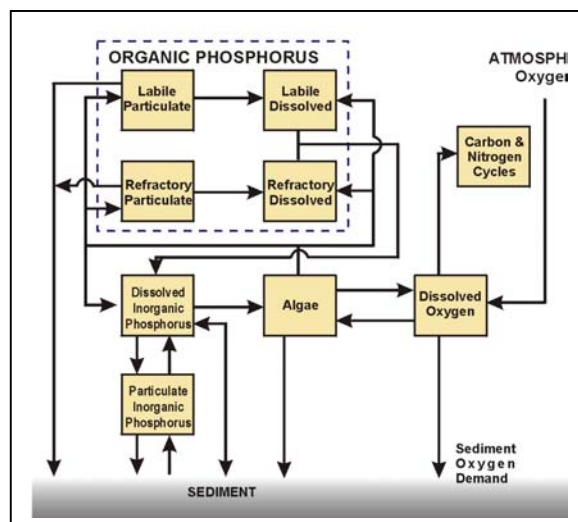


Advanced Eutrophication Model of the Upper Mississippi River

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Draft Summary Report
April 1999



ABSTRACT

An advanced eutrophication model has been developed to evaluate the effectiveness of point and nonpoint source nutrient controls for achieving water quality objectives in Pools 2, 3, and 4 of the Upper Mississippi River. The approach adopted in this work was selected to address areas of uncertainty remaining after previous modeling analyses of this study area. Areas of uncertainty specifically addressed include the fate and transport of phosphorus entering the river from point and nonpoint sources, including the role that suspended solids play in phosphorus transport. The exchange of phosphorus between the water column and sediment is another important area directly addressed in the current study. The modeling framework used in this study includes linked 3 dimensional, time variable hydrodynamic, sediment transport and eutrophication components. Each of these components is a state-of-the-art model that has previously been applied in a variety of settings. The eutrophication model is a descendent of the Chesapeake Bay Eutrophication Model and includes a sediment flux submodel that calculates nutrient fluxes to the water column in response to the deposition of particulate organic matter. In this study, particulate inorganic phosphorus was added to the eutrophication kinetics to account for the transport, settling, and resuspension of sorbed inorganic phosphorus. Resuspension and settling rates are calculated in the sediment transport model.

Approximately 90% of phosphorus inputs to the study area enter the Mississippi River in Pool 2. The 220-mgd Metropolitan Wastewater Treatment Plant (Metro Plant), operated by Metropolitan Council Environmental Services (MCES), accounted for approximately 22% of the total phosphorus discharged to the study area between 1985 and 1996. In the low flow year of 1988, however, the Metro Plant contributed almost 50% of the total phosphorus load. Nonpoint source loads contribute approximately 50% of the total phosphorus load, on average. In high flow years, nonpoint sources loads contribute nearly two-thirds of the total phosphorus to the study area; however, in low flow years, nonpoint sources contribute less than 20% of the total phosphorus load. In order to evaluate the response to nutrient controls, the model needed to be capable of determining the effect of elevated nonpoint-source phosphorus inputs under high flow conditions, such as 1986, on subsequent low flow years (i.e., 1987 through 1989). The model was calibrated with data collected over a range of hydrological conditions during a 12-year pe-

riod, from 1985 through 1996. In projection simulations, the 12-year hydrodynamic transport was repeated through two cycles to simulate water quality conditions between 1998 and 2021.

Sources of total phosphorus to the sediment bed include settling organic matter and phosphorus sorbed to nonvolatile suspended solids (NVSS). Model results indicate that the average solids trapping efficiencies of Pools 2, 3, and 4 are 23, 7, and 69%, respectively. Net phosphorus accumulation in the sediments of Lake Pepin is computed in 10 of the 12 years modeled. In the low flow years of 1987 and 1988, however, vertical stratification produced hypoxic or anoxic conditions in the lower waters of Lake Pepin, resulting in substantial releases of dissolved inorganic phosphorus (DIP) from the sediment. Model results reproduce the dramatic increases in DIP through Lake Pepin, which was observed during the summer of 1988.

The calibrated model was used to simulate future water quality conditions for the next 24 years under several scenarios of point- and nonpoint-source nutrient load reductions. Three point-source phosphorus control scenarios were evaluated, representing total phosphorus reductions of between 67 and 89%. Two nonpoint-source control strategies, developed by the Minnesota Pollution Control Agency, were run in combination with the point-source reductions. The nonpoint-source scenarios were developed on a seasonal basis and specified as a function of flow. The magnitude of the nonpoint-source reductions ranged from 0 to 43%. Despite substantial reductions in total phosphorus and DIP sources, resulting ambient phosphorus concentrations do not produce significant nutrient limitations on algal growth. Changes of more than 5 $\mu\text{g/L}$ in summer average chlorophyll-*a* concentrations in Lake Pepin are calculated only during the low flow years, using river flows from 1987-89, and in one additional year, using 1992 river flows.

The modeling framework, comprised of hydrodynamic, sediment transport, and eutrophication components, provides a detailed representation of the fate and transport of phosphorus in Pools 2, 3, and 4 of the Upper Mississippi River. By imposing a strict mass balance on both the water column and sediment of the study area, the modeling analysis includes the effect of current nutrient inputs, as well as inputs reaching the sediment in prior years. The multi-year simulation allows the water quality response of the system to be computed over a range of hydrologic and point- and nonpoint-source loading conditions.

