EXECUTIVE SUMMARY

A linked hydrodynamic-sediment transport-water quality model was developed for the Upper Mississippi River from Lock and Dam No. 1 through Lock and Dam No. 4 below Lake Pepin. The model, called the Upper Mississippi River - Lake Pepin Water Quality Model (UMR-LP model), was developed to support a TMDL for turbidity and nutrient-chlorophyll *a* impairments in Pools 2, 3, and 4 of the Upper Mississippi River.

The overall project approach followed EPA's Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models (EPA 2003). Based on this guidance, the general approach to model development and application adhered to the following steps in the regulatory environmental modeling process: 1) problem specification; 2) model framework selection and formulation; 3) model development; 4) model evaluation; and 5) model application. An important overarching component of this project was the adherence to an open modeling process throughout the project that involved continual interaction with all stakeholders at each step in the process. Another important part of the open modeling approach was ongoing model peer review of the entire modeling process by a Science Advisory Panel (SAP) consisting of academic and government scientists and MPCA staff familiar with the system under study.

The UMR-LP modeling framework consists of LimnoTech-modified versions of two public domain models: the ECOMSED hydrodynamic/sediment transport model and the Row-Column AESOP (RCA) water quality model. The two models operate on the same computational grid, and hydrodynamic and sediment transport predictions from the ECOMSED model are linked directly to the RCA model to inform the water quality simulation. The "ECOM" component of the ECOMSED modeling framework is used to simulate three-dimensional and time-dependent hydrodynamic behavior in the Upper Mississippi River from Lock and Dam No. 1 to Lock and Dam No. 4. As a complementary module to the "ECOM" hydrodynamic module, the "SED" component of the overall ECOMSED framework is used to simulate the transport and fate of cohesive and non-cohesive sediments, which together constitute non-volatile suspended solids. Advective/dispersive transport and deposition and resuspension processes are simulated for cohesive sediments, which represent clays, fine and medium silts, and associated organic material. Likewise, transport and deposition/resuspension is simulated for a non-cohesive sediment class, which typically represents medium to coarse sands.

The basic RCA framework includes a suite of state variables to represent carbon, nitrogen, phosphorus, silica, oxygen and algal dynamics, and it is configured to interface directly with the ECOMSED model, including linkage of hydrodynamic, water temperature, and sediment transport results. In addition to simulation of water column processes affecting water quality, the RCA framework includes a coupled sediment diagenesis sub-model that simulates the cycling of detrital material and nutrients in the surface sediments and subsequent impacts on near-bed sediment

oxygen demand and release of dissolved nutrients, including dissolved inorganic phosphorus.

Every effort was made to incorporate all of the available data for the Upper Mississippi River (UMR) system during the model development and calibration/confirmation process. The UMR system has a long history of abundant water quality and biological data collected over the past 22 years by federal, state, and local government agencies. Within pools 2 and 3, the Metropolitan Council of Environmental Services (MCES) has collected a majority of the monitoring data, while the United States Geological Survey (USGS) through the Long Term Resource Monitoring Program (LTRMP) has collected a majority of the data in Pool 4. Other agencies that regularly collect data within the UMR system include the U.S. Army Corps of Engineers (USACE), Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (MDNR), and the Wisconsin Department of Natural Resources (WDNR).

With twenty-two years of data available for the UMR-Lake Pepin system, the decision was made to use half of the data for model calibration and half for confirmation. The model was calibrated using monitoring data for 1996-2006, and the monitoring data from 1985-1995 was used as a confirmation dataset. Both the calibration and confirmation data sets included a low flow and a high flow year. The calibration period included the intense low-flow monitoring program conducted in 2006 (10^{th} percentile summer (June – September) flow at Prescott) and the 86^{th} percentile annual flow at Prescott in 2002. The earlier confirmation period included the one percent summer flow in 1988 and the highest annual flow on record in 1993. It was important to test the model's ability to simulate the system response over the full range of flow conditions because high flows represent the critical conditions for turbidity, while low flows represent the critical conditions for nutrient-stimulated phytoplankton growth.

The approach and results of the calibration/confirmation process are discussed in detail. Results of this iterative process include complete listings of calibration parameters, graphical presentations of the calibrated model, comparison with system data along with a presentation of model-data comparisons for the confirmation period, the metrics used to quantitatively evaluate the model calibration/ confirmation, and diagnostic analyses of the modeling results with regard to important features of the system behavior. Overall model performance for the calibration period and confirmation periods was found to be quite good, especially given the complexity of the model framework and the extent of the model domain. An illustration of the model's ability to reproduce the system's behavior in response to external forcing conditions is presented in Figure ES-1-1 below, which shows a one-to-one scatter plot of the summer (June-September) average viable chlorophyll *a* concentrations in Lake Pepin (one of the TMDL targets) as computed by the model versus the average observed values.

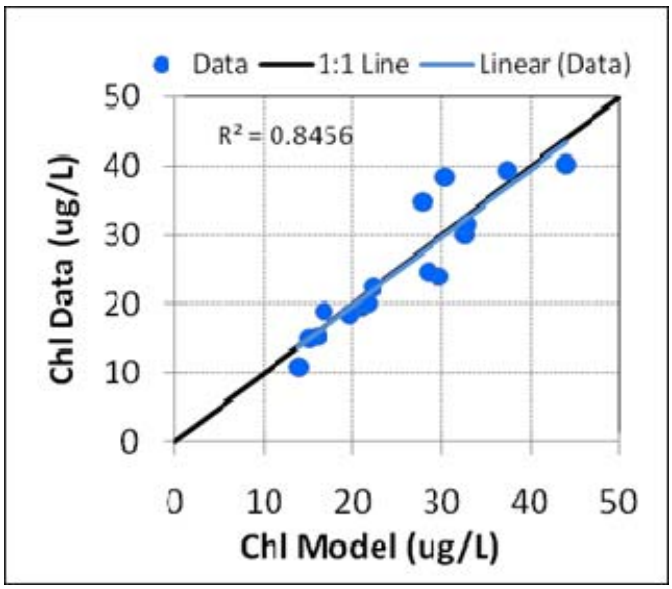

Figure ES-1-1. One-to-One Plot of Model Chlorophyll *a* Results vs. Monitoring Data for Lake Pepin (June-September average, 1991-2006)

Once the best possible model parameterization had been achieved, a suite of model application runs was conducted to provide a computation of the sediment and nutrient load – response relationships to support the TMDL process. The results will inform establishment of turbidity (suspended solids) and eutrophication TMDLs that will include the sum of non-point source (major tributary and direct runoff) loads, point source loads, and a margin of safety (MOS). A Management Analysis Tool (MAT) has been developed to permit all stakeholders to visualize and compare the results of 19 different load reduction scenarios in relation to TMDL targets for chlorophyll *a*, total phosphorus, Secchi depth, and turbidity.

The results of the model application analysis confirmed that the critical conditions for meeting the turbidity targets are high spring and early summer flow periods, while the critical conditions for meeting eutrophication targets are summer low flow periods. Achieving the eutrophication targets in Lake Pepin will require significant phosphorus load reductions in major tributaries, especially the Minnesota River and the Upper Mississippi River at Lock and Dam No. 1. Phosphorus load reductions on the order of 20% for the Upper Mississippi River at Lock and Dam No.1, 50% for the Minnesota River, and an effluent limit of between 0.3-0.5 mg P/L will be required to assure summer average TP concentrations throughout Lake Pepin less than 0.100 mg P/L, chlorophyll *a* levels less than 32 µg/L, and Secchi depths greater than 0.8 m during critical low-flow periods (MPCA, 2008b; Wasley and Heiskary, 2009).

With regard to the turbidity impairment, a site-specific standard has been proposed to support the establishment of submerged aquatic vegetation (SAV) in Pool 2 to Upper Lake Pepin. The current proposed site-specific criterion for SAV in Pool 2 to Upper Lake Pepin is a long-term median of summer average total suspended solids (TSS) concentrations less than 32 mg/L (Sullivan et al., 2009). Model results from load reduction scenarios indicate that TSS load reductions should be on the order of 20%

for the Upper Mississippi River at Lock and Dam No. 1 and 50% for the Minnesota River in order to meet this target.

The outcome of this project is a calibrated and confirmed, linked hydrodynamic-sediment transport-water quality model for the Upper Mississippi River from Lock and Dam No. 1 through Lock and Dam No. 4. Much analysis remains to be done in order to fully develop a TMDL for this system. First, each of the major tributaries to this model domain and the Upper Mississippi River above Lock and Dam No. 1 should be modeled or otherwise evaluated in order to develop a quantitative relationship between point and non-point source inputs from their individual watersheds and the tributary water quality and loading of turbidity and eutrophication related parameters to the Mississippi River mainstem. In this way, the response of the current model domain, including Spring Lake and Lake Pepin, to specific point source and non-point source load reduction actions in these tributary watersheds on water quality in the main river can be quantified.

In the near-term, the following activities should be conducted to assist the State of Minnesota in completing the TMDL process for this system:

- Use existing UMR-LP model results to develop 1) a summer average total phosphorus – chlorophyll *a* relationship in Lake Pepin, and 2) a flow – turbidity relationship at Lock and Dam No. 3 for the 10^{th}, 50^{th}, and 90^{th} percentile summer (June-September) flow conditions.
- Review existing model scenario results to develop an understanding of how solids and total phosphorus (TP) load reduction scenarios translate into long-term changes in TP concentrations in the upper sediment layer of Lake Pepin.
- Coordinate with the Minnesota River HSPF and CE-QUAL-W2 modeling efforts to better define Minnesota River load reduction management scenarios in order to further inform the TMDLs for the UMR-LP system.
- Develop delivery ratios of phosphorus for Upper Mississippi River reaches between Brainerd and Lock and Dam No. 1 (based on the UMR phosphorus model developed by LTI).
- Use the model-data statistical comparisons presented in this report to estimate a margin of safety (MOS) that can be used in the TMDL computation.
- Develop and run additional scenarios that are requested by MPCA in consultation with technical experts (e.g., SAP) and the stakeholder groups. For example, additional scenarios might include future population/land use projections, individual tributary load reductions, and investigation of differing load reductions for the nutrient, suspended solids, and algal components of tributary loadings.