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WORKPLAN TO EVALUATE THE FATE AND TRANSPORT MODELS FOR THE LOWER FOX RIVER AND GREEN BAY

Introduction

The work described in this workplan is designed to evaluate and potentially enhance the PCB fate and transport models for the Fox River and Green Bay as set forth in the agreement between the State of Wisconsin and certain companies regarding the Fox River. This evaluation is intended to supplement and build on previous evaluation work conducted by the Companies and the State of Wisconsin. This workplan sets forth a series of tasks that provide for the evaluation of the existing models and potential development of enhanced versions.

The following items are included as part of this workplan: 1) a brief summary of the intended uses and critical outputs of the models, 2) a detailed description of the technical tasks and deliverables, 3) an estimated schedule for completion of tasks, and 4) a table presenting allocation of work, estimated budget and roles among technical work group participants.

Intended uses of these models

These PCB fate and transport models for the Fox River and Green Bay models will be used to assist in:

1) PCB exposure pathway determination, and analysis of restoration alternatives for the Natural Resource Damage Assessment, and

2) remedial planning activities, including discriminating among natural recovery and other specified remedial alternatives.

Critical Model Outputs

The critical model outputs have been identified as: 1) predicted PCB concentrations in water and sediments; and, 2) fish body burdens in the Fox River and Green Bay. Total PCBs are the primary state variables of interest; however, selected PCB congeners needed for the Natural Resource Damage Assessment (NRDA) will also be simulated. Additional model outputs may be of interest during calibration and validation (e.g. solids concentrations in the Fox River and Green Bay).

Task 1: Development and Prioritization of Model Evaluation Metrics and Quality Criteria

This task entails the development and prioritization of model evaluation metrics and quality criteria to evaluate the current suite of Fox River/ Green Bay PCB fate and transport models. Based on comparison of model output to the established metrics, an assessment will be made of the suitability of the current models for use in remedial planning and the NRDA plan. Two classes of model evaluation metrics will be considered: 1) Metrics that evaluate the ability of the models to describe existing data, and 2) A metric to evaluate the uncertainty in model projections of future conditions. Finally, quality criteria will be defined that consider model performance against both types of calibration metrics, to allow selection of a final model framework.

Metrics to evaluate the ability of the models to describe existing data will include:

- model-data comparisons of TSS and PCBs in water for the data-rich calibration period of 1989 through the present, and the historical hindcast period of 1955 through 1997 where data are available.

- model-data comparisons of lateral and vertical PCB concentrations in sediments for the data-rich calibration period of 1989 through the present,. and the historical hindcast period of 1955 through 1997 where data are available.

- model-data comparisons of fish PCB concentrations for the data-rich calibration period of 1989 through the present,. and the historical hindcast period of 1955 through 1997 where data are available.

- Comparison of model computed and data computed flow averaged cumulative flux of PCBs and TSS at selected cross sections at different temporal scales.

Other metrics that will be considered include:

- Consistency of model predicted solids and PCB deposition rates to rates interpreted from dated Cesium core profiles at selected locations in the Fox River and Green Bay.

- Consistency of model predictions of bed elevation changes to changes interpreted from field measurements (transects) and past dredging history.

This preliminary list will be modified and expanded as part of this task.

An additional metric will be developed based upon the uncertainty in model projections of future conditions. This metric is required because addition of new features to existing models may improve their ability to describe historical data, but may increase their uncertainty.

The final list of model evaluation metrics and corresponding quality criteria will be generated as part of facilitated discussions among modeling technical workgroup participants. The quality criteria will consider both groups of metrics (i.e. ability to describe observed data as well as uncertainty in future predictions). Quality criteria for evaluating the ability of the models to describe observed data will be expressed, where possible, using accepted techniques such as a relative percent agreement between model predictions and observed data, or statistical significance of differences between model and data.

Deliverable: The deliverable for this task will be a technical memorandum setting forth the final prioritized list of evaluation metrics and quality criteria.

Task 2: Development of historical and current solids and PCB loads to the Fox River.

Inaccurate assessment of historical solids and PCB loads can result in an inaccurate hindcast and/or improper model calibration. For example, if solids loads are underestimated, larger than actual resuspension rates and/or smaller than actual settling rates might be erroneously specified. In addition to affecting the hindcast, these errors in turn affect the utility of the modeling tools for decision making.

Rigorous evaluation of the current suite of fate and transport models would benefit by reliable estimates of historical (between approximately 1957 and the mid 1990s) solids loads to the Fox River and Green Bay. Estimates of historical PCB loading will also assist in using hindcasts for model calibration and validation. Because of data limitations, it will be necessary to characterize the uncertainty of these load estimates. This uncertainty will be represented within upper and lower bound estimates.

The following subtasks will be conducted as part of this task.:

2a) Computation of watershed solids and non-point PCB load estimates for the Fox River. Due to historical solids concentration data limitations for tributaries to the Fox River, a watershed-based approach will be applied to the Fox River to estimate historical solids and PCB non-point source loads. Recent non-point source modeling of the Fox River system has been conducted using a continuous simulation watershed model. If this model is available it will be evaluated and applied if time constraints allow. Otherwise, an alternative estimation technique will be considered.

2b) Computation of watershed solids and non-point PCB load estimates for Green Bay. Similar to the Fox River, historical solids concentration data limitations necessitate application of a watershed-based model to generate historical non-point source solids and PCB loads to Green Bay. These loads will be estimated using a continuous simulation watershed model or drainage area ratios (DARs) in conjunction with available solids concentration measurements. A continuous simulation watershed model will be driven by the historical rainfall record, land use, topography, and soil type. The DAR approach will be driven by measured flows on tributaries in and adjacent to the Green Bay watershed, soil type, and land use patterns. To generate historical loads changes in landuse will be identified based on available areal photography, LANDSAT data, and regional planning agency records. Each approach will generate solids and PCB loading histories for the major tributaries to Green Bay, in addition to direct runoff load estimates. The available tributary solids concentration data will be used to constrain inputs to the watershed model.

2c) Computation of internal production of solids in Green Bay and the Fox River. Nutrient dynamics and primary production rates in Green Bay and the Fox River have changed significantly during the time period 1955 through 1997. Since nutrient dynamics and transformations among various solids sorbent compartments have a significant impact on PCB fate and transport, it is crucial to compute the internal solids production in Green Bay and the Fox River. This task will generate time series of internal solids loads based on available nutrient data, chlorophyll-a data, and primary productivity data for Green Bay and the Fox River.

2d) Computation of point source solids and PCB loads to the Fox River. This task, which will be conducted by WDNR, will provide estimates of monthly average solids and PCB loads for the entire period of interest (1957 through 1997) from all significant sources discharging into the Fox River. The WDNR has estimated 30 point sources of solids loads to the River (20 paper and pulp mills and 10 publicly owned treatment works).

For the period prior to 1972, a number of methods will be used to estimate the TSS discharges. For paper and pulp mills, production capacities based on Lockwood and Post directories, will be used to pro rate discharges measured and reported after 1972. Effluent treatment methods applied by each facility will be used to modify these estimates during the appropriate treatment periods. If production records are not available, extrapolations of existing records will be used.

Solids loads from publicly owned treatment plant records will be extrapolated based on flow and data available in the WDNR computer data base for each facility. Extrapolations will be modified by effluent treatment methods applied at each facility and dates of plant expansions.

The settling characteristics of the discharges will be approximated by ranges based on the type of solids discharged by each facility. The type of treatment at each facility, if any, and internal process changes will also be considered in making this determination.

Point source PCB load estimates will be based on the currently available estimates by Patterson et al., 1995. Although the companies do not intend, by the use of the Patterson estimates, to suggest that those estimates are necessarily accurate, they believe that the estimates are adequate for developing a credible hindcast. If and when new information becomes available, these load estimates will be revised and refined as necessary.

The above tasks will provide load estimates for the following time periods:

- the current calibration period - approximately 1989 through 1995;
- the future projection time period; and,
- the historical hindcast period.

Deliverable(s): The deliverable for each subtask will be a technical report prepared by the appropriate technical lead detailing all aspects of the work conducted. Electronic copies of all loads in a format suitable for inclusion in the fate and transport models will also be provided.

Task 3: Evaluation of the current suite of fate and transport models using the estimated historical loads and the established metrics.

After model evaluation metrics have been established, the current suite of fate and transport models will be evaluated. This task will include evaluation of the Upper Fox River Model (UFRM), the Lower Fox River Model (LFRM), the Green Bay Toxic Chemical Fate and Transport Model (GBTOX), the Green Bay Food Chain Model (GBFOOD), and the BSAF approach. Model results will be subjected to the metrics established under Task 1 and evaluated. If each model meets the criteria established for a successful evaluation, the models will be accepted for use in the NRDA and remedial planning efforts. If the models fail to meet identified metrics, specific changes and enhancements of the models will be undertaken as set forth in subsequent tasks in this workplan, as deemed necessary and appropriate.

Deliverable: The deliverable for this task will be a technical report describing the models evaluated, the model evaluation process, and the results of the evaluation. It will also provide recommendations on any additional work, if found necessary.

Task 4: Development and implementation of alternative model structures.

Potential improvements to the current model structure and/or representation of the system will be identified, developed, and implemented. Alternatives which will be considered include: 1) application of a “floating frame of reference” system in the sediment bed handling routines, 2) lateral segmentation of the water column segments, and 3) representation of multiple particle types. Additional alternatives will be evaluated as time and resources permit.

Prior evaluations have identified the need to consider an alternative conceptual approach to handling the sediment bed in the LFRM. This alternative approach has been referred to as a “floating frame of reference”, whereas the approach currently used by all three of the fate and transport models being evaluated has been referred to as a “fixed frame of reference”. The need for adopting the floating frame approach to the UFRM and GBTOX will be assessed after it is implemented and evaluated in the LFRM.

This alternative model framework will be implemented in the LFRM, as a test case, through modification of the existing model framework. The first step will be to create a “stack” of sediment layers under the existing simulated bed layers. If erosion results in the entire surface layer being eroded during an event, renumbering of the segments will be triggered instead of mass being added to layer 1 from the deeper layer 2. The top layer of the “stack” will be incorporated in the computational framework as the bottom bed sediment. During periods of deposition the surface layer will be allowed to grow in thickness (the bed solids density is kept constant, as in the existing IPX framework as implemented in the LFRM) until renumbering is triggered based on a user-specified maximum thickness that the surface layer can attain. This top layer will then be split into two layers and the sediment segments renumbered accordingly. The bottom sediment layer will then be “pushed” downward out of the simulated sediment layers and on to the top of the “stack”. This approach will also ensure that over long time scales model predictions of the average thickness of the surficial mixed layer is consistent with any available field data. This improved version will be evaluated, after implementation, utilizing the metrics developed in Task 1. This evaluation will result in a recommendation to accept or reject this alternative framework.

Lateral segmentation of the water column may serve to better represent the spatial heterogeneity in solids settling velocities and deposition areas, especially in the vicinity of point source outfalls. The need for this will be assessed for all fate and transport models through the iterative process of model evaluation and enhancement.

Representation of multiple particle types in the river could help provide a better representation of sediment bed dynamics. Similarly to the lateral water column segmentation, the need for this additional complexity will be assessed through the model evaluation and enhancement process.

Deliverable: The deliverable for this task will be a technical report outlining all alternatives considered, the development and implementation of the alternatives, and the implications of the alternatives for future projections.

Task 5: Developing Constraints to Parameterization of Sediment Dynamics in the Fate and Transport Models

The goal of this task is to develop constraints to the sediment dynamics in the Fox River fate and transport models. Rigorous evaluation and subsequent enhancement (if needed) of the fate and transport models will require development of as many constraints to model parameters as possible. In addition to a variety of model-data comparisons that will be used as constraints (see Task 1 and 6), the sediment dynamics in the fate and transport models will be further constrained and specified by three subtasks below. Each of the alternatives will be evaluated for suitability to constrain the lower Fox River fate and transport model. The understanding of the strengths and limitations of each approach to constrain the fate and transport model will be used to identify the most appropriate approach to adopt.

5a) Development and application of a sediment erodibility study.

For the sediment and PCB erodibility study, LTI proposes to apply the Depth of Scour Model developed for the Hudson River. This study will estimate the probability of scour at select sediment core locations within the river for a range of flows, and serve to bound the scour predictions in the fate and transport model. This model will also provide an assessment of the success of natural recovery at the core locations.

The proposed approach to conducting the erodibility study includes the following tasks.

1. Identify flow events of interest, including a 100 year event.

2. Generate fine-scale information on bottom shear stresses for the peak flow corresponding to each event using a hydrodynamic model.

3. Based on sediment physical properties, estimate likelihood of scour for each core location where fine scale hydrodynamic model bottom shear stresses are available. The likelihood of scour is characterized by uncertainty bounds on the predictions that take into account variability in the sediment properties.

4. Develop GIS-based maps of PCB erodibility potential.

5. Develop empirical functions describing settling and resuspension based on the flow hydrograph.

To drive the erodibility study, fine scale bottom shear stress information is needed. This information will be obtained from a site-specific modification of LTI's RMA-based hydrodynamic model for the Hudson River.

Deliverable: The deliverable for this task will be a technical memorandum detailing the application of the model to the lower Fox River, the evaluation of the model and an assessment of the suitability of the model for constraining the LFRM.

5b) Application of a sediment transport model for the Lower Fox River.

The latest obtainable version of the SEDZL sediment transport model will be applied to the lower Fox River from DePere Dam to Green Bay. The SEDZL sediment transport predictions will be used to constrain the Lower Fox River Model sediment dynamics, specifically, settling and resuspension rates. After a site-specific application of the model has been developed, the model performance will be evaluated over the intended simulation period (i.e. the hindcast period) and an assessment will be made of the suitability of the model for constraining the LFRM. The evaluation of this application of SEDZL will include investigation of: bed elevation change over long term simulations, response to various combinations of flow events, sensitivity to model parameters, and the process mechanisms in the model.

Deliverable: The deliverable for this task will be a technical memorandum detailing the application of the model to the lower Fox River, the evaluation of the model and an assessment of the suitability of the model for constraining the LFRM.

5c) Determination of preferred approach to constrain models.

This task will evaluate each of the above proposed alternatives (Tasks 5a and 5b) to select the preferred approach to constraining solids dynamics in the fate and transport models. It is conceivable that each approach may yield similar constraints on the fate and transport models. Under this scenario a subsequent evaluation will select the approach to constrain other fate and transport models if necessary.

5d) Development of a Translation Algorithm.

Subtasks 5a and 5b will produce resuspension and settling rate functions at a finer scale than the mass balance model segments. To incorporate this information into the LFRM, the fine-scale information will need to be spatially integrated. The functions within each segment will be spatially aggregated to yield one settling and resuspension function for each segment in the mass balance model. By using fine-scale sediment-transport information, the mass balance model(s) are more likely to be able to represent the spatial heterogeneity in bed behavior that has led to development of the observed patterns of PCB and solids distribution in the river over the long term.

This task will consist of developing a translation algorithm that will "link" the sediment transport model(s) to the fate and transport mass balance models. This algorithm will be coded to read results of each model and produce "model-ready" resuspension and settling time series for the LFRM.

Deliverable: The deliverables for this task will be: 1) a technical memorandum describing the development of the translation algorithms and their application; and 2) computer programs for linking both, the SEDZL results and the erodibility study results to the mass balance models.

Task 6: Recalibration and subsequent re-evaluation of the Fox River and Green Bay fate and transport models.

It is anticipated that implementation of new solids load estimates and adoption of alternate model structures will necessitate recalibration of the suite of models. Recalibration of an upstream model (UFRM or LFRM) may require recalibration of the downstream models (LFRM, GBTOX, or GBFOOD). This task will include evaluation of the need for recalibration of any of the downstream models in the event that one of the upstream models is changed.

In order to recalibrate the models, a calibration approach will be established with consideration of all possible calibration constraints. A step-by-step calibration procedure will be established with consideration of the constraints developed under Task 5 in addition to model-data comparison metrics developed as part of Task 1.

If upon evaluation of the recalibrated models, the models still do not pass all of the specified model metrics, additional modifications to the models will be considered and adopted if they are deemed necessary and reasonable.

Deliverable: The deliverable for this task will be a technical report documenting all aspects of the recalibration process including the rationale, approach, and results.

Task 7: BSAF and Food Chain Model Assessment

This task is designed to evaluate the application of the BSAF and bioenergetic food chain models currently being applied in the Fox River and Green Bay. The task will be divided into three components: 1) Evaluate BSAF, 2) Evaluate bioenergetic models, 3) Determine which of the two approaches provides better predictive abilities for future predictions.

7a) Evaluate BSAFs

Biota-sediment accumulation factors (BSAFs) are being used in the current Fox River models to estimate future fish tissue PCB concentrations based upon predicted sediment quality. BSAFs are simple statistical procedures that can either under-predict or over-predict future fish concentrations, depending on how the assumed relationship between sediment and water column PCB concentrations change in the future. Assumptions inherent to many BSAF applications include:

- Temporal steady-state (or near steady-state) conditions exist between sediment and fish tissue concentrations.
- There must be spatial congruence between the sediment area used to compute exposure concentration and the actual fish feeding area.

Review of the BSAF approach for the Fox River will consist of two steps: 1) review of the ability of the BSAF approach to predict historical fish tissue concentrations, 2) evaluation of how the assumptions made in the approach may impact the ability of BSAFs to predict fish tissue concentration in response to significant changes to the system (i.e. dredging). Potential review activities could include:

1) determining the extent of (dis)equilibrium between and water and sediment PCB concentrations. PCB concentrations in the water column and sediments in the Fox River are probably not in equilibrium with each other. This is a consequence of a long period of high external loadings, accumulation of a large sediment PCB reservoir, and lack of existence of any significant, present-day external loadings. Changes in sediment PCB concentrations would tend to alter the present sediment:overlying water column partition coefficients in the Fox River. Sediment PCB concentrations could change in the future due to long-term sediment "bleeding", sediment transport during storm events, burial of surficial sediments under less-contaminated sediments, or remedial actions.

2) estimating the feeding preferences of target fish. Carp feed primarily from the benthic food chain. Use of the BSAF method to estimate PCB body burdens in carp is a reasonable first approximation. Walleye, and their food sources, feed from both the benthic and pelagic food chains.

3) conducting a statistical analysis of the existing BSAF database, including multiple regression analyses of fish body burdens versus water column and sediment PCB concentration. The results of the above analysis will indicate the appropriateness of existing BSAFs for predicting future fish tissue concentrations, and will indicate whether inclusion of a water column component may lead to a more reliable predictive tool.

4) verify that sediment areas used to compute PCB exposure concentrations are congruent with fish feeding areas.

7b) Evaluate Bioenergetic Model(s)

The Green Bay and other possible mechanistic food chain models will be reviewed and assessed. Similar to the BSAF review, this review will consist of two components: 1) review of the ability of the bioenergetic model(s) to predict historical fish tissue concentrations, and 2) evaluation of how the assumptions made in the approach may impact the ability of the bioenergetic model(s) to predict fish tissue concentration in response to significant changes to the system (i.e. dredging). It is expected that the majority of this specific review will be conducted under Tasks 3 and 6.

7c) Determine Preferred Approaches

The understanding of the strengths and limitations of each model approach will be used to identify the most appropriate approach to adopt for the lower and upper Fox Rivers and Green Bay.

Deliverable(s): Work products for this task will include technical memoranda describing: 1) results of the evaluation of the BSAF approach, including discussion of its ability to describe existing fish tissue data and potential applicability for future scenarios, 2) results of the evaluation of the bioenergetic model approach, including discussion of its ability to describe existing fish tissue data and potential applicability for future scenarios, and 3) recommendation of modeling approach for future scenarios.

Task 8 : Selection and Application of the Final Suite of Models.

The final suite of models will be selected for application in the NRDA and the remedial planning process based on the results of Tasks 2 through 7. Model selection will be based on relative performance against the metrics described in Task 1.

These linked fate and transport models will then be used to conduct the required model application runs in support of the NRDA process and the remedial planning effort. This task will include model application, uncertainty analysis, and interpretation and documentation of all model runs conducted. Model runs will be conducted for the entire site of interest, i.e. the Lower Fox River from Lake Winnebago to the river mouth and all of Green Bay.

Deliverable: The deliverable for this task will be technical memoranda describing: 1) model uncertainty methodology, 2) model selection, and 3) results of model selection.