FINAL RESPONSE TO QUESTIONS FOR MODEL VALIDATION REPORT

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Introduction

The Peer Review Committee (PRC) has spent much time reviewing the results of the modeling exercises and analyzing the modeling performance. It has devoted a significant level of effort to suggestions as to how to improve the model performance and enhance its predictive capabilities in its application to remedial scenarios. However, to my mind the PRC has also perhaps focused excessively on model omissions and shortcomings and, in the process, has tended to overlook the very real benefits that have come from the modeling exercise, benefits that are substantial, irrespective of the perceived model shortcomings.

First, I believe that the most valuable aspect of the modeling exercise has been the discipline that has been imposed to the assessment of a detailed Housatonic River mass flux balance for the PCBs, total suspended solids (TSS) and water. The key factor in the assessment of any remedial strategy is going to be how it affects these mass fluxes. The modeling exercise enabled a detailed assessment of the relative order of magnitude of the mass fluxes in the various river system components and how these would change under different source flux hypotheses. Although these absolute fluxes may be somewhat in error due to the model shortcomings (to be discussed below), the relative order of magnitude under different hypotheses enables the key leverage points of control for the PCB fluxes to be identified. The available flux data appear to indicate that, although the modeling may have some problems, at least the predicted orders of magnitude appear to be in the range of available data. This suggests that the flux distributions, as described in Figures 1-5 and 1-6, and Figures 1-9 through 1-15, of the document "EPS Responses to Questions from Model Validation Document Overview Meeting", are most probably "in the ball park" and, when properly validated, can be used to develop potential remedial strategies.

In general terms, the modeling tends to show excellent agreement for water mass fluxes, which is not at all surprising as models to simulate the flow of water in channels have been in use for a long time and a failure on this score would be cause for real alarm. There is only one adjustable parameter for such models and this is the friction factor for the stream, if this parameter is correctly chosen, and the stream cross-sectional area is correct, then the water levels and flow rates can be very accurately simulated. On the other hand, models to simulate the movement of sediment in a fluvial stream are significantly more problematic. The basic difficulty lies in the erodible stream bed. Bed erosion is uniform neither transversally nor longitudinally in the stream. In addition, the bed erosion and the consequent bed form changes result in a change in the stream friction factor, which feeds back into a modification of the hydrodynamics of the flow. If, in addition, the stream bank erodes then long term changes in the direction and shape of the channel can result. Because the PCBs are an integral part of the stream sediments the difficulties of TSS mass balances carry through to the PCBs. To compound the difficulty, the PCB mass flux has two components: one associated with the sediments and the other with the dissolved phase in the water. A further complication is the kinetics of the partitioning process of the PCB between the water and the sediment, which was a matter of some discussion at the Peer Review meeting and may need addressing.

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

It is acknowledged that it is probably quite impracticable to model the sediment transport and at the same time compute the resulting changes in river bottom topography and their effects on the hydrodynamics. It would seem that a logical approach would be to use a quasi-steady approach in which the stream bed is divided transversally into three or more computational elements that enable at least a partial simulation of the bottom profile and the resulting velocity distribution and bed erosion. An alternative would be to take a longitudinal section of the stream and do a detailed three-dimensional computational fluid dynamics (CFD) analysis of the flow distribution and resulting erosion, then compare the results of this analysis to the one-dimensional approach to determine if a realistic one-dimensional parameterization is at all possible. Perhaps the single best alternative approach to this problem is simply to use empirical sediment and flow rating curves, which is the "old fashioned" empirical way these problems were solved before computers became involved (see, for example, http://www.epa.gov/warsss/sedsource/rivrelat.htm and http://water.usgs.gov/osw/techniques/TSS/Horowitz.pdf, where it is shown that accuracies of ±20% are possible for empirically-derived sediment concentration predictions). Incidentally, the hydraulic modeling could probably also benefit from a comparison of the predicted and actual stage-discharge curves, if this has not already been done.

Apart from this basic problem, which is of particular concern to me, other members of the PRC have other fundamental problems that will only be peripherally referenced here in the specific responses to charge questions that follow.

Question 1:
Considering the changes implemented in the Phase 2 Calibration, does the model as calibrated and validated, based on your technical judgment, reasonably account for the relevant processes affecting PCB fate, transport, and bioaccumulation in the Housatonic River to a degree consistent with achieving the goal of the modeling study?
"i.e., quantify future spatial and temporal distributions of PCBs (both dissolved and particulate forms) within the water column and the bed sediment"

Response:

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

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

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

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

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

In my professional opinion these two items are really key issues in the fate and transport analysis for the PCB. If neither phenomenon can be explained then how can any model hope to represent what is now occurring or, even more important from the point of view of this project, what will occur in the future. The second item I suspect may be a result of not including wind stresses and wind-induced mixing in Woods Pond. Wind waves continually stir up the sediment and when the wind dies the fine sediment (which apparently is high in PCB) settles last and stays there until the next set of wind waves occurs. The wind waves result in a preferential winnowing of fine material into the surficial sediments of the pond.

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

Question 2:
Are the comparisons of the model predictions with data sufficient to evaluate the capability of the model on the spatial and temporal scales of the final calibration and validation?
Response:
The EFDC comparisons between measured and simulated flow and stage offered in Figures 6.2-3 of the Model Validation Report for years 1979-1999 present essentially no measured data and should not be offered up as part of the validation. The comparisons for years 2002-2004 are convincing that EFDC does a good job of representing flow and stage. However, the equivalent time series of Total Suspended Solids (TSS) concentrations for 2002-2004 (Figures 6.2-19 through 6.2-22) do not really provide an adequate basis to conclude that the sediment transport is being properly modeled (which is not surprising considering the points made above). The field data are simply too sparse to make any meaningful comparison between simulation and measured data. Even the data for two specific flow events modeled (Figures 6.2-23 and 6.2-24) offer only a few measured data points for comparison. The use of actual measured sediment rating curves either for calibration or for analysis is urged. The PCB sediment data offered in Figures 6.2-49, 6.2-50, and Figure 6.2-51 indicate just how difficult is the process of validating the PCB fate and transport model and how unlikely it will be that the existing model will provide any real hope of predicting the future fate and transport of the PCB.

Question 3:
Is there evidence of bias in the models, as indicated by the distribution of residuals of model/data comparisons?
Response:
With respect to the PCB modeling the results are so tenuous (see Figure 6.2-49) that it is not possible to draw any really solid conclusion with respect to bias. However, an important point is demonstrated by Figure 6.2-50. This figure indicates that the sediment concentrations of PCB in the lower reaches of the project study area have declined somewhat since 1990 (i.e., since remediation activity started). Furthermore, there appears to be a similar decline in the water column concentrations of PCB, as is somewhat evident in the lower panel of Figures 6.2-44. (It is noted that there is no statistical measure of the significance of the decline in either the sediment or the water column, but the data are very suggestive). However, the modeling does not give any indication that any similar rate of decline has occurred (see Figure 6.2-50). In fact the comparison between the data and the model in this figure is strongly suggestive that the model does have a bias. The bias of the model is further reinforced by the results of the hypothetical remedial scenarios plotted in the un-numbered figure on page 56 of the EPA Response to Questions from Model Validation (Document DCN: GE-061406-ADFI), where, despite a reduction in the flux of PCB from the sediments in the upper river reaches, there is no significant change in projected sediment concentration of PCBs in the lower reaches. Thus the model does not match the reduction in sediment concentration that has occurred subsequent to actual post-upstream remediation, and projects no reduction as a result of an hypothetical reduction in the upstream PCB flux, as in the hypothetical examples. This problem needs to be understood and/or fixed before the model is used in real applications.

Question 4:
Have the sensitivities of the models to the parameterization of the significant state and process variables been adequately characterized?
Response:
My opinion is that the underlying processes involved with the PCB fate and transport do not appear well enough understood for a meaningful model to be developed. If the processes that seem to define the PCB fate and transport are not included in the model then their sensitivity cannot be assessed.

Question 5:
Are the uncertainties in model output(s) acknowledged and described?
Response:
Since the basic processes for the fate and transport of PCB are clearly not properly included in the model their uncertainty cannot be assessed.

Question 6:
Upon review of the model projections of changes in PCB concentrations in environmental media in the example scenarios, are such projections reasonable, using your technical judgment, and are they plausible given the patterns observed in the data?

Response:
I am not a biologist, but having said that, to a layperson the broad distributions of the PCB in the biota appear to be reasonably well described, at least at the central tendency level. This may well be due to the fact that partitioning of PCB into biota appears to be closely associated with the spread of concentrations in the environment. In the example scenarios there is no projected effect on the mean PCB concentration in the Woods Pond sediments, which does seem surprising, especially given the results in Figure 6.2-50, where there is a seemingly significant drop in the PCB concentration in the sediment between 1990 and 2000. However, there is a projected rough order of magnitude reduction in the water concentration of PCB in Woods Pond as a result of the hypothetical scenarios. The actual data for Woods Pond referenced above seem to show that there is a reduction in both water column and sediment concentrations coincident with the remediation that has occurred so far. It is not clear why the modeling should necessarily uncouple the water concentration from the sediment concentration in Woods Pond in the hypothetical examples.

Question 7:
Is the final model framework, as calibrated and validated, adequate to achieve the goal of the modeling study to simulate future conditions 1) in the absence of remediation and 2) for use in evaluating the effectiveness of remedial alternatives?
Response:
I do not think so. For the reasons stated above.

Overall Response

".......the Panelist shall describe the alternative approach that, in their opinion, would be sufficient to answer the question and achieve the goal of the modeling study."

The primary difficulty here is that the processes that result in the observed concentration distributions of PCBs in the sediment are not known and therefore cannot be included in the model. Second, the geometry of the system is probably too complex to apply properly the sediment transport theory that is known. However, these difficulties should not prevent the development of adequate empirically-based relationships between observed PCB concentrations and fluxes and the water and sediment fluxes. The sediment transport modeling attempts to use a fine scale theory that is applicable to a uniform flow and applies it over an entire river cross-section as if the river had this uniform flow. Many careful observations in the field, of PCB concentrations and fluxes together with stream flow and sediment fluxes, would have provided empirical relationships that would likely have proven much more accurate, useful and predictable. There is nothing wrong with such empirical relationships when the basic theory is unknown or too complex, and in fact EPA and the USGS already use such relationships (see the two websites referenced above).