MODELING STUDY OF PCBs IN THE HOUSATONIC RIVER PEER REVIEW

Modeling Framework Design
Final Written Comments

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RESPONSE TO CHARGE FOR THE HYDRODYNAMIC MODELING PEER REVIEW

I. General Overview of Response

A quantitative model of the transport, fate and bioaccumulation of PCBs in the Housatonic River will be developed by EPA. This model and its predictions will be used by EPA, together with other information, in making decisions regarding potential remediation actions for river sediments and associated floodplain soils for a portion of the Housatonic River. This portion is from the confluence of the east and west branches of the Housatonic down to and including Woods Pond (hereafter called the model test section).

As is usual with models of this type, there will be a large number of parameters in the model that can not be determined a priori but will be determined by calibration or “fine tuning” of the model, i.e., by comparing computational results from the model with observed data and then varying parameters until the calculations and observations agree. In this way, the model (and all similar models) will be “successful” in that the results of model calculations eventually will compare favorably with observed data.

Unfortunately, models can be made to fit limited observational data in a number of ways, with a wide range of processes, and a wide range of parameters that govern these processes. Although a good comparison of calculated and observed data is necessary, it is not sufficient for remediation purposes.

For scientists and users to have confidence in the model, especially sufficient confidence to make remediation decisions that require large amounts of money, time, and inconvenience to those on the river, it is necessary to have confidence in the submodels, i.e., to be sure they are describing the major processes accurately. As much as possible, the determination of parameters by calibration should be kept to a minimum. Parameters should be determined a priori on the basis of laboratory experiments or field tests. It is only in this way that confidence in the modeling results sufficient for remedial action will be developed.

II. Response to Peer Review Questions

In considering the foregoing general issues and evaluating the EPA documents, the Peer Review Panel shall give specific consideration to the following questions. As modeling activities proceed, additional specific questions may be identified the panel to address.

A. ***Modeling Framework and Data Needs***

1. ***Do the modeling frameworks used by EPA include the significant processes affecting PCB fate, transport, and bioaccumulation in the Housatonic River; and are the descriptions of these processes in the modeling framework(s) sufficiently accurate to represent the hydrodynamics, sediment transport, PCB fate and transport, and PCB bioaccumulation in the Housatonic River?***

The modeling framework described in the report includes three models: HSPF, EFDC, and Aquatox. Each of these models is very general and their descriptions include almost all conceivable processes that affect the hydrodynamics, sediment transport, and PCB transport, fate, and bioaccumulation in the Housatonic. Even if some processes have not been previously included in the models, the report indicates that additional processes will be considered, investigated, and possibly included at some future time.

However, including every possible process in a model does not make a good model; only the most significant processes should be included. Overly complex models are difficult to interpret and evaluate; too many parameters make calibration difficult and/or inaccurate. What is missing in the report is preliminary estimates of the significance (especially relative significance) of different processes. Once this is done, the most significant processes can be retained while processes with negligible influence can be ignored. This can usually be done without use of a complex model; simplified descriptions of the processes and estimates of the essential parameters are needed.

Although almost all significant processes are included in the models, the details of how these processes will be treated are missing. This is unfortunate, since "The devil is in the details". It is easy to say, for example, that cohesive sediments, bed load, suspended load, and bioturbation will be included in the model, but how are you going to do this? The details are missing and, I suspect, have not been considered thoroughly.

In a summary response to Question #1: (a) Almost all significant processes have been included in the model; (b) In fact, more processes than necessary have at least potentially been included and hence the model is overly complex; and (c) Detailed descriptions in the report of the process models are insufficient and inadequate. Some positive suggestions on how to improve this are given below.

2. Based upon the technical judgment of the Peer Review Panel:

a. ***Are the modeling approaches suitable for representing the relevant external force functions (e.g.. hydraulic flows, solids and PCB loads, initial sediment conditions, etc.), describing quantitative relationships among those functions, and developing quantitative relationships between those functions and PCB concentrations in environmental media (e.g., water column, sediments, fish and other biota, etc.)?***

HSPF seems to be suitable for predicting flows, solids, and probably PCB loadings before GE's remediation. It is not obvious that it is suitable after remediation without additional measurements and calibration because of changes in the 2-mile reach above the confluence.

There is insufficient information on initial sediment properties such as particle size, density, and erosion rates as a function of horizontal distribution.

b. ***Are the models adequate for describing the interactions between the floodplains and the river?***

At the meeting, it was mentioned that momentum was not conserved between the river and floodplain. This may be justified, but some estimates need to be given. Better yet, momentum should be conserved.

Despite comments to the contrary, the coupling between EFDC and Aquatox seems to be overly complex, especially at the river-floodplain boundary. EFDC should be used to predict sediment and PCB transport throughout the river-floodplain system, while Aquatox (if necessary) should be used as a food chain model only.

Aquatox is an ecosystem model and presumably will predict changes with time of biomass and populations of species and in trophic levels as well as PCB transport and fate, both abiotic and biotic.

Abiotic transport and fate should be left to EFDC. Model linkages are too complex otherwise. Although Aquatox may be an excellent ecosystem model, predicting the time variation of species in the Housatonic River (with little or no supporting data) is difficult and potentially misleading. A much simpler food chain model should be sufficient.

c. ***Are the models adequate for describing the impacts of rare flood events?***

Rare flood events are probably the dominant cause of sediment and PCB transport and fate in the Housatonic. This is indicated by the distributions of sediments and PCBs in the river, large deposits on the floodplain, and large historical flows, which are larger by factors of 20 to 40 than average flows. Because of this, transport and fate during these big events must be described properly.

In the report, the description of the models is inadequate to determine whether they can describe the impacts of rare flood events. There is no emphasis in the report on modeling big events or any details on how it will be done. This is unfortunate.

In order to model big events accurately, fundamental information on sediment erosion rates as a function of sediment depth and shear stress is needed. The reasons for this are that (a) erosion rates change by orders of magnitude with depth and (b) there is a very nonlinear relation between erosion rates and shear stresses (which increase by large amounts during big events). Hypothesizing some functional forms for erosion and deposition and then obtaining the appropriate parameters by calibration is not sufficient (Tracy and Keane, 2000; appendix by Lick). Large errors can result from this procedure. Sedflume data is essential for determining erosion rates, and this data must then be properly incorporated into the transport model (see below).

d. Are the models adequate for discriminating between water-related and sediment-related sources of PCBs to fish and other biota?

3. Again, based upon the technical judgment of the Panel, are the spatial and temporal scales of the modeling approaches adequate to address the principal need for the model - producing sufficiently accurate predictions of the time to attain particular PCB concentrations in environmental media under various scenarios (including natural recovery and different potential active remedial options) to support remedial decision-making in the context described above in the Background section? If not, what levels of spatial and temporal resolutions are required to meet this need?

Various grids (both curvilinear and rectangular) with different spatial scales have been suggested. My comments here are primarily for the spatial grid of EFDC and the description of hydrodynamics, sediment transport, and PCB transport and fate in the river and its floodplain. Because of the very convoluted path of the Housatonic, a curvilinear grid is probably not the best choice because of singularities and small elements in the grid. A rectangular grid throughout (with coupled grids of different sizes) is probably the best choice.

Recent advances in sediment transport modeling along with the capability of obtaining erosion rate data from Sedflume have demonstrated that accurate and predictive modeling of sediment transport is possible. However, to take advantage of these improved models, a grid fine enough to distinguish and delineate features within the river (such as changing bathymetry and changing sediment types) is necessary. A grid on the order of 5 m within the river including banks and regions close to the river is necessary. This is where the action is!

Farther away from the river on the floodplain, a 20 or 40 m grid is probably sufficient. This assumes that the floodplain is primarily depositional and will not erode significantly even in large floods. Some estimates of the validity of this hypothesis are necessary by a combination of estimates of water velocities, shear stresses, and erosion rates during flooding.

I do not agree with GE's statement that they will use a 20 m grid in the river area. If this size grid is used, significant features and variations in the river will be obscured by averaging and, as GE acknowledged, more parameterization will be needed. As models become coarser and less realistic with more parameterization necessary, confidence in the model and its predictions decrease rapidly. The model can always be calibrated and hence "successful" but with a loss of confidence in the model.

This is not necessary and should be avoided.

The above implies that a two-dimensional (vertically integrated), time-dependent model of the transport and fate of sediments and PCBs will be used. A one-dimensional, time-dependent model is insufficient based on extensive previous analyses by EPA, GE, and others (including myself). A three-dimensional, time-dependent model consumes much more development and computational time and is probably no more accurate in practice than a two-dimensional, time-dependent model (with a correction for quasi-equilibrium distribution of sediments in the vertical). This latter model is also much more computationally efficient. This has been shown in numerous cases. Even for the pond, a two-dimensional model is sufficiently accurate to predict sediment and PCB transport. As an example, see Wang et al (1996) where results of sediment transport calculations in Green Bay are compared for (a) a constant density, three-dimensional flow, (b) a vertically stratified, three-dimensional flow, and (c) a vertically integrated, two-dimensional flow. For all practical purposes, the results of the three cases are identical. This would be true for PCB transport also.

4. Is the level of theoretical rigor of the equations used to describe the various processes affecting PCB fate and transport, such as settling, resuspension, volatilization, biological activity, partitioning, etc., adequate, in your professional judgment, to address the principal need for the model (as defined above)? If not, what processes and what resolution are required?

As stated above, the description in the report of the basic processes affecting sediment and PCB transport and fate is insufficient. Various suggestions to improve the modeling of sediment and PCB transport and fate are as follows.

It is assumed that any description of sediment transport will be based on Sedflume data, i.e., erosion rates as a function of shear stress and depth in the sediments, not just a critical shear stress as seems to be implied in the report.

With this assumption, additional Sedflume data beyond that already reported needs to be collected. This is especially necessary, (i) in river regions where sediment properties are changing rapidly, (ii) on the floodplains, and (iii) on the river banks.

As far as Sedflume data is concerned, it is desirable when collecting data to obtain erosion rate data near the original sediment water surface as accurately as possible, with a resolution of as little as 1 mm. The reason for this is that this is the region where resuspension/deposition occurs during low to moderate flows, and hence is also the region, which most influences any calibration/validation that is done. Accurate measurements of density variations with depth are also necessary for accuracy. This can be obtained by a density profiler using ^{137}Cs as a source and measuring the absorption of that radiation (Gotthard, 1998).

In general, for a valid sediment transport and fate model, the following needs to be included: (i) Sedflume data, (ii) multiple sediment size classes, (iii) inclusion and unified treatment of bed load and suspended load, and (iv) the effect of bed load on erosion rates, i.e., bed coarsening. For medium sediments, bed load is mostly important because it modifies surficial sediments by armoring and hence decreases erosion rates. For coarser sediments, bed load is an important transport process.

These processes and parameters have been recently included in sediment transport calculations and have been shown to be significant (Jones and Lick, 2001). This type of sediment dynamics, or equivalent, needs to be included in EFDC.

With these improvements, an accurate and predictive description of sediment transport and fate in the river can be made. The extension to the floodplains (although never done previously) is probably also valid (with Sedflume data for the floodplains). Bank erosion is more difficult. Little work has been done on this problem, but some reasonable estimates based on observations and simple theories can probably be made.

As far as formation or cut-offs of ox-bows during big events, I don't believe this has ever been modeled in detail, but I don't see why it can't. In big events, these ox-bows are probably underwater. The standard hydrodynamics and sediment dynamics models should be able to predict variations in bathymetry and topography under these circumstances. Since it's never been done before, it would take some effort, but it would be nice to try.

Settling speeds of sedimentary particles are modified by flocculation. The sizes of flocs and their settling speeds are functions of sediment concentration and fluid shear (Burban et al., 1989, 1990; Lick et al., 1993). If anything is to be done about settling speeds besides parameterization, settling speeds of flocs should be measured in the laboratory as functions of these quantities and the resulting parameters then introduced into the model. Measuring settling speeds of flocs as they are in the river, as indicated in the report, is insufficient since conditions and hence sizes and settling speeds of flocs change as a function of suspended sediment concentration and fluid shear, especially during big events during which measurements have not been made in the field.

In order to accurately model PCB transport and fate, an average partition coefficient is not sufficient. Partition coefficients, K_p's, for PCBs vary widely, often from 10^2 to 10^6 or even more (see refs). A legitimate average over quantities that vary by orders of magnitude is hard to define. The value of K_p makes a difference in partitioning but also in transport. PCBs with low K_p's will generally be mostly dissolved in the overlying water and hence be transported out of the Housatonic test section in hours or days. PCBs with high K_p's will be absorbed to sediments in the overlying water and move with them as they are deposited, later resuspended and deposited, etc., or may be more or less permanently deposited on the bed and covered by other sediments. The transport out of the system, if it occurs at all, is much slower than the transport of water or PCBs with low K_p's.

This process is difficult to average. Worse, an average K_p from short-term observations and calibration will be much different from an average K_p needed to describe partitioning and transport over long time.

Time-dependent sorption of PCBs should also be included in the model since it has been shown to have a major effect (Chroneer et al., 1996). Differences of 2 to 5 have been demonstrated. Rates are known or can be estimated for PCBs with different K_p's, (e.g., Lick and Rapaka, 1996; Jepsen and Lick, 1999). However, because (i) K_p's for PCBs are sometimes not well known, (ii) sorption rates may also not be well known, and (iii) minimal modeling of this type has been done, maybe the inclusion of time-dependent sorption is too ambitious at this point.

However, the effects of time-dependent sorption should at least be estimated so that a better idea of the accuracy of the predictions can be made.

The major cause of PCB flux between sediments and overlying water is sediment resuspension and deposition and the subsequent absorption/desorption. However, other processes such as diffusion, bioturbation, pore-water convection (all modified by sorption) may be significant under certain circumstances, or may even be dominant under low flow conditions. Although each one of these processes has been investigated and modeled, the relative significance of each one of these processes is generally not known and the overall contaminant flux due to all of these processes has never been modeled.

Because of these difficulties, the contaminant flux (except for resuspension/deposition) must be modeled by use of a bulk mass transfer coefficient acting over some length scale. These are both empirical parameters to be determined by calibration and should be labeled as such. There should be no pretense that somehow these processes are being modeled from basic principles.

For extra credit, estimates of the effects of these different processes on the contaminant flux should be made, again to ascertain the accuracy and predictability of the model.

5. What supporting data are required for the calibration/validation of the model on the spatial and temporal scales necessary to address the principal need for the model (as defined above)? What supporting data are required to achieve the necessary level of process resolution in the model?

[See 6]

6. Based upon your technical judgment, are the available data, together with the data proposed to be obtained by EPA, adequate for the development of a model that would meet the above referenced purposes? If not, what additional data should be obtained for these purposes?

Remediation of region above confluence.

The two-mile region of the Housatonic above the confluence is being remediated by GE. This will continue for approximately the next two years. As this happens, conditions at the confluence (the upstream boundary condition for the region presently being modeled) will change. PCB concentrations should decline, although temporary increases are possible. Sediment concentrations may also change. These changes will certainly modify conditions throughout the model test section.

This is an ideal situation to test the model in order to understand effects of boundary conditions on conditions in the test section, and also to build confidence in the predictive capability of the model.

I strongly recommend (a) measurements of flow, TSS (concentration and size distribution), and PCB concentrations at the confluence, at the outflow from Woods Pond, and in the test section during the remediation period. Flow and TSS measurements are cheap and should be done at least daily, preferably several times a day. PCB concentrations (preferably by congener or at least for PCBs with similar K_p's) are more expensive; as many PCB measurements should be done as the budget allows.

Modeling of the test section should then be done based on this data.

A further question is the modeling of the remediation region above the confluence. It seems to me that this is quite difficult since the processes and consequences of GE's remediation are quite complex and difficult to measure. However, this modeling might be useful as a means to understand the remediation actions. If the modeling is done, extensive measurements of flow, TSS, and PCB concentrations within the remediation region would be needed; conditions at the confluence would serve as a check on the modeling and would be another reason for making measurements at the confluence.

III. Specific Comments on the Modeling Framework Design Report and/or the Quality Assurance Project Plan.

IV. Concluding Comments

The EPA models seem to be overly complex. They include almost all conceivable processes, but do not justify the inclusion of most of them.

HSPF is valid for predicting boundary conditions of flow, sediment, and PCBs as long as background conditions do not change. Any remediation would require re-parameterization of HSPF, or better yet, measurements of flow, sediment, and PCBs at boundaries.

EFDC is a valid transport model. The details of how it will include sediment transport and PCB transport and partitioning are weak or absent. However, much improved sediment dynamics models have been recently developed, are available, and should be included in EFDC.

Aquatox is overly complex and should be replaced by a simpler food chain model. Besides being overly complex, Aquatox will create difficulties with linkages and differences in representations of PCBs with EFDC.