the ratio of predicted 90<sup>th</sup>-percentile to 10<sup>th</sup>-percentile PCB  
17 concentrations is a factor of 3 to 5. This matches my expectations from other systems, and  
18 indicates a high-quality model.

#### 19 **RESPONSE 5-DE-2:**

20 EPA agrees that the model performance compares favorably with results from  
21 modeling other systems. The uncertainty bounds (percentiles) likely overstate  
22 the uncertainty about central tendencies of PCB concentration because some  
23 input distributions in the Monte Carlo analysis included variability among  
24 individuals in addition to model incertitude. Further information on model  
25 performance will be available following model validation and extrapolation of the  
26 model downstream of the PSA.

27 Of course, this is just uncertainty due to model parameters, which is only a part of real model  
28 uncertainty. I am told that the really fatal model uncertainties are the things you don't know  
29 about and cannot be anticipated. That is why (aside from curiosity) I would like to see EPA  
30 collect more data on this system, as identified above (response to question 3).

## Model Calibration Responsiveness Summary

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1           **RESPONSE 5-DE-3:**

2           EPA believes the data already collected on this system are sufficient to achieve  
3           the goals of the modeling study. The large amount of data, combined with the  
4           reasonable results from the short-term calibration and the demonstrated risks at  
5           the site, suggest that the goals of the modeling study will be met with the data  
6           that have been collected and that the project should move forward.

7           **Marcelo H. Garcia:**

8           At this stage, the model has been used to predict sediment and PCB transport and fate during  
9           storm events. So the model-data differences might not be very important for the time and space  
10          scales considered for model calibration, but could very well increase in relevance for the scales  
11          needed to compare remedial actions.

12          **RESPONSE 5-MG-1:**

13          Please refer to the response to General Issue 2.

14          **Frank Gobas:**

15          As for the HSPF model, the model-data differences are sufficiently small to use the model to  
16          predict mean flow, TSS and temperature in the River following remedial actions.

17          **RESPONSE 5-FG-1:**

18          EPA agrees with the Reviewer's assessment.

19          On balance, the hydrodynamic model and sediment transport model appear to produce relatively  
20          small differences between model predictions and observations. The small differences between  
21          observations and predictions are partly caused by the calibration methodology which uses the  
22          observed data to make the model predictions. Hence, a good agreement between observations  
23          and predictions should be expected.

24          **RESPONSE 5-FG-2:**

25          Please refer to the response to General Issue 2.

26          It is unclear from the study so far how predictive the model really is and hence what the model's  
27          uncertainty is. This can be determined by conducting a model validation (better is model  
28          performance evaluation), where the observed data are not used to make the model predictions.

29          **RESPONSE 5-FG-3:**

30          Please refer to the response to General Issue 2.

## Model Calibration Responsiveness Summary

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1 However, despite some limitations in the approach so far, the model is a reasonable tool to start  
2 making certain predictions among remedial options.

3 The performance of the PCB fate model is only tested in its ability to estimate PCB mass in the  
4 water column. While the performance of the model as characterized by differences between  
5 observed and predicted concentrations are reasonable they do not shed much light on the ability  
6 of the model to estimate spatial differences in PCB concentrations (as concentrations of PCBs do  
7 not appear to show statistical differences among the stretches of the River of concern), or the  
8 model's ability to estimate the temporal response of the PCB concentrations in water and  
9 sediments in the River.

10 **RESPONSE 5-FG-4:**

11 Please refer to the response to General Issue 12.

12 If it is further considered that the model may not have fully represented some key fate processes,  
13 I recommend considerable caution in the application of the model in a predictive sense, in  
14 particular if the long term temporal response of the model is important. I think uncertainty  
15 analyses need to be added.

16 **RESPONSE 5-FG-5:**

17 Please refer to the response to General Issue 11.

18 Model – data differences in PCB concentrations in the bioaccumulation model are considerable  
19 despite significant calibration efforts.

20 **RESPONSE 5-FG-6:**

21 Please refer to Responses 1-JL-6 and 1-JL-7 (regarding model-data differences)  
22 and 4-FG-2 (regarding degree of calibration) above.

23 Biological data often exhibit a large degree of variability. Hence, it is not uncommon in  
24 bioaccumulation modeling efforts that there are significant discrepancies between predicted and  
25 observed concentrations. The latter should not be viewed as criticism of the model or an  
26 impediment in the application of the model. As long as the uncertainty in the model calculations  
27 is appropriately recognized, the results of the model can be interpreted accordingly and the  
28 model can be used productively to assess the impact of remedial actions.

29 **RESPONSE 5-FG-7:**

30 EPA generally agrees with the above comment. However, the term  
31 “discrepancy” should only be used for model-data comparisons that represent  
32 “apples-to-apples” conditions (i.e., central tendency of measured concentrations  
33 versus central tendency of simulated concentrations).

34 The issue of uncertainty requires further attention in the development of the bioaccumulation  
35 model. Currently, the report contains statements about “the majority of PCB tissue

## Model Calibration Responsiveness Summary

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1 concentrations being within a factor of 2 of the deterministic values”. These statements does not  
2 appear to be representative of the real model-data differences shown in Figure C.3-27 or even  
3 Figure C.3-28 (which I presume are mean concentration values). Only, when uncertainty is  
4 appropriately recognized, application of the model should be considered.

### 5 **RESPONSE 5-FG-8:**

6 Please refer to the response to General Issue 11 and to Response 4-FG-9  
7 above.

8 Although I do not think that the uncertainty of the FCM model is correctly represented in the  
9 report, I do think that when this is done, the model can be used to predict differences in PCB  
10 concentrations in biota resulting from remedial options despite the fact that differences in  
11 observed and predicted concentrations are considerable.

### 12 **RESPONSE 5-FG-9:**

13 EPA disagrees with the conclusion that “differences in observed and predicted  
14 concentrations are considerable” when data and model simulations are  
15 considered as central tendencies. Please refer also to Responses 1-JL-6 and  
16 1-JL-7.

17 It is possible that, in some cases, there may not be statistically significant differences in PCB  
18 concentrations in fish resulting from different remediation scenarios but, if so, this is important  
19 information to know.

### 20 **RESPONSE 5-FG-10:**

21 In evaluating different remedial options, both the magnitude of differences (effect  
22 size) and the significance of differences are important. Statistical significance  
23 measures are useful but can be misleading unless the statistical power of the  
24 tests and the costs (consequences) of both Type I and Type II statistical errors  
25 are considered. Please refer also to the response to General Issue 1.

### 26 **Wilbert Lick:**

27 No (see response to question 4).

### 28 **RESPONSE 5-WL-1:**

29 EPA notes that the uncertainty analyses for HSPF and EFDC were not  
30 performed as part of the model calibration and therefore, were not included in the  
31 Model Calibration Report. These analyses will be performed on the longer-term  
32 simulations and will be included in the Model Validation Report.

## Model Calibration Responsiveness Summary

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### 1 **E. John List:**

2 In order to resolve a formulated hypothesis that one remedial option has a better “performance”  
3 than another, (however that performance may be quantified), there has to be a comparative  
4 statistical test developed. The test must be capable of resolving the probability of both false  
5 positives and false negatives and knowledge of sample means alone is insufficient information to  
6 resolve any formulated hypothesis.

#### 7 **RESPONSE 5-JL-1:**

8 EPA agrees that means, or other measures of central tendency, alone do not  
9 provide sufficient information for statistical tests; however, the model, as is the  
10 case with most models, does not output directly the information on variability  
11 needed to conduct such tests. The proposed procedure for evaluation of  
12 uncertainty of model output will provide estimates of model output variability that  
13 will allow some approximation of hypothesis-testing procedures. Evaluation of  
14 alternatives via more qualitative inspection of model results, combined with the  
15 output of the uncertainty analysis noted above, will also be used to provide useful  
16 information for decisionmakers.

17 There are certainly non-parametric tests that can be used, but these require some knowledge as to  
18 the nature of the distributions and the ability to resolve false negatives may be impaired.

#### 19 **RESPONSE 5-JL-2:**

20 The usual purpose of non-parametric tests, also known as “distribution-free”  
21 procedures, versus parametric tests is to allow hypothesis testing without  
22 needing to specify the distribution of the data being tested. Non-parametric tests  
23 vary widely in their power and robustness, and can be more powerful than  
24 parametric tests if the assumptions for the equivalent parametric test are not met.

25 As previously discussed, there is definite uncertainty in the model predictions and some of this  
26 has not been quantified, which will definitely impair the ability to resolve statistical hypotheses  
27 regarding the relative performance of remedial options.

#### 28 **RESPONSE 5-JL-3:**

29 Please refer to the response to General Issue 11.

30 More attention should be directed at developing the data required for hypothesis testing.

#### 31 **RESPONSE 5-JL-4:**

32 The data collection phase of the project has concluded, and EPA believes that  
33 the data collected to support the modeling study are sufficient to support  
34 achievement of the goals of the modeling study. EPA also believes that the  
35 recently completed human health and ecological risk assessments demonstrate  
36 elevated risks at this site, and that it is prudent to proceed with the remainder of

## Model Calibration Responsiveness Summary

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1 the modeling study. Accordingly, with very limited exceptions, no additional data  
2 will be collected.

3 As discussed in several responses in this document, and particularly in the  
4 response to General Issue 11, EPA is investigating a number of methods to  
5 evaluate model uncertainty and believes that quantification and evaluation of  
6 model uncertainty will provide a better means of evaluating the differences  
7 between remedial alternatives than will a definitive statistical hypothesis-testing  
8 protocol.

### 1 Overall Adequacy of Calibration

2 **6. Are the processes in the model calibrated to the extent necessary for predicting future**  
3 **conditions including future concentrations of PCBs in the environment under natural**  
4 **processes and under potential remedial options for sediments and floodplain soils in the**  
5 **Housatonic River in the reach below the confluence? If not, what additional work needs to**  
6 **be done to calibrate the model?**

#### 7 **E. Adams:**

8 See response to Questions 1, 2 and 4 which also include suggestions for improving model  
9 calibration.

#### 10 **W. Frank Bohlen:**

11 No. The fundamental problem (beyond the issues discussed above) with the current model  
12 calibration is its limited duration. Since data seem to be available for the extension of this period  
13 it is my recommendation that the period be extended in year steps out to five years. As suggested  
14 above, the five year period appears to be sufficient to allow measureable change in sedimentation  
15 and the associated sediment/contaminant concentrations to occur.

#### 16 **RESPONSE 6-FB-1:**

17 Please refer to the response to General Issue 2.

#### 18 **Douglas Endicott:**

19 As I mentioned above (see response to question 1), we can only anticipate the calibration of  
20 processes that are influential to long-term model predictions. In this context, I am primarily  
21 concerned with the calibration of resuspension fluxes, the sediment-water diffusion flux, and the  
22 surficial sediment residence time as defined by the mixed layer thickness.

#### 23 **RESPONSE 6-DE-1:**

24 Please refer to the responses to General Issues 6, 7, and 8.

25 I also worry about unquantified PCB sources that will remain after remediation is completed.

#### 26 **RESPONSE 6-DE-2:**

27 Under the terms of the Consent Decree, there are requirements to address the  
28 sources of PCBs at the GE facility and other areas specified in the Consent  
29 Decree. In addition, MDEP is working with GE to address all known sources  
30 other than those specified in the Consent Decree. With regard to potential

## Model Calibration Responsiveness Summary

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1 contributions from tributaries and the Pittsfield WWTP, please refer to Responses  
2 O-DE-8 and 3-DE-4.

3 There have been protracted arguments about whether the thickness of the surficial mixed  
4 sediment layer, or (alternatively) the bioavailable sediment layer, should be 6 inches as opposed  
5 to 3 or 4 inches. I think it is fair to say that each side prefers a number intended to produce a  
6 modeling outcome favorable to their own interest. EPA has not convincingly demonstrated that  
7 the current model parameterization of mixed layer depth is scientifically defensible. The truth is  
8 we have almost no system-specific data to guide the specification of this parameter, and there is  
9 little guidance currently available in the literature from other sites. All lines of evidence should  
10 be used to evaluate this parameter. That should include physical, chemical and biological data as  
11 well as what the model can tell us via calibration. The modeling team should consult with  
12 scientists familiar with the various biotic and abiotic benthic processes.

### 13 **RESPONSE 6-DE-3:**

14 Please refer to the response to General Issue 6. Additional specific responses to  
15 comments made above include:

- 16 ■ EPA does not have a preference for any specific value of the parameter other  
17 than to optimize the predictive value of the model.
- 18 ■ EPA demonstrated that application of a thick layer of biological mixing was an  
19 adequate simplifying assumption for the calibration period. The best  
20 “scientifically defensible” thickness for use in longer-term simulations was not  
21 determined at the time of the Model Calibration Report.

22 Site-specific data are available and these were considered in the specification of  
23 biological mixing depth (see the response to General Issue 6). EPA agrees that  
24 a weight-of-evidence approach is useful for specification of this parameter.

25 Finally, it should be recognized that simulations of long-term remediation alternatives will  
26 dramatically alter the sources and pathways followed by PCBs in the PSA. Instead of the  
27 dominant role played by advection of PCBs from the upstream boundary (the major flux pathway  
28 during the calibration period), PCB flux via diffusive and particulate fluxes from the sediment  
29 will eventually predominate. This will change the general sensitivity and uncertainty behavior of  
30 at least EFDC and may reveal errors that are not currently evident. I think some scenarios of this  
31 sort should be tested during model calibration, to ensure that the models behave in a way that is  
32 at least consistent with our overall understanding of the system. Models sometimes behave  
33 unusually when the major contaminant pathways are altered.

### 34 **RESPONSE 6-DE-4:**

35 Please refer to the response to General Issue 12.

# Model Calibration Responsiveness Summary

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1 **Marcelo H. Garcia:**

2 The calibrated model ability to predict future concentrations of PCBs as well as the impact of  
3 potential remedial actions in the Housatonic River and its floodplains, will be very limited. The  
4 main issue with the calibrated model is the size of the computational grid employed both for the  
5 river and its floodplain as well as the fact that the model has been calibrated for a relatively short  
6 period of field observations. While the latter is driven by data availability, the former can be  
7 solved with today's computational resources.

8 **RESPONSE 6-MG-1:**

9 Please refer to the responses to General Issues 2, 3, and 4.

10 My recommendation is to include stream bank erosion in the model since this is a very important  
11 process which has the potential for greatly impacting the modeling outcome. While the  
12 mechanics of stream bank erosion is not well understood, it is possible to assess how much  
13 sediment enters the channel through bank erosion with a simple 1-D model for meandering  
14 streams. Such model is described in an attached paper by Abad and Garcia (2005).

15 **RESPONSE 6-MG-2:**

16 Please refer to the response to General Issue 9.

17 There is a clear need for the model to be able to resolve flow and sediment transport within the  
18 channel and along its stream banks. To model mass transfer processes at the sediment-water  
19 interface fine-scale hydrodynamic (i.e. flow velocity, shear stresses) predictions are needed. As it  
20 stands, the calibrated model cannot do this. A 3D hydrodynamic and sediment transport model  
21 should be used for in-channel flows and a 2D model (like the one currently employed) for the  
22 floodplain. This is computationally challenging but can be done as shown in the attached paper  
23 by Rodriguez et al. (2004).

24 **RESPONSE 6-MG-3:**

25 EPA does not believe it would be advisable to use the approach suggested by  
26 the Reviewer. As stated in Rodriguez et al. (2004):

27 "This paper presents numerical simulations of flow through a natural  
28 meandering river using two different models: a depth-averaged numerical  
29 code with secondary flow correction and a fully 3-D, state-of-the-art  
30 Computational-Fluid-Dynamics (CFD) code. The scale of the problem  
31 examined here is in the overlapping domain of applicability of the two  
32 models, providing a basis for moving from these simulations both to  
33 larger- and smaller-scale analyses. The 2-D model generates only depth-  
34 averaged results and can be applied to large spatial domains, while the 3-  
35 D model generates a complete and detailed picture of the flow field, but at  
36 the expense [sic] of considerable computational time. In fact, the  
37 numerical simulation is rather ambitious for application of a full 3-D CFD  
38 model, as demonstrated by the lack of previous simulations at the scale

## Model Calibration Responsiveness Summary

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1                   and degree of complexity of the reach examined in this study. Neither of  
2                   the models has been applied at the field-scale using data for a natural  
3                   meandering stream.”

4                   It is concluded, therefore, that the approach described in Rodriguez et al. (2004)  
5                   is not appropriate for application to the Housatonic River modeling study. Please  
6                   refer also to the response to General Issue 3.

### 7                   **References:**

8                   Rodriguez, José F., Fabián A. Bombardelli, Marcelo H. García, Kelly M.  
9                   Frothingham, Bruce L. Rhoads, and Jorge D. Abad. 2004. High-resolution  
10                  numerical simulation of flow through a highly sinuous river reach. *Water*  
11                  *Resources Management* 18: 177-199.

### 12                  **Frank Gobas:**

13                  The report documents that model calibration has been carried out to a significant degree in the  
14                  hydrodynamic, sediment, chemical fate and bioaccumulation models. In my personal view, the  
15                  model development has embraced calibration a little too strongly at the expense of evaluating  
16                  model performance and model uncertainty. The calibration of the model has produced a model  
17                  that has reasonable central tendencies and produce reasonable values for mean conditions such as  
18                  flow rates, TSS and PCB concentration on TSS and in biota. However, the uncertainties in the  
19                  model predictions require further attention before the model can be used productively to explore  
20                  remedial options.

### 21                  **RESPONSE 6-FG-1:**

22                  More information on model performance will be presented during the Phase 2  
23                  Calibration and Validation. Please refer also to the response to General Issue 11  
24                  and to Response 4-FG-2 (reliance on model calibration).

25                  In terms of additional work, it is possible to collect new PCB concentration data sets to carry out  
26                  a model performance analysis that is not dependent on the collected data. Alternatively, it may  
27                  be possible to revisit existing data sets and calibrate the model to certain data while using other  
28                  available data for model performance analysis and uncertainty analysis. A more daring approach  
29                  is not to use PCB concentration data at all in the model calibration phases. This should be  
30                  possible for the PCB fate and bioaccumulation model.

### 31                  **RESPONSE 6-FG-2:**

32                  The data collection phase of the project has concluded. EPA believes that the  
33                  recently completed human health and ecological risk assessments demonstrate  
34                  elevated risks at this site, and that it is prudent to proceed with the remainder of  
35                  the modeling study. Accordingly, with very limited exceptions, no additional data  
36                  will be collected.

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1           The modeling approach has been modified (see response to General Issue 2) in  
2           response to comments from the Reviewers; the most recent data will be retained  
3           for use in evaluating model performance for validation.

4           One area where the model calibration is lacking is in the temporal behavior of the PCB  
5           concentrations in sediment and biota in the River. This characteristic could not be calibrated very  
6           well because PCB concentrations did not show significant changes over time during the study  
7           period. As a result, there is little information on the performance of the model in terms of  
8           predicting future PCB concentrations in response to remedial options. There is not a simple  
9           solution to this problem. One approach that could be pursued is to better characterize some key  
10          loss processes of PCBs in the River. This would involve characterizing PCB degradation rates  
11          and volatilization rates. These rates may have a significant effect on the temporal response of  
12          PCB concentrations in the River. Although this work would not actually test the temporal  
13          response of the model, the credibility of the model would be improved by a better presentation of  
14          mechanisms of chemical loss.

### 15           **RESPONSE 6-FG-3:**

16          EPA agrees that the temporal gradients in PCB concentrations are weak over the  
17          calibration period, and that the sensitivity of model parameters may change  
18          during longer-term simulations; however, given the data, longer-term calibration  
19          and validation may not satisfy this concern because of a lack of clear temporal  
20          gradients in the data over the period of record. Please see also the response to  
21          General Issue 2.

22          Please refer to the response to General Issue 5 regarding volatilization, and  
23          Response 3-FG-1 regarding PCB degradation.

24          Despite the large amount of effort that has been devoted to modeling and data collection, I am  
25          not convinced that, at this point, a holistic understanding of the fate of PCBs in the River has  
26          emerged. The report is unclear about what the key processes are controlling the fate of PCBs in  
27          the River.

### 28           **RESPONSE 6-FG-4:**

29          The processes controlling the fate and transport of PCBs in the Housatonic River  
30          system have been discussed in the Modeling Framework Design (WESTON,  
31          2004a), the RFI Report (BBL and QEA, 2003) and the Model Calibration Report  
32          (WESTON, 2004b). Although the understanding of these processes may not be  
33          perfect, EPA believes that the important fate-controlling processes have been  
34          identified and are sufficiently well understood to support achieving the goals of  
35          the modeling study.

36          One, in my view, useful approach is to add PCB flux diagrams to the report. Flux diagrams are a  
37          useful and simple tool to integrate a lot of information with the goal to determine the controlling  
38          processes in the River.

## Model Calibration Responsiveness Summary

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1           **RESPONSE 6-FG-5:**

2           EPA agrees that summary figures are useful for integrating substantial amounts  
3           of information and communicating the important features of the system. The  
4           development of process-based flux diagrams for inclusion in the Model Validation  
5           Report will be considered. Although not broken down by processes, the PCB  
6           mass flux diagrams in the Model Calibration Report (Figures B.4-45 through  
7           B.4-47) were included to synthesize substantial amounts of information and  
8           summarize the transport of PCBs through the PSA during the calibration period.

9           **Wilbert Lick:**

10          The model has serious deficiencies as far as the descriptions of (a) erosion, especially at high  
11          shear stresses, (b) flocculation and deposition, (c) PCB flux and depth of mixing layer in the  
12          river, and (d) PCB flux and depth of mixing layer on the floodplain.

13           **RESPONSE 6-WL-1:**

14           Please refer to the responses to General Issues 6, 7, and 8, and, with regard to  
15           (d), Response 3-WL-34.

16          In addition, the spatial scale of the model in the river is inadequate to even approximately  
17          describe the variability of erosion/deposition in the river and hence any remediation activities in  
18          the river.

19           **RESPONSE 6-WL-2:**

20           Please refer to the response to General Issue 4.

21          Suggestions for improvements are as follows.

22          (a) Erosion at high shear stresses. Because of the low values of  $n$  used in the erosion equation,  
23          the erosion rate at high shear stresses and big events is not predicted properly. A re-examination  
24          of the data with a grouping of the data for similar sediments and similar depths and use of Eq. (5)  
25          should be helpful. In any event, the fact that  $n \cong 2$  or more is a very strong experimental fact  
26          and hence must be considered seriously.

27           **RESPONSE 6-WL-3:**

28           Please refer to the response to General Issue 7.

29          Additional testing by means of Sedflume on well-mixed sediments would be useful. This would  
30          be relatively simple and would be as follows. Test three types of sediments (each well-mixed for  
31          uniformity within the core, one typical of coarse-grained sediments and one typical of finer-  
32          grained sediments from the main channel and one from Woods Pond). For each type of sediment  
33          and for two to three consolidation times, measurements of erosion rate as a function of shear

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1 stress should be made. This would show the effects of consolidation (which is needed in the  
2 model) and also demonstrate more clearly whether n is approximately two.

### 3 **RESPONSE 6-WL-4:**

4 The data collection phase of the project has concluded. EPA believes that the  
5 recently completed human health and ecological risk assessments demonstrate  
6 elevated risks at this site, and that it is prudent to proceed with the remainder of  
7 the modeling study. Accordingly, with very limited exceptions, no additional data  
8 will be collected.

9 The formulation of bed armoring needs to be improved. This can be done by introducing a thin  
10 active layer (a few particle diameters thick) which is due to physical mixing at the sediment-  
11 water interface.

### 12 **RESPONSE 6-WL-5:**

13 Please refer to Response 3-WL-11.

14 (b) Flocculation and deposition. As described in the response to Question 3, a simple, time-  
15 dependent model of flocculation is available and should be used. This, along with experimental  
16 results on settling speeds, should give a better and more rational description of settling as  
17 compared with making up an equation for settling.

### 18 **RESPONSE 6-WL-6:**

19 Please refer to the response to General Issue 7.

20 (c) PCB flux and depth of mixing layer in river. Based on existing information, the depth of the  
21 mixing layer is much less than 6 inches (15 cm) and is probably more like 2 to 4 cm. A thorough  
22 review of the literature and on-going work should be done to ascertain this. Some evidence of  
23 this layer from field observations and measurements on the Housatonic would be useful. Some  
24 evidence of number, type, and activity of benthic organism is needed. Field tests of PCB  
25 diffusive fluxes from the sediment to the overlying water should be made. These have been done  
26 elsewhere, so that it's not a new procedure.

### 27 **RESPONSE 6-WL-7:**

28 Benthic community analyses, including identification, enumeration, and life  
29 history categorization of infaunal and epifaunal organisms, were conducted for  
30 the study area as part of the ecological risk assessment. This assessment has  
31 included both a thorough evaluation of the literature and consideration of site-  
32 specific data. Please refer also to the responses to General Issues 6 and 8.

33 As discussed in the response to Question 3, the magnitude of the diffusive flux needs to be re-  
34 examined. Its value is not justifiable.

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1           **RESPONSE 6-WL-8:**

2           Please refer to the response to General Issue 8.

3   In the modeling, the concept of a well-mixed layer should be abandoned; it is not correct  
4   physically and it is not necessary mathematically. It should be replaced by a diffusion with non-  
5   equilibrium sorption model (Lick et al., 2004) which is more realistic, more accurate, and  
6   requires little extra computational time (hardly noticeable).

7           **RESPONSE 6-WL-9:**

8           As is typically the case for the widely used contaminant fate models, EFDC  
9           incorporates a finite difference approximation for the vertical profile of a  
10          contaminant in sediment. Thus, the surface layer and each of the other layers is,  
11          by definition, completely mixed in a mathematical sense (i.e., the contaminant  
12          concentration within each layer is a single number). In addition, there is particle  
13          mixing between layers that are within the upper 15 cm of the bed (which was  
14          specified during calibration), and there is also diffusion of dissolved (i.e., in pore  
15          water) contaminant throughout the entire depth of the sediment bed. However,  
16          the net effect of these processes is not necessarily a well-mixed layer.

17          The equilibrium-based approach is routinely used to represent conditions in  
18          sediment where the particle residence time is typically relatively long in  
19          comparison to sorption and desorption time scales.

20          The use of a non-equilibrium approach represents an interesting alternative to  
21          the more common approach used in contaminated sediment studies such as the  
22          Fox River and Hudson River studies (Velleux and Endicott, 1994; Connolly et al.,  
23          2000, respectively). Such a major shift in the modeling approach is not possible  
24          at this point in the project. The approach implemented by EPA is consistent with  
25          the MFD and the Reviewer's comment made during the MFD Peer Review:

26                    "Because of these difficulties, the contaminant flux (except for  
27                    resuspension/deposition) must be modeled by use of a bulk mass transfer  
28                    coefficient acting over some length scale. These are both empirical  
29                    parameters to be determined by calibration and should be labeled as  
30                    such. There should be no pretense that somehow these processes are  
31                    being modeled from basic principles." (W. Lick; May 17, 2001)

32          **References:**

33                  Connolly, J.P., J.A. Zahakos, J. Benaman, C.K. Ziegler, J.R. Rhea, and K.  
34                  Russell. 2000. A model of PCB fate in the Upper Hudson River. *Environ. Sci.*  
35                  *Technol.* 34(19):4076-4087.

36                  Velleux, M. and D. Endicott. 1994. Development of a mass balance model for  
37                  estimating PCB export from the Lower Fox River to Green Bay. *J. Great*  
38                  *Lakes Res.* 20(2):416-434.

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1 (d) PCB flux and the depth of the mixing layer on the floodplain. Although some work has been  
2 done on sediment-water fluxes in a river, sediment-water fluxes on the floodplain are quite  
3 different in character. A more detailed investigation of this process is necessary including (a)  
4 field tests of the diffusive flux and (b) some evidence for a mixing layer. What is the cause of the  
5 flux and is there a mixing layer?

6 **RESPONSE 6-WL-10:**

7 The relative importance of these two processes on the floodplain was discussed  
8 in Responses 3-WL-34 and 3-WL-35. In addition, note that these processes are  
9 active only during times when the floodplain is inundated; therefore, they are of  
10 relatively minor importance in comparison to processes in the channel.

11 (e) Grid sizes and number of cells in river. Because of the dissimilar amounts of erosion in the  
12 deeper parts and erosion/deposition in the shallower parts of the cross-section of a river, a  
13 minimum of three cells across the river (two shallow, near-shore cells and one deeper, center  
14 cell) should be used in the calculations. This of course increases the computational time.

15 **RESPONSE 6-WL-11:**

16 Please refer to the response to General Issue 4.

17 However, the computational time can be greatly decreased by (a) separating the hydrodynamic  
18 and sediment transport calculations, (b) for small and moderate flows, approximate and calculate  
19 the hydrodynamics as a sequence of steady-state flows at discrete values, (c) do similar  
20 approximate calculations for sediment transport, and (d) only treat big events in detail. This will  
21 greatly decrease the computational time – more than sufficient to offset the increase in the  
22 number of grid cells. It might also be worthwhile to increase the length of the grid cells and  
23 hence decrease the number of cells along the river.

24 **RESPONSE 6-WL-12:**

25 Please refer to the response to General Issue 3.

26 It is not clear to me at this time how the model deals with erosion/deposition together with  
27 molecular diffusion and bioturbation. To do this properly, the sediment bed should be vertically  
28 divided into layers no more than a centimeter thick with additions and subtractions of mass from  
29 the surface layer as erosion/deposition occurs. Adding on the order of 10 to 20 layers of this  
30 type in the sediment bed does **not** appreciably increase computational time. These are layers  
31 which have essentially no computations associated with them and are only there until needed; in  
32 essence, their presence only requires minimal bookkeeping and no significant computation.

33 **RESPONSE 6-WL-13:**

34 The Reviewer's interpretation of a layered bed with additions or subtractions from  
35 the surface layer due to deposition or erosion is correct. Bioturbation is  
36 represented in EFDC by vertical mixing of contaminants between adjacent  
37 sediment layers to a maximum depth, which is specified through model input,

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1 within which benthic mixing is assumed to occur. Molecular diffusion is  
2 represented by vertical mixing of contaminant concentrations in pore water of  
3 adjacent sediment bed layers.

4 However, it is not correct to assume that there is a minimal effect on  
5 computational time associated with an increase in the number of vertical  
6 sediment layers. An implicit matrix solution scheme computes changes in  
7 concentration in each layer in the entire vertical column of sediment layers of a  
8 particular grid cell. The efficiency of the solution scheme would be lost if  
9 conditional (“if”) statements were added to control the program-logic to segregate  
10 the solution into zones based on biological mixing. In tests of the effect of using  
11 20 vertical layers in the sediment, the total simulation time increased by 40%  
12 because “virtual memory” was required to accommodate the additional array  
13 sizes associated with the increased vertical segmentation in the sediment. The  
14 associated disk input/output (I/O) caused the substantial increase in runtime.

15 These suggestions are not radical, untried, unproved, new ideas. A sediment and contaminant  
16 transport model, SEDZLJ, already exists (Jones and Lick, 2000, 2001, 2002; Lick et al., 2004)  
17 which incorporates most of these ideas. It uses Sedflume data and includes multiple size classes,  
18 a unified treatment of suspended load and bedload, bed armoring, an active layer due to physical  
19 mixing at the surface, HOC flux due to molecular diffusion and bio-diffusion as well as  
20 transport, and fine layering in the vertical in the sediment bed to adequately describe sediment  
21 bulk properties and HOC flux. SEDZLJ is presently being incorporated into EFDC.

### 22 **RESPONSE 6-WL-14:**

23 Although it appears to be the case that SEDZLJ is well developed, not all of the  
24 ideas discussed above (i.e., only “most of these ideas”) are included in the  
25 present version. Thus, further development and testing would be required before  
26 the preceding features would be fully operational, and it is uncertain that the  
27 implementation of this alternative approach would be successful without further  
28 refinements to the model.

29 As recently as February 2005, SEDZLJ was still a one-dimensional model and  
30 not available for distribution (Craig Jones, personal communication, 2005). The  
31 author of SEDZLJ has been working to incorporate SEDZLJ into an earlier  
32 version of EFDC, however, as of August 2005 this code was still being tested  
33 (Jesse Roberts, personal communication, 2005). At this point, EPA does not  
34 believe that it is practical to extract the SEDZLJ code from an alternate version of  
35 EFDC and incorporate it into the version of EFDC being applied to the  
36 Housatonic River. Substantial code changes would be required and would need  
37 to be tested, introducing unacceptable delays in the project.

38 Any state-of-the-art model (such as EFDC) that is applied to a complex system  
39 such as the Housatonic River must undergo continual testing and development.  
40 It will always be possible, in hindsight, to identify more recently developed  
41 models or formulations that may provide new and useful features, but have not

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1           undergone the rigorous testing that would be required for implementation within  
2           the modeling study.

3           Further discussion related to this general subject matter is included in the  
4           response to General Issue 3.

### 5           **References:**

6           Jones, C. 2005. Personal communication (e-mail) from Craig Jones, Sea  
7           Engineering, to Edward Garland, HydroQual, re: response to inquiry about  
8           availability of computer model, SEDZLJ.

9           Roberts, J. 2005. Personal communication (e-mail) from Jesse Roberts, Sandia  
10          National Laboratories, to Edward Garland, HydroQual, re: status of efforts to  
11          incorporate SEDZLJ in EFDC.

### 12          **E. John List:**

13          Overall I am impressed at the depth and breadth of the work that has been completed and feel  
14          much more positive about the outcome than I did four years ago. The shortcomings in the  
15          modeling that have been identified here, and by others on the Peer Review Committee, can most  
16          probably be rather easily overcome. There is some additional calibration work that is necessary  
17          before the model can be used to predict future conditions with any degree of confidence. The  
18          issues that I see that need resolving are:

19          1.        Attempt to resolve why PCB concentrations within the river reach have such extreme  
20          spatial variability on a horizontal scale. Is it because the PCB was initially released as free  
21          product and formed droplets that were carried by the stream and deposited out of the water  
22          column, or is it some other reason? Does the spatial inhomogeneity of PCB in the sediments  
23          reflect spatial inhomogeneity of organic carbon, and if so, why is the organic carbon distribution  
24          spatially inhomogeneous? Now that no further new releases of PCB are occurring will the  
25          erosion-deposition processes in the river lead to homogenizing the PCB concentrations in the  
26          sediment? If not, what is the mechanism by which the inhomogeneity is being maintained? How  
27          can this mechanism be included in the fate and transport model? If it cannot be readily  
28          incorporated is it still possible to use such a model to describe the fate and transport of the PCB?  
29          It is not a satisfactory response to simply ignore the issue. Given that the modeling exercise is  
30          chartered with predicting the outcome of remediation strategies it is my opinion that the fate and  
31          transport modeling process applied so far, which focuses only on spatially-averaged  
32          concentrations in a situation where there is extreme spatial variability, is inappropriate. The  
33          failure of the study team to investigate and understand the basis for this extreme, and apparently  
34          temporally sustained, spatial variability in concentration, is somewhat disturbing, especially  
35          when it appears to be of such importance to understanding the fate and transport of the PCB.

36          It is not sufficient to simply acknowledge this deficiency with the statement (pg. 5-58): “This  
37          variability, which is a combination of stochasticity and analytical variability, is not represented  
38          in the model inputs, and therefore it is not represented in the model output.”

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1           **RESPONSE 6-JL-1:**

2           Although there is small-scale spatial variability in sediment TOC, it is not  
3           sufficient to explain the more pronounced variability in PCB concentrations, i.e.,  
4           carbon-normalized PCB concentrations are not uniform throughout the PSA. As  
5           discussed in the response to General Issue 5, although it may be desirable to  
6           understand such small-scale processes, EPA does not believe such an  
7           understanding is necessary to achieve the goals of the modeling study.

8           EPA's approach is consistent with observations from the same Reviewer during  
9           the Peer Review of the Modeling Framework Design:

10                   “The model that is proposed will attempt to describe the rates of erosion  
11                   and deposition on a 20-meter grid plan. . . . It is implausible to think that  
12                   the riverbed sediments can be characterized on a grid scale this small, so  
13                   that attempting to model the fate of the sediment on such a scale appears  
14                   quite inappropriate. In any case, the model output is to be aggregated . .  
15                   . on a grid scale that is about 250 times as large.” (J. List, May 22, 2001)

16           Please refer also to the response to General Issue 1.

17           2.       Representation of a section of river by a single element that averages over the lateral  
18           extent of the basic channel is unlikely to provide the resolution of erosion and deposition that is  
19           required. In my opinion at least three basic elements are needed to represent the potential for  
20           erosion and deposition to occur at the same river mile, which is what really happens in most  
21           streams with which I am familiar.

22           **RESPONSE 6-JL-2:**

23           In his observations during the MFD Peer Review, the same Reviewer indicated  
24           that a single element across the lateral extent of the channel would be adequate:

25                   “It therefore would appear to make much more sense to use these data to  
26                   calibrate a transport model that is based upon a one-dimensional  
27                   representation of the river system.” (J. List, May 22, 2001)

28           and

29                   “The basic problem is not with the theoretical rigor of the equations, but  
30                   with the context within which they are placed. For example, the description  
31                   of resuspension and erosion of particles can be described quite  
32                   adequately by using the empirical data developed by the SEDFLUME  
33                   apparatus. The issue becomes how to use these data in the modeling  
34                   when it is known from the sediment sampling in the river channel and  
35                   flood plains that the sediments are extremely variable with respect to the  
36                   rate of erosion. It is not possible to describe completely the surface and  
37                   depth distribution of the sediment properties that control erosion at the fine

## Model Calibration Responsiveness Summary

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1 scale necessary to apply a two-dimensional model with a 20-meter (or  
2 less) grid scale.” (J. List, May 22, 2001)

3 Please refer also to the response to General Issue 4.

4 3. The issue of why the modeling does not adequately reproduce the variance of tPCB  
5 concentration in the water column and in the biota needs resolving. If the model cannot resolve  
6 the variance of the distributions of PCB it is difficult to see how any statistical hypothesis  
7 regarding the relative efficacy of different remediation strategies can be properly resolved by the  
8 output of the modeling.

9 **RESPONSE 6-JL-3:**

10 EPA does not agree that it is necessary to resolve the variance of the  
11 distributions of PCB to achieve the goals of the modeling study. As the Reviewer  
12 observed during the MFD Peer Review:

13 “. . . from the sediment flux data that have been developed in the field it  
14 should be possible to give average sediment properties that can be used  
15 to describe in a general way the resuspension of river bed sediments and  
16 flood plain sediments. This is not unusual in fluid mechanics; sometimes  
17 less is more.” (J. List, May 22, 2001)

18 Please refer also to the responses to General Issues 1 and 10.

19 4. Some basic statistical analysis on both the data input to the EFDC model and its output  
20 appears not to have been completed. In the absence of this analysis it is not clear if variations in  
21 the input data (e.g., mean PCB concentrations in the sediment elements along the river) have any  
22 statistically significant variation from one end of the 11-mile river reach to the other.

23 **RESPONSE 6-JL-4:**

24 Please refer to Response 4-JL-3.

25 The predicted fluxes of PCB and sediment similarly appear to have no uncertainty analysis.  
26 These are serious omissions that can easily be corrected.

27 **RESPONSE 6-JL-5:**

28 Please refer to the response to General Issue 11.

29 5. The apparent bias in the food chain model in Reach 5D needs resolution. In the absence  
30 of any field data in this reach it is difficult to make an unequivocal judgment that it is actually  
31 model bias, but the results are so far out of congruence with the other reaches that it is very  
32 suggestive of something amiss in the modeling.

## Model Calibration Responsiveness Summary

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- 1        **RESPONSE 6-JL-6:**
- 2        Please refer to Response 2-JL-1.

### 1 **ADDITIONAL COMMENTS**

#### 2 **Douglas Endicott:**

3 I think a good technical writer could do a lot with this report in terms of improving readability  
4 and clarity.

#### 5 **RESPONSE AC-DE-1:**

6 EPA recognizes that the Model Calibration Report (particularly the technical  
7 appendices) presents a large amount of highly technical information. In fact, the  
8 document did undergo careful and iterative editing to improve consistency,  
9 clarity, and readability.

10 EPA will direct more effort toward streamlining and reformatting the Model  
11 Validation Report to improve readability.

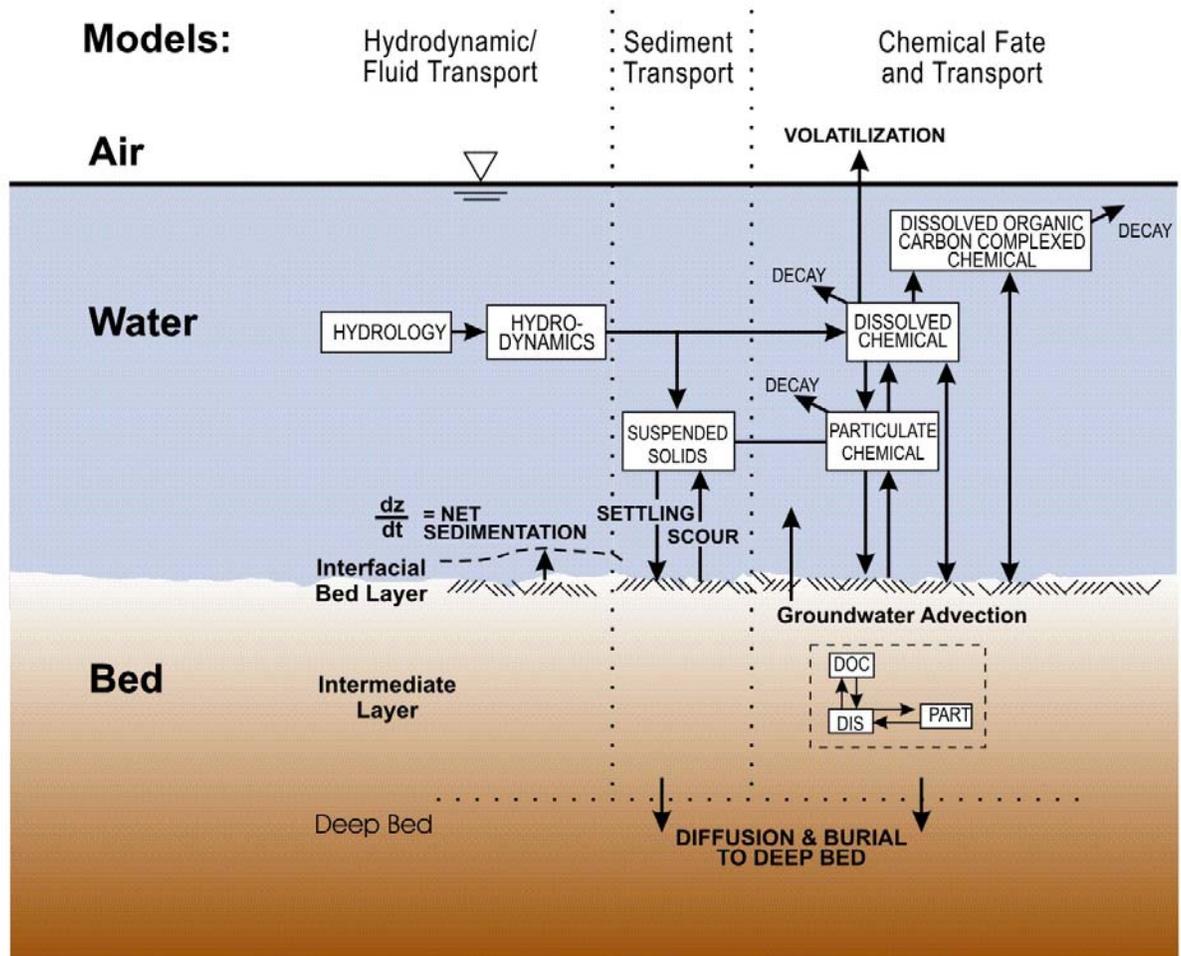
#### 12 *PCB Fate and Transport Schematic:*

13 I usually take the time to examine model schematics, and I find them particularly valuable in  
14 understanding how the conceptual model is applied. In this case (Figure B.4-1) there are a  
15 number of errors in the schematic which should be corrected. These errors should be obvious to  
16 the modeling team.

#### 17 **RESPONSE AC-DE-2:**

18 A revised version of the schematic is presented as Figure AC-DE-2. The  
19 bioaccumulation portion of the original figure has been eliminated because those  
20 calculations are performed in FCM.

# Model Calibration Responsiveness Summary



1

2

**Figure AC-DE-2 Schematic of EFDC and Linkage of Hydrodynamic/Fluid Transport, Sediment Transport, and Fate and Transport Submodels**

3

4  
5 *Bioaccumulation of coplanar PCBs:*

6 As previously commented, I don't believe that the "correction factor" approach used in the food  
7 chain model to reduce the bioavailability of coplanar PCBs is scientifically correct. Based  
8 primarily on comparisons of the highest-quality measured PCB BSAFs for fish to model  
9 predictions assuming no metabolism (Burkhard et al., ES&T 2004), it appears that congener 77  
10 and possibly congener 126 to a lesser extent are very slightly reduced through metabolism. Since  
11 the congener-specific metabolism would probably be aryl hydrocarbon receptor (AHR)  
12 mediated, metabolism in invertebrates is unlikely (i.e., it should only be taking place in the  
13 FISH). One cannot rule out a bioavailability effect associated with affinity of more planar PCBs  
14 with small amounts of black carbon in water and sediments. I think this should be addressed in  
15 greater depth in the Bioaccumulation section of the Calibration report.

## Model Calibration Responsiveness Summary

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### 1           **RESPONSE AC-DE-3:**

2           EPA believes that there are multiple potential explanations and uncertainties  
3           associated with the observed phenomenon of lower bioavailability of certain  
4           coplanar PCB congeners. Although metabolism was identified as a potentially  
5           relevant process in the Model Calibration Report, EPA did not intend to imply that  
6           metabolic clearance was the only explanation for the observed differences. The  
7           approach used in the Model Calibration Report does not include an assumption  
8           about the specific mechanism by which reduced uptake occurs. As such, the  
9           derivation of an empirical scaling factor based on fish BSAFs (i.e., comparisons  
10          of fish:sediment concentration ratios for coplanar congeners versus ratios for  
11          recalcitrant congeners) does not discriminate between differences in  
12          bioavailability for prey (including invertebrates) or fish.

13          Because no assumptions regarding the mechanism resulting in the reduction in  
14          bioaccumulation for certain congeners were made, the application of the  
15          empirical scaling factors to the base of the food web is a reasonable approach  
16          that results in acceptable model calibration for these congeners in fish. The  
17          uncertainty in invertebrate PCB concentrations is greater, however, and the  
18          Reviewer is correct that these uncertainties should have been discussed in  
19          greater detail in the Model Calibration Report.

20          EPA agrees that if congener-specific differences are mediated only by the Ah  
21          receptor, the simulations of invertebrate tissue concentrations would be biased  
22          low by FCM for the congeners in question. On the other hand, if congener-  
23          specific differences are mediated by the bioavailability effect associated with the  
24          affinity of more planar PCBs to small amounts of black carbon, reduced PCB  
25          bioaccumulation in invertebrates would be expected. Based on examination of  
26          simulated versus measured coplanar concentrations in benthic invertebrates  
27          (Figure C.3-16), it is unclear whether the model should adjust coplanar  
28          bioavailability at the base of the food web (affecting all organisms), or only in fish  
29          and not in invertebrates.

30          EPA acknowledges that incorporating congener-specific correction factors for  
31          coplanar congeners introduces some additional uncertainty. EPA does not  
32          believe there is sufficient information in the literature to mechanistically specify  
33          processes of reduced uptake related to metabolism, black carbon, or other  
34          congener-specific factors with any more certainty. As such, the invertebrate  
35          simulations are more uncertain for these congeners than the simulations for fish,  
36          and should be either excluded from the report, or the uncertainties discussed in  
37          more detail in the report.

38          Even with these uncertainties, EPA believes that the evaluation of model  
39          performance for specific congeners in fish (with or without bioavailability  
40          adjustments for coplanar congeners) provided a useful test of model robustness  
41          for this class of contaminants.

## Model Calibration Responsiveness Summary

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1 *PCB elimination by fish:*

2 Biphasic (multicompartment or deep storage) elimination is sort of a hidden feature within the  
3 QEA foodchain model. By that, I mean the literature documenting the development and  
4 application of this model does not address this fairly important feature (as far as I am aware).

5 **RESPONSE AC-DE-4:**

6 Section 6.2.5.4 of the Model Calibration Report discusses biphasic elimination  
7 under the heading "Contaminant Elimination in Fish." This brief summary also  
8 points the reader to Section 1.4.4 of the "Detailed Model Description"  
9 (Attachment C.1, pages 15-18). These four pages describe the rationale for the  
10 biphasic elimination model in more detail. Several lines of evidence to support  
11 the model are explored and numerous references are provided. This material  
12 was obtained from the QEA Hudson River model report (QEA, 1999).

13 **Reference:**

14 QEA (Quantitative Environmental Analysis, LLC). 1999. PCBs in the Upper  
15 Hudson River. Volume 2 - A Model of PCB Fate, Transport, and  
16 Bioaccumulation. Report prepared for the General Electric Company, Albany,  
17 NY. Amended July 1999. URL:  
18 [http://www.ge.com/files/usa/en/commitment/ehs/hudson/Volume\\_2.pdf](http://www.ge.com/files/usa/en/commitment/ehs/hudson/Volume_2.pdf)

19 Again, this should be addressed in greater depth in the Bioaccumulation section of the  
20 Calibration report. In addition, computed elimination rates should be compared to rates measured  
21 in fish.

22 **RESPONSE AC-DE-5:**

23 As part of model calibration, EPA did conduct tests of rate parameters (e.g.,  
24 elimination rate tests) and gauged the model output against values obtained from  
25 the literature. EPA will consider documenting some of these tests in the Model  
26 Validation Report. Please refer also to Response AC-DE-4 above  
27 (documentation of biphasic elimination).

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**ATTACHMENT 1**

**FRESHWATER BIOTURBATION DEPTH**

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## ATTACHMENT 1

### FRESHWATER BIOTURBATION DEPTH

#### 1. INTRODUCTION

##### 1.1 OBJECTIVES

The EFDC model (and the linkage between EFDC and FCM) requires specification of the depth of the surface sediment layer(s) that exchange PCBs with overlying water via the processes of advection and/or diffusion (variously termed the "active," "well-mixed," "bioavailable," or "bioturbation" layer).

The objectives of this review were to:

- Estimate the sediment depths over which biological mixing of sediment occurs in Housatonic River sediment (i.e., bioturbation depths).
- Estimate how the bioturbation depths vary as a function of substrate/habitat type within the Primary Study Area (PSA).
- Determine the depth of the surface sediment layer that best estimates the average exposures of benthic organisms in the food web. This depth is related to the bioturbation depths described above.

No direct site-specific measurements of bioturbation depths have been made in the PSA. Therefore, estimates of bioturbation depths were based on literature studies that were screened for relevance to the Housatonic River. Characterizations of physical substrate and biology of the Housatonic River (e.g., Ecological Characterization presented in the Ecological Risk Assessment [WESTON, 2004a]), sediment profiling, and invertebrate taxonomy and life history were considered in the review.

##### 1.2 TERMINOLOGY

The evaluation of bioturbation requires definition of several terms. The definitions below are intended to specify how these terms are used in this document:

## Model Calibration Responsiveness Summary

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- 1           ▪ *Bioturbation* – The displacement and mixing of bed sediment particles by benthic  
2 organisms. All animals that feed, burrow, move, or excrete in or on the sediment  
3 cause bioturbation (Campbell et al., 1988). Bioturbation is defined to include  
4 biologically mediated sediment mixing, and excludes abiotic processes such as  
5 sediment erosion and deposition.
- 6           ▪ *Bioturbation depth* – The total depth over which bioturbation occurs. This total depth  
7 has been conceptualized as two sublayers, including the *biologically mixed layer* (i.e.,  
8 shallow thorough mixing) and the *biologically influenced layer* (i.e., deeper, less  
9 intense, mixing) (see Figure 1).
- 10          ▪ *Sediment mixing* – The rearrangement of sediment particles from all processes,  
11 including both bioturbation and physical fate and transport processes, such as  
12 sediment erosion and deposition.
- 13          ▪ *Well-mixed layer* – The layer of sediment that lacks a consistent vertical profile in  
14 PCB contamination due to sediment mixing.
- 15          ▪ *Well-mixed depth* – The depth of the well-mixed layer within the sediment bed.
- 16          ▪ *Biologically mixed layer* – The surface sediment layer in which bioturbation results in  
17 substantial reworking of sediment particles. The depth of this layer is significantly  
18 influenced by the maximum depth to which benthic organisms feed, because feeding  
19 activities generally play the greatest role in sediment reworking (see Figure 1).
- 20          ▪ *Biologically mixed depth* – The depth of the biologically mixed layer within the  
21 sediment bed.
- 22          ▪ *Biologically influenced layer* – The subsurface sediment layer over which  
23 bioturbation occurs, but where infaunal densities are lower and rates of sediment  
24 reworking decrease. The depth of this layer is generally greater than that of the  
25 biologically mixed layer described above, because benthic organisms occur at depths  
26 greater than their maximum feeding depth, and exert some physical influence on  
27 sediment at these depths. Therefore, although the greatest magnitude of sediment  
28 mixing is observed within the zone of active feeding, bioturbation can also occur  
29 from other processes (e.g., biodiffusion).
- 30          ▪ *Biologically influenced depth* – The depth of the biologically influenced layer within  
31 the sediment bed.
- 32          ▪ *Bioavailable depth* – The depth of the surface sediment layer that best approximates  
33 the average sediment PCB exposures of infaunal invertebrates. Depending on the  
34 vertical distribution of organism densities, bioavailable depth can differ from the  
35 bioturbation depth.

## 1 2. LITERATURE REVIEW

### 2 2.1 METHODS

3 To identify relevant information on infauna-mediated vertical mixing in sediment, a detailed  
4 literature review was conducted. Extensive bibliographies relating to bioturbation and sediment  
5 flux were compiled by EPA contractors, and supplemented with information provided by  
6 General Electric (GE) (QEA, 2005). These bibliographies, which included a total of 139  
7 documents, were the starting point for the literature review.

8 For each of the 139 documents, the following evaluation procedure was applied:

9 **Document Screening** – Documents that did not meet the minimum requirements for relevance  
10 were screened out. Documents eliminated from the review included cases for which:

- 11       ▪ The document lacked information regarding depth of sediment (e.g., studies of flux of  
12       contaminants from sediment, studies limited to lateral mixing).
- 13       ▪ The document described the development of a mathematical model for bioturbation  
14       but without accompanying field or laboratory data.
- 15       ▪ The document described a benthic study unrelated to sediment mixing or the  
16       influence of biota on sediment (e.g., studies on bioaccumulation, life cycles,  
17       bioenergetics, etc.).

18 **Data Summary** – In tabular format, relevant data were extracted, including:

- 19       ▪ Sediment substrate characteristics (e.g., grain size, TOC).
- 20       ▪ Types of organisms investigated.
- 21       ▪ Physical environment (e.g., marine vs. freshwater, in situ study vs. microcosm).
- 22       ▪ Mixing depth (either directly reported or inferred).
- 23       ▪ Other relevant data (e.g., vertical distribution of benthos, depth-related influence of  
24       biota on sediment).

25 **Relevance Ranking** – For each study retained following the screening stage, a qualitative  
26 assessment of relevance to the Housatonic River PSA was assigned. The quality and relevance

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1 of each document was categorized as “high,” “moderate,” or “low” based on the following  
2 criteria:

- 3       ▪ High Relevance – A document was categorized as having high relevance if it  
4 considered a freshwater environment and met all of the following criteria:  
5 (1) contained data on vertical mixing; (2) sediment characteristics (e.g., grain size,  
6 TOC) were provided and approximated those in the PSA; (3) the types of organisms  
7 responsible for the sediment mixing described in the paper were similar to those in  
8 the PSA. The requirement for freshwater studies was based on the observation that  
9 biologically mixed layers in marine systems tend to be slightly deeper than in rivers  
10 and lakes (Clarke et al., 2001).
- 11       ▪ Moderate Relevance – A document was categorized as having moderate relevance if  
12 it considered a freshwater environment and did not satisfy all the criteria for high  
13 relevance, but satisfied one of the following conditions: (1) included data on vertical  
14 mixing but insufficient information to determine whether the sediment type  
15 resembled that of the PSA; (2) vertical mixing depth in sediment was not directly  
16 reported, but the information provided was sufficient to infer the biologically active  
17 depth. Examples of the latter included the following: studies reporting the maximum  
18 depth at which a chemical tracer compound was released to the water column  
19 following sediment mixing; information on the physical influence of benthos on pore  
20 water redistribution; and information on maximum feeding depths of benthos.
- 21       ▪ Low Relevance – Documents that did not meet the criteria for classification as  
22 moderate or high relevance, but that met one or more of the following criteria were  
23 categorized as having low relevance: (1) the document provided information on the  
24 vertical distribution of benthic organisms but did not provide direct information on  
25 the influence of the organisms on sediment mixing; (2) the document described  
26 bioturbation in an environment of limited relevance to the Housatonic River (e.g.,  
27 very coarse sediment, marine or estuarine environments). Marine data were included  
28 in the literature review (but categorized as having low relevance) because there is  
29 some correspondence between marine and freshwater benthic communities in terms  
30 of distribution and intensities of bioturbation processes (Clarke et al., 2001; McCall  
31 and Tevesz, 1982; Rhoads and Boyer, 1982).

32 Identification of biologically mixed depths was made using a combination of directly reported  
33 results from the documents and inferences (using professional judgment). Greater use of  
34 judgment was required for interpretation of studies with low to moderate relevance.

### 1 2.2 RESULTS

#### 2 2.2.1 General Findings

3 Several general themes emerged from the literature review that were useful for evaluating  
4 specific studies and for inferring biologically mixed depths when they were not reported directly.

5 The depth to which bioturbation occurs is a function of the burrowing depth of resident  
6 organisms, the density of the organisms in the substrate, and the behaviors of diverse  
7 assemblages of benthic organisms and their interactions with the physical environment  
8 (Schaffner et al., 1997; Wheatcroft et al., 1994). Bioturbation is primarily the result of feeding  
9 and burrowing behaviors of infaunal and, to a lesser degree, epifaunal benthos. Bioturbation by  
10 most benthos is generally characterized by random mixing. However, mixing by tubificid  
11 oligochaetes is directional due to a feeding behavior characterized by ingestion of sediment at  
12 depth within the sediment bed and egestion at the sediment-water interface (McCall and Fisher,  
13 1979).

14 A variety of macrobenthos play a role in bioturbation, although their contributions may vary due  
15 to differences in factors such as feeding behaviors and burrowing depth. Tubificid oligochaetes  
16 are often considered some of the most effective bioturbators due to their feeding behavior and  
17 maximum feeding depths (generally on the order of 10 cm). Freshwater insects (including  
18 chironomids) and amphipods are also considered important bioturbators, although they tend to  
19 influence a smaller depth range within the sediment bed (Clarke et al., 2001). Bivalves may also  
20 play a significant role in bioturbation with some groups (e.g., Unionidae; large freshwater clams)  
21 influencing more sediment than others (e.g., Sphaeridae; fingernail or pea clams).

22 Bioturbation depth increases with increasing biomass density due to increased competition for  
23 food sources and associated movement. Although some invertebrates burrow deeper than 10 cm,  
24 bioturbation rates are generally considered to decrease with increasing depth in the sediment bed  
25 because organism densities generally decline with increasing depth (Bromley, 1996).

26 Clarke et al. (2001) conceptualized vertical profiles of biological activity as having multiple  
27 distinct bioturbation zones (Figure 1). A surficial zone of intensively reworked sediment is  
28 biologically mixed over relatively short time scales. This layer, which is continually mixed, is

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1 defined herein as the “biologically mixed layer.” Beneath the biologically mixed layer, a mid-  
2 depth zone is characterized by decreasing biological activity with increasing depth. This layer is  
3 defined herein as the “biologically influenced layer.” Deeper zones are poorly understood in  
4 comparison with the overlying zones and are assumed to have negligible to low concentrations of  
5 biological mixing. Clarke et al. (2001) recommended that, at a minimum, bioturbation should be  
6 treated as a two-layer system with an overlying continually mixed layer and an underlying bio-  
7 diffusion layer.

8 The depth of the upper biologically mixed layer has been linked to the activity levels of  
9 invertebrates, and in particular, the depth at which active feeding occurs. Sediment mixing by  
10 oligochaetes is predominantly a function of their feeding behavior rather than mixing caused by  
11 movement (burrowing). Therefore, in sediment where oligochaetes are abundant, the depth of  
12 the biologically mixed layer often corresponds to the maximum feeding depth, which is generally  
13 less than the maximum depth to which benthos frequently burrow (Cunningham et al., 1999;  
14 Fisher et al., 1980).

### 15 **2.2.2 Specific Findings**

16 Of the 139 papers reviewed, 43 passed the preliminary screening stage. Of these, 7 were ranked  
17 as having high relevance, 13 were ranked as having moderate relevance, and 23 were ranked as  
18 having low relevance. The papers that failed the preliminary screening are not included in Table  
19 1 or the list of references. Table 1 summarizes the relevant data from each document. As  
20 expected, the individual documents reported a wide range of biological mixing depths,  
21 depending on the physical and biological environments evaluated.

22 Several of the bioturbation documents consisted of reviews of multiple freshwater environments  
23 and offered general guidance for selection of biological mixing depths, including:

- 24       ▪ Campbell et al. (1988) emphasize the importance of freshwater oligochaetes for  
25       bioturbation, and indicate that bioturbation effects are “most pronounced” in the  
26       upper 6 cm (2 inches) of sediment, with little or no bioturbation below 20 cm (8  
27       inches).
- 28       ▪ Clarke et al. (2001) identified an upper layer subject to frequent and thorough mixing  
29       by shallow bioturbating organisms. This surficial zone, associated with the transition

## Model Calibration Responsiveness Summary

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1           between oxic and anoxic sediment, may extend to a depth of 10 cm (4 inches) or  
2           more.

3           ▪ Fisher (1982) indicated that bioturbation depths for amphipods and sphaeriid clams  
4           are limited to the top few centimeters, but oligochaetes and unionid clams mix  
5           sediment to depths of approximately 10 cm in freshwater environments.

6           ▪ Krezoski et al. (1978) and Ford (1962) suggested that freshwater benthic  
7           macroinvertebrates are often found as deep as 10 cm, but are concentrated within the  
8           top 4 cm (1.5 inches) of sediment.

9           ▪ EPA (2002) conducted a survey of aquatic biologists from several research facilities  
10          around the Great Lakes to evaluate bioturbation depth in a theoretical sandy  
11          freshwater sediment cap colonized mainly by chironomids and oligochaetes.  
12          Although some organisms indigenous to the Great Lakes can burrow 10 to 40 cm in  
13          soft silt or clay sediment, most of the researchers surveyed believed that most  
14          bioturbation in a sand cap would be limited to the top 5 to 10 cm.

15       Overall, the literature summaries suggest that bioturbation is pronounced within the top 5 to 10  
16       cm of sediment at most sites, resulting in frequent and thorough mixing of sediment in this upper  
17       layer. These generic bioturbation estimates were combined with more specific studies  
18       (summarized in Table 1) and site-specific assessment of the Housatonic River (Section 3) to  
19       derive site-specific estimates of bioturbation depths (Section 4).

### 20    **3. SITE-SPECIFIC CONSIDERATIONS**

#### 21    **3.1 HABITAT/SUBSTRATE CHARACTERIZATION**

22       The PSA includes sediment with different physical and biological characteristics that mediate  
23       bioturbation potential. The main channel PSA benthic communities exhibit distinct differences  
24       between upstream and downstream habitats, as described in WESTON (2004a, b). The upstream  
25       habitats (Reach 5A) are dominated by coarser sediment particle sizes (medium sands) relative to  
26       the downstream habitats (Reaches 5B, 5C, and 6) that are dominated by silt. The backwaters  
27       (Reach 5D) represent a third habitat type, characterized by fine sediment but a different  
28       hydrological regime. The downstream reaches have higher sediment total organic carbon (TOC)  
29       content, benthic abundance/biomass, and density of aquatic macrophytes relative to upstream  
30       areas (WESTON, 2004a, b). The biological communities in the PSA reaches reflect these habitat  
31       differences, as discussed in Section 3.2 below.

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1 Mixing depths are expected to vary within the study area based on the differences between the  
2 three general habitats. Therefore, rather than identifying a single mixing depth for the entire  
3 study area, mixing has been described for each of the three habitats. A comparison of three  
4 broad PSA environments is provided in Table 2. The portion of the PSA for which each  
5 document was considered relevant (i.e., Area 1: coarse-grained PSA sediment; Area 2: fine-  
6 grained PSA sediment excluding backwaters; Area 3: Reach 5D backwaters) is noted in Table 1.

7 Combining the vertical stratification of the sediment bed into biologically mixed sediment and  
8 biologically influenced sediment for each of the three habitat types results in the specification of  
9 six discrete biological mixing layers (i.e., 3 habitat types times 2 layers) for the PSA.

### 10 **3.2 SITE-SPECIFIC BIOLOGICAL COMMUNITIES**

11 Clarke et al. (2001) stressed that available knowledge on local bioturbators should supplement  
12 generic assumptions concerning bioturbation processes. Ecological characterization and  
13 taxonomic enumeration of the Housatonic River benthic invertebrate communities are of value  
14 for refining the generic bioturbation estimates cited in Section 2.2.

15 There are two main sources of information for the identification and classification of Housatonic  
16 River bioturbators:

17     ▪ EPA conducted macroinvertebrate community structure sampling in 1999  
18 (WESTON, 2004a, b). At each of 13 locations (12 in the Housatonic River and 1 in  
19 Threemile Pond), EPA collected 12 replicate benthic community samples using a  
20 Petite Ponar sampler. Five of these locations were located in the relatively coarse-  
21 grained substrate upstream of the Pittsfield wastewater treatment plant (WWTP).  
22 Four were located in the finer (silty) substrate between the WWTP and Woods Pond,  
23 and the remaining four stations were established outside the PSA. The sediment  
24 samples were representative of the broad substrate types found throughout the PSA.

25     ▪ On behalf of GE, Chadwick (1994) investigated aquatic ecology at 10 stations in the  
26 Housatonic River, of which 3 were located in the PSA. Station HR1 was located at a  
27 “shallow water” site in the northern half of the PSA, near the confluence with Sykes  
28 Brook. Stations HR2 and WP1 were located in the southern portion (low gradient,  
29 depositional) of the PSA at “deep water” locations. A modified Hess sampler (0.1  
30 square meters [ $m^2$ ], 500 micron [ $\mu m$ ] mesh) was used to sample erosional habitat at  
31 shallow-water stations. An Ekman grab sampler (0.02  $m^2$ ) was used at the deep-  
32 water locations.

## Model Calibration Responsiveness Summary

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1 The communities from each of these programs are summarized in detail in Attachment C.11 of  
2 the Model Calibration Report (WESTON, 2004b) and in Appendix D of the Ecological Risk  
3 Assessment (WESTON, 2004a). Information on habitat, behavior, and trophic relationships was  
4 obtained from summaries provided in Merritt and Cummins (1996), and was used to determine  
5 whether the observed organisms exhibited burrowing behaviors or were mainly associated with  
6 the sediment-water interface (e.g., clingers, climbers, and net-spinners). This information,  
7 together with measurements of total abundance and biomass, and the biomass of known  
8 bioturbators (e.g., tubificid oligochaetes), was used to assess bioturbation potential in each of the  
9 three habitat types. The following sections summarize the main findings used in the refinement  
10 of bioturbation depth estimates.

### 11 **3.2.1 Coarse-Grained PSA Sediment**

12 The Chadwick (1994) study indicated that the majority of organisms in coarse-grained sediment  
13 were dipteran larvae. Of the total composite density (4,471 individuals/square meter), 37% were  
14 sediment burrowers and 60% were surface feeders (3% could not be assigned to either category).  
15 The EPA Ponar samples also indicated that dipterans (e.g., chironomids) were numerically  
16 dominant. However, oligochaetes and bivalves were also common, comprising approximately  
17 half of the invertebrate biomass at most Reach 5A stations (WESTON, 2004a). The most  
18 abundant invertebrate (*Polypedilum calaenum*) was a grazing chironomid larva that dwells upon  
19 vascular hydrophytes, and therefore, has low bioturbation potential. However, numerous other  
20 chironomid species with high Reach 5A abundance (e.g., *Cryptochironomus* spp., *Saetheria*  
21 spp.) burrow in the sediment bed.

22 The overall biomass of invertebrates in the EPA Reach 5A stations was lower (by an order of  
23 magnitude) relative to downstream fine-grained habitats. Part of this difference was attributed to  
24 the higher mean PCB concentrations measured in Reach 5A; however, differences in biomass  
25 were also related to habitat differences (particularly TOC and particle size). The lower organic  
26 carbon content of the coarse-grained sediment results in a poorer source of food energy for  
27 deposit feeding organisms. As a result, the bioturbation potential in Reach 5A is expected to be  
28 lower than for downstream reaches.

### 1 3.2.2 Fine-Grained PSA Sediment

2 The invertebrate community at station HR2 (Chadwick, 1994) was dominated by sediment-  
3 feeding Diptera larvae, including *Dicrotendipes* sp., a burrowing chironomid that was  
4 approximately 25% of the total abundance. Tubificid oligochaete worms were also abundant, at  
5 nearly 15% of the total abundance. Overall, most of the invertebrate fauna were burrowers and  
6 can be assumed to have strong bioturbation potential. The invertebrate community in Woods  
7 Pond (WP1) also exhibited a number of potential bioturbators. The most abundant organism was  
8 the burrowing chironomid larva *Ladopelma* sp., which was approximately 40% of the total  
9 organism abundance. Other common organisms included oligochaetes and numerous burrowing/  
10 sprawling/predatory Diptera larvae.

11 The EPA Ponar sampling (WESTON, 2004a, b) indicated a wide range of life histories and  
12 feeding strategies. The most abundant invertebrates in the fine-grained samples were sphaeriid  
13 clams, chironomids, gastropods, and tubificid worms. Overall, the Ponar grabs indicated a  
14 significant number of burrowing organisms, including a high density of oligochaetes. These  
15 organisms are expected to have high bioturbation potential.

16 Overall, the bioturbation in the fine-grained habitat of the PSA is expected to be more  
17 pronounced than in the coarse-grained habitat. This is due both to the increased abundance and  
18 biomass of organisms and to the increased proportion of organisms that burrow into sediment.  
19 Furthermore, megafauna, primarily large invertebrates and fishes (e.g., carp), may be locally  
20 significant bioturbators (Atkinson and Taylor, 1991) and increase the overall rate and depth of  
21 biological mixing. Carp and goldfish, both of which burrow into sediment, comprise a  
22 significant component of the fish community in downstream fine-grained sediment, but are rare  
23 in Reach 5A.

### 1 **4. APPLICATION TO THE MODEL FRAMEWORK**

#### 2 **4.1 DERIVATION OF BIOTURBATION DEPTHS**

3 For each of the three major habitats in the PSA, two zones of bioturbation influence were  
4 defined, the biologically mixed layer and the biologically influenced layer. Below the  
5 biologically influenced layer, bioturbation is minimal and can effectively be assumed to be zero.

6 Depths of biological mixing were derived primarily considering information extracted from the  
7 documents and are categorized as moderate or high relevance. The information from documents  
8 rated as low relevance was used only as corroborating evidence. For each habitat type, the  
9 subsets of documents considered directly relevant were considered as a group and professional  
10 judgment was used to estimate appropriate bioturbation depths (Table 3).

11 As shown in Table 3, the biologically mixed depth ranges from 4 cm in Reach 5A to 10 cm in  
12 Reach 5D backwaters. These differences among habitats are warranted based on the differences  
13 in organism abundance, biomass, and life history. On average, the biologically mixed depths in  
14 the PSA are lower than default values (i.e., 10 cm) commonly used to estimate well-mixed  
15 depths in marine systems (Boudreau, 1998; Thibodeaux and Bierman, 2003), reflecting the  
16 differences between freshwater and marine environments. There is significant uncertainty  
17 associated with the assignment of the depth and mixing rates, however, based on the variability  
18 measured within and between organisms reported in the literature.

#### 19 **4.2 MODEL LINKAGES**

##### 20 **4.2.1 Derivation of Bioavailable Depth**

21 The bioaccumulation model (FCM) requires specification of a layer of sediment that represents  
22 average sediment PCB exposures to infaunal invertebrates. As shown in Figure 1, sediment  
23 infaunal densities decrease significantly below the biologically mixed layer. PCB concentrations  
24 in the biologically mixed layer are likely to better represent average exposure conditions to  
25 invertebrates that form the base of the food web. Therefore, the bioavailable depth used for the  
26 EFDC to FCM linkage will be defined as roughly equivalent to the biologically mixed depths  
27 shown in Table 3. When EFDC-modeled sediment layers do not correspond directly to the depth

## Model Calibration Responsiveness Summary

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1 intervals shown in Table 3, weighted averaging of the applicable surface sediment concentrations  
2 may be used as estimates of PCB exposure concentrations.

### 3 **4.2.2 Computation of Overall Sediment Mixing**

4 The mixing of sediment in EFDC includes both biological mixing and physical mixing due to  
5 hydrodynamic processes. The bioturbation depths specified in Table 3 will be used to specify  
6 layers of sediment in EFDC, with separate biological mixing coefficients specified for the  
7 biologically mixed layer and the biologically influenced layer, respectively. Professional  
8 judgment will be required to select mixing coefficients that simulate “thorough” and “partial”  
9 mixing in these two zones. The erosion and deposition kinetics in EFDC will introduce  
10 additional mixing that is handled separately from bioturbation.

## 11 **5. SUMMARY**

12 Based on an extensive literature review of freshwater bioturbation, and considering site-specific  
13 data on habitat and resident benthic communities, bioturbation depths were estimated for each of  
14 three PSA habitat types. The biologically mixed depth, which represents the sediment layer that  
15 is thoroughly mixed due to bioturbation, was determined to range from 4 cm to 10 cm across the  
16 PSA, depending on habitat, with deeper mixing found in depositional areas with high sediment  
17 TOC. Deeper, but less pronounced, biological mixing (i.e., biologically influenced depth) is  
18 estimated to occur at depths up to 20 cm below the sediment-water interface.

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Table 1

## Summary of Bioturbation Literature Review

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
Clarke et al.	2001	Technical note presenting guidance on estimation of bioturbation profiles, depths, and process rates in relation to subaqueous sediment cap design	General	General	General	Freshwater silts/clays: 0-10 cm fully mixed; 10-30 cm partial mixing; freshwater sands: 0-10 cm fully mixed; 10-20 cm partially mixed	Relevant for all categories; mixing depths based on a literature review completed as part of the study.	1, 2, and 3	High	Sufficient data on mixing and sediment characteristics
Davis	1974b	Study of stratigraphic effects of tubificids in profundal lake sediment	Tubificid worms	Messalonskee Lake sediment; TOC 13-19% (dry weight basis)	Microcosm: freshwater lake sediment, total sediment depth >50 cm	Feeding primarily at 2-5 cm below surface; displacement of tracers predominantly in upper 8 cm and exclusively in upper 15 cm		3	High	Sufficient data on mixing and sediment characteristics
Fisher et al.	1980	Study of vertical mixing of lake sediment by tubificid oligochaetes	Oligochaete ( <i>Tubifex tubifex</i> )	Silt-clay from Lake Erie	Microcosm: freshwater lake sediment, total sediment depth 13-15 cm	Complete mixing up to 7 cm; some mixing up to 9 cm		2 or 3	High	Sufficient data on mixing and sediment characteristics
Krezoski et al.	1984	Study of maximum depth of radio-labeled compound redistribution	Oligochaete ( <i>Stylodrilus heringianus</i> ), amphipod ( <i>Pontoporeia</i> )	Sandy silt from southern Lake Michigan	Microcosm: freshwater, 20 cm sediment depth	4-5 cm for oligochaetes, 1.5 cm for amphipods	Study also includes sediment transport rates.	2	High	Sufficient data on mixing and sediment characteristics
Krezoski et al.	1978	Study of influence of benthos on mixing of profundal sediment in Lake Huron	Amphipods, Oligochaetes, Pelecypoda (some Mysidae, Diptera)	Sandy silt from Lake Huron	In situ: Lake Huron	3-6 cm (greater mixing depth with greater oligochaete abundance)		2	High	Sufficient data on mixing and sediment characteristics
Larsson	1983	Study of transport of PCBs from sediment to water and from water to air	Chironomids ( <i>Chironomus plumosus</i> -type) and tubificids ( <i>Tubifex tubifex</i> )	Sandy sediment from Lake Havgardsson (southern Sweden)	Microcosm: freshwater, sediment depth 11 cm	PCB mixing down to 3 cm		1	High	Sufficient data on mixing and sediment characteristics
McCall and Fisher	1979	Study of effects of oligochaetes on physical and chemical properties of lake sediment	Tubificid oligochaetes ( <i>Tubifex tubifex</i> )	Lake Erie mud (clay content 21% to 65%; TOC 6% to 9%)	Microcosm: freshwater, Lake Erie sediment (total depth 10 cm)	Well mixed at 5-10 cm	Sediment depth in microcosm may not have been sufficient to adequately characterize mixing depths.	3	High	Sufficient data on mixing and sediment characteristics
Campbell et al.	1988	Review of information on biologically available metals in sediment. Includes some general information on bioturbation	General	General	General	Well mixed up to 6 cm; no mixing below 20 cm.		General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Davis	1974a	Study of effect of tubificids on redox potential and pH in profundal lake sediment	Tubificids ( <i>Limnodrilus hoffmeisteri</i> , <i>L. claparedeianus</i> )	Messalonskee Lake (Maine) sediment: noncalcareous copropelic gyttja, TOC 13-19%	Microcosm: freshwater, sediment depth 18 cm	Not directly provided	Tubificids influenced redox and pH in upper 15 cm of sediment.	3	Moderate	Information on influence of benthos on sediment, mixing depths could not be identified

Table 1

## Summary of Bioturbation Literature Review (Continued)

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
EPA	1987	Development of mathematical descriptions of processes controlling the exchange of chemicals between sediment and overlying water; depth of re-working provided for various species from other sources	Various	Not given	Not given	Marine gastropods: 2 mm; estuarine bivalves: 2 cm; freshwater oligochaetes: 4-6 cm	Mixing depths cited in the paper are based on data from other sources.	General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
EPA	2002	Overview of considerations for in situ cap design	General	Sand, silt, clay	Great Lakes - freshwater	Approximately 5-10 cm in sand; greater in silts and clays	Burrowing up to 10-40 cm expected for a silt or clay; depth of bioturbation by marine benthos generally greater than freshwater benthos.	General	Moderate	General information regarding sands provided; insufficient information regarding physical or biological environment
Fisher	1982	Review of effects of macrobenthos on chemical changes in sediment occurring during and after burial	General	General	General freshwater	Amphipods, sphaerid clams: 1-3 cm; tubificid oligochaetes, unionid clams: ~10 cm		2 or 3	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Jernelov	1970	Study of release of methylmercury from sediment	Tubificidae and Anodonta (mussels)	Eutrophic lake sediment; grain size and TOC not provided	Microcosm: freshwater, sediment depth 20 cm	Not directly provided	Release from up to 3 cm for Tubificidae, up to 10 cm for Anodonta; extent of mixing not quantified; sediment physical characteristics not provided.	Likely 2 or 3	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Karickhoff and Morris	1985	Study of impact of tubificid oligochaetes on pollutant transport in sediment; focus not on mixing depth, limited microcosm sediment depth	Tubificid oligochaetes ( <i>Limnodrilus hoffmeisteri</i> , <i>Tubifex tubifex</i> )	Sand (50-80%); TOC 0.5-1.5%	Microcosm: freshwater stream sediment, total depth 2-5 cm	At least 3 cm	Based on interpretation of data presented graphically in the paper.	1	Moderate	Data on mixing inferred from the information provided in the paper
Krantzberg	1985	General review of the influence of bioturbation on physical, chemical, and biological parameters in aquatic environments	General benthic invertebrates; oligochaetes and amphipods considered important for bioturbation	Various	Various	3-20 cm		General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Krantzberg and Stokes	1984	Study of effect of benthos on copper and zinc partitioning in sediment; focus on geo-chemical changes and release of metals to water column	Chub Lake: Chironimidae, Tanypodinae, Chaoborus Lohi Lake: Chironomidae, Chaoborus, Tubificidae Port Credit: Tubificidae	Freshwater lake sediment, no details on grain size or TOC	Microcosm studies using sediment from Chub Lake, Lohi Lake, and Port Credit; total sediment depth 10 cm	Not directly provided	Data indicate possible greater influence of benthos in upper 5 cm compared to 5-10 cm depth (microcosm sediment depth = 10 cm).	General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Matisoff and Wang	1998	Study of solute transport in sediment by infaunal bio-irrigators	Chironomids ( <i>Coelotanypus</i> sp. and <i>Chironomus plumosus</i> ) and mayfly larvae ( <i>Xexagenia limbata</i> )	Lake Erie sediment: silt and clay	Microcosm: 20-25 cm depth	Not directly provided	Solute transport depth: <i>Coelotanypus</i> sp: 3.0 cm; <i>Chironomus plumosus</i> : 5-9 cm; mayfly: 5 cm.	2 or 3	Moderate	Focus on influence of benthos on solute transport and not sediment mixing

Table 1

## Summary of Bioturbation Literature Review (Continued)

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
Matisoff et al.	1999	Study of biological redistribution of lake sediment by tubificid oligochaetes	Oligochaetes: <i>Branchiura sowerbyi</i> , harbour worms ( <i>Limnodrilus hoffmeisteri</i> , <i>Tubifex tubifex</i> )	Lake Erie mud	Microcosm: freshwater, sediment depth 10-15 cm	Harbour worms: well mixed to approx. 5 cm, some mixing to at least 10 cm; <i>B. sowerbyi</i> : well mixed to approx. 13 cm	Based on interpretation of data presented graphically in the paper.	2 or 3	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
McCall and Tevesz	1982	General review of effects of benthos on freshwater sediment physical properties	General	General	General	Mixing depth varies but generally well mixed up to 8 cm or less	Oligochaete feeding depth varies up to 8 cm, depending on species and density.	General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Mermillod-Blondin et al.	2005	Study of influence of tubificids on fate of organic matter and pollutants in stormwater sediment; focus on biogeochemical processes	Tubificid worms ( <i>Tubifex tubifex</i> )	Sediment from bed of a stormwater infiltration basin, no information on grain size or TOC	Microcosm: total sediment depth 10 cm	Not directly provided	Tubificids appear to influence primarily the upper 5 cm of sediment.	General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Thibodeaux and Bierman	2003	General review of the process of bioturbation-driven release of chemicals from the sediment bed	General	General	General	Not directly provided	Bioavailable surface layer typically around 10 cm depth.	General	Moderate	Sufficient data on mixing, insufficient information on sediment characteristics
Bishop	1973	Study of vertical distribution of benthos in a Malaysian stream; no details on mixing	General (primarily chironomids)	Some fine sediment mixed with coarser sands and gravels	In situ, freshwater, moderately flowing riffle area	Not directly provided	Highest percentage of organisms found at 0-10 cm depth but significant proportions found up to 40 cm.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Boudreau	1998	Development of a resource-feedback model of bioturbation that predicts the existence of a finite-depth bioturbated zone with a universal mean mixing depth of 9.7 cm, which is consistent with a previously defined mixing depth of 9.8 cm $\pm$ 4.5 cm, based on empirical data from marine environments	General	Marine sediment (general)	Marine sediment (general).	9.7 cm		-	Low	Marine
Boudreau	1994	Evaluation of relationship among mixing coefficient, mixing depth, and burial velocity using data from coastal, shelf, slope, and deep-sea environments	General	Marine sediment (general)	Marine sediment (general)	9.8 $\pm$ 4.5 cm		-	Low	Marine
Brannon et al.	1985	Study of cap depth required to isolate contaminated dredged material from biota and overlying water	Clam ( <i>Rangia cuneata</i> ), Polychaete ( <i>Nereis virens</i> )	3 types of capping materials: sand, silt, and clay	Microcosm: marine, varying sediment and cap depths	Not directly provided	A cap of 50 cm was sufficient to prevent chemical transfer from contaminated sediment to overlying water; a cap of 5 cm was not sufficient.	-	Low	Marine
Cunningham et al.	1999	Focus on pyrene loss in upper 15 mm sediment due to flux, degradation, and/or enhanced microbial processes associated with bioturbation	Oligochaete ( <i>Limnodrilus cervix</i> )	Campus Lake sediment: silty loam; TOC 1.12%	Microcosm: freshwater, 3.5 cm depth of sediment	Not directly provided	Effects on sediment geochemistry observed throughout upper 1.5 cm (no data for deeper sediment).	-	Low	Insufficient study depth: focus on geochemistry of upper 1.5 cm

Table 1

## Summary of Bioturbation Literature Review (Continued)

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
Danielopol	1976	Study of distribution of invertebrates in river sediment; no information on mixing; coarse sample intervals (i.e., large depth range for samples)	Various	Various (freshwater)	Danube River	Not directly provided	Highest densities in the upper 0.5 m.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Davis	1983	Study of effect of polychaetes on sediment-water interface and exchange of copper between sediment and sea water	Polychaete ( <i>Nephtys incisa</i> )	Fine-grained, high silt-clay; 10-11% TOC	Microcosm: marine	Total bioturbation zone 20-30 cm		-	Low	Marine
Ford	1962	Study of distribution of invertebrates; no information on mixing	Various	Mud from a small stream	Stream	Not directly provided	Chironomids: 79% in upper 2.5 cm, 98% in upper 5 cm; oligochaetes found throughout total sample depth (upper 20 cm); other less abundant invertebrates found up to 15 cm depth.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Godbout and Hynes	1982	Study of distribution of invertebrates in a creek	Various	Cobbles with pebbles, gravel, and sand	Uniform riffle, Salem Creek (Ontario)	Not directly provided	Most invertebrates present in upper 25 cm, highest abundance in 5-15 cm sample.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Green and Chandler	1994	Study of meiofaunal bioturbation effects on partitioning of sediment-associated cadmium	Harpacticoid copepod ( <i>Amphiascus tenuiremis</i> ), Foraminiferan ( <i>Ammonia beccarii</i> )	<63 µm, TOC 3.8%	Microcosm: sediment depth 1.2 cm; salinity 30.4 ppt	Foraminifera: 0-3 mm well mixed; 3-5 mm some mixing; copepods: 0-5 mm well mixed; 5-1.2 mm some mixing		-	Low	Marine
Gunnison et al.	1987	Development and evaluation of a small-scale predictive test for identifying minimum cap thickness for contaminated sediment	Various	Various types of capping materials	Microcosm: marine, varying sediment and cap depths	Not directly provided	A cap depth of 22 to 50 cm was required for isolating contaminated sediment from benthos and overlying water.	-	Low	Marine
Kirchner	1975	Study of effect of oxidized material on vertical distribution of benthos. Focus on vertical distribution of benthic invertebrates	Ostracoda, Nematoda, Oligochaeta, Harpacticoida, Cyclopoida, Chironomidae	Fine silt (primarily dolomite)	Char Lake, Northwest Territory	Not directly provided	Biomass predominantly in upper 3-4 cm.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Maridet et al.	1996	No information on mixing but detailed information on vertical distribution of organisms	Primarily Chironomidae, Elmidae, and Leuctridae	Stream sediment; no details on grain size or TOC	Mountain stream sediment (France), in situ	Not directly provided	70-96% of individuals found in upper 15 cm.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment

Table 1

## Summary of Bioturbation Literature Review (Continued)

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
Martin et al.	2005	Qualitative assessment of bioturbation influence on Lake Baikal sediment	Various (most abundant were oligochaetes, nematodes, copepods)	Mud	Lake Baikal (water depths 128 m to 623 m) - freshwater	6 cm at water depth of 128 m, with benthos penetration to 15 cm; thinner depths observed at deeper sites	Depth of mixing decreased with increasing water depth.	-	Low	Deep lake environment
Morris and Brooker	1979	Study of vertical distribution of macroinvertebrates	Various	Not given	River Wye, Wales	Not directly provided	82% of organisms found in upper 22 cm.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Piercey	1980	Study of effect of benthic community on pore water chemistry	Various	Not given	Potomac River estuary, fluctuating salinity	Not directly provided	Pore water in top 10 cm of well-burrowed sediment was well mixed; poorly burrowed sediment had a diffusion gradient.	-	Low	Marine
Poole and Stewart	1976	Study of abundance of benthos at various depths in Brazos River sediment; no information on mixing	Various	Coarse gravel	Brazos River	Not directly provided	Macrobenthos predominantly present in upper 20 cm, but significant numbers found up to 40 cm depth.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Rhoads and Carey	1997	Role of bioturbation in the context of cap design in estuarine and coastal settings	Various	Various types of capping materials	Coastal and estuarine	Not directly provided	Colonization of organisms on capped materials results in deeper feeding after several years (approximately 10 cm biologically mixed depth). Late stages of colonization may develop large organisms that feed to depths close to 30 cm.	-	Low	Marine
Schaffner et al.	1997	Effects of physical chemistry and bioturbation by estuarine macrofauna on the transport of hydrophobic organic contaminants in benthos	Not given	Marine (>18 ppt salinity) Chesapeake Bay sediment; 50% sand, 35% silt, 15% clay; <1% TOC	Microcosm: sediment depth 14 cm, saline (~20 ppt)	Contaminant burial to maximum 2 cm after 56 days	-	-	Low	Marine
Shull	2001	Development of a model of bioturbation and comparison with field data	Bivalve ( <i>Nucula annulata</i> , <i>Yoldia limatula</i> ), polychaete ( <i>Mediomastus ambiseta</i> , <i>Polycirrus eximius</i> , <i>Sabaco elongatus</i> , <i>Macroclymene zonalis</i> )	Narragansett Bay sediment: TOC 0.9%-1.2%	In situ, marine	Well-mixed to 5 cm; some mixing 5 cm-15 cm		-	Low	Marine
Swift et al.	1996	Development of time- and space-dependent biodiffusion coefficients for the sea bed, based on the composition and distribution of the benthic community	Various	Not documented	60-m isobath off the Palo Verdes shelf, California	Fully mixed zones ranged from under 5 cm to almost 30 cm	Mixing rates provided.	-	Low	Marine environment

Table 1

## Summary of Bioturbation Literature Review (Continued)

Author(s)	Date	Description	Type of Organism/Species	Sediment Characteristics	Physical Environment	Bioturbation Depth Information	Notes	Most Relevant Habitat*	Relevance to PSA	Rationale
Tevesz et al.	1980	Describes stratification of sediment by oligochaete feeding	Oligochaete	Muddy sand from Vermillion River (OH)		Not directly provided	Layer formation in upper 1.5 cm.	-	Low	
Thomson et al.	2000	Study of bioturbation and Holocene sediment accumulation fluxes in the northeast Atlantic Ocean	Various	Carbonate materials overlying clays at depths greater than 15 cm	Northeast Atlantic Ocean	Range of 8 to 17 cm	-	-	Low	Marine, deep ocean
Van de Bund and Groenedijk	1994	Study of chironomid larvae distribution	Chironomid larvae	Sand	Oligo-mesotrophic lake	Not directly provided	Larvae found almost exclusively (>99%) in upper 5 cm.	-	Low	Vertical distribution data only, no information on effects of benthos on sediment
Wheatcroft	1992	Study of bioturbation in deep ocean and the influence of particle size	Various	Various	Deep ocean	Not directly provided		-	Low	Marine
Wheatcroft et al.	1994	Study of particle bioturbation in Massachusetts Bay using tracers	Various	Massachusetts Bay sediment, sand, and silt	In situ microcosms: marine, one with silt and one with sand	Not directly provided	Spring: average vertical penetration 4-6 cm, max. 15 cm; sand average vertical penetration <2 cm, max. 6 cm; fall: sand and silt both had peaks at 10 cm and 20 cm.	-	Low	Marine
White et al.	1987	Study of sediment reworking by oligochaetes over a range of temperatures and organism densities	Oligochaete ( <i>Stylodrilus heringianus</i> )	Lacustrine muds	Mesocosm	Not directly provided	Depth to which organism fed was positively related to worm density. Report cites other studies (Robbins, 1982) in which constant mixing of as much as the upper 15 cm of sediment occurs in Laurentian Great Lakes.	-	Low	No information on well mixed layers; study emphasized reworking rates
Zwarts and Wanink	1989	Study of relationship between burying depth and shell size for bivalves; no information provided on mixing	Bivalves ( <i>Mya arenaria</i> , <i>Cerastoderma edule</i> , <i>Scrobicularia plana</i> , <i>Macoma balthica</i> )	Mud; clay content 6.5%	Intertidal mudflats of the Dutch Wadden Sea, marine	Not directly provided	Approximate maximal burying depths: <i>M. arenaria</i> 25 cm, <i>C. edule</i> 2 cm, <i>M. balthica</i> 8 cm, <i>S. plana</i> 15 cm.	-	Low	Marine

1 \* See Table 2 for description of habitats; codes assigned only for studies with high or moderate relevance to PSA.

# Model Calibration Responsiveness Summary

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**Table 2**

**Broad Habitat Types in Housatonic River PSA Sediment**

Habitat		Dominant Sediment Type	Typical TOC	Dominant Organism Types	Relative Biota Density
1	Upstream main channel (Reach 5A)	Medium sand	1%	Many non-burrowing chironomids (e.g., <i>Tanytarsus</i> sp.), some burrowing chironomids (e.g., <i>Saetheria</i> sp.), tubificid oligochaetes (e.g., <i>Limnodrilus</i> sp.), sphaeriid clams, some mayflies, some caddisflies.	Low
2	Downstream (Reaches 5B, 5C, Woods Pond)	Silt, some fine sand	5%-6%	Many sediment burrowing chironomids (e.g., <i>Dicrotendipes</i> sp., <i>Einfeldia</i> sp.), some non-burrowing chironomids (e.g., <i>Polypedilum</i> sp.), tubificid oligochaetes (e.g., <i>Limnodrilus</i> sp.), gastropods (e.g., Hydrobiidae), sphaerid clams, amphipods, damselflies.	High
3	Backwaters (Reach 5D)	Mainly fines (silt and clay)	10-15%	Expected to be similar to Area 2, perhaps with increased proportion of deposit feeders.	Not quantified; inferred to be high

4

**Table 3**

**Summary of Biological Mixing Depths in PSA Sediment**

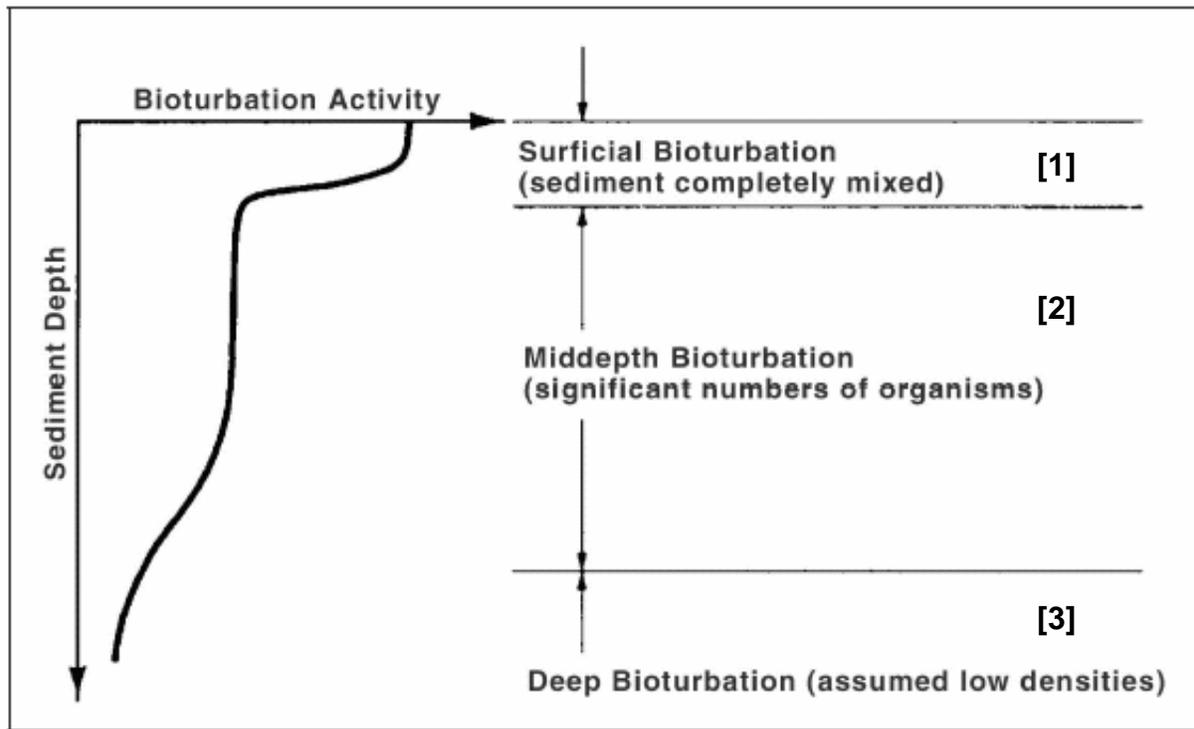
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Habitat		Biologically Mixed Depth Interval *	Biologically Influenced Depth Interval *
1	Upstream main channel (Reach 5A)	0 – 4 cm	4 – 10 cm
2	Downstream (Reaches 5B, 5C, Woods Pond)	0 – 8 cm	8 – 15 cm
3	Backwaters (Reach 5D)	0 – 10 cm	10 – 20 cm

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\* The depths shown represent depth intervals below the sediment surface. The total bioturbation depth is represented by the bottom of the biologically influenced depth interval (e.g., 10 cm for Reach 5A). Definitions for terms are provided in Section 1.2.

## Model Calibration Responsiveness Summary



1  
2 Notes. [1] Biologically mixed layer – high densities of infaunal organisms completely rework the sediment  
3 matrix.

4 [2] Biologically influenced layer – mid-depth zone, in which infaunal densities are lower and rates  
5 of sediment reworking decrease with depth.

6 [3] Deep bioturbation zone – bioturbation potential is negligible to low.

7 Figure extracted from Clarke et al. (2001).

8 **Figure 1 Concept of Bioturbation “Zones” that Correspond to Intensities and**  
9 **Vertical Distribution of Organisms**

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**ATTACHMENT 2**

**KOLMOGOROV-SMIRNOV APPROACH TO EVALUATION OF  
UNCERTAINTY FOR EFDC**

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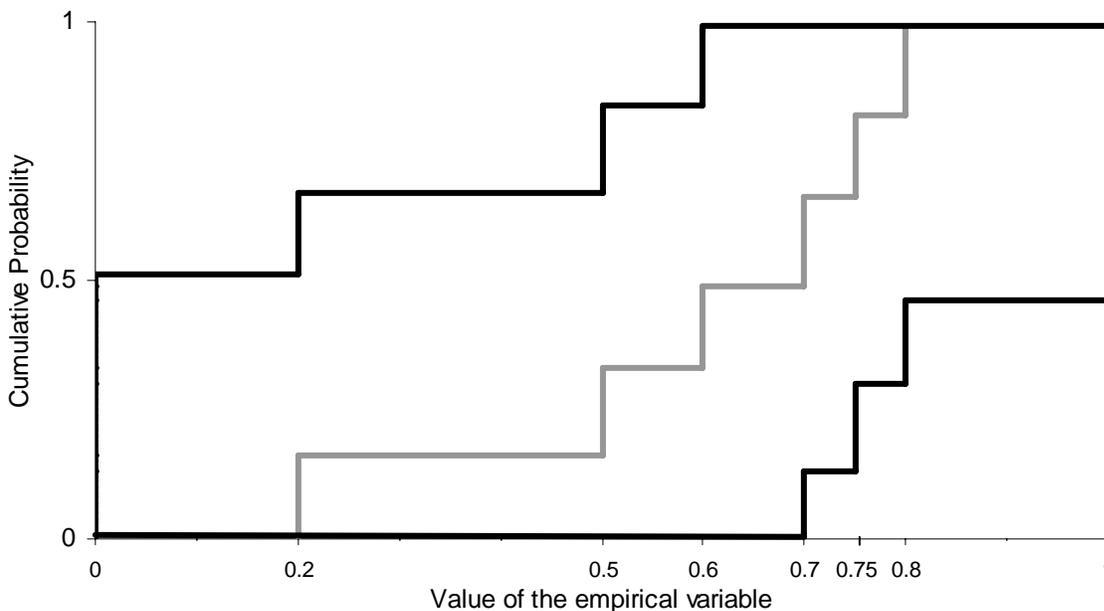


## Model Calibration Responsiveness Summary

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1 from the distribution (95%), they will bound completely the true cumulative frequency  
2 distribution. The bounds would be tighter if there were more data points, or if a lower  
3 confidence level were used.

4 EPA proposes to use the Kolmogorov-Smirnov method for evaluating uncertainty in EFDC  
5 simulations on the same spatial scale as the data are provided by EFDC to FCM. In such an  
6 application, the uncertainty in simulated results for the parameters of interest (tPCBs in sediment  
7 and particulate organic matter [POM], respectively, are the principal parameters to be examined  
8 because they are the parameters output from EFDC to which FCM is most sensitive) will be  
9 evaluated for the modeling subreaches used by FCM, i.e., 5A, 5B, 5C, 5D, and 6. At a  
10 minimum, the uncertainty analysis will be conducted for results at the end of the Phase 2  
11 Calibration period (1990 to 2000), but may also be evaluated at the conclusion of any daily time  
12 step, which is the frequency at which EFDC passes data to FCM, during the entire validation  
13 period (1979 to 2004).



14

15 **Figure 1 Kolmogorov-Smirnov 95% Confidence Bounds on an Empirical**  
16 **Distribution Made up of Eight Values (0.2, 0.5, 0.6, 0.7, 0.75, and 0.8)**  
17 **Assuming the Distribution Ranges from 0 to 1**

## Model Calibration Responsiveness Summary

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### 1 3. REFERENCES

- 2 Sokal, R.R. and F.J. Rohlf. 1994. *Biometry*. 3<sup>rd</sup> edition. Freeman and Company, New York, NY.