Final Model Documentation Report for the Lower Fox River and Green Bay, Wisconsin

Wisconsin Dept. of Natural Resources &
The RETEC Group, Inc.

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Final Model Documentation Report

Lower Fox River and Green Bay, Wisconsin
Remedial Investigation and Feasibility Study

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1 Introduction

The modeling effort described in this report was applied as part of the remedial investigation (RI), risk assessment (RA) and feasibility study (FS) for the Lower Fox River and Green Bay. The purpose of the modeling effort was to improve the estimation and forecast of the movement of sediments contaminated by polychlorinated biphenyls (PCBs) in the river and bay. This Model Documentation Report provides a concise compilation of the models used in the RI/FS. This effort was conducted under the direction of the Wisconsin Department of Natural Resources (WDNR) and authorized by the U.S. Environmental Protection Agency (USEPA) by Cooperative Agreement #V985769-01. Models were one tool used in the RI, RA and FS to evaluate the degree and extent of contamination, risks to human health and the environment, and long-term benefits of implementing remedial approaches for the Lower Fox River and Green Bay study area.

The process to evaluate models used in the Lower Fox River and Green Bay RI, RA and FS were established through an agreement between the WDNR and the Fox River Group (FRG) in January 1997. The agreement established a model evaluation process (MEP) described in the Workplan to Evaluate the Fate and Transport Models for the Fox River and Green Bay (Workplan). The workplan and technical memorandum prepared as part of the MEP are described in Section 2 of this report. Full copies of the model evaluation process work plan and all technical memoranda are included as an Appendix A to this report.

The modeling effort conducted for the RI, RA and FS consisted of five interrelated programs to simulate the movement of PCBs in the environment:

- Lower Fox River and Green Bay interpolated bed maps that define sediment thickness, physical properties (e.g., TOC, bulk density) and total PCB concentrations;

- Whole Lower Fox River Model (wLFRM) used to simulate the movement of PCBs in the water column and sediment of the Lower Fox River from Lake Butte de Morts to the mouth of the river at Green Bay;

- Fox River food chain model (FRFood) used to simulate the uptake and accumulation of PCBs in the aquatic food chain in the Lower Fox River based on the model results from wLFRM;

- Enhanced Green Bay PCB transport model (GBTOXe) used to simulate the movement of PCBs in the water column and sediment of Green Bay from the mouth of the Fox River to Lake Michigan, including loading rates to Green Bay based on model results from wLFRM;

- Green Bay food chain model (GBFood) used to simulate the uptake and accumulation of PCBs in the aquatic food chain in the lowest reach of the Fox River and in Green Bay.

These computer models have been developed and used in the FS to project changes in total PCBs in water, sediment, and fish over time. These models are mathematical representations of transport and transfer of PCBs between the sediments, water, and uptake into the food webs described in Section 3 of the FS. While the models discussed below are useful for comparing between potential action alternatives, there should be no mistaking that utility for precision. All the models are calibrated over a short time frame (6 years or less), but projected over 100 years. While there is a reasonable assurance that the relative trends are accurate, there are no assurances that the predictions are precise.

The relationship between the models, their projected output, and how the output is used in evaluating risks, is shown in on Figure 1. The bed maps produced as part of the RI are the foundation of the modeling inputs. The surface sediment total PCB concentrations for the baseline and action levels discussed in Section 5 of the FS are used as the inputs to both hydrodynamic models: the wLFRM and GBTOXe. These two models project total PCB concentrations in water and sediment. The output from the two transport models are used by the bioaccumulation models: FRFood and Green Bay Food (GBFood) to project whole fish tissue concentrations of PCBs. The output from all of the models are then compared to the remedial action levels specified in the FS.

Together, these models provided a method for evaluating the long-term effect on PCB concentrations in water, sediment, and aquatic biota under different remedial alternatives in the Lower Fox River and Green Bay. The relationship between models and their respective applications is given in Figure 1. Alternatives were based on the removal of PCB-contaminated sediment above different action levels. By changing the initial PCB concentration in sediment such that all remaining sediments are below an action level, the models were then used to predict PCB concentrations in the aquatic environment over the next 100 years. The model results and conclusions from the model effort are discussed in the FS.

In addition to the MEP, the FRG also conducted a model peer review through the American Geological Institute (AGI). The AGI formed a review panel under the direction of Dr. John C. Tracy to evaluate existing models, which had been developed for the assessment of the Lower Fox River. The AGI only reviewed models as they pertained to the last seven miles of the river. Modeling above the De Pere dam or in Green Bay were not part of their review. The panel prepared a report, which included a number of comments on the existing Fox River models and recommendations for improving the model frameworks and conducting more robust and defensible modeling efforts. WDNR modified its model development effort to address many of the AGI concerns and modifications were made in response to many of the comments.

This report presents a brief synopsis of the following:

Section 2	Model evaluation process, agreed to workplans, and the supporting technical memoranda that were agreed to and finalized between WDNR and the FRGs;
Section 3	An overview of how the various models were used in the RI and FS;
Section 4	A summary of the individual model documentation reports for each of the respective hydrodynamic and bioaccumulation models; and
Section 5	WDNR's responses to the AGI peer review comments.

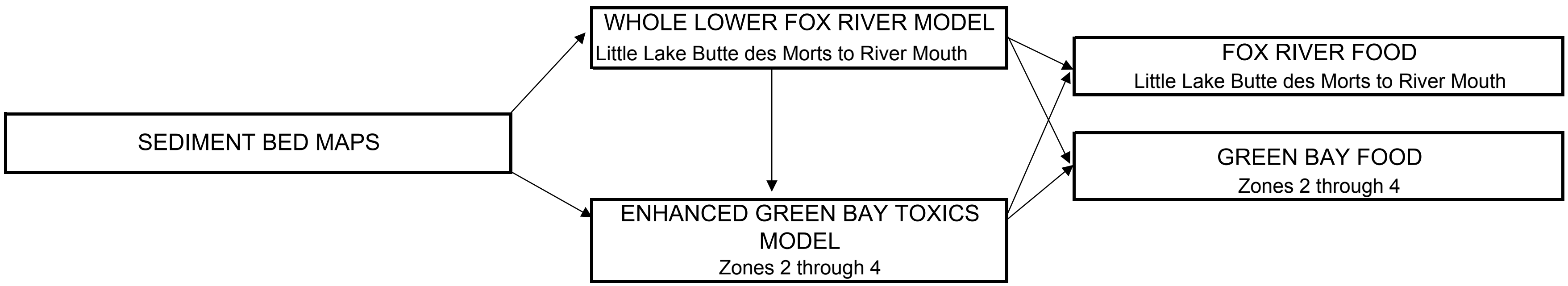
Attached as appendices to this report, are the complete set of finalized technical memoranda, the full detailed model documentation reports and user manuals, and a CD-ROM for each model. The appendices are organized as follows:

Appendix A	A complete set of the 16 technical memoranda that comprise the model workplan, evaluation metrics, and supporting documentation to the construction of bed maps, the formation and inputs to the hydrodynamic model, and the analyses and recommendation for food webs and bioaccumulation modeling.
Appendix B	The model documentation report (B1) and user's manual (B2) for the wLFRM.
Appendix C	The model documentation report (C1) and user's manual (C2) for GBTOXe.
Appendix D	The model documentation report (D1) and user's manual (D2) for FRFood.
Appendix E	The model documentation report (E1) and user's manual (E2) for GBFood.

Appendix F A series of CD-ROM discs for each model that includes (1) a "read me" file that lists all of the files on the discs, (2) a working copy of the model, (3) a complete copy of the program code, (4) an electronic version of the user's manual, and (5) a complete set of the input and output files for all model runs conducted to support the RI/FS and WDNR's proposed plan.

Figure 1 Relationship of Models Used for Risk Projections in the Lower Fox River and Green Bay

	BASELINE AND REMEDIAL CONDITIONS	**FATE AND TRANSPORT MODELS**	**BIOACCUMULATION MODELS**
MODEL	SEDIMENT BED MAPS	WHOLE LOWER FOX RIVER MODEL – Little Lake Butte des Morts to River Mouth; ENHANCED GREEN BAY TOXICS MODEL – Zones 2 through 4	FOX RIVER FOOD – Little Lake Butte des Morts to River Mouth; GREEN BAY FOOD – Zones 2 through 4



OUTPUT	• Baseline and Remedial Action Level Surface Sediment Concentrations • Surface Weighted Average Concentrations • Residual DDE and Mercury Risks (RAO 2 & 3)	• Total PCBs in Water (RAO 1) • Total PCBs in Sediments (RAO 3) • Downstream PCB Transport (RAO 4)	• Total PCBs in Forage Fish (RAO 3) Alewife, shiners, shad • Total PCBs in Benthic Fish (RAO 2 & 3) Carp • Total PCBs in Piscivorous Fish (RAO 2 & 3) Walleye, perch
DOCUMENTATION	*Remedial Investigation* *Technical Memorandum 2e* *Technical Memorandum 2e Addendum* *Technical Memorandum 2f*	*Model Documentation Technical Report* *wLFRM Model Documentation Report (Appendix B)* *GBTOXe Model Documentation Report (Appendix C)*	*Baseline Risk Assessment* *FRFood Model Documentation Report (Appendix D)* *GBFood Model Documentation Report (Appendix E)*
APPLICATION	*Remedial Investigation* *Baseline Risk Assessment* *Feasibility Study*	*Baseline Risk Assessment* *Feasibility Study*	*Baseline Risk Assessment* *Feasibility Study*

2 Model Evaluation Process, Workplan and Technical Memoranda

A model evaluation work (MEW) group was established to in part fulfill the Memorandum of Agreement (MOA) between the State of Wisconsin and seven potentially responsible parties (PRPs), dated January 31, 1997. Model evaluations were undertaken according to the procedures discussed in the Workplan, which was submitted by Limno-Tech, Inc. (LTI) on behalf of the PRPs to WDNR on September 19, 1997. The Workplan was conditionally approved by WDNR on September 26, 1997. The purpose of the MEP and workplan developed as part of it was to evaluate and potentially enhance the PCB fate and transport models of the Fox River and Green Bay. The MEP workplan provides a summary of intended model uses and critical outputs of the models, a detailed description of the technical tasks and deliverables, an estimated schedule for completion of tasks and a table presenting the allocation of work, budget and roles.

The following is a brief description of the workplan and individual technical memoranda prepared. Full copies of the model evaluation process work plan and all technical memoranda are included as an Appendix A to this report.

Workplan to Evaluate the Fate and Transport Models for the Lower Fox River and Green Bay. Prepared by Limno-Tech, Inc. - September 1997. The Workplan was designed to cooperatively evaluate and provide a process to 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 the PRPs regarding the Fox River. The Workplan was developed cooperatively by WDNR staff and representatives of and/or consultants to the potentially responsible parties known as the Fox River Group (FRG). The workplan set forth a series of tasks for the evaluation of all Fox River/Green Bay models, which existed in January 1997,and potential development of enhanced versions. The Workplan included the following items:1) a brief summary of the intended uses and critical outputs of the models, 2) a detailed description of the technical tasks and potential deliverables, 3) an estimated schedule for completion of tasks, and 4) a table presenting allocation of work, estimated budget and roles among MEW participants. Following the completion of the Workplan, the WDNR issued a letter of conditional approval. Under the MOA, the state was identified as the director of all joint efforts, with the exception of monitoring which was undertaken by the FRG, independently. Under this authority, the Workplan was approved with the following conditions:

<u>TM 1 Series</u> – Documents developed within the TM 1 Series cover the development and prioritization of model evaluation metrics and performance criteria.

Technical Memorandum (TM) 1, Model Evaluation Metrics; Prepared by Limno-Tech, Inc. March 1998. This technical memorandum establishes model evaluation metrics. The individual metrics that are developed in detail in the body of this memorandum include:

- Evaluation of the mathematical representation of the natural system
- Short-term and long-term hindcast simulation metrics
- Forecast simulation metrics

This list presents an ordered yet flexible set of procedures. The prioritization of the metrics provides a guide to the model performance evaluations that are potentially useful, and to the order in which to employ these tests. This memorandum further provides a process of model development, short-term simulations (calibration), and long-term simulation (hindcasts and forecasts).

TM 2 Series - TM 2 Series covers development of historical and current solids and PCB loads to the Fox River.

Technical Memorandum 2a - Simulation of Historical and Projected Total Suspended Solids Loads and Flows to the Lower Fox River, N.E. Wisconsin, with the Soil and Water Assessment Tool (SWAT). Prepared by Fox-Wolf Basin 2000. August 19, 1998. The basin scale model SWAT was applied to the 1,580 km^2 Lower Fox River Basin to simulate historical and projected daily stream flows and total suspended solid loads at watershed outlets. This information was required to supply the Lower Fox River and Green Bay PCB Fate and Transport Model with estimated total suspended solids (TSS) loadings and flows to model water column segments within the Lower Fox River. The SWAT model is capable of simulating hydrologic and related processes to predict the impact of management on water, sediment, nutrient and pesticide yields in rural basins. Large river basins can be sub-divided into hundreds of sub watersheds for modeling purposes. Major processes simulated within the SWAT model include: surface and groundwater hydrology, weather, soil percolation, crop growth, evapotranspiration, agricultural management, sedimentation, nutrient cycling and fate, pesticide fate, and water and constituent routing. TM2a presents a estimate of tributary flows and suspended solids loads to the Lower Fox River.

Technical Memorandum 2b - Computation of Watershed Solids and PCB Load Estimates for Green Bay; Prepared by Limno-Tech, Inc. January 6, 1999. The sorption of PCBs to solids has a significant impact on PCB fate and transport in the Lower Fox River and Green Bay. Estimation of suspended solids delivered to the system from all sources is an important component of the overall solids balance. Estimates of historical solids and PCB loadings will assist in using hindcasts for model evaluation. This technical memorandum describes an assessment of available approaches for computing watershed solids and PCB loads to Green Bay, exclusive of loads delivered by the Lower Fox River.

Technical Memorandum 2c - Computation of Internal Solids Loads in Green Bay and the Lower Fox River; Prepared by Limno-Tech, Inc. February 12, 1999. Nutrient dynamics and transformations among various solids sorbent compartments may have a significant impact on PCB fate and transport in the Lower Fox River and Green Bay. Estimation of suspended solids from all sources is an important component of the overall solids balance for the system. This technical memorandum describes the existing methods used to compute internal, or biotic suspended solids (BSS) loads, discusses the applicability of these approaches to the hindcast period, and presents the alternative approaches, that were the recommendations of the MEW for model evaluation.

Technical Memorandum 2d - Compilation and Estimation of Historical Discharges of Total Suspended Solids and Polychlorinated Biphenyls from Lower Fox River Point Sources. Prepared by Wisconsin Department of Natural Resources. First Issued: June 3, 1998/Last Revised: February 23, 1999. This technical memorandum presents the estimate of solids and PCB loads from all significant point sources that may have contributed solids and PCBs to the Lower Fox River from the mid-1950s to 1997. The report documents the historical data discovered in this process, reports the findings and methods used to calculate loads, and presents load estimates. Nearly all PCB discharges to the Lower Fox River are believed to have resulted from the production and recycling of NCR carbonless copy paper (NCR paper) made with coating emulsions that contained PCBs. Three pathways of release to the river were identified relevant to PCBs used in the production of NCR paper. These three pathways were investigated to determine the total PCB discharge and annual load for each facility that carried out any of the three types of activity during the period of 1954 to 1997.

Technical Memorandum 2e - Estimation of Lower Fox River Sediment Bed Properties. Prepared by Wisconsin Department of Natural Resources. March 1999. Numerous investigations of Lower Fox River sediments completed since the 1989 Green Bay Mass Balance Study (GBMBS) provide information about sediment bed properties at discrete points in space (and time). However, due to the areal focus of a number of the investigations, and therefore the limited scope of the specific project work, no investigation provided comprehensive information about sediment properties through the entire areal and volumetric extent of the sediment bed. The results of these studies have been interpolated in a consistent and technically sound manner to provide a continuous representation of sediment bed properties. The objective of this technical memorandum was to present a methodology to estimate sediment bed properties from the results of field investigations and its application to the Lower Fox River to estimate the physicochemical properties of the sediment bed.

__Technical Memorandum 2e Addendum__ **- Estimation of Sediment Bed Properties for the Lower Fox River: 4 reach efforts. Prepared by the Wisconsin Department of Natural Resources. October 2000.** This addendum describes changes in the development of Technical Memorandum 2e - Estimation of Sediment Bed Properties for the Lower Fox River. There were three specific modifications to the GIS interpolation approach described in the original TM 2e documentation. First, the river was divided into four segments, with each reach undergoing a slightly different method of interpolation depending on its hydrologic characteristics. Second, data from the 1998 Blasland, Bouck, and Lee, Inc., study and 1998 data from additional WDNR investigations were added. Third, the data sets used in the interpolation were filtered so that more recently collected data superseded older data from sites in close proximity. This approach helped to isolate modeled changes in PCB concentration to the spatial dimension only.

__Technical Memorandum 2f__ **- Estimation of Sediment Bed Properties for Green Bay Prepared by Wisconsin Department of Natural Resources. December 2000.** Numerous investigations of Green Bay sediments provide information about sediment bed properties at discrete points in space (and time). However, no investigation has provided information about sediment properties through the entire spatial and volumetric extent of the sediment bed. The results of these studies have been interpolated in a consistent and technically sound manner to provide a continuous representation of sediment bed properties. This technical memorandum presents a methodology and through its application estimates sediment bed properties from the results of field investigations in Green Bay, to estimate the physicochemical properties of the sediment bed.

__Technical Memorandum 2g__ **- Quantification of Lower Fox River Sediment Bed Elevation - Dynamics through Direct Observations. Prepared by Wisconsin Department of Natural Resources. July 23,1999.** This technical memorandum quantifies the spatial and temporal dynamics of elevation changes in the sediment bed of the Lower Fox River through direct observations. The results presented in this document are based on the analysis of field data from three sources: the U.S. Army Corps of Engineers (USACE), the U.S. Environmental Protection Agency (EPA), and the U.S. Geological Survey (USGS). Data from these sources describe Lower Fox River sediment bed elevations for the period 1977 to 1998; most of these data were collected downstream of the De Pere dam in the last 15 kilometers seven miles) of the river. The USACE is responsible for operations and maintenance of the Lower Fox River navigation channel and maintains a survey history by conducting bathymetric mapping surveys of prescribed cross-sections of the channel.

__**TM 3 Series -**__ TM 3 Series covers evaluation of the current suite of fate and transport models using the estimated historical loads and the metrics established in the TM 1 series.

<u>Technical Memorandum 3a</u> - Evaluation of Flows, Loads, Initial Conditions, and Boundary Conditions. Prepared by Wisconsin Department of Natural Resources. February 2001. In order to assure a consistent evaluation process, TM 3a was developed to provide the necessary input files for the suite of models. Flows, solids loadings and PCB loads, initial conditions, and boundary conditions have been estimated and applied in existing models for two sections of the Lower Fox River (upstream and downstream of the De Pere dam) and for Green Bay. As part of the overall model evaluation process, these model inputs were developed by the MEW as part of Task 2 of the Workplan and related efforts. This report summarizes the results of those efforts and evaluates the representation of flows, loads, initial conditions, and boundary conditions in the existing models relative to the Task 2 and related effort results. The comparisons presented in this memorandum between existing and Task 2 flows and loads are for the short-term simulation period (1989-1995). Summary table comparisons, time series comparisons, and distribution comparisons are presented. For clarity, a sub-period was selected for graphical presentation of time series comparisons. The data-rich GBMBS period (April 1, 1989 through March 31, 1990) was selected as the period for comparison.

<u>TM4 Series</u> - TM 4 Series covers development of alternative model structures.
<u>Note: No technical memoranda for the TM 4 series were ever finalized</u>.

<u>TM 5 Series</u> - TM 5 Series covers developing constraints to parameterization of sediment dynamics in the fate and transport models.

<u>Technical Memorandum 5a</u>, DRAFT Development and Application of a Sediment Erodibility Study, June 1999. Prepared by Limno-Tech, Inc.
<u>Note: Technical Memorandum 5a was not finalized</u>.

<u>Technical Memorandum 5b</u> - ECOM-siz-SEDZL Model Application: Lower Fox River Downstream of the De Pere Dam, *Prepared by* W.F. Baird & Associates Ltd. April 2000. This technical memorandum documents the results of the application of the ECOM-siz-SEDZL model to the Lower Fox River between the De Pere Dam and the mouth of Green Bay. SEDZL is a two-dimensional hydrodynamic and sediment transport model. ECOM-siz-SEDZL is a 3D sediment transport model, which combines SEDZL, with the 3D hydrodynamic model, ECOM-si. This is a finite difference model, in which regular grids or orthogonal grids are applied. WDNR and the FRG wanted the SEDZL model applied to the Lower Fox River downstream of the De Pere dam in order to develop an alternative method of estimating resuspension, sediment transport and deposition processes. The model consists of a hydrodynamic module, and a sediment transport module. The hydrodynamic module is the time-dependent, three-dimensional, estuarine and coastal circulation model developed by Blumberg and Mellor (1987). The model can simulate water flows, salinity, and temperature in estuarine and coastal areas with the turbulent consideration (κ-ε). The sediment transport module can simulate the transport and fate of suspended sediment, both cohesive and non-cohesive sediment. In the sediment transport calculations, flocculation of cohesive sediment, bed deposition, consolidation, and armoring of non-cohesive beds are considered. The model was applied to the Lower Fox River between the De Pere Dam and Green Bay, a distance of approximately 7 miles (11.2 km).

Technical Memorandum 5c - Evaluation of the Hydrodynamics in the Lower Fox River Between Lake Winnebago and De Pere, Prepared by HydroQual Inc. December 2000. This technical memorandum evaluates the Upstream Fox River Model (UFRM) developed by Steuer et al. (1995) to determine if the representation of the hydrodynamics in the UFRM is consistent with the available data and the current understanding of hydrodynamics in riverine environments. To develop a more complete understanding of the hydrodynamics of the river, a new hydrodynamic model, called the Upstream Fox River Hydrodynamic Model (UFRHydro), was developed. This report documents UFRHydro itself and then describes the evaluation of UFRM in terms of the newly computed hydrodynamics. UFRHydro is a high-resolution, hydrodynamic model of the Lower Fox River between Lake Winnebago and De Pere. The model utilizes the ECOMSED modeling framework (HydroQual, 1996). The spatial model segmentation consists of a two-dimensional, vertically integrated grid with up to 10 segments in the across-flow direction and 175 segments in the along-flow direction. The effect of dams on the hydrodynamics in the river was accounted for by dividing the river into six pools. UFRHydro was used to evaluate the hydrodynamics in UFRM. Several tracer release scenarios were simulated in UFRHydro and UFRM. The results of the analysis show that the UFRM model has a larger dispersion than the UFRHydro model. The difference which varies with time and location is about a factor of ten. Also, there are differences in the water column volumes in the two models, which cause the UFRM model to have a shorter travel time than the one in UFRHydro. The difference in travel time depends on the flow rate; the travel time in UFRM ranges from 13% lower at low flow to 37% lower at high flow than the travel times computed by UFRHydro.

Technical Memorandum 5d - ECOMSED Model Application: Upstream Lower Fox River From Lake Winnebago To De Pere Dam. Prepared by W.F. Baird & Associates Ltd. July 2000. This technical memorandum describes the modeling work in the Upstream Lower Fox River from Lake Winnebago to De Pere dam in applying the ECOMSED model. WDNR and FRG wanted to have the ECOM-SED model applied to the Upstream Lower Fox River from Lake Winnebago to De Pere Dam in order to produce a set of "constraints" on the current UFRM resuspension time functions. ECOM-siz-SED is a version of the SEDZL code that has been applied to use the hydrodynamic solvers contained in the ECOM-si model, which is, in turn a modification of the Princeton Ocean Model (POM). SEDZL is a two-dimensional hydrodynamic and sediment transport model. SEDZL has been applied to the Lower Fox River between the De Pere Dam and Green Bay. Baird and Associates applied ECOM-siz-SEDZL to the same stretch of river in 1998-1999. For this project, HydroQual created a series of hydrodynamic model applications covering the existing UFRM domain and provided Baird with the model grids, hydrodynamic forcing functions and parameters. Baird extended HydroQual's work by parameterizing and applying the sediment transport portion of the ECOM-siz-SEDZL model application.

Technical Memorandum 5e - Hydrodynamics, Sediment Transport, and Sorbent Dynamics in Green Bay. Prepared by HydroQual and Remediation Technologies, Inc., March 1999. This technical memorandum evaluates the PCB fate and transport model for Green Bay called GBTOX. As part of this evaluation three new models were developed using state-of-the-art modeling technology. A high resolution, three-dimensional hydrodynamic model called GBHYDRO was developed to evaluate water column transport. To evaluate sediment transport two new models were constructed. First, a wind-wave model called GBWAVE was developed to account for the effect of wind-induced waves on sediment transport in the bay. Then a high resolution, three-dimensional sediment transport model called GBSED was constructed. The water column transport in GBTOX was evaluated using tracer simulations. The results indicate that the residence time in GBTOX is less than half that in GBHYDRO. Further analysis indicated that the smaller than expected residence time was caused by numerical dispersion that is attributable to the large size of the water column segments in GBTOX. The result is that GBTOX over predicts the exchange at segment interfaces in the bay and with Lake Michigan. The sediment transport in the total solids sub-model (GBTS) is in reasonable agreement with GBSED. However, the re-suspension velocities in the organic carbon sorbent sub-model (GBOCS) are much larger. The effect of this is a larger than expected mixing between the sediment and water column. Internal solids loads estimated by the GBEUTRO eutrophication sub-model are similar to load estimates developed using different techniques. However, GBEUTRO does not accurately reproduce the carbon and nutrient dynamics of the bay; the GBEUTRO results may have large uncertainties. Therefore, the successful application of this sub model under different forcing functions (e.g. changes in nutrient loads) may be limited.

TM 6 Series - TM 6 Series covers recalibration and subsequent re-evaluation of the Fox River and Green Bay fate and transport models.
No technical memorandum for the TM 6 series was ever developed.

TM 7 Series - TM 7 Series covers BSAF and food chain model assessment.

Technical Memorandum 7a - Analysis of Bioaccumulation in the Fox River. Prepared by Exponent, Inc. February 1999. This technical memorandum evaluates the potential use of the biota to sediment accumulation factor (BSAF) approach to estimate the bioaccumulation of PCBs in Green Bay. Evaluating the impact of different sediment management strategies on future PCB concentrations in tissue of fish from the Lower Fox River requires that the relationship between PCB concentrations in fish and sediment be well understood. A directly proportional relationship between PCB concentrations in sediment and tissue is often presumed to exist, based on the chemical properties of PCB (i.e., its lipophilicity) and the assumption that chemical equilibrium is rapidly attained. However, several other factors may also affect the nature and strength of the relationship between PCB in sediment and fish. These factors include: Whether sediment is the major source of PCB to fish, either directly or indirectly; Whether the exposure pathway is direct (e.g., dermal contact or incidental ingestion of sediment while feeding) or indirect (e.g., via a food chain); Whether biological processes (e.g., blood flow rate-limited uptake, active degradation) act to regulate fish body burdens of PCB.

Technical Memorandum 7b - Review of the Green Bay Food Web Model - Prepared by Exponent, Inc.; Edited by Wisconsin Department of Natural Resources. August 1999.

This technical memorandum evaluates the potential application of the food web approach to model the bioaccumulation of PCBs in the Lower Fox River/Green Bay ecosystem. It specifically reviews the Green Bay Food Web Model (GBFood), which was developed by HydroQual, Inc. (Connolly et al. 1992; HQI 1995) for the U.S. Environmental Protection Agency as part of the GBMBS conducted in 1989. This model focuses on calculating PCB bioaccumulation in several representative fish species collected in Green Bay and the last seven miles of the Lower Fox River

Technical Memorandum 7c - Recommended Approach for a Food Web/ Bioaccumulation Assessment of the Lower Fox River/Green Bay Ecosystem. Prepared by Wisconsin Department of Natural Resources. January 2001. Based on the assessments presented in TM 7a and 7b, the bioenergetics-based food web approach was selected as the preferred approach for calculating fish tissue contaminant concentrations. To apply a food web approach to a site, it is necessary to specify information regarding food web structure and contaminant exposure. The report presents the information needed to apply the food web approach to the Lower Fox River/Green Bay site and includes an identification of habitats, descriptions of the life histories and dietary preferences of relevant fish species, population dynamics, and fish migration patterns. This information was then used to specify the food web structure and define the exposure assumptions necessary to simulate contaminant bioaccumulation in the Lower Fox River and Green Bay.

3 Model Use in the RI/FS

The purpose of this section is to present a brief background discussion on each of the models used in the RI/FS and to briefly describe the how the information from TM 2e, the TM 2e addendum, and TM 2f were used to generate data grids that were used to generate the bed maps. The brief discussion below covers the models.

3.1 Models

Computer models have been employed in the RI/FS to assist in the evaluation of PCB fate and transport, historically and into the future. These models also enable the evaluation of various remedial scenarios on future PCB distribution in various environmental media as well as the food web in the Lower Fox River and Green Bay. The models are briefly described below and additional information is included in the documentation report for each specific model.

Whole Lower Fox River Model - The wLFRM was developed from the two models developed for analysis of flow in the Lower Fox River; the Upper Fox River (UFR), which covered the river between Lake Winnebago and the De Pere dam and the Lower Fox River model (LFR), which extended from the De Pere dam to the mouth of the river. The wLFRM retains the spatial resolution of the UFR/LFR models, but allows the simulation of the entire lower Fox River from Lake Winnebago to the mouth of the river using a single model. The wLFRM is calibrated to data collected between 1989 and 1995. Calibration consisted of comparisons between the data and model results for total suspended solids and dissolved/particulate PCB in water, sediment bed elevation, and net sediment burial rate.

The wLFRM is used to simulate the fate and transport of solids and PCBs in the water and sediments in the Fox River. The model area is divided into 40 water column segments, 165 surficial sediment segments, and 330 subsurface sediment segments. The model predicts the movement of solids and PCBs among these various model segments. In addition, the model simulates the concentration of organic carbon in the water column. Transport mechanisms in wLFRM include advection, dispersion, volatilization, deposition, and resuspension. Deposition is a function of particle size or density with different settling rates to represent sand, silt and clay-size particles. The settling rate for clay-size particles can also be used to simulate the settling of low-density organic matter. Resuspension is based on surface water velocity and the effect of sediment bed armoring over time.

The results from the wLFRM are used as input to other modeling efforts being conducted for the Fox River/Green Bay RI/FS. The wLFRM results from reaches above the De Pere dam are used as input to the FRFood model. Results from below De Pere dam to the mouth of the river are used as input to both FRFood and GBFood models. Finally, the predicted solids and PCB discharges at the mouth of the river are used as inputs to the GBTOXe model.

The wLFRM model calibration and forecast results are summarized further is Section 4 of this report. The model documentation and calibration for wLFRM are presented in Appendix B1. The IPX User's Manual in Appendix B2. A CD-ROM containing a working copy of the model, the source code, and all input and output files is in Appendix E.

GBTOXe Model - The Enhanced Green Bay toxics model (GBTOXe) was developed by (HydroQual) to simulate the fate and transport of PCBs in Green Bay for the RI/FS. GBTOXe is an enhanced version of an existing WASP4 based toxics model developed as part of the GBMBS by Bierman, et al., (1992) and updated by DePinto, et al., (1993). Enhancements include a higher spatial resolution and linkage to a hydrodynamics model (GBHYDRO) and a sediment transport model (GBSED) of Green Bay. GBTOXe was calibrated against 1989-90 GLNPO PCB and carbon data. GBTOXe was used to run 100-year simulations of PCB fate and transport for several management scenarios, including no action.

GBTOXe is used to model total PCBs and three phases of carbon in the water column and sediments. The carbon phases considered are dissolved, biotic, and particulate detritus. The model domain consists of 1490 water column and 596 sediment segments. The water column consists of 10 layers of 149 horizontal segments. Segment volumes vary to maintain a water balance. The layers represent biologically active sediments and deeper biologically inactive sediments. The volume of the segments in the upper 10cm of the sediment are assumed to be constant in time, while the fourth sediment layer changes in volume in response to deposition and resuspension. PCB transport mechanisms include advection, dispersion, volatilization, deposition and re-suspension of sorbed phase, and pore water exchange. GBTOXe accounts for sediment bed armoring.

GBTOXe model calibration and forecast results are summarized further in Section 4 of this report. The model documentation and calibration are presented in Appendix C1. GBTOXe user's manual is in Appendix C2. A CD-ROM containing a working copy of GBTOXe, source code, and all input and output files is in Appendix E.

FRFood Model - The FRFood bioaccumulation model is a mathematical description of PCB transfer within the food web of the Lower Fox River and Green Bay Zone 2. The model is designed to take the output of sediment and water concentrations of PCBs from the wLFRM model, as well as GBTOXe to estimate concentrations in multiple trophic levels in the aquatic food web (i.e., benthic insects, phytoplankton, zooplankton, and fish). This food web model is functionally similar to, and spatially overlaps with, the food web model for Green Bay (GBFood), with the exception that the FRFood Model can be run in reverse where the inputs are fish concentrations and the outputs are predicted sediment concentrations.

The primary objectives in using the FRFood model were to (1) estimate potential risk-based remedial clean-up levels, called sediment quality thresholds (SQTs) and (2) project fish tissue concentrations that would be associated with a specific remedy. To facilitate the selection of a remedy that will result in a decrease in human and ecological risks, it is necessary to establish a link between levels of PCBs toxic to human and ecological receptors, and the principal source of those PCBs, the Lower Fox River and Green Bay sediment. The FRFood model defines this link.

FRFood model calibration and forecast results are summarized further is Section 4 of this report. The complete FRFood model calibration and forecast results are included as an Appendix D1 to this report. The user's manual is in Appendix D2. The CD-ROM includes a working copy, the source code, and all input and output files, is given in Appendix E.

GBFood Model - The GBFood bioaccumulation model is a mathematical description of contaminant transfer within the food web. The food web is comprised of the primary energy transfer pathways from the exposure sources (sediment and water) to the fish species of interest. These pathways include: chemical uptake across the gill surface, chemical uptake from food and chemical losses due to excretion and growth dilution. The mathematical descriptions are generic (common to all aquatic food webs) and were updated as part of this RI/FS. The model has been applied in a variety of aquatic systems to a variety of compounds, the most common of which have been PCBs.

GBFood was used in the RI/FS to estimate PCB concentrations in the food webs leading to brown trout and walleye in the Lower Fox River (from the dam at De Pere to the mouth) and Green Bay. This was accomplished by specifying values for the various physiological, bioenergetic and toxicokinetic parameters in the model and the PCB exposure levels in sediments and water. The parameter values were derived from peer reviewed studies published in the literature and/or site-specific data. The sediment and water column PCB concentrations were provided by wLFRM and GBTOXe model outputs. The calibrated GBFood was used to evaluate the efficacy of several remedial alternatives in reducing PCB levels in fish of the Lower Fox River and Green Bay.

The GBFood model calibration and forecast results are summarized further is Section 4 of this report. The complete GBFood model calibration and forecast results are included as Appendix E1 to this report. A user's manual is in Appendix D2. The CD-ROM includes a working copy, the source code, and all input and output files, is given in Appendix E.

3.2 Bed Maps

Bed map Construction and PCB Computations - General information on total PCB results for each deposit/SMU group/zone are listed in the RI. These results have been used to map PCB distribution in the river and bay, as well as to estimate both the PCB mass and volume of sediments containing PCBs.

Bed Maps and Sediment Data Interpolation Methods - Bed maps were prepared showing the sediment thickness and occurrence of PCBs in the Lower Fox River and Green Bay from data in the Fox River Database (FRDB). The methods used to produce these maps were the same as those outlined in TM 2e, the addendum to TM 2e, and TM 2f (Appendix A). In order to prepare these bed maps for the river and the bay, it was necessary to extrapolate PCB concentration and sediment thickness between specific data points. These data interpolations were conducted for PCB concentration, sediment thickness, and sediment bulk density. The sediment thickness and PCB concentration interpolations were used to construct the distribution maps. Bulk density data were interpolated only to compute the PCB mass in sediments, and consequently are not plotted.

The interpolation analyses were conducted using ArcView 3.0 and Spatial Analyst 1.0 (ESRI) in both the river and the bay. However, slightly different approaches were used in each water body due to the availability of data and the size of the water bodies. The following sections discuss the specific methods used in the interpolations in each water body.

PCB Concentration Interpolations for the Fox River - The interpolations for the Fox River are based on the results included in the FRDB as of March 1, 2000, consisting of about 900 sample results and locations in the Lower Fox River from the following FRDB studies:

- 1989/90 Fox River Mass Balance Study
- 1989/90 Green Bay Mass Balance Study (GLNPO)
- 1994 Woodward-Clyde Deposit A Sediment Data
- 1992-1993 BBL Deposit A Sediment Data
- 1994 GAS/SAIC Sediment Data
- 1995 WDNR Sediment Data
- 1996 FRG/BBL Sediment/Tissue Data
- 1997-1998 Demonstration Project Data - SMU 56/57
- 1998-1999 Deposit N Post-Dredge Sediment Data

- 1998 FRG/BBL Sediment/Tissue Data
- 1998 RETEC RI/FS Supplemental Data

The interpolation of data for the Fox River involved both a screening of historic data and interpolation of the data to each river reach. In order to use the most recent data available, the data were assigned to three different time periods: 1989-1992, 1993-1995, and 1996-1998. All of the data from the period 1996-1998 were considered sufficiently recent and were used in the interpolation. However, data collected prior to 1996 were screened to remove data points that were in close proximity to locations with recent data.

To determine an appropriate distance for deleting pre-1996 data points, a relationship was developed between similar ranges of PCB concentrations and the distances between data points in that range. From this analysis it was determined that pre-1996 sample points located less than 133 m (436 ft) from a more recent sample point should not be used in the interpolations. This analysis was conducted first on the 1993-1996 data set to make a new data set for the 1993-1998 period. The analysis was then repeated using the 1989-1992 data set. In this way, the entire data set from 1989-1998 was used, but older data were superseded by more recent data as appropriate.

The interpolation was then conducted using this revised 1989-1998 data set. The procedure used for the interpolation was to break down the entire area of the Fox River into a square grid with points 10 meters apart. The data were then used to interpolate the value at each grid point.

The interpolation was developed using the inverse distance method, which results in the value at a grid point being more strongly affected by the sampling location(s) closest to the grid point. The inverse distance method gives more weight to closer points by using an inverse distance to the fifth power, meaning that points farther way have significantly less effect on the interpolated value at a point. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes 32 times more to the interpolation than does the second point.

In addition to the inverse weighting, a set distance was selected for which data points would influence grid point results. For example, if there were no data points close to the grid point, then the grid point value would be interpolated from data that may be located a significant distance away. This can lead to erroneous interpolations as the data have been extrapolated over a long distance. To prevent this condition, grid point values were computed using data within a certain distance or radius of the grid point location. Data points located further from the grid point than the established radius were not used in the interpolation. If there were no data points within the interpolation radius of a grid point, then no value (a "null point") was interpolated for that grid point in Spatial Analyst and the program then ignored these points.

The interpolation radius for computing sediment thickness was set at 100 m. For PCB and bulk density the interpolation radius varied among the river reaches. In the LLBdM reach, complete coverage of the river required that a radius of 400 m (1,312 ft) be used. For the Appleton to Little Rapids reach, the river is more narrow and linear. For this reach, the interpolation radius was computed as one third of the average river width, or 79 m (259 ft), to minimize the influence of separate deposits on the interpolation. For the Little Rapids to De Pere and De Pere to Green Bay reaches, an interpolation radius of 1,000 m (3,280 ft). This is specified in TM 2e and TM 2f.

Data interpolations for the Fox River were conducted for nine different layers of sediment depth: 0-10 cm, 10-30 cm, 30-50 cm, 50-100 cm, 100-150 cm, 150-200 cm, 200-250 cm, 250-300 cm, and greater than 300cm. These sediment depths were selected based on previous and current modeling efforts, as well as being defined by WDNR.

PCB Concentration Interpolations for Green Bay - Interpolation of sediment data from Green Bay followed the same methods as used in the Fox River. The data set for the Green Bay interpolations included approximately 240 sample results and locations from the following FRDB studies:

- 1989/90 Fox River Mass Balance Study
- 1989/90 Green Bay Mass Balance Study (GLNPO)
- 1995 WDNR Sediment Data
- 1996 FRG/BBL Sediment/Tissue Data
- 1998 FRG/BBL Sediment/Tissue Data

Because the hydraulic and sediment deposition characteristics of Green Bay are more uniform over larger distances, compared to the Lower Fox River, sediment data interpolations were adjusted accordingly. The methods used are the same as those outlined in TM 2f. Green Bay was divided into a square grid with 100 m between points, as opposed to a 10 m grid on the Fox River. The same inverse distance approach was used on both the Fox River and Green Bay, but the analysis on Green Bay used the distance squared rather than the distance rose to the fifth power (WDNR, TM 2e Addendum). Therefore, interpolated results in Green Bay are more affected by data points farther way from the grid point than in the Fox River interpolation. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes 4 times more to the interpolation than does the second point.

The interpolation radius for Green Bay was set at 8,000 m (26,250 ft). This means that data points more than 8000 m (26,250 ft) from a grid point were not used in the interpolation for that grid point. Conversely, grid points more than 8000 m (26,250 ft) from any data point have no interpolated value, and this is evidenced by the lack of data in some areas of the bay, particularly along the west shore of Zone 3A and in Zone 4.

Data interpolations for Green Bay were conducted for four different layers of sediment depth: 0-2 cm, 2-10 cm, 10-30 cm, and greater than 30 cm. In addition to these four sediment layers, a composite sediment layer was developed for a thickness of 0-10 cm. This layer was computed as a thickness-weighted average of the 0-2 and 2-10 cm layers. The 0-10 cm composite layer was developed for use in the RA and food web modeling. The other two layers were selected to coincide with the layering developed for the river, as well as also supporting modeling efforts.

Sediment Thickness Interpolations - In addition to PCB and other environmental parameters discussed above, interpolated grids were also developed for the presence or absence of sediment in the Fox River and Green Bay. The Fox River grid showing the occurrence of sediment was developed from field measurements of sediment thickness. Sediment distribution maps for each river reach were shown on Plates 3-1 through 3-4 of the RI. The occurrence of sediment was interpolated separately for all nine layers on the Fox River. For each layer, if the thickness at a sampling location was less than half the layer thickness, then the area was identified as an absence of sediment in that layer. Using this approach, sediment was also identified as absent in deeper layers if the sample depth did not extend to the modeled depth (e.g. if a sample was collected from 0 to 50 cm, the interpolation results indicate that there is no sediment present in the 50 to 100 cm layer).

For Green Bay, the occurrence-of-sediment grid was developed from the GBMBS (Manchester Neesvig *et al*., 1996) using a 5,000 m (16,400 ft) by 5,000 m (16,400 ft) grid. Based on sampling results, each grid cell was determined to be either soft sediments or glacial till (no soft sediments present). Grid cells that were not sampled were assigned to either the soft sediment or glacial till categories based on professional judgment, which included consideration of adjacent cells where sampling occurred and the depositional environment. For instance, areas near the mouth of the Fox River that were not sampled were considered to contain soft sediment, as this is a depositional zone for sediments from the river. The 5,000 m (16,400 ft) grid was translated into a 100 m (328 ft) grid to match the sediment interpolation grids and allow a direct overlaying of the different grids. The sediment distribution map was shown on Plate 3-5 of the RI.

The occurrence-of-sediment grids were used to edit the PCB concentration grids. This is necessary due to limitations in the PCB interpolation analysis. The PCB concentration interpolations do not consider whether sediment is present or absent. Consequently, PCB concentrations can be interpolated into areas that do not contain sediment. By using the occurrence-of-sediment grids, the PCB interpolation was restricted to those areas where sediments are present.

PCB Bed Maps - Maps showing the distribution of PCBs in sediment were constructed directly from the interpolated grids using ArcView and Spatial Analyst. The interpolated grid was color contoured into different ranges based on PCB concentration. The PCB bed maps for the Lower Fox River are shown on Plates 5-1 through 5-4 and the Green Bay bed map is shown on Plate 5-5 of the RI. Areas were sediment is absent or outside the interpolation radius are not included in the color contouring.

PCB Volume and Mass Estimates - The interpolated grids provide a means of computing the PCB mass and contaminated sediment volume in the Lower Fox River and Green Bay. Each grid point represents a grid cell with an area 10 m (33 ft) by 10 m (33 ft) in the Fox River and an area 100 m (330 ft) by 100 m (330 ft) in Green Bay. The sediment volume at each grid cell in a layer is computed as the grid cell area multiplied by the layer thickness. The volume within a layer above some PCB concentration can be estimated by summing the number of grid points above the PCB concentration and multiplying by the area of a grid cell and the thickness of the layer. The grid points can also be counted within a river reach, deposit/SMU area, or Green Bay zone to determine the volume of contaminated sediment within an area of the river or bay. The estimated volume of sediments with PCBs is discussed for each reach or zone below.

Mass calculations are computed in a manner similar to the volume calculation. The PCB mass is computed by multiplying the sediment volume by the bulk density and the PCB concentration at a grid cell. Summing the mass over the grid cells within a reach, deposit/SMU or zone yields the mass of PCB within that area of the river or bay.

4 RI/FS Model Documentation Summary

The water quality and food chain models presented are one of several tools to examine contaminant transport in Green Bay. The primary contaminant of concern are PCBs. The models were used to estimate the benefit of various remedial alternatives based on reduction of PCB concentrations in water, sediment, and biota of the lower Fox River and Green Bay.

Documentation of the theoretical framework and user manuals for each of the models are includes as appendices to this report.

4.1 Lower Fox River Water Quality Model

The goal of this effort is to provide estimates of: 1) PCB discharge to Green Bay, and 2) exposure of biota to PCBs in the Fox River. The whole Lower Fox River Model (wLFRM) is a water quality model used to simulate the movement of PCBs in the Fox River from Lake Winnebago to the mouth of the river at Green Bay. The model was implemented using the USEPA IPX Version 2.7.4 water quality modeling code.

The IPX Version 2.7.4 source code is written in FORTRAN77. To generate an executable, the compiler used should support sequential evaluation of terms in compound Boolean expressions. Numerical simulations were performed on several computing systems to ensure code portability. Short-term simulations were performed on a Compaq AlphaServer DS/20 computer running the Digital UNIX (Version 4.0F) operating system. On that platform, model code was compiled using the Compaq FORTRAN compiler for Alpha-powered UNIX systems. Long-term simulations were performed on an Intel Pentium IV-powered computer running the Mandrake Linux (Version 7.2 with the Version 2.4 Kernel) operating system. On that platform, model code was compiled using the Portland Group FORTRAN compiler.

The wLFRM was developed from the results of the MEW that was formed in collaboration with the FRG on the basis of a January 31, 1997 Agreement. The MEW prepared a series of technical reports that define values for the most critical model features such as flows, loads, initial conditions, boundary conditions, and sediment transport. The MEW reports represent the most detailed description possible of pertinent river conditions and provided the majority of the information necessary for model development. These reports are attached to this report as Appendix A. The FRG also initiated a peer review of model performance that was managed by AGI. To the greatest extent practical, peer review panel recommendations were integrated into wLFRM development efforts and are discussed in Section 5.

Efforts to assess PCB transport in the Lower Fox River using water quality models have been extensive. The wLFRM model, developed as part of RI/FS effort, is the result of continued assessments of Lower Fox River water quality model performance and represents the fourth generation of model development. This fourth generation model is identified as the whole Lower Fox River model (wLFRM). The wLFRM describes PCB transport in all 39 miles of the Lower Fox River from Lake Winnebago to the river mouth at Green Bay in a single spatial domain. The model is used to simulate the movement of suspended solids and total PCBs in the Lower Fox River. Suspended sediments were divided into three different particle types: organic matter and two grain size ranges. Short-term and long-term simulations were conducted. The short-term simulation period was 1989-95 and was used for model calibration. The long-term simulation period was 100 years and was used to project future PCB export to Green Bay and exposure trends in the river.

Model performance was evaluated according to the metrics identified in TM 1. For the water column, relative differences between observed solids and PCB concentrations and model results were within ±30%. Relative differences for the sediment column were much larger. Nonetheless, the wLFRM was able to capture the trend and magnitude of inferred PCB concentration changes over time in surface sediments. Given these considerations, the wLFRM calibration was judged to adequately meet the criteria identified in TM 1.

Since direct discharges of PCBs to the Fox River have been terminated, the only significant source of PCBs to the Lower Fox River is the river sediments. PCB concentrations in the water are essentially zero at Lake Winnebago (the upstream boundary) and increase to an average of more than 50 ng/L at the river mouth. The wLFRM was able to simulate the magnitude of this trend along the Lower Fox River.

The wLFRM was used to prepare long-term projections of the trend and magnitude of PCB concentrations in the river for a range of different sediment management alternatives. The alternatives included a no action alternative as well as removal of river sediments above various PCB concentrations (actions levels). Over time, water column and sediment PCB concentrations decrease for all cases. This is an expected result since, without significant PCB inputs from point source discharges, the surrounding watershed, or the atmosphere, the PCB inventory of river surface sediments will decrease by dilution and dispersal.

Relative differences in forecast simulation results are clearly present. Compared to all other cases, the no action simulation has the greatest PCB concentrations and cumulative export to Green Bay over time. As action levels decrease, there is a greater difference from the no action simulation. In each action level simulation, the initial PCB concentration in sediments was reduces by removing sediments above the action level. The greater long-term decrease in PCBs at lower action levels is a reflection of this decreased sediment PCB initial conditions for each case. At lower action levels, which represent larger sediment management efforts, the relative decrease in PCB concentration and export between action levels becomes smaller. For example, the difference between the 250 and 125 µg/kg action level alternatives is smaller than the difference between the 500 and 250 µg/kg cases. The relative difference between the 250 and 125 µg/kg cases is comparatively small since the average reduction in initial surface sediment PCB concentrations is small.

Results from the wLFRM were used to prepare input parameters to the Green Bay water quality model (GBTOXe) and as input to the Lower Fox River food chain model (FRFood). Both of these models are discussed below.

4.2 Green Bay Water Quality Model

The goal of this effort is to enhance and reevaluate an existing Green Bay water quality model GBTOX developed by Bierman et al. (1992) and updated by De Pinto et al. (1993). Enhancements were made to GBTOX as part of this project, resulting in the model referred to as GBTOXe. The enhancements made to GBTOX include the following:

- development of a new model segmentation;
- incorporation of water column circulation and mixing processes from a high resolution hydrodynamic model (GBHYDRO);
- incorporation of sediment resuspension and sediment solids flux rates from a high resolution sediment transport model (GBSED);
- updated loading functions based on more recent estimates.

GBTOXe, GBHYDRO, and GBSED are FORTRAN programs compiled using the Portland FORTRAN compiler. The programs were executed on Linux work stations using IBM compatible microcomputers.

Water column circulation included in GBTOXe is based on results from GBHYDRO, a high-resolution, three-dimensional hydrodynamic model (HydroQual, 1999), which contains over 10,000 water column segments. Analyses conducted as part of the development of GBHYDRO indicated that course grid resolution in GBTOX (12 water column segments) resulted in an underestimation of the residence time in Green Bay. Computational resource constraints, however, make running 100-year contaminant fate projection analyses infeasible with the GBHYDRO segmentation. An aggregation of the GBHYDRO grid, therefore, was performed to develop the GBTOXe segmentation, which contains 1490 water column segments. Hydrodynamic information from GBHYDRO was aggregated onto the GBTOXe grid and used in the analyses presented in this report.

A sediment transport model, GBSED, coupled to GBHYDRO, was developed (HydroQual, 1999) and used to calculate the transport of cohesive solids in Green Bay. GBSED results indicate that wind driven waves are the dominant factor affecting resuspension of PCB contaminated sediments in Green Bay, particularly in the shallow portions of the lower bay near the mouth of the Fox River. Because the sorbent systems in GBTOXe, living and detritial particulate organic carbon (POC), are different than the non-living cohesive solids included in GBSED, only a portion of the GBSED results were used in GBTOXe. Settling velocities calculated for cohesive solids in GBSED were not applied to the GBTOXe POC systems. The primary information from GBSED used by GBTOXe includes time variable resuspension and sedimentation velocities.

GBTOXe was calibrated for a 17-month period from January 1989 through May 1990 using data from the Green Bay Mass Balance Study (GBMBS). The 17-month calibration period coincided with the calibration period used in the Fox River water quality modeling. This is necessary because output from the Fox River model is used to generate Fox River loading inputs to GBTOXe. Comparisons between computed and measured water column PCB concentrations indicate that the model generally reproduces the available data. Computed PCB concentrations in the shallow portions of the lower bay exhibit much more variability than deeper areas of the bay due to wind and wave-induced resuspension. Monitoring data are generally not available during these resuspension events, and therefore, an assessment of the magnitude of the computed water column PCB concentrations during resuspension events cannot be made. Water column data are generally available at times when computed PCB concentrations are declining after resuspension events. At these times, the model results are in general agreement with the measured concentrations. Because measurements of PCB concentrations in the sediment are not available for multiple times within the duration of the 17-month calibration, comparisons between computed and measured PCB concentrations were not developed for the sediment segments of the model.

GBTOXe was applied to generate a series of fifteen future projection simulations combining various Fox River and Green Bay remedial action scenarios. The projection simulation period was 100 years in length. For this 100-year period, the advective and dispersive flows, resuspension events, sediment transport information, minor tributary loads (Menominee, Peshtigo, Oconto, and Escanaba), and atmospheric PCB loads used in the calibration effort were reapplied as a repeating annual pattern. The 16% annual rate of decline estimated in TM 2b for watershed PCB sources was applied to the annual pattern of the minor tributary and atmospheric PCB loads. Fox River sediment and PCB loading rates from the Fox River 100-year model simulations were used directly as input values for the GBTOXe long-term simulations.

The results of 100-year long term projection simulations for 15 combinations of natural attenuation and various levels of remediation of sediments in the Fox River and Green Bay indicate that a small fraction of the PCB mass in Green Bay is exported to Lake Michigan. Losses of PCBs from the bay due to volatilization to the atmosphere exceed the estimated loads to the bay, which are dominated by loads from the Fox River. Reductions in loadings from the Fox River associated with remediation of Fox River sediments with PCB concentrations greater than 5,000 µg/kg result in lower water column and sediment concentrations in Zone 2 of Green Bay, but fairly small changes in the remainder of the Bay. Remediation of additional Fox River sediments, with concentrations between 125 and 5,000 µg/kg produces little incremental reduction in Green Bay water and sediment PCB concentrations. Remediation of Green Bay sediments with concentrations above 1,000 µg/kg produces substantial changes in Zone 2 of Green Bay and results in fairly uniform water and sediment concentrations throughout much of the bay after roughly 25 years. Expanding the remediation to sediments with PCB concentrations between 500 and 1,000 µg/kg produces smaller incremental improvements, which diminish with time. The effect of these computed changes in exposure concentrations on the food web of Green Bay have been evaluated (QEA, 2001).

Results from the GBTOXe simulations were used as input to the Green Bay food chain model (GBFood), which is discussed below.

4.3 Lower Fox River Food Chain Model

The FRFood bioaccumulation model is designed to take the output of sediment and water concentrations of PCBs from the wLFRM and the GBTOXe (described below) to estimate concentrations of PCBs at multiple trophic levels in the aquatic food web of the Lower Fox River and Green Bay.

FRFood is based upon the algorithms originally developed for Lake Ontario PCBs (Gobas et al., 1993). While the Gobas model was developed specifically for application in lake systems, the mathematical relationships have been successfully applied to predicting fish tissue concentrations in some river systems. Applications of this model in other systems include derivation of bioaccumulation factors, bioconcentration factors, and food chain multipliers in the development of the Great Lakes Water Quality Initiative (GLWQI) criteria (EPA, 1993b; 1994a). The model was first used for projecting sediment quality thresholds in the 1996 RI/FS for the upper Fox River (SAIC 1996), and has since been used for setting action levels at the Sheboygan River (EVS, 1999), and for predicting long term effects on biota at the Hudson River, New York (EPA, 2000).

As noted above, the 1996 RI/FS for the Fox River found good correlation between predicted and observed fish tissue concentrations. Likewise, a good fit between predicted and observed fish tissue concentration was observed when the model was used to describe the bioaccumulation of PCBs in Hudson River ecosystems (EPA, 2000), and the Sheboygan River (EVS, 1998). In part, this may be because the lock and dam system on the Fox and Hudson rivers creates a series of large "pools" that behave more like reservoir or lake systems (e.g., Little Lake Butte des Morts).

The modeling framework for FRFood is a series of mathematical equations, which are described in Section 2 of the FRFood Model Documentation Report (Appendix D1). FRFood is a database application written in Visual Basic for Applications (VBA) 5 and hosted in Microsoft Access 97. The application can be run on Windows 95/98/Me/2000 or NT 4 workstations. Recommended computer specifications are a Pentium 200 with 64 MB of RAM. Minimum requirements are Pentium 133 with 16 MB of RAM.

Calibration of the FRFood Model was conducted using site-specific total PCB data for sediment and water as well as site-specific dietary relationships and lipids. For Green Bay Zones 1 and 2, fish were assumed to receive 100% of their PCB exposure within the specific reach. Dietary inputs were based upon published values in the scientific literature, but were used as a calibration parameter. All site analytical values were derived from the FRDB. Lipid concentrations for fish were the average concentration on a reach-specific basis for each species selected. The output was checked against both single point estimates (i.e., using reach-wide sediment and water averages) against the sum of all fish data in FRDB, and then by using the calibration output from wLFRM and GBTOXe as input. For both calibrations, the bioactive zone was considered to be 0-10cm in both the river and the bay. In both cases, the FRFood model output was compared to actual measured fish concentrations from Little Lake Butte des Morts, Little Rapids to De Pere, De Pere to Green Bay (Green Bay Zone 1), and Green Bay Zone 2. There were only sufficient data for these four sites to calibrate the model.

Model calibration was deemed adequate when the output was within the model evaluation metrics used in the GBMBS and agreed upon by the WDNR in cooperation with the FRG (Limno-Tech, 1998). These are defined in TM 1 (Appendix A). The goals are to achieve agreement of ±30 percent between model predictions and observations within ±½ order of magnitude for fish. A more detailed discussion of calibration metrics and results is given in the documentation report (Appendix D1).

For all reaches and zones, the calibrated output was well within one-half order of magnitude of observed concentrations for total PCBs. Within the upper reaches, the point calibrations provided good estimates that were within the range of observed values, and generally between 0.6 to 1.5 times of the mean or 95% UCL. While yellow perch were within ½ order of magnitude of the observed values, the model predictions were 1.6 to 4 times those observed. It should be noted that there are limited observations of perch; a single observation in Little Lake Buttes des Morts and one in the Little Rapids to

De Pere reach. For Green Bay Zones 1 and 2, FRFood predictions for walleye, perch, and carp were within the range of observed values. Predicted tissue concentrations were 0.6 to 2.2 times observed values. Forage fish were (alewife, shiners, shad and smelt) generally underpredicted: between 0.3 to 1.2 times observed. Based upon these observed/predicted results compared to the model evaluation metrics, the FRFood was judged suitable for use.

The calibrated FRFood supports the overall RI and FS for the Lower Fox River and Green Bay (RI/FS) in two ways: (1) to estimate risk-based sediment quality thresholds (SQTs) that would be protective of human health and ecological receptors, and (2) as a projection tool to estimate long term biological effects from selected remedial action levels in the RI/FS. Development of SQTs are discussed in Section 7 of the Baseline Risk Assessment, and are applied in the selection of the remedial action levels in Section 5 of the FS.

FRFood was applied to generate a series of eight 100 years simulations based upon potential remedial actions implemented in the Fox River. Using the weekly surface weighted average concentrations of total PCBs in sediments and the volume weighted average concentrations of dissolved total PCBs in water output from wLFRM, changes in fish tissue body burdens of PCBs were projected for each river reach. Projections from FRFood, (as well as wLFRM, GBTOXe, and GBFood) are used in Sections 8 through 10 of the FS to assess alternative specific risks, and to compare the relative reductions of PCBs in water and fish tissue. Those results are presented in Appendix D1.

FRFood was not used to project fish tissue concentrations in Green Bay; GBFood was used for that purpose. FRFood was, however, used to estimate Green Bay sediment quality thresholds. Hence, the need for calibrating FRFood to Green Bay Zone 2.

There many structural similarities between GBFood and FRFood, but there are key differences here:

- Mathematical algorithms have similarities, but treat growth and metabolism differently.
- GBFood fixed the diet and lipid components; FRFood treated these as calibration parameters.
- GBFood treated migration between Zone 1 and 2 as a calibration parameter, FRFood assumed complete residing for exposure.

Both models met the model metric of ±½ order of magnitude for the calibration period in zone 2. As a check on the potential difference between the two models, the natural attenuation alternatives (i.e., no action) projections for walleye in Zone 2 was plotted and compared. The GBFood projections for walleye in Zone 2 were between 1.6 and 1.8 times higher than those projected by FRFood; the overall trend over time was the same.

4.4 Green Bay Food Chain Model

GBFood is a computer simulation model of PCB bioaccumulation in Green Bay/Lower Fox River. It describes the transfer of PCBs through the aquatic food web leading to walleye and brown trout. The modeling framework was first developed by Connolly et al. (1992) as part of the GBMBS and later updated by HydroQual (1995), both on behalf of the EPA. The objective of the present effort was to update GBFood and then to use it to project the impacts of sediment remediation on PCB levels in fish from the Lower Fox River and Green Bay. Updates to the model include the following:

- Species- and location-specific octanol-water partition coefficients were incorporated. Values for fish were based upon an analysis of the GBMBS data. Values for zooplankton were estimated by calibration.
- Fish growth rates were modified based on data available in the FRDB.
- Fish lipid contents were revised based on data available in the FRDB.
- The theory underlying the model computation of PCB elimination rates was updated.
- Three alternative descriptions of fish migration patterns between Zones 2 and 1 were included:
    - ❑ Fish spend most of the year in Zone 2 and migrate for one month in the spring into the Lower Fox River (Zone 1).
    - ❑ Fish spend May through October in Zone 1.
    - ❑ Fish spend the entire year in Zone 1, except for one week in winter.

The model was recalibrated to the 1989 GBMBS fish PCB data, using exposures provided by GBTOXe and wLFRM. Model simulations were performed for the calibration period for all three alternative migration patterns. However, only the results of the first set alternatives - fish predominantly in Zone 2 – were used in the FS.

GBFood is a FORTRAN program compiled using DIGITAL Visual Fortran v.6.0, and run on a Hewlett Packard Kayak (Intel Pentium II) using Windows NT.

GBFood was calibrated for an 8-month period extending from April to November 1989. This calibration period was selected for two reasons: 1) it coincided with the calibration periods for the Fox River and Green Bay water quality models (wLFRM and GBTOXe, respectively); and 2) fish tissue PCB measurements collected during the GBMBS offered a robust data set upon which to calibrate. PCB concentrations in the water column and surface sediments computed by wLFRM and GBTOXe were used directly to define PCB exposures for the fish. The GBMBS, other site-specific studies and information compiled from an extensive review of the available literature formed the basis for estimating the remaining model parameters.

The first step in calibration involved matching computed PCB concentrations in zooplankton to the GBMBS data. This was done by adjusting their octanol/water partition coefficients. For the fish, parameters already constrained by site- or species-specific laboratory or field data were not adjusted. The elimination rate constant (c_R) could not be well defined by field or laboratory data, and therefore its value had to be constrained by calibration. One value of c_R was used for all species in all zones. No other parameters were adjusted for any fish in any Zone, with one exception. The time spent by the fish that migrate from Zone 2 to Zone 1 for a brief period in spring is uncertain and therefore was adjusted to provide the best model/data comparison.

The computed fish PCB concentrations generally matched the average PCB concentrations measured in the field, with the exception that PCB concentrations computed in fish from Zone 4 underestimated the average measured values; computed predator levels were lower than the average of the data by about a factor of two. Potential causes and implications of this are discussed in QEA (Appendix E1).

The calibrated GBFood model was used to project the response of fish tissue PCB concentrations to remediation of Fox River and/or Green Bay sediments. As in the calibration, water column and sediment PCB exposure concentrations were taken directly from wLFRM and GBTOXe. The projection simulations lasted 100 years. A total of fifteen simulations were performed. Results were summarized using the computed PCB concentrations in each species of fish averaged over the final 10 years of each simulation. These results are discussed in FS.

5 American Geological Institute Peer Review Sponsored by the Fox River Group

In addition to the model evaluation process conducted jointly by WDNR and the FRG under the MOA signed in January 1997, the FRG independently sponsored a peer review of the models previously used by WDNR and LTI to assess PCBs and sediment fate and transport for the Lower Fox River. This review was administered by the AGI in Alexandria, Virginia and the report was edited by John C. Tracy, Desert Research Institute and Christopher M. Keane, AGI. The AGI formed a review panel to evaluate existing models that had been developed for the assessment of the Lower Fox River. This panel generated the following report: Peer Review of Models Predicting the Fate and Export of PCBs in the Lower Fox River Below De Pere Dam; A Report of the Lower Fox River Fate and Transport of PCBs Peer Review Panel. The full report is available at the AGI website (http://www.agiweb.org/FoxRiver).

The timing of this independent model review presented some logistical and practical problems. The joint model evaluation process was underway with a stated goal by WDNR and the FRG to have a common method to evaluate the performance of all models for use in the Fox River/Green Bay remediation planning effort. This process provided for the development of enhancements to existing models, as necessary. To the extent practicable, the MEP has been followed. However, the AGI review was limited to the WDNR models as they existed in January 1997 and an FRG model, developed by LTI, which was crafted in order to provide comments on the draft RI/FS released by WDNR in February 1999. Furthermore, the AGI review was limited to the model for last seven river miles and could only assess models as they existed, and to the level that they were documented, at the time the review was conducted.

In following the model evaluation process, with the FRG, model performance could be assessed in comparison with the mutually developed metrics as part of this process. In addition, the process provided for the development and evaluation of enhancements to models. For the RI/FS, the WDNR and its contractors have utilized a series of enhanced models as has been discussed above. This RI/FS modeling effort was well underway prior to the AGI peer review results being available. The AGI review resulted in a number of recommendations, and observations, which mirror the results of the model evaluation process. While the AGI review could not include assessment of the subsequent enhanced model developed by the WDNR, wLFRM, used in the development of the RI/FS. WDNR did modify its model development effort to address AGI concerns and many modifications were made. WDNR was, however, already addressing many of the issues AGI raised long before the AGI report was released.

Many of the recommendations of the AGI review, as they appear in Section 3.2 of the AGI report, have been addressed. These comments and the actions taken by the DNR are addressed below. In general, the peer review panel indicated that a consensus modeling approach would be beneficial. The DNR believes this was attempted in the MEW process and the results of the technical memoranda developed as part of that effort have been utilized to the extent feasible.

As a result of this MEP work and other work performed, a more complete and accurate picture exists PCB and solids transport in the Fox River and Green Bay. This is reflected in the enhanced models. This information has been used in modeling the Fox River and Green Bay. The Model Documentation report includes all the documentation of the modifications made to the various models, the input and output files, the calibration documentation, the user manuals, and the forecast information.

The review panel's recommendations from Section 3.2 are listed below along with a discussion on the actions taken by WDNR concerning how the existing model addresses the issues.

COMMENT 1 - The WDNR model should adopt a numerical integration scheme that avoids the artificial mixing of deep sediments into the shallow sediment zone of the riverbed.

ANSWER - To the extent practical, this peer review panel recommendation was integrated into wLFRM and this issue has been addressed. All simulations of the wLFRM were performed using the IPX 2.7.4 framework (Appendix B2). To simulate contaminant transport, values must be assigned to each model parameter and the mass balance equations defined by the conceptual model framework must be solved. Numerical integration techniques are typically used to solve the model equations. Numerical simulations were performed using the IPX Version 2.7.4 water quality-modeling framework. IPX uses a finite segment implementation of the generalized contaminant mass balance equation and Euler's method for numerical integration. To generate solutions, the framework computes dynamic mass balances for each state variable simulated and accounts for all material that enters, accumulates within, or leaves a control volume (segment) through loading, transport, and physicochemical and biological transfers and transformations. IPX Version 2.7.4 also features a "semi-Lagrangian" sediment bed submodel to address potential concerns regarding particle and chemical mass transfer within the sediment column. A detailed description of the computational framework is provided in the IPX User's Manual (Appendix B2). Please see Sections 2.4 and 3.2 of the wLFRM model documentation for additional information.

COMMENT 2 - The upstream boundary of both the LTI and WDNR models should be extended to a section above the beginning of major contaminated sediment deposits in the Lower Fox River.

ANSWER - This comment of the peer review panel has been addressed in that wLFRM represents the Lower Fox River from Lake Winnebago to the mouth of the river at Green Bay. Lake Winnebago has been documented to a "clean" upstream boundary, above the contaminated sediment deposits in the Lower Fox River system. Please see the discussion in Section 3.3 of the wLFRM model documentation.

COMMENT 3 - Both the LTI and WDNR models should employ multiple size classes for solids so as to predict the correct deposition rates. At a minimum, three types of solids should be included, these being: fine inorganic, coarse inorganic, and organic solids.

ANSWER - This peer review panel comment to treat solids as (at least) three state variables has been addressed in wLFRM. Solids are now treated as three state variables throughout the model spatial domain. Please see the discussion in Section 3.5.2 of the wLFRM documentation.

COMMENT 4 - Data on particle size distribution for incoming flows (as input data for the model) and for the outflow (as part of the calibration and verification process) must be obtained. This is crucial for the accurate prediction of solids transport and deposition. At present, no data of this type are available, and these measurements can be accomplished relatively easily. One year of would be useful. With this, even previous data on flows and solids concentrations could at least be interpreted more accurately.

ANSWER - No new solids loading data has been collected since the completion of the AGI model peer review effort. TM 2a quantifies historical and projected total suspended solids loads and flows to the Lower Fox River through the use of the Soil and Water Assessment Tool (SWAT) model. In the absence of field data, the Department has used the results of TM 2a to estimate the suspended solids loadings in flows to the river, by size class. Section 3.5 of the wLFRM documentation discusses the methods used to make these estimates. Please see the discussion in Section 3.5.2 of the wLFRM documentation.

COMMENT 5 - A mechanistic resuspension mechanism related to water shear based on the most current scientific understanding and laboratory analyses of the Lower Fox River sediments should be employed by both the LTI and WDNR models. In addition, the effects of high-flow events on sediment mixing (e.g., as suggested by erosion (and subsequent deposition of sediments) in the SEDFLUME experiments of McNeil (1994) and McNeil et al. [1996]) may require an explicit description of surficial and deeper sediment mixing during high-flow events. These mixing events could potentially play an important role in allowing buried PCBs to re-enter the biologically active zone. Before implementing additional sediment mixing processes in the model, Fox River sediment cores should be re-examined for evidence to confirm that such mixing events have occurred during previous high-flow events.

ANSWER - WDNR concurs that the water shear mixing mechanism is an important process in redistributing sediment column PCBs. We describe the modeling constructs for these processes in detail in Sections 3.5.6 and 3.6.5 of the wLFRM model documentation. As part of the model evaluation process developed by the FRG and WDNR, as well as by work conducted by an independent researcher, field data has been evaluated to confirm evidence of sediment mixing within the Lower Fox River. An analysis of Lower Fox River sediment bed elevations, over time as documented by USACE, is presented in TM 2g, "Quantification of Lower Fox River Sediment Bed Elevation – Dynamics through Direct Observations." Disturbances of sediments by flow events will drive the exchange of particles (and associated contaminants) between layers within the sediment column. This process is discussed in detail in TM 2g. We have significant data that have documented the mixing of the sediment column over both short and long time frames. TM 2g shows that sediment bed elevations in the Lower Fox River are very dynamic. Over monthly to annual time scales, sediment bed elevations have been observed to regularly fluctuate between 10 to 30 cm. Larger fluctuations of approximately 200 cm have also been recorded. The independent evaluation of radioisotope tracer data from the Lower Fox River sediments confirms extensive mixing in the upper sediments (Fitzgerald et al., 2001). In the wLFRM, sediment mixing coefficients were specified to account for biological and flow induced particle exchange. Based on differences in the physical and chemical properties with depth, the sediment column was divided into a series of vertical layers as described in Section 3.3. In wLFRM, sediment mixing coefficients were specified to account for biological and flow induced particle exchange. As noted in Section 3.5.6.5, the mixing coefficient was set to a value of 1.0×10^{-10} m^2/s for the spring, summer and fall months and set to zero for the winter months. Mixing was specified between the top three layers. Mixing between layers 1 and 2 is more rapid than mixing between layers 2 and 3. Given the specified mixing coefficient, the volumes of the sediment layers, and mixing lengths, this equates to a complete mixing time of 2-4 years for layers 1 and 2 and 25-40 years for layers 2 and 3. A thorough discussion of the presentation of sediment mixing processes and sediment mixing of particulate phase PCBs in wLFRM are discussed in Sections 3.5.6 and 3.6.5, respectively, of the wLFRM model documentation

COMMENT 6 - Variations in sediment properties (especially erosion rates) with sediment depth and horizontal location must be taken into account. This is necessary to: (a) determine whether a particular location is erosional or depositional; and (b) if it is erosional, to determine to what depth a large flood will erode the sediments.

ANSWER - Sediment properties are discussed and variations accounted for in TM 2e. In order to represent sediment properties on a finer scale than in previous models, water velocity and shear stress functions were computed for the area over each sediment deposit, inter-deposit, and SMU. Resuspension (erosion) is discussed specifically in Section 3.5.6.3, of the wLFRM documentation. These enhancements to the data handling capabilities have been used in wLFRM and provide the ability to better represent the erosional and depositional history of the river as documented in TM 2g. However, and perhaps more to the point, the evaluation of sediment bed elevation changes presented in TM 2g confirms that the riverbed elevations are very dynamic.

COMMENT 7 - Re-evaluate spatial patterns of sedimentation in the Lower Fox River. Specifically, consider how sedimentation rates may have been affected by the curtailment of channel dredging, and how sedimentation patterns will be affected in the future by remedial dredging projects.

ANSWER - The sediments of the Lower Fox River and Green Bay have been mapped and sampled numerous times over the last fifteen years. Some of this data collection has been developed system-wide, and some of it has been collected for very small, site-specific projects. The data has been used extensively in the development of the RI/FS, but also for remediation planning at Deposit "N," SMU 56/57, and also for navigational dredging planning and assessment by the USACE. This monitoring data shows the historical changes in bed properties over area, depth and time (TM 2e). These data record changes since the "abandonment" of the upper portions of the navigation channel. This information has been used to compile the summary of sediment bed properties found in TM 2e, the Addendum to TM 2e, TM 2f and TM 2g. Please see the discussion of these technical memoranda, in the Model Documentation Report and the technical memoranda themselves.

COMMENT 8 - If dredging operations were to occur, the initial dredging operations should serve the ancillary benefit of an experiment to assess the immediate environmental impact of dredging (i.e., how much sediment PCB is actually liberated from the mechanical act of dredging). Further, if the system were monitored during and immediately following dredging, the results might clarify the additional repercussions of the remedial action.

ANSWER - Monitoring was conducted at pilot projects at Deposit N and at SMU 56/57 on the Lower Fox River. The losses from remediation of the pilots represent a fraction of what the project sites lost on a continuing basis during the extensively tested monitored natural recovery period. For example, Deposit N was losing 4 to 5 kg every year to the river under the no action or natural recovery period prior to the cleanup. The Fox River Remediation Advisory Team (FRRAT) study concluded that 1.8 kg was lost during remediation of the west lobe at Deposit N. So what was potentially lost during remediation was less than 1/2 of the annual flux of PCBs under no action. In contrast the cleanup permanently removed 45 kg of PCBs at Deposit N from the environment that will never be available for transport or biological uptake. The results from Deposit N are similar to the results from the Site 56/57 pilot where the FRRAT study measured losses equal to about 8% of the mass annually transported by the river past this site. While this operational and environmental monitoring is informative for the development of the RI/FS, longer term monitoring will be valuable in assessing the results of remediation projects that remove PCB mass from the system.

COMMENT 9 - There is wide disagreement between the LTI and WDNR models related to the action of bottom organisms on sediment particle mixing and sediment-water transport. A review of available information as well as additional measurement of bottom organism density, and depth and magnitude of bioturbation should be conducted to reduce this uncertainty. At present, the model assumes a 10-cm surficial sediment layer that is vertically well mixed by physical processes and/or bioturbation. Actual mixing particles by benthic organisms may not be fast enough to keep the top 10 cm of sediment well mixed over short time periods (e.g., during high-flow events) and a more explicit description of sediment mixing (e.g., 1-cm sediment layers with defined particle mixing rates between each layer) may be necessary.

ANSWER - The enhanced model, wLFRM continues to use the 0-10 cm sediment column layer as the zone of bioturbation. This is discussed is Sections 3.5 and 3.6 of the wLFRM documentation. Radioisotope tracer studies of Lower Fox River sediments revealed that rapid sediment mixing occurs through depths of 10 cm as determined by the presence of beryllium-7 (Fitzgerald et al. 2001). Periodic mixing through deeper sediment strata resulting from flow disturbances may also occur as described in TM 2g.

COMMENT 10 - All of the models must employ the same data sets during model development, calibration and testing. In particular, some consensus as to the depositional/erosional nature of the river has to be agreed upon. At the present time, there appears to be wide disagreement on characterizing this mechanism amongst the modeling groups. In addition, robust sets of statistical measures for evaluating the performance of the models must be developed and adhered to when judging the utility of the models.

ANSWER - We concur, considerable effort has been expended to develop a common database of sediment properties and model performance measures. This recommendation summarizes the belief of the participants in the development of the 1997 model evaluation workplan. Under this effort, developed jointly by the FRG and WDNR, the series of technical memorandum covered under Task 2 or the workplan have been developed and these specify the data input for all models being used in the Lower Fox River system assessment and planning.

COMMENT 11 - To date, model calibration and model performance evaluation have focused largely on PCB water column concentrations and sediment-water column exchange rates. Although these efforts have been very useful in addressing PCB export to Green Bay, they do not appear to be sufficient in assessing human and ecological risks in the Fox River. Assuming that PCB concentrations in fish are directly linked to surficial sediment concentrations (e.g., through the use of BSAFs), the model needs to do a more convincing job in projecting PCB concentrations in the biologically active zone of the Fox River sediments below De Pere dam. Toward this end, the following tasks should be considered.

ANSWER - Section 3.6.5 of the wLFRM documentation addresses partitioning, sediment transport, and other mass transfer mechanisms. More specifically, Section 3.6.5.4 deals with sediment-water exchange of dissolved and DOC bound phase PCBs. In wLFRM, a sediment diffusion coefficient value of approximately 3.5 cm/day was selected based on literature values. It should be noted that field data to directly estimate a sediment diffusion coefficient for the Lower Fox River, such as sediment pore water dissolved and bound PCB concentrations, do not exist. In the absence of site-specific data, the coefficient value was based on consideration of the site-specific sediment diffusion information for the Hudson River presented by QEA. Calibration results are then discussed in Section 4 of the wLFRM documentation. Concerning the assessment of human and ecological risks, the Department prepared technical memoranda to describe both the Lower Fox River and Green Bay food web. Post-processed output from wLFRM was used as input for expose and load information for FRFood and GBTOXe. Output from GBTOXe was used as input for GBFood. FRFood and GBFood are food chain models used to assess uptake in the food chain as described in TM 7c and forecast concentrations within certain fish species. FRFood is used to determine the relationship between sediment concentration and fish tissue concentration and the effect on various ecological receptors and humans. Each of these model documentation reports includes a discussion on computer platform and operating system.

COMMENT 12 - All models used for decision making should be subject to sensitivity analysis to assess their robustness and sensitivity to their underlying assumptions, boundary conditions and initial conditions. Such an approach was employed in the QEA model presentation at the February 3, 2000, meeting in Green Bay. The panel found this presentation highly illuminating regarding the effectiveness of the model in explaining the observations.

ANSWER - It is important to note that the models which are developed and applied to the Lower Fox River system are simply one set of tools to assist in the decision-making process. They, themselves will not be the sole tool used in the decision making process.

COMMENT 13 - At a certain point, some consideration should be given to the computational efficiency of each of the frameworks. Efficiency could prove extremely useful to decision makers by allowing them to rapidly evaluate many scenarios in a cost-effective manner. If highly efficient algorithms could be developed, an uncertainty analysis might be performed to estimate the uncertainties connected with model projections.

ANSWER - A discussion on the computer platform and operation system used to run wLFRM for calibration and forecast situation is in included in Section 2 of the documentation report. We are confident that the model has the computational efficiency necessary to perform uncertainty analyses to address the effectiveness of the model in explaining observations in the river system. A qualitative discussion on uncertainty is included in Section 4.4 of the wLFRM documentation report (Appendix B1).

6 References

References supporting each of the technical memoranda and model documentation reports are found in each of the respective documents in Appendices A through F.