MODELING STUDY OF PCBs IN THE HOUSATONIC RIVER PEER REVIEW

Modeling Framework Design
Final Written Comments

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June 12, 2001

RESPONSE TO CHARGE FOR THE HYDRODYNAMIC MODELING PEER REVIEW

I. General Overview of Response

The proposed Modeling Framework Design (MFD) is a very well prepared document that provides a very good foundation for a major undertaking: Modeling of PCB Contamination in the Housatonic River.

The intent of this response is to point out some of the potential problems that the reviewer has found mainly with some of the modeling approaches proposed in the MFD. At the same time, many references are provided in the response so that the modeling team should be able to enhance the capabilities of the hydrodynamic and sediment transport models to be used for the Housatonic River.

The problem at hand is very complex and the project goals are very ambitious. However, this is a great opportunity to learn about the dynamics of contaminated sediments. Thus the imperative need to use the best tools available and to develop those that are needed but do not currently exist.

On a more personal note, this reviewer feels that the evaluation of the MFD would have been facilitated if the members of the review panel had been able to communicate directly with the modeling teams. The possibility of discussing different issues directly with the modelers would have been very beneficial in many ways, in particular, the expertise provided by the review panel would have been used to its fullest extent.

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 proposed by EPA does include most of the significant processes that need to be accounted for in order to model PCB transport and fate in the Housatonic River. However, several processes such as floodplain sedimentation, erosion, transport, and deposition of sediment mixtures, streambank erosion, lateral stream migration and associated morphological changes, and flow through vegetated channels are not well formulated under the current framework and lack the level of understanding needed in an effort of this magnitude. At this stage, the proposed modeling framework is adequate to model PCB transport and fate, but provides only a reasonable starting point and should not be considered as the most accurate way for predicting the dynamics of PCBs in the Housatonic River.

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.)?***

The modeling approaches proposed to represent external forcing functions and boundary conditions, are well suited. Perhaps less clear is the issue of how far upstream should the modeling start. There would be some very clear advantages if the modeling were extended further upstream, in particular for the evaluation of future remediation activities.

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

Not in their present stage. The dynamics of sediments in floodplains is very poorly understood, in particular the role of vegetation on trapping sediments and associated pollutants. Simply increasing roughness coefficients will not tell much about the fate and transport of PCB in woody areas commonly found in the floodplain of the Housatonic River. A useful reference on this topic is Lopez F. and Garcia, M., "Open-Channel Flow Through Simulated Vegetation: Suspended Sediment Transport Modeling," Water Resources Research, vol. 34, No9, p. 2341-2352, 1998.

Most numerical problems are encountered in the transition from inbank to overbank flow conditions. A good set of experiments to test the numerical model, including also vegetation effects, can be found in the following reference: James, C.S., et al., "Conveyance of meandering channels with marginal vegetation," Water and Maritime Eng., Proc. of the Institution of Civil Engineers, 97-106, vol. 148, issue 2, June 2001. An excellent set of data to test the hydrodynamic model can also be found in: Shiono, K., and Muto, Y., "Complex flow mechanisms in compound meandering channels with overbank flow," Journal of Fluid Mechanics, vol. 376, pp. 221-261, 1998.

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

The hydrodynamic model might be capable of predicting flood routing through the Housatonic River. However, sediment resuspension and transport during floods can be substantially different from normal flow conditions. The hydrologic record indicates that sediment transport in the Housatonic River is mainly driven by storm events. The proposed models do not account for the lag effects and adaptation lengths commonly observed for suspended sediment transport by unsteady flows. A useful reference is Admiraal, D. et al., "Entrainment Response of Bed Sediment to Time-Varying Flows," Water Resources Research, vol. 36, No1, p. 335-348, 2000.

During large floods, water levels could be determined first with a 1-D model such as the one commonly used by the National Weather Service, and this information could then be used to test the overall predictive capabilities of a 2-D model.

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

The models would seem adequate to discriminate between water related and sediment-bound sources of PCBs. However, sediment itself could have an impact on habitat regardless of whether or not its laden with PCB (Huang, X., and Garcia, M., "Pollution of Gravel Spawning Grounds by Deposition of Suspended Sediment," Journal of Environmental Engineering, vol. 126, No. 10, October, 2000).

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?

The challenge for this modeling effort is that time and space scales are quite different depending on what process is to be modeled. For example, most streambank erosion takes place during and right after floods associated with storm events. So the time scale here can extend from a couple of hours to a few days, depending on the duration of the hydrologic event responsible for the flood. While overbank flows will take place during a flood as well, sediment deposition and accumulation on the floodplain will take place over time scales that are much longer, on the order of several years. Thus the need to determine very clearly what are the spatial (i.e. local erosion or watershed-scale erosion) and temporal scales (i.e. sediment transport event or natural recovery) being addressed by the modeling effort. This issue is not clearly addressed in the proposed modeling framework.

Of particular relevance will be the numerical grid size and type (e.g. curvilinear, rectangular) used to model the main channel and the flood plain of the Housatonic River. For flows up to bankfull, I would be in favor of using EFDC with curvilinear coordinates. EFDC seems capable of reproducing secondary flows induced by stream meandering, and would also give a good approximation of near bank flow velocities to compute fluvial erosion. Momentum transfer by secondary flows to the banks plays a major role on streambank erosion. For overbank flow conditions, the use of a rectangular grid throughout the river channel and floodplain would be a wise approach. I would strongly recommend against the use of the computational grid proposed in page 54 of the EPA Response to Peer Review Panelist Questions (April 12, 2001). The challenge still remains for the modeling of moderate floods, when the flow of water through the floodplain is not very different from that in the main channel.

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?

It is adequate but far from complete. The references provided above could shed some light for the development of more sound algorithms. I am particularly worried about the fact that sediment transport algorithms developed for bedload and suspended transport of uniform-size sediments (e.g. Van Rijn) are being considered to model sediment transport and fate in a river system with a broad range of sizes such as the Housatonic. Two useful references about existing formulations that could be used for modeling purposes are: Garcia, M.H., "Modeling Sediment Entrainment into Suspension, Transport and Deposition in Rivers," Chapt. 15, in Model Validation: Perspectives in Hydrological Science, Edited by M.G. Anderson and P.D. Bates, John Wiley & Sons, Ltd., 2001. For a compendium of different approaches see also: Garcia, M.H., "Sedimentation and Erosion Hydraulics" Chapter 6 in Hydraulic Design Handbook, Edited by Larry W. Mays, McGraw-Hill, 113 pages, 1999.

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?

The data already available should be useful for the calibration of the models. However, I am concerned about the use of models calibrated with short-term observations to predict long-term transport and fate of PCBs in the Housatonic River. However in the absence of more data, there are not many options to pursue other than to try to generate synthetic time series for a range of model input parameters and boundary conditions, with the goal of generating model outputs of statistical significance. Such exercise could be done by performing Monte Carlo simulations that would hopefully shed some light on the behavior of the reach of the Housatonic River being modeled, thus facilitating any future predictions of PCBs transport and fate. This undertaking should be done very carefully while being aware of the models limitations and shortcomings. Uncertainties and risks associated with model predictions should be clearly stated by the modeling team. There are tools available in the literature to help with this (e.g. Lopez and Garcia, "Risk of Sediment Erosion and Suspension in Turbulent Flows," Journal of Hydraulic Engineering, vol. 127, No3, March, 2001). The Quality Assurance Project Plan (QAPP) seems to have several provisions in place to ensure that the uncertainties associated with the modeling predictions as well as the data are clearly noted.

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?

The available data seems adequate for the development of a model for predictive purposes. One concern is the lack of any information about streambank erosion data and how this will be modeled without such data (i.e. erodibility properties of streambanks). Aerial photographs taken several years apart could be analyzed to determine streambank erosion rates and the location of potential meander cut-offs. A meandering stream model developed for Illinois streams in the 1990's has shown that sediment resulting from bank erosion can be a major source of pollution to streams (Garcia et al., "Mathematical Modeling of Meandering Streams in Illinois: a tool from stream management and engineering," Civil Engineering Studies, Hydraulic Engineering Series No43, UILU-ENG-94-2012, University of Illinois, November 1996).

It would be particularly useful to find out if there are bathymetric data for Woods Pond as well as dredging records. This information could in turn be used to assess a mean annual sediment load for the Housatonic River upstream of Woods Pond. These data could then be used to assess if the hydrodynamic and sediment transport models can predict sediment loads, before using them to predict PCB transport and fate.

Another data analysis that would be useful, is the development of sediment load rating curves for the Housatonic River. These curves could be very helpful to corroborate the predictions made by the hydrodynamic and sediment transport models, and could also be used to set boundary conditions.

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

The MFD is not very specific about streambank erosion and this is a very important component for the modeling of PCBs transport and fate in the Housatonic. In what follows, some comments and guidelines are provided so that if desired the MFD could be improved.

Processes of bank retreat and advance may occur together or separately at different locations and times along the same reach of the Housatonic River. Modeled rates of bank advance and retreat on both banks at a single section determine the rate of width adjustment.

Fluvially controlled processes of bank retreat are essentially twofold. Fluvial shear erosion of bank materials results in progressive incremental bank retreat. Additionally, increases in bank height due to near-bank bed degradations or increases in bank steepness due to fluvial erosion of the lower bank may act alone or together to decrease the stability of the bank with respect to mass failure. Bank collapse may lead to rapid, episodic retreat of the bankline. Depending on the constraints of the bank material properties and the geometry of the bank profile, banks may fail by any one of several possible mechanisms (Thorne 1982), including planar- [e.g., Lohnes and Handy (1968)], rotational- [e.g., Bishop (1955)], and cantilever- [e.g. Thorne and Tovey (1981)] type failures. A separate analysis would be required for analysis of bank stability with respect to each type of failure.

Nonfluvially controlled mechanisms of bank retreat include the effects of wave wash, trampling and grazing by livestock, as well as piping- and sapping-type failures [e.g., Hagerty (1991a,b) and Ullrich et al. (1986)] associated with stratified banks and adverse groundwater conditions.

For models of noncohesive bank erosion, hydraulic shear erosion of the banks is commonly simulated through application of the sediment transport model in the nearbank zone. Comparatively little is known about the mechanics of cohesive bank fluvial entrainment. Excess shear stress formulations are difficult to apply as the value of shear stress required to entrain the bank particles varies widely and is influenced by diverse processes (Grissinger 1982). For example, processes such as frost heave or dessication, which result in weakening of the intact material, may exert a more dominant control on observed rates of fluvial erosion than the intensity of the near-bank flow (Lawler 1986).

It is important to include a method in the MFD to predict the hydraulic shear erosion of cohesive bank materials in width adjustment modeling because erosion directly influences the rate of retreat of the banks and it also steepens the bank profiles and promotes retreat due to mass bank instability. These could contribute large amounts of contaminated sediments to the river. Approaches that exclude analysis of fluvial erosion of bank materials are, therefore, somewhat limited. Widening models that attempt to account for fluvial erosion of cohesive bank materials utilize empirically based methods, such as that of Arulanandan et al. (1980), which was reviewed extensively by Osman and Thorne (1988). Borah and Dashputre (1994) and Darby and Thorne (1996b) have, however, suggested that these methods are subject to some serious shortcomings.

Thorne, C.R. (1982). "Processes and mechanisms of river bank erosion." *Gravel-bed rivers*, R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds., John Wiley & Sons, Inc., Chichester, U.K., 227-271.

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Thorne, C.R. and Tovey, N.K. (1981). "Stability of composite river banks." *Earth Surface Processes and Landforms*, 6, 469-484.

Hagerty, D.J. (1991a). "Piping/sapping erosion.I:Basic considerations." *J. Hydr. Engrg*., ASCE, 117(8), 991-1008.

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Arulanandan, K., Gillogley, E., and Tully, R. (1980). "Development of a quantitative method to predict critical shear stress and rate of erosion of naturally undisturbed cohesive soils." *Rep. No. G1-80-5*, U.S. Army Wtrwy. Experiment Station, Vicksburg, Miss.

Osman, A.M., and Thorne, C.R. (1988). "Riverbank stability analysis. I:Theory." *J. Hydr. Engrg.*, ASCE, 114(2), 134-150.

Borah, D.K., and Dashputre, M.S. (1994). "Field evaluation of the sediment transport model "STREAM" with a bank erosion component." *Proc., Hydr. Engrg. '94*, G.V. Cotroneo and R.R. Rumer, eds., ASCE, New York, N.Y., 979-983.

Darby, S.E., and Thorne, C.R. (1996b). "Modeling the sensitivity of channel adjustments in destabilized sand-bed rivers." *Earth Surface Processes and Landforms*, 21, 1109-1125.

IV. Concluding Comments

The MFD and QAPP for the Modeling Study of PCB contamination in the Housatonic River are both very well prepared documents. In particular, the MFD has a substantial amount of detail about the way numerical models will be used and the field data available to test and validate model predictions.

Perhaps a more efficient way of preparing the MFD, would have been to determine first all the processes relevant to better understand the dynamics of PCBs in the Housatonic River, followed by a literature review to explore what models would be more suitable to accomplish the objectives of the project. This second intermediate step would have provided a better idea of the strengths and limitations of the different models available in the literature and would have pointed out gaps in knowledge (e.g. streambank erosion, floodplain sedimentation) that could eventually make any modeling predictions useless for the goals of the project.

Without doubt, there will be many challenges facing the modelers when they start the calibration and validation process. However, by maintaining a fluid dialogue with the review panel it should be possible to achieve the goals of the project.