PART 7

APPENDICES

Appendix 7.2 Comments as Received From Dr. James Martin Peer Review Summary: Lake Michigan Mass Balance Project

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7.2.1 General Comments

These comments are based upon a review of the draft (June 24, 2004) documentation "Results of the Lake Michigan Mass Balance Project: PCBs Modeling Report" as well as materials presented and discussed at the July 27-28, 2004 Peer Review Workshop held in Romulus, Michigan. The charge of the peer review was to focus on and address three major categories each with subcomponents, considering strengths and weaknesses:

1. Overall Multimedia Ecosystem Modeling Approach
2. Overall Model Performance
3. Suitability for Management

Each of these topics are discussed below followed by a summary of recommendations for continued and future development.

7.2.1.1 Overall Multi-Media Ecosystem Modeling Approach

The overall multi-media and mass balance approach is a necessity to a system like Lake Michigan where both the biota concentrations are an end-point for management decisions and biota impact the PCB cycling (since such a large component of the organic solids are of biotic origin). It is also necessary to include the hydrodynamics of Lake Michigan, since hydrodynamics impacts contaminant transport. For the analysis of loadings, consideration of loadings from all media (tributaries, the atmosphere, etc.) is also essential. The overall multi-media approach as implemented in the Lake Michigan Mass Balance Project included all of these components. The specific components and their relative importance will shift as issues progress from whole-lake to nearshore areas and from PCBs to other contaminants such as mercury. However, the framework developed for the Lake Michigan mass balance studies will provide a suitable base for the extension of the overall approach into other areas and to other chemicals of concern.

7.2.1.2 Overall Model Performance

The model(s) is (are) considered by this reviewer to adequately represent the physical/biological/chemical processes impacting PCB concentrations in the water, sediment, and biota of Lake Michigan. The present construct is considered limited in its applicability to whole lake issues. However, the extension of the framework to the LM3 level should allow for the modeling system to be used to address nearshore issues as well. The modeling framework is also suitable as a basis for the development of models of other chemicals of concern, such as mercury.

7.2.1.3 Suitability for Management

An assessment of the suitability of the modeling framework for management requires first delineating the specific management questions that framework will be asked to address. The strength of the studies completed to date is that they provide a framework that can be used in the contributing toward the "weight-of-evidence" with regard to the relative importance of loading sources on the average concentrations of PCBs in the lake as well as in estimating the time required for natural recovery in the water column and biota. To the extent that this weight-of-evidence relates to the management goals for the Lake, the modeling framework is suitable. It integrates the present understanding of factors impacting PCBs in Lake Michigan. While the spatial segmentation of the LM2-Toxic model is more detailed than that of the Level 1 models, the structure is perhaps best suitable for refining whole Lake estimates of PCB concentrations rather than predicting local variations.

However, there are a number of issues, such as nearshore and tributary issues, that the present model Level 2 models cannot address. For example, the LM2-Toxic model cannot be used to address issues related to specific Areas of Concern, other than as a lake-wide average. It is expected that the LM3-Toxic model, when completed, would be more suitable for addressing local variations in PCB concentrations and exposure.

An additional major strength of the study is serving as a framework for the evaluation of available data and in the planning of future data (and modeling) efforts. For example, analyses designed to determine model uncertainty provide not only information concerning predictive uncertainty but can guide monitoring efforts to reduce that uncertainty. An iterative program of model development and data collection may provide for the most efficient use of limited resources, particularly given the reasonably long time frame before some of the issues (such as the Total Maximum Daily Load (TMDL) for Lake Ontario) need to be addressed. This iterative approach to the collection and analysis of data, exemplified by the Levels 1 and 2 studies and leading to Level 3 is clearly an effective means of organizing all of the myriad efforts and parties involved in the collection and analysis of data. The participants are to be commended on the demonstrated efficacy of the use of the mass balance approach in the design of the PCB study.

7.2.2 Specific Recommendations

7.2.2.1 POM and Linkages

1. Continue development of the linked POM and Level 2 and Level 3 models.

2. Provide documentation of the POM application, perhaps as an appendix to the modeling report.

3. Assist in developing ice cover algorithms and linkages with water quality model.

4. Investigate potential linkages issues between POM and with SEDZL.

5. Investigate assumptions/limitations of using a sigma grid, particularly in resolving both nearshore and open-lake issues.

7.2.2.2 LM2-Eutro and LM3-Eutro

1. Continue to develop the Eutro model, for both linkages to the Toxic model as well as for use related to addressing conventional pollution in Lake Michigan and its tributaries/embayments.

2. Explore and document methods to relate measurable field data to model input values (e.g., refractory particulate organic matter).

3. Conduct additional calibration (e.g., to nitrogen series) as an additional test of the model's performance and if the model may be used to address questions in the future with regard to conventional pollution.

4. Consider including a sediment diagenesis model if Eutro will be used in the future to address management questions related to conventional pollution.

5. Consider exploring a more direct linkage with the food chain model, to address potential changes in the food chain structure.

7.2.2.3 Level 1 Model

1. Continue to maintain the Level 1 model, particularly for comparison with Level 2 predictions.

2. Explore incorporating specific algorithms, such as the steady-state algorithm, with the Level 2 and potentially Level 3 models.

7.2.2.4 LM2-Toxic

1. Test the linkage with the POM model by running conservative tracer test to insure that a mass balance is maintained.

2. Revisit and refine sediment component of the model (e.g., number of layers).

3. Extend the calibration period to an evaluation of historical loadings and/or a period encompassing all available data (not just the 1994-1995 data set).

4. Investigate why similar predictions were obtained to those from the Level 1 for what appears to be dissimilar reasons (differences in settling velocities, diffusion rates, bed thickness, etc.).

5. Apply the model to refine whole-lake estimates of PCB concentrations.

6. Extend the modeling framework to include other contaminants of concern (e.g., mercury).

7.2.2.5 LM Food Chain

1. Continue to develop and refine the food chain model.

2. Extend the calibration period to an evaluation of historical loadings and/or a period encompassing all available data (not just the 1994-1995 data set).

3. Consider investigating a more direct linkage with biotic models (such as LM3-Eutro).

4. Use the model along with any revisions made to LM2-Toxic to refine estimates of future trends in fish PCB concentrations.

5. Initiate extending the model (and data analysis) to other pollutants of concern (e.g., mercury).

7.2.2.6 LM3-Toxic

1. Continue to develop the LM3 model in order to test against the LM2-Toxic predictions to estimate the potential impact of a more physically realistic model on lake-wide PCB impacts.

2. Continue to develop the LM3 model in order to aid in addressing nearshore impacts which can not be addressed using the LM2 structure.

3. Continue to develop and test the linkage between the POM and LM3 models (both Eutro and Toxic), such as testing to ensure that mass conservation is maintained.

4. Continue to explore linkages or incorporation of SEDZL routines in the Level 3 models. This linkage may be of particular importance in evaluating nearshore trends and issues.

7.2.3 Specific Comments

What follows are some specific comments and observations regarding each of the modeling components. Some of these comments request clarification of specific assumptions and methods used in the development of the models. While the documentation provided was extensive, there were specific areas identified where additional information and/or clarification would be helpful.

7.2.3.1 Hydrodynamics and POM Linkage

The hydrodynamic model used in this application for LM3-Eutro, and planned for LM3-Toxic, is the Princeton Ocean Model (POM). POM is widely used and accepted and is similar in construct to several other hydrodynamic models in common usage (e.g., the ECOM model, which was based largely on POM, and EFDC). However, there was no information provided in the subject modeling report as to the model application and testing of the model, particularly with regard to an assessment of the applicability of the model to the transport of PCBs and other water quality constituents. The information provided was limited to a brief presentation by D'mitry Beletsky and David Schwab. As such, there was not sufficient information presented to assess the application or performance of the hydrodynamic model. Since the hydrodynamic model is a critical component of the Levels 2 and 3 studies, it is suggested that documentation of the model application be provided in the PCB modeling report, perhaps as an appendix.

One potential limitation to the POM model construct (relative to this application) is related to the coordinate system used in the vertical dimension (a sigma grid). A sigma grid requires a constant number of vertical layers throughout the model domain (beneath each of the 5 km horizontal grid cells (the number of vertical layers was variously cited as from 15 to 20 in the modeling report, which should be corrected). This use of the sigma grid may impact the ability of the model to resolve vertical gradients, particularly in deeper sections of the lake while still sufficiently capturing nearshore circulation patterns. In addition, sigma grids may produce artificial horizontal transport patterns. While there are numerical schemes for compensating for this, I am not aware that they have been implemented in POM or that any sigma transport tests have been conducted for an application such as Lake Michigan.

A second potential limitation of the POM model is its present inability to predict ice cover. From the presentations, it was suggested that ice algorithms will be added to the model and it is recommended that the incorporation of ice algorithms be pursued.

The linkage of the POM model with the LM3-Eutro grid was only briefly discussed. The incorporation of the QUICKEST-ULTIMATE routines from the U.S. Army Corps of Engineers CE-QUAL-ICM model should provide a suitable numerical framework for that linkage. However, the linkage of hydrodynamic and water quality models, even using a one-to-one spatial grid, is not a trivial task. For example, because of differing solution schemes, mass imbalances can occur which, if not properly treated, can accumulate and impact long-term model predictions. As such, testing is required to ensure that water and constituent mass are conserved globally and locally in the linked water quality model. This testing needs to be documented and should be included in the modeling report, perhaps as an appendix.

An overlay grid, such as between the POM model and LM2-Eutro and LM2-Toxic is often more problematic than using a one-to-one spatial grid (between a hydrodynamic and water quality model). In this application, it was suggested that linkage problems did occur resulting in the necessity of adding "water balancing flows" (Part 4, Chapter 3, Section 4.3.3). Adding water-balancing flows is not an uncommon practice in linking three-dimensional hydrodynamic and water quality models. Typically those flows are small but without them water volume imbalances accumulate over time. However, it was indicated during presentations that in this study, not including the "balancing" flows resulted in water volumes going to zero in some water quality segments (in Green Bay). This is indicative of a linkage problem that should be further investigated. In addition, the approach used to compute vertical exchanges (Equation 4.1.1) should not have been applicable if vertical flows (gross not net) were included with the hydrodynamic linkage. It is suggested that additional testing of the linkage be conducted and documented within the modeling report, perhaps as an appendix.

In addition to spatial averaging, there was apparently time-averaging of hydrodynamic predictions as well, allowing a daily time-scale for the LM2-Toxic model. The procedures used to average the hydrodynamic predictions, and tests conducted to determine the impact of that averaging, should be documented.

In general, the linkage of POM with the LM models represents an advancement and provides additional capabilities that should be continued to be developed. For example, the coupled model should more accurately predict the transport patterns in the lake, which are always of questionable accuracy when based on purely descriptive techniques. In addition, the coupled model may be more readily applied to predict conditions in more localized areas, such as nearshore, and to predict conditions (such as extreme events) that cannot be adequately characterized using a descriptive approach.

7.2.3.2 LM2-Eutro and LM3-Eutro

The eutrophication model is an important component of the overall multi-media modeling approach. The addition of an eutrophication model is of particular importance for Lake Michigan due to the reported large fraction of total sorbents that are of biotic origin (reported to be 90 percent of the total organic carbon load to the lake, Part 4, Chapter 3, Section 4.3.4). The overall structure of the eutrophication model seems reasonable, and seems comparable to other eutrophication models. The majority of the comments provided below are related to clarifications that would be helpful in the modeling report.

Some additional description is needed as to how the field data (as listed in Table 1.1.2) were converted to model input or used for model comparisons. Table 2.4.6 lists the two "types" of data but does not describe how the transformations were made. Table 1.1.2 does not indicate that zooplankton were a measured parameter, although it is a model state variable and the text indicate that zooplankton data were collected (Part 2, Chapter 4, Section 2.4.2.2.4). Also, while I agree that the expansion of variables to include dissolved organic and labile and refractory particulate organic forms allows for more realistic description (which is an increasingly common practice) there are no established protocols for measuring these forms. Therefore, it must have been necessary to make assumptions regarding, for example, the partitioning of particulates among labile and refractory forms. Those assumptions should be described in the report, and perhaps some sensitivity analyses performed as to the impact of differing assumptions on model predictions. The assumptions regarding the split were indicated (Part 2, Chapter 4, Section 2.4.1.1) for atmospheric loads, but not for other loading sources that this reviewer could find.

In Part 2, Chapter 4, Section 2.4.4.2, it is stated that laboratory primary production rates were used to verify the overall production rates in the model. These comparisons should be included in the modeling report.

The characterization of non-diatoms versus diatoms is a useful breakdown. Since blue-greens were the dominant algae, some additional explanation would be worthwhile as to how nitrogen limitation was computed for these algae.

The section of the report (Chapter 1) dealing with the calibration of the LM2-Eutro and LM3-Eutro was somewhat confusing, with regard to which model was calibrated against existing data.

The comparisons of model predictions and field data were somewhat limited in Chapter 5. Additional comparisons should be provided, both graphical and statistical, between model predictions and observed data. Comparisons should be provided if possible for all state variables. For example, no comparisons are presently provided for nitrogen species.

Presently, the LM2-Eutro and the LM3-Eutro codes specify sediment fluxes as zero order rates, which is a common practice. However, there are models of sediment diagenesis that allow prediction, rather than description, of those rates. While probably not critical in the context of using the Eutro predictions for input to the Toxic model, incorporation of a sediment diagenesis model may be worthwhile should the LM3-Eutro model be used in the future to assess eutrophication-related management questions.

In general, the linkage of the Lake Michigan eutrophication and toxicant models represents an advancement and provides additional capabilities that should be continued to be developed. This reviewer considers the existing eutrophication model construct sufficient for its intended use, to provide biotic solids for the toxicant model. However, the eutrophication model is also considered important in its own right, and should have applicability in addressing questions regarding conventional pollutants in Lake Michigan. In addition, perhaps some more direct coupling of the eutrophication and food chain model could be considered in future applications, to aid in addressing questions regarding impacts of changes in food chain structure on uptake of PCBs and other toxicants.

7.2.3.3 Level 1 Models

The inclusion of the Level 1 model in the modeling report and presentations, and the contrasting of model construct and predictions with the Level 2 model, was considered by this reviewer to be very useful. First, the Level 1 model and its predictions were useful in providing insights into factors impacting PCBs in Lake Michigan and addressing interim management questions. In addition, the Level 1 modeling studies illustrated what this reviewer considers to be one of the best uses of models and modeling studies: to first aid in mining and interpreting available data, to then identify deficiencies in available data and modeling approaches, and finally to aid in planning additional studies and model refinements.

One area that perhaps deserves further investigation is the similarity in predictions of the Level 1 and Level 2 models. Both models predicted remarkably similar changes in total PCB concentrations over time in the long-term projections. However, there were differences between the two models such as in the rates of settling/resuspension used and in the characterization of the sediment bed. As a result, the two models predicted similar results for somewhat dissimilar reasons. It would be of interest to further investigate factors leading to the similarity in predictions, which may provide some additional insights as to factors controlling PCBs in Lake Michigan.

There were some capabilities of the Level 1 model which should be considered for incorporation into the Level 2 model. One such capability is the steady-state solution. A goal in future studies, as expressed during the presentations, was to assess uncertainty in the Level 2 model. Uncertainty is most commonly assessed using steady-state rather than dynamic predictions. The long simulation time required to achieve steady-state predictions in the dynamic Level 2 model may preclude conducting uncertainty analyses. Incorporating steady-state solution techniques in the Level 2 (and ultimately the Level 3 model) would facilitate the analysis.

7.2.3.4 LM2-Toxic

The Level 2-Toxic model represents an advancement over its predecessor, the Level 1 model. These advancements not only include simulation of PCB congeners, but improvements in transformation kinetics, such as volatilization. A number of these improvements resulted from Level 2 investigations, and the study serves as a very good example of the benefits achieved through the iterative development and refinements of models

The coupling of the POM predictions to the Level 2 model seems a reasonable approach. However, using a 1-1 grid rather than a course-grid overlaying a fine-grid hydrodynamic model is a preferable approach, which is the approach planned for the Level 3 model. Several recommendations regarding testing of the linkage between the POM hydrodynamic model and both the LM2-Toxic and LM3-Toxic model were discussed in a previous section.

With regards to solids transport, the approach used for computing sediment resuspension seems reasonable. However, it is hoped that a more detailed sediment model (SEDZL, which was part of the original plan) can be incorporated into the Level 3 framework. The settling velocities used also seem reasonable but are lower than those used in the Level 1 study. Since the estimated resuspension velocities will vary with the settling velocities, the rates used are also presumably lower than those used in the Level 1 studies. Since the projections of the two models were remarkably similar, some additional investigation as to why similar predictions were obtained using dissimilar rates would be worthwhile.

The sediment bed model seems reasonable. However, some additional clarification of the semi-Lagrangian method for simulating the sediment bed (Part 4, Chapter 3, Section 4.3.4.2.3) would be useful. In addition, the present construct does not allow for the tracking of materials buried out of the layer, or perhaps entrained into the layer from deeper contaminated sediments. Some additional development of the sediment algorithms would be useful for the Level 2 model and for incorporation into the Level 3 framework (where it may be more important with regard to nearshore issues).

As indicated in Part 4, Chapter 6, Section 4.6.2, the flux contributed by the diffusive term from the sediment bed was unexpectedly large relative to the resuspension flux. This may have been due to the relatively large specified diffusion coefficient used relative to the Level 1 model. As suggested above, some additional testing is recommended to compute and compare factors causing predicted variations between the Level 1 and Level 2 studies, and the diffusive fluxes should be considered in that testing. In addition, it was indicated in Part 4, Chapter 6, Section 4.6.2 that the total PCB residence time for Lake Michigan were on the order of 100 days. This estimate seems low to this reviewer. It would be interesting to see how this compares to predictions from a Level 3 model which may more realistically estimate vertical exchanges in layers isolated from the water surface. The Level 3 model could be used to determine if the rapid removal may be in part an artifact of the modeling approach used in the Level 2 studies. As an example, given the rates of settling used, surface particles would require approximately one year to reach the bottom, while with a single vertical-box model it would be assumed that vertical transport is on-average instantaneous.

The comparisons of measured and simulated concentrations seem reasonable. However, since differences occur between factors controlling PCBs in Lake Michigan and Green Bay, the results for these two systems should be reported separately.

One limitation to the Level 2 application, and to many similar studies, was the limited time-scale to which the model was applied. The model was applied and calibrated using data from the 1994 and 1995 field studies. Given the time scale of changes in Lake Michigan PCB concentrations, this period is not sufficient to test the model against long-term trends in the PCB concentrations for Lake Michigan. Similarly to the Level 1 studies, it would be worthwhile as an additional test to run the model with estimated historical loadings and for comparison to all existing data, including data from this sampling period. Such an application would provide additional testing of the robustness of the model, particularly since the models intended use is in the projection of long-term trends in PCB concentrations for Lake Michigan.

7.2.3.5 LM Food Chain

The food chain model used in this study was based upon what I consider to be a widely accepted approach and which I consider adequate for the purposes of this study. However, my experience in food chain modeling is limited and dated so I would defer to others with more recent experience to evaluate this component of the model. As with the LM2-Toxic model, the application of the model to a longer period of record is recommended as an additional test of the model.