REPORT OF THE HUDSON RIVER PCBs SITE MODELING APPROACH PEER REVIEW

—Final Report—

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NOTE

This report was prepared by Eastern Research Group, Inc. (ERG), an EPA contractor, as a general record of discussion for the peer review meeting. This report captures the main points of scheduled presentations and highlights discussions among the reviewers. This report does not contain a verbatim transcript of all issues discussed during the peer review. Additionally, the report does not intend to embellish, interpret, or enlarge upon matters that were incomplete or unclear. EPA will evaluate the recommendations developed by the reviewers and determine what, if any, modifications are necessary to the current modeling approach. Except as specifically noted, no statements in this report represent analyses or positions of EPA or of ERG.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ABBREVIATIONS

DOC	dissolved organic carbon
EMC	environmental management council
EPA	U.S. Environmental Protection Agency
ERG	Eastern Research Group, Inc.
GE	General Electric Company
PCB	polychlorinated biphenyl
PMCR	“Preliminary Model Calibration Report”
QEA	Quantitative Environmental Analysis, LLC
TEQ	toxic equivalent
TSS	total suspended solids

EXECUTIVE SUMMARY

Seven independent peer reviewers critiqued the October 1996 "Preliminary Model Calibration Report" (PMCR), a document prepared as part of the U.S. Environmental Protection Agency's (EPA's) reassessment of the Hudson River PCBs Superfund site. After discussing at length the scientific rigor of the proposed modeling approach, most of the reviewers commended EPA on its extensive modeling efforts, but they unanimously agreed that the modeling approach described in the PMCR was "acceptable with major revision." At the close of the peer review meeting, the reviewers developed a short list of major findings and recommendations, which are summarized below. Except as noted otherwise, all of the peer reviewers agreed with these major findings and recommendations. Specific examples of other suggested revisions and recommendations made by the peer reviewers can be found throughout this report.

- The reviewers recommended that EPA make the following improvements in the description of sediment resuspension and deposition processes in the fate and transport models: address the fate of resuspended material; address the role of uncovered, potentially contaminated surfaces; address the issue of non-cohesive sediment resuspension; assure consistency in resuspension rates between the TIP and HUDTOX models; and identify the effect of flood resuspension on the rate of long-term recovery of the Hudson River. Some reviewers indicated that these changes could be made within the existing modeling framework (i.e., with several different fate and transport models that are linked), while other reviewers thought these changes should be made by incorporating sediment transport mechanisms directly into the HUDTOX model, instead of keeping the models separate.

- The reviewers recommended that EPA employ time- and space-dependent mechanistic models that reflect the abiotic and biotic dynamics of the Hudson River system.

- The reviewers indicated that the models should consider bioavailability and sediment sequestration with respect to congener sorption/desorption and transformation kinetics, sediment particle characteristics, and biotic characteristics.

- The reviewers recommended that EPA link, to the greatest extent possible, the spatial and temporal scales of the different fate and transport and bioaccumulation models.

- The reviewers recommended that EPA clearly identify in its modeling approach the risk assessment targets as related to forms and concentrations of PCBs (e.g., to what guidelines or advisories will the modeled concentrations be compared). More

specifically, the reviewers thought risk assessors and managers should be involved with the development of the transport and fate and bioaccumulation models to ensure that the model outputs will generate the data needed for completing human health and ecological risk assessments.

- The reviewers recommended that EPA develop a mechanistic food web model based on exposure dynamics of the identified forms of PCBs relevant to risk quantification, and that EPA identify appropriate data needs for the fate and transport models.

- The reviewers recommended that EPA develop an explicit plan for model calibration and independent validation that includes criteria for validation, makes use of numerous data sets that span a long time period, and includes chemicals in addition to PCBs.

- Noting that analytical methods have improved and will continue to improve, the reviewers recommended that EPA develop, and agree on how to use, a method for interpreting historical PCB monitoring data, including data quality factors.

- Noting that EPA has already addressed or considered many of the recommendations listed above, the reviewers suggested that EPA hold an open workshop (involving all interested parties as well as independent reviewers) to evaluate current modeling efforts.

1.0 INTRODUCTION

This report summarizes a peer review by seven experts of the site modeling approach that the U.S. Environmental Protection Agency (EPA) proposed for reassessing the Hudson River PCBs Superfund site. The peer reviewers addressed information provided in three documents:

- The October 1996 review copy of the "Preliminary Model Calibration Report" (PMCR) (Limno-Tech et al., 1996)
- The July 1998 draft copy of the revised scope of work for baseline modeling (Limno-Tech et al., 1998)
- Written responses to selected comments that stakeholders made following the initial release of the PMCR

The seven reviewers participated in the peer review meeting, which took place in Saratoga Springs, New York, on September 9–10, 1998. Eastern Research Group, Inc. (ERG), a contractor to EPA, organized the expert peer review and prepared this summary report. This introductory section provides background information on several topics relevant to this report, including a brief background of the Hudson River PCBs site, the scope of the current peer review, and the organization of this report.

1.1 Background

In 1983, EPA classified approximately 200 miles of the Hudson River in the state of New York as a Superfund site, due to elevated concentrations of polychlorinated biphenyls (PCBs) in sediments. The sediments are believed to have been contaminated by discharges of PCBs over approximately 30 years from two General Electric (GE) capacitor manufacturing plants, one in Hudson Falls and the other in Fort Edward. The Superfund site runs from Hudson Falls to the Battery in New York City. After an initial site assessment, EPA issued an "interim No Action decision" in 1984 for the contaminated sediments at the Hudson River PCBs site.

Since 1990, EPA has been reassessing its "interim No Action decision" to determine whether the PCB contamination in the Hudson River necessitates a different course of action.

EPA proposed to complete this reassessment by compiling and analyzing existing data ("Phase I"), collecting additional data and using models to conduct human health and ecological risk assessments ("Phase II"), and performing a feasibility study of selected remedial alternatives ("Phase III"). As part of "Phase II" of the site reassessment, EPA's contractors completed the PMCR, which is the subject of the current peer review. The purpose of the PMCR was to describe models that EPA will use to characterize the fate and transport of PCBs in sediments, water, and biota in the Hudson River. More specifically, the PMCR was prepared "to provide interested parties with information about the data and assumptions that are being used in the models, prior to completion of the actual modeling work" (Limno-Tech et al., 1996). Several parties provided comments on the PMCR during the report's public comment period in 1996.

To ensure that the assumptions and preliminary findings presented in the PMCR are based on sound scientific principles, EPA decided as per policy to obtain an expert peer review of the document. The remainder of this report describes the scope and findings of the peer review of the PMCR.

1.2 Scope of the Peer Review

To organize a thorough review of the PMCR, ERG selected seven independent peer reviewers who are engineers or senior scientists with demonstrated expertise in any combination of the following areas:

- Transport and fate models for sediments and the water column
- Fish body burden models
- Calibration and validation of models
- Sensitivity analysis of models
- Familiarity with PCBs or other compounds that bioaccumulate

To ensure the peer review's independence, ERG considered only individuals who could provide an objective and fair critique of EPA's work. ERG did not consider in the reviewer

selection process individuals who were associated in any way with preparing the PMCR or individuals affiliated with GE or any other specifically identified stakeholder.

Appendix A lists the seven reviewers ERG selected for the peer review meeting. Brief summaries of each reviewer's area of expertise can be found in Appendix C. Recognizing that few individuals specialize in every topic area listed above, ERG ensured that the collective expertise of the selected peer reviewers covers the topic areas listed above (i.e., at least one reviewer has expertise in transport and fate models, at least one reviewer has expertise in fish body burden models, and so on).

To focus peer reviewer comments, ERG worked with EPA to develop written guidelines for the technical review. These guidelines (commonly called a "charge") asked reviewers to address at least the following topics: if the proposed models could be used to make scientifically credible decisions; whether EPA's proposed models, datasets, and assumptions could answer the principal study questions of the PMCR; and if the modeling approach had any serious flaws that would invalidate its conclusions. A copy of the charge, which includes many additional topics and questions, is included in this report as Appendix B.

Several weeks before the meeting, ERG distributed copies of the PMCR, the revised scope of work for baseline modeling, and the responses to selected stakeholder comments to the reviewers and asked them to prepare written responses to the charge questions, based on their initial reviews of the documents. ERG compiled these "premeeting comments," distributed them to the reviewers, and made copies available to observers during the peer review meeting. These initial comments are included in this report, without modification, as Appendix C. It should be noted that the premeeting comments are preliminary in nature and some reviewers' technical findings may have changed based on discussions during the meeting. The premeeting comments should not be considered as the reviewers' final opinions.

It should also be noted that the reviewers were asked to base their reviews on the written materials distributed by ERG: the PMCR, the revised scope of work, and the responses to public

comments. Even though EPA has currently completed several "Phase II" reports in addition to the PMCR, the reviewers were not asked to consider these additional reports, which will be (or already have been) subject to public comment and separate peer reviews. Though not required for this peer review, some reviewers may also have researched site-specific reports they obtained from other sources.

1.3 Meeting Organization and Agenda

The peer review meeting, which was held at the Sheraton Saratoga Springs Hotel and Conference Center in Saratoga Springs, New York, on September 9–10, 1998, was attended by the seven expert reviewers and at least 29 observers. Appendix D lists the observers who confirmed their attendance at the meeting registration desk. The schedule of the peer review meeting generally followed the agenda, presented here as Appendix E. As the agenda indicates, the meeting began with introductory comments both by the designated facilitator and by the designated chair of the peer review meeting. (Section 1.4 of this report summarizes these and other introductory comments.) The rest of the meeting consisted of discussions that focused on responding to the questions in the charge. During the technical discussions, the reviewers provided many comments, observations, and recommendations. The agenda included two time slots for observer comments, which are summarized in Appendix F of this report. An ERG writer attended the meeting and prepared this summary report.

1.4 Summary of Opening Remarks at the Meeting

On the first day of the meeting, Jan Connery of ERG—the designated facilitator of the review—welcomed the seven reviewers and the observers to the 2-day meeting. In her opening remarks, Ms. Connery introduced Dr. Al Maki (a peer reviewer and the technical chair of the meeting), stated the purpose of the peer review meeting, and identified the documents under review. To ensure that the peer review remained independent, Ms. Connery asked reviewers to discuss technical issues among themselves during the meeting and to consult EPA only for necessary clarifications. Ms. Connery explained the procedure observers should follow to make comments. Finally, she reviewed the meeting agenda, which appears in this document as Appendix E.

Following Ms. Connery's opening remarks, the peer reviewers introduced themselves, noted their affiliations, identified their areas of expertise, and stated that they had no conflicts of interest in conducting the peer review. Selected representatives from EPA and from EPA's contractors then introduced themselves and identified their roles in the site reassessment. To orient the peer reviewers to EPA's ongoing site reassessment efforts, Mr. Doug Tomchuk (EPA) then gave a presentation describing the history, current status, and planned future activities for the Hudson River PCBs site. Mr. Tomchuk explained how the PMCR relates to EPA's overall site reassessment, though he did not interpret, or expand on, the assumptions and findings documented in the report.

As a transition into technical discussions, Dr. Maki reviewed the 11 questions in the charge and identified several common themes among the peer reviewers' premeeting comments. For the remainder of the meeting, the peer reviewers discussed the questions in the charge, following the agenda. This report summarizes the peer reviewers' discussions and documents their major findings and recommendations.

1.5 Report Organization

The structure of this report reflects the order of questions in the charge to the reviewers: Section 2 of this report summarizes the reviewers' discussions on Question A in the charge, Section 3 summarizes the discussions on Question B, and so on. Section 7 of this report lists all references cited in the text.

As mentioned earlier, the appendices to this report include a list of the peer reviewers (Appendix A), the charge to the reviewers (Appendix B), the premeeting comments organized by author (Appendix C), a list of the observers present at the meeting (Appendix D), the meeting agenda (Appendix E), and summaries of the observer comments (Appendix F).

2.0 DISCUSSION ON QUESTION A: On the Appropriateness of Using the Models, Datasets, and Assumptions to Make Scientifically Credible Decisions

The peer reviewers opened their technical discussions by addressing the first question in the charge: "Is EPA using appropriate models, datasets and assumptions on which to base a scientifically credible decision?" To answer this question, each reviewer presented his or her initial thoughts and comments, which the reviewers as a group then further discussed. Summarizing the discussions, the technical chair suggested that the reviewers thought some of the selected models were appropriate, but that the reviewers also thought EPA could achieve its ultimate goals only after making major revisions. A general record of the peer reviewers' discussion on this question, organized by topic, follows (but, it should be noted, that Sections 6.2 and 6.3 present the reviewers' final list of major recommendations):

- *Limitations posed by the question.* When responding to Question A, several peer reviewers commented that their responses may have been limited by ambiguities in the question. For example, finding the question too broad, three reviewers indicated that they would present only general comments in response to this question but would provide detailed comments in response to other questions in the charge. Further, several reviewers thought the question could be interpreted in many ways: What kinds of scientific decisions will EPA make? What makes a decision "good enough" to be considered scientifically credible? Will the decisions be used in legal proceedings or regulatory determinations? To clarify the intent of the question, representatives from EPA explained that they were particularly interested in whether the reviewers thought the models could answer the three "principal study questions" of the PMCR. Recognizing that Question B of the charge addresses the principal study questions (see Section 3.0), several reviewers again indicated that they would provide their detailed comments in response to Question B and other questions that focus on more specific topics.

- *The proposed bioaccumulation models.* Three reviewers recommended (and all of the reviewers later agreed) that EPA should use predictive or dynamic models to address bioaccumulation, instead of using the descriptive models proposed in the PMCR. More specifically, the reviewers suggested that EPA use a more complex model based on a mechanistic understanding of bioaccumulation, rather than use a simpler model based on empirical relationships. The reviewers indicated that they would provide more detailed comments on the bioaccumulation models when responding to other questions in the charge.

- *The proposed transport and fate models.* The two reviewers who commented on the proposed transport and fate models (in response to Question A) found them to be generally appropriate. One reviewer provided detailed comments, noting that he approved of the proposed grid sizes, model calibration, and selected steady-state assumptions. Regarding improvements to the models, this reviewer recommended that the "depth of scour" model for the Thompson Island Pool consider erosion of non-cohesive sediments, that the models consider how turbulent flows affect erosion, and that EPA reconsider the assumption that bed shear stresses reach their maximum values instantaneously.

- *Involvement of risk assessors.* Several reviewers emphasized the importance of ensuring that EPA's proposed modeling approach can meet the data needs of the human health and ecological risk assessments planned for the Hudson River PCBs site. As an example, one reviewer indicated that the modelers should know whether the risk assessors intend to evaluate exposures to total PCBs, to a subset of Aroclors, or to individual congeners. To demonstrate a clear link between the PMCR and the risk assessments, the reviewer suggests the modeling reports should describe "acceptable risk levels" and other concepts relevant to the planned risk assessments. Another reviewer wondered if the risk assessors might evaluate environmental contaminants other than PCBs, thus necessitating modeling for a greater number of contaminants.

- *Consideration of bioavailability.* One peer reviewer indicated that the models should more prominently acknowledge the issue of bioavailability, including kinetics of adsorption and desorption, though the reviewers reserved specific comments on this topic for later in the peer review meeting.

- *Links between the proposed models.* Several reviewers did not think the PMCR adequately addressed how EPA plans to interface the different transport and fate models and bioaccumulation models. A reviewer noted that the modeling effort could face future problems if the temporal and spatial scales of the various sub-models are not linked.

- *Consideration of other relevant data sources.* A peer reviewer gave two examples of how the modeling approach in the PMCR can be strengthened by considering data from other relevant sources. First, the reviewer was surprised that the PMCR did not compare any of the monitoring data or preliminary model predictions to data and predictions from PCB modeling efforts in other river systems. Second, the reviewer thought EPA should make use of data sets for pollutants other than PCBs. As an example, the reviewer indicated that monitoring data for other chemicals (e.g., inorganics) could illustrate fate and transport in the Hudson River over the long term. The reviewer acknowledged that the relative importance of various fate and transport processes differ from one chemical to the next, but noted that the same processes result in the transport of all chemicals. Thus, the rigor of the model testing and validation could be greatly improved by considering other chemicals.

- *Use of historical monitoring data.* Several reviewers were concerned about the appropriate use of historical monitoring data for the Hudson River. For instance, one reviewer stressed that historical monitoring data for PCBs are particularly difficult to interpret because analytical methods and sensitivities have changed significantly in the last 20 years—an issue the reviewer intended to describe in greater detail during later discussions. According to another reviewer, the fact that many different agencies and parties have collected Hudson River samples for different purposes may also complicate efforts to understand historical data. This reviewer wondered whether some unique trends in the historical data (e.g., relatively high concentrations of BZ4 in the distribution of PCBs) reflect actual levels of environmental contamination or indicate evolving analytical techniques.

- *Links between the aquatic, terrestrial, and atmospheric systems.* One reviewer was concerned because the proposed modeling approach apparently ignores possible physical or biological links between the aquatic, atmospheric, and terrestrial systems. Two reviewers cited examples of other systems in which they thought such links have been addressed. The examples were PCB transport between the atmospheric and aquatic systems for the Great Lakes and PCB transport between the aquatic and terrestrial systems for the St. Lawrence River. The reviewers did not provide specific references for these examples during the meeting.

- *Impact of uncertainty.* One reviewer wondered if there might be enough uncertainty in the proposed models to limit their use in making scientifically credible decisions. This reviewer stressed that the uncertainty in the models' predictions does not necessarily imply that the selected models, datasets, or assumptions are inappropriate or invalid. Rather, he indicated that current "quantitative understanding" of the transport and fate and bioaccumulation of PCBs in river systems may be too limited for models to predict future river conditions with "sufficient certainty."

- *Inability to verify references to the "gray literature."* One reviewer found references in the PMCR to the "gray literature" troubling in two regards. First, the reviewer thought EPA should cite peer-reviewed literature to the greatest extent possible. Second, the reviewer was frustrated that the public generally cannot access much of the "gray literature" that was cited. As a result, the reviewer suggested that EPA encourage wider dissemination of the "gray literature," in cases where reference to such sources is truly necessary. Another reviewer was frustrated that details of the Thomann model—a major feature of the overall modeling effort—were not readily accessible and possibly not complete.

- *Incomplete information on the available data.* Several reviewers commented on different topics related to the monitoring data available for the Hudson River. For example, some reviewers were unsure of exactly how much monitoring data are available for the site and exactly what subset of these data EPA plans to consider in its modeling analysis. As a

result, one reviewer said he did not have enough information to determine whether EPA was using appropriate data sets. Two reviewers thought that, to address concerns regarding the use of available data, the PMCR should not only list the available data sources but should also state the criteria used to include and exclude these sources from the modeling analysis. On a related topic, one reviewer thought the extent to which EPA considered data outliers was unclear; the reviewer recommended that outliers be considered in the modeling analysis, because they may provide clues to unique trends and patterns in the river system. Finally, one reviewer thought giving reviewers access to the monitoring data might have helped the reviewers evaluate the PMCR more comprehensively.

- *Assumptions in the modeling approach.* One reviewer noted that the modeling approach documented in the PMCR essentially assumes "ecological steady state" for the Hudson River. The reviewer presented several scenarios (e.g., development of wetlands in the area, invasion of the Hudson River by foreign species, and so on) that could invalidate this assumption. When reviewing these discussions at the end of the peer review meeting, however, the group of peer reviewers unanimously agreed that the modeling assumption of "ecological steady state" was neither a "major" or a "minor" flaw in the proposed modeling approach.

- *Location of the upstream modeling boundary.* In response to Question A, two reviewers recommended that EPA consider moving the upstream boundary of its models to a location upstream from Hudson Falls. The reviewers thought this change would not only allow the models to provide a more complete mass balance of PCBs in the Hudson River but would also allow the models to characterize "background" levels of PCBs at locations upstream from the major sources. As Sections 5 and 6 describe, the peer reviewers' recommendations on this topic changed during the meeting, and they eventually decided that moving the upstream boundary may not be necessary.

- *Insufficient time for the peer review.* Noting that, in the time prior to the peer review meeting, the reviewers had to (1) become familiar with the Hudson River system and (2) research and critique the proposed models, one reviewer thought EPA should have given the group of reviewers more time and more background information earlier in the peer review process to critically evaluate the PMCR.

3.0 DISCUSSION ON QUESTION B: On the Ability of the Models to Answer the Principal Study Questions of the Preliminary Model Calibration Report

The peer reviewers continued their technical discussions by addressing Question B in the charge: "Will the models, with the associated datasets and assumptions, be able to answer the following principal study questions as stated in the PMCR:

1. When will PCB levels in the fish population recover to levels meeting human health and ecological risk criteria under No Action?

2. Can remedies other than No Action significantly shorten the time required to achieve acceptable risk levels?

3. Are there contaminated sediments now buried and effectively sequestered from the food chain which are likely to become 'reactivated' following a major flood, resulting in an increase in contamination of the fish population?"

At the beginning of the discussions, the meeting facilitator (Jan Connery, ERG) emphasized that Question B does not ask the reviewers to answer the three principal study questions, but rather asks the reviewers whether the models will be able to answer the three principal study questions. The following subsections summarize the reviewers' discussion on Question B. Their comments are organized by the principal study question under discussion. It should be noted, however, that Sections 6.2 and 6.3 present the reviewers' final list of major recommendations.

3.1 Predicting Future Levels of PCBs in Fish

The reviewers made the following comments, observations, and recommendations regarding Question B.1 of the charge:

- *Comments on the question.* One reviewer noted that some aspects of Question B.1 overlap with aspects of Questions B.2 and B.3. For example, the reviewer thought the ability of the models to predict sediment resuspension during floods (Question B.3) significantly affects the ability of the models to predict levels of PCBs in fish (Question B.1). As a result, the reviewers occasionally indicated when their specific responses

applied to more than one question. As described later in this subsection, another reviewer wondered exactly what "human health and ecological risk criteria" EPA will consider in its risk assessments.

- *Improvements to the bioaccumulation models.* Much of the reviewers' discussion focused on the bioaccumulation models' inadequacy to predict future levels of PCBs in fish. Consistent with the responses to Question A, several reviewers reiterated the importance of using dynamic and mechanistic bioaccumulation models, instead of using empirical models that have no predictive capacity. Elaborating on the inadequacies of the models, one reviewer explained that the bivariate and probabilistic models provide only "pairwise comparisons" of concentrations of PCBs in different media, without mechanistically linking the different media. For instance, the proposed models assume that if the concentrations of PCBs in the sediment and in the water column decrease by a factor of two, then the concentrations of PCBs in the biota will also decrease by a factor of two. The reviewer cited examples from Lake Ontario where such simple "pairwise comparisons" are not observed in the food web. In short, the reviewer noted that concentrations of PCBs in the different media—biota, sediment, and water—will change at different rates, a scenario that the proposed bioaccumulation models cannot consider.

  To improve the bioaccumulation models, the reviewers offered several recommendations. First, several reviewers recommended that EPA use a bioaccumulation model, such as one of the Gobas models, with mechanisms for predicting how concentrations of PCBs in biota will respond to changing levels of PCBs in the river system. The reviewers indicated that such mechanistic models can explore different pathways of exposure and uptake. Second, another reviewer recommended that the bioaccumulation models link with the temporal scales of the HUDTOX model and that these temporal scales be short enough to address key life cycle stages in biota. Third, another reviewer thought the bioaccumulation models should consider, to the extent possible, congener-specific rates for PCB metabolism, uptake, and excretion. Finally, yet another reviewer recommended holding a separate workshop to review the available bioaccumulation models before selecting the most appropriate model for the Hudson River PCBs site.

- *Modeling the appropriate compounds for the risk assessment.* One reviewer was concerned that the PMCR did not specify the form of PCBs that will be considered in the human health and ecological risk assessments. To illustrate his concern, the reviewer wondered whether the risk assessments will consider total PCBs, a subset of Aroclors, individual PCB congeners, or possibly a toxic equivalency (TEQ) analysis. Asserting that the modeling outputs will eventually be critical inputs to the risk assessments, the reviewer recommended that EPA ensure that the fate and transport and bioaccumulation models evaluate the same forms of PCBs that the risk assessments will consider.

- *Models' consideration of bioavailability.* Several reviewers suggested that the fate and transport models should place a greater emphasis on bioavailability (in contrast to simple

chemical detectability). As an example, one reviewer thought the models should not only predict the amounts of sediments that are resuspended, but also should consider the sorption and desorption kinetics of PCBs in these resuspended sediments (i.e., how much is desorbed or becomes bioavailable as a result of resuspension). The reviewer recommended using available congener-specific sorption and desorption kinetics, or estimates of these parameters if they are not available, in the fate and transport models, especially because some PCB congeners (higher-chlorinated PCBs) tend to bioaccumulate in fish more than lower chlorinated PCB congeners. A reviewer also noted that those congeners that sorb most to sediments also tend to bioaccumulate. Therefore, the models need to address the bioavailability of PCBs sorbed to resuspended sediments.

- *Long-term validation of models.* One reviewer acknowledged that long-term PCB fate and transport modeling is a difficult, and often unsuccessful, endeavor. As a result, the reviewer recommended that EPA perform long-term validation studies on levels of PCBs in the fish and in the river, and possibly even on levels of other chemicals for which data are available. The reviewer thought the results of such long-term validation studies might best indicate whether the models will be able to answer the first principal study question of the PMCR.

- *Benefits of conducting uncertainty and sensitivity analyses.* One reviewer thought it would be useful for EPA to develop a plan for conducting uncertainty analyses and sensitivity analyses on the transport and fate and bioaccumulation models. The reviewer suggested that these analyses may help EPA identify which variables and parameters have the greatest impact on future river conditions.

- *Inconsistently predicted sediment resuspension rates.* Citing a significant inconsistency between the sediment resuspension rates predicted for flood events by HUDTOX and the rates for flood events predicted by the "depth of scour" model, one reviewer wondered if the models can characterize sediment transport during flood events accurately. The reviewer further noted that an inability to characterize this sediment transport would ultimately compromise the models' ability to forecast concentrations of PCBs in fish. As a result, the reviewer recommended that EPA explain why the HUDTOX and "depth of scour" models seem to predict extremely different sediment resuspension rates during floods.

- *Location of the upstream modeling boundary.* One reviewer thought the ability of the models to forecast future levels of PCBs in fish is limited by the primary source of PCB loadings to the Hudson River being upstream of the modeling domain. More specifically, the reviewer indicated that if EPA cannot predict how the source of PCBs in the Upper Hudson River will change in the future, then the models certainly would not be able to predict future river conditions. Upon request for clarification, EPA explained that remedial actions at the GE Hudson Falls plant have greatly reduced the upstream loading of PCBs into the HUDTOX modeling domain since 1993. Further, EPA noted that

monitoring upstream of the Hudson Falls plant consistently fails to detect PCBs in the water column (with a detection limit of 11 parts per trillion). As Sections 5 and 6 describe, the peer reviewers' recommendations on the placement of the upstream boundary for modeling changed during the meeting, and they eventually decided that moving the boundary may not be necessary.

3.2 Evaluating Remedies Other Than "No Action"

The reviewers made the following comments, observations, and recommendations regarding Question B.2 of the charge:

- *Comments on the question.* Because neither the PMCR nor the charge to the reviewers specify what remedial options EPA is considering for the contaminated sediments, several reviewers found it difficult to comment on whether the models can determine if remedies other than "No Action" could accelerate the rate at which environmental concentrations of PCBs might reach "acceptable risk levels." In addition, one reviewer was uncomfortable answering the question without knowing exactly what the "acceptable risk levels" are and how EPA derived them (e.g., are the acceptable levels expressed for total PCBs, selected Aroclors, or individual congeners?). Further, a reviewer said it was difficult to comment on whether remedial actions other than "No Action" could shorten the time for PCB contamination in the river to reach "acceptable risk levels," without first knowing how soon such levels would be reached under a "No Action" scenario. This reviewer also found the question difficult to answer because specific remedial actions, such as dredging sediments, can affect the ecological balance of the river system, regardless of how the actions change levels of PCBs in the river.

- *Significance of higher concentrations of PCBs in the Thompson Island Pool.* Citing the models' inability to identify the mechanisms causing the increase of PCB loading across the Thompson Island Pool, several reviewers wondered if the models would have the predictive capacity to conduct longer (e.g., 20-year) simulations, such as evaluating outcomes of different remedial actions. Elaborating on this point, a reviewer noted the calibration described in the PMCR failed to explain the significant increase of PCB concentrations over a relatively short calibration period within a relatively short section of the Hudson River. Until the models can characterize the unique observations during the model calibration period, some reviewers feared the models might not be able to answer the second principal study question. For this same reason, one reviewer thought the models may not be able to answer the first principal study question either.

- *Emphasis on source attribution.* Related to the previous topic, a reviewer thought the modeling should place a greater emphasis on source attribution. As an example, another reviewer suggested that the models should be able to determine whether PCB loads

originate from recent discharges or from historical sediment sources. Referring to page 4-2 of the PMCR, this reviewer noted that the models currently might not be able to differentiate between these sources of PCBs. These reviewers indicated that understanding the sources of PCBs during different flow conditions is critical to evaluating different remedial options.

- *Need for long-term model validation.* Reiterating a concern raised in response to Question B.1, a reviewer thought EPA should conduct long-term validation studies on the proposed models under different flow conditions. The reviewer recommended that EPA conduct these validation studies both for PCBs and for other chemicals with sufficient historical data. Successful validation, according to the reviewer, could ultimately increase confidence in the models' predictive capacity.

- *Better hydrogeological characterization of the Thompson Island Pool area.* Noting that the PMCR hypothesizes that groundwater advection might explain the observed increased PCB loads across the Thompson Island Pool, one reviewer suggested that greater hydrogeological characterization in this section of the Hudson River is needed to verify this hypothesis. Subsequent discussions following the observer comment period suggested that this may not be necessary as the apparent increase across the pools may be an artifact of bias in a downstream monitoring location, as an observer suggested.

- *Consideration of two-stage partitioning models.* On several occasions, one reviewer recommended the possibility of using simple, two-stage partitioning models instead of the more elaborate fate and transport and bioaccumulation models described in the PMCR. The other reviewers commented on this proposition during their discussions on Question D and E (see Section 5).

3.3 Characterizing the Fate of "Reactivated" Sediments Following Major Floods

The following discussion summarizes the reviewers' comments, observations, and recommendations regarding Question B.3 of the charge:

- *Characterization of sediment erosion.* One reviewer listed three areas in which the models could better characterize sediment erosion. First, the reviewer recommended that the models account separately for how cohesive and non-cohesive sediments erode, instead of considering erosion of only cohesive sediments. Second, noting that turbulent flow can enhance sediment erosion, even during periods of "average" river flows, the reviewer suggested that EPA consider incorporating the role of turbulence in its models. Third, noting that sediments can erode during "average" flows as well as during flood events, the reviewer wondered whether the cumulative amounts of sediment eroded during "average" flows might be of greater concern than the large amounts of sediment eroded

during 100-year floods. Other reviewers agreed with these findings, and one reviewer thought the relative significance of "average" flow and 100-year flood events was particularly important for EPA's modeling efforts (as is discussed in greater detail in the following bulleted items).

- *Significance of a 100-year flood event.* The reviewers had difficulty reconciling the models' predictions of sediment resuspension during a 100-year flood event in the Hudson River and observed sediment resuspension during major flood events in other rivers. For example, one reviewer noted that the "depth of scour" model predicts that 55 pounds of PCBs would be eroded from the Thompson Island Pool during a 100-year flood event in the Hudson River. The reviewer noted further that 55 pounds of PCBs is several orders of magnitude less than the amount of PCBs believed to be originally discharged to the river. Based on these observations, the reviewer suggested that a 100-year flood event in the Hudson River may not cause significant erosion of sediments. On the other hand, two reviewers provided quite different accounts of sediment erosion during major floods in other river systems: one reviewer said tropical storm Charlie caused floods that almost "completely scoured" the sediments in parts of the Rio Grande, and another reviewer mentioned that rains from hurricane Agnes diluted the entire salt-water content of the Chesapeake Bay. By these accounts, the reviewers implied that 100-year flood events could quite effectively remove contaminants in sediments from rivers. To make sense of these very different outcomes, a reviewer asked EPA to describe what conditions are expected during a 100-year flood in the Hudson River. In response, one of EPA's contractors indicated that, due in part to the fact that the Upper Hudson River has several "controls" (e.g., locks and dams), water levels during a 100-year flood event for the Upper Hudson River would not be significantly higher than those during a typical spring high-flow event. The EPA contractor further noted that PCBs remain in the Hudson River even though several notable high-flow events have occurred over the past 20 years. The following three bulleted items list the reviewers' recommendations that evolved from this discussion of 100-year floods.

- *Emphasis on modeling 100-year floods.* Assuming that sediment erosion occurs during "average" flows (see the first bulleted item under Section 3.3) and that erosion during 100-year flood events resuspends only a small fraction of the "sequestered" PCBs (see the previous bulleted item), one reviewer wondered if EPA should place less emphasis on evaluating the effects of a 100-year flood event and more emphasis on modeling the daily "average" flows. Another reviewer cautioned that this suggestion assumes that 100-year flood events do not erode significant quantities of sediments—a finding that is based on only preliminary modeling results.

- *Role of freshly uncovered sediments.* Two reviewers were concerned that the PMCR focuses on modeling the amounts of resuspended sediments and not on characterizing freshly exposed, and possibly highly contaminated, surfaces following flood events. Unsure whether these freshly uncovered sediments are a more significant source of PCBs

to fish than the resuspended sediments, the reviewers recommended that EPA examine the significance of uncovered sediments in greater detail.

- *Role of resuspended sediments.* One reviewer raised the possibility that resuspended, PCB-contaminated sediments during flood events may act as a "source" (e.g., the sediments that were previously sequestered from the environment may become bioavailable) or they may act as a "sink" (e.g., flood waters may flush some contaminated sediments from the Hudson River altogether). The reviewer recommended that EPA clarify which scenario is most likely.

- *Links between the proposed models.* One reviewer noted that the mass balance in the HUDTOX model would not be complete if the model does not consider the amounts of sediments resuspended during a 100-year flood. Thinking the ultimate fate of resuspended sediments is just as important as the amount of the sediments that are resuspended, the reviewer recommended that EPA link the HUDTOX and the "depth of scour" models in a time-dependent fashion to ensure that HUDTOX models the transport and fate of sediments that are resuspended during flood events.

- *Influence of other factors on PCB loadings.* One reviewer indicated that factors other than 100-year flood events can significantly increase PCB loadings in the Hudson River. As examples, the reviewer suggested that bioturbation, "propeller backwash" from ships and boats, and even earthquakes (which might damage or destroy containment systems) all can affect sediment erosion, possibly significantly. The reviewer thought that EPA should acknowledge these factors in its modeling efforts.

- *Better characterization of suspended solids.* Citing information documented in other reviewers' pre-meeting comments, one reviewer recommended that the models incorporate a better physical characterization of resuspended sediments (e.g., particle size and fraction of organic carbon).

4.0 DISCUSSION ON QUESTION C: Specific Questions Regarding the Models

The peer reviewers continued their discussions by answering the five specific questions listed in Question C of the charge. For these five questions, the following subsections restate a specific question in the charge and summarize the reviewers' relevant discussions. When answering the five specific questions, some reviewers referred to their comments from Questions A and B. The following subsections note these references, where appropriate. It should be noted, however, that Sections 6.2 and 6.3 present the reviewers' final list of major recommendations.

4.1 Developing Quantitative Relationships Between Forcing Functions and PCB Concentrations

Question C.1 of the charge asked the peer reviewers:

> "Are the modeling approaches suitable for developing quantitative relationships between external forcing functions (e.g., hydraulic flows, solids and PCB loads, sediment initial conditions, etc.) and PCB concentrations in the water column, sediments and fish? Are the models adequate for discriminating between water-related and sediment-related sources of PCBs?"

The following bulleted items summarize the reviewers' comments, observations, and recommendations regarding this question:

- *Evolution of analytical methods for PCBs.* Because laboratories, over the last 20 years, have used different methods with different sensitivities to measure levels of PCBs, one reviewer recommended that EPA make the issue of resolving historical differences in analytical chemistry a priority for the ongoing modeling efforts. As an example, noting peculiar trends in the distribution of congeners in selected sediment samples (e.g., relatively high levels of BZ4 in comparison to levels of other congeners), another reviewer wondered if such peculiarities accurately reflect actual levels of environmental contamination or possibly result from EPA misinterpreting historical monitoring data.

- *Improvements to the bioaccumulation models.* Two reviewers thought, and all of the reviewers later agreed, that only a mechanistic bioaccumulation model can discriminate between "water-related and sediment-related sources of PCBs." Noting that the statistical and probabilistic models proposed in the PMCR do not address mechanisms of bioaccumulation, one reviewer recommended that EPA use mechanistic models that, to

the greatest extent possible, address congener-specific rates of uptake, metabolism, excretion, and storage of PCBs in biota.

- *Inputs from the watershed.* One reviewer thought PCB inputs from the watershed might be a relevant forcing function for the models, especially for long-term forecasting, but the reviewer indicated that the PMCR currently assumes such inputs are negligible. The reviewer acknowledged that current understanding of PCB inputs from watersheds may be too limited to incorporate in EPA's modeling approach. Nonetheless, another reviewer thought the PMCR should at least compare PCB inputs from the Hudson River watershed to other PCB loads in the system. This reviewer indicated that EPA may be able to characterize watershed loadings by moving the boundary of the modeling domain to locations upstream of Hudson Falls—a recommendation which the next bulleted item describes in greater detail.

- *Location of the upstream modeling boundary.* As the reviewers noted when discussing Questions A and B, the proposed location of the upstream modeling boundary may limit the models' ability to relate external forcing functions to concentrations of PCBs in the Hudson River. One reviewer indicated that moving the modeling boundary upstream of Hudson Falls will allow EPA to characterize the background levels of PCBs that enter the modeling domain. (As Sections 5 and 6 describe, the peer reviewers' recommendations on the placement of the upstream boundary for modeling changed during the meeting, and they eventually decided that moving the boundary may not be necessary.)

- *Consideration of "apparent" dissolved phase PCBs.* One reviewer thought that PCB measurements that do not distinguish "truly dissolved PCBs" from PCBs that are bound to dissolved organic carbon (DOC), such as the "Phase 2" measurements made in the Upper Hudson River, can be a major problem for the modeling results. The reviewer recommended that EPA make a better distinction between these two forms of PCBs. Further, another reviewer thought the PMCR should better characterize the DOC typically found in the Hudson River.

- *Bias in modeling results.* Based on a comparison of the modeling results during low-flow and high-flow events, one reviewer thought the predicted concentrations of PCBs and concentrations of total suspended solids (TSS) may have been biased. The reviewer recommended that EPA closely examine the relationship between flow, total suspended solids, and PCBs, and explain any peculiar trends; rather than dismiss outliers, as was done.

4.2 Adequacy of Spatial and Temporal Scales

Question C.2 of the charge asked the peer reviewers:

"Are the spatial and temporal scales of the modeling approaches adequate to answer the principal study questions? If not, what levels of spatial and temporal resolution are required to answer these questions? What supporting data are required for calibration/validation of these spatial and temporal scales?"

The following discussion summarizes the reviewers' comments, observations, and recommendations regarding this question:

- *Spatial resolution of the HUDTOX and "depth of scour" models.* The reviewers agreed that the HUDTOX and "depth of scour" models have adequate spatial resolution for modeling flows in the Hudson River. Further, one reviewer thought that use of finer resolution in these models will significantly increase the time needed for computation, without providing much greater insight into fate and transport of PCBs in the Hudson River.

- *Links between the models.* Reiterating comments they made when discussing Questions A and B, several peer reviewers recommended that EPA link the spatial scales and temporal scales of every proposed model (e.g., the HUDTOX model, "depth of scour" model, Thomann model, and bioaccumulation models). The reviewers thought these links were important for modeling the Hudson River over the long term.

- *Boundaries of the models.* The reviewers commented on two aspects of the boundaries of the proposed models. First, two reviewers wondered if EPA could use a single model to characterize PCBs in the entire Hudson River, instead of using the Thomann model for the Lower Hudson River and the HUDTOX model for the Upper Hudson River. In the event that EPA continues to use separate models, these reviewers thought the models should at least be properly linked (see previous bulleted item). Second, consistent with comments made on Questions A and B, several reviewers again noted that the models currently neglect segments of the Hudson River upstream from Hudson Falls. (However, as Sections 5 and 6 describe, the peer reviewers' thinking on the placement of the upstream boundary for modeling changed during the meeting, and they eventually decided that moving this boundary may not be necessary.)

- *Temporal scale of the bioaccumulation models.* Several reviewers noted that the proposed bioaccumulation models have no temporal component, thus preventing them from predicting how changing levels of PCBs in the Hudson River will affect levels of PCBs in fish. One reviewer explained that the proposed models do not account for temporal changes in fish feeding patterns, which are known to vary daily and seasonally, or sensitive life stages. Citing these temporal changes, another reviewer thought time-dependent concentrations of PCBs in the water column may be important for characterizing PCB uptake by fish. This reviewer recommended that EPA use a

"bioenergetically-based food chain model" with adequate temporal components. A different reviewer noted that EPA may have already started using such a food chain model.

- *Temporal scale of the "depth of scour" model.* One reviewer thought the temporal scale in the "depth of scour" model was generally adequate, but he disagreed with the model's assumption that bed shear stresses reach their maximum values instantaneously. However, the reviewer did not recommend alternative assumptions for addressing temporal variations in bed shear stresses.

- *Model calibration issues.* The reviewers made several comments regarding how EPA proposes to calibrate its models. For example, noting that calibration data were available for only 6 of the 13 river segments in the HUDTOX model, one reviewer thought EPA should reconcile the number of modeling segments with the available data before conducting the final model calibration. Regarding the model calibration period, another reviewer was discouraged by the statement in the PMCR that "it is not yet clear whether the PCB dynamics operative during this simulation period are fully representative of historical PCB dynamics, or whether they will be representative of PCB dynamics under future conditions" (Limno-Tech et al., 1996). Yet another reviewer recommended that EPA calibrate only a certain set of parameters in the models, rather than calibrating "the entire process."

- *Data validation issues.* Several reviewers discussed the importance of data validation, particularly with respect to levels of PCBs in fish. One reviewer suggested that data validation should consider concentrations of PCBs in sediment, the water column, and fish, but two reviewers stressed that EPA should place much greater emphasis on validating fish body burdens (e.g., average concentrations of PCBs and standard deviations of the concentrations). One of these reviewers thought using the models to estimate fish concentrations back to 1977 is also important, but only after EPA resolves historical differences in PCB analytical methods. This reviewer further recommended that validation not only consider PCBs, but also other chemicals with sufficient data. Finally, one reviewer emphasized that EPA should develop specific validation criteria (e.g., ranges of concentrations of PCBs in fish that would be considered "acceptable") before it actually performs the data validation.

4.3 Use of Several Bioaccumulation Models

Question C.3 of the charge asked the peer reviewers:

> "It is contemplated that PCB concentrations in fish will be estimated using several modeling approaches: an empirical probabilistic model derived from Hudson River data, a steady state model that takes into account mechanisms of bioaccumulation body burdens, and a time-varying mechanistic model (not included in the PMCR).

A bi-variate statistical model may also be used to provide insight into accumulations. This multi-model approach is being contemplated because of the uncertainties associated with any individual model. Is this a reasonable approach or should predictions be made using a single 'best' model?"

The following bulleted items summarize the reviewers' comments, observations, and recommendations regarding this question:

- *Use of multiple bioaccumulation models.* After lengthy discussions on the topic, the peer reviewers agreed that EPA's proposed use of multiple bioaccumulation models to estimate concentrations of PCBs in fish is advisable, even though the reviewers thought the best option ultimately will be to use a time-dependent, mechanistic model. One reviewer noted that comparing predictions from multiple models has been a productive exercise for other modeling endeavors, even when predictions from the individual models differ. Another reviewer urged EPA to review the assumptions of the candidate models and to develop expectations of what the different models will predict, before comparing results from the different models. This reviewer also suggested that EPA consider the quality of each model's input data as a factor when selecting which model is most appropriate.

- *Input from risk assessors.* Recognizing that risk assessors will ultimately use the outputs from the bioaccumulation models as inputs for risk modeling, two reviewers stressed the importance of early and frequent involvement of risk assessors in the transport and fate and bioaccumulation modeling, including the selection of appropriate models.

- *Use of experimental data.* To provide greater insight into bioaccumulation of PCBs in the Hudson River system, one reviewer thought, EPA should consider conducting simple laboratory studies designed to mimic the Hudson River. Although another reviewer agreed that additional laboratory studies might help EPA parameterize its models better, two other reviewers were not convinced that additional experimental studies should precede EPA's modeling efforts: one of these reviewers noted that models can be used to identify where experimentation is needed, and the other reviewer indicated that laboratory experiments probably would not provide useful information in the short term, due to the long time scales needed to observe bioaccumulation of PCBs in fish.

4.4 Adequacy of the Models' "Level of Process Resolution"

Question C.4 of the charge asked the peer reviewers:

"Is the level of process resolution in the models adequate to answer the principal study questions? If not, what processes and what levels of resolution are required

to answer these questions? What supporting data (such as data to support specifications of a mixed depth layer, solids and scour dynamics, groundwater inflow, etc.) are required for these processes and levels of resolution?"

As Appendix C shows, the charge explains that " 'level of process resolution' refers to the theoretical rigor of the equations used to describe the various processes affecting PCB fate and transport . . ." The following discussion summarizes the reviewers' comments, observations, and recommendations regarding this question:

- *Enhanced consideration of several processes.* The peer reviewers identified several areas that might require higher levels of process resolution, such as sorption and desorption kinetics, pore water advection, and bioavailability. Because the reviewers discussed these topics when responding to Questions A and B, they decided not to discuss them in detail when responding to Question C.4. One reviewer suggested reference to the premeeting comments for a list of other areas that, according to the reviewers, could require higher or lower levels of resolution.

- *Relevance of lipid contents to modeling bioaccumulation.* One reviewer noted that the extent to which PCBs bioaccumulate in fish strongly depends on lipid content. The reviewer explained that lipid contents in fish and other biota are known to change with time, but the reviewer noted that the bioaccumulation models described in the PMCR currently assume constant lipid values. Although the reviewer thought it was important for bioenergetic bioaccumulation models to consider variations in lipid content, she acknowledged that it is "very common" for modelers to assume constant lipid values.

- *Consideration of PCB degradation.* Two reviewers discussed the significance of PCB degradation in the Hudson River system. One reviewer thought the HUDTOX model should account for how PCBs degrade in the sediments, since degradation in sediments would ultimately affect the profile of PCBs that are bioavailable. Another reviewer thought the bioaccumulation models, to the greatest extent possible, should consider PCB degradation in biota, since degradation in fish and other biota determines the profile of PCBs expected to bioaccumulate in fish. The reviewers thought PCB degradation would be particularly important to consider in the proposed long-term simulations of river conditions.

- *Balance between details and generalizations.* Regarding the six different fish species selected for bioaccumulation modeling, two reviewers debated the balance between modeling general scenarios and modeling detailed scenarios. For example, one reviewer argued that EPA could run its bioaccumulation models for only two of the six species, without losing process resolution. However, noting that EPA considered many criteria

(e.g., endangered species and importance for fishing) when selecting fish species for modeling, another reviewer thought the six selected species were adequate and suggested that modeling fewer species might lower process resolution.

- *Level of resolution needed for final decisions.* One reviewer found the question difficult to answer without knowing what level of process resolution EPA requires to make its decisions on remedial actions. As an example, the reviewer explained that the level of process resolution for the models would have to be extremely high if EPA needed to predict concentrations of PCBs in fish with very tight error bounds; lower levels of process resolution might be adequate if broader error bounds in the predicted concentrations of PCBs in fish are acceptable.

4.5 Usefulness of Modeling Results for Risk Assessment

Question C.5 of the charge asked the peer reviewers:

> "The results of the modeling effort will be used, in part, to support human and ecological risk assessments. In your judgment, will the models provide estimates adequate for this purpose?"

The following discussion summarizes the reviewers' comments, observations, and recommendations regarding this question:

- *Involvement of risk assessors.* Consistent with comments made to Questions A and B and C.3, two reviewers emphasized the importance of early and frequent involvement of risk assessors in EPA's ongoing modeling efforts. The reviewers explained that this involvement should help ensure that outputs from the fate and transport and bioaccumulation models will coincide with the desired inputs for the risk assessments.

- *Relevant forms of PCBs.* Also consistent with comments raised earlier in the peer review meeting, one reviewer was not convinced that the proposed models and the risk assessments will consider the same forms of PCBs. As a result, the reviewer suggested that the models described in the PMCR might need to characterize concentrations of only total PCBs, instead of characterizing levels of individual PCB congeners, selected PCB homologues, or selected Aroclors. Noting that some health outcomes are linked to specific PCB exposures (e.g., exposure to lower homologues of PCBs may be a more likely cause of neurotoxic developmental effects in children than exposure to higher homologues of PCBs), another reviewer did not agree that modeling only total PCBs was advisable. These reviewers agreed, however, that EPA should model fate and transport

and bioaccumulation of at least those forms of PCBs that the human health and ecological risk assessments will consider.

- *Adequacy of the proposed bioaccumulation models.* Again reiterating a topic from earlier discussions, one reviewer emphasized that the proposed bioaccumulation models may not generate data adequate for the risk assessment. The reviewer recommended that EPA use a dynamic, mechanistic bioaccumulation model instead of the bivariate and probabilistic models.

- *Specifics for the ecological risk assessment.* Two peer reviewers suggested that the ecological risk assessment should consider mink, and possibly snapping turtles, as sentinel species, since, once revised as suggested, the models described in the PMCR would provide estimates adequate for assessing risks to these species and their consumers or others (e.g., otter). (The reviewers agreed that the models should provide data from which exposures relevant to the ecological risk assessment can be estimated.)

5.0 DISCUSSION ON QUESTION D AND E: Recommended Changes to, and Serious Flaws in, the Proposed Modeling Approach

The peer reviewers continued their technical discussions by answering Questions D and E in the charge:

> "D. Are there any changes to the work effort outlined in the revised work plan that would significantly improve the outcome?
>
> E. In terms of evaluating the overall and specific effects and behavior of PCBs in the Hudson River, are there any serious flaws in the modeling approach (theory, structure, physical parameters, etc.) that would limit or invalidate any conclusions or further work based upon the results of these models?"

The peer reviewers decided to address these questions at the same time, because they thought serious flaws in the modeling approach (i.e., responses to Question E) would imply the need for revising the modeling work plan (i.e., responses to Question D). Before answering these questions, however, some peer reviewers indicated that they were uncomfortable commenting on improvements EPA has made since the PMCR was published. Other peer reviewers noted that their responses to Questions D and E would be quite similar, if not identical, to their responses to Questions A, B, and C.

The reviewers made the following comments, observations, and recommendations regarding Questions D and E of the charge (but, it should be noted that Sections 6.2 and 6.3 present the reviewers' final list of major recommendations):

- *Improved characterization of sediment transport.* Several peer reviewers' responses to Questions D and E focused on issues related to sediment transport. For instance, consistent with responses to Question B.3, one peer reviewer thought the proposed models could be enhanced by considering how non-cohesive sediments erode and how turbulence affects sediment resuspension. The reviewer noted that these factors have been considered in other recent modeling efforts (Cao, 1997). Further, this reviewer emphasized that sediment erosion can occur during low-flow conditions, thus potentially causing the cumulative effects of sediment erosion during "average" flows to be just as

significant as effects of sediment erosion during floods. Building on these findings, another peer reviewer suggested that EPA can better characterize sediment transport by: (1) providing some justification for assuming that the "active layer" of sediments is 5 centimeters thick; (2) accounting for the ultimate fate of resuspended sediments; (3) considering the significance of freshly uncovered, potentially contaminated sediments; and (4) incorporating semi-empirical sediment resuspension algorithms in HUDTOX, rather than characterizing sediment resuspension rates by model calibration.

Although the reviewers generally agreed on how the models should characterize sediment transport, the reviewers did not agree on an approach EPA should take to revise its models. One reviewer recommended that EPA incorporate the "depth of scour" model directly into the HUDTOX model, rather than leaving the models decoupled. This reviewer thought the use of a single, comprehensive model is needed to track the fate of resuspended sediments. Another reviewer disagreed, however, thinking EPA can improve its characterization of sediment transport while still using two different models. More specifically, noting that the HUDTOX and "depth of scour" models were developed to address two different principal study questions, this reviewer thought it may be appropriate to keep the models separate. In any case, this reviewer thought, it was sufficient for the peer reviewers simply to identify the shortcomings in the proposed modeling approach and to let EPA decide how to improve its models.

- *Statistical analysis of the modeling results.* Two reviewers thought the use of Student's t-tests to evaluate the performance of the HUDTOX model (e.g., see page 4-20 of the PMCR) was statistically invalid. Both reviewers agreed that these invalid analyses may have biased conclusions in the PMCR regarding performance of the models. The two reviewers suggested that EPA instead use regression analyses or simple plots of modeling results against observed values.

- *Link between the Thomann and HUDTOX models.* One reviewer thought the use of two models with different assumptions to address PCB transport in two different regions of the Hudson River could be a "serious flaw." The reviewer suggested that there should be more agreement between how HUDTOX characterizes PCB transport in the Upper Hudson River and how the Thomann model characterizes PCB transport in the Lower Hudson River.

- *Use of congener-specific data.* Citing an example of how Henry's Law constants may differ for individual congeners within a PCB homologue, one reviewer recommended that EPA consider, to the greatest extent possible, congener-specific data for Henry's Law constants, fish uptake and metabolic rates, degradation rates, and other relevant physical, chemical, and biological mechanisms.

- *Use of predictive bioaccumulation models.* Consistent with comments made on Questions A through C, two reviewers emphasized the importance of using predictive,

mechanistic bioaccumulation models instead of (or possibly in addition to) using either the probabilistic or bivariate models described in the PMCR.

- *Location of the upstream modeling boundary.* Revisiting a recommendation they made when responding to Questions A through C, two reviewers decided that it was not important to recommend that EPA move the modeling boundary to include regions upstream of Hudson Falls. These reviewers decided this recommendation was not necessary because (1) the upstream loadings during the 1993 calibration period may not have been representative of the general river conditions (i.e., conditions may still have been affected by the Allen Mill event) and (2) the PCB loadings in the Hudson Falls area may be impossible to quantify. As Section 6 notes, other peer reviewers also agreed to retract their earlier recommendation of moving the upstream boundary of the modeling domain.

- *Issue of PCBs in the Thompson Island Pool.* One peer reviewer emphasized the need to understand the mechanisms causing the apparent increase of PCBs in the Thompson Island Pool. This reviewer recommended that EPA investigate the possibility that biased sampling results from a downstream monitoring location might have caused the apparent increase, as was suggested during the observer comments.

- *Use of simpler models.* One reviewer suggested that simple, two-stage partitioning models may be sufficient for characterizing PCB transport and fate and bioaccumulation in the Hudson River; however, three reviewers disagreed with this suggestion. These three reviewers indicated that simple partitioning models are inappropriate for this application, mainly because they have no predictive capabilities. More specifically, the reviewers thought simple partitioning models could not forecast how levels of PCBs in the sediment, river, and fish would change following different remedial actions or flood events (i.e., simple partitioning models could not answer the principal study questions of the PMCR). These reviewers agreed that mechanistic models could serve this purpose.

- *Miscellaneous comments.* When discussing Questions D and E, several peer reviewers offered miscellaneous comments about the proposed modeling approach. For example, noting that over 90 percent of the PCBs originally discharged to the Hudson River may have moved downstream from the Thompson Island Pool, one peer reviewer wondered why modeling was necessary if only a small fraction of the PCBs that were discharged still remain in that area. Several other peer reviewers explained that the amount of PCBs suspected of being in the Thompson Island Pool, though a small fraction of the PCBs that were originally discharged, might contaminate fish for many years to come. Another reviewer thought the current modeling effort might not be applicable to other river systems if it becomes too specific to the Hudson River. However, several other reviewers were confident that an understanding of the mechanisms of sediment transport and bioaccumulation would be quite useful for future modeling endeavors, regardless of the river of concern.

- *Topics discussed earlier in the meeting.* At the end of their discussions on Questions D and E, the peer reviewers mentioned that they could have addressed several additional topics from their earlier discussions on Questions A through C. These additional topics include, but are not limited to, incorporating the risk assessment paradigm, involving risk assessors early and often, validating the model, addressing factors that affect bioavailability, and resolving analytical chemistry issues. Rather than repeat their discussions on these topics, however, the peer reviewers instead decided to classify their findings into "major recommendations" and "minor recommendations," as described in Section 6.

6.0 REVIEWERS' OVERALL RECOMMENDATIONS

After completing their technical discussions on Questions A through E, the reviewers spent the final hours of the peer review meeting identifying their major findings and recommendations for the proposed PCB modeling approach. The peer reviewers generally separated initial findings from their earlier discussions into three categories: major recommendations, minor recommendations (or suggested revisions), and findings they no longer considered important. This section summarizes the reviewers' discussions that led to identifying major recommendations (Section 6.1), then lists the reviewers' major recommendations (Section 6.2), and finally documents the peer reviewers' closing statements to EPA (Section 6.3).

6.1 Discussions That Led to Identifying Major Recommendations

As the first step in identifying their major recommendations, the peer reviewers engaged in a detailed discussion on the relative importance of the many recommendations presented earlier in the peer review meeting. During these discussions, the peer reviewers noted that their understanding of the modeling approach had evolved significantly since the time when they prepared their premeeting comments (see Appendix C), and even had evolved since the first day of the peer review meeting. The peer reviewers also consistently acknowledged that the issues they brought up may have already been addressed, since 2 years have passed since the PMCR was published.

When trying to identify their most important findings for the proposed PCB modeling approach, the reviewers made the following comments, observations, and recommendations. It should be noted, however, that Sections 6.2 and 6.3 present the reviewers' final list of major recommendations.

- *Importance of involving risk assessors.* The peer reviewers discussed at length the importance of involving risk assessors early and often in EPA's ongoing modeling efforts. For example, several reviewers emphasized as a "key message" of the peer review that the transport and fate and bioaccumulation modelers must be aware, if they are not already so, of the different exposure endpoints and forms of PCBs that the risk assessors will consider. These reviewers thought the modeling approach would be "fatally flawed" if the

modelers were unaware of the ultimate risk assessment targets. These reviewers were concerned that even scientifically rigorous transport and fate and bioaccumulation models will be rendered useless if their outputs do not interface with the inputs for risk assessment. To enhance risk assessor involvement, one reviewer suggested, EPA should hold a workshop or series of workshops to identify bioaccumulation models that provide data sufficient for conducting the planned human health and ecological risk assessments.

When discussing this topic, one reviewer was uncomfortable making a strong recommendation to EPA without knowing the extent to which EPA has involved, and continues to involve, risk assessors in the modeling efforts. Responding to this concern, several other reviewers indicated that the PMCR shows no evidence that risk assessors provided input to the modeling approach. These reviewers listed several specific questions that risk assessors should have answered at the onset of EPA's modeling efforts: What forms of PCBs (e.g., congeners, Aroclors, homologues, total PCBs) will the risk assessors consider? Will the risk assessors conduct a TEQ analysis? What exposure pathways will be considered? What species will be considered in the ecological risk assessment? What durations of exposure will the risk assessments consider? Without finding any indication in the PMCR that these issues have been resolved, most of the reviewers assumed that risk assessors have had limited involvement in EPA's ongoing modeling efforts.

Due to limitations in the transport and fate and bioaccumulation models, one reviewer thought a compromise may eventually be necessary between what the risk assessors would ideally like to consider and what the modelers can actually provide. More specifically, this reviewer noted that insufficient data may be available to calibrate the transport and fate models for every PCB congener, possibly even for congeners selected for analysis in the risk assessment. Another reviewer disagreed, noting that modelers can consider chemically similar PCB congeners to evaluate transport and fate and bioaccumulation of congeners that cannot be validated or tested directly. In any case, all of the reviewers agreed that the modeling efforts will be most useful if risk assessors specify at least (1) the types of species the bioaccumulation models should consider, (2) the forms of PCBs that need to be quantified, and (3) the durations of exposure that will be evaluated (i.e., acute or chronic).

- *Improvements to the sediment transport algorithms.* Noting that sediment transport can play a critical role in the bioaccumulation of PCBs in fish, the peer reviewers listed several areas in which EPA could improve its characterization of sediment transport. For instance, one peer reviewer thought the HUDTOX and "depth of scour" models should address how non-cohesive sediments erode, but he acknowledged that EPA may have considered this issue since the PMCR was published. This reviewer did not identify any "fatal flaws" with the HUDTOX and "depth of scour" models from a purely scientific basis, but the reviewer indicated there may be problems with how EPA intends to use them (e.g., how EPA will calibrate and link the models). Another reviewer echoed this

concern by indicating that the models will be only as good as the data against which they are calibrated. As an example, this reviewer indicated that the apparent increased loadings of PCBs in the Thompson Island Pool may have resulted from a sampling bias at a downstream monitoring location as suggested during the observer comment period (see Appendix F. To prevent biased monitoring data from invalidating the modeling results, this reviewer recommended, EPA should carefully verify the accuracy of all data used for calibration. Yet another reviewer commented on sediment transport by recommending that HUDTOX include a more mechanistic treatment of sediment resuspension and track the fate of resuspended sediments.

- *Use of mechanistic bioaccumulation models.* Several peer reviewers agreed that use of only the bivariate and probabilistic food chain models (i.e., the models described in the PMCR) would be a "fatal flaw" in EPA's effort to evaluate bioaccumulation of PCBs. These reviewers thought use of a mechanistic, predictive bioaccumulation model would be necessary to answer the principal study questions listed in the PMCR. These reviewers also acknowledged that EPA currently plans to include a mechanistic bioaccumulation model in its future work.

- *Links between individual models.* One reviewer thought EPA's proposed modeling approach may ultimately be rejected if the HUDTOX and Thomann models are not linked "in a seamless manner" and if these models do not share common assumptions. This reviewer thought the links were necessary (1) because PCBs will eventually flow from the Upper Hudson River (the domain of HUDTOX) to the Lower Hudson River (the domain of the Thomann model) and (2) because EPA will eventually assess human health and ecological risks to receptors throughout the entire Hudson River valley.

- *More sophisticated consideration of bioavailability.* Citing comments raised in responses to Questions A through C, the peer reviewers recommended that the modelers consider bioavailability in greater detail, possibly by developing chemical fate parameters (e.g., sorption and desorption kinetics) and biological fate parameters (e.g., uptake and metabolic rates), and incorporating these parameters into a bioaccumulation model—an approach that is not currently proposed in the PMCR.

- *Involvement of stakeholders.* One reviewer suggested that EPA's ongoing modeling efforts would benefit from the involvement of multiple stakeholders. This reviewer thought such involvement would ensure not only the scientific rigor of modeling results, but also the appropriateness of selected remediation options. The reviewer noted that this suggestion was related more to EPA's site reassessment process than to the technical validity of the models described in the PMCR. During this discussion, EPA explained that stakeholder involvement (including community interaction programs) has been a critical element of the site reassessment process, even though the PMCR did not describe this involvement.

- *Comprehensive evaluation of different remedial options.* Noting that the models described in the PMCR can only predict the effects of remedial options on concentrations of PCBs in the Hudson River and in fish, one reviewer recommended that EPA should also focus its resources on conducting a "life-cycle type of assessment" in order to evaluate the overall environmental burden of the different remedial options. This reviewer acknowledged that EPA already uses several criteria to evaluate the feasibility of different remedial options. (Another reviewer clarified that a "life-cycle type of assessment" considers several technical, economic, and political criteria for making decisions.)

6.2 Peer Reviewers' Major Recommendations

The peer reviewers briefly discussed selected responses to Questions A through E before identifying their major recommendations for the modeling effort. During this discussion, the reviewers agreed that they no longer considered moving the boundary of the modeling domain to a location upstream of Hudson Falls as an important issue, and they identified selected key findings, such as ensuring that the individual models will be linked, incorporating the modeling approach into the risk assessment paradigm, and considering bioavailability in greater detail.

To prepare a final list of their overall recommendations to EPA, the peer reviewers decided to have each peer reviewer list his or her major recommendations and then to characterize the extent to which the peer reviewers agreed or disagreed with each individual's recommendations. The comprehensive list of the reviewers' major findings and recommendations is provided below, as well as in the Executive Summary. Unless noted otherwise, all of the peer reviewers agreed with these major recommendations.

- The reviewers recommended that EPA make the following improvements in the description of sediment resuspension and deposition processes in the fate and transport models: address the fate of resuspended material; address the role of uncovered, potentially contaminated surfaces; address the issue of non-cohesive sediment resuspension; assure consistency in resuspension rates between the "depth of scour" and HUDTOX models; and identify the effect of flood resuspension on the rate of long-term recovery of the Hudson River. Some reviewers indicated that these changes could be made within the existing modeling framework (i.e., with different fate and transport models that are linked), while other reviewers thought these changes should be made by incorporating sediment transport mechanisms directly into the HUDTOX model, instead of keeping the models separate. A reviewer added that EPA should analyze error

propagation in the linked models and place a greater emphasis on "source attribution of PCBs to fish."

- The reviewers recommended that EPA employ time- and space-dependent mechanistic models that reflect the abiotic and biotic dynamics of the Hudson River system.

- The reviewers indicated that the models should be based on a consideration of bioavailability and sediment sequestration with respect to congener sorption/desorption kinetics, sediment particle characteristics, and biotic characteristics.

- The reviewers recommended that EPA link, to the greatest extent possible, the spatial and temporal scales of the different fate and transport and bioaccumulation models.

- The reviewers recommended that EPA clearly identify in its modeling approach the risk assessment targets as related to forms and concentrations of PCBs (e.g., to what guidelines or advisories will the modeled concentrations be compared). More specifically, the reviewers thought risk assessors and managers should be involved with the development of the transport and fate and bioaccumulation models, such that the model outputs will generate the data needed for completing human health and ecological risk assessments.

- The reviewers recommended that EPA develop a mechanistic food web model based on exposure dynamics of the identified forms of PCBs relevant to risk quantification, and that EPA identify appropriate data needs for the fate and transport models.

- The reviewers recommended that EPA develop an explicit plan for model calibration and independent validation that includes criteria for validation, makes use of numerous data sets that span a long time period, and includes chemicals in addition to PCBs.

- Noting that analytical methods have improved and will continue to improve, the reviewers recommended that EPA develop, and agree on how to use, a method for interpreting historical PCB monitoring data.

- Noting that EPA has already addressed or considered many of the recommendations listed above, the reviewers suggested that EPA hold an open workshop (involving all interested parties as well as independent reviewers) to evaluate current modeling efforts.

6.3 Peer Reviewers' Final Statements

The peer review meeting concluded with each peer reviewer providing closing statements on the proposed modeling approach, including an "overall recommendation" in response to the final question in the charge: "Based on your reading and analysis of the information provided,

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6.3 Peer Reviewers' Final Statements

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1. Acceptable as is
2. Acceptable with minor revision (as indicated)
3. Acceptable with major revision (as outlined)
4. Not acceptable (under any circumstance)"

During their final statements, several peer reviewers commended EPA on its ongoing efforts to model PCBs in the Hudson River, and some reviewers applauded EPA for using peer review to test the scientific rigor of the site reassessment process. Every reviewer found the overall modeling approach, as described in the PMCR, to be "acceptable with major revision"; however, one reviewer found the HUDTOX and "depth of scour" models to be "acceptable with minor revision." Noting that this classification is based primarily on the information documented in the PMCR, several reviewers acknowledged that EPA may have already addressed several of the major recommendations in the past 2 years.

7.0 REFERENCES

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